HUMAN FACTOR RELIABILITY INFLUENCE ON AVAILABILITY OF POWER DISTRIBUTION NETWORKS

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The main objective of the paper is to present suitable reliability models for electricity distribution networks considering the human influence through the maintenance activity. Reliability optimisation techniques are also included and represent the second major objective. Reliability modelling of human factor is based on detailed Markov type models where maintenance is closed related to human activity. The paper focuses on the specific features of maintenance like its influence on the total failure rate of a component or system, the dependence between the maintenance rate and the failure rate and its influence on the system performance, etc.

Keywords: human reliability, maintenance, optimization

1. Introduction

Failure-less operation of an electricity distribution system is strongly depending on its maintenance principles. For this kind of repairable system, the reliability is a necessary condition but it is not enough. The system availability means easy to maintain and its maintainability is depending on:

- system accessibility to remove and replace the failed component;
- the available spare-parts;
- the human repair team: number, qualification.

The maintenance categories are well known: preventive, corrective and complex maintenance, reactive and proactive maintenance, reliability centred maintenance or, one of the last maintenance principles, so called *preventive opportune maintenance* based on the modern monitoring and diagnosis techniques. Figure 1 presents some quality relationship between cost and maintenance categories and clearly shows the optimal values corresponding to a given target.

The new maintenance philosophy as well as the new strategies, based on information technology and techniques must allow the technical potential advantages to profit transformation.

A practical formula to implement a preventive maintenance program is

$$FN \cdot AFC \cdot \alpha \succ TCPM \qquad (1)$$

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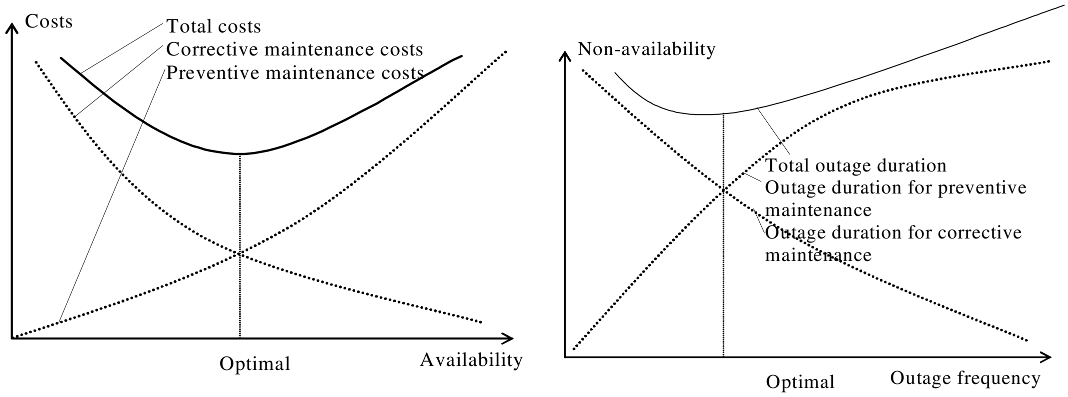
where FN is the number of failures, AFC average failure cost, TCPM the total cot of preventive maintenance and α is a 0.7, usually, factor.



a) b)

Fig.1 Relationship between: maintenance cost and optimal availability (a) and outages duration-number (b)

2. Human reliability

The human factor plays an important role during the life cycle of a distribution power network in the design, production, operation and maintenance stages. The human errors are affecting negatively every mentioned phases. The human errors sources are poor equipment design, poor work environment, poor work layout, improper tools, insufficient specific training.

Human errors can be classified into six categories: design, assembly, inspection, installation, operation and maintenance.

The maintenance, as an availability component together with reliability is mainly influenced by human errors.

The human errors on the maintenance process on the distribution networks life cycle are equally distributed between the maintenance and operation personnel as it is shown in fig.2.

Statistics presented by different authors [1], [2] demonstrated that human errors are really dangerous according to the industry field: aviation, electronics, electricity, chemistry. As an average, the human reliability is 0.9871. This means that one should expect errors by maintenance personnel on the order of 13 times in 1000 attempts [2].

In the electronics industry human errors represent 67-75% in diagnosis, 15-25% in remedial actions and 5-15% in checking while in the electricity field there is some information especially for nuclear power plants due to the highest corresponding risk.

For power distribution network the detailed information about human reliability are not available but the maintenance is the zone where it plays a major role.

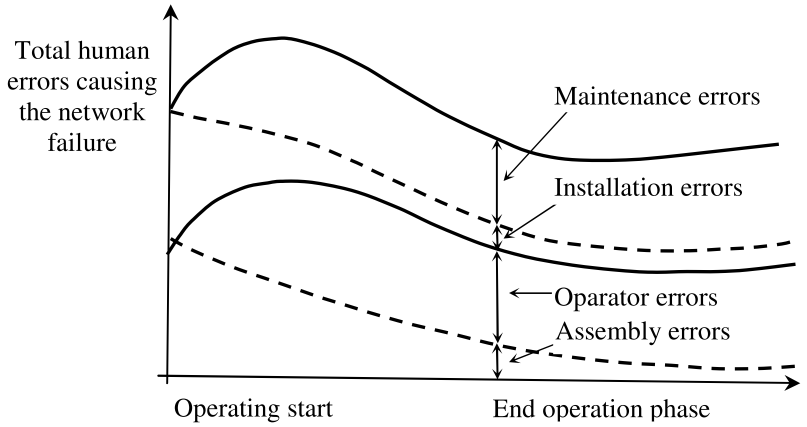


Fig.2 Different human errors on network life cycle

3. Markov models including the human reliability

Two general Markov reliability models with details on human errors influence on availability indices are presented in fig. 3.

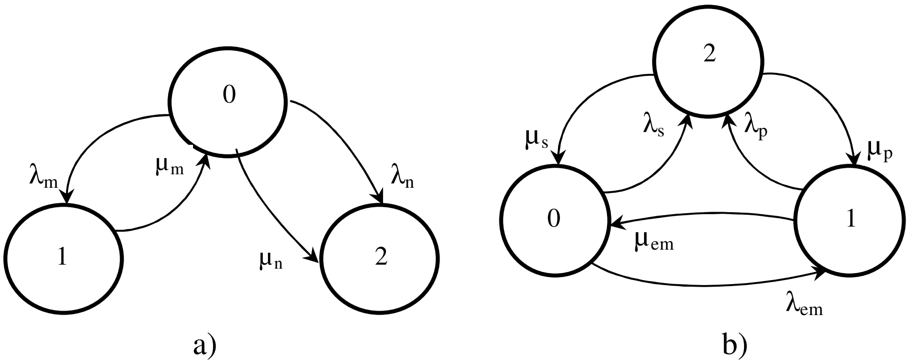


Fig.3 Markov type models for human errors analysis

The first model (fig.3a) considers a system which can fail due to human maintenance errors or to other reasons. The initial presumptions are: the failed system is repaired and it is periodically preventive maintained; the system failure rate is constant and after a repair action the system is back to initial state.

It was noted:

- 0 is the system normal state, 1 is the failed state due to preventive maintenance errors (human errors) and 2 is the system failed state due to other reasons than human errors;
- λ_m, failure rate due to maintenance errors;
- λ_n, failure rate dut to non maintenance errors;
- μ_m, repair rate from state 1;
- μ_n, repair rate from state 2.

The second model, fig.3b, is based on consideration that it can fail only due to non maintenance errors. The maintenance errors can allow only for lowering the system performance. The initial assumptions are: the system is repaired after the total or partial failures; the maintenance errors can allow only for partial failures (lower performance: diminished capacity of power lines, etc.); from a partial failure state the system can reach a total failure state but not due to maintenance (human) errors. In fig.4b the following symbols were used:

- 0 is the system normal state, 1 is the system state with partial failure due to preventive maintenance errors (human errors) and 2 is the system failed state;
- λ_{em}, partial failure rate due to maintenance errors;
- λ_s, total failure rate;
- λ_p, system failure rate from partial failure state;
- μ_{em}, repair rate from partial failure state 1;
- μ_s, system repair rate to normal state 0;
- μ_p, system repair rate from total failure state to partial failure state.

In [3] there are presented the solutions of the system equations corresponding to Markov models of fig.3.

For the system in fig.3a, for the specific case when $\mu_m = \mu_n = 0$, the absolute state probabilities are:

$$P_0(t) = e^{-(\lambda_m+\lambda_n)t} \tag{2}$$

$$P_1(t) = \frac{\lambda_m}{\lambda_m+\lambda_n}\left[1-e^{(\lambda_m+\lambda_n)t}\right] \tag{3}$$

$$P_2(t) = \frac{\lambda_n}{\lambda_m+\lambda_n}\left[1-e^{(\lambda_m+\lambda_n)t}\right] \tag{4}$$

For the system in fig.4b, the absolute state probabilities are given by eq. 5 – 7, as it was demonstrated in [3].

$$\begin{aligned}P_0(t)=&\frac{\mu_{em}\mu_s+\lambda_p\mu_s+\mu_{em}\mu_p}{c_1\cdot c_2}+\\&+\left[\frac{\mu_{em}c_1+\mu_s c_1+\mu_p c_1+c_1\lambda_p+c_1^2+\mu_{em}\mu_s+\lambda_p\mu_s+\mu_{em}\mu_p}{c_1(c_1-c_2)}\right]e^{c_1 t}+\\&+\left\{1-\left(\frac{\mu_{em}c_1+\lambda_p\mu_s+\mu_m\mu_p}{c_1c_2}\right)-\right.\\&\left.-\left[\frac{\mu_{em}c_1+\mu_s c_1+\mu_p c_1+c_1\lambda_p+c_1^2+\mu_{em}\mu_s+\lambda_p\mu_s+\mu_{em}\mu_p}{c_1(c_1-c_2)}\right]\right\}e^{c_2 t}\end{aligned}\tag{5}$$

$$\begin{aligned}P_1(t)=&\frac{\mu_{em}\mu_s+\lambda_{em}\mu_p+\lambda_s\mu_p}{c_1\cdot c_2}+\left[\frac{c_1\lambda_{em}+\lambda_{em}\mu_s+\lambda_{em}\mu_p+\lambda_s\mu_p}{c_1(c_1-c_2)}\right]e^{c_1 t}-\\&-\left[\frac{\lambda_{em}\mu_s+\lambda_{em}\mu_p+\lambda_s\mu_p}{c_1c_2}+\frac{c_1\lambda_{em}+\lambda_{em}\mu_s+\lambda_{em}\mu_p+\lambda_s\mu_p}{c_1(c_1-c_2)}\right]e^{c_2 t}\end{aligned}\tag{6}$$

$$\begin{aligned}P_2(t)=&\frac{\lambda_{em}\mu_p+\mu_{em}\lambda_s+\lambda_s\lambda_p}{c_1\cdot c_2}+\left[\frac{c_1\lambda_s+\lambda_{em}\lambda_p+\lambda_s\mu_{em}+\lambda_s\lambda_p}{c_1(c_1-c_2)}\right]e^{c_1 t}-\\&-\left[\frac{\lambda_{em}\lambda_p+\mu_{em}\lambda_s+\lambda_s\lambda_p}{c_1c_2}+\frac{c_1\lambda_s+\lambda_{em}\lambda_p+\mu_{em}\lambda_s+\lambda_s\lambda_p}{c_1(c_1-c_2)}\right]e^{c_2 t}\end{aligned}\tag{7}$$

In eq. (5) – (7) , c_1 and c_2 are:

$$\begin{aligned}&c_1,c_2=-\frac{b}{2}\pm\\&\left(\frac{b^2-4(\mu_{em}\mu_s+\lambda_p\mu_s+\mu_{em}\mu_p+\mu_s\lambda_{em}+\lambda_{em}\mu_p+\lambda_{em}\lambda_p+\mu_{em}\lambda_s+\lambda_s\mu_p+\lambda_s\lambda_p}{2}\right)^{1/2}\end{aligned}\tag{8}$$

$$b=\lambda_{em}+\lambda_s+\lambda_p+\mu_{em}+\mu_s+\mu_p\tag{9}$$

The steady-state probability of the partial failure state given can be derived from eq. (6) and it becomes:

$$P_{1ss}(t)=\frac{\mu_{em}\mu_s+\lambda_{em}\mu_p+\lambda_s\mu_p}{c_1\cdot c_2}\tag{10}$$

For the system illustrated in fig.3a the graphical dependence of the preventive maintenance erors during its starting life cycle is presented in fig.4.

The most imprtant obsevation is this dependence is more important between first 100 and 2000 operating hours.

For the second type system, fig.3b, the steady-state probability with partial failure (P_1) is depending on the maintenance human erros (λ_{em}) as much as the repair rate form this state (μ_m) is lower, as illustrated in fig.5.

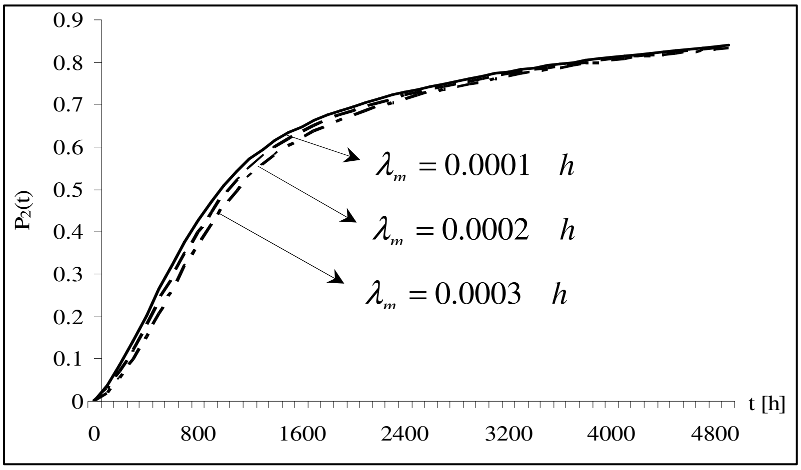


Fig.4 The probability of system failure (fig.4a) as a function of the human maintenance errors λ_m

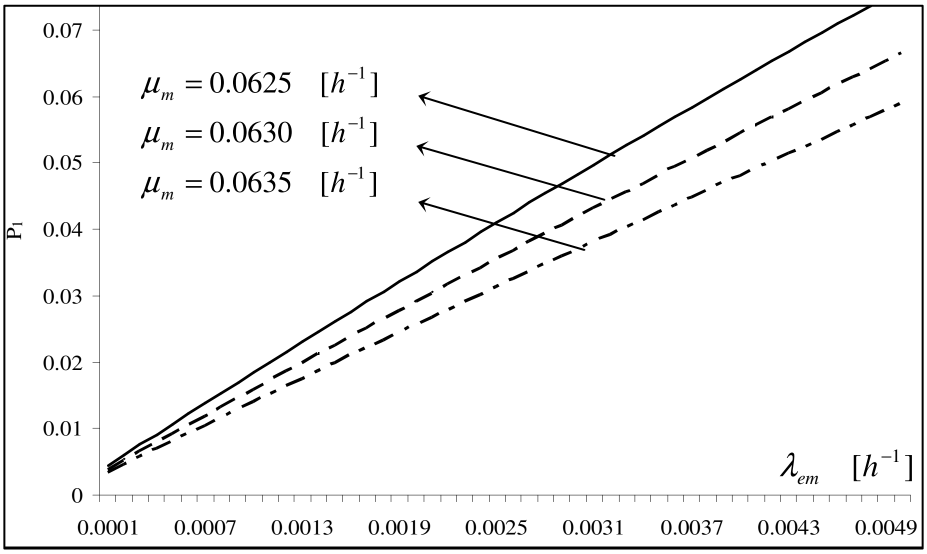


Fig.5 The influence of maintenanace (human) errors on the probability of partial failure state

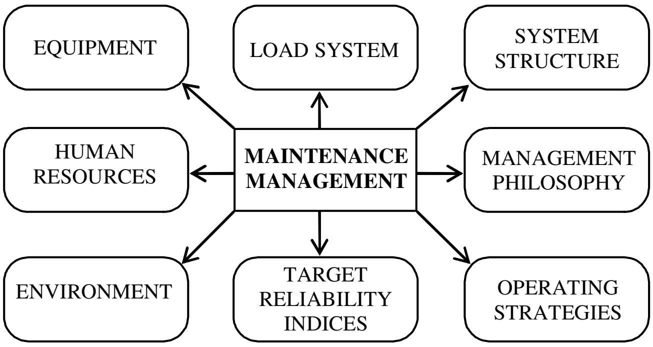


Fig.6 The maintenance system components for a electricity distribution network

3. Optimal balance between preventive maintenance and repairing

The human reliability is included in both preventive maintenance rate (λ_{pm}) and the failure rate (λ), considering the last one is depending also by preventive maintenance rate.

In distribution electricity networks field, the factors influencing the maintenance management [4] are shown in fig.6.

If we consider a relationship like in eq. 11 for a distribution network,

$$\lambda(\lambda_{pm}) = \lambda_{wm} e^{-\alpha\lambda_{pm}} \tag{11}$$

where λ_{wm} is the component failure rate without preventive maintenance and α is a constant depending on the component type and the maintenance efficiency, we can optimize the preventive maintenance according to the different criteria:

a) *The minimum total failure rate*

The total failure rate, due to failures and maintenance outages, is given by

$$\lambda_T = \lambda_{pm} + \lambda(\lambda_{pm}) = \lambda_{pm} + \lambda_{wm} e^{-\alpha\lambda_{pm}} \tag{12}$$

from where we can calculate the optimal value as:

$$\lambda_{pm\ optimal} = \frac{1}{\alpha}\ln(\alpha\cdot\lambda_{wm}) \tag{13}$$

b) The minimum total outage duration

This duration is given by

$$T = \lambda_{pm}\cdot T_m + \lambda\cdot T_r = \lambda_{pm}\cdot T_m + \lambda_{wm} e^{-\lambda_{pm}\cdot T_r} \tag{14}$$

where, for the considered component, T_r is the average repair time and T_m is the average maintenance time. The minimum duration is calculating as it follows:

$$\frac{dT}{d\lambda_{pm}} = 0 \qquad \text{and} \qquad \lambda_{pm\ optim} = \frac{1}{\alpha}\ln\frac{\alpha\cdot\lambda_{wm}\cdot T_r}{T_m} \tag{15}$$

c) The minimum total (repair and maintenance) cost

The total annual cost to repair is:

$$C_{ar} = (k_{1r} \cdot T_r + k_{2r})\lambda \tag{16}$$

and the annual cost for preventive maintenance is:

$$C_{am} = (k_{1m} \cdot T_m + k_{2m})\lambda_{pm} \tag{17}$$

In eq. (16) and (17) we noted:

- k_{1r} , the constant cost per time unit to repair the component;
- k_{2r} , the constant cost for a repairing activity;
- k_{1m} , the constant cost per time unit to maintain the component;
- k_{2m} , the constant cost per maintenance.

The total annual cost is:

$$C = (k_{1r} \cdot T_r + k_{2r})\lambda + (k_{1m} \cdot T_m + k_{2m})\lambda_{pm} \tag{18}$$

Considering the eq. (2) the total annual cost is

$$C = (k_{1r} \cdot T_r + k_{2r})\lambda_{wm} e^{-\alpha \cdot \lambda_{pm}} + (k_{1m} \cdot T_m + k_{2m})\lambda_{pm} \tag{19}$$

The minimum total annual cost to repair and maintain is for:

$$\lambda_{pm\,optim} = \frac{1}{\alpha} \ln(\alpha \cdot \lambda_{wm} \frac{(k_{1r} \cdot T_r + k_{2r})}{(k_{1m} \cdot T_m + k_{2m})} \tag{20}$$

These optimal values are strongly influenced by human reliability through the repair and preventive maintenance time.

4. Conclusions

The human activity is influencing the availability of technical systems mainly by maintenance. The two types of systems, with total and partial failures states due to maintenance, are presented as well the human errors on their reliability indices. Balancing the preventive maintenance and repairing parameters it is possible to optimize the availability of a system component according to different criteria. More research has to be done related to human reliability details and to dependence between total outage rate and maintenance rate for a given component.

REFERENCES

[1]. *Meister, D.*, The problem of human-initiated failures, Proceedings of the 8th national Sysmposium on Reliability and Quality Control, 1962, 234-239.

[2]. *Maister, D.,* “Human factors: theory and practice”, John Wiley and Sons, New York, 1976.

[3]. *Nemes. C, Munteanu, F., Ivas, D.,,* “Metode moderne de analiza a disponibilitatii elementelor si sistemelor”, Editura Politehnium, 2008.

[4]. *Munteanu, F., Ivas, D., Nemes, C., “Ingineria disponibilitatii subsistemelor de distributie a energiei electrice”. Ed. Spectrum, 1999.*