MAINTENANCE OPTIMIZATION OF HIGH VOLTAGE SUBSTATION MODEL

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Summary The real system from practice is selected for optimization purpose in this paper. We describe the real scheme of a high voltage (HV) substation in different work states. Model scheme of the HV substation 22 kV is demonstrated within the paper. The scheme serves as input model scheme for the maintenance optimization. The input reliability and cost parameters of all components are given: the preventive and corrective maintenance costs, the actual maintenance period (being optimized), the failure rate and mean time to repair - MTTR.

1. INTRODUCTION

The objective of the paper is formulate such a maintenance strategy (for the HV substation 110/22 kV) so that the total operating costs may be minimized at keeping the necessary degree of the reliability and safety of equipment operated. Basic optimization methodology has already been demonstrated by first author of the paper within previous ESREL conference [2]. This methodology is based on simulation approach and it has been lately substantially innovated and improved.

The similar problems for cost optimization model for substation facilities solve an expert team of Belgian university with ELIA (the Belgian transmission powers system operator) cooperation [5], [6], [7] and interesting is also research work deal with maintenance optimization for power distribution networks in Sweden [8].

The paper has also purpose define the state of the real system so that in next step of progress was possible use the scheme as input model scheme for more complex mathematical modelling. The objective of the paper is perform such a data analyse (for the HV substation 110/22 kV) so that the model substation could be created. Technical university of Ostrava has very good work cooperation with power Distribution Company. This fact has been made the best for obtain of plans of substation and importance informations about it. The paper is organized in the following manner. Maintenance and cost models are explained and problem to solve is formulated.

2. MAINTENANCE AND COST MODEL, PROBLEM FORMULATION

2.1 The basic preconditions

The failure rate is expressed as an average value for the given type of equipment, although for each type we assume an exponential model of failures. For these reasons, we do not distinguish between different equipment types in Table 1. CMC – Corrective Maintenance Cost, PMC – Preventive Maintenance Cost, PPM – Period of Preventive Maintenance, λ – The failure rate, MTTR – Mean Time to Repair

Tab. 1. The databases of needed parameters

	D*	FCD	CB	TOC	CT	VT	T
CMC (10^3.CZK)	20	40	50	40	15	15	100
PMC (10^3.CZK)	1	1,5	6	6	1	1	20
PPM (year)	4	4	4	4	4	4	2
λ (10^{-3}/year)	4	4	6	8	7	7	48
MTTR (h)	80	80	820	260	160	160	1500

* Type of disconnector (MD, TD, FD, GD)

The legend of Tab. 1:

A disconnector of the main busbars system (MD), a disconnector of the transfer busbars system (TD), a feeder disconnector (FD), a ground disconnector (GD).

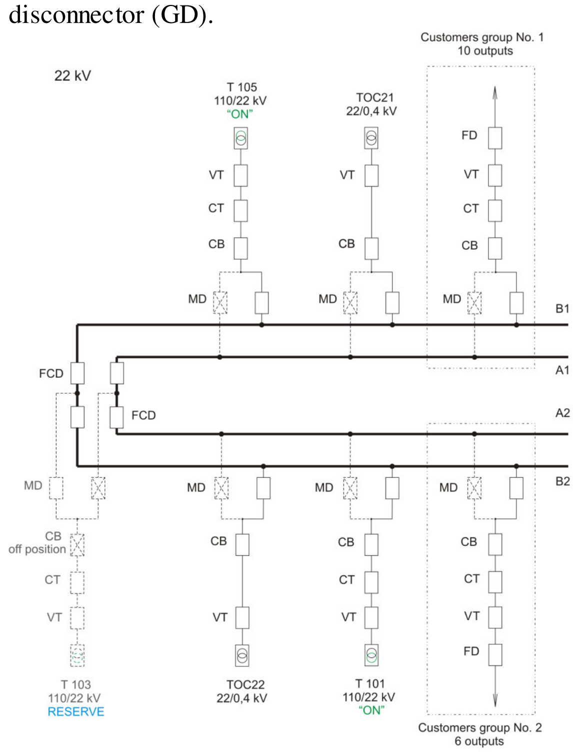

Fig. 1. The basic scheme of HV substation model

A fuse compression disconnector (FCD), a circuit breaker (CB), a transformer of own consumption (TOC), a current transformer (CT), a voltage transformer (VT), a source transformer 110/22 kV (T).

The method data obtained and HV substation described has been demonstrated by first author of the paper within conference proceedings [1].

2.2 Preventive maintenance model

In the paper we will assume that the preventive maintenance (PM) actions improve the reliability of input component to "as good as new". It means that the element's age is restored to zero (replacement). Cost of the above mentioned preventive maintenance policy of a given system is simply given by summarizing each of the PM inspections done on the components that are under maintenance:

$$C_{PM} = \sum_{i=1}^{N} \sum_{j=1}^{n_{e(i)}} C_j(e(i)), \qquad (1)$$

$n_{e(i)}$ represents the total number of inspections of the i^{th} component in the course of mission time

Cj(e(i)) is the cost of the j^{th} inspection of the i^{th} component

the total number of components is N

In most cases, the cost of inspection of a given input component is constant in the course of mission time, i.e.

$$C_{PM}(e(i)) = \sum_{j=1}^{n_{e(i)}} C_j(e(i)) = n_{e(i)} \times C(e(i), \qquad (2)$$

where $C(e(i))$ is the cost of one inspection of the i^{th} component. Total number of inspections is

$$n_{e(i)} = 1 + \left\lfloor \frac{T_M(e(i)) - T_0(e(i))}{T_P(e(i))} \right\rfloor, \qquad (3)$$

where symbol on right side of the equation is the integer part of the fraction, T_M, T_0, T_P, are respectively, mission time, first inspection time and inspection period of ith component.

The time in which a component is not available due to PM activity, is negligible if compared to the time elapsed between consecutive activities.

Basic assumptions of this paper are as follows:

1. Testing actions (or inspections) are carried out periodically, for j-th component with the period of $TP(j)$. Inspections are ideal which means that the component is renewed (as good as new). The inspection of the j-th component begins at the time $T0(j)$.
2. Each component is characterized by its exponential failure rate function, given by λ, MTTR (Mean Time to Repair), PMC-cost of one inspection and CMC- cost of one repair.

2.3 Corrective maintenance model

Basic methodology for the computation of total corrective maintenance cost CCM was formulated in [3]. Resulting from the reference, the mean corrective maintenance cost of i^{th} component in the course of mission time TM can be estimated as

$$C_{CM}(i) = n_R(i).CMC(i), \qquad (4)$$

where $n_R(i)$ is mean number of corrective actions in the course of mission time TM, and the total mean corrective maintenance cost is

$$C_{CM} = \sum_{i=1}^{N} C_{CM}(i), \qquad (5)$$

2.4 Total maintenance cost and problem formulation

Main objective of the paper now is to optimize, for each component of the power transmission system, the maintenance policy minimizing the total cost function

$$C = C_{CM} + C_{PM} = \min, \qquad (6)$$

in the course of mission time T_M, and respecting the availability constraint $AAV \geq A_0$. (AAV will be explained in next paragraph).

It is necessary to find optimal vector of PM periods (cost minimizing) $\boldsymbol{T_P} = (T_P(1), T_P(2) \ldots T_P(N))$, under given availability constraint.

3. RELIABILITY CHARACTERISTICS & OPTIMIZATION TECHIQUE

3.1 Reliability and availability calculation

Basic reliability and availability calculations of the paper were done by using simulation technique. Reliability and availability assessment method applied in the paper is based on the simulation program described in [2]. Directed Acyclic Graph composed from nodes and edges, was used as a system representation.

Basic reliability characteristics of the system, given by the input data from the Table 1 brings Fig. 2, that demonstrates the system unreliability or distribution function of the first system failure within given mission time TM = 10 years.

We are able to compute the dependence of availability on time as well. But this reliability characteristic can not be used for optimization purpose in this paper because we suppose exponential distribution for failures of system components. Taking into account "no memory property" of the exponential distribution, the instantaneous availability is not dependent on PM actions. The instantaneous availability could be used for optimization purpose just in case of ageing system components (for example Weibull distribution of failures).

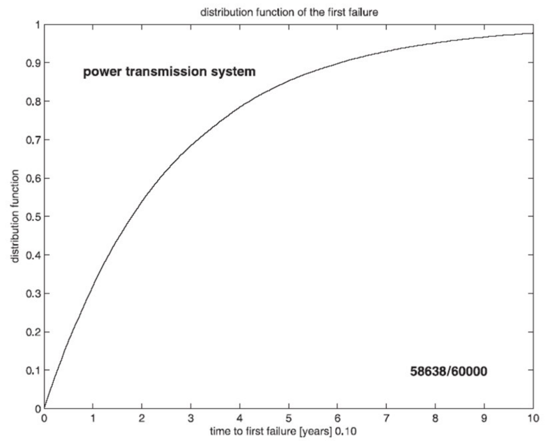

Fig. 2. Distribution function of the first system failure

As useful quantity for optimization process we used the asymptotic availability characteristics, here denoted as *AAV* that is defined as a worse limiting availability value to which instantaneous availability converges. This asymptotic availability value *AAV* we can compute as follows.

Assuming the asymptotic availability value of i^{th} component AAV_i as

$$AAV_i = \lim_{t \to +\infty} A_i(t) = \frac{1/\lambda_{ic}}{MTTR_i + 1/\lambda_{ic}}, \qquad (6)$$

where

λ_{ic} [year^{-1}] = corrected value (under influence of PM actions) of the failure rate of i^{th} component, which is computed according to methodology given in [3],

$A_i(t)$ = availability of the i^{th} component at the time t,

we obtain the *AAV* for the whole power transmission system as:

$$AAV = h(\underline{A}), \qquad (7)$$

where $\underline{A} = (AAV_1, AAV_2,\ldots,AAV_N)$ and, h = availability of the structure function given by the system (in this research the structure is represented by Directed Acyclic Graph).

This *AAV* characteristic is already dependent on PM actions and consequently it can be used for optimization process.

3.2 Cost optimization technique

We developed the cost optimization technique in previous research work referenced in [4], where full details concerning the application of the technique of genetic algorithms to basic cost optimization problem are clearly demonstrated.

4. RESULTS & DISCUSSION

Before we present the final results, we make one more assumption: first inspection time vector $\boldsymbol{T_0} = (T_0(1), T_0(2)\ldots T_0(N))$ has not been included into the process of optimization. Because we optimized PM periods in dependency on asymptotic availability characteristic, the results have not been influenced by the first inspections (at least not significantly). That is why we accepted the following strategy: first inspections are realized uniformly for all maintained components of the system just in the time which equals the length of period of the current component.

For the reliability parameters given in Table 1 we obtained the values of *AAV* for two extreme cases:

1. *AAV* without PM: 0.9864
2. *AAV* with given PM: 0.9997

On the basis of the results we see that PM plays relevant role to increase the *AAV*.

Total maintenance cost including PM from the Table 1 is estimated as follows:

$C = C_{CM} + C_{PM} = 0.724 + 0.283800$

$= 1.0078$ [mil. CZK / per 10 years]

Now we take into account the availability constraint $A_0 = 0.9997$. For this value of A_0 we are able to find optimal vector of PM periods $\boldsymbol{T_P} = (T_P(1), T_P(2)\ldots T_P(N))$ that brings Table 2.

Tab. 2. Comparison of the original and optimized PPM (year)

	D*	FCD	CB	CT	V	T
Original PPM	4	4	4	4	4	2
Optimal PPM	5.8	6.4	2.5	4.5	4.5	7.3

* Type of disconnector (MD, TD, FD, GD)

Total cost result computed according to the criteria: $C = C_{CM} + C_{PM} = \min$, gives the final value C:

$C = CCM + CPM = 0.862\ 440$ [mil. CZK/per 10 yrs.].

For comparison purpose (see Fig. 3) we also computed the system distribution function for the optimized preventive maintenance policy, within given mission time T_M = 10 years. We can see that obtained results are in good agreement with the original distribution function demonstrated in Fig. 2.

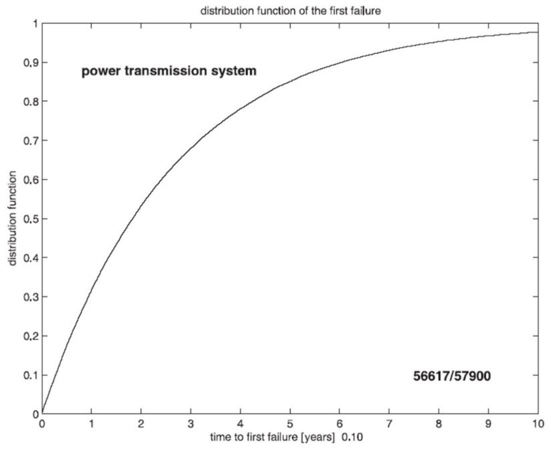

Fig. 3. Distribution function of the first system failure for optimal PM policy

5. CONCLUSION

On the basis of the results we can formulate the final conclusions:

- Source transformers T that have expensive preventive and corrective maintenance given by Table 1 are not necessary to be maintained with the period of 2 years, but the period might be increased to 7.3 years.
- From the set of the first order components the most important one seems to be CB. The conclusion is not surprising when we realize the fact that the maintenance of the component is second-most expensive, after source transformer. Our recommendation for period of PM is 2.5 in place of 4 years.
- On the other side the periods of PM of the components MD, FD, FCD might be a bit increased (to the value of 5.8 years) in comparison with initial maintenance policy.

We can formulate general conclusion as follows. New optimal strategy has been found that decreases the maintenance cost and, at the same time preserves the original value of *AAV= 0.9997*, as well as the distribution function of the first system failure. We reached the savings about 0.14536 mil. CZK /per 10 years which is not relevant value taking into account the mission time 10 years. Other words, original preventive maintenance data of all components, mostly given by the period of PM = 4 years is well-founded. PM period of the source transformers can be significantly increased (from 2 to 7.3 years). As future activity in that research we will try to finish the development of the software that enables to take into account the instantaneous availability (in place of *AAV*) in the process of optimization. This characteristic is relevant particularly in a more general case, when the ageing and wear-out processes have to be taken into account. Then we will be able include into the optimization also the vector of first inspections $T_0 =(T_0(1), T_0(2)\dots T_0(N))$.

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REFERENCES

[1] Briš, R., Gala, J.: *Model for maintenance optimization of selected high voltage substation in Moravian power transmission system*, ESREL 2006, European Safety and Reliability Conference, Conference proceedings Vol. 2, ISBN 0-415-41620-5, Portugal, Estoril, September 2006, pp. 483 – 489

[2] Briš R. 2005: *One computation algorithm for multiobjective maintenance optimization*, In Proceedings of European Safety and Reliability Conference ESREL 2005. p. 249-255, ISBN 0-415-38340-4

[3] Briš, R., Rusek, S., Goňo, R. 2005: *Maintenance optimization of a common simple distribution system*. In Proceedings of European Safety and Reliability Conference ESREL 2005,p. 257-262, ISBN 0-415-38340-4

[4] Briš, R., Châtelet E. & Yalaoui F. 2003: *New method to minimize the preventive maintenance cost of series–parallel systems*. In Reliability Engineering & System Safety, ELSEVIER, 2003, Vol. 82, Issue 3, p.247-255.

[5] Fouathia O., Maun J.C. & Labeau, Wiot D. P.E. 2005: *Cost-optimization model for the planning of the renewal, inspection, and maintenance of substation facilities in Belgian power transmission system*. In Proceedings of European Safety and Reliability Conference ESREL 2005.p. 631-637, ISBN 0-415-38340-4

[6] Fouathia O., Maun J.C. & Labeau, Wiot D. P.E. 2006: *Component-based modeling and simulation of an electrical substation for dependability study and replacement optimization*. In Proceedings of European Safety and Reliability Conference ESREL 2006.p. 687-693, ISBN 0-415-41620-5

[7] Fouathia O., Maun J.C. & Labeau, Wiot D. *Stochastic approach using Petri nets for maintenance optimization in Belgian power systems*. Proc. Probability Methods Applied to Power System 2004, Ames, Iowa

[8] Hilber P., *Maintenance Optimization for Power Distribution Systems,* Doctoral thesis, Royal Institute of Technology Stockholm, Sweden, 2008. ISSN 1653-5146