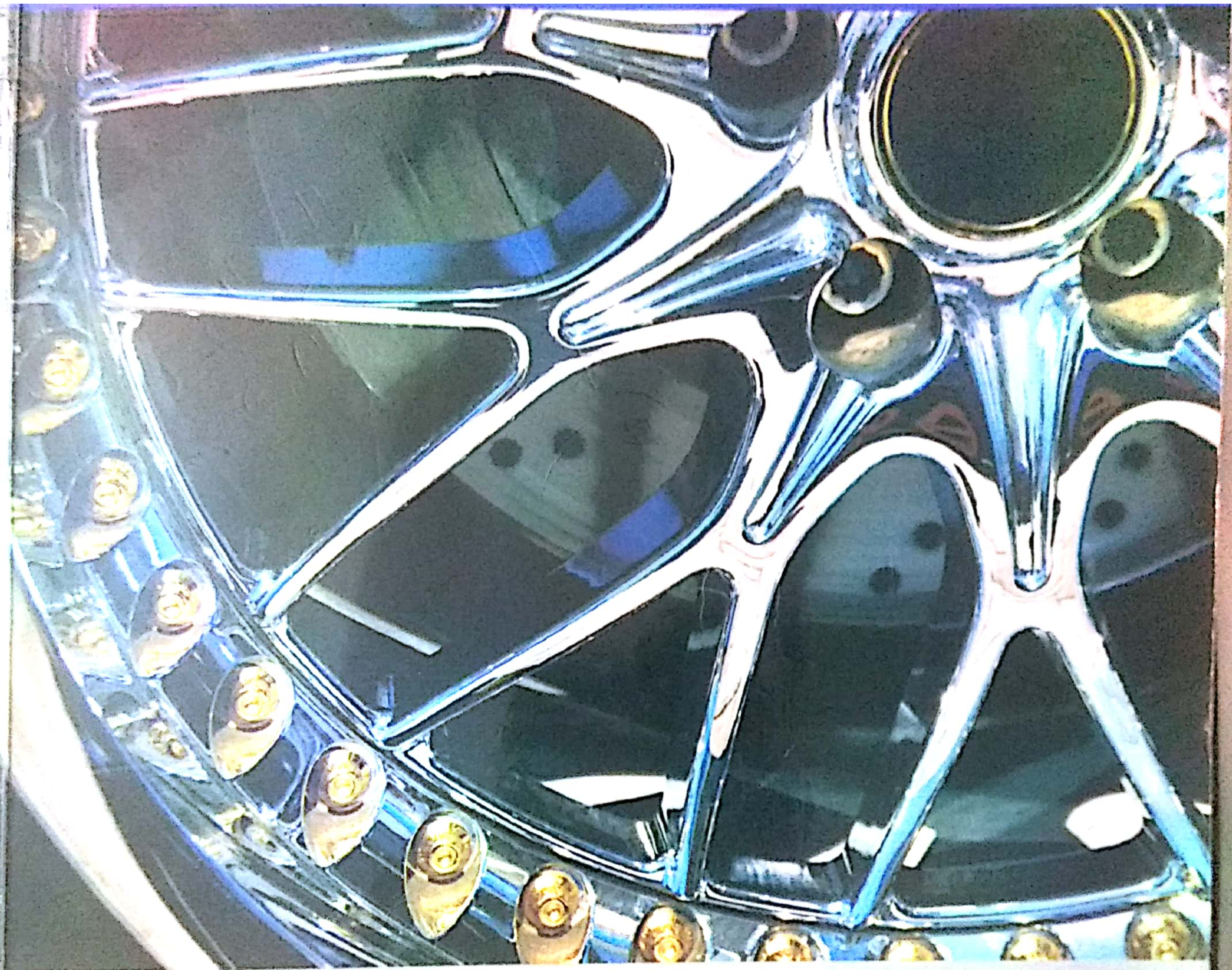

Modern Control Engineering

Yaduvir Singh • S. Janardhanan

Chapter 1

BASICS OF CONTROL SYSTEMS

INTRODUCTION

Control systems form the heart of an automatic process/plant. These are widely used in process operations and their management, defence applications, mechanical systems, electrical drive systems, electronics, and telecommunication systems.

These application areas necessitate an engineer to have an in-depth knowledge of various control systems and their behaviour and applications. Today, all industries in production sector worldwide use some or other kind of control system. This chapter brings forth the classification of control systems and their nomenclature.

1.1 SYSTEM, PROCESS, AND PLANT

A *plant* is an aggregation of various small units (called subunits) that interact with each other in a logical manner so as to give an entire system operation. The system operation is always objective based, depending upon its domestic/industrial applications.

For example, an automobile system has suspension, engine, electronic gadgets, etc., as its various subsystems. A management system consists of production, marketing, finance, and personnel subsystems. Depending upon the size and operational complexity and analyses to be carried out, these subsystems may be treated as a system which can then be logically decomposed further into subunits. For example, in production subsystem, the various machines used in production process will become smaller subsystems.

In an abstract sense, a system can be shown as in Fig. 1.1 with the unit's mutual interdependencies.

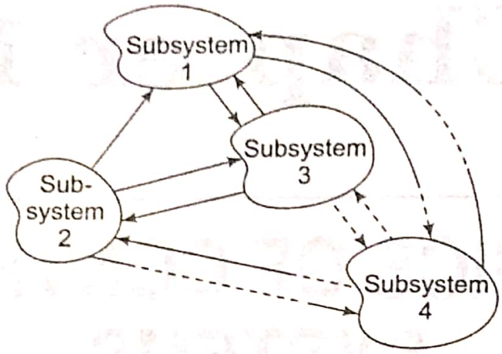

Figure 1.1 A system

A

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An operator or a control engineer needs to have a perfect knowledge of subsystems, which together make a system. It helps not only in smoother system operation but also in removing any bug/failure quickly so as to minimize the plant shutdown time. When a system is malfunctioning, a particular subsystem or a group of subsystems may be involved, which need to be diagnosed and corrected.

Systems are taken to be the same as the process or plant in context of their operations involving control, for example, a power plant and a chemical plant.

The plant itself can involve some kind of processes. For example, a chemical plant involves heating, cooling, filtering, and precipitation processes. Plant and process may be defined as given below.

Plant: It is a set of various machine components or parts functioning together to perform a particular operation.

Process: It is a logical series/continuing operation, thus giving a total plant operation. Some of the operations may be happening simultaneously, i.e., in parallel mode.

A control engineer needs to control the plant operations so as to get the desired response from the plant. A system or process/plant may have a single input or multiple inputs. Inputs are also called 'cause'. Similarly, a plant may have single output or multiple outputs. Outputs of a plant are also called 'effect'. Some theorists term input as stimulant also. Hereinafter, the term *plant* will be used throughout this text to mean a system or process, as plant is the widely used term among process control engineers. Figure 1.2 represents a plant.

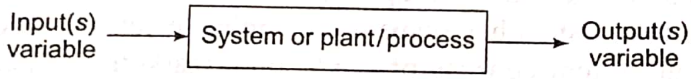
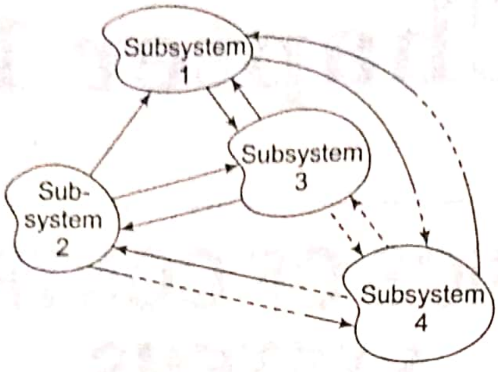


Figure 1.2 A plant

As shown in Fig. 1.2, input affects the behaviour of the plant. A wrong input would lead to an undesirable output. Hence, a proper input is required for control of plant behaviour.



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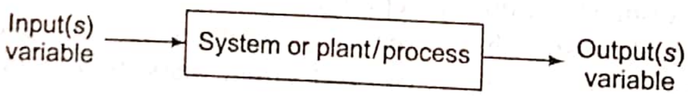

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1.2 CONTROL AND CONTROLLER

Control is the corrective action taken on the plant by external means so as to get the desired output from it. Control refers to regulation, directing, or governing. If the control action is taken by a human being, then the control is called *manual control*. On the other hand, the control action is taken by some gadget or a device, it is called an *automatic control*. The device that offers control is called a *controller*.

.2.1 Controller

\ controller is an agent (device/human) that offers control action on the plant. Sometimes, in a small ontrol application, such a device may also be called a *regulator*. Control action may be either correcive or compensatory in nature. Figure 1.3 illustrates a control action, a controller, and a system.

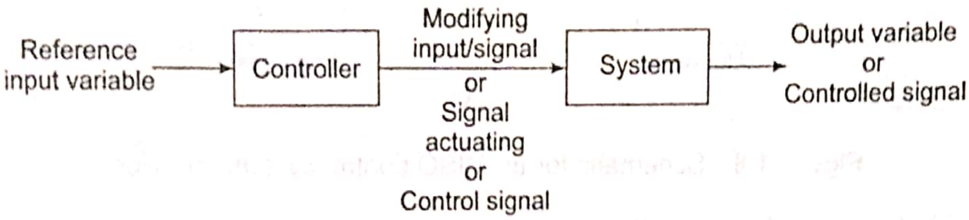

Figure 1.3 A controller in action

The above two blocks can be shown together as in Fig. 1.4. This single representative block of the two devices is called a *control system*.

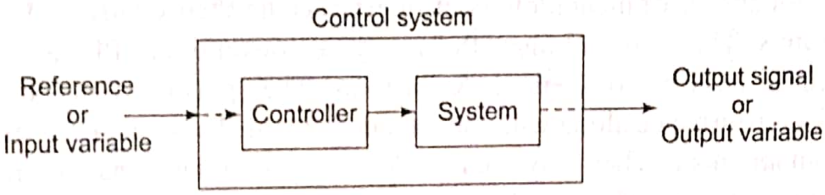

Figure 1.4 A control system

Now-a-days, engineers and researchers prefer embedded control systems. Figure 1.5 illustrates a single-input control of a system by human controllers. Here, a person is filling up a pail of water. When the pail gets full, the human controller makes the water pipeline tap valve fully closed.

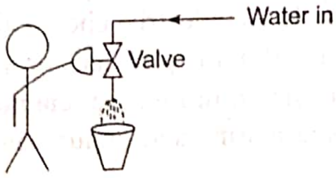

Figure 1.5 Schematic diagram for pail filling

A plant may have multiple inputs unlike Fig. 1.5, in which, it is a single-input–single-output (SISO) process. A system may also be of multiple-input–single-output (MISO), single-input–multiple-output (SIMO), or multiple-input–multiple output-(MIMO) type. The increasing number of system or plant inputs and outputs increase the complexity of system and its control requirements.

Figure 1.6 illustrates a two-input control by a human controller for regulating a single output, that is, a shower, while taking bath. It is an example of a MISO control system.

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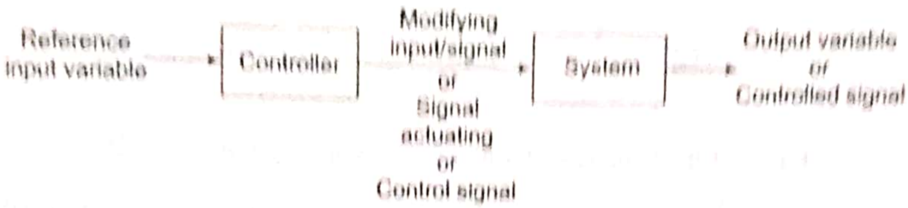

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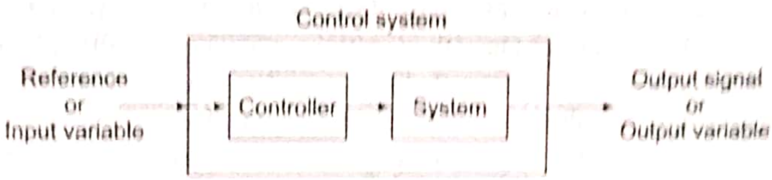

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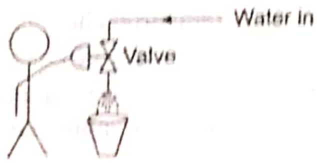

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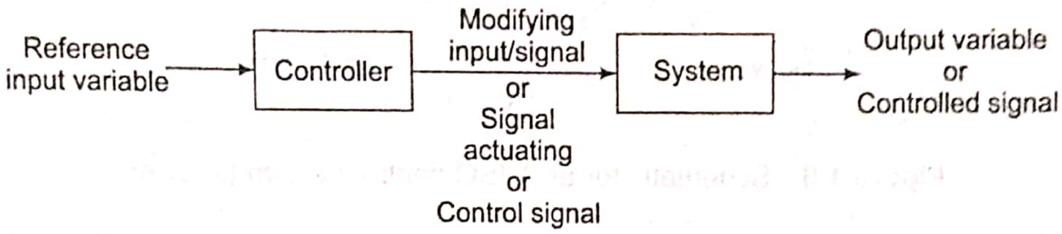

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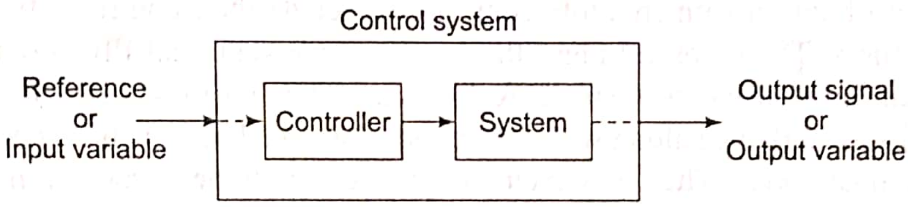

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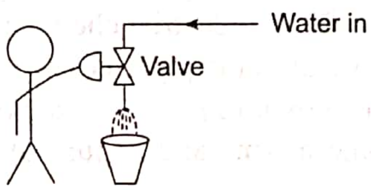

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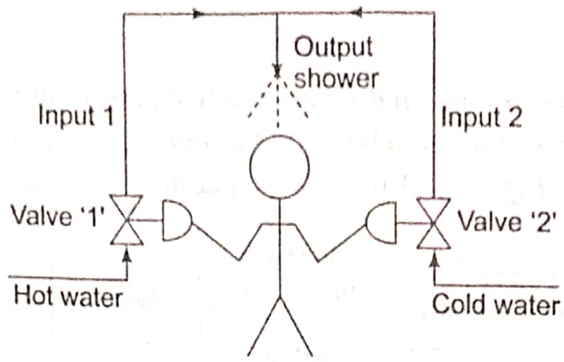

Figure 1.6 Schematic for an MISO control system (shower)

In an embedded system, the controller circuit and system circuit are put together on a single chip using VLSI technology. Presently, embedded controllers are in vogue in biomedical applications such as in cardiac control devices/gadgets. As shown in Fig. 1.6, the controller removes the unwanted superfluities or replenishes the spurious signal and thus makes it compatible/conducive for the plant as per its input specifications.

In PC-based control and instrumentation, controllers execute their control actions with the help of their control algorithms. These control algorithms may be conventional PID alogrithms or the latest Fuzzy, artificial neutral network, or Genetic Algorithms. The spurious signal to the controller may consist of some noise/disturbance along with the intended signal. These disturbances may enter a plant instrumentation from any node. They may intercept/interfere with the signal communication channels between two instrumentation blocks/modules. Disturbance may be defined as follows:

Disturbance: A disturbance input is a variable that affects the plant outputs but cannot be adjusted by the control system. Disturbances may be probabilistic, stochastic, or deterministic in nature. On the basis of the source of disturbances, these are classified as internal and external disturbances.

Internal disturbances are intrinsic to the plant and arise within the plant. The parametric variations of plant parameters that occur due to ambient conditions or some other factors are called internal disturbances. Internal disturbances may also be capacitance or resistance variations of some electrical circuit fitted in an electrical application. In an industrial chemical process, the internal disturbance may be, say, increased scaling/precipitation within the pipelines or a hole opening in the pipeline.

An external controller, like the one shown in Fig. 1.3, cannot offer compensation to such internal disturbances. For their diagnosis, some alarms and annunciators with help of certain sensors, and transducers must be used.

External disturbances arise outside the plant, say, in the input(s) going to the plant. They can only be controlled by a feedback controller, which we will discuss later.

Internal disturbances are always probabilistic. External disturbances are mostly probabilistic but they can also be stochastic and deterministic in a few cases. The notion of control system is used by and large for offering corrective action to probabilistic disturbances, whether external or arising internally to the system. The stochastic disturbances to some extent and the deterministic disturbances to their full extent can be compensated or corrected during design of the control system itself. As discussed earlier, disturbances enter a process or plant from the same module or channel from various locations. In order to develop a control system for offering control/corrective action to such disturbances occurring within the system, the process, during its operation, must be treated as inputs only, as shown in Fig. 1.7. Inputs are classified as either manipulated or disturbance variables and the outputs are lassified as measured or unmeasured variables. To control the operation(s) of this plant system, neasurements of process outputs or disturbance inputs have to be done in order to make decisions ertaining to the control/corrective action (compensation) to be taken on the inputs going to the plant ystem. As the inputs are to be changed for applying the needed control action to the plant system, the nputs are termed as manipulated inputs.

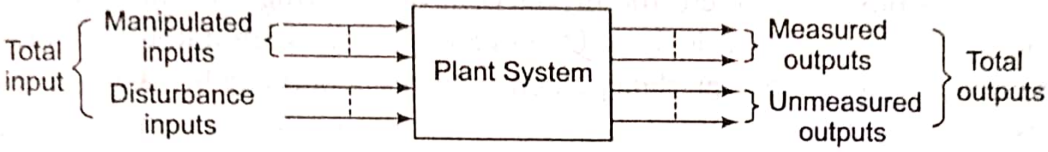

Figure 1.7 A typical industrial system requiring control

1.3 CONTROL SYSTEM

Control system is the name given to a group of components for facilitating control of a system. A control system has been illustrated earlier in Fig. 1.4. It consists of two fundamental blocks/units, viz., controller and the system/plant. A control system is defined as an aggregation of a controller and the plant needing it. Figure 1.8 illustrates a control system for a typical industrial system.

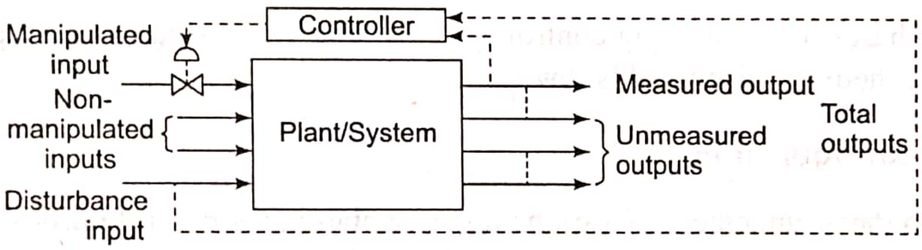

Figure 1.8 A typical industrial control systems basic schematic (value is control element)

As shown in Fig. 1.8, the controller manipulates an input variable on the basis of corrective action derived by it. The corrective action is generated on the basis of the information coming to the controller relating to the output and the disturbances of the plant. The examples of control systems are aircraft control by pilot, automatic refrigerator temperature control at homes, traffic control system, etc.

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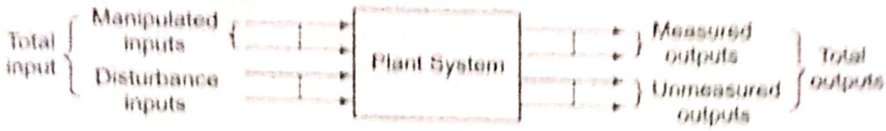

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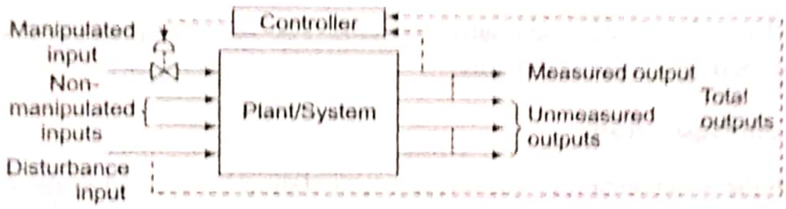

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1.4 NATURE OF CONTROL SYSTEMS

The nature of a control system may be classified by the degree of automation it possesses. It has the following three categories:

(i) Manual control systems
(ii) Semi-automatic control systems
(iii) Automatic control systems

Each of these types of control systems are described below.

1.4.1 *Manual control systems*

Manual control systems possess an operator as the controller in them. Here, the control system is regulated through human intervention, e.g., operation of lathe machine in mechanical workshops and human-operated stage lighting control system. These control systems are very common in general use, especially in cottage and small-scale industries.

1.4.2 Semi-automatic control systems

Semi-automatic control systems involve both human beings and a device/gadget as a part of the controller, e.g., present-day cars, where the driver controls steering and the temperature control is separately performed by thermostatic devices. Other examples are semi-automatic washing machines, microwave ovens, and control of power plants. Such control systems can be easily seen in modern-day home appliances.

1.4.3 Automatic control systems

Automatic control systems do not require human intervention for their operation and control purposes in normal use(s). The examples of such systems are pilot-less light aircrafts used in defence, metro rails in Korea, CNC (computerized numerically coded) lathe machine, etc. Automatic control systems do not need any human intervention.

1.5 CLASSIFICATION OF CONTROL SYSTEMS

There are different bases for classifying control systems. The various bases and types of control systems within each of them are discussed below.

1.5.1 Based on configuration

This basis relates to the arrangement of various instrumentation for control purposes and the adopted control philosophy. Two major categories are described below.

1.5.1.1 Open-loop control systems

These control systems have no feedback path. The schematic of an open-loop control systems (OLCS) is shown in Fig. 1.9. In such control systems, the controlling or regulating action is independent of the output.

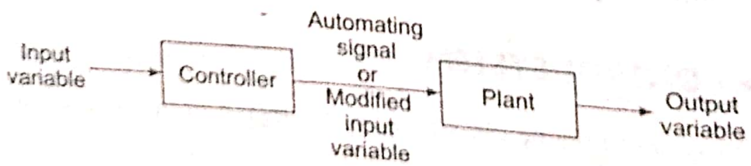


Figure 1.9 An open-loop control system

As shown in Fig. 1.9, the controller does not have any information of the output variable. Phrasing it other way, it can be stated that in the above control philosophy, the output has no effect on the controller action. Performance of such a control system depends on the accuracy of the input calibration and any deviation in this input will affect the output variable. OLCS require fewer instrumentation blocks/modules as compared to their counterparts, viz., closed-loop control systems. As a result, OLCS are generally simple to build and cheap. In OLCS, the parametric disturbances/non-linearities of the plants will not be compensated by the controller and hence the operation of the control system will be affected. An example of an OLCS is traffic lights control system in our country, which goes red, orange, and green irrespective of the number of the vehicles in the various lanes.

OLCS can be manual in nature or at the most semi-automatic. They can never be automatic as their control action scope is highly limited due to absence of feedback loop.

1.5.1.2 Closed-loop control systems

Closed-loop control systems (CLCS) are control systems in which the controlling or regulating action is dictated by the output. The only difference in this control system configuration is that it carries some instrumentation in the feedback path. Figure 1.10 exemplifies a CLCS.

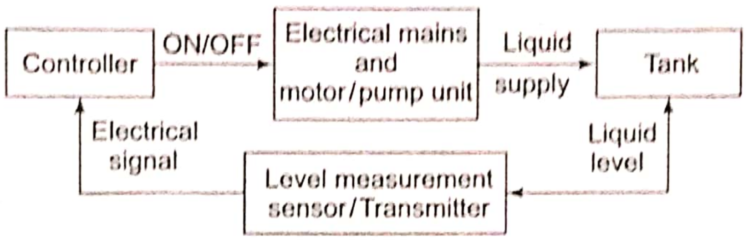


Figure 1.10 A liquid-level control system

In the closed-loop (feedback) control system shown in Fig. 1.10, a level sensor is placed inside a tank. Mains are made ON and OFF by this level sensor and a driver. Mains act as controller and make the motor/pump ON for requisite time and then OFF.

Another example of a CLCS is home thermostat, which uses the air conditioning system to correct the temperature in a system/process comprising a room and the air inside. It sends an electrical signal (output) to turn the air conditioner ON, whenever the error between the actual temperature (the system/process variable) and the desired temperature (the set point) is too high. A general schematic of a CLCS is shown in Fig. 1.11.

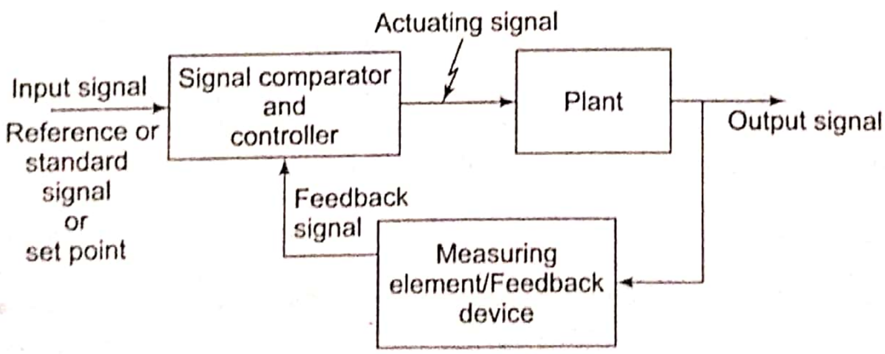


Figure 1.11 A closed-loop control system

A CLCS contains two additional instrument blocks/modules:

(i) A signal comparator (normally embedded with the controller)
(ii) A measuring element or feedback device

The above configuration forms a loop. The feedback devices are sensors, transducers, and transmitters, which measure the output signal of the plant and feed it back to the controller side for necessary action. In Indian process-control industries, the feedback devices from YOKOGAWA, ROSEMOUN BLUESTAR, and L&T are in vogue. The feedback signal is compared with a reference signal (als called a standard signal or a set point) by the comparator. The comparator then generates an err signal as a consequence of the differential action of the two signals given to it. This error signal (i proper magnitude and polarity) goes to the controller and the controller necessitates a control actic leading to the generation of an actuating signal (modified input) for the plant. This modified input the compensated/corrected input signal, which leads to a proper output signal/variable generation fro the plant.

CLCS are normally automatic control systems possessing self-diagnostic, predictive, and correcti capabilities. In certain cases, CLCS can be semi-automatic in nature, which entails human contr component at some stage. Most of the Indian process industries have semi-automatic CLCS, for ex ample, distributed control systems (DCS), in which the set point to the distributed controllers ar entered from various plant locations. These distributed controllers are controlled by a central host, c master controller.

Present-day CLCS are highly advanced (accurate and fast) due to the use of smart sensors an transmitters. The data-logging devices (popularly known as data loggers) have greatly enhanced cor trol capabilities of present-day controllers. Refrigerators at home, aircrafts, and CNC lathe machine are some of common examples of CLCS.

1.5.1.3 Comparison between open-loop and closed-loop control systems

As compared to open-loop control systems, closed-loop control systems are more accurate (due t feedback path and error generation) but are more complicated to design.

The parametric disturbances and non-linearities arising within the plant system are compensated b the closed-loop control systems.

1.5.2 Based on change of plant parameters

The control systems can be categorized on this basis into the classes as mentioned below.

1.5.2.1 Time-varying control systems

In such control systems, the plant parameter(s) vary with time. The output signal or response of suc systems depends upon the time of application of the input, for example, an automobile control system where the mass decreases with time as the fuel is consumed during its movement. Other examples ca be environment system and economic system of a country.

1.5.2.2 Time-invariant control systems

These are also called constant-coefficient control systems. These plants systems do not hav parameteric variations with respect to time. The response of such control systems is independent of th time at which the input is applied. Such control systems are described by a differential equation wit constant coefficients. The examples are automatic cash management system (ACMS), spring mass and damper system.

1.5.3 Based on behaviour

The 'behaviour' should not be confused with the above categories. In the above categories, the plan parameter's variation(s) were taken as a basis of categorization. Here, the nature of the plant outpu behaviour is the criterion. It has the following two categories:

1.5.3.1 *Linear control systems*

In these control systems, input/output relationships may be represented by linear differential equations. Linear control systems follow the principles of superposition and homogeneity. Their output signals vary linearly with respect to input(s). In linear control systems, the response to several simultaneous inputs can be calculated by treating one input at a time and then adding their independent responses. The linear control systems can be time variant or time invariant as per their intrinsic nature. These systems are mathematically represented by simple linear differential equations, e.g., Newton's laws of motion.

1.5.3.2 *Non-linear control systems*

These control systems do not obey the principles of superposition and homogeneity. Their response to multiple inputs cannot be calculated by treating one input at a time and adding the results. These systems are mathematically represented by non-linear differential equations.

Control of linear systems is very easy as compared to the control of non-linear systems. Most of the real-world systems are non-linear in their behaviour, thus requiring a non-linear control. In order to facilitate an easy linear control to these non-linear systems, they are controlled linearly in piecewise manner according to the concept of piecewise linear approximation of non-linear functions. This way, non-linear systems are linearized for small ranges of variations of parameters and then controlled.

1.5.4 Based on distribution of parameters over the structure of control system

This basis relates to the size and analysis considerations of control systems. The two categories of control systems as per this basis are given below.

1.5.4.1 *Lumped parameter control systems*

These control systems are described by ordinary differential equations (ODEs), often based on a perfect mixing assumption like $\dot{x} = fn(x, u)$, where x may be a variable and u another variable, say, input.

1.5.4.2 *Distributed parameter control systems*

These control systems can be represented only using partial differential equations (PDEs).

1.5.5 Based on control learning capabilities

Modern-day control systems are made to mimick human capabilities such as adaptation, learning, self-regulation, etc. The various control capabilities of control systems classify them as mentioned below.

1.5.5.1 *Adaptive control systems*

Control systems having an ability of adaptation are called adaptive control systems. These systems identify the dynamic characteristics of the plant and then decide the modifications to be made in the actuating signal (controller output). The act of 'self-redesign' or 'self-organization' so as to compensate for unpredictable changes in the plant is adaptation capability. The control system becomes versatile and reliable. Such control systems can self-adjust or self-modify in accordance with erratic changes in the conditions of the environment or its structure. Examples of such systems are spacecraft control systems and ecological systems.

1.5.5.2 Learning control systems

These control systems possess the ability to learn. The learning control systems can recognize familiar features and patterns of a circumstance/situation and they use their past learned experience: an optimal fashion to generate the output. These controllers are designed using artificial intellig techniques like artificial neural network, neuro-fuzzy systems, expert systems, etc. Learning cont systems are high-level systems as compared to adaptive control systems. These control systems alrea include the capability of adaptation.

1.5.5.3 Self-regulating control systems

These control systems possess both adaptation and learning abilities. The best example of these sy tems is human being.

1.5.5.4 Optimal control systems

These control systems are designed to optimize certain performance indices of the system perfo mance. The function that must be minimized and carries these performance indices is called *objecti function* or *cost function*. Modern-day optimal control systems work on an optimization algorithm ar after certain conditions of optima are fulfilled, the output at the controller is available. A few exampl of optimal control systems are maximizing profit and increasing fuel efficiency of a car.

1.5.6 Based on the number of inputs and outputs

Industrial systems requiring control usually consist of multiple input variables and multiple outpu variables. Seldom, these systems are of single input or single output types. The following fou categories represent the control systems on this basis:

(i) Single-input–single-output (SISO)
(ii) Single-input–multiple-output (SIMO)
(iii) Multiple-input–single-output (MISO)
(iv) Multiple-input–multiple-output (MIMO)

In SISO systems, only one parameter enters as the input and only one parameter represents outpu In MIMO systems, several parameters may enter as the inputs and the outputs (multiple variables) SISO control systems are much simpler than SIMO, MISO, and MIMO with regard to their structur and the control needed. MIMO systems are the most complex control systems among the categorie owing to the multiple numbers of input variables and output variables. Current control practices ar selecting a measured output, which is most strongly affected by a particular manipulated input. A already mentioned, SISO control systems are much simpler than others for their easy understandin and ready availability of the hardware and software for SISO controllers. Hence, on a multivariabl process/plant, several SISO controllers are used. Such control configuration is termed as MVSISO (multivariable single input–single output) control system. The selection of a measured output to be paired with a particular manipulated input is known as *pairing* and is a challenging task in control system designing.

1.5.7 Based on the type of signal and signal conditioning requirements

The control systems in this category can be of the following two types:

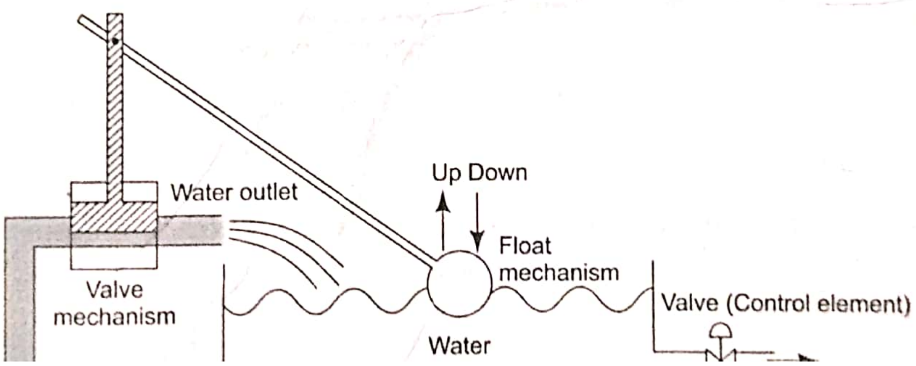
(i) Analog control systems
(ii) Digital control systems

1.5.7.1 Analog control systems

In this control configuration, the input signals and output signals of the process are essentially analog in nature. All the instrumentation involved in the forward and feedback paths of control configuration are analog. Such systems largely use electromechanical components. The analog controller generates a continuous control on the basis of analog error. Continuous control applications involve the process variables that can change at any instant, for example, flow, temperature, and pressure variables. The process industries, particularly petrochemicals were once heavily dependent on the continuous control systems that could manipulate continuous process variables at all times.

True continuous control systems are virtually extinct now. Gone are the electrical, pneumatic, and mechanical devices that could apply corrective forces directly to a process by mechanically magnifying the forces generated by the process sensors.

Analog control systems (ACS) involve instrumentation devices, viz., sensors and transmitters. In Indian process industries, sensors and transmitters by YUKOGAWA-Blue Star (Japan) and Fisher-Rosemount-(USA) are very popular. Analog control systems are slower than their counterparts, i.e., digital control systems, but offer accurate control. The best and very often encountered example of analog control system is the float mechanism, as shown in Fig. 1.12. A toilet's level control system measures the level in the tank and slowly closes the inflow value as the level rises. This is the simplest continuous controller.



at discrete intervals of time and the control moves/actions are made at discrete intervals of time. A digital control system may involve a digital processor (say, a microprocessor or microcontroller) or a computer. Nowadays, digital control-based control systems are in vogue in industries. The computer offers advantages in instrumentation field through centralized control system. These advantages are optimization, alarm and logging function, historic analysis, trending, sequence control, and self-diagnostic techniques. The digital control systems comprise discrete control systems, sampled data control systems, and other computer-based control configurations. Current trends in digital control systems are discussed here.

1.5.7.2.1 Direct digital control

Direct digital controls (DDC) employ a computer as controller. The control panel is very simple consisting of a digital display and few buttons.

In modern-day DDCs, the engineers offer real-time control through virtual instrumentation, built on a controlling computer with relevant hardware and its driver software. Such a virtual instrumentation for control purposes can be built by using the commercially available virtual instrumentation development software packages like DAISY Lab, and Lab VIEW from National Instruments, USA.

The components/devices required in implementation of direct digital control in an application are sensors, multiplexers, A/D converters, microprocessor, serial input/output ports, memory, D/A controllers, timer/counter, clock, and actuator.

1.5.7.2.2 Discrete control systems

These are opposite to continuous control systems. Continuous and discrete control systems behave very differently and are generally designed according to different mathematical principles. A discrete control system can manipulate a discrete variable only, when the schedule calls for the next operation. Discrete variables change at specified intervals and are subject to discrete control. An assembly line is a classic example of discrete control system. The count-of-completed assemblies is a discrete variable that changes only at the instant, when the line moves forward and a finished product rolls off the line.

1.5.7.2.3 Sampled data control systems

In this control configuration, continuous and discrete control systems come together, say, the process variables change continuously but can only be measured at discrete intervals. Figure 1.13 illustrates the concept of sampled data control system.

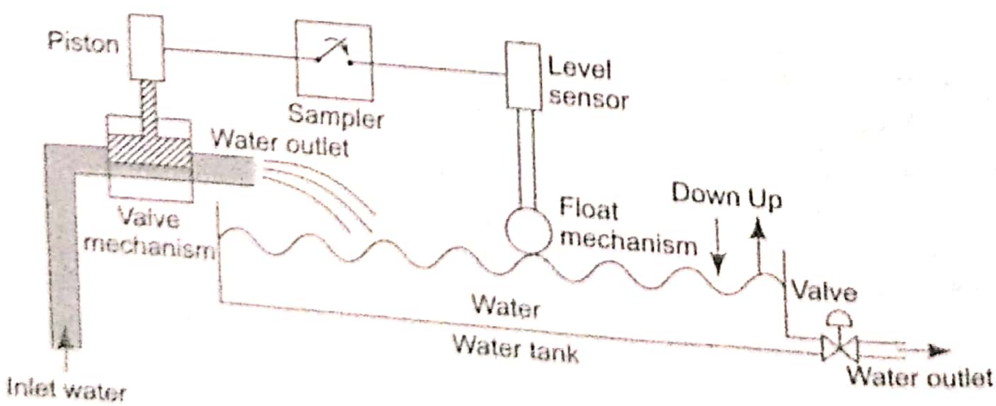


Figure 1.13 A sampled data control system for toilet tank level control system

Here, the switch is the sampler, which closes periodically and sends electronic measurements to the iston.

.5.8 Distributed control systems

distributed control system involves several microcomputers, which can be geographically distributed ver a large area, each assigned with a specific task and all are mutually linked through a data link, vhich can be co-axial or fibre-optic. Each of these microcomputers performs its own task concurrently nd independent of the other microcomputers in the control system. It is parallel processing, which rovides excellent control system reponse time and eliminates the possibility of any single-point ailure, thus, crashing the whole control system set-up. DCS is contrary to centralized computer control opology. Table 1.1 gives a comparison of ACS, discrete control system, and SDCS.

Table 1.1 Comparison of ACS, discrete control system, and SDCS

Control system type	*Control function*	
	Measurement action	***Controlling action***
Analog control system (ACS)	Analog or continuous	Analog or continuous
Discrete control system	Discrete	Discrete
Sampled data control system (SDCS)	Analog or continuous	Discrete

Modern automation problems in the industry require control ranging from monitoring, supervision, and control of a small part of the production plant to the integral control and management of a large plant. It involves hierarchy in the system control operations. A distributed control system (DCS) divides the overall system control needs in the following hierarchical levels:

Level 1 – Process level
Level 2 – Unit control level
Level 3 – Group control level
Level 4 – Process control level
Level 5 – Operation control level

A distributed control system provides the intended control needed at each of these levels and yet this multi-level is well-coordinated so as to give a smooth flow across the various levels.

The first DCS (TDC 2000) was developed by Honeywell company, USA, in 1969 for solving reliability problems.

DCS offers a unique advantage of upgradation without making the entire system obsolete. DCS is supplemented by fibre-optics technology for wide-band communications between different computers in the control systems. Figure 1.14 illustrates the various levels of distributed control system (DCS).

Nowadays, TDC 3000 systems are in vogue, which provide extended control capability over TDC 2000 for continuous as well as batch or sequential processes.

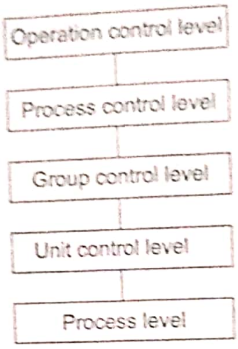


Figure 1.14 Various levels of DCS

1.5.9 Programmable logic controller

The Programmable logic controller (PLC) based systems offer discrete or continuous control. The National Electrical Manufactures Association (NEMA), USA, defines PLC as a digital electronic apparatus with a programmable memory for storing instructions to implement specific functions, such as logic, sequencing, timing, counting, and arithmetic to control machines and processes.

The PLCs were first developed by General Motors Corporation in 1968. In India, PLCs are supplied by TATA Honeywell, GE-Fanuc, Allen-Bradley, etc.

The architecture of programmable logic controllers is shown in Fig. 1.15.

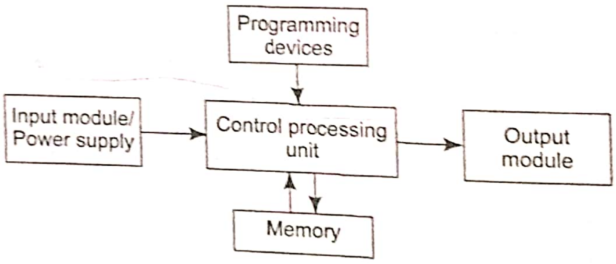


Figure 1.15 PLC general architecture

In PLCs, CPU receives instructions from memory and status information from input devices. A command (output) is generated so as to control a load through motor starters, relays, solenoid valves, lamps etc. The microprocessors used in PLCs are 8-bit, 16-bit, or more advanced depending upon the size and speed requirements of PLC. Even a much faster instruction execution can be achieved by using bit-slice microprocessors within PLCs. Whenever a program is executed for new inputs, the PLC updates all the outputs. This sequence of events is called *PLC program scan*. Thus, program scan in PLCs is the process that involves input reading, control application program execution, and output updating.

Programmable logic controllers today have grown into intelligent decision-making machines with wide scope of applications, which range from variable control functions, data acquisition to report generations, and supervisory control. PLCs are used in numerous industrial control operations for tool manufacturing, tool changing, material handling, chemical batching, plastic injection moulding, ma machine faults monitoring and in diagnostics, transformer units, robot controls, flexible manufacturing systems (FMS), special-purpose machines, etc.

1.5.10 Supervisory control and data acquisition system

A supervisory control and data acquisition (SCADA) system is basically a computer-based control for complete process automation. SCADA is said to be the first step towards automation. In a network of computers offering plant operation control (e.g., DCS), the central computer may be made to work as a SCADA module. Its basic work in that case will be to acquire data from remote locations, remote control of plant, and diagnostics to maintain the complete system and keep it in working condition. Figure 1.16 shows the basic structure of SCADA.

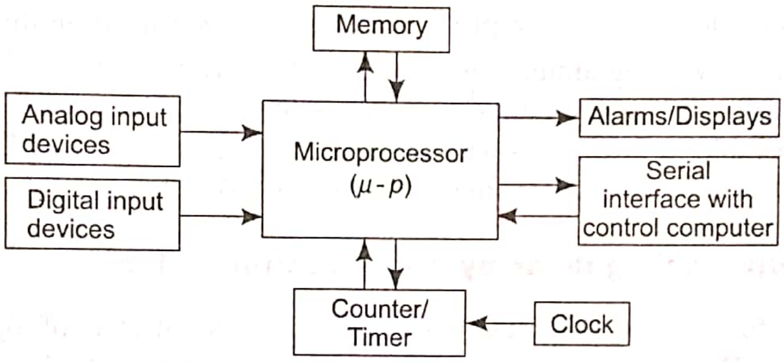


Figure 1.16 SCADA system

The basic functions of SCADA system are given below:

(i) It addresses the channels and reads the data. It is called *polling* or *channel scanning*.
(ii) It converts the read data (from the output of ADC) into equivalent engineering units for analysis and data display/recording.
(iii) The read data is processed by microprocessor for generation of alarms if data item crosses the limit, generation of printout, limit checking, and performance analysis.

Nowadays, distributed SCADA systems are very much in use because of extremely large number of data channels and their interfacing requirements. These involve use of multiplexers at different levels. The distributed SCADAs have to be interfaced with a central computer in star configuration and daisy chain configuration, respectively. In industries, the distributed SCADA systems are called remote terminal units (RTUs). RTUs are popularly used in oil drilling, irrigation canals, etc.

1.5.11 Microcontroller-based systems

Microcontrollers are integrated chips having processor, memory, time/counter, ADCs, DACs, and intercept handling for control purposes. Most commonly used microcontrollers are Z8 from Zilog; M6801 and 68HC11 from Motorola; 8048, 8051, and 8096 series from Intel; IM 6100 from Internal Incorporation; 1650 from General Instruments, etc. Common microcontroller architectures include ARM, MIPS, AVR, PIC, V-850 Power PC, and AT-MEGA 16.

1.5.12 Simple programmable logic devices

A simple programmable logic device (SPLD) is the simplest and most popular programmable logic architecture. Chips for control purposes are conventional discrete fixed logic devices, e.g., a 74LS00-contains four AND gates. Its pinouts are fixed. Routing is done through copper tracking on the PCB (printed circuit board).

SPLDs are composed of logic cells to perform AND and OR operations. In industrial control applications, SPLDs have replaced PROM-based programmable logic devices, like 74LS cells arranged in rows and columns. In these devices, signal routing can be changed by logic equations. Programming is relatively simple, of about the same complexity level as an assembler. Very popular architecture for SPLDs is 22V10, which has 22/40 pins, of which 10 can be used as outputs. AMD were early exponents of SPLDs.

1.5.13 Complex programmable logic devices

In complex programmable logic devices (CPLD), logic cells are arranged on the periphery of a central shared routing resource. Now, programming is a little harder because the signal routing is not a trivial task. This task is similar to the tasks required for routing signals in PCBs. CPLDs are programmed in ABEL, which is comparable to BASIC. Altera was an early exponent of CPLDs with EPROM-based technology. CPLDs are now also available using EPROM or RAM technology from, say, Atmel or Xilinx.

1.5.14 Field programmable gate array based control systems

In FPGA systems, the chip uses an architecture of a two-dimensional array of logic cells as islands in a sea of routing resources. Routing is more complex than that required for CPLDs. FPGAs are typically programmed in languages like verilog or VHDL. FPGAs necessitate use of high-level languages because manual low-level design becomes impractical as designs become large. Verilog is similar to C and VHDL and ADA. Verilog allows functions that VHDL might not and also allows more low-level design controls. VHDL, on the other hand, allows greater high-level design controls. Xilinx was the first big player in FPGAs using RAM-based logic cells. Altera has now become a major player.

1.6 SERVO CONTROL SYSTEMS

A servo control system is a feedback control system for controlling the mechanical signals from process, such as position, velocity, or acceleration. These are the control systems, where the reference or input varies continuously and the control system operates seen that the output follows the reference.

It is also called a follower system or a servo mechanism. Most of the mechanical actuators in mechanical processes requiring control or automation use servo systems, e.g., CNC (computerized numerically coded) machines, where machine tools are operated as per the programmed instructions. A solar power panel tracks the sun continuously for optimum power generation. It is also a servo system. In many control cases like robot hand control, hard disk drive control systems, printers, aircraft automatic landing system, etc., the desired value of the controlled variable (output of the process) or set point is not fixed but constantly changing. In such control applications, a follow-up action is needed which is performed by servo control systems or servo mechanisms.

1.7 REGULATORS OR AUTOMATIC REGULATING SYSTEM

In certain control applications such as voltage control, room temperature control, process pressure temperature controls, etc., the desired value of the controlled variable or the set point in a control system is not changed much but is relatively fixed. A regulator system is a control system where the reference (input) is normally fixed. Regulators are used in such situations. A regulator or an automatic regulating system is a feedback control system in which the set point (reference input) or the desired output (controlled signal) is either constant or slow varying with respect to time and in which the primary task is to maintain the actual output at the desired value in the presence of disturbances.

1.8 PROCESS CONTROL SYSTEMS

Process control systems are feedback control systems, which regulate process outputs or variables such as pH level, temperature, pressure flow, humidity, distribution, batch reaction, etc. Obtaining a process model and then studying its dynamic behaviour are must before designing such control mechanisms.

1.9 SOME EXAMPLES OF CONTROL SYSTEMS

The following are some examples of control systems:

1.9.1 Steam turbine speed control system

A steam turbine speed control system is shown in Fig. 1.17. Whenever load on the turbine changes, the turbine speed changes. The governor acts as a controller and the valve as final control element. The centrifugal governor operates an amplifier, which regulates the opening and closing of valve, and thus, the steam flow passes from boiler on to the blades of turbo-generator. As the generator load increases, the turbine speed reduces. To keep the turbine rotational speed at a reference level (set point), the valve is opened more so that more steam flow takes place from boiler to turbine and to cope up with the difference in speed from the current speed level to the reference speed level and vice-versa in the case of off-loading, thus bringing the turbine to the reference speed.

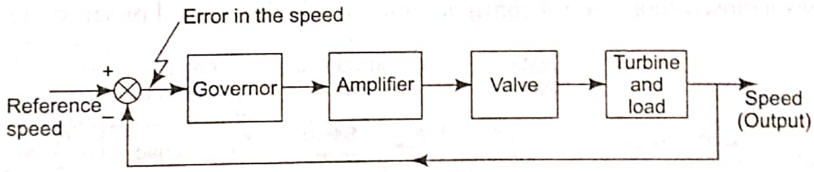


Figure 1.17 Closed-loop speed control of a steam turbine

1.9.2 Manual feedforward and feedback control of temperature

Manual feedforward and feedback control of temperature is shown in Fig. 1.18. A human being closes or opens the valve depending on the flow rate of steam and the temperature of water inside the heater. Thus, it is a closed-loop control system with both feedforward and feedback modes concurrently. The control of flow is based on the feedback of the temperature and the feedforward control of the steam flow rate.

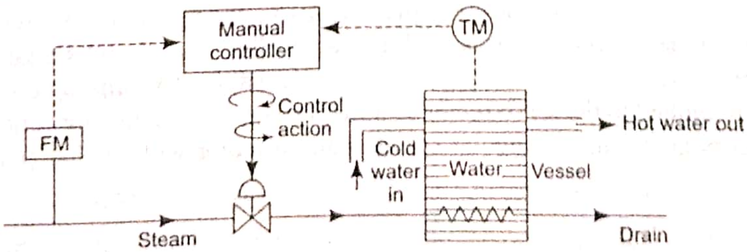


Figure 1.18 Manual control of a heater