THE INFLUENCE OF THE RESERVE AUTOMATIC RELEASE DEVICE ON THE ENERGY SYSTEMS RELIABILITY

Lecturer Eng. **Pavel ATĂNĂSOAE,** PhD

"Ştefan cel Mare" University of Suceava
Faculty of Electrical Engineering and Computer Science

REZUMAT. Asigurarea funcționării optime a sistemelor de alimentare cu utilități (energie electrică, căldură, apă) depinde în mare măsură şi de procesul de anclanşare automată a rezervei. În lucrare se face o estimare a fiabilității echipamentelor energetice luând în considerare şi influența dispozitivului de anclanşare automată a rezervei. Se prezintă cazul particular al unei stații de pompare echipată în varianta 3x50% (două pompe în funcțiune şi una în rezervă).

Cuvinte cheie: fiabilitate, disponibilitate, anclanşare automată a rezervei, asigurarea continuității furnizării

ABSTRACT. Ensuring the optimal operation of utility supply systems (electricity, heat and water) depends to a large extent by the automatic release of the reserve. The paper presents an estimation of the reliability of energy equipment taking into account the influence of the reserve automatic release device. It also presents the particular case of a pumping station equipped as 3x50% (two pumps in operation and one in reserve).

Keywords: reliability, availability, reserve automatic release, structures components, ensuring continuity of supply

1. INTRODUCTION

The reliability is the probability of a system/device to perform required function for a specified duration of time without any failure under stated conditions for which it is designed.

Redundancy is defined as the use of additional components or sub-systems beyond the number actually required for the system to operate reliably.

A basic parallel system has inherent redundancy since the failure of one or more components does not result in a system failure as long as one component remains functional.

Redundancy exists when one or more components of a system can fail and the system can continue to perform its intended function satisfactorily (figure 1).

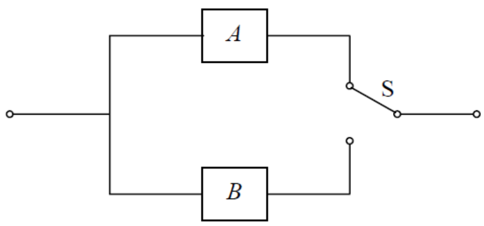

Fig. 1. Standby system

It is therefore of interest to analyse the reliability of redundant systems considering the effects of imperfect switching. The redundancy represented by the use of parallel networks may be used to model systems which are either operating continuously but are kept in a standby or those which are only placed in operating mode when the normally operating component fails.

The adjectives cold, warm, and hot denote the redundancy state.

2. PRESENTATION SYSTEM EXAMINED

A pump station (figure 2) is dimensioned in a 3x50% version: two pumps in operation and one in reserve. The pump located in the reserve comes into operation automatically with the reserve automatic release (AAR) device in case of failure of one of the pumps in operation.

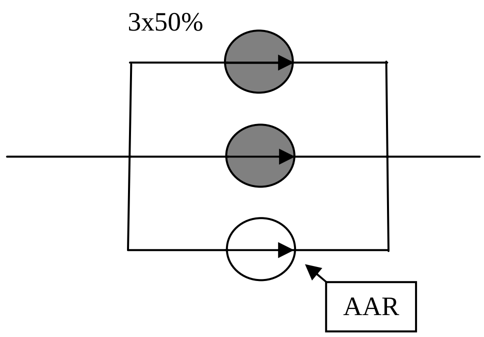

Fig. 2. Technological scheme

The components of the technological scheme of Figure 2 can be booked in the following forms:

- hot standby (active). In this case the pump located in the reserve is idle working (without load);
- warm standby (semi active). It is a prepared reserve which is on standby that requires a switching time (the automatic starting automation is connected);
- cold standby (passive). It is a reserve that is unprepared for entry into service which requires a longer time to start (necessary for starting preparatory maneuvers).

The three reservation ways differ in how the equipment reserves are at fault and the time required for the backup equipment to take over the basic equipment in case of failure.

3. THE MATHEMATICAL MODEL FOR THE CALCULATION OF THE RELIABILITY INDICATORS

To calculate reliability, the continuous-time Markov processes are used. The Markov chain is an effective statistical modeling technique which can describe complex behavior of various stochastic systems and has a well-developed mathematical apparatus.

The possible states of the system are:

Table 1

The states of the system

State	running	standby	failure
1	2	1	-
2	2	-	1
3	1	-	2
4	-	-	3

The equivalent circuit for the calculation of the reliability indicators is presented in Figure 3.

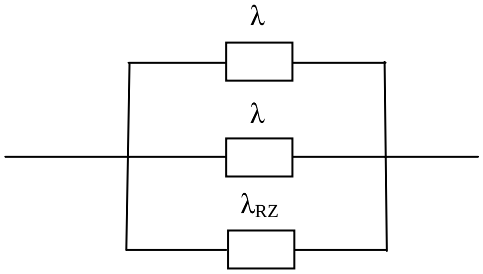

Fig. 3. Equivalent circuit reliability

The graph transitions between states are presented in Figure 4.

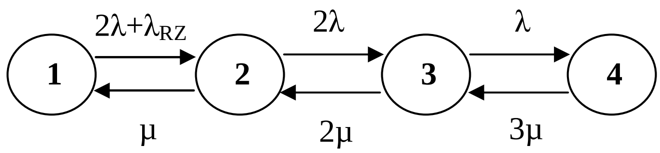

Fig. 4. Graph of transitions between states

Generally, for long periods of time, the process turns into a stationary state, the absolute state probabilities tend to constant values that are independent of time.

The matrix of transitions between states:

$$[q_{ij}]=\begin{bmatrix} -(2\lambda+\lambda_{RZ}) & \mu & 0 & 0 \\ 2\lambda+\lambda_{RZ} & -(2\lambda+\mu) & 2\mu & 0 \\ 0 & 2\lambda & -(\lambda+2\mu) & 3\mu \\ 0 & 0 & \lambda & -3\mu \end{bmatrix} \quad (1)$$

The matrix equation:

$$\left[q_{ij}\right]\cdot\left[P_i\right]=0 \quad (2)$$

on condition:

$$\sum_{i=1}^{n} P_i = 1 \quad (3)$$

The absolute probabilities of the states result from solving the system:

$$\begin{cases} -(2\lambda+\lambda_{RZ})\cdot P_1+\mu\cdot P_2=0 \\ (2\lambda+\lambda_{RZ})\cdot P_1-(2\lambda+\mu)\cdot P_2+2\mu\cdot P_3=0 \\ 2\lambda\cdot P_2-(\lambda+2\mu)\cdot P_3+3\mu\cdot P_4=0 \\ \lambda\cdot P_3-3\mu\cdot P_4=0 \\ P_1+P_2+P_3+P_4=1 \end{cases} \quad (4)$$

The solutions to equation (4) are:

$$\begin{cases} P_1=\dfrac{3}{1-\dfrac{\lambda_{RZ}}{\lambda}+3\left(1+\dfrac{\lambda_{RZ}}{2\lambda}\right)\cdot\left(1+\dfrac{\lambda}{\mu}\right)^3} \\ P_2=2\left(\dfrac{\lambda}{\mu}\right)\cdot\left(1+\dfrac{\lambda_{RZ}}{2\lambda}\right)\cdot P_1 \\ P_3=\dfrac{2}{3}\cdot\left(\dfrac{\lambda}{\mu}\right)^2\cdot\left(1+\dfrac{\lambda_{RZ}}{2\lambda}\right)\cdot P_1 \\ P_4=\dfrac{2}{3}\cdot\left(\dfrac{\lambda}{\mu}\right)^3\cdot\left(1+\dfrac{\lambda_{RZ}}{2\lambda}\right)\cdot P_1 \end{cases} \quad (5)$$

The probability of success, bearing in mind that only the statuses 1 and 2 are two elements in operation, is:

$$P_S = P_1 + P_2 \quad (6)$$

and the probability of rejection:

$$P_R = P_3 + P_4 \quad (7)$$

4. RELIABILITY INDICES

The reserve is an element that can take all the functions of another element, partially or totally. Reservation is one way to increase system reliability.

The parameters characterizing a reserve are:

- the failure rate of the reserve in the waiting period λ_{RZ};
- the failure rate during the working period;
- the time required to get into operation from when the request comes until the setpoint t_{CRZ};
- the reserve p probability response on a request (including the automation system).

In the case of the analysed system the following values were used:

- failure rate $\lambda = 0{,}0009\ h^{-1}$;
- repair rate $\mu = 0{,}05\ h^{-1}$;
- reference time T = 10 years;
- AAR break $t_{ka} = 0{,}5$ s;
- manual switching time $t_{km} = 10$ minutes;
- failure rate $\lambda_{RZ} = 0{,}00081\ h^{-1}$ ($\lambda_{RZ}=\alpha\lambda$).

In the case of the reserve automatic release device, interruptions in the operation can be classified into:

- interruptions followed by automatic switching lasting for t_{ka};
- interruptions followed by manual switching lasting for t_{km};
- interruptions followed by repair lasting for t_{rep}.

The automatic release of the reserve will be applied when there is a transition from state 1 to state 2.

The average number of requests of the reserve automatic release device:

$$MNS = P_1 \cdot \lambda \cdot T \quad (8)$$

The average number of successful automatic switching followed by lengthy interruptions t_{ka}:

$$MNKA = p_{AAR} \cdot MNS = p_{AAR} \cdot P_1 \cdot \lambda \cdot T \quad (9)$$

The average number of failures followed by manual switching (lengthy interruptions t_{km}):

$$MNKM = (1 - p_{AAR}) \cdot MNS = (1 - p_{AAR}) \cdot P_1 \cdot \lambda \cdot T \quad (10)$$

The average number of interruptions followed by repair:

$$MND = (P_3 + P_4) \cdot \lambda \cdot T \quad (11)$$

The total average operation time during the reference system T:

$$MUT = (P_1 + P_2) \cdot \lambda \cdot T - MNKA \cdot t_{ka} - MNKM \cdot t_{km} \quad (12)$$

The total average system failure during the reference period T:

$$MDT = (P_3 + P_4) \cdot \lambda \cdot T + MNKA \cdot t_{ka} + MNKM \cdot t_{km} \quad (13)$$

Mean Time Between Failures:

$$MTBF = \frac{MUT}{MND + MNKM} \quad (14)$$

Mean Time To Repair:

$$MTTR = \frac{MDT}{MND + MNKM} \quad (15)$$

The equivalent failure rate to the system:

$$\lambda_e = \frac{1}{MTBF} \quad (16)$$

The equivalent repair rate to the system:

$$\mu_e = \frac{1}{MTTR} \quad (17)$$

The system availability:

$$A = \frac{MTBF}{MTBF + MTTR} \quad (18)$$

Figure 4 shows the variation of the availability of the system according to the probability of operation of the device for automatic release of the reserve:

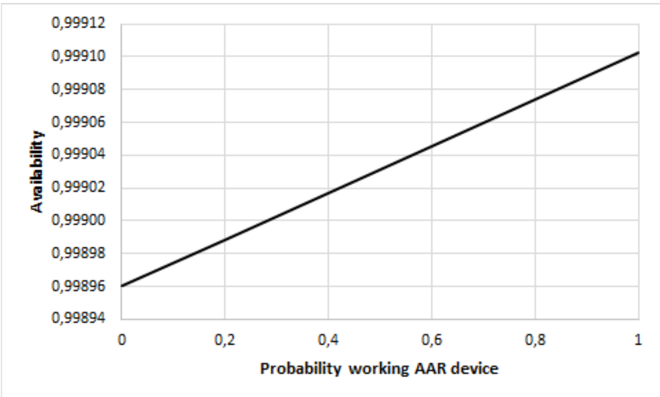

Fig. 4. The influence of the AAR device on system availability

The switching time range is in the form of a time-out interrupt-frequency (figure 5).

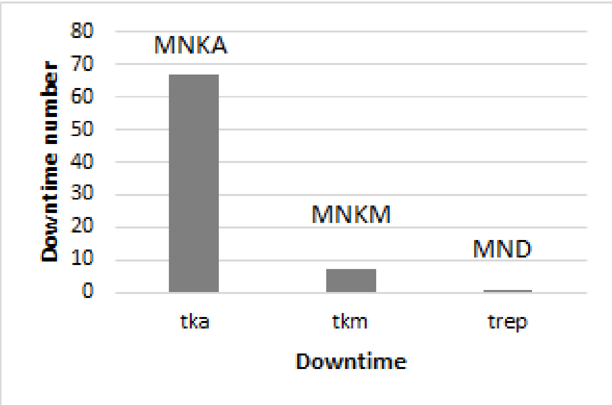

Fig. 5. Interruption duration-frequency spectrum (p_{AAR}=0.9)

The system reliability (figure 6):

$$R(t) = e^{-\lambda_e \cdot t} \tag{19}$$

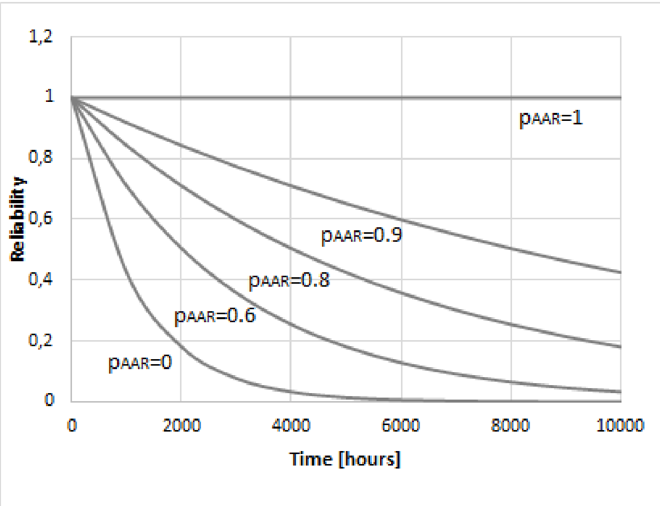

Fig. 6. The influence of the AAR device on system reliability

It can be seen that the presence of a switching device has a significant effect on the reliability of a standby system. So it is important when modeling standby redundancy to incorporate the switching device reliability properties.

5. CONCLUSIONS

The problem of operational safety or reliability of the power installations has now become a major problem in energy because it has economic implications.

The redundancy plants is one of the most used methods to prevent power interruptions when supplying the consumer.

The constructive solutions increase investment cost, but the increased safety for the entire plant is obvious. Such measures are warranted to reduce the damage to served consumers.

The automatic release of reserves is a vital automation in configuration energy installations due to the fact that the accuracy of its operation depends on the continuity of supply to consumers.

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About the authors

Lecturer. Eng. **Pavel ATĂNĂSOAE,** PhD
"Ştefan cel Mare" University of Suceava
email:atanasoae@eed.usv.ro

Graduate of the Faculty of Electrical Engineering of the "Ştefan cel Mare" University of Suceava, the Power Engineering Program, year 1992. PhD. graduated at the "Gheorghe Asachi" Technical University of Iasi, Faculty of Electrical Engineering, the Power Engineering Program, year 2001. Currently he is lecturer at the "Ştefan cel Mare" University of Suceava, Faculty of Electrical Engineering and Computer Science. The research topics: combined heat and power plants, the electricity market, thermal and electrical power generation, reliability.