OPTIMIZATION OF RELIABILITY CENTERED MAINTENANCE (RCM) FOR POWER TRANSMISSION AND DISTRIBUTION NETWORKS

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ABSTRACT

The paper develops a model for preventive maintenance planning based on reliability (RCM), by optimizing the number of maintenance actions on power transmission and distribution networks. Maintenance actions on the system, known in the technical literature as "renewal process", have the effect of restoring system performance in the presence of technical limitations (maximizing safety in power supply) and economic constraints (minimizing the number and the costs of interventions).

The optimization model of maintenance based on reliability has been applied to the situation of a 20 kV electric line from Romania, resulting:

- the optimal number of interventions on the entire line for different time intervals;

- the optimum number of interventions on components of the line: pillars, insulators, conductors, for an interval of time.

1. INTRODUCTION

Currently, limiting preventive maintenance strategies in planning or workloads at fixed intervals cannot be accepted, both technically and economically. Thus, it is considered that preventive maintenance strategies should have mathematical models, based in turn on the probabilistic interpretation of the actual state of transport facilities and electricity supply while planning maintenance actions. The solutions to these mathematical models should lead to preventive maintenance actions that result in restoring the status of the system, changing wear, respectively of reliability. Determination as objective needs, priorities and scale/number of such preventive maintenance actions, are known in the technical literature that as preventive actions of renewal. The study of renewal processes and their influence on shaping the system will make the following assumptions:

- the system is known by function of reliability and indicators of reliability, based on data mining;
- the renewal actions aimed at reducing the influence of wear and thus improving reliability system considered in this regard as preventive maintenance actions;
- the renewal does not change all system features and after renewing the system follows the same evolution law of reliability to a new renewal;
- determine the frequency of renewals on the system will be on optimization models based on technical criteria and/or economic;
- renewal system components will be made under the same assumptions as the study of the system as a whole.

2. ESTIMATION OF SYSTEM RELIABILITY

Knowing the availability of a system at a time impose the knowledge of mathematical statistics using analytical form (type) function of distribution/function of reliability known by the numerical values of her parameters.

The energy systems in general and power lines in particular, contain parts with mechanical and electrical character whose function is directly influenced by weather, so it can be said with certainty that the failure of systems due to wear and aging slowly.

Given these findings, for modelling the reliability function of such processes of survival, using Weibull distribution law, characteristic of systems with wear, so and power lines. Of the known forms of law to accept the Weibull distribution for modelling the reliability function P_0 (t), in the absence of preventive maintenance, as the mathematical expression with two parameters:

$$\mathbf{P_o (t) = exp (- \lambda * t^{\beta})} \qquad (1)$$

where:

$\lambda, \beta > 0$ – is the scale parameter and form parameter of Weibull distribution.

For estimating λ, β parameters of Weibull distribution for the system in study and optimize preventive maintenance, we can use statistics while the behaviour of system by:

- the number and duration of periods of operation and interruption, due to preventive maintenance actions and/or corrective;
- the costs of such actions on the whole system and/or his components.

3. SHAPING PROCESSES OF RENEWAL

In this preventive maintenance, while the behaviour of the system will be in the form of reliability function:

- $\mathbf{P_r (t)}$ for new systems put into operation

$$\mathbf{P_r (t) = exp (- \lambda (r+1)^{(1-\beta)} * t^{\beta})} \qquad (2)$$

or, $\mathbf{P_{or}(t)}$ for systems in operation

$$\mathbf{P_r (t) = P_o \, exp (- \lambda (r+1)^{(1-\beta)} * t^{\beta})} \qquad (3)$$

where:

r – is the number of preventive renwal system;

$\mathbf{P_o}$ – system relaibility when planning preventive maintenance.

Influence of the number of renewal **r** on growth in system reliability function expressed by relationship (2), is shown in Figure 1, for a time.

t = 1800 days and $\mathbf{P_o}$, $\boldsymbol{\lambda}$, $\boldsymbol{\beta}$ are constants.

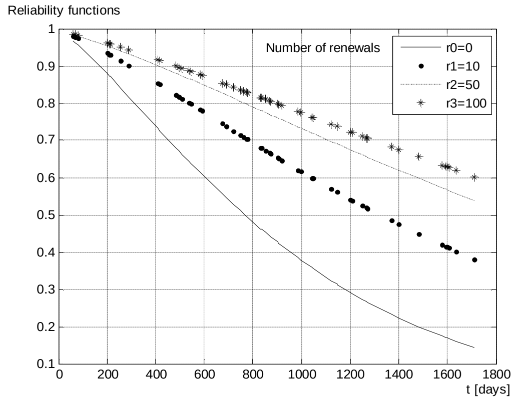

Figure 1. Influence of the number of renewals on system reliability

3.1 Shaping processes of renewal per interval time

Evolution of a renewal system with different time intervals will be represented by a number of renewal sequence r_1, r_2, ….r_n and the intervals between them $\Delta \mathbf{T_i}$ | i = 1,2…n at each period end with system reliability Pi, shown in Figure 2.

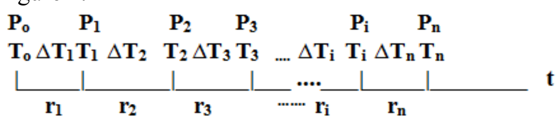

Figure 2. The parameters of the periods $\Delta \mathbf{T_i}$ of renewal

Starting from relation (2), $\mathbf{P_n}$ system reliability can be calculated at the end of „**n**" time periods $\Delta \mathbf{T_i}$ | i=1,n , each time with a number of renewal „$\mathbf{r_i}$" | i=1,n, with relationship:

$$P_n = P_0 \exp\left\{-\lambda_0 \sum_{i=1}^{n}\left[\prod_{j=1}^{i}(r_j+1)^{(1-\beta)} * \Delta T_j^{\beta}\right]\right\} \quad (4)$$

Representing the variation of system reliability in the relationship (4), on three intervals time **ΔT=1000** days with different renewal period for each $\mathbf{P_o}$, **λ** , **β** constant, resulting the graph shown in Figure 3.

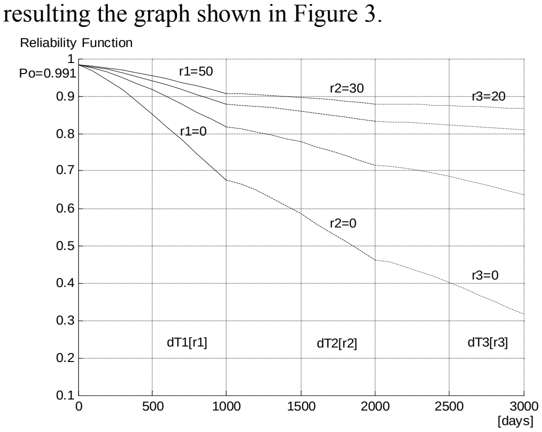

Figure 3. Influence of the renewals "r_i" on the reliability of the line, for three intervals of time ΔT_i

3.2. Shaping processes of renewal per components of electrical line

The operating state of a electrical line is directly influenced by the status of each component, so that the establishment of preventive maintenance of a line through the components involves the following steps and assumptions for calculation:
- constructive functional knowledge of the line profile and her components: pillars, conductors, isolators, protections;
- analysis and processing based on statistical and probabilistic models of data mining, resulting in the final the indicators of operating reliability and probability of electrical line and components, as long a period of operation;
- modelling and optimization of preventive maintenance of electrical line through the components;
- preventive renewal system components will be made under the same assumptions as the study of the system as a whole , in this case reliability function of each component follows a Weibull distribution of the form (1).

For case of electrical line for power transmission and distribution simple circuit, in terms of reliability, security scheme is a scheme with all elements connected in series represented in Figure 4, each component having parameters $\mathbf{Pi_0}$; **λi; βi | i=1,3.**

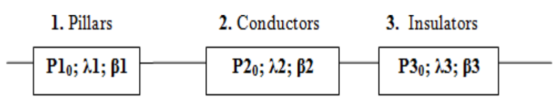

Figure 4. Equivalent safety scheme for power line

Assuming a mentenance functions of the form (3) on each component of the line, the probability of functioning of the entire line at the end of the time **ΔT**, will be given by (5):

$$\mathbf{P}_L(\Delta \mathbf{T}) = \prod_{i=1}^{3}\mathbf{P_i}(\Delta \mathbf{T}) = \prod_{i=1}^{3}\mathbf{P}_{i_0} * \exp\left[-\lambda_i(\mathbf{r_i}+1)^{(1-\beta_i)} * (\Delta \mathbf{T})^{\beta_i}\right] \quad (5)$$

where for the component „i" we have:

$\mathbf{r_i}$ – the number of renewal on time **ΔT**;

$\mathbf{Pi_0}$ – the reliability of the component in the moment of planning preventive maintenance.

4. THE OPTIMIZATION OF PROCESSES OF RENEWAL PREVENTIVE

In base of relations (4) and (5), it can be establish a mathematical model for Optimizing Reliability Based Maintenance (RCM), model that would allow determining the optimal number of renewal actions for a system or his components for one or more intervals time, on the basis of technical limitations and/or economic. Such a mathematical model has the following structure:

4.1. Variables by optimized

We choose the variables by optimized measurements:

$\mathbf{r_i}$ - number of renewals in the system, every time $\Delta T_i \mid i = 1,n$

or,

r_i – the number of renewals on components with i=1,2,3. Crowd these parameters whose optimal value we want to establish, are treated unit by ***X*,** vector of optimized variables of the form:

$$X = [x_1 x_2 \dots x_n]^T \quad (6)$$

with:

$$x_1 \equiv r_1 \quad x_2 \equiv r_2 \quad x_3 \equiv r_3 \quad \dots\dots \quad x_n \equiv r_n \quad (7)$$

4.2. Objective function

The objective function is an expression of mathematical optimization criterion chosen, which requires that expression to model as accuracy reliability renewal $P_S(X)$, or the costs of maintenance processes C(X) involved in the maintenance and operation, expressed as the function of optimized variables X, or:

$$max\ \{ P_S(X) \},\ \text{respective}\ min\ \{Q(X) = 1 - P_S(X)\} \quad (8)$$

or, $$min\ \{ C(X) \} \quad (9)$$

in the presence of constraints imposed to variables by optimized "X", or functions of these variables.

4.3. Constraints of the model

The constraints model can have two types:

4.3.1. Formulated to the optimization variables $x_i \mid i = 1, n$ if having this form on the conditions:

- variables $x_i \mid i = 1, n,$ were considered real and continuous on the interval $x_i^{\min} \le x_i \le x_i^{\max}$ (10)

where:

$x_i^{\min}$ – the minimum number of renewals;

$x_i^{\max}$ – the maximum number of renewals.

This set of constraints, form a system of linear constraints.

4.3.2. Formulated on technical and economic parameters of the system in study, for example:

- reliability of consumer $P_S(X)$ or, after a period of time following renewal applied to be greather than a minimum required reliability of the safety $P^{\min}$ or,

$$P_S(x) \ge P^{\min} \quad (11)$$

- time of unplanned interruption to the consumer for a period of time ΔT should not exceed a required value $T^{\max}$ established by contractual relationship with the consumer, or: $$[1 - P_S(x)] * \Delta T \le T^{\max} \quad (12)$$

- the number of unplanned interruptions to the consumer for a period of time ΔT does not exceed a maximum number imposed $NV^{\max}$, through contractual relationship with the consumer, or:

$$[P_S(x) * \lambda_m * \Delta T] \le NV^{\max} \quad (13)$$

- the total cost of system maintenance, not exceed a targeted $CT^{\max}$, or:

$$CMP(x) + CMC(x) \le CT^{\max} \quad (14)$$

where:

$CMP(x)$ – preventive maintenance costs;

$CMC(x)$ – corrective maintenance costs due.

In all cases, the constraints by the form (11) - (14) are in terms of mathematical "nonlinear constraints", forming one or more systems of nonlinear inequalities.

As worded, the mathematical model for Optimizing Reliability Based Maintenance (RCM) forming a nonlinear programming problem. This problem was solved with the specialized software package MATLAB 7.0.

5. NUMERICAL RESULTS

Optimization model presented in paragraph 4, it was applied to electrical power line 20 kV TGM-L, with the length of 89 km, 1106 pillars and conductors of OL-AL at 50 mm². To establish the reliability function of the line currently **Po(t),** relationship (1), from the "sheets of interventions" on maintenance in recent years the line was chosen as variable parameters:

a) time moments (expressed in days) corresponding to incident i when the functioning of line was interrupted, considering only corrective instances to restore line function;

b) duration of corrective instances (expressed in minutes) to restore the line after corresponding incident i; presented in Table 1, resulting in the Weibull function parameters:

λ = - 0.00126688

β = 1.29398252

Table 1. The incidents, moments and corresponding interruption time

Incident number (i)	1	2	3	...	52	53	54
t_i (days)	62	68	80	...	1608	1638	1712
T_{ri} (min)	213	118	352	...	403	178	841

Based on these parameters of reliability of the line at baseline and optimization model were established in assumptions 4.3., the optimal number of renewals " r_o " on electric line or her components during a year, resulting these graphs of variation.

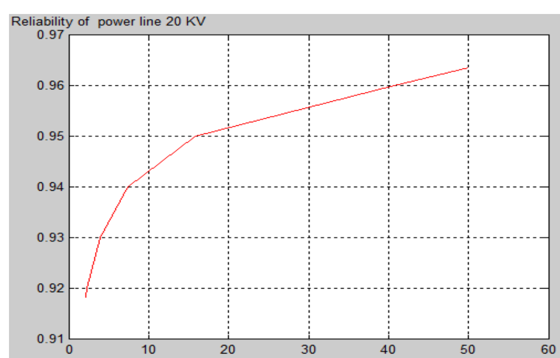

Figure 5. The variation of the optimal number of renewals with minimum reliability required line

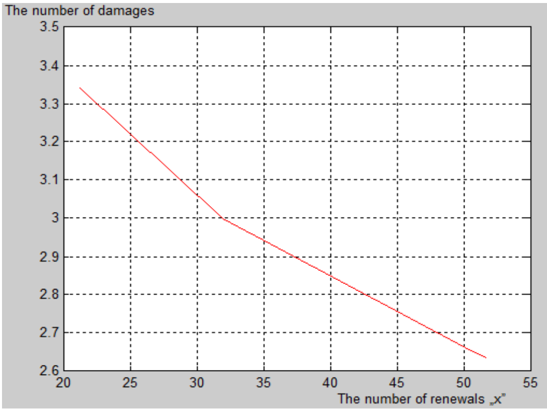

Figure 6. The variation of the optimal number of renewals depending on the maximum number of allowed damage

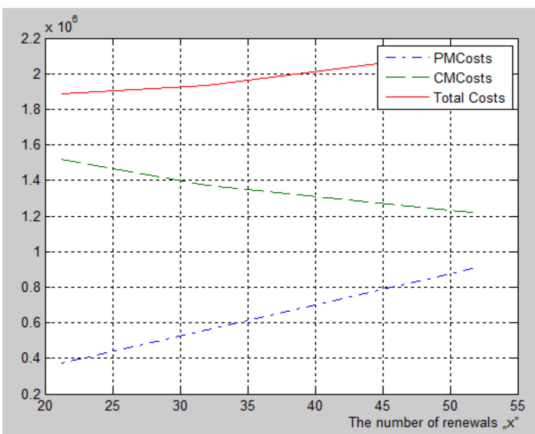

Figure 7. The variation of costs with power line mentenance depending by the optimal number of renewals

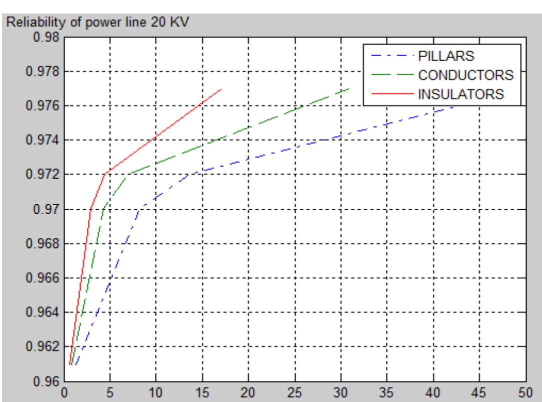

Figure 8. The variation of renewals number on the electrical power line components, depending by minimum reliability required on each component

6. CONCLUSIONS

This paper presents results of research in mathematical modelling of the reliability of stochastic systems with type wear, so that's the prediction of future behaviour can only with some probability and is based on knowledge of its evolution in the past and planned interventions - known in work "renewal". Determining the optimal number of renewals planned (expected?) on a 20 KV electric lines for aces while maintaining performance - that maintainability, is applied to the reliability-based Maintenance (RCM).

7. REFERENCES

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