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Effect Of Combined Transmission Line (Overhead Line/Underground Cable) On Power System Reliability Indices

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Effect of Combined Transmission Line (Overhead Line/Cable) on Power System Reliability Indices

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Abstract**-- Reliability is a very important factor in designing of power network, because in the power system with low reliability, maintenance costs for power system is increased and causes creating damage that it is not compensated. Combined transmission line with cable line has considerable effects on power system reliability indices, because high voltage insulations are weak points in power systems in view of reliability that they are used in design of high voltage cables. On the other hand, in each power system with combined lines, optimum design of insulation system and considering suitable protection for cable lines by surge arrester against over voltage, increase power system reliability. Therefore in this study, reliability analysis of power system with combined line is done using event tree method. Also effect of location and number of surge arresters on the combined line reliability indices is studied and then variations the reliability indices have been analyzed by changing in length and age of cable line in the network. Results show that effect of length and age of cable and number of surge arresters in combined line on power system reliability indices is significant.**

Index Terms**-- Combined line, power system reliability, surge arrester.**

I. Introduction

NOWADAYS, expansion of power system and competing the electrical energy market, cause is to optimum designing power system and optimizing power system maintenance methods with decreasing unnecessary cost without affecting overall power system reliability.

Combined overhead transmission line with underground cable line is one of the factors that affect on power system reliability indices, because cable lines are manufactured with high voltage insulations, while high voltage insulations are known as weak points in power system in view of reliability. Therefore many efforts has been done for increasing high voltage reliability insulation, e.g. improving insulation endurance and optimizing insulation system design [1].

Reliability analysis of power system that contains combined line is very important because most faults on transmission lines are transient and these faults don't cause that overhead line be permanently out of service. Transient faults are typically caused by lightning activity and they have very short duration. Transient faults automatically cleared by auto-recluser operation of the line circuit breakers. Automatic clearing operation time takes less than a second and clearing operation does not required human intervention. Whereas auto-recluser operation can not clear cable insulation faults and also cable insulation does not restore like air insulated transmission line. Therefore, cable fault always causes that cable line completely be out of service [2]. Repairing damaged cable line takes several days or even some weeks [3].

Overvoltage caused by lightning must be considered when designing the cable insulation system [4] because it can be a major cause for underground cable failure. Surge arrester is used to decrease cable line faults [5]. On the other hand, the effect of cable length on cable line's transient behavior and consequently on the stressing condition of its insulation is very vital. The voltage peak in length of cable line becomes above the refracted wave from overhead line because of the successive reflection between cable ends, especially for short cable line. Therefore cable line length has a vital role in the insulation coordination [6].

One of the others factors that affects the cable line reliability is age of cable in the power system, because of cable line failure increases by increasing cable line age [7].

Above mentioned parameters are effective factors on power systems reliability that include combined overhead line with power cables. Therefore, in this study, effect of length and age of cable lines on reliability indices have been investigated. Also effect of location and number of surge arresters on the combined line reliability indices have been analyzed.

II. Cable Failure Rate

The cable failure rate depends on several factors from which the important factors are:

- Voltage stress;
- Environmental condition;
- Age of cable;
- Insulation defects;
- Design of cable and
- External mechanical damage

In this study for investigating effect of cable line length and its age on the power system reliability, the equation (1) has been used that $\lambda(t)$ is as instantaneous failure rate function of cable to time (t) [8].

$$\lambda(t) = kt^{n} \quad Failures\,/\,100\ mile\,/\,year \tag{1}$$

In (1) parameters of k and n depend on kind of cable.

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III. Reliability Analysis

In this study, for reliability analyzing, availability and unavailability have been used as reliability indices. Reliability analysis has been performed using event tree method. For computing reliability indices, it is assumed that the failure of each component has exponential distribution function. With this assumption, unavailability indices are calculated using the following equation [9]:

$$U = \frac{1}{T_c}\int_0^{T_c}\left(1-e^{-\lambda t}\right)dt = 1-\frac{1}{\lambda T_c}\left(1-e^{-\lambda T_c}\right) \quad (2)$$

where T_c is time period between consecutive tests and λ is failure rate of component.

If $\lambda T_c<<1$, the equation (2) becomes as:

$$U = \frac{\lambda T_c}{2} \quad (3)$$

Availability index is calculated using the following equation

$$A = 1-U \Rightarrow A = 1-\frac{\lambda T_c}{2} \quad (4)$$

IV. Reliability Model

The following cases have been considered for investigating effect of combined transmission line (overhead line/cable) on power system reliability indices.

- Case 1: power system only contains two consecutive overhead lines.
- Case 2: power system contains one cable line between two overhead lines.
- Case 3: power system contains one cable line between two overhead lines with surge arrester that locates in enter point (sending point) of cable line.
- Case 4: power system contains one cable line between two overhead lines with surge arrester that locates in receiving point of cable line.
- Case 5: power system contains one cable line between two overheads line with two surge arresters that locate in cable line ends.

As an example, Fig.1 shows one cable between two overhead lines with two surge arresters in cable line ends (case 5). The event tree for Fig. 1 is shown in Fig. 2. In Fig. 2 overhead lines are shown by L1 and L2, surge arresters are shown by B1 and B2 and cable line is shown by C.

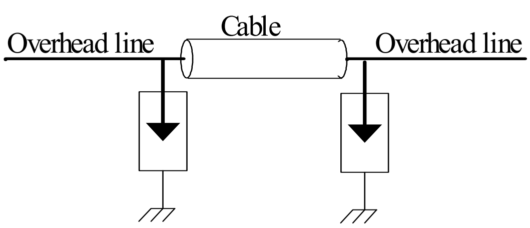

Fig. 1: Power system for Case 5

Event tree for Case 5 are explained as follows:

If the line L1 does not become failure in contrast overvoltage and surge arrester B1 operates suitable, route 1 will be constructed. In following, if line L1 does not become failure against of overvoltage but surge arrester B1 does not have suitable operation and also, cable can tolerate overvoltage and surge arrester B2 has suitable operation, route 2 will be constructed. Route 3 will be constructed if surge arrester B2 does not have suitable operation and line L2 tolerates overvoltage. Now if line L2 becomes failure in contrast overvoltage, route 4 will be constructed. Route 5 will be constructed if overhead line L1 tolerates overvoltage but surge arrester B1 and cable line do not limit overvoltage. Failure of line L1 causes constructing route 6.

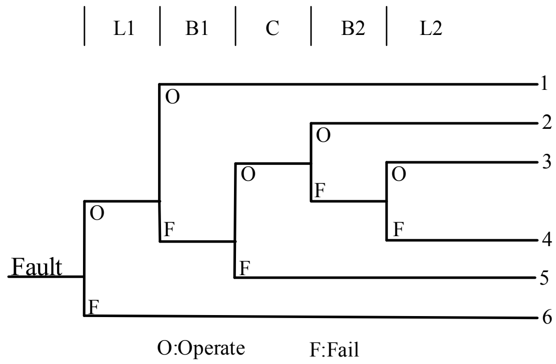

Fig. 2: Event tree for Case 5

In event tree for Case 5, routes (1), (2) and (3) are prosperity routes of system and routes (4), (5) and (6) are failing routes of system. Probability of these routes and reliability indices for Case 5 are calculated using (5).

$$\begin{aligned}
P_1 &= A_{L1}\times A_{B1}\\
P_2 &= A_{L1}\times U_{B1}\times A_C\times A_{B2}\\
P_3 &= A_{L1}\times U_{B1}\times A_C\times U_{B2}\times A_{L2}\\
P_4 &= A_{L1}\times U_{B1}\times A_C\times U_{B2}\times U_{L2}\\
P_5 &= A_{L1}\times U_{B1}\times U_C\\
P_6 &= U_{L1}\\
A &= P_1+P_2+P_3\\
U &= P_4+P_5+P_6
\end{aligned} \quad (5)$$

V. Simulation Results

In this study, failure rate of overhead line, cable line and surge arrester which on presented in Table 1 has been used for reliability analysis [10].

TABLE I
FAILURE RATES FOR COMPONENT

Component	Failure rate (Failures/ Year)
Overhead line	0.01
Cable line	0.001
Surge arrester	0.001

A. Result of Basic Condition

In basic Condition, failure rates in Table 1 have been used and the time between two consecutive tests has been considered one year. Availability and unavailability indices for Case 5 are calculated by (5). These indices for other cases are determined similar to Case 5. Table 2 shows results of comparison among mentioned ceases.

TABLE II
RELIABILITY INDICES FOR ALL CASES

Investigated Case	Availability	Unavailability
Case 1	0.9950166	0.0049834
Case 2	0.9895632	0.0104368
Case 3	0.9950139	0.0049861
Case 4	0.9945168	0.0058632
Case 5	0.9950164	0.0049836

With respect to Table 2, following results are extracted:

1- When there is surge arrester in combined lines, power system reliability increases such that system availability has been increased from 0.9895632 for a power system that contains one cable line between two overhead lines to 0.9950164 for a power system that contains one cable between two overhead lines with considering surge arresters installed the two ends of cable.

2- Location of surge arrester in combined line affects on system reliability when number of surge arrester is equal among cases. For examples, system unavailability increases from 0.0049861 for Case 3 to 0.0054832 for Case 4.

3- Power system reliability with only two overhead lines is more than power system reliability with combined line. For example, system availability amount decreases from 0.9950166 for case 1 to 0.9895632 for Case 2.

B. Effect of Failure Rate of Surge Arrester on Reliability Indices

Case 5 has been considered for analyzing the effect of surge arrester failure rate on reliability indices with changing surge arrester failure rate from zero (10^{-7}(Failures / year)) to 0.01 (failures / year) and other date are similar to previous case. Results have been shown in Figs. 3 and 4.

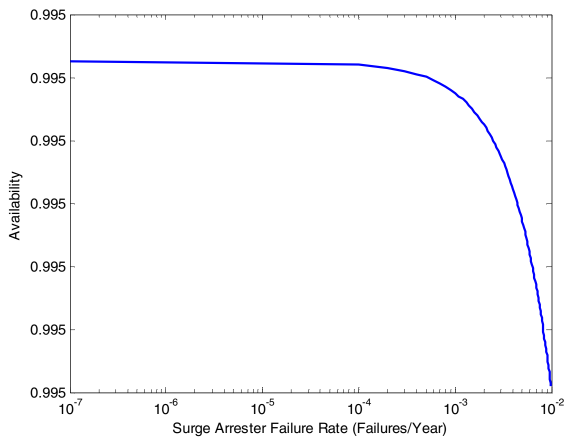

Fig. 3: Variations of availability index

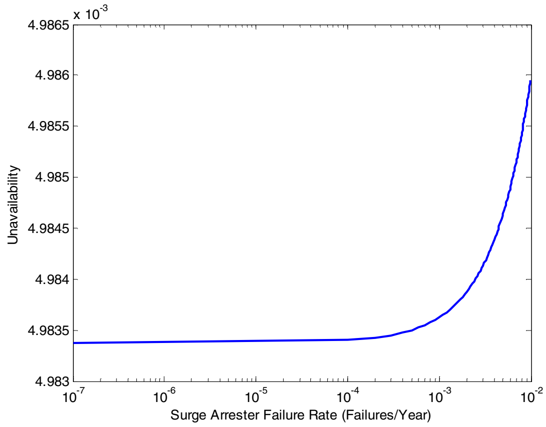

Fig. 4: Variations of unavailability index

Fig. 3 is shown that the system availability amount decreases from 0.9950166 to 0.9950140 when surge arrester failure rate increases from 10^{-7} to 0.01 (Failures / year).

C. Effect of Cable Length on Reliability Indices

For investigating the effect of cable length on combined line reliability, equation (1) has been used for determination cable line failure rate. In this study, polyethylene cable are investigated that for this cable, in equation (1) n=1 and k=0.28 (failures/100mile-year^2) [8],

With the mentioned assumptions, Figs. 5 and 6 and Table 3 show the effect of cable line length on system reliability with combined line with the assumption consecutive time one year, for Case 5.

TABLE III
VARIATIONS OF AVAILABILITY INDEX WITH INCREASING CABLE LINE LENGTH

Cable Line Length (km)	Availability
1	0.9950162
10	0.9950123
20	0.9950080
30	0.9950038
40	0.9949997
50	0.9949956

The presented results in Figs. 5 and 6 are shown that with the increase length of cable line, system availability index decreases. With respect to results of Table 3, the amount of availability index for cable line with length 1 (km) decrease from 0.9950162 to 0.9949956 for cable line with length 50 (km).

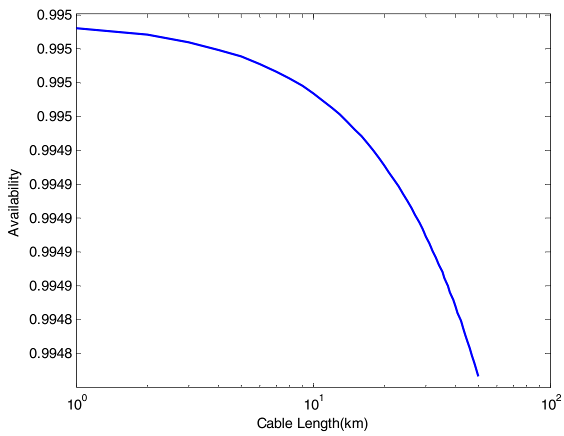

Fig. 5: Variations of availability index with increasing cable line length

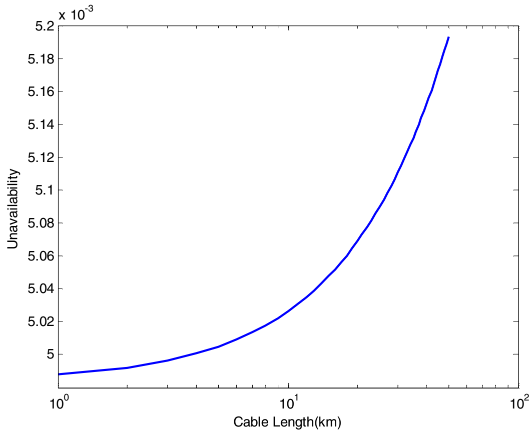

Fig. 6: Variations of unavailability index with increasing cable line length

D. *Effect of Cable Age on Reliability Indices*

With respect to equation (1), cable line failure rate depends on time that cable line is in service. So, for investigating variation of power system reliability with respect to age of cable line, simulation has been done for polyethylene cable line with length 10 (km). Figs. 7 and 8 are shown the effect of cable line age on the power system reliability indices.

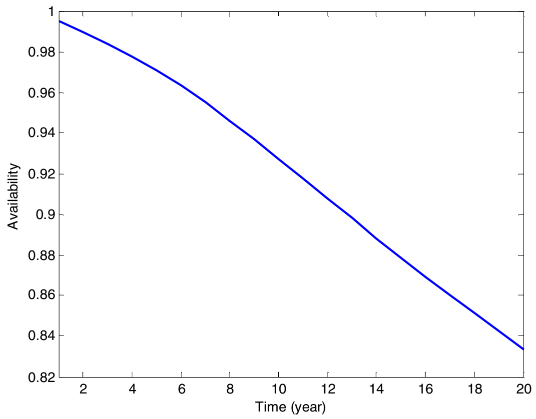

Fig. 7: Variations of availability index with increasing age of cable line

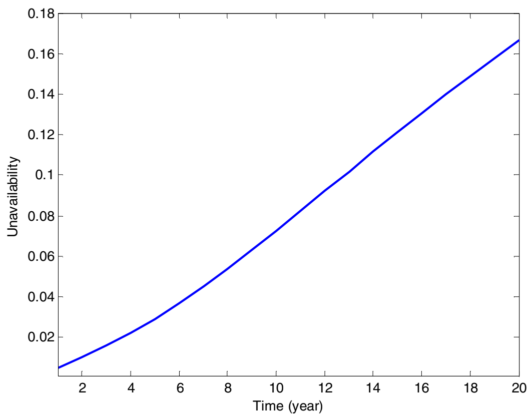

Fig. 8 :Variations of unavailability index with increasing age of cable line

As depicted in Figs. 7 and 8, with increasing of age of cable line, power system availability decreases. For example, the amount of decreasing for five years duration is 2.02%. Therefore decreasing of power system reliability with respect to age of cable line is considerable so it should consider in design of combined transmission line with power cables.

VI. Conclusion

In this paper, the effect of age and length of cable line and the effect of location and number surge arrester on combined line reliability indices have been investigated. Results are shown that system reliability without combined line is more than system reliability with combined line. System reliability will increase if there is surge arrester in cable line. Of course, increasing the number of surge arrester has the same result. With considering surge arrester in sending point of cable, system reliability is more than the system reliability that surge arrester is located in receiving point of cable. Also system reliability decreases with increasing failure rate of surge arrester. With increasing cable length for specific service duration of cable line and with increasing age of cable line for specific length, system reliability decreases. So, with respect to results of simulation, age and length parameters of cable line and also location and number of surge arresters should be exactly considered, otherwise power system reliability indices significantly decrease.

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VIII. Biographies

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