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ECONOMICAL MODEL FOR MAINTENANCE OF ELECTRIC DISTRIBUTION SYSTEM

In presented paper the model for economical and reliability based maintenance system of electric power distribution system is considered. This model considers the age based reliability of every distribution component of the power system. In our research the restricted test network is analyzed and the optimum reinvestment point of the whole network is found. The investment period of the single component is compared to the investment period of the whole network. In our research neither linear nor nonlinear optimization algorithm is used. The reason is that our test network is so small that it doesn't take to much computing time to go through all valid investment alternatives.

В представленной статье рассматривается модель экономичной и надежной системы обслуживания электростанции. В этой модели учитывается основанная на сроке службы надежность каждого компонента энергетической системы. Проанализирована ограниченная испытательная сеть и найдена оптимальная реинвестиционная точка всей сети. Инвестиционный период каждого компонента сравнивается с инвестиционным периодом всей сети. В данном исследовании не используется ни линейный, ни нелинейный алгоритм оптимизации. Причина состоит в том, что рассматриваемая испытательная сеть является настолько маленькой, что не требуется большого количества вычислительного времени, чтобы перебрать все действительные инвестиционные альтернативы.

1. Introduction. Electric energy transmission is powerly capital intensive activity, where most of the costs includes the capital costs of distribution components. In Finland distribution is based as well to the monopoly activity where the distribution company is responsible of all electric transmission in its activity area. Because there is no competition in electric transmission, it is valuable that the investments to the transmission are in effective use.

In the distribution companies the timing of the new- and replacement investment is traditionally based on vision of drift- and design personnel. The other aspect is the fault frequency of the distribution components. The third aspect is the checking activity of the transmission company. All these three elements are based on the systematic but most to the observation and vision of the personnel.

The alternative attitude to the maintaining could be based on the maintaining program of the components. Maintaining program includes database where the time depending fault frequency of the components is stored. This database can be dated by the service personnel of the distribution company. In the database the prices of the replacement of the components can be included. The price of the replacement could be compared to the price of the fault risk for the customers.

2. Fault risk as a function of the age. The reliability of the component and the system can be described by the failure rate λ. In distribution system reliability assessment, the component failure rates are usually assumed to be constant [1]. A better model would predict failure rates that very from year to year, increasing until the next periodic maintenance activity is performed [2]. In fig.1 are presented different failure models in air traffic and in ships.

Using these different models in electric distribution is not possible without reserve. The reason is that electric distribution is different from air traffic and so the risks in air traffic are very high. These are the reasons that components in air industry are changed before aging.

For our model, the most practical failure rate crows exponentially depending on the time. In the beginning years the failure rate is linear depending on time, but in the resent years the exponential failure rate is solved. Exponential failure cost function

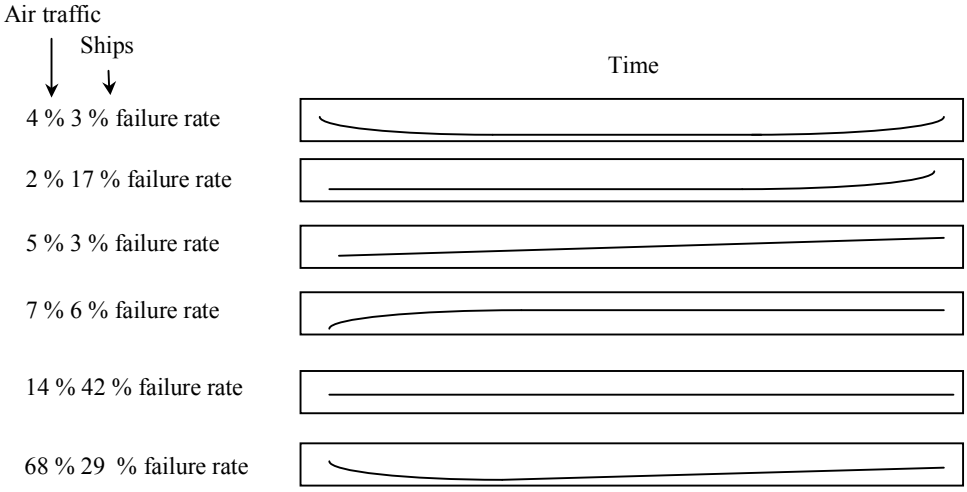


Fig.1. Failure models in air traffic and ships (K.Komonen VTT Tuotteet ja tuotanto, Presentation 14.11.2005)

$$\lambda(t) = b_0 \, e^{b_1 t} \quad . \qquad (1)$$

In our model the failure rate drops according to different overhauls actions during time t. But the failure rate doesn't drop to the initial value if the component is not changed. Anyway the failure rates increase exponentially in time, unless preventive maintenance actions are performed.

3. Maintenance model of distribution system. In our maintenance model there are four possible directions [2]. 1) Maintenance costs minimization. 2) Reliability maximization. 3) Overall costs minimization and 4) overall risk minimization. We have chosen alternative 2) Overall costs minimization. Our model consists of distribution components, where every component has the price, reliability and effect on the fault cost for the customers. In the basic situation the component can be overhauled or even changed when the cost of overhauling or replacement investment is lower than the fault cost for the customers.

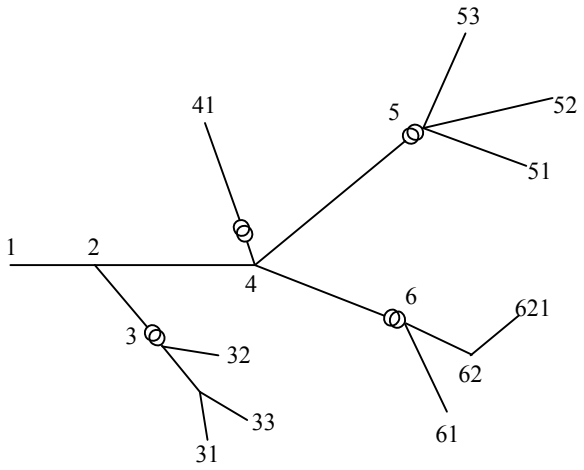


Fig.2. 20 kV/ 0,4 kV test network. Test network includes lines and transformers. 110 kV/20 kV transformer is not included. 20 kV network is in the same protection area. 0,4 kV lines are protected separately

In the very basic model the overhauling of one component can be decided separately from other components. So in this model comparing the interest cost of replacement or overhauling cost to the fault cost for the customers, the priority list for the maintenance can be found. The case of independent overhauled components can be compared to the case where all the components of the transmission branch are replaced in the same time. The net present value of the maintenance costs, replacement costs and the fault cost for the customers are compared to the representative net present values in the different time steps.

In several studies [3] different optimization algorithms are used to analyze the optimal strategy of investments and maintenance activities. The problem in the optimization models is that depending on the size of the distribution network, the complexity of the model grows exponentially. The possible states of the system depend geometrically on the size of the system. Traditionally methods to deal with the optimization problem are stochastic models, dynamic programming and linear programming.

4. Test network. In the fig.2 below is presented the test network used. The input data to the model is presented in Table.

Input data used in the test network

line	length km	failures 1/km,a	failure length,h	energy kWh	loadeffect kW	failure €/kWh	age	investment €	write-off period, a	write-off €
12	4	0,06	2	410000	86,16	5,0	15	100000	30	3333
23	5	0,065	2	100000	86,16	5,0	15	125000	30	4167
trans 3	1	0,1	1,5	100000	21,03	5,0	15	40000	30	1333
31	0,2	0,06	2	15000	3,16	5,0	15	5000	30	167
32	0,3	0,085	2	60000	12,62	5,0	15	7500	30	250
33	0,5	0,07	2	25000	5,27	5,0	15	12500	30	417
24	6,2	0,06	2	310000	86,16	5,0	10	155000	30	5167
trans 4	1	0,11	1	40000	8,42	5,0	10	40000	30	1333
41	0,3	0,05	2,5	40000	8,42	5,0	10	7500	30	250
46	7,3	0,03	1,5	130000	86,16	5,0	9	182500	30	6083
trans 6	1	0,16	1,8	130000	27,34	5,0	9	50000	30	1667
61	0,15	0,06	2	40000	8,42	5,0	9	3750	30	125
62	0,17	0,065	2	60000	12,62	5,0	9	4250	30	142
621	0,3	0,08	2	30000	6,32	5,0	9	7500	30	250
45	8	0,07	2	140000	86,16	5,0	6	200000	30	6667
trans 5	1	0,09	2,8	140000	29,44	5,0	6	50000	30	1667
51	0,2	0,04	2,35	50000	10,52	5,0	6	5000	30	167
52	0,4	0,06	2,35	30000	6,32	5,0	6	10000	30	333
53	0,5	0,055	2,35	60000	12,62	5,0	6	12500	30	417

In table the failure length includes the time for reparation of the fault. The failure cost includes the cost of the failure both for the energy distribution company and for the customers.

In our model, the failure cost is linear the first 25 years according Equation 2. After that the failure cost is exponential according Equation 3.The reason is that on the other hand this could be near the real world but on the other hand so it is possible to get realistic priority list for overhauling. In fig.3 is presented the failure cost of line 12 depending on the age of the line (years). Equation for the failure rate according time t in first 25 years. x is the failure rate in table multiplied by the length of the line. y is the failure rate depending on the year t.

$$y = \frac{2}{30}xt + x\,.$$

Equation for the failure rate according time after 25 years. t is the year, x the failure rate according table multiplied by the length of the line and y is the failure rate in year t.

$$y = \frac{1}{72{,}848}e^{t-25}x + 1{,}9627x\,.$$

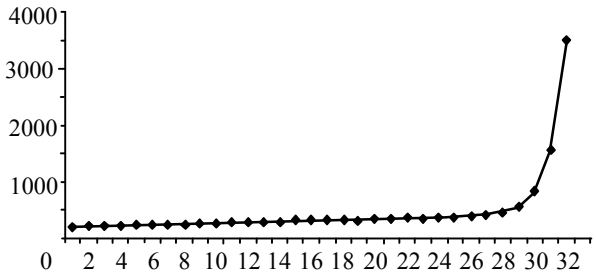


Fig.3.Failure cost of line 12, euros/year. Y – axis according equations 2 and 3 multiplied by the cost, load effect and failure length in table

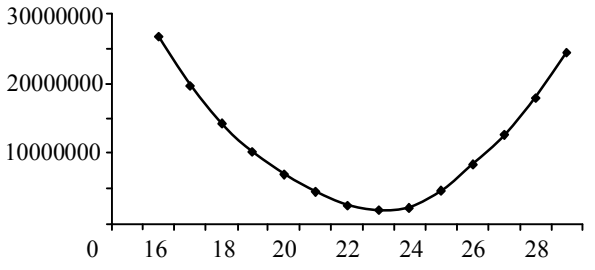


Fig.4. Net present value of the failure costs and reinvestment costs depending on the moment of reinvestment. Y – axis in euros, x – xis is the year of the reinvestment

The reinvestment time for the components is between 33-36 years after the investment if the whole network is built in the beginning of the period. If the age of the network is taken in account, the optimum reinvestment age is 23 years after the reference period. Every single component is optimazed so that we calculate is it profitable to change component before or after 23 years reinvestment age. In Figure 4 is presented the net present value of the investments costs and failure costs depending on time. Interest is 5 % and the running time 60 years. The model use as cost 80 % of the reinvestment costs (investment cost in table) if the reinvestment is made in the same time for all components. If single component is overhauled in any other time, the cost is 100% of the investment cost according to table. Fault costs are calculated for lines and transformers based on table according equation 2 and 3 and multiplied by load effect and failure length.

In our model, the failure rate is the most important input variable. Because the failure rate is exponential, this function rules the age of reinvestment of the component. Varying the factors of the exponential function has strong impact to the final result of the model.

5. Conclusion. The maintaining program of the distribution network is strongly depending on the input factors of the model. Is it more valuable make overhauling to the network long before the fault or is it valuable to wait until the component is broken and the fault exists? Because in the future electric distribution companies should pay compensation for the customers, the first alternative is more topical.

In the modelling of the distribution system the choice of the optimization method is valuable. In the small networks all the essential alternatives can be calculated through but the growing of the distribution network grows the amount of choices geometrically.

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