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Reliability centered maintenance (RCM) on main feedwater system

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1. Introduction

Equipment reliability is one of key areas of concern in ensuring power plant availability during operation. In nuclear power plant (NPP), equipment reliability is attained by using several techniques. One of techniques commonly used recently is the Reliability centered maintenance (RCM). RCM is a maintenance methodology that relies on systematic consideration of system functions, their failure and consequences, to identify applicable and effective preventive maintenance (PM) tasks that increase the probability that a component will function in the required manner over its design life-cycle [1]. In this paper, RCM has been applied on the main feedwater system (MFWS) for APR1400 reactor. RCM process includes: System selection and definition; functional failure analysis; critical component selection; failure mode and effect criticality analysis (FMECA); selection of maintenance actions; preventive maintenance comparison analysis; and implementation. The scope covers system selection to maintenance task selection. The outcome of maintenance tasks selection process will be recommended to the plant reliability engineers for their consideration.

2. Methods and Results Discussions

The first five steps of RCM process were applied to the system. Probability Safety Analysis (PSA) technique and Delphi questionnaires were the methods that were used to collect data on criticality of components. Each of the steps is described as follows:

2.1 System selection, boundary and description

MFWS was selected based on its importance in maintaining plant availability, by supplying feedwater (FW), to generate steam required for generation of power and also as a heat sink for the reactor. Failure of the system or any major component can directly cause reactor trip, turbine trip or significant power reduction (> 20 %). The major components of MFWS are; three (3) motor-driven main feedwater booster pumps (FWBP), three (3) turbine-driven feedwater pumps (MFWP), One (1) motor-driven start- up feedwater pump (SUP), six (6) high pressure heaters (HP HX), four (4) feed water control valves (FWCV), eight (8) Main Feedwater Isolation Valves (MFIV), four (4) Feedwater check valves (FWChV), four (4) Feedwater discharge valves (FWDV), and one (1) start- up feedwater control valve (SUCV) [2]. Fig 1 is a schematic diagram of the system.

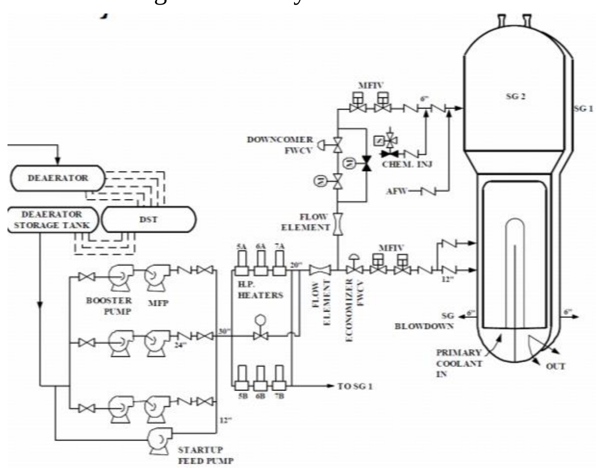

Fig.1. Schematic diagram for MFWS

2.2 Functional failure analysis

Functional failures describe ways that the equipment may fail to perform its intended functions. The results of function failure analysis, based on the essential functions of the MFWS, are shown in Table I.

Table I: Functional failure analysis for MFWS

System functions	**Functional failure**
To supply feedwater to the steam generators at required pressure, temperature, flow rate, and water chemistry	• Total loss of feedwater (FW) flow • FW flow rate exceeds required amount • Insufficient FW flow at 100 % reactor power
To increase pressure and temperature of FW in the regenerative cycle	• Supply FW at a lower pressure and temperature

Control SG water level	• Unable to control the SG level • SG level exceeds maximum level • SG level below minimum level
Maintain SG level when Rx power is ≤ 5 %	• Restricted FW flow • Supply excess FW flow
Terminate feedwater flow in the event of a malfunction	• Unable to terminate the FW flow
Provide FW and containment isolation in the event of design basis accident	• Unable to isolate the containment and SG • Partial isolation of SG and containment

2.3 Critical component selection

Critical component selection step involves identification of components that are potentially critical with respect to the functional failures. PSA, through SAREX Software, was used for identification of critical components. Three importance measures namely: Risk Achievement Worth (RAW), Risk Reduction Worth (RRW), and Fussell-Vesely (FV) were used to identify potentially safety-significant components based on the following screening criteria [3-4]. The results of analysis, shown in Table II, indicates that all the major components listed are critical.

- RAW for basic event of interest > 2.
- RRW for basic event >1.005
- Sum of F-V for basic events > 0.005

Table II: PSA risk significance determination

Component	Sum of F-V	RAW	RRW	Ranking
MFWP	0.7004	10.915	1.305	HSS
FWPB	0.0406	10.915	1.014	HSS
MFIV	0.0953	10.915	1.012	HSS
FWDV	0.0547	10.915	1.010	HSS
FWChV	0.0004	10.915	1.010	HSS
FWCV	0.0376	10.915	1.009	HSS
HP HX	0.0001	10.915	1.000	HSS
SUP	0.0107	10.915	1.000	HSS
SUCV	0.0019	10.915	1.002	HSS

2.4 Failure Mode Effect and Criticality Analysis (FMECA)

The FMECA addresses each system function, all possible failures, and the dominant failure modes associated with each failure. Criticality analysis of FMEA was assessed based on equation (1). Measure of Criticality (MoC) of the functional failure was assessed based on the consequences on failure on: safety of personnel (**S**), availability (A), and cost (C) [5]. The overall criticality class, linked to the range of MoC value, is as follows: E (3.0-4.0); F (2.0-3.0); G (1.5-2.0); and H (1.0-1.5). Class E indicates high criticality that requires condition monitoring, while class of H implies less significant failure mode that can be run to failure. The average critical value was obtained from analysis of Delphi questionnaires which were supplied to the expert panel for their opinions From FMEA results, shown in Table III and IV, none of the component falls in the run to failure category

$$MoC = 0.5S+0.3A+0.2C \quad (1)$$

Table III: FMECA results for MFWS components

Component	*FM	Criticality				Class
		S	A	C	MoC	
MFWP, FWPB	ftr, el	1.8	3.4	2.6	2.4	F
MFIV	ftro, vop, el	2.9	3.4	3.0	3.1	E
FWDV	ftro, vop, el	1.6	2.6	2.6	2.1	F
FWChV	ftro, vop, el	1.2	2.3	2.1	1.73	G
FWCV	ftro, vop, el	1.3	2.8	2.4	2.0	G
HP HX	ftop, el	1.4	3.0	2.4	2.09	F
SUP	fts, ftr	1.3	2.8	2.6	2.01	G
SUCV	fto	1.3	2.9	2.1	1.96	G

*FM-failure mode, ftr-fail to run, ftro-fail to remain open, el-external leakage, fto-fail to open, fts-fail to start, vop-valve out of position, ftop-fail to operate

Table IV: FMECA results for failure effect and causes

Component	Failure effect	Failure causes
MFWP FWBP	• Loss of FW supply to SG • Insufficient FW flow to SG. • Reactor trip/ significant power reduction.	• Rotor fails to rotate • Shaft, impeller, and seal break • Thrust bearing failure • Coupling breakage • Over speed trip
MFIV	• Fail to isolate containment and FW system	• Loose internal parts • Failed seal rings • Seized bearings on valve shaft
FWDV FWChV	• Fail to direct the FW flow • Restricted FW flow	• Body wear • Internal corrosion • Seal deterioration • Fastener loosening
FWCV	• Fail to control SG level • Increase in FW flow leading to reactor trip	• Erosion of valve body • Vibration induced cracks • Normal wear • Seal deterioration
HP HX	• Decrease in FW temperature • Loose efficiency of SGs	• Blocked flow conditions • Thermal fatigue • Excess vibration

	• Reduce reactor power < 20%.	
SUP	• Fail to recirculate FW	• Material lodging in rotor • Large vibrations • Thrust bearing failures • Coupling failures
S/UCV	• Fail to control FW flow	• Internal corrosion • Body wear

2.5 Maintenance task selection

Maintenance task selection was done by combination of criticality class analysis, from the FMECA, and the use of logic tree analysis (LTA) as shown in Fig.2. Criticality E - F is not acceptable failure while G is acceptable failure. Class E components require condition related tasks, F requires time directed task, and G requires failure finding tasks while H can be run to failure. Table V shows the maintenance task selection. MFIV are the most critical components whose failure should be prevented at all cost. Some of class F categories have both condition based and time based task based on the analysis obtained from LTA, similar to class G components. Also there are no components which requires run to failure because there is no criticality class H in the analysis.

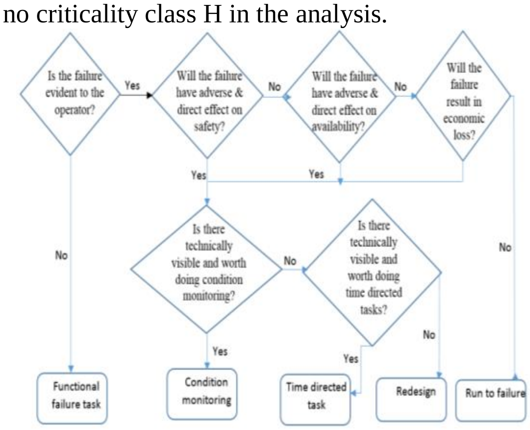

Fig.2. Logic tree analysis diagram

Table V: Maintenance tasks selected

Component	Selected task
MFWP FWBP	<u>Condition monitoring</u> • Vibration analysis • Lube oil analysis <u>Time directed task</u> • Rotor binding check • Visual examination and inspection • Coupling check
SUP	<u>Failure finding tasks</u> • Surveillance and leak rate tests • In-service inspection
MFIV	<u>Condition monitoring</u> • Ultrasonic noise detection • Infrared thermography • System engineer walkdowns
FWDV FWChV FWCV	<u>Time directed tasks</u> • In-service, visual inspection • Leak detection <u>Failure finding task</u> • Surveillance testing
SUCV	<u>Failure finding tasks</u> • Surveillance and leak rate tests • In-service inspection • Routine observation
HP HX	<u>Condition monitoring</u> • Infrared thermography • System engineer walkdowns <u>Time directed task</u> • Visual inspections • Leak detection

3. Conclusions

MFWS performs important functions to ensure plant availability, thus it is important to invest in a maintenance methodology that will guarantee effectiveness of the components and system and ensure efficiency in plant operation. RCM was successfully applied on the MFWS in which MFIV was the most critical component that require condition monitoring. With the combination of criticality class and logic tree analysis, maintenance tasks namely condition monitoring, time directed, and functional analysis were selected.

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