Design for Reliability

Reliability is defined as the probability that a component, equipment or system will satisfactorily perform its intended function under given circumstances.
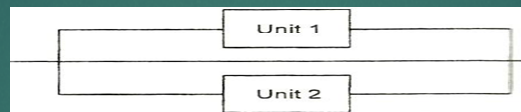
Improving Reliability
• Making failures less likely to happen in the first place
        (e.g. By maintaining the equipment properly or fitting more reliable equipment)
• Making changes such that the overall system continues to function satisfactorily even when a failure occurs
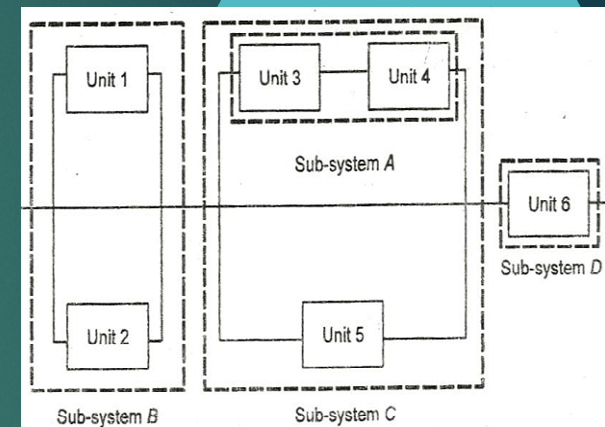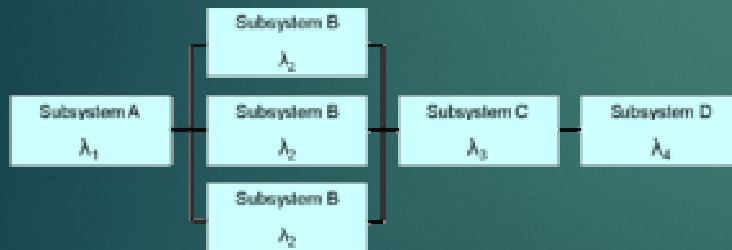   (e.g. By fitting standby equipment)

Reliability Network

Series Connection

Parallel Connection

Series-Parallel Network

4.17 System reliability

System reliability stands for the reliability of a system consisting of two or more components. It is difficult to estimate the reliability of the system composing of many elements. Following approach is used to determine the reliability of a system.

Method of determining system reliability

Following are the steps involved in one approach of finding the system reliability of a system consisting of sub-system components.

1. Reliability of sub-systems and individual components of the system is determined.

2. Manner in which sub-systems and components are arranged in the system is identified. i.e., logical manner in which elements are arranged is represented in a block diagram.

3. Based on the manner in which the sub-systems are connected in the system, the probability rules are applied to find the system reliability.
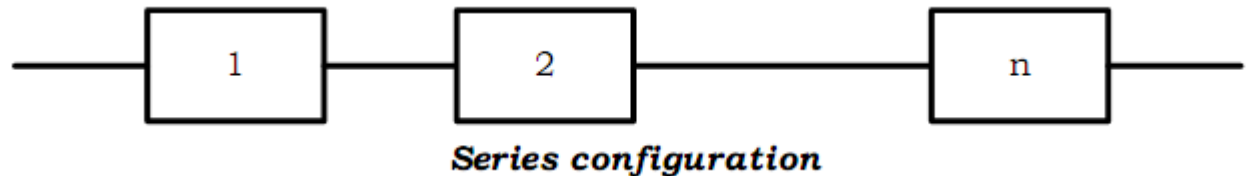
4.17 System reliability

Types of configurations

Various types of configurations are discussed below.

Series configuration

In series configuration elements or components are arranged in a series. Figure shows a system consisting of '*n*' units which are connected in series. For the successful operation of the system it is necessary that all 'n' units function satisfactorily. If the successful operation of each unit is independent of the successful operation of the remaining units (for example heat dissipated by the first unit which may be a resistor should not affect the performance of remaining units), then system reliability is expressed as follows

Series configuration

$$\text{System reliability, } P(S) = P(X_1) \times P(X_2) \times P(X_3) \times \ldots \times P(X_n)$$

where, P(X1) is the reliability of the first unit, P(X2), reliability of the second unit and so on. So, system reliability will be worse than the poorest component in the system. For example, if 0.6 is the reliability of the component having the least reliability and other components has reliabilities 0.7, 0.8 and 0.9 connected in series then,

Series configuration

$$P(S) = 0.6 \times 0.7 \times 0.8 \times 0.9 = 0.3024.$$

The system failure rate is the sum of failure rates of individual components.

$$\text{i.e.,} \quad \lambda_s = \sum_{i=1}^{n} n_i \lambda_i$$

where, λ_s is the failure rate of system and λ_i is the failure rates of individual components and n_i is the number of each component

$$MTBF \text{ or } MTTF = \frac{1}{\lambda_s}$$ and reliability is given by, $P(S) = e^{(-\lambda_s t)}$

4.17 System reliability

Parallel configuration

In parallel configuration elements or components are arranged in a parallel. Figure shows a system consisting of *n* units which are connected in parallel. In parallel configuration, satisfactory functioning of any one of the elements leads the successful operation of the system. If 'n' elements are identical and independent of one another, then,

Parallel configuration
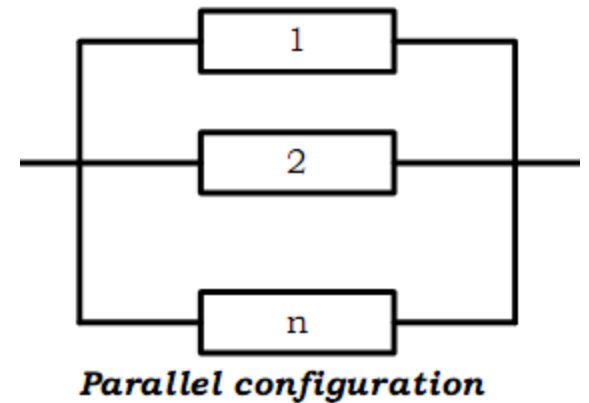
$$System\ reliability,\ P(S) = 1 - [1 - P(X)]^n$$

If two elements are connected in parallel, then the system reliability is found using the probability expression.

$$P(a\ or\ b) = P(a) + P(b) - P(a) \times P(b)$$

where, P(a) is the reliability of one element in the parallel configuration and P(b), the reliability of other. Hence, P(S) is always greater than either P(a) or P(b).

4.17 System reliability

Mixed configuration

In practice, the components of a system are not connected in simple series or parallel manner. A simple structure of a non-series parallel structure is represented in the figure.


Mixed configuration
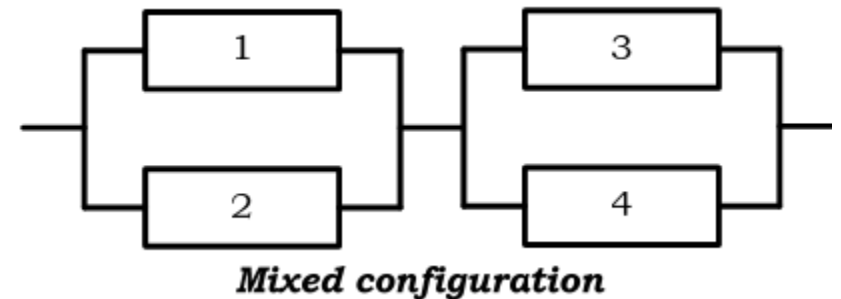
4.18 Redundancy

Redundancy is the existence of more than one means for performing a required function. Redundancy does not mean to have duplicate hardware. This involves deliberate creation of new parallel paths in the system. For example, to have generator and KSEB supply for power supply in a hospital. In parallel configuration, satisfactory functioning of any one of the elements leads the successful operation of the System. Therefore redundancy is a simple method for improving the reliability of a system when the element reliability cannot be increased. Though successful operation of one of the elements is required for the success of
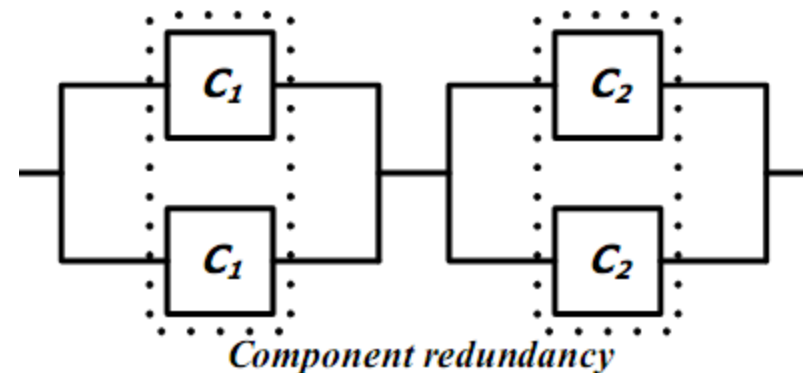
4.18 Redundancy

the system, deliberate use of both elements increases the probability of success of the system causing the system to be redundant (surplus). Few areas where redundancy is extensively used are : aircraft propulsion system, satellite communication system, temperature control system for space vehicle, etc. Various approaches for introducing redundancy are *unit redundancy and component redundancy.*

In *unit redundancy*, additional path for the entire system itself is provided. In the figure shown, C1 and C2 are components of a system and two such components are provided in parallel resulting in improving the reliability of the entire system.
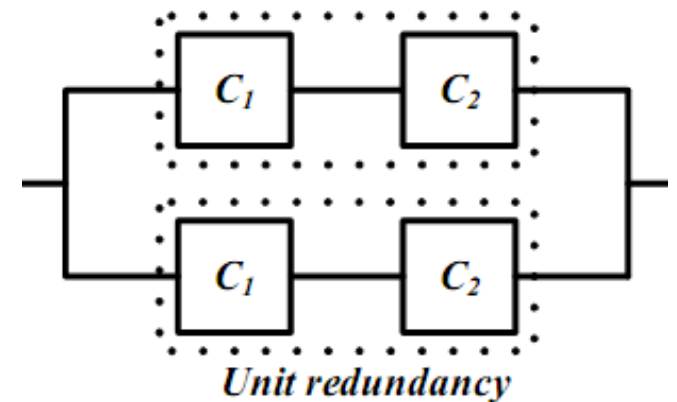
Unit redundancy

In *component redundancy*, additional path for each component of the system is provided. In the figure shown, additional components of C 1 and C 2 which are the individual components of the system are provided resulting in improving the reliability of each component thereby the entire system.

Component redundancy

4.18 Redundancy

Problems : 1

An electronic equipment is operated by 4 dry cells, each giving 1.5 $volts$. The cells are connected in series. The probability of the successful operation of each cell under the given operating conditions is 0.90. Calculate the reliability of the power system.

Solution : 1

The batteries are connected in series and the successful operation of one battery does not affect the operation of other batteries. Hence, the events are independent.

$$P(S) = 0.9 \times 0.9 \times 0.9 \times 0.9 = 0.656$$

Problems : 2

In an hydraulic control system, the connecting linkage has a reliability factor of 0.98. The pressure sensor actuates the linkage has a reliability factor of 0.92. The pressure sensor which actuates the valve has a reliability factor of 0.90. Assume that all the three elements namely; the actuator, the linkage and the hydraulic valve are connected in series with independent reliability factors. What is the reliability of the control system?

Solution : 2

Given, reliabilities of components connected in series are 0.98, 0.92 and 0.9.

We have, system reliability, $P(S) = P(X_1) \times P(X_2) \times P(X_3) \times .... \times P(X_n)$

$$\therefore P(S) = 0.98 \times 0.92 \times 0.9 = 0.811$$

Problems : 3

A system has 10 identical components connected in series. It is desired that the system reliability be 0.95. Determine how good each component be.

Solution : 3

As the components are connected in series,

System reliability, $P(S) = P(X_1) \times P(X_2) \times P(X_3) \times .... \times P(X_n)$

$$P(S) = 0.95 = p^{10}$$

$$\therefore p = 0.9949$$

Problems : 4

Consider a system consisting of 3 identical units connected in parallel. The unit reliability factor is 0.90. If the unit failures are independent of one another and if the successful operation of the system depends on the satisfactory performance of any one unit, determine system reliability

Solution : 4

Given, $P(S) = 0.90$

For parallel system, system reliability, $P(S) = 1 - [1 - P(X)]^n$

i.e., $P(S) = 1 - (1 - 0.90)^3 = 0.999$

4.18 Redundancy

Problems : 5

A parallel system is composed of ten identical independent components. If the system reliability *P(S) is to be 0.95,* how poor the components can be.

Solution : 5

Let reliability of the system be *P(S)* and reliability of the components be *P(X)*
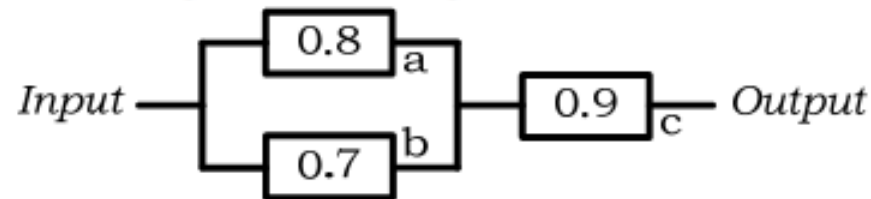
$$P(S) = 0.95 = \left[1 - [1 - P(X)]^n \right] = \left[1 - [1 - P(X)]^{10}\right]$$

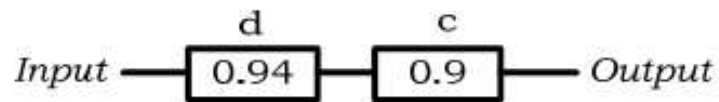$$\therefore P(X) = 0.2581$$

4.18 Redundancy

Problems : 6

Determine the system reliability of the system shown.

System reliability-Problem-6

Solution : 6

Above system can be reduced to the following system by replacing the parallel path by an equivalent single path.

System reliability-Problem-6-Solution

$P(a \text{ or } b) = P(a) + P(b) - P(a) \times P(b) = 0.8 + 0.7 - (0.8 \times 0.7) = 0.94$
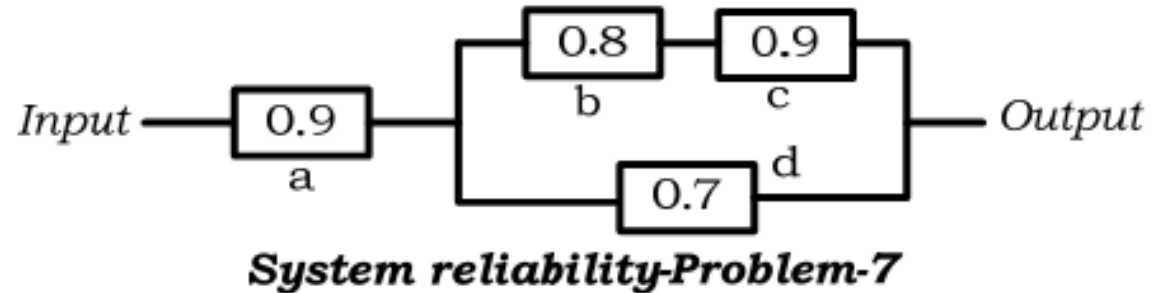
The reliability of the system is computed as follows.

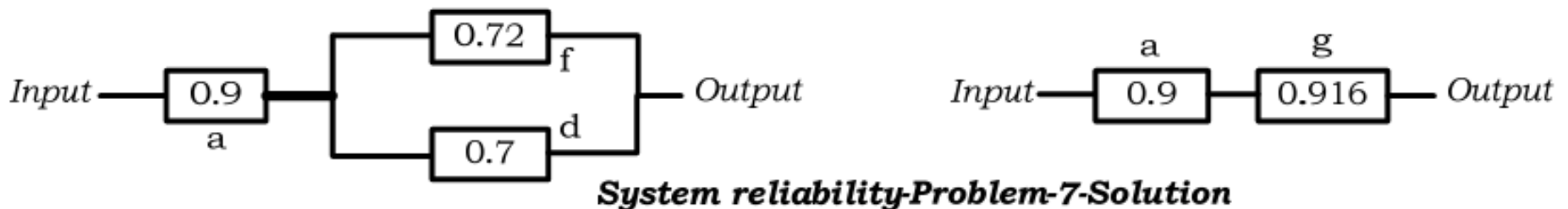$P(S) = P(d) \times P(c) = 0.94 \times 0.9 = 0.846$

4.18 Redundancy

Problems : 7

Determine the system reliability of the system shown below.

System reliability-Problem-7

Solution : 7

The above system is modified to obtain the following system by replacing 'b' and 'c' elements by a single element 'f'. Further the system is reduced by replacing 'f' and 'd' by a single element 'g'.
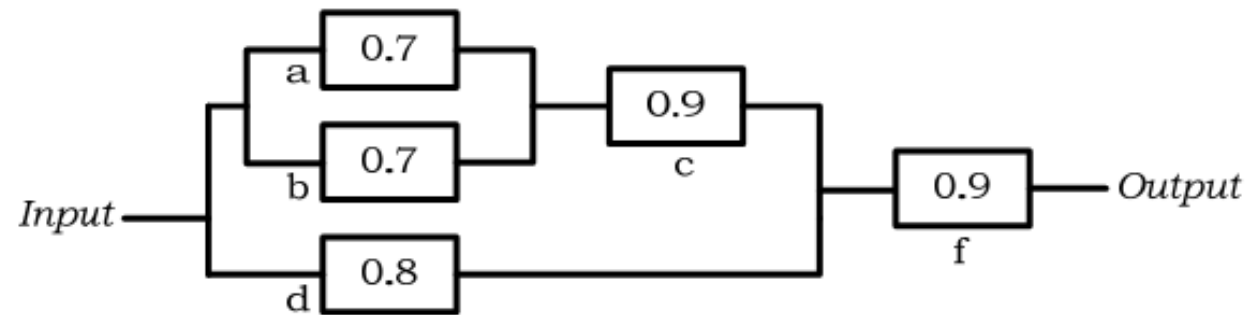

System reliability-Problem-7-Solution

The reliability of the above system computed as follows.

$$P(S) = P(a) \times P(g) = 0.9 \times 0.916 = 0.8244$$

4.18 Redundancy

Problems : 8

Determine the system reliability of the system shown below.

System reliability-Problem-8

Solution : 8

Sub-system containing parallel elements 'a' and 'b' are reduced to one element named 'g'.

$$P(g) = P(a) + P(b) - P(a) \times P(b)$$
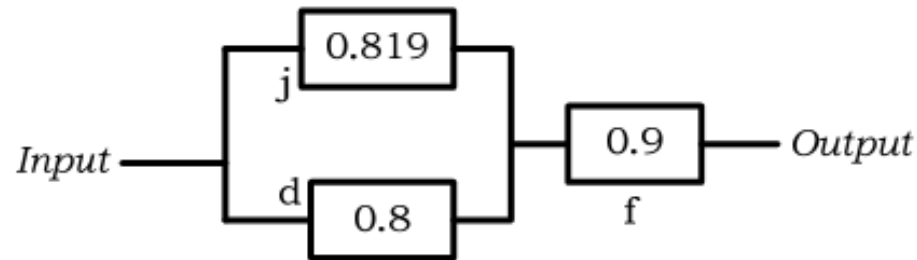$$= 0.7 + 0.7 - 0.7 \times 0.7 = 0.91$$

Further elements 'g' and 'c' are reduced to element 'j'

$$P(j) = P(g) \times P(c) = 0.91 \times 0.9 = 0.819$$

4.18 Redundancy

Solution : 8

The reduced system is shown below.

System reliability-Problem-8-Solution

Further elements 'j' and 'd' are reduced to element 'k'

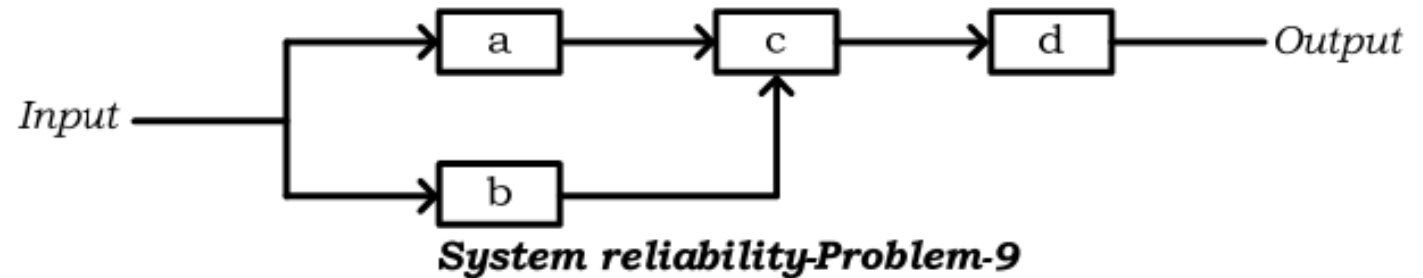$$P(k) = P(j) + P(d) - P(j) \times P(d) = 0.819 + 0.8 - (0.819 \times 0.8) = 0.9638$$

Finally, system reliability is computed as follows.

$$P(S) = P(k) \times P(f) = 0.9638 \times 0.9 = 0.86742$$

4.18 Redundancy

Problems : 9

Determine the system reliability of the system shown below.

System reliability-Problem-9

Solution : 9

$$P(S) = P\left[(a \text{ or } b) \text{ and } (c \text{ and } d)\right] = \left[P(a \text{ or } b)\right] \times \left[P(c) \text{ and } P(d)\right]$$

$$= \left[P(a) + P(b) - P(a) \times P(b)\right]\left[P(c) \times P(d)\right]$$

$$= P(a) \times P(c) \times P(d) + P(b) \times P(c) \times P(d) - P(a) \times P(b) \times P(c) \times P(d)$$