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CONTRIBUTIONS REGARDING THE PREDICTIVE RELIABILITY ANALYSIS OF THE HYDRO MECHANICAL EQIUPMENTS FROM HYDRO POWER PLANTS

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***Abstract* – The reliability level of hydro mechanical equipments can have a major impact on the operational reliability of HPP (Hydro Power Plants). In consequence, there are justified the concerns regarding the predictive reliability of them. In this paper, these studies of hydro mechanical equipments predictive reliability will be made taking into consideration their functions in framework of hydro energetic arrangement.**

Keywords: *hydro mechanical equipment, valves, cut-off plate, predictive reliability, reliability indicators.*

1. INTRODUCTION

In every hydro energetic arrangement, the water approaches, in differently construction elements and trough them, are equipped with valves. These valves assure the normal functioning of equipments, respectively there operatively insulation in case of failures or repairs.
The accomplished studies [3, 4, 5], indicate that some valves type are more performant under the reliability aspects than other equipments (hydraulic turbines). In succession, on the reliability studies, the valves are treated as bivalent elements (Functioning; Faulting). The predictive reliability analysis of hydro mechanical equipments it has been made using their functions and structure in framework of hydro energetic arrangements.

2. THE PREDICTIVE RELIABILITY ANALYSIS OF CUT-OFF PLATE (VIR 4,0x5,1/23) FROM HPP TILEAGD

The cut-off plate from HPP Tileagd (VIR 4,0x5,1/23), is a complex ensemble used to protect the hydraulic turbine (KVB 9,4-23,2) against the over speed. The VIR belong to the automation system, for protection. The closing of water admittance to the hydraulic turbine is made with guiding apparatus.

2.1. The reliability analysis depending on VIR structure

During the reliability analysis, the cut-off plate (VIR) from HPP Tileagd, it has been regarded like a system compound of following subsystems (fig. 1):

- the rolling and guiding subsystem (RGS);
- the closing or obstructing subsystem (CSS);
- the sealing subsystem (SSS);
- the control subsystem (NSS);
- the operate subsystem (OSS);
- the protection subsystem (PSS).

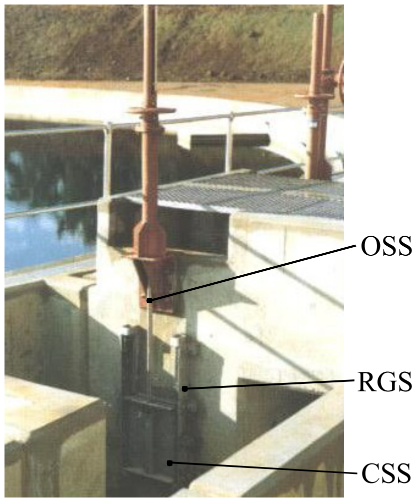

Figure 1: The VIR structure and subsystems.

According to previously specifications (for the simplified reliability analysis) VIR it has been treated as a system compound of six subsystems. In consequence, it can represent the simplified equivalent diagram (fig. 2), who reflects the necessity that, all the subsystems to be in work for satisfied all the cut-off plate functions.

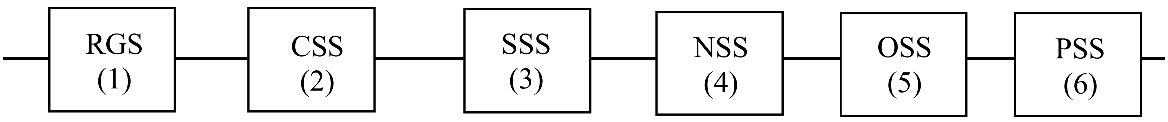

Figure 2: The equivalent diagram of VIR

The reliability states graph is typical of series systems.

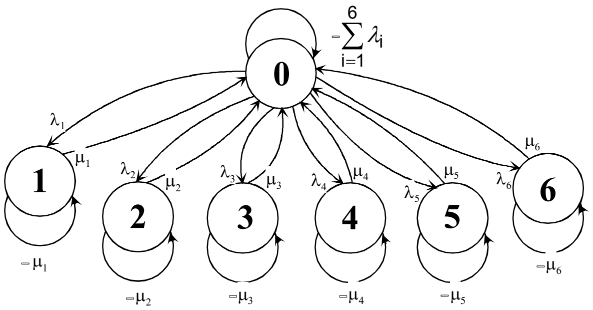

Figure 3: The reliability states graph for cut-off plate: 0 – the successful state (all subsystems are in work), $i=\overline{1,6}$ - the failure states (one subsystem isn't work)

Using the graph represented in figure 3 it can applies the Markov model to evaluate the reliability indicators $[R; F; \alpha(T_A); \beta(T_A); \nu(T_A); MTBF; MTM; \lambda_e; \mu_e]$[1].

2.2. The predictive reliability analysis of VIR using her functions in HPP Tileagd

The detailed reliability analysis of the cut-off plate from HPP Tileagd, it's made, defining her functions and related the analysis to them:

- f_1 – the self-protection function;
- f_2 – the closing-sealing function;
- f_3 – the workable function in specific conditions
- f_4 – associate-protection (of turbine and hydro-generator) function.

The f_1 function it's report to the valve possibility to provides the intrinsic safety by adequately response of the PSS elements.

The f_2, closing and sealing function is a double function. It can be regards from two perspectives: in the first row it is report at keeping of displacement performances, the synchronized CSS elements motion, in time and space; in the second row it is report at keeping the pshycal-chemical and mechanical properties of the sealing subsystem elements, in view of insurance a constant and optimum sealing level.

The f_3 function is report to provide concomitantly, interdependent and successively working conditions of subsystems RGS, CSS, NSS, OSS elements in order to total or partial closing /opening cut-off plate.

The f_4 function is report to the valve roll like safety turbine-hydro generator element, which assure the normal functioning of equipments, respectively there operatively insulation in case of failures or repairs.

For all these functions it's obligatory the integrity of protection subsystem (PSS).

The functions conditioning by the state (integrity) of VIR subsystems it is presented in table 1.

Function	Subsystems structural	Function	Subsystems
f_1	PSS	f_3	RGS Λ CSS Λ NSS Λ OSS
f_2	RGS Λ CSS Λ SSS	f_4	SS(f_3) Λ SSS

Table 1 The functions conditioning by the state of VIR subsystems

Taking into account the VIR functions it can represent the states graph of VIR related to them (figure 4).

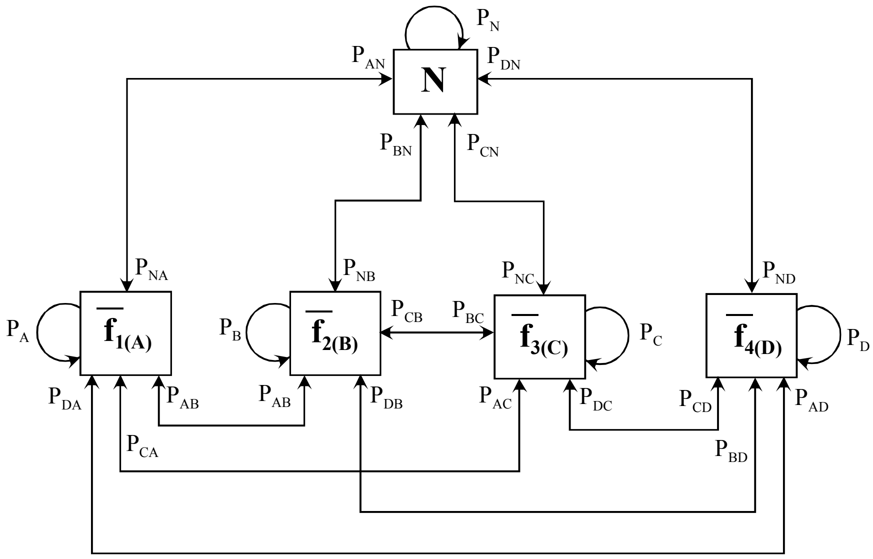

Figure 4: The states graph of VIR in view of her functions using as indicators the state and transitions probabilities (N – normal state, $\overline{f}_i$ - failure state relating to f_i functions

The states and transitions probabilities from figure 4 are represented using the typical expressions [7]:

$$\Pr ob(E_1 \cap E_2 \cap \ldots \cap E_m) = \Pr ob(E_1) \cdot \Pr ob(E_2) \cdot \ldots \cdot \Pr ob(E_m) \qquad (1)$$

$$\mathrm{Prob}(E_1 \cap E_2 \cap \ldots \cap E_m) = \sum_{j=1}^{m} \mathrm{Prob} E_j - \sum_{j=2}^{m}\sum_{i=1}^{j-1} \mathrm{Prob}(E_i E_j) + \sum_{j=3}^{m}\sum_{i=2}^{j-1}\sum_{k=1}^{i-1} (E_i E_j E_k) + \ldots + (-1)^{m-1} \mathrm{Prob}(E_1 E_2 \ldots E_m) \qquad (2)$$

The elementary events (E_i) are reported to functioning or failure of the cut-off plate (i) subsystems.

For example, the state and transition probabilities in a few cases are:

♦ The all satisfying functions probability (state N probability):

$$P_N(t) = \Pr ob(1 \cap 2 \cap 3 \ldots \cap 6) = \prod_{i=1}^{6} R_i(t) \qquad (3)$$

♦ The state A probability:

$$P_A(t) = \Pr ob\left(\bigcap_{i=1,5} i \bigcap \bar{6}\right) = F_6(t) \prod_{i=1}^{5} R_i(t) \qquad (4)$$

where: i – means that i element functioning;

$\bar{i}$ - means that i element failed.

♦ The state D probability:

$$P_D = \mathrm{Prob}\left[\left(\bar{1} \bigcap_{i=2,5} i\right) \bigcup \left(1 \bigcap \bar{2} \bigcap_{i=3,5} i\right) \bigcup \left(1 \bigcap 2 \bigcap \bar{3} \bigcap 4 \bigcap 5\right) \bigcup \left(\bar{4} \bigcap 5 \bigcap_{i=1,3} i\right) \bigcup \left(\bar{5} \bigcap_{l=1,4} i\right)\right] \qquad (5)$$

So:

$$P_D(t) = F_1(t)R_2(t)R_3(t)R_4(t)R_5(t) + R_1(t)F_2(t)R_3(t)R_4(t)R_5(t) + R_1(t)R_2(t)F_3(t)R_4(t)R_5(t) + R_1(t)R_2(t)R_3(t)F_4(t)R_5(t) + R_1(t)R_2(t)R_3(t)R_4(t)F_5(t) \qquad (6)$$

♦ Some transitions probability are:

$$P_{NA}(t) = \Pr ob(6) = F_6(t) \qquad (7)$$

$$P_{NB}(t) = \Pr ob\left[\bar{1} \bigcup \bar{2} \bigcup \bar{3} \bigcup (\bar{1} \bigcap \bar{2}) \bigcup (\bar{1} \bigcap \bar{3}) \bigcup (\bar{2} \bigcap \bar{3}) \bigcup (\bar{1} \bigcap \bar{2} \bigcap \bar{3})\right] \cong F_1(t) + F_2(t) + F_3(t) \qquad (8)$$

$$P_{BC}(t) = \Pr ob\left[\bar{4} \bigcup \bar{5} \bigcup (\bar{4} \bigcap \bar{5})\right] \cong F_4(t) + F_5(t) \qquad (9)$$

Depend on results obtained from the operational reliability studies [3,5], it can estimate the subsystems reliability indicators [R_i, Fi, μ_i, M_i].

The assessment of these indicators is made admitting exponential distribution from random variables TBF and TMC.

The calculus relations are:

$$F_{VIR} = \frac{\lambda}{\lambda + \mu}$$
$$F_i = \frac{\nu_i[\%]}{100} \cdot F_{VIR} \qquad (10)$$
$$\mu_i = \frac{\nu_i[\%]}{\beta_i[\%]} \cdot \mu$$
$$M_i = 1 - e^{\mu_i \cdot t_r}$$

where: λ, μ - the VIR reliability indicators;

F_{VIR} – failure probability of VIR;

ν_i, β_i – the weight of number failures and failures time, of the (i) subsystems from the total value of these indicators at the level of VIR.

For each subsystem the values of υ_i, β_i are obtained from cut-off plate working [3,5] and they are:

RGS ($\nu_i = 1{,}3\%, \beta_i = 1{,}8\%$);
CSS ($\nu_i = 2{,}9\%, \beta_i = 2{,}7\%$),
SSS ($\nu_i = 3{,}5\%, \beta_i = 3{,}2\%$),
NSS ($\nu_i = 5{,}9\%, \beta_i = 7{,}6\%$), (6)
OSS ($\nu_i = 72\%, \beta_i = 68\%$),
PSS ($\nu_i = 14{,}3\%, \beta_i = 16{,}7\%$)

The maintainability values (M_i) are determined using condition that the maintenance corrective operations must finished in t_r = 70 h.

The values are represented in table 2.

Subsystem	RGS	CSS	SSS	NSS	OSS	PSS
F_i x 10^4	15,2114	33,9333	40,9539	69,0367	608,459	167,326
μ_i $\|h^{-1}\|$	0,0038	0,005652	0,005756	0,004085	0,0055724	0,0045
M_i	0,2336	0,3267	0,3316	0,2487	0,3229	0,2705
R_i	0,998478	0,996606	0,995904	0,9930963	0,939154	0,983267

Table 2 The reliability indicators values for the VIR subsystems

The values of states and transitions probability are represented in table 3. The graph of VIR states in view of her functions, are represented in figure 5.

Indicator	The calculus expression (simplified)	Result
0	1	2
P_N	$\prod_{i=1}^{6} R_i(t) = R_{VIR}$	0,8861761
P_A	$F_6 \prod_{i=1}^{5} R_i(t)$	150,803 x 10^{-4}
P_B	$F_1R_2R_3R_4R_5 + R_1F_2R_3R_4R_5 + +R_1R_2F_3R_4R_5$ sau $R_4R_5(F_1R_2R_3 + F_1R_2R_3 + F_1R_2R_3)$	81,441646 x 10^{-4}
P_C	$R_3(F_1R_2R_4R_5 + R_1F_2R_4R_5 + R_1R_2F_4R_5 + R_1R_2R_4F_5)$	936,193 x 10^{-4}
P_D	$F_1R_2R_3R_4R_5 + R_1F_2R_3R_4R_5 + + R_1R_2F_3R_4R_5 + R_1R_2R_3F_4R_5 + R_1R_2R_3R_4F_5$	976,733 x 10^{-4}
P_{NA}	F_6	167,326 x 10^{-4}
P_{NB}	$F_1+F_2+F_3$	90,098786 x 10^{-4}
P_{NC}	$F_1+F_2+F_4+F_6$	726,64052 x 10^{-4}
P_{ND}	$\sum_{i=1}^{5} F_i$	1001,6173 x 10^{-4}
P_{AB}	$F_1+F_2+F_3$	90,098786 x 10^{-4}
P_{AC}	$F_1+F_2+F_4+F_6$	726,64052 x 10^{-4}
P_{AD}	$\sum_{i=1}^{5} F_i$	767,59451 x 10^{-4}
P_{DC}	M_3	0,3316445
P_{BC}	F_4+F_5	911,5187 x 10^{-4}
P_{BD}	F_4+F_5	911,5187 x 10^{-4}
P_{CD}	F_3	40,95399 x 10^{-4}
P_{AN}	M_6	0,2705425
P_{BN}	med(M_1, M_2, M_3)	0,2973422
P_{CN}	med(M_1, M_2, M_4; M_5)	0,2830259
P_{DN}	med (M_i, $i = \overline{1,5}$)	0,2927496
P_{BA}	med (M_i, $i = \overline{1,3}$)	0,2973422
P_{CA}	med(M_1, M_2, M_4; M_5)	0,2830259
P_{DA}	med (M_i, $i = \overline{1,5}$)	0,2927496
P_{CB}	med(M_4; M_5)	0,2858607
P_{DB}	med(M_4; M_5)	0,2858607

Table 3 The values of state and transition probabilities between VIR states

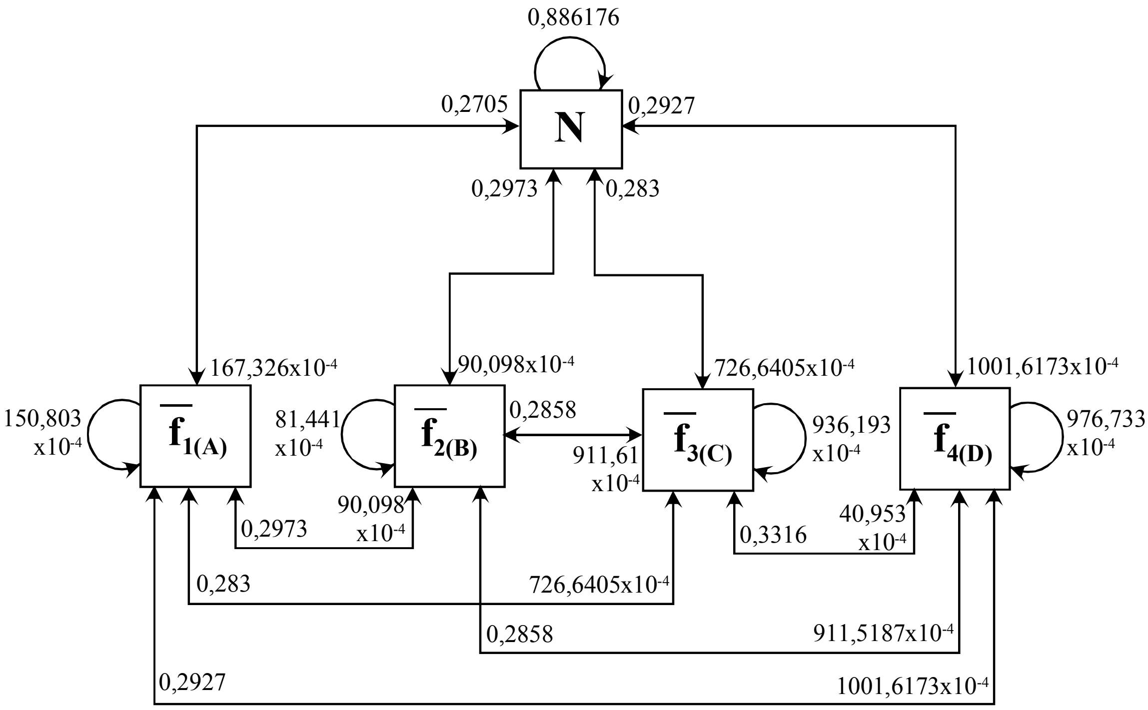

Figure 5 The states graph of VIR in view of her functions using as indicators the state and transition probabilities (N – normal state, $\overline{f}_i$ - failure state relating to f_i functions)

4. CONCLUSIONS

As a result of analysis and studies achieved it obtained the following conclusions:

1. Analyzing the cut-off plate structure from HPP Tileagd, it has been ascertained that VIR is a complex system formed of six subsystems serially bound.

2. For detailed the reliability analysis of VIR, it has been defined her functions and it can report the reliability analysis at these functions.

3. The VIR reliability indicators evaluation it make using the reliability indicators of subsystems, the equivalent diagram method, binomial method or the Markov method, after it represented the states graph.

4. Using the numerical results obtained, it have been represented the subsystems impact on the hydro mechanical equipment non reliability, as in figure 6:

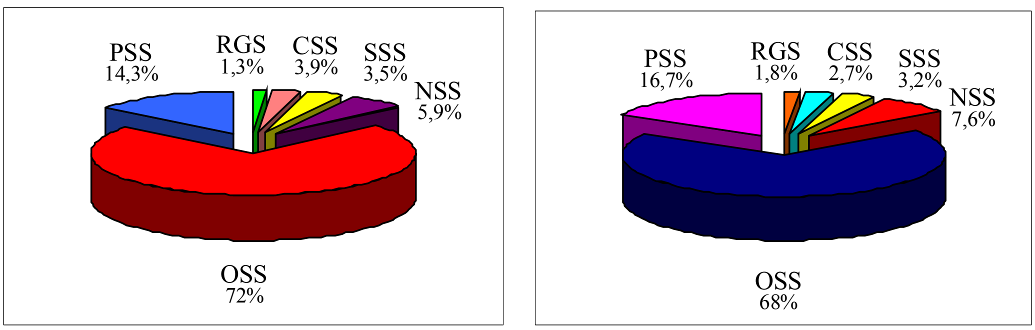

Figure 6 The number and duration failures distribution on VIR subsystems

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