Interconnections between Reliability, Maintenance and Availability

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Abstract. The assurance of power quality depends on factors which influence the performances of the availability: the reliability and its support – the maintenance. This paper deals with the interactions between the indicators of reliability, maintenance, availability and with the methods for the calculation of the reliability indicators. For an overhead line of 110 kV the characteristics of the reliability of the system are determined by modeling and analyzing its functionality by the Markov process of continuous time. The value of the availability index and the maintenance function function contributes to ascertain for the studied case that the value of the availability coefficient has the same value with the probability of success and the probability of repairing an equipment is closely connected to the maintenance function

Keywords: Reliability, maintenance, availability, Markov process, electric lines,

1 Introduction

The equipment used on the power systems is relatively old and increases the financial effort for their maintenance.

Therefore appear features of the electrical systems that are closely interrelated, such as: reliability, availability and maintenance, their interactions determining the qualitative and quantitative aspects of the analyzed system, its safe operation.

The reliability, as a feature of the system in fulfilling the specific functions in a certain period of time, continues to be the subject of many researches [1],[5],[7] and [10]. There are many papers [2],[8],[12] and [13] that have as a research subject the maintenance, their goal being to determine the optimum technical – organisational actions to maintain or to repair the system functionality. Concerning the system availability, there is analysed from this point of view: the system capacity of fulfilling its function in a certain moment within a period of time.

Taking in account the necessities for an increasing quality of the delivered electrical energy, there emerges the importance of a new approach in dealing with the aspects of reliability, availability and maintenance, in order to develop efficient methods for calculating the parameters/characteristics in relation with the operation time.

This paper analyses the connections between reliability, availability, maintenance and the “Markov chains” is the proposed method for determining the indicators of the correlation between reliability, availability maintenance and the probability of failure for an overhead line of 110 kV.

2 Contribution to Technological Innovation

The evaluation of repairing probability for equipment, that can be integrated rapidly in the maintenance program of studied systems, represents an innovation in technical domain based on the analysis of reliability indicators, contributing to implementation of the integrated concept reliability, maintenance and availability.

3 Characteristics Measures for Reliability, Maintenance and Availability

The safe operation of a technical system is defined by the totality of characteristics, Reliability, Maintenance and Availability.

The function of Reliability is defined by the relation:

$$R(t) = \mathrm{e}^{-\int_0^t z(t)\cdot \mathrm{d}t}, \tag{1}$$

where $z(t)$ - rate of failure is defined like the probability of uninterrupted operation until the moment of time t.

The relation (1) applies to any law of distribution of operation time. For the exponential repartition of operation time, the rate of failure is: $z(t) = \lambda(t) = \lambda = const.$ It results:

$$R(t) = e^{-\lambda(t)\cdot t} \tag{2}$$

Maintainability (M) represents a safety function and consists in the probability for an installation (or an equipment) to re-enter into operation after a certain time when the maintenance actions were made [1].

The maintenance function is defined by the relation:

$$M = 1 - e^{-\mu t} \tag{3}$$

where: μ is the intensity of repair, representing the probability that for a device which was faulty at the moment t, to be repaired in the next very short period of time. For an exponential repartition of the repairing periods: $\mu(t) = const.$

3.1 Reliability Measures

Reliability measures of repairable systems can be categorized into three groups [3]:

- Measures based on the system's first failure,
- Steady-state measures,
- Time-specific measures.

As time advances progresses, the repairable system reaches a steady-state condition. This means that certain estimates of system measures do not change with time. These measures include availability, mean time between failures MTBF, mean time to failure MTTF, mean time to repair MTTR, and the expected number of failures per unit time (failure frequency). The following relations are well known:

$$MTBF = \frac{1}{\mu(\infty)}$$
$$MTTF = \frac{A(\infty)}{\mu(\infty)} \qquad (4)$$
$$MTRF = \frac{1 - A(\infty)}{\mu(\infty)}.$$

Here $A(\infty)$and $v(\infty)$ are respectively the steady-state availability and failure frequency of the system. Therefore,

MTTF, MTTR, and MTBF can easily be found from the steady-state availability and failure frequency.

In Fig. 1 there are shown the links between Reliability, Maintenance, Availability.

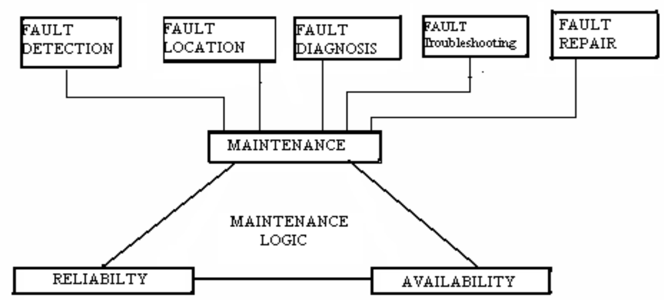

Fig. 1. Connections between reliability, maintenance and availability.

Analyzing Fig. 1, it can underline that the reliability of a system is characterized by the set of measures that give information on the performance of the system functionality in a period of time.

4 Calculation of System Reliability Indicators. Case Study

It consider the case of a 110 kV overhead power line shown in (Fig.2), with repair and failure intensities used in the design and provided by the Normative [9].

It aims at determining the characteristics of system analysis and adopting a model of its operation using continuous time Markov processes that can be used for operation and maintenance services of overhead power line owner.

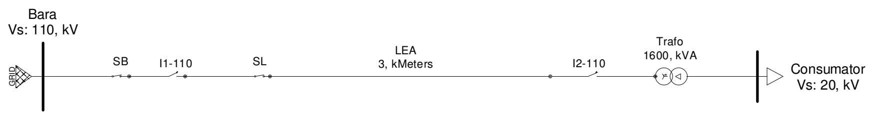

Fig. 2. The scheme of supply of a consumer to 20 kV through 110 kV overhead line.

In Table 1 There are listed the average values cited in technical literature [6] for the following parameters: the intensity of failure, the intensity of repair for a 110 kV installation.

Table 1. Intensities of repair and failure in installations of 110 kV.

Elements of overhead power line	Intensity of failure λ_i [year^{-1}]	Intensity of repair μ_i [year^{-1}]
Collector bar	1,3x10-2	175,2
Breaker line cell	3x10-2	175,2
Transformer 110 kV/MV	2x10-2	21,0
110 kV overhead line	1,3x10-2	547,5
Bar and line separator	0,4x10-2	438

Being a serial system components, to study some elements of the scheme is considered a system of 7 elements characterized by indicators of reliability λi and μi. In such a scheme, failure of any of the items that goes into them has the effect of removing all successful schemes in the state.

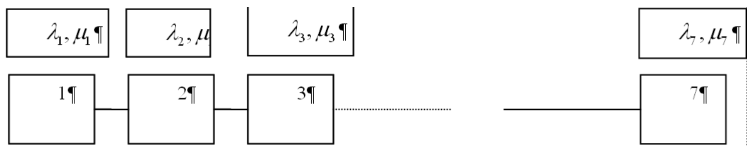

Fig. 3. Equivalent scheme for calculating the reliability indicators of 7 elements connected in series.

The schema elements can be considered dependent or independent, the states which may take different elements of the scheme. If the items are functionally dependent, the number of states is equal to (n +1).

- in state 0 - all elements are in operation,
- in state 1 - element 1 is defective,
- in state n - element 2 is defective.

There is no possibility of transition from states with a defective component in states with two defective elements or states with two defective elements in states with three defective elements, since at the failure of one element, the scheme is decommissioned, therefore there is assumed that the other elements can not be damaged.

States denomination:

-successful state (all elements in service): 0

-failure state: 1, 2, 3,...,7.

Transition graph for a system with elements in series is shown in Figure 4.

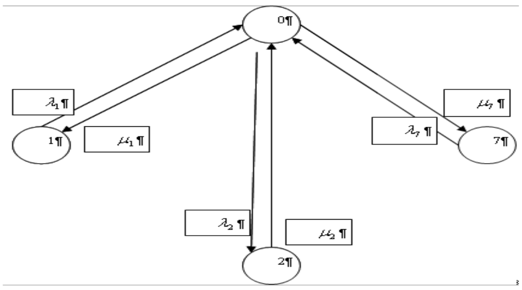

Fig. 4. Graphical representation of transitions for the series schedule.

4.1 Calculation and Analysis of Reliability Measures

Based on the analysis of state transitions [11] has made the transition intensities matrix. Transition intensities matrix, column matrix of absolute probability and matrix equation of state of absolute possibility tending to constant values independent of time.

If the system with n elements series, matrices are given below:

$$\begin{bmatrix} -\sum_{1}^{n}\lambda_1 & \mu_1 & \dots & \mu_n \\ \lambda_i & -\mu_1 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ \lambda_n & 0 & \dots & -\mu_n \end{bmatrix} \begin{bmatrix} P_0 \\ P_1 \\ \dots \\ P_n \end{bmatrix} = 0 \tag{5}$$

Calculation of success and failure probabilities is carried out by solving the relation (5), where P0 is the probability for the system to be in working order, P1-P7 corresponding to 7 states of transition. In this case:

$$P_0 = \frac{1}{1+\sum \frac{\lambda_i}{\mu_i}} = 0{,}998 \, ; \qquad P_i = \frac{\lambda_i}{\mu_i} \cdot P_0 = \begin{Bmatrix} 0{,}007 \cdot 10^{-2}; \\ 0{,}00089 \cdot 10^{-2}; \\ 0{,}016 \cdot 10^{2}; \\ 0{,}0089 \cdot 10^{-2}; \\ 0{,}0006 \cdot 10^{-2}; \\ 0{,}016 \cdot 10^{-2}; \\ 0{,}089 \cdot 10^{-2} \end{Bmatrix} . \tag{6}$$

For an operation time planned for the *T*p = 8200 h/year the following measures are calculated:

Probability of success:

$$P_S = P_0 = 0{,}998 \tag{7}$$

Probability of rejection:

$$P_R = \sum_1^7 P_i = 0{,}002 \tag{8}$$

Mean total success time:

$$M[\alpha(T_p) = P_s T_p = \frac{1}{1+\sum_1^7 \frac{\lambda_i}{\mu_i}} T_p = 0{,}998 \cdot 8200 = 8183{,}6 \quad h/\,year \tag{9}$$

Mean total failure time:

$$M[\beta(T_p) = P_R T_p = \frac{\sum_1^7 \frac{\lambda_i}{\mu_i}}{1+\sum_1^7 \frac{\lambda_i}{\mu_i}} T_p = 0{,}002 \cdot 8200 = 16{,}4 \quad h/\,year \tag{10}$$

Mean number of damages:

$$M[\nu(T_p)] = \sum P_i \sum q_{0j} T_p = P_0 \sum q_{0j} T_p = P_0 \left(\lambda_i + \ldots + \lambda_n\right) T_p = \frac{T_p \sum \lambda_i}{1+\sum \frac{\lambda_i}{\mu_i}} \tag{11}$$

$$= 0{,}998 \cdot 14 \cdot 10^{-2} \cdot 0{,}936 = 0{,}13$$

Mean duration of a successful state:

$$M[(T_f)] = \frac{M[\alpha(T_p)]}{M[\beta(T_p)]} = \frac{1}{\sum \lambda_i} = \frac{1}{14 \cdot 10^{-2}} \quad year \tag{12}$$

Mean duration of continuous operation (a state of failure):

$$M[(T_d)] = MTBF = \frac{M[\beta(T_p)]}{M[v(T_p)]} = \frac{\sum \frac{\lambda_i}{\mu_i}}{\sum \lambda_i} = 0{,}0087 \quad year \qquad (13)$$

Since the system is studied with a series structure is inferred that the failure of any component of the system generates damage of the entire line. Therefore, it is of tantamount importance to have a system with intensity of repair and an intensity of failure, such as:

$$\lambda_e = \frac{1}{M[T_p]} = \sum \lambda_i = 0{,}14 \quad year^{-1}$$
$$\mu_e = \frac{1}{M[T_d]} = \frac{\sum \lambda_i}{\sum \frac{\lambda_i}{\mu_i}} = 114{,}75 \quad year^{-1} \qquad (14)$$

Determination of availability and maintenance functions

To write the coefficient of availability and maintenance function will be used for repair and failure, the intensities equivalent to the system analyzed.

$$M[T_d] = \frac{1}{\mu_e} = \frac{1}{114{,}75} \cdot 8760 = 60{,}518 \quad days$$
$$A = \frac{\mu_e}{\lambda_e + \mu_e} = \frac{114{,}75}{114{,}75 + 0{,}14} = 0{,}998 \qquad (15)$$

Maintainability function is:

$$M = 1 - e^{-\mu_e t} \qquad (16)$$

After analysis, we have the following cases presented in Table 2.

Table 2. Probability of repair of overhead line.

Time required for repair [h]	Probability to be repaired [%]
$t = 1$	1.6%
$t = 24$	32.73 %
$t = 48$	54.75 %
$t = 200$	96.32 %

It is noted that for the time to repair the overhead line of 110 kV, for *t = 1 h*, the probability for that line to be repaired is 1.6%, and the acceptable probability (96.32%) repair for overhead line studied, leads to a minimum for 8 days.

5 Conclusions

The method used for determining the characteristics of reliability is easy to apply and almost draw up and provided maintenance plans and procedures and likewise and maintenance programs related equipment or systems studied.

The case study was performed with the parameters of professional norms, which is useful for design calculations.

For operating systems is useful to introduce the value of operating parameters that may substantiate more rigorous maintenance plans.

Calculated data were compared with data mining from SC Electrica SA (Electricity Distribution Company from Romania) and they are the values around which confirms the validity of the calculation.

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