ANALYSIS OF SOME SAFETY ASSESSMENT STANDARD ON GROUNDING SYSTEMS
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Abstract. There are different safety assessment standards of grounding systems in different countries. Some of standards are widely adopted in the world, such as IEEE-80-2000, IEC-471-1, EA-TS41-24 and BS7354. In order to choose reasonable safety assessment standard in the design of grounding system of substation, these four standards are compared using a practical case. It showed that BS7354 is more conservative than IEEE-80-2000 and EA-TS41-24, and the definitions of allowable current are different between IEEE-80-2000 and IEC-471-1.

Keywords: grounding system, safety assessment standard, touch voltage, step voltage.

Introduction
Grounding grid is an important guarantee for substation safe operation. It can not only provide public reference for various equipment inside substation, but also excrete fault current rapidly, reduce the rise of substation's ground potential and ensure the person's and equipment's safety when the system is failure. The main electric parameters of substation grounding grid is grounding resistance, touch potential and step potential.

The grounding system safety assessment is a test which compare the maximum touch potential and step potential of the human body withstand with given safety standards. For the safety assessment of grounding systems, different nations have different standards. Some of standards are widely adopted in the world, such as IEEE-80-2000, IEC-471-1, EA-TS41-24 and BS7354. In order to provide a reference for safety assessment of actual grounding system, those four standards are analyzed and compared via a practical example in this paper.

Circuit Model
Before discussing the voltage that human body can withstand, we should briefly explain the current which human body can withstand. The effect when current through the vital organs of human body depends on the times of current passing through the body, the intensity and frequency of the current. The greatest danger is that the current can cause ventricle tremor and breathing stops when the current through the body. In the range of 0.03 seconds to 3 seconds, the current which will not cause ventricle tremor and breathing stops, $I_B$, depends on the energy absorbed by the body, $S_B$.

$$S_B = I_B^2 \times t_s$$ (1)
Where, \( t_s \) is the time of current through human body. Touch voltage and step voltage can be expressed in the following equivalent circuit, Fig.1.

![Fig. 1. equivalent circuit of touch voltage and step voltage](image)

In the Fig.1, \( R_B \) is the resistance of the body, \( V_{th} \) is the voltage between H and F when the electric shock doesn't occur; \( Z_{th} \) is the equivalent impedance of power source when the electric shock occurs.

**Comparison of the Definition of Safety Standard**

**IEEE Std 80-2000.** IEEE Std 80-2000 proposed the current which the human body can withstand, \( I_B \). For those whose weight were 70kg,

\[
I_B = \frac{0.157}{\sqrt{t_s}} \tag{2}
\]

The calculation formula of the standard touch voltage \( E_t \) and the actual touch voltage \( E_m \) are also given in this standard as following equation (3) and equation (4).

\[
E_t = (1000 + 1.5C_s\rho_s) \frac{0.157}{\sqrt{t_s}} \tag{3}
\]

Where, \( C_s \) is the reduction coefficient of resistivity, \( \rho_s \) is the resistivity of the surface gravel layer.

\[
E_m = \frac{\rho I_G k_m k_i}{L_m} \tag{4}
\]

Where, \( k_m \) is geometric factor of grounding grip, \( k_i \) is error correction factor of \( k_m \), \( L_m \) is effective length of buried conductors, \( \rho \) is resistivity of the soil, \( I_G \) is influx fault current.
This standard comparing the values of the actual touch voltage and the standard touch voltage to
determine whether the touch voltage is safety. It should be pointed out that the resistance of the
shoes is not considered in this standard.

**BS Std 7354.** The section headings are in boldface capital and lowercase letters. Second level
headings are typed as part of the succeeding paragraph (like the subsection heading of this
paragraph). BS Std 7354 provides the calculation formula of the actual touch voltage, $V_T$.

\[
V_T = \frac{\rho V}{R \pi} \left\{ \ln\left( \frac{h}{d} \right)^{0.5} + C_S \right\} k_i
\]

Where, $C_S$ is reduction coefficient of resistivity, $R$ is the mesh resistance, $L$ is the total length of
grounding conductor, $h$ is the burial depth of grounding, $d$ is the diameter of the conductor, $V$ is
mesh potential, $k_i = (0.15n + 0.7)$, $n$ is the total number of parallel conductors. In this standard, $V_T$
is defined as the sum of the voltage at one meter outward along the diagonal of grounding grid
and the voltage of grounding grid to the surface.

The calculation formula of standard touch voltage is not given in BS Std 7354, but it provides the
equivalent circuit of touch voltage, as showed in Fig. 2. Where, $R_{LF}$, $R_{RF}$ are the resistance of left
and right foot shoes, $R_C$ is touch resistance, $R_B$ is body resistance.

![Fig. 2. the equivalent circuit of touch voltage](image)

Using the equation (6), the current through the human body, $I_T$, can be calculated, compare $I_T$
with the current that the human body can withstand, which is given in IEC-471-1.

\[
V_T = I_T (R_B + \left( \frac{R_C}{2} \right))
\]

**EA-TS Std41-24.** The calculation formula of the actual touch voltage, $E_t$, was given by EA-
TS41-24 as following equation (7),

\[
E_t(grid) = \frac{K_e K_d \rho_I}{L}
\]

It is similar to the formula in IEEE-80-2000, but the parameter calculation has some difference.
Where, $K_e$ is the factor concerned with the distributed current, $K_d$ is modified coefficient to
uneven distributed electrode current, $L$ is the length of all conductors, including vertical
grounding rods, $L_p$ is the perimeter of grounding grid. EA-TS41-24 requires that there must have
fences around the grounding grip and the distance is two meters, the touch voltage formula of the fences is as following equation (8),

\[ E_t(fence) = \frac{K_f K_e \rho I}{L} \]  

(8)

Where, \( K_f = 0.26 K_e \).

EA-TS41-24 didn't given the formula of the standard touch voltage, but using the current vs. time curve which was given in IEC-471-1 to determine whether it is safe.

In Fig.3, line a is the line that the electric shock current is 0.5mA, which people has feeling and reaction. On the left of line a, people has no feeling and no reaction to the electric shock current, called no reaction zone, showed as the "region 1" in Fig.3. On the right of line a, the area is called "region 2", in which people has feeling and reaction to the current. Line b is called safety curve. "Region 3" which between line b and line c is non-fatal pathological and physiological effect area, in this area the electric shock current may cause convulsion, difficulty breathing and heart function disorder. On the right of line c is "region 4", in which it may cause fatal ventricular fibrillation and severe burns danger. IEC 471-1 didn't give the calculation formula of standard touch voltage and actual touch voltage, it only provides the effect curves of current through human body, and body resistance curves in different conditions.

In these standards we usually consider that step voltage is less than touch voltage, and generally believed that if the touch voltage meets the safety value, the step voltage also meets it.

Example Analysis

Now we can give some analysis through a concrete engineering example. A 115kV substation: length \(a = 60\)m, width \(b = 50\)m, grounding grid area \(A = 2867m^2\), thickness of gravel layer \(h_s = 0.1m\), resistivity \(\rho_s = 5000\Omega \cdot m\), resistivity of soil \(\rho = 52.33\Omega \cdot m\).

The maximum fault current is 10kA, and the fault time is 1s, grounding grid spacing \(D = 5m\); the number of grounding conductor \(n_A = n_B = 12\), total length of grounding grid \(L_C = 1200m\), depth...
h=0.8m, diameter d=0.0125m, the grounding rods are at the edge of the grounding grid, the total number n=34, and the total length $L_r=81.6m$, diameter $d_2=0.02m$, each length $L_2=2.4m$.

**IEEE 80-2000.** Calculate the actual touch voltage

$$E_m = \frac{\rho l G k_m k_i}{L_M}$$

Where, $k_m$ is the geometric factor of grounding grid, $k_m=0.6$, $k_i$ is the error correction factor of $k_m$, $k_i=2.72$, the value is 2.72. $L_M$ is the effective length of buried conductor

$$L_M = L_c + [1.55 + 1.22(\frac{L}{\sqrt{L_1 + L_2}})]L_B = 1330m$$

It can be drawn that actual touch voltage $E_m$ is

$$E_m = \frac{\rho l G k_m k_i}{L_M} = 642V$$

Standard touch voltage $E_t$ is,

$$E_t = (1000 + 1.5C_s \rho_s) \frac{0.157}{\sqrt{\tau_s}} = 781V$$

Where, $C_s$ is the reduction coefficient of resistivity. We can find that actual touch voltage $E_m$ is less than standard touch voltage $E_t$, so the grounding grid is considered to be safe.

**BS 7354.** Calculate the actual voltage

$$V_T = \frac{\rho V}{\pi R_T} \{1 \ln(h/d) + 0.5 + C_S \} k_i = 848V$$

$R_T$ is the grounding resistance, it can be calculated according to the formula and its value is 0.4784Ω; $V$ is ground potential rising, its value is 4784V.

$$V_T = I_T (R_B + \left( \frac{R_F + R_C}{2} \right))$$

$R_B=1000$, $R_F=4000$, $R_C=15000$, the current passing through the human body $I_T$ can be obtained, $I_T=81mA$. According to the current vs. time curve as showed in Fig.3 in IEC-471-1, this grounding grid doesn't meet the safety standards.

**EA-TS 41-24.** The touch voltage of the fence is,

$$E_i(fence) = \frac{K_i K_d \rho I}{L} = 0.26 E_i(grid) = 215.6V$$

$E_i = I_T (R_B + R_F)$, so the current passing through the human body is $I_T=4mA$.

According to the current vs. time curve as showed in Fig.3 in IEC-471-1, this grounding grid meets the safety standards.
Conclusion

According to calculation result of a practical engineering example, it can be found that BS 7354 is more conservative than the other two standards. The standard of the current which the human body can withstand in IEEE 80-2000 is larger than that of human body safety current which is proposed by IEC 471-1. So the safety assessment standard should be applied according to the practical situation.

References


