**The lecture 1**

**Introduction to systems**

Most systems that surround us are multidimensional, extremely complex, time varying, and nonlinear in nature as they are comprised of large varieties of actively or passively interacting subsystems. These systems consist of interacted subsystems, which have separate and conflicting objectives. The term *system* is derived from the Greek word *systema*, which means an organized relationship among functioning units or components. It is used to describe almost any orderly arrangement of ideas or construct. According to the *Webster’s International Dictionary*, “A system is an aggregation or assemblage of objects united by some form of regular interaction or interdependence; a group of diverse units so combined by nature or art as to form an integral; whole and to function, operate, or move in unison and often in obedience to some form of control.…”

A system is defined to be a collection of entities, for example, people or machines that act and interact together toward the accomplishment of some logical end. In practice, what is meant by “the system” depends on the objectives of a particular study. The collection of entities that compose a system for one study might be only a subset of another larger system. For example, if one wants to study a banking system to determine the number of tellers needed to provide adequate service for customers who want just to encash or deposit, the system can be defined to be that portion of the bank comprising of the tellers and the customers. Additionally, if, the loan officer and the safety deposit counters are to be included, then the definition of the system must be more inclusive accordingly. The state of a system is to be defined as an assemblage of variables necessary to describe a system at a particular instant of time with respect to the objectives of the study. In this case of study of a banking system, possible state variables are the number of busy tellers, the number of customers in the bank, and the line of arrival of each customer in the bank.



Figure 1

The fundamental feature in the system’s concept is that all the aggregation of entities united, have a regular interaction, as a finite number of interfaces as shown in Figure 1.1. Considering a hierarchy among systems, a system can also be expressed as a collection of various subsystems and the subsystem is a further collection of interconnected components. The system behavior can be comprehended as combined interconnected components behavior. So, a large system can be regarded as a collection of different interconnected components.

More appropriately, a large-scale system may be viewed at the supremum of the hierarchy

and components at the bottom most level (root level). The power of the system’s concept is its sheer generality, which can be emphasized by general systems theory.

Some examples of the systems are

• Esoteric systems

• Medical/biological systems

• Socioeconomic systems

• Communication and information systems

• Planning systems

• Solar system

• Environmental systems

• Manufacturing systems

• Management systems

• Transportation systems

• Physical systems—electrical, mechanical, thermal, hydraulic systems, and combinations of them

Every system consists of subsystem or components at lower levels and supersystems at

higher levels. One needs to be extremely careful to define such a hierarchically nested system because this will determine the kind of results one will obtain.

A system is characterized by the following attributes:

• System boundary

• System components and their interactions

• Environment



Figure 2

**System boundary**

To study a given system, it is necessary to determine what comprises (falls inside and what

falls outside) a system. For this a demarcation is required to differentiate entities from the environment. Such a partition is called a system boundary. The system boundaries are observer-dependent, time-dependent, and most importantly system-dependent. The different observers may draw different boundaries for the same system. Also, the same observer may draw the system boundaries differently for different times.

Finally, they may also be drawn differently with respect to the nature of the study, that is, steady state or transient. For example, in case of steady-state study of series R–L circuit,

only R is to be included in the system boundary, but in transient study, both R and L must

be considered in the system.

Some salient points about the system boundary are

* It is a partitioning line between the environment and the system.
* System is inside the boundary and environment is outside the system.
* A real or imaginary boundary separates the system from the rest of the universe, which is referred to as the environment or surroundings.
* System exchanges input–output from its environment.
* This boundary might be material boundary (like the skin of a human body) or immaterial boundary (like the membership to a certain social group).
* Considering a system boundary in systems analysis and evaluation is of immense importance as it helps in identifying the system and its components. The interaction between a system and its environment takes place mainly at the boundaries. It determines what can enter or leave a system (input and output).
* System boundary may be crisp (clearly defined) or fuzzy (ill defined). In crisp boundaries, it is quite clear that what is inside the boundary (i.e., part of system) and what is outside the boundary (i.e., part of environment). In fuzzy boundaries, it is not very clear whether a particular component belongs to the environment or the system.

**System Components and Their Interactions**

System component is a fundamental building block. It is quite easy to find the input–output relations for the system components with the help of some fundamental laws of physics, which is called the mathematical model for components. It may be written in the form of difference or differential equations. They are pretty simple and easily understandable. Business system environment includes customers, suppliers, other industries, and government. Its inputs include materials, services, new employees, new equipment, facilities, etc. Output includes product, waste materials, money, etc.

* It is static or dynamically changing with time, input, or state of the system.
* Interaction may be constrained or nonconstrained type.
* The component interaction may be unidirectional or bidirectional.
* Interaction strength may be 0, 1, or between 0 and 1.
1. If interaction strength is zero (0) then there is no interaction.
2. If interaction strength is one (1) it means full interaction and if the interaction strength lies between zero and one, then the interaction is partial interaction.

**Environment**

A living organism is a system. Organisms are open systems: they cannot survive without continuously exchanging matter and energy with their environment. When we separate a living organism from its surrounding, it will die shortly due to lack of oxygen, water, and food. The peculiarity of open systems is that they interact with other systems outside of themselves. This interaction has two components: input, that is, what enters the system from outside the boundary, and output, that is, what leaves the system boundary to the environment. In order to speak about the inside and the outside of a system, we need to be able to distinguish between the system and its environment, which is in general separated by a boundary (for example, living systems, skin is the boundary). The output of a system is generally a direct or indirect result to a given input. For example, the food, drink, and oxygen we consume are generally separated by a boundary and discharged as urine, excrements, and carbon dioxide. The transformation of input into output by the system is usually called throughput.

**Classification of systems**

Systems can be classified on the basis of time frame, type of measurements taken, type of

interactions, nature, type of components, etc.

**According to the time frame**

Systems can be categorized on the basis of time frame as

* Discrete
* Continuous
* Hybrid

A ***discrete***system is one in which the state variables change instantaneously at separated

points in time, for example, queuing systems (bank, telephone network, traffic lights, machine breakdowns), card games, and cricket match. In a bank system, state variables are the number of customers in the bank, whose value changes only when a customer arrives or when a customer finishes being served and departs.

A ***continuous***system is one in which the state variables change continuously with respect

to time, for example, solar system, spread of pollutants, charging a battery. An airplane

moving through the air is an example of a continuous system, since state variables such as

position and velocity can change continuously with respect to time.

Few systems in practice are wholly discrete or wholly continuous, but since one type of

change predominates for most systems, it will usually be possible to classify a system as

being either discrete or continuous.

A ***hybrid*** system is a combination of continuous and discrete dynamic system behavior.

A hybrid system has the benefit of encompassing a larger class of systems within its structure, allowing more flexibility in modeling continuous and discrete dynamic phenomena,

for example, traffic along a road with traffic lights.

**According to the complexity of the system**

Systems can be classified on the basis of complexity, as shown in Figure 3.

* Physical systems
* Conceptual systems
* Esoteric systems

***Physical systems***can be defined as systems whose variables can be measured with physical

devices that are quantitative such as electrical systems, mechanical systems, computer systems, hydraulic systems, thermal systems, or a combination of these systems. Physical system is a collection of components, in which each component has its own behavior, used for some purpose. These systems are relatively less complex.

***Conceptual systems***are those systems in which all the measurements are conceptual or

imaginary and in qualitative form as in psychological systems, social systems, health care

systems, and economic systems. Conceptual systems are those systems in which the quantity of interest cannot be measured directly with physical devices. These are complex systems.

***Esoteric systems***are the systems in which the measurements are not possible with physical

measuring devices. The complexity of these systems is of highest order.

**According to the interactions**

Interactions may be unidirectional or bidirectional, crisp or fuzzy, static or dynamic, etc. Classification of systems also depends upon the degree of interconnection of events from none to total. Systems will be divided into three classes according to the degree of interconnection of events.

1. *Independent—*If the events have no effect upon one another, then the system is classified as independent.

2. *Cascaded—*If the effects of the events are unilateral (that is, part A affects part B, B affects C, C affects D, and not vice versa), the system is classified as cascaded.

3. *Coupled—*If the events mutually affect each other, the system is classified as coupled.





**According to the Nature and Type of Components**

1. Static or dynamic components

2. Linear or nonlinear components

3. Time-invariant or time-variant components

4. Deterministic or stochastic components

5. Lumped parametric component or distributed parametric component

6. Continuous-time and discrete-time systems

**According to the uncertainties involved**

***Deterministic***—No uncertainty in any variables, for example, model of pendulum.

***Stochastic***—Some variables are random, for example, airplane in flight with random wind

gusts, mineral-processing plant with random grade ore, and phone network with random arrival times and call lengths.

***Fuzzy systems***—The variables in such type of systems are fuzzy in nature. The fuzzy variables are quantified with linguistic terms.

***Static vs. Dynamic Systems***

Normally, the system output depends upon the past inputs and system states. However, there are certain systems whose output does not depend on the past inputs called static or memoryless systems. On the other hand, if the system output depends on the past inputs and earlier system states which essentially implied that the system has some memory elements, it is called a dynamic system. For example, if an electrical system contains inductor or capacitor elements, which have some finite memory, due to which the system response at any time instant is determined by their present and past inputs.

***Linear vs non-linear systems***

The study of linear systems is important for two reasons:

1. Majority of engineering situations are linear at least within specified range.

2. Exact solutions of behavior of linear systems can usually be found by standard techniques.

Except, a handful special types, there are no standard methods for analyzing nonlinear systems. Solving nonlinear problems practically involves graphical or experimental approaches. Approximations are often necessary, and each situation usually requires special handling. The present state of art is such that there is neither a standard technique which can be used to solve nonlinear problems exactly, nor is there any assurance that a good solution can be obtained at all for a given nonlinear system. The *Ohm’s law* governs the relation between the voltage across and the current through a resistor. It is a linear relationship because voltage across a resistor is linearly proportional to the current through it.

$$V∝I$$

But even for this simple situation, the linear relationship does not hold good for all conditions. For instance, as the current in a resistor increases exceedingly, the value of its resistance will increase due to increase in temperature of the resistor:

$$R\_{t}=R(1+αT)$$

The amount of change in resistance is being dependent upon the magnitude of the current,

and it is no longer correct to say that the voltage across the resistor bears a linear relationship

to current through it. Similarly, the *Hooke’s law* states that the stress is linearly proportional to the strain in a spring. But this linear relationship breaks down when the stress on the spring is too great. When the stress exceeds the elastic limit of the material of which the spring is made, stress and strain are no longer linearly related. The actual relationship is much more complicated than the Hooke’s law situation, that is,

$$Stress(σ)\infty Strain(ε)$$

Therefore, we can say that restrictions always exist for linear physical situation, saturation,

breakdown, or material changes with ultimate set in and destroy linearity. Under ordinary circumstances physical conditions in many engineering problems stay well within the restrictions and the linear relationship holds good.

Ohm’s law and Hooke’s law describe only special linear systems. There exist systems that are much more complicated and are not conveniently described by simple voltage–current or stress–strain relationships.