DYNAMIC AVAILABILITY ASSESSMENT ON TEHRAN RESEARCH REACTOR WATER COOLING SYSTEM

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ABSTRACT

Failures in important safety equipment of nuclear reactors can result in grave deterioration of defense-in-depth barriers of safety. Thus, using an efficient and proactive approach in reliability and safety analysis of nuclear reactors is of utmost importance. Dynamic reliability methods are powerful mathematical frameworks capable of handling interactions among components and process variables explicitly. In principle, they constitute a more realistic modelling of systems for the purpose of reliability analysis. In this paper, ageing effects on availability are evaluated using dynamic analysis by considering impact of maintenance policy and scheduled tasks on Tehran research reactor (TRR) cooling water system, with the help of dynamic fault tree analysis (DFTA), the estimation results for 40 years ageing of the reactor are presented. Keeping maintenance variables constant and in view of decreasing reliability it is noted that availability of the cooling water system decreases with time.

KEYWORDS: Ageing, Availability, Cooling water system, Dynamic reliability, Dynamic fault tree analysis.

There are many methods available to be used to evaluate a system’s reliability. In order to efficiently evaluate or predict a system’s reliability performance, an appropriate system reliability model is required (Robidoux). Most reliability modeling approaches are based on statistical methods. Their typical examples are reliability block diagram (RBD), fault tree analysis (FTA), and Markov chains (Rausand, 2003). The above methods, however, can only provide system reliability models where a system component must be either operating or failed phase; thus, their capability are very limited to accurately model system’s dependencies and dynamic reliability properties (Labeaua, 2000). Dynamic fault tree analysis (DFTA) is a tool that can support modeling functional dependencies in a system, where the failure of a component causes some other dependent components to become inaccessible or unusable (Manian). This paper uses dynamic fault tree analysis for Tehran research reactor (TRR) cooling system in order to calculate dynamic reliability and ageing impacts on availability of system during 40 years of operation using BlockSim software code.

BRIEF DESCRIPTION OF TRR COOLING SYSTEM

Generally, Tehran research reactor cooling system has two parts: primary and secondary:

PRIMARY COOLING SYSTEM

Primary cooling system includes storage of distilled water in two pools by approximate temperature of 37.8°C. The water is pumped through fuel assemblies and flow down by gravity through the down comer with flows rate estimated 500m3/hr or 2200gpm and temperature nearly 46°C (depend in the configuration of the core. Afterwards, it goes through hold up tank to allow for decay of N16 and finally after passing the heat exchangers, returns to the main pool.

One plenum and safety flapper is embedded in the bottom section of reactor core which provides a closed route in order to transfer the coolant through fuel assemblies and the grid plates into the primary cooling system. Safety flapper is normally closed because of negative pressure caused by passage of coolant through plenum, but if the coolant flow drops lower than 50% of nominal value, safety flapper will automatically open and allows for natural circulation in reactor core. It is worth mentioning that safety flapper is closed at start up by a manual instrument which is connected to the bridge and its inadvertent opening while the power of the reactor exceeds 100 KW will cause Loss of Flow Accident (LOFA) (INVAP S.E., 1988).

SECONDARY COOLING SYSTEM

The purpose of designing secondary cooling system is removal of heat generated in the first coolant loop via heat exchanger, to the cooling towers and finally to the atmosphere. Required flow rate in secondary circuit at power level of 5MW is 2300gpm. In this case, inlet temperature from secondary cooling to heat exchanger is 30.6°C and the outlet temperature would be 38.9°C. Direct drive pump in secondary circuit, pushes secondary circuit coolant through the heat exchanger valves and pumps it into the cooling the tower located in the vicinity of reactor building. This tower is of forced air evaporative-type (AMF, 1966), (Ghofrani, 2002).

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DYNAMIC FAULT TREE ANALYSIS

Fault tree analysis is a traditional technique in reliability engineering, based on the failures of components. FTA is a component-oriented method, starts with an undesirable event as top event, and continues with a systematic process of identification of undesirable events (Manian). Thus, sequences of events would be identified and finally, a FT using Boolean logic symbols is drawn so as to describe events and the relation among them graphically to determine the probability of occurrence of the top event. The role of FTA in decision-making process is revealed from valuable information it provides for prioritization of important events contributing in occurrence of top event. FT is a graphical model comprised of complex related series and parallel fault combinations causing predefined undesirable occurrence, therefore, we can say, FTA can be viewed as a driving engine for the vehicle of system reliability (Distefano, 2007).

Dynamic Fault Tree (DFT) is a stochastic model for the reliability evaluation that synthesizes the ways how an undesired and time dependent event can occur. As compared with a Static Fault Tree (SFT), a DFT is composed of a top gate which represents the most undesired event (TE, top event) and a certain number of lower level gates and basic events (BEs) that, combined according with the logic of the accident scenario, cause the occurrence of the TE. The dynamic fault tree is extended with the time requirements using and the time dependent probabilistic models for the basic events. It represents a better estimation of the classic FT by including the passage of time (Modarres), (Cepin, 2001).

WEIBULL DISTRIBUTION

Many electro-mechanical systems typically degrade over time, and are more likely to follow a distribution with a strictly increasing hazard rate with time. In some other cases, systems become less likely to fail when used longer, implying a decreasing hazard rate. The Weibull distribution can model both increasing and decreasing hazard rates. Some of the lifetime distribution representations for the Weibull distribution are:

\[ S(t) = k \exp(-\lambda t), h(t) = k\lambda \kappa (t_\kappa - 1) \]  \hspace{1cm} (1)

Where \( k > 0 \) and \( \kappa > 0 \) are the scale and shape parameters of the distribution. The hazard function approaches zero from infinity for \( \kappa < 1 \), and increases from zero when \( \kappa > 1 \).

The Weibull distribution has some special properties for certain values of \( \kappa \): for \( \kappa = 1 \), it is the exponential distribution; for \( \kappa = 2 \) it is the Raleigh distribution; and for \( 3 < \kappa < 4 \), the probability density function (pdf) resembles that of the Normal distribution's pdf, and the mode and median of the distribution are equal when \( \kappa = 3.26 \).

AGEING EFFECT ON AVAILABILITY

One of the main factors, which could affect component reliability, is ageing process. Ageing issue is becoming an eminent subject as average age of operating nuclear plants is passing over 25 years. Since the age of TRR is about 40 years, it is vital to consider ageing effects in the calculations by choosing an appropriate time dependent model reliability distribution. (Rastayesh S. Bahrebar S., 2014)

When the Weibull distribution has a shape parameter of 2, it is known as the Raleigh distribution. This distribution is often used to describe measurement data in the field of communications engineering, such as distribution is also commonly used in the life testing of electro vacuum devices.

In this paper, this distribution is used to model ageing of reactor operation over 40 years. (Rastayesh S. Bahrebar S. Sepanloo K., 2014)

As the data was in exponential distribution, changes was made to convert them into Rayleigh distribution.

BLOCKSIM

BlockSim is a system reliability analysis software, which provides a comprehensive platform for probabilistic analyses. The software offers a rather sophisticated graphical interface that allows the user to model the reliability of simplest to the most complex systems and processes using fault tree analysis. BlockSim supports an extensive array fault tree analysis gates and events, including advanced capabilities to model complex configurations. Using exact computations and/or discrete event simulation, the code facilitates a wide variety of analyses (ReliaSoft).

METHODOLOGY


After drawing DFTA, properties for each component are input as the following:

First of all, by inputing failure model which obeys Weibull distribution with \( \kappa \) equal to 2 because in this case ageing effect on components could be seen, increasing failure behavior of components is modeled in this way. Secondly corrective tasks was considered, duration for each repair, the effects of repair on restoration of components are included by using a factor called restoration factor, which means the component after repair won’t return to the last situation. Experience has shown that on the average the restoration factor in water cooling
system of TRR is about 85%; this is an important part for modeling dynamic behavior of a component. At last, schedule task is inserted.

**POINT AVAILABILITY**

Point, or instantaneous, availability is the probability that a system (or component) will be operational at any random time, t. This is very similar to the reliability function in that it gives a probability that a system will function at the given time, t. Unlike reliability, the instantaneous availability measure incorporates maintainability information. At any given time t, the system will be operational if the following conditions are met:

- It functioned properly during time t with probability $R(t)$, or,
- It functioned properly since the last repair at time u, $0 < u < t$, with probability:

  $$\int_{0}^{t} R(t-u)m(u)du$$

(2)

With $m(u)$ being the renewal density function of the system. The point availability is the summation of these two probabilities, or:

$$A(t) = R(t) + \int_{0}^{t} R(t-u)m(u)du$$

(3)

**MEAN AVAILABILITY**

The mean availability is the proportion of time during a mission or time-period that the system is available for use. It represents the mean value of the instantaneous availability function over the period $(0, T)$:

$$A_{m}(T) = \frac{1}{T} \int_{0}^{T} A(t)dt$$

(4)

**CONCLUSION**

Point reliability for Tehran research cooling water system is illustrated in (Fig. 1), which shows the independency of it to corrective and scheduled tasks. It is shown that reliability of a system the main contribution is made by only failure model and the resulting fault trees. This is why the reliability reach zero at about 1 year.

The availability of system over 40 year decreases. As it can be seen from the two following figures, the maintenance policy, shows its effect here. That mean ageing has effect on availability because it decreases by decreasing reliability and constant maintenance.

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Figure 1. Point reliability vs. time

Figure 2. Mean availability vs. time

Figure 3. Point availability vs. time
Being available of water cooling system of TRR is very important to prevent occurring of such accidents like LOCA, LOFA, LOHA and LOOP. So results of this paper would be useful because all maintenance and schedual tasks and dynamic behaviour of the water cooling system took into account.

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