Ageing Phenomenon in Probabilistic Safety Assessment Studies

M. Das, R. N. Bhawal
Nuclear Power Corporation, Bombay, India

OBJECTIVE:

The reliability of components and systems in a nuclear power plant is of utmost importance since healthiness of the power plant system and probabilities of serious accident sequences will solely depend on it. Based on the in-depth reliability studies of systems and components, PSA studies are carried out to see how different system performances in combination, help in achieving a target availability/reliability of plant. Usually components and systems are assigned a design or expected reliability which are assumed to be constant throughout the expected life of components/plants. However, it is recognised that the effect of operating environments and service wear can degrade the condition of components and system. So, to achieve a fixed reliability/availability target throughout the plant life or for extended plant life, it is required to assess the trend of component or system ageing and to find out preventive measures so that ageing effect can be counter balanced. Two independent actions in the nuclear power industry motivate additional research into ageing and its management. The goal of these actions are improved ageing management and availability, assuming public health and safety during the current licence renewal (say about 40 yrs.) and for licence renewal for safety operation beyond current licensed terms. In this paper an attempt has been made to establish a mathematical model to predict ageing effect and to find out time dependent suitable inspection or test interval to upgrade the component/system availability.

METHOD:

While trying to quantify the increase in failure rate of a component the following two assumptions are made:

Change in failure rate per year can be expressed as

$$\frac{d\lambda}{dt} \propto t \text{ and } \lambda$$

where, t = Total time for which the component is in use and

λ = Failure rate of the system at that time.

That is to say, that a component is expected to deteriorate at a faster rate than the others if it is used for a longer time and if the component is less reliable than others.

so, $$\frac{d\lambda}{dt} = K*t*\lambda \qquad K = \text{proportionality constant.}$$

On integrating,

$$\ln \lambda = Kt^2/2 + C \qquad C = \text{constant of integration.}$$

Using boundary conditions

at $t = 0$, $\lambda = \lambda_o$ (Initial failure rate)

at $t = T$ (some long period of operation); $\lambda = f*\lambda_o$ [f > 1.0]

where 'f' is a deterioration factor by which failure rate increases after some long period of plant operation.

Solving the differential equation

$$\lambda = \lambda_o * f^{t^2/T^2} \qquad \text{-------------- (1)}$$

The factor 'f' may vary for different system or it may be same for similar type of components having initial failure rate of the same order and used under similar type of working conditions. Using this equation if a curve is drawn as time vs λ then, the curve passes through the point ($T, f*\lambda_o$) as specified and exponentially increases with time. To assess reasonably the trend of ageing i.e. increase in λ, factor 'f' should be updated based on the available failure data as the time progresses. Specifically when the assessment is required to see the unavailability of the equipment or system for extended plant operation beyond the normal plant life (say > 40 yrs), the initial values of λ_o should be λ, as evaluated at the end of normal plant life and time 't' should be the time beyond normal plant life (i.e. t = Actual time - Normal plant life). In case of the systems where demand failure rate is also involved the same formula can be applied on demand failure rate.

To counter balance the deterioration and to maintain a constant unavailability, the testing/maintenance time interval have to be updated as the time progresses.

The unavailability of a standby system is defined as:

$$U = Qd + \lambda*T/2 + T_t/T + \lambda*T_r \qquad \text{-------------- (2)}$$

where

Q_d = demand failure rate; λ = operational failure rate

T = test interval; T_t = testing time

T_r = repair time

The initial unavailability U_o can be found out by using initial demand failure rate (Qd_o), operational failure rate (λ_o), testing time interval and repair time. Now using the equation (1) for ageing, the Qd and λ values can be calculated after any long time intervals (say at an interval of 5 years).

In equation (2) if the deteriorated values of Qd & λ are used and equated with the initial U value, the desired testing time interval 'T' can be found out which will ensure that the initial unavailability is unchanged. While finding out 'T' it has to be kept in mind that testing interval should not be less than the optimum test interval T(opt).
where

$$T(opt) = \sqrt{2*T_t / \lambda}$$

ANALYSIS:

The onsite electric power supply system is divided into four classes namely class IV, class III, class II & class I, depending on the importance of loads connected from the point of view of reactor safety. Class IV is the normal AC station service supply derived either from the unit generator or from the grid. The loads which are important to reactor safety but can tolerate some interruption are connected to class III. Class III electric power supply system consists of four 6.6 kv and four 415 v bus bars. Each of the 6.6 kv bus bar is connected with a 50% capacity diesel generator set. The system is divided into two physically separate and independent divisions, each having two DGs and can provide 100% standby power to class III system loads. Under normal operating condition this system derives its power from class IV power supply. Fig. 1 shows the schematic of the class III electrical power supply system. In the absence of class IV power supply, unavailability of the system will depend on the unavailability of power to three buses powered by DG sets. In this analysis the ageing effect of DGs on class III power supply system unavailability have been studied. These are described below.

Applying the eqn. (1) and assuming a deterioration factor (f) of magnitude 3 & 2 for demand failure rate (Qd) and operational failure rate (λ) respectively at the end of plant life (40 yrs), values of Qd and λ have been calculated at different intervals of time. Fig. 2 shows the time dependent variation of Qd and λ. The initial value of Qd_0 and λ_0 have been taken as 2×10^{-4}/d and 1.5×10^{-4}/hr respectively.

With an initial DG testing interval of one month, the increase in unavailability of DGs due to ageing have been calculated neglecting the contribution due to testing time (since DG testing time is very small). These values have been used to analyse overall effect on class III power system unavailability. To evaluate the unavailability, fault tree has been prepared for the supply system without considering class IV supply. Cut sets having maximum four elements have been considered. Computer code FTAP has been used to generate the minimal cut sets. Unavailability of DGs due to common cause failure (pertaining to a single division), scheduled outage time for maintenance have also been considered. Only one DG has been considered for maintenance at a time. It is seen from the Fig. 3 that unchanged testing interval increases the system unavailability by about a order of magnitude (from 1×10^{-4} to 8×10^{-4}) at the end of 40 yrs.

Now, using equation (2) different testing interval time have been calculated at various time intervals during the plant life, so the unavailability figures for the DGs remain unchanged. Fig. 4 shows time vs. new testing intervals and Fig. 5 shows that the unavailability of the DGs can be brought down to its initial value following the new test intervals. Actually depending upon the maximum acceptable limit of DG unavailability (fig. 5) there may not be any need for changing the test interval time at the initial period of reactor operation.

CONCLUSION:

The above methodology can be of use in ageing management for predictive maintenance to improve availability of a system, counter balancing its deterioration effect with time. While increasing the testing frequency it has to be kept in mind that more frequent testing also results in equipment degradation, thus optimisation is required. Along with other methods of improving ageing effect like periodic replacement of components, reducing the intensity of stressors (like improvement of environmental condition etc.), on line continuous performance monitoring (where ever possible and economical), the above method can also contribute in taking timely maintenance activities. The selection of deterioration factor ´f' should be based on actual experience or testing. It is a dynamic process which would change with time. For new components, initial test data (like failure rate for the same component in normal environmental condition and severe environmental condition) can be used for selecting ´f'.

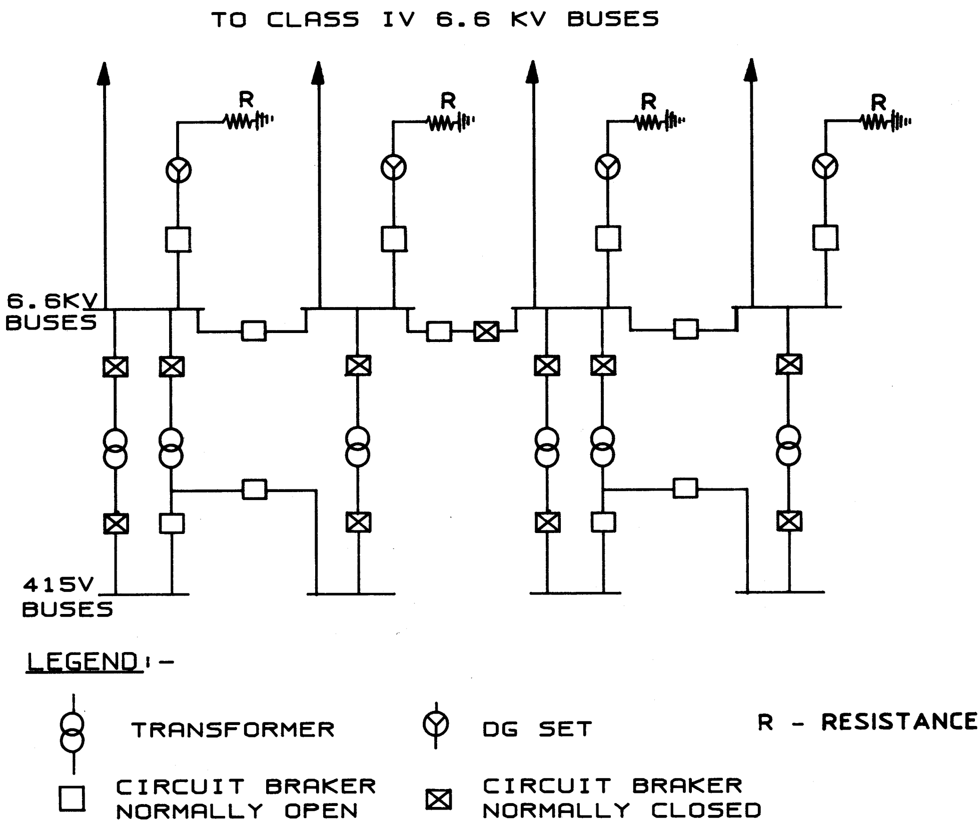

FIG.-1 SCHEMATIC OF CLASS III POWER SUPPLY

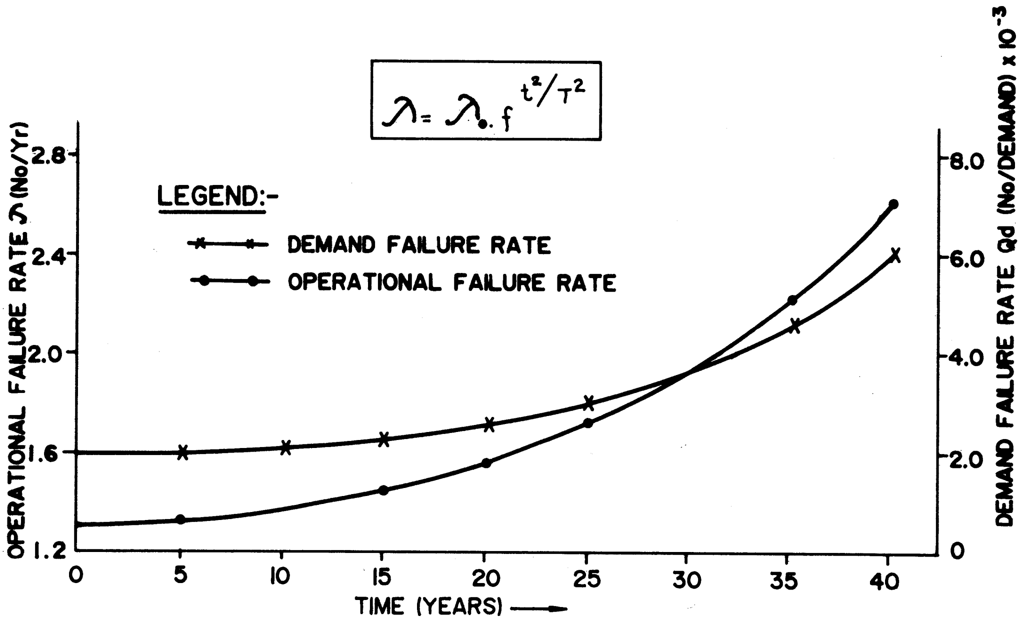

FIG-2 DEMAND & OPERATIONAL FAILURE RATE INCREASE Vs TIME

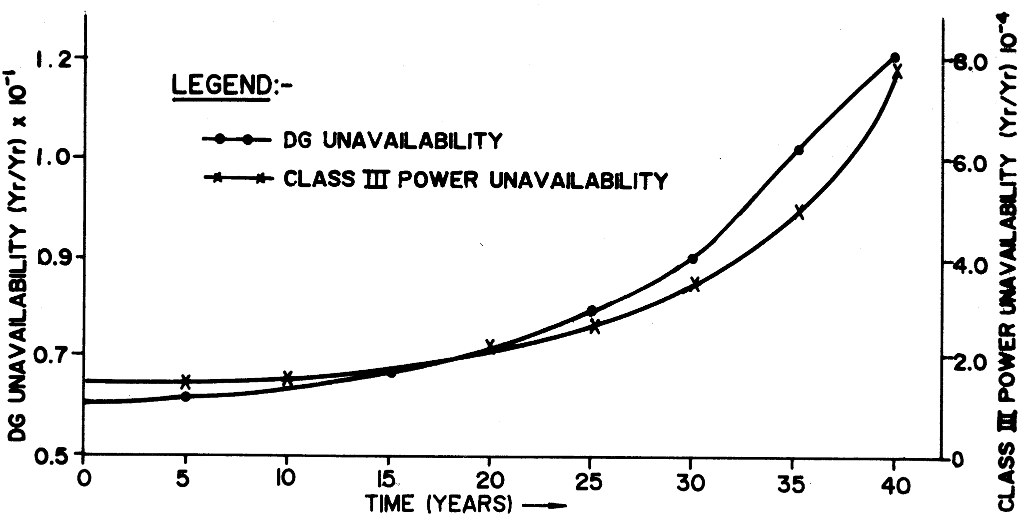

FIG-3 DG & CLASS III POWER SUPPLY UNAVAILABILITY Vs TIME

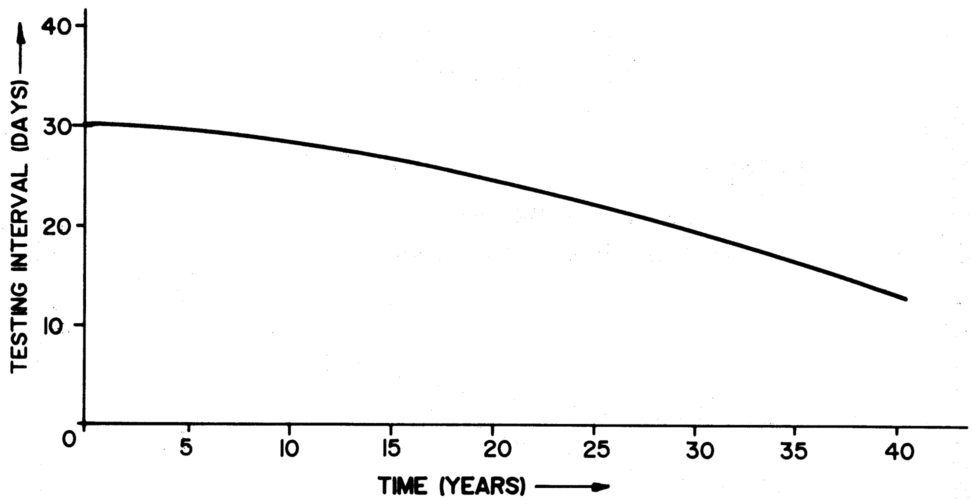

FIG-4 TESTING TIME INTERVAL Vs TIME

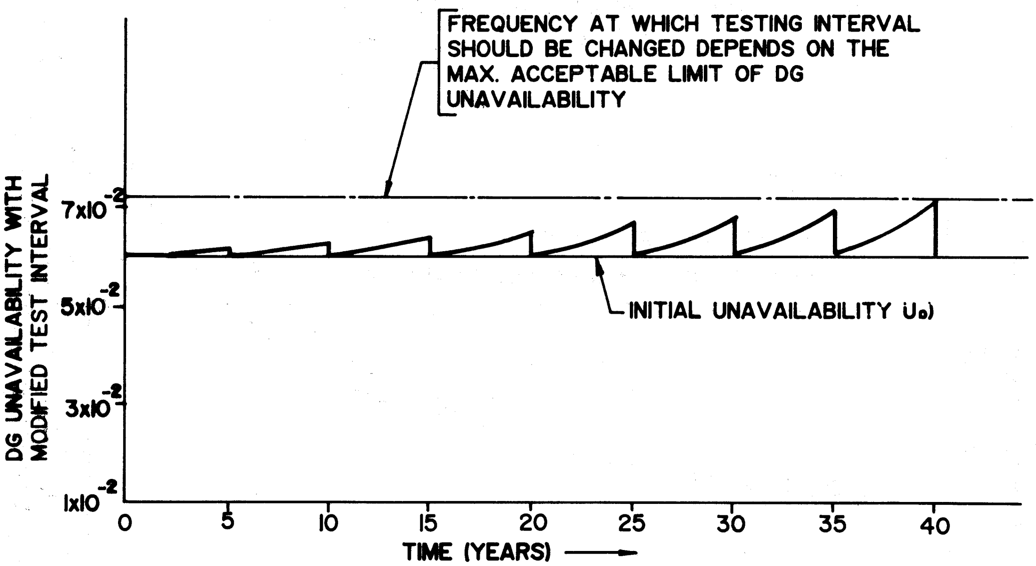

FIG-5 DG UNAVAILABILITY WITH MODIFIED TEST INTERVAL