

Second Year Degree Course In  
Electrical Engineering (SEM - IV)

SU

# CONTROL SYSTEMS - I



Dr. S. D. RUIKAR

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A TEXT BOOK OF

# CONTROL SYSTEMS – I

FOR  
SEMESTER – IV

SECOND YEAR DEGREE COURSE IN  
ELECTRICAL ENGINEERING

As Per New Revised Syllabus of  
Shivaji University, Kolhapur

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# PREFACE

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It gives me a immense pleasure to present this book "**Control Systems–I**" for the Students of Second Year Degree Course in Electrical Engineering of Shivaji University, Kolhapur.

The book is strictly written as per the New Revised Syllabus of Shivaji University with effective from 2015.

I am sure, the book will also be useful to the teaching faculties while teaching this subject and also student communities.

The book is written such that all the basic concepts are explained in simplified manner, eliminating all complex calculation. It is presented in more conceptual manner rather than mathematical as required by the new examination system.

The objectives of this text are :

- Unit I** : It covers History of Control System, Block diagram representation and Transfer function.
- Unit II** : It covers Introduction to time domain analysis and stability concept.
- Unit III** : It covers Introduction to DC and AC servomotors and transfer functions of all these motors.
- Unit IV** : It covers definition and concepts of Root Locus.
- Unit V** : It covers Introduction to frequency response techniques such as Bode plot, Nyquist criterion etc.
- Unit VI** : It covers Introduction to state space representation and concept of controllability and observability.

I take this opportunity to express my thanks to Shri Dineshbhai Furia, Shri Jignesh Furia and Shri Mallikarjun P. Munde and all the staff members of Nirali Prakashan namely, Mrs. Deepali Lachake (Co-ordinator), for their tremendous dedication and hard work in bringing out this book in an excellent form.

I also thankful to **Mr. Virdhaval Shinde**, Branch Manager, Kolhapur office and **Mr. Ashok Nanaware**, Branch Manager, Sangli District for their valuable help and efforts for promotion of my book.

Suggestions and comments are always welcome for the improvement of this book.

**Pune**

**Authors**

# SYLLABUS

## **Unit I – Modeling and Representation of Control System and Transfer Function (09 hrs)**

History of control system, Laplace transform review, Transfer function of electrical, mechanical, thermal, hydraulic system, Electrical circuits analogs, Block dia. Representation and reduction, types of feedback systems, signal flow graph, Mason's gain rule, SFG.

## **Unit II – Time Domain Analysis an Stability Concept (10 hrs)**

Response of first and second order system, general second order system, response with additional pole and zeros, steady state error for unity feedback system, static error constants and systems type, steady state error specifications, Routh criteria for stability.

## **Unit III – Servo Components (08 hrs)**

Error detectors ,Potentiometer, synchros, optical rotary encoders, DC and AC Servomotors, stepper motor, gear trains, A C and DC tacho-generators, Transfer function and applications of these.

## **Unit IV – Root Locus (06 hrs)**

Definition of root locus, Rules for plotting root loci, Root contour, stability analysis using root locus, effect of addition of pole and zero.

## **Unit V – Frequency Response Technique (08 hrs)**

Bode plot, Nyquist criterion, stability, gain margin, phase margin by Nyquist diagram and bode plot, Determination of transfer function from bode plot.

## **Unit VI – State Space Concept (07 hrs)**

State space representation, phase variable form, converting transfer function to state space and vice versa, Canonical form, companion form, Jordan Canonical form, Solution of state equations. Concept of controllability and observability, eigen values and stability.

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**UNIT III : SERVO COMPONENTS 3.1 – 3.36**

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**UNIT VI : STATE SPACE CONCEPT 6.1 – 6.24**



## Unit-I

# MODELING AND REPRESENTATION OF CONTROL SYSTEM AND TRANSFER FUNCTION

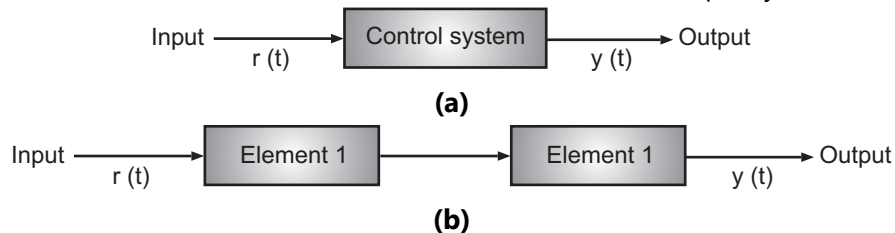
## 1.1 HISTORY OF CONTROL SYSTEM

In the industrial world the field of control engineering is very crucial. Control systems are designed to achieve specified objectives within a given set of constraints. An automatic control system played a very important role in development in science and technology. Such as space, vehicle system, guided missile system. Hence it is necessary to study control system.

**System** : It is an assembly of component to perform a specific job. It consists of Plant, Controller, Feedback, Signal conversion circuitry, Error detector.

**Control System** : A system which control any quantity in a desired manner is called as control system. A physical system or process is to be accurately controlled.

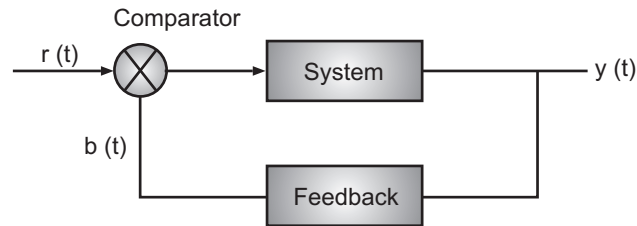
A control system may contain many blocks. Each block represents an element. The diagrammatic representation is known as 'Block Diagram'. Each block has an input and an output. The relationship between input signal and output signal is characteristic of speciality of the block. The signal flows through the blocks in one direction only i.e. in the direction of the arrow. Some of the lines and arrows are not shown here for simplicity.



**Fig. 1.1 : Block diagram of a system**

**Manual Control System** : In an automobile we continuously control the speed and direction by manually controlling accelerator and handle / steering wheel. A manual control system involves a human operator for continuous control. Manual control is complex and fast acting systems.

**Automatic Control System** : If the controlling action is made automatically (output is controlled automatically in desired manner) it is called as automatic control system. All automatic control systems are basically Feedback Control System. An error detector compares input (the desired performance or set point) with the output response. The output response is fed to this comparator through Feedback element.



**Fig. 1.2 : Block diagram of Automatic Control System**

## 1.2 TYPES OF CONTROL SYSTEM

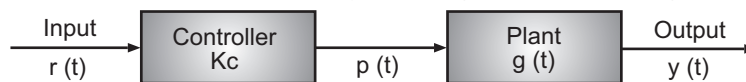
Basically, a control system can be operated in two modes i.e. with and without automatic control. Control system can be classified into two groups based on these modes as,

- Open loop control system
- Close loop control system (Control system with Feedback action)

### 1.2.1 Open Loop Control System

Open loop control system is a control system in which the output is controlled directly by the **input**. It does not correct automatically for variations in output  $[c(t)]$ . A system in which controlling action is independent of the output and environment. This type of control system is called as **open loop control system**. The output remains constant for a constant input signal. The output may be changed to desired value by appropriately changing input signal  $[r(t)]$ . The environmental conditions may cause the output to vary from the desired value. The open loop system can be employed / used only if such variations in output can be tolerated. It is relatively simple and, therefore, often cheap.

A block diagram for the open loop control system is given below in Fig. 1.3.



**Fig. 1.3 : Block diagram of open loop control system**

Here,

$r(t)$  = Input signal i.e. set point

$g(t)$  = Function / Relationship describing how the plant behaves

$p(t)$  = Control output

**Plant** : The part of a system which actually processes the physical parameter and produces output.

**Controller** : The part of a system which converts input signal  $[r(t)]$  to a quantity  $[p(t)]$  which the plant uses to produce desired output.

This is further explained in the examples to follow.

The Set Point  $[r(t)]$  and characteristics of the plant  $[g(t)]$  are unchangeable by control engineer. The point transfer function,  $g(t)$ , has to be determined through experimentation. The only variable that can be adjusted for changing output  $[y(t)]$  is the proportional gain of the controller  $[K_c]$  to produce a different controller output  $[p(t)]$ . For example an open-loop speed control system of DC Motor cannot compensate for load variation (disturbance) and the bearings friction variation (plant parameter).

#### **Examples of Open Loop Control System :**

**1. Road Traffic Signal-Operation :** The road traffic signal regulates the traffic flow at the square at the crossing of two roads. The time setting of timers for turning on and off the red and green lights is not based on density of vehicles on the road. The traffic signal does not take in to account traffic density. It keeps on sequentially operating as per setting. The system operates in Open Loop.

The moment there is a traffic jam, a police-man turns off the traffic lights. He allows the traffic for more time in the direction density. This clears the jam. The system now operates in closed loop i.e. the police-man takes feedback of traffic density through his eyes.

**2. Washing Machine :** We wash clothes in a washing machine. The washing machine goes through the fixed washing cycle as programmed by the user. The washing duration is not based on cleanliness of clothes. The system operates in Open Loop.

If we decide washing duration based on the clarity of the rinsed water outlet. We can increase or decrease washing duration based on this. Then the washing machine system will operate in closed loop.

The concept of feedback is usefully employed in many control systems. The introduction of feedback gives rise to possibility of undesirable oscillations. This means a police-man may make frequent changes in the directions to allow traffic flow and washing machine may keep on washing till clothes are torn out and only pure water comes out.

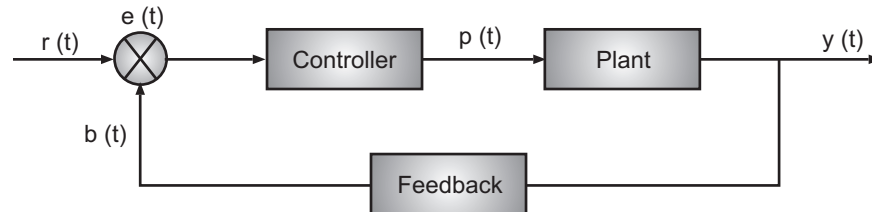
### **1.2.2 Closed Loop Control System**

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In a closed loop control system, the input signal to the controller is affected by the system **output** and the environment. It is more accurate and effective in producing specific system output than an open loop control system. This system uses feedback from output. That's why it is also called as Feedback Control System (FCS). A more accurate system would be a **closed loop system**. It utilizes a feedback loop to create **an error signal** to control output. It consists of the following components.

- 1. Input :** What is fed into the system.
- 2. Plant :** Performs some function on the input and error signal.

3. **Output** : The net result of what the plant does to the input and error.
4. **Feedback** : It samples output of plant and sends signal to summing junction. Used to help in controlling the output.
5. **Summing Junction** : Algebraically combines the feedback signal  $[b(t)]$  with the input signal  $[r(t)]$  to produce error signal  $[e(t)]$ , which in turn controls the output  $[c(t)]$  in a desired manner.



**Fig. 1.4 : Block diagram of close loop control system**

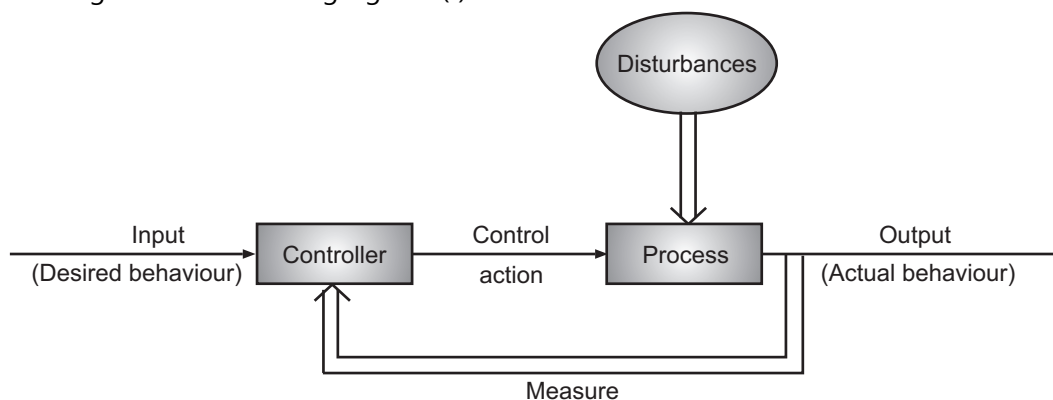
An output variable  $[y(t)]$ , called the response, is adjusted by the error signal  $[e(t) = r(t) - b(t)]$  by the controller. The controller produces output  $p(t)$ , so as to make error  $e(t)$  as small as possible.

**Feedback** : Feedback is an essential requirement for the control of any process. It consists of various transducers measuring the conditions on the rig and feeding this information back to the controller.

The examples of closed-loop (feedback) Control Systems are,

**Feedback Control System** : The most common control strategy is feedback or closed loop control. The process output is monitored, and control actions are taken to counteract deviations from required behavior.

**Comparator or Error Detector** : To compare the feedback signal  $b(t)$  with the reference input and generated actuating signal  $e(t)$ .



**Fig. 1.5 : The Closed-loop (feedback) Control Strategy**

**Unity Feedback Control System** : If the entire output is used as feedback then the system is called as unity feedback system.

## Examples of Closed Loop Control Systems

### 1. Servo System (Servomechanism)

It is a feedback control system in which the output is mechanical position or its time derivatives such as velocity, acceleration. In a servomechanism, the output has to follow a varying input.

Examples of servo control are

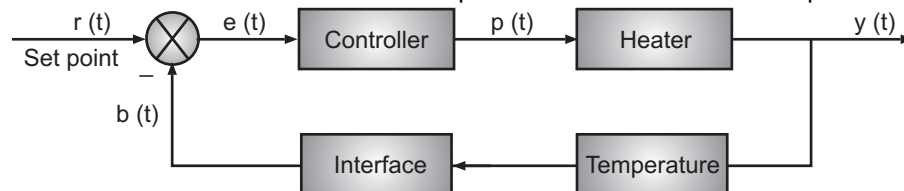
1. Machine tool position control
2. Missile launchers
3. Aircraft Automatic Landing System
4. Robot Manipulator : Feedback is taken through a digital camera. The feedback gives present position of the robot arm and it is compared with the desired position. The difference gives the error. The controller will produce output so as to minimize the error.

### 2. Automatic Regulators

It is feedback control system in which for a present value of reference input, the output is kept constant at its desired value. The purpose of regulator is to keep the output constant.

Examples of automatic regulating system are

1. Voltage Stabilizer
2. Oven Temperature regulator : A temperature sensor is used to measure temperature, which is the output variable. It is fed to the controller through an interface. The controller will turn on-off the heater to maintain temperature constant at the set point.



**Fig. 1.6 The Closed-loop (feedback) Control Strategy for Temperature Control**

3. Frost-freeze Refrigerator
4. Speed control system for an engine : If engine speed drops (say due to increased load) open throttle a little (supply more fuel) and if engine speed increases (say due to drop in load) close throttle a little (supply less fuel).

### 3. Process Control Systems

These are feedback control systems used for controlling the parameters of manufacturing process.

The set point is varied as per time schedule to carry out a particular sequence of operations through a program.

Example : Maintaining Chemical concentration in liquids, liquid levels, pressures, temperatures, etc.

#### 4. Vehicle Driving with Constant Speed

As the road condition changes one has to change accelerator opening to maintain the speed constant.

#### 5. Speed Control of DC Motors

One of the older factories is currently being revamped to accommodate the assembly of a new product line. In order for the factory to continue assembly of old products as well as the new one, the conveyor system will have to be modified to allow for variable speeds. Tests on both open and closed loop DC motor control systems to determine the optimum settings to meet all stated criteria.

It was determined that a closed loop control system would be better suited for a conveyor belt application. A closed loop system can maintain a constant angular velocity under varying frictional loads, which are likely to occur in the manufacturing process. Furthermore, the time required to reach the steady state speed of the motor is less for the closed loop system resulting in a more responsive system overall.

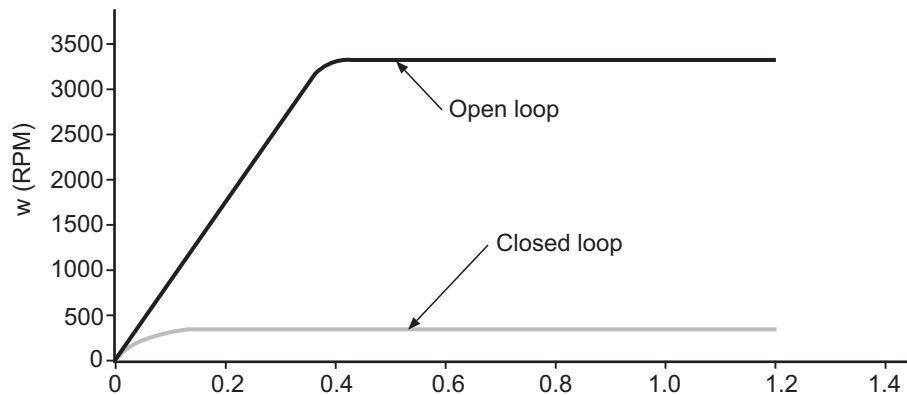
The DC motor is driven by an electrical power supply that acts as an amplifier for computer D/A output. The angular velocity of the motor is measured by a tachometer that outputs proportional to the angular velocity. The output from the tachometer and the power supply is displayed on an oscilloscope and recorded by the computer.

1. **Open Loop Control** : Several step responses are recorded as the input voltage was from 0 to 20 volts.
2. **Closed Loop Control** : Data is collected by varying the desired rotational rate, the proportional gain and the saturation voltage.

**Open Loop Control** : We have to measure the step response of the open loop system subjected to varying input voltages. When the motor is subjected to an additional frictional force, the angular velocity of the motor decreases rapidly and the input voltage remains constant. Consequently, an open loop control system can not maintain constant speed as the load on the motor is not uniform at all times and the characteristics of the motor may deviate due to climatic inconsistencies.

**Closed Loop Control** : The closed loop steady state speed of the motor is reached in significantly lower time than that of the open loop steady state speed.

The open loop is not a good way to set the motor speed because, it does not compensate for any extra friction of the motor; unlike the closed loop where the voltage increased to compensate for added friction. Therefore it is recommended to use the closed loop motor system for the conveyor belt.



**Fig. 1.7 : Plot of Open Loop and Closed Loop Rotational Speed ( $\omega_{ss}$ ) Against Time**

**Toilet Water Tank :** Objective is to maintain desired water level of flushing water, so that a fixed quantity of water is filled and then filling stops. A ball-cock mechanism is used. As the tank gets filled a ball floating on the water in the tank starts closing the cock and at the desired level of water the inlet water supply to the tank is closed.



**Fig. 1.8 : Toilet water tank**

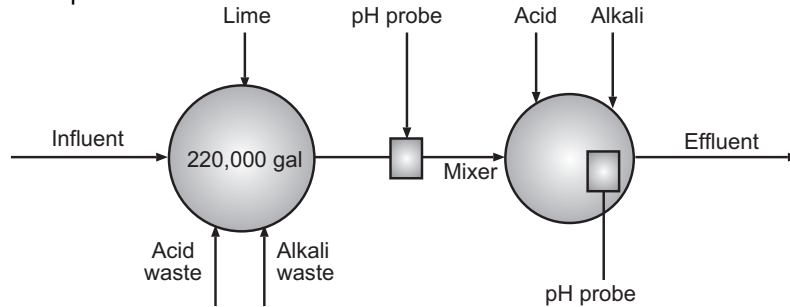
**pH Control System :** The pH is measured by an electrode system. The signals are transmitted to a control point.

If operating with an acid condition, the sensor reacts to a pH below the desired level and starts the alkali feeder. The feeder pumps until the predetermined condition, pH 7, is reached and then stops.

There are many ancillary devices possible e.g. annunciation, recording, alarm, manual override, etc. Various indicating lights and gauges may be mounted on a panel. The front panel incorporates a flow diagram of the plant units. The operator can determine the operating condition of each component at a glance.

A plating operation consists of a sulfuric acid bath, hydrochloric acid and several alkali rinses. Various acid/alkali wastes are collected in a large tank. The capacity of the tank will be sufficient to hold one day's production capacity. The equalized flow from the tank will be

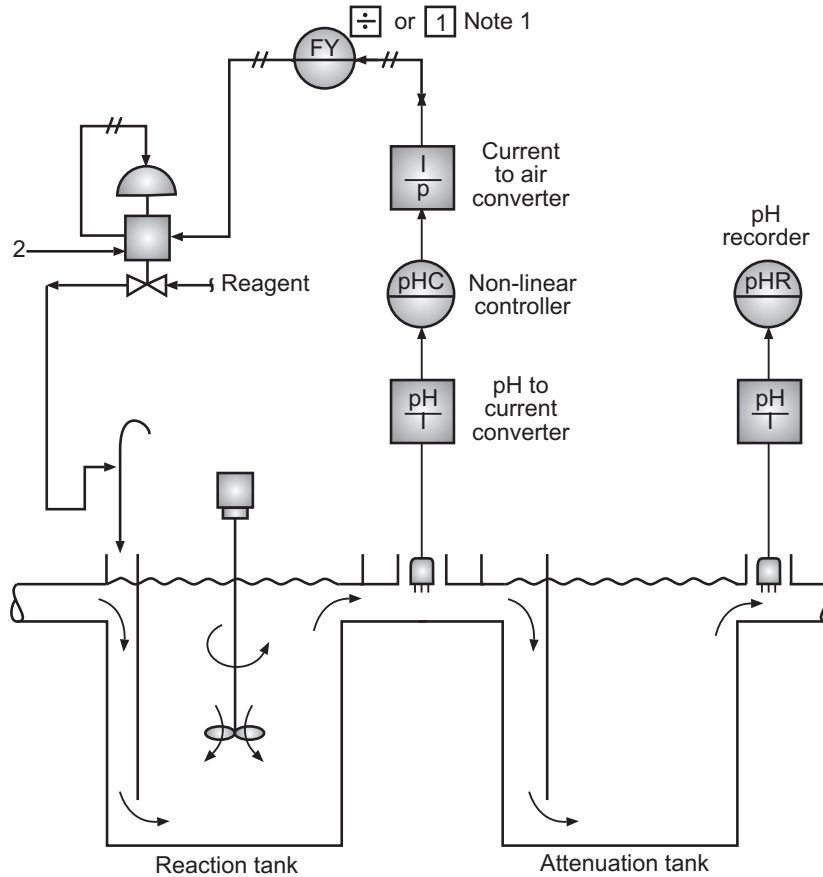
released to a neutralization tank. Regardless of the input pH, it is necessary that the effluent pH be  $7 \pm 1$ . All operations are to be fully automated, and controllable from the central control room, with manual overrides at the CCR and local alarms include : failure to meet pH, loss of flow, loss of pressure.



**Fig. 1.9 : Model of pH control system**

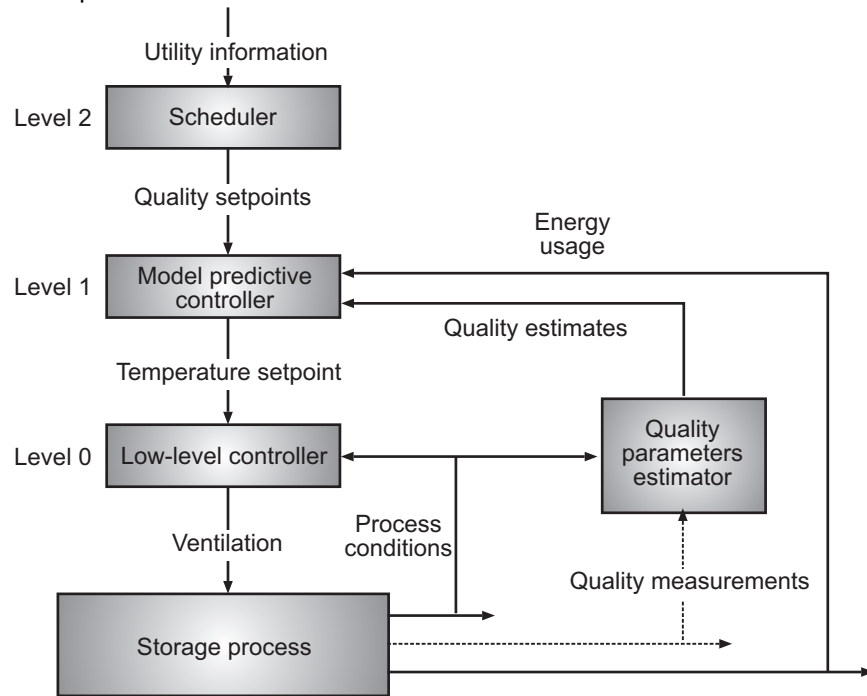
**pH Controller : A Feedback Control System**

The result is looked at and this information paces the amount of chemical which delivered the influent.



**Fig. 1.10 : The Closed-loop (feedback) Control Strategy for pH control system**

**Process Control of Perishable Storage :** Agricultural or agro-material products are routinely undergoing various post-harvest processes. Dynamic process modelling involves dynamical aspect that are introduced by varying properties of the agro-material, external disturbances and setpoint, changes. A dynamical, model is necessary for (model-based) control purposes. It enables monitoring of product quality in the process and the use of feed forward control through the prediction capabilities of the physical model. Product quality is translated into setpoints for the process.



**Fig. 1.11 : The Closed-loop (feedback) Control Strategy for Process Control of Perishable Storage**

### Comparison between Open Loop and Closed Loop Control System

Open loop Control system	Closed loop control system
1. It is less stable.	1. It is more Stable.
2. Output of open loop control system can't be controlled automatically.	2. Output of closed loop control system can be controlled automatically.
3. Error detector and feed back elements are absent.	3. Error detector and feedback elements are present.
4. Simple in construction and easy for maintenance.	4. It is complicated in construction.
5. Stability is not a problem.	5. Stability of a system is problem.
6. Cost is low.	6. Cost is high.
7. It is inaccurate and unreliable.	7. Highly accurate and reliable.

# Control Systems-I



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