Assessment of the Performances of the Grounding System of the Transmission Lines

Nikolce Acevski[1] and Risto Ackovski[2]

Abstract – **Step and touch potentials at transmission line (TL) structures are sometimes important parameters in the design of the grounding system (GS). To have confidence in conventional (deterministic) methods of potential calculation, worst-case values of the design parameters must be assumed. This often leads to overly pessimistic results. A probabilistic approach enables more realistic values to be obtained with the same degree of confidence. A study has recently been performed to calculate the probability distributions of step and touch potentials in 400 kV transmission line Shtip - Dubrovo.**

Keywords – **transmission line, grounding system, probability distribution, and touch (step) voltage**

I. Introduction

The recent ten years have been characterized by a worldwide trend in using stochastic approaches for calculation of potential differences at touch or step in the surrounding of EE objects, instead of using the custom deterministic approach. Applying the deterministic approach, the maximum values of the potential differences at step or touch to which a human being could be exposed in case of an error in the grounding system of (in this case) a transmission line were calculated. This means that the worst case was presented. The results of investigations of numerous cases have shown that these maximal values occur very rarely. Namely, the probabilities for occurrence of such potential differences are very low. On the other hand, using stochastic approach, the probabilities for occurrence of certain potential difference - respectively the frequencies of occurrence - can be calculated. Using this approach, so called "frequency histograms" (FH) of the potential differences at touch or step for each tower grounding can be drawn, as well as, in general, the cumulative probabilities for the whole grounding system of the considered transmission line. This approach can be applied not only to choose a solution for the GS of the TL, but also for assessment of the risk when operating with running transmission lines. This means that the safety conditions from too high potential differences at touch or step – as defined with the regulations – can be tested in a more realistic way by using a stochastic approach.

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II. Risks from Dangerous Electrical Strokes Close to Transmission Lines

Coincidence of numerous stochastic events, each one with different probability for occurrence, is necessary for occurrence of an accident caused by an electrical stroke close to an energetic object (in our case the towers of a transmission line):

1. A fault to ground has occurred on the transmission line.
2. In the moment of the fault to ground, a person bridging certain potential difference at touch or step is located close to one of the towers.
3. The electrical currents through the body of the person are strong enough and are of sufficient duration to cause ventricular fibrillation.

Let P_{KV} be the probability that at the moment of observation, a fault to ground occurs on the observed TL. Then we have [3]:

$$P_{KV} = \frac{N_{KV} \cdot r_{KV}}{T_{god}} , \tag{1}$$

where N_{KV} is the average number of faults to ground of the line per year, r_{KV} is the average duration of a fault to ground (h), and T_{god} is a one year period (T_{god} =8760 h). The probability P_d that the observed person touches a TL tower, and, in that way, bridges a potential difference at touch will be:

$$P_d = f_d \cdot t_d \, . \tag{2}$$

Applying a similar reasoning, the probability P_c that an observed person is close to a certain tower in a certain moment, and, in that way, is bridging a potential difference at step will be:

$$P_c = f_c \cdot t_c \, . \tag{3}$$

In the relations (2) and (3), the frequencies at touch and at step are marked with f_d and f_c, and the average duration of a touch or a step is marked with t_d and t_c respectively. These amounts can be obtained as a result of long lasting observations of the stochastic approaches of persons to a TL, as it was done, for ex., in [4]. Based on these observations, the average yearly figures N_d and N_c of approaching towers and exposure to touching a TL by casual passers-by and the respective frequencies are f_d and f_c.

$$f_d = N_d / T_{god}; \quad f_c = N_c / T_{god} \tag{4}$$

Taking into consideration the information given above, according to the probability distributions of compound events, the risk R can be calculated, i.e. the probability a person to be a victim of an electric stroke caused by a fault to ground of a TL:

$$R = P_{KV} \cdot \left(\sum_{d} P_d \cdot R_d + \sum_{c} P_c \cdot R_c \right) \qquad (5)$$

In (5), R_d and R_c are the death probabilities (ventricular fibrillation) caused by an exposure to a dangerous voltage touch, step respectively. The summing in (5) is made for all possible touches (d) and all possible steps (c) close to an observed TL.

III. Calculation of Risks for Death Caused by a Dangerous Touch (Step) Voltage Due to a Short Circuit on Any Part of the Line

At first, the distribution of the phase currents of a one-phase short circuit for an error on any location along the line will be calculated, using, for example, the procedure elaborated in [1]. After the calculation of the values of the currents J_k, J_{p-k}, J_{q-k} ($k = 1, n$), these values will be used for calculation of the potentials along the longitude of the transmission line φ_{ki} ($i = 1, n$), in case of arising a one-phase short circuit on any part k (tower no. k) of the TL.

For calculation of the distribution of the phase currents J_k, J_{p-k}, J_{q-k} during a fault to ground on any part k along the line (see Fig. 1), it is sufficient to know the standard data which are output of custom calculations of short circuit currents in the EE systems. Those are the phase current in a three-phase and the phase current in a one-phase short circuit for the three characteristic periods: sub transient, transient and permanent. This procedure is repeated n times, for each tower place k of the TL ($k = 1, n$). The results of the calculations are put in a square matrix $[\varphi]$ with dimensions *nxn*. In that case, the elements of row k of this matrix, will consist of the potentials φ_{ki} ($i = 1, n$) that will occur at all n towers in case of a one-phase short circuit on the tower k. Similarly, the elements of the column i of this matrix will contain the potentials φ_{ki} that will occur on different locations of the error k on the tower i.

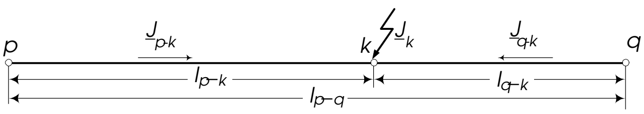

Fig. 1. Distribution of phase currents during a fault to ground

Let us observe the case of a one-phase short circuit on one of the towers of a TL. Let $P_{KV}(i)$, $(i = 1, n)$ be the probability for occurrence of a short circuit on the i-th tower of the TL. We assume that this probability is equal for all n towers of the observed TL (this assumption is approximately true on flat ground where the towers have uniform resistance to ground and uniform heights), meaning that they are equally exposed to discharges from the atmosphere and to recurrent skips of the isolation. Then:

$$P_{KV}(i) = \frac{P_{KV}}{n} \qquad (6)$$

Let us assume that a one-phase short circuit has occurred on a certain part of the observed TL and let t be the time of elimination of the short circuit, i.e. the duration of the error. If φ_{ki} is the potential that will occur on the tower i, under condition that the error has occurred on the tower k, then the risk for occurrence of a dangerous touch voltage that would cause death of the person who in that moment has been touching the tower i, will be:

$$R_d(i) = \sum_{k=1}^{n} P_{KV}(k) \cdot PA_{Ed}(\varphi_{ki}, t_{isk}) = \\ = \frac{1}{n} \cdot \sum_{k=1}^{n} PA_{Ed}(\varphi_{ki}, t_{isk}) \qquad (7)$$

when the tower i have a GS of type A, and respectively when the towers i have a GS of type B:

$$R_d(i) = \sum_{k=1}^{n} P_{KV}(k) \cdot PB_{Ed}(\varphi_{ki}, t_{isk}) = \\ = \frac{1}{n} \cdot \sum_{k=1}^{n} PB_{Ed}(\varphi_{ki}, t_{isk}) \qquad (8)$$

In the relations given above, the following symbols were used: N – total number of towers; φ_{ki} – potential (V) that occurs on the tower number i during a fault to ground that has occurred on the tower number k; $R_d(i)$, $R_c(i)$ – death occurrence risk caused by a too high touch and step voltage, respectively, on the tower i, during the occurrence of a short circuit on any place k of the observed tower; $PA_{Ed}(\varphi_{ki}, t_{isk})$, $PB_{Ed}(\varphi_{ki}, t_{isk})$ – risk (probability) for death occurrence caused by a dangerous touch voltage at a GS of type A, and at a GS of type B respectively, when the duration of the error is t_{isk} seconds, and the voltage of the tower equals to φ_{ki}; $PA_{Ec}(\varphi_{ki}, t_{isk})$, $PB_{Ec}(\varphi_{ki}, t_{isk})$ – risk (probability) for death occurrence caused by a dangerous step voltage at a GS of type A, and at a GS of type B respectively, when the duration of the error is t_{isk} seconds, and the voltage of the tower equals to φ_{ki}.

A. *Types of Grounding Systems Encircling High Voltage Towers*

The contour GS are the most frequently used ones for grounding of high voltage towers ($U_n \geqslant 10$ kV). The foundation of these towers is composed of 4 symmetrically lined

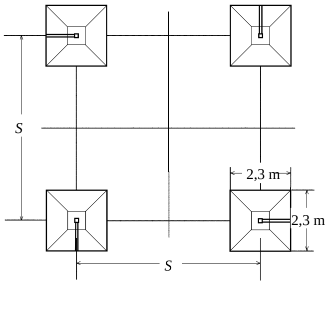

Fig. 2.a Appearance of the GS of type A (view from above)

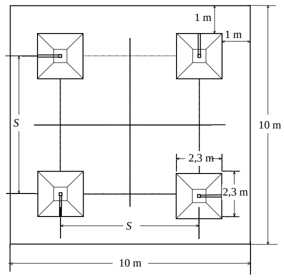

Fig. 2.b Appearance of the GS of type B(view from above)

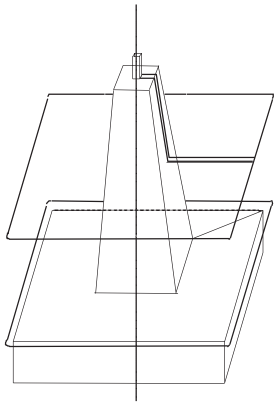

Fig. 3. Appearance of the GS encircling each foot of the tower

feet (Fig. 2.a, 2.b). The distance among the foundation feet S and their dimensions, depend on the height of the towers and on the capacity of the foundation. A common characteristic of all contours GS is that two square rings (contours) are being placed around each of the four feet. The first contour is placed at depth of 0.5 m, and the depth at which the other contour will be placed, depends on the depth of the foot. It depends on the dimensions of the foundation (Fig. 3). Besides the contours around each foot, for some types of GS, placement of an additional contour, encircling the feet of the foundation at depth of 1 m, is foreseen. The shape of this contour is a square with variable longitude of the side. The dimension of the side depends on the distance among the feet, i.e. - once again - it depends on the height of the tower and the capacity of the ground. The contour is positioned in a way that the horizontal distance from the sides of the contours that encircle the foundation is 1 m (Fig. 2.b).

According to the adopted indication, the marks for the GS without a common square contour encircling the feet of the tower start with A. The GS with a common square contour encircling the feet of the tower start with B. They are used for tower places that can be easily reached by people (or animals) (e.g. close to a road, settlement, etc.). The insertion of a joint contour encircling the four feet brings to reduction of the resistance along the GS and to shaping the potential in the surrounding of the tower, aiming at reduction of the risk for occurrence of too high touch voltages, or step voltages respectively.

When dealing with 400 kV towers, two families of standard GS– type A and type B - are used in our country. All contours are made of steel wires coated with zinc, 10 mm in diameter. Most frequently, the distance among the feet S varies from 2.5 m for the shortest, to 6 m for the highest towers. The average longitude of the side of the two square contours encircling the foundation foot is 2.35 m. The average depth of burying the lower contour is 2 m. The average longitude of the side of the square which is a joint grounding system encircling all feet is 10 m.

B. Probability for Death Occurrence in Case of a Short Circle on a Transmission Line

The death caused by a too high touch voltage caused by a person touching the tower $i$in the moment when a short circle arises, is a compound event, for which coincidence of two events is necessary: 1. There is a person close to the tower i, who decides to touch it in a certain moment, and 2. The touch voltage to which the person is exposed is too high (dangerous). The probability of the first event is marked as $P_d(i)$, and the probability of the second event is $R_d(i)$. Accordingly, we will get the probability $P(i)$ for a fatal result of the observed event that has occurred on the tower i, by multiplying the probability $P_d(i)$ in the critical moment when the person touches the tower i, with the probability $R_d(i)$ that the voltage to which the person will be exposed will be too high (dangerous), namely:

$$P(i) = P_d(i) \cdot R_d(i);\ i = 1, n\ . \tag{9}$$

Having calculated the risks $P(i)$ for each tower place i of the long-distance power line, the total probability for death occurrence caused by a dangerous touch voltage on the power line can be calculated. Introducing indications: $p_i = P(i)$ and q_i = 1-p_i, i = 1, n. Then, according to the probability laws, the probability Q that no death will occur at any tower place of the TL will be:

$$Q' = \prod_{i=1}^{n} q_i = \prod_{i=1}^{n} (1 - p_i) \tag{10}$$

The complement of the probability Q, $P' = 1 - Q'$, gives the probability for occurrence of at least one death at one of the towers, due to a short circle on the TL. If we know the average yearly number of one-phase short circles that occur on a power TL N_{KV}, then the total probability Q that no death case will occur during the year caused by a dangerous touch voltage will be:

$$Q = (Q')^{N_{KV}} \tag{11}$$

This means that the total risk R_d for occurrence of at least one death case during the year due to a dangerous touch voltage will be (12). The same principle is applied to calculate the risk for an accident for one year, caused by dangerous step voltage R_c.

$$R_d = 1 - Q = 1 - (Q')^{N_{KV}} \tag{12}$$

IV. Example

The procedure for calculation of the risk for death occurrence caused by a dangerous touch voltage will be illustrated in the case of the long-distance power TL Dubrovo – Shtip, which currently works at a 110 kV voltage. The data used for calculation are presented in [9]. Due to the short period of functioning of the TL, the average yearly number of one-phase short circles N_{KV} that occur on this TL is not known sufficiently precise. Also, there is no information on the probabilities $P_d(i)$ and $P_c(i)$ of exposure of persons to touch and step voltage in the surrounding of the towers of this long-distance power TL. For these reasons, the calculations were made with assumed values, close to the values on these parameters found in the literature. Parametric analysis of the total risks R_d and $R_c$for different values of the parameters N_{KV}, $P_d(i)$ and $P_c(i)$ was performed.

The 400 kV long-distance powers TL use two types of GS: A and B. The basic characteristics are presented in the table below.

Table 1. Characteristics of the Grounding type A and B

	Resist. R_{100}, Ω	Poten. diff. of touch E_d (%)			Poten. diff. of step E_c(%)		
type		max	med	min	max	med	min
A	4,58	24,2	15,8	12,1	17	2,84	0
B	3,91	13,5	9,4	7,1	13	2,62	0

The distribution of the potentials in different directions in the surrounding of the GS is different. It is more favorable in case of GS of type B. This is illustrated in Fig. 4. Conclusion can be drawn that, from the point of view of security, use of type B would be recommended for towers whose surrounding is charac-terized with higher frequency of movement of people or animals.

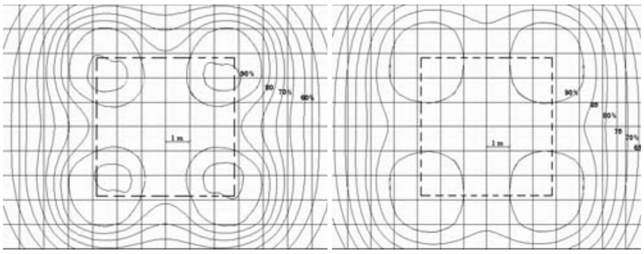

Fig. 4. Equipotent lines on the surface of the ground in the surrounding of the GS: type A to the left, type B to the right

The probability curves for death occurrence due to dangerous touch voltage (R_d), in relation to the potential on the tower and the duration of the short circulation for the GS of type A and of type B are presented in Fig. 5 and 6. According to the professional departments of the ESM for relay protection, the cutting duration due to short circuits on this long-distance power TL is:

a) 0.5 s for short circuits that have occurred on the first 20% and on the last 20% of the longitude of the TL;

b) 0.1 s for the rest (in between) of the transmission line.

This means that along approximately 40% of the TL, there is an increased risk for death occurrence. Using of B-type GS can lower the risk.

In Fig. 7 the numeration of the towers of the TL goes from the TS Dubrovo 400/110 kV to the TS Shtip 110/35 kV. The data on the geometry of the head of 400 kV towers used for calculation of the single electric parameters of the line (z and y) are given in [1] and [9], as and currents of short circuits in TSs.

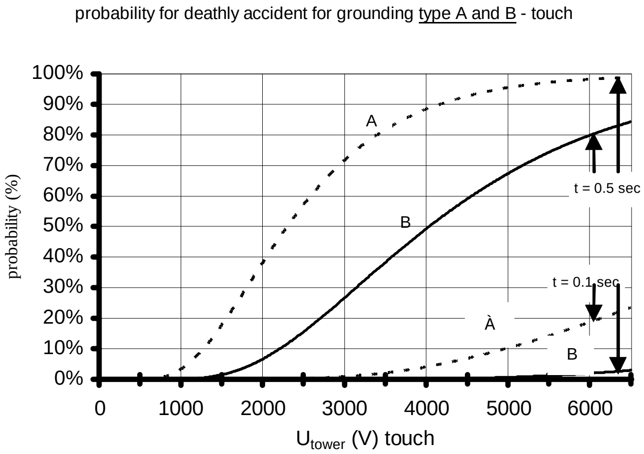

Fig. 5. Probability for death occurrence caused by dangerous touch voltage, depending of the potential of the tower

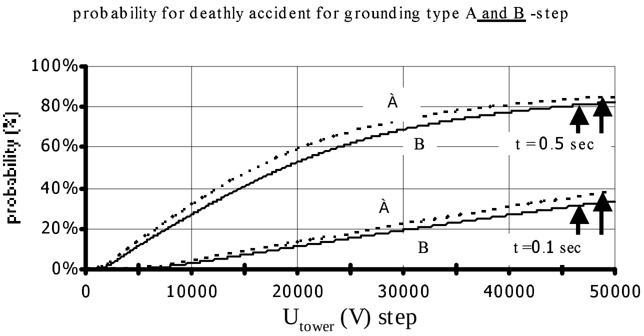

Fig. 6. Probability for death occurrence caused by dangerous step voltage, depending on the potential of the tower

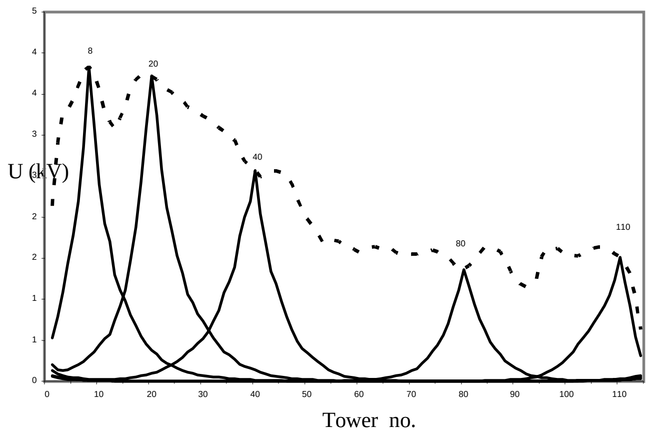

Fig. 7. Potential U on tower k, where a one-phase short current has occurred, k = 8, 20, 40, 80, 110, and distribution of U on the remaining towers i

V. Conclusion

A stochastic procedure for assessment of the risk (probability) for death occurrence caused by high touch and step potentials during a short circuit on a TL has been presented in this paper. In difference from the classical methods with application of conventional methods for assessment of these potentials, where the worst scenario, taking into consideration the maximum values of these parameters is applied, the stochastic approach gives more realistic results. The more realistic estimation of the risks contributes to improvement of the implementation of GS offering upgraded tech-economic implementation of GS on the TL, as well as gives a clear picture on the level of security at work for running TL. The stochastic procedure was applied for risk assessment of the

400 kV long-distance TL Dubrovo – Shtip. The results of the analysis showed that at the starting and at the ending parts of the line, there is an increased risk for high touch potentials. On these parts of the line, the security system cuts the high touch potentials with delay of 0.5 s. The highest risk has been assessed in the vicinity of the TS Dubrovo, where, due to the high value, the short circuits on these towers cause high potentials on the GS. The probability for death occurrence decreases if a B-type GS is used for these towers. In any case, for towers on locations with increased frequency of moving and residence of people and animals, B-type GS is recommended. Certainly, for assessment of the total public risk, the calculations have to be based on precise information on the probabilities for occurrence of short circuits along those parts of the TL, as well as on information about the probability for presence of people.

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