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EFFECTIVE GROUND RESISTANCE OF THE HUMAN FEET IN HIGH VOLTAGE SWITCHYARDS

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Abstract - The ground resistance of the feet is an important factor that determines the current flow in the body of a person exposed to dangerous touch voltage in a high voltage switchyard. It is modified by the proximity of the two feet and the presence of the energized grounding grid below the feet. Based on the Thevenin approach a general method for determining the effective ground resistance of the feet that takes into account the two above mentioned modifying factors is presented in this paper. The proposed method is verified with the help of analog model study. Results show that in most practical situations the effect of the two modifying factors can be ignored. The situations where it is necessary to consider these factors are also identified.

Keywords: Footing Resistance, Grounding, Safety, Body Currents, Substations.

INTRODUCTION

Grounding systems in substation yards are designed to keep the exposure to touch and step voltages to a safe value for a person standing on his/her feet inside or near a substation yard. Usually exposure to touch voltage poses greater danger than the step voltage. It causes current to flow from one hand or both hands to the ground through the feet in parallel. Figure 1 shows the fault current, I_f, being discharged to the ground by the grounding system of the station and a person touching a grounded metallic structure at H. The current, I_b, flowing from H through the body of the person to the ground at F is estimated by dividing the voltage between points H and F that would exist without the presence of the person in the circuit, by the resistance of the accidental circuit comprising the following:

(a) Resistance of the gloves and contact resistance of the hands of the person.
(b) Resistance of the body of the person.
(c) Resistance of the shoes and the socks.
(d) Ground resistance of the two feet in parallel. This is the resistance offered by the soil to the flow of current from the two feet.

The voltage between H and F without presence of the person can be calculated for a given configuration of the grounding system and soil conditions. The maximum touch voltage in a station is the mesh voltage. In high voltage transmission switchyards the total fault current, I_f, is assumed to be independent of the presence of the person in the path of the current as the system impedance and the resistance of the current path through the person are much greater than the ground resistance of the grounding system of the station.

The contact resistance of the hand and the resistance of the gloves, shoes and socks are of a very uncertain nature and can be very low. They are all assumed to be zero. Resistance of a human body may vary widely. IEEE Standard 80 recommends a value of 1000 ohms to be used for calculation of shock currents.[1].

The ground resistance of the feet in practical situations is the most important factor that controls the shock current flowing through the body of a person. A proper estimation of this ground resistance is, therefore, important. The ground resistance of the two feet in parallel is a function of the following parameters.

(a) Size of the foot and spacing between the feet.
(b) Thickness and resistivity of the surface layer of gravel in substation yard.
(c) Resistivity of the soil.
(d) Presence of the energized grounding grid below the feet.

The presently available simple methods to determine the ground resistance of the feet neglect the presence of the energized grounding grid in the proximity of the feet. In most cases the proximity of the two feet, giving rise to mutual ground resistance between the two feet is also neglected. The effect of these parameters on the ground resistance of the feet can be computed for a specific case with the help of computer programs.[2]. However a general method, without the use of complex computer analysis, to account for the proximity of the energized grid in determining the ground resistance of the feet is not available.

This paper presents a general method to include the proximity of the energized grid in the calculation of the ground resistance of the two feet in parallel. The situations where consideration of the presence of the energized grid is necessary are identified. The proposed method is verified with the help of analog models.

ISOLATED FEET ON THE GROUND

In its simplest form the ground resistance of the foot (the resistance of human foot to remote ground) is taken as equivalent to the ground resistance of a circular conducting disc having a radius of 8 cm and placed horizontally on the surface of the ground. The ground resistance, R_f, of a circular conducting disc of radius b on the surface of a homogenous earth of resistivity ρ_s is given by:[1]

$$R_f = \rho_s/(4b) \qquad (1)$$

For $b = 0.08$ m, $R_f = 3\rho_s$

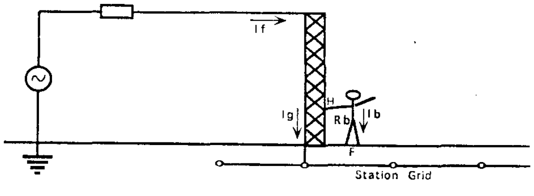

Figure 1 - Exposure to touch voltage.

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In substation yards an 8 to 20 cm thick layer of gravel or crushed rock is usually spread over the surface of earth. As compared to the size of the foot the depth of the gravel layer is not large enough to assume that the material is homogenous in the vertical direction. To take into account the limited thickness of the surface layer of gravel, equations in the form of infinite series and graphs are available.[1,3]. The ground resistance of the foot on the gravel in a substation yard is given by:[3].

$$R_f = \frac{\rho_s}{4b} G(Y) \qquad (2)$$

Where G(Y) is a function of size of the foot, thickness of the gravel surface layer, h, and the reflection factor K.

$$K = (\rho - \rho_s)/(\rho + \rho_s) \qquad (3)$$

ρ_s = Resistivity of the gravel, ohm-m.
ρ = Resistivity of the soil, ohm-m.

Figure 2 gives the value of G(Y) versus h, and K for b equal to 0.08 m.

If the two feet are far apart compared to their size, the mutual ground resistance between them can be ignored. In this situation the ground resistance of the two feet in parallel, R_{2fp}, is given by:

$$R_{2fp} = \frac{1}{2} R_f = \frac{1}{2} \frac{\rho_s}{4b} G(Y) \qquad (4)$$

For b=0.08 m, R_{2fp}=1.5 ρ_s G(Y)

IEEE Standard 80 recommends that for routine use the parallel resistance of the two feet be expressed by an equation similar to equation (4) except that the function F(X) is used in place of the function G(Y).[1]. Both the functions F(X) and G(Y) are based on the size of the foot, h and K. The difference in the values obtained from the two functions is due to the different approximations used in deriving these functions.[3]. Mathematically, the function G(Y) gives more accurate results and is used in this paper.

The following two parameters modify the ground resistance of the two feet given by equation (4).

(a) The mutual ground resistance between the two feet.
(b) Presence of the energized grid below the feet.

Mutual ground resistance between the two feet tend to increase the ground resistance of the feet whereas the presence of the energized grid in practical situations decreases the ground resistance of the feet. These two factors compensate each other to some extent. It will be shown in the subsequent sections that in high voltage switchyards the ground resistance of the feet given by equation (4) is usually very close to the ground resistance of the feet that is effective when the above mentioned two parameters are also considered.

PROXIMITY OF THE TWO FEET

At the time of exposure to touch voltage the distance between the two feet of a person may be 20 to 70 cm. At this distance the mutual ground resistance, R_{fm} between the two feet is not negligible. When R_{fm} is considered, the ground resistance of the two feet in parallel, R_{2fpm}, is given by:

$$R_{2fpm} = \frac{1}{2}(R_f + R_{fm}) \qquad (5)$$

The effect of R_{fm} is to increase the ground resistance of the feet by the feet proximity factor α.

$$\alpha = R_{2fpm}/R_{2fp} \qquad (6)$$

The mutual ground resistance between the two feet separated by a distance of d meters on the surface of a homogenous ground of resistivity ρ_s is given by the following equation if the feet are represented by an equivalent hemisphere.[1].

$$R_{fm} = \rho_s/(2\pi d) \qquad (7)$$

From equations (2), (4) to (7)

$$R_{2fpm} = \frac{\alpha}{2} R_f \qquad (8)$$

$$\alpha = 1 + \frac{2b}{\pi d} \qquad (9)$$

Figure 3 gives α versus d for b equal to 0.08 m.

The hemispherical representation of the foot used in equation (7) is valid if d>>b. To check the validity of equation (8) for small values of d, analog model tests were conducted. The foot was represented by an equivalent rectangular plate 28.4 cm long and 5.7 cm wide. This plate gives the same ground resistance in a uniform medium as that of a circular plate of 8 cm

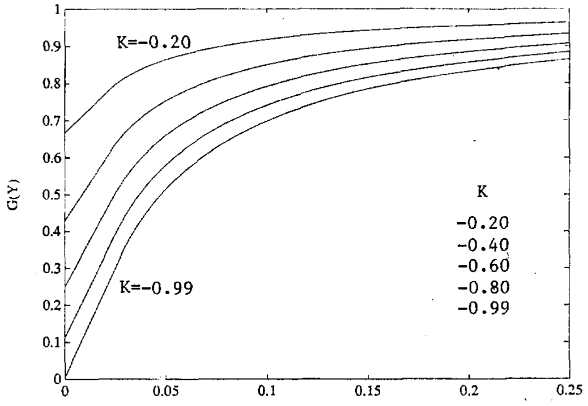

Figure 2 - G(Y) versus h and K.
(Foot represented by an equivalent rectangular plate)

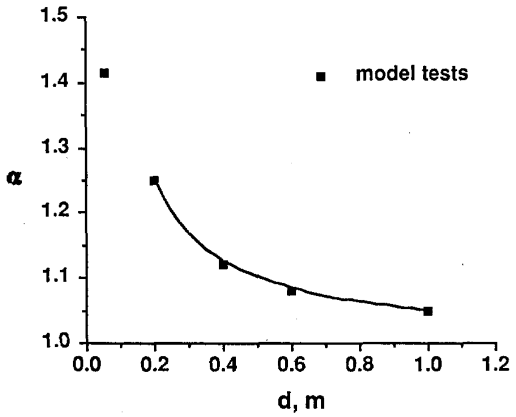

Figure 3 - α versus d.

radius. Models of the rectangular plates at a scale of 1:10 were used to measure the ground resistance of the two feet in parallel at various separation distances on the surface of water in a steel tank. The value of α for various values of d obtained from the model tests are shown in Figure 3. The values obtained from the model tests are very close to the respective values obtained from equation (9). Therefore equations (8) and (9) should give good results for the practical range of the separation distance between the two feet.

A finite thickness of the surface layer of ground has similar effect on R_f and R_{fm}. Therefore, finite thickness of the surface layer of the gravel will have insignificant effect on the value of α.

PRESENCE OF THE GROUNDING GRID

The presence of the grounding grid in a high voltage switchyard facilitates the flow of current from the feet to the soil and decreases the ground resistance of the feet. The reduction depends on the depth of the grid, H, location of the feet and the size of the meshes and the grid conductor. The reduction is greater when the depth and the mesh size of the grid are smaller. For a given location of the feet and depth of the grounding grid, the ground resistance of the feet decreases as the number of meshes is increased. The lower limit is reached when the number of meshes is infinity i.e. the grid develops into a plate.

To facilitate the calculations of the ground resistance of the feet in the presence of the grid, the grid is assumed to be a large conducting plate. This avoids the introduction of the parameters of the grid like size of the grid, size and spacing of the grid conductors, in the calculations of the ground resistance of the feet. However, this assumption introduces a small error which is on the safe side.

The ground resistance of the foot on a uniform soil with a large metallic plate at a depth H is derived in appendix A and is given by:

$$R_{fg} = \beta R_f \tag{10}$$

Where β (Grid proximity factor) $= 1-0.693(2b)/(\pi H)$ (11)

When the foot is on a layer of gravel, β will be modified by the ratio ρ/ρ_s and the depth of the layer of gravel. Appendix B gives the derivation of β based on the conical model of the gravel.[4]. β in this case is given by:

$$\beta = 1 - 0.693 \frac{2b}{\pi H} \frac{\rho}{\rho_s} \frac{1}{G(Y)} \tag{12}$$

The two proximity factors, α and β, given by equations (9) and (12) respectively, can be combined to obtain the ground resistance of the two feet in parallel on the gravel in a switchyard. This ground resistance, R_{2fpg}, takes into account the presence of the unenergized grounding system of the station as well as the proximity of the two feet and is given by:

$$R_{2fpg} = (1/2)\alpha\beta R_f \tag{13}$$

In practical situations β may vary from 0.95 to 1. Because of the small variation in β from 1, the representation of a grid with a plate is not expected to introduce any significant error. Any error that is introduced is on the safe side.

EFFECTIVE GROUND RESISTANCE OF THE FEET

The effective ground resistance of the feet is the resistance offered by the soil to the flow of the current from the two feet when the fault current is flowing through the grounding system and a person is exposed to the touch voltage. Thevenin equivalent circuit approach applied to the two port network can be used to evaluate the effective ground resistance of the feet.[2].

According to the Thevenin theorem the following steps give the current, I_b, flowing through the body of a person exposed to the touch voltage as shown in Figure 1.

(a) Remove the person from the circuit. Let the plates representing his/her feet stay on the ground.

(b) Find Thevenin voltage, V_{th}, which is the voltage between H and F when the person is not present. This is the touch voltage. Maximum value of this voltage in a station is the mesh voltage, E_m.

$$V_{th} = E_m \tag{14}$$

(c) Find the Thevenin impedance, Z_{th}, which is the impedance of the system as seen from points H and F with the voltage sources short circuited. In high voltage stations the system impedance is high as compared to the ground resistance of the grounding system of the station. Therefore, the Thevenin impedance is for all practical purposes the ground resistance between the plates representing the feet at F and the grounding system of the station. This resistance, R_{2fpe} is given by:

$$R_{2fpe} = R_{2fpg}+R_g-2R_m \tag{15}$$

$$= (1/2)\alpha\beta R_f+R_g-2R_m \tag{16}$$

Where R_g = Ground resistance of the grid.
R_m = Mutual ground resistance between the grounding grid and the two feet.

(d) The current I_b through the body of a person when he/she comes in contact with H and F is then given by:

$$I_b = \frac{V_{th}}{Z_{th}+R_b} = \frac{E_m}{R_{2fpe}+R_b} \tag{17}$$

Where R_b = Resistance of the body (1000 ohms)

The ground resistance of the grid, R_g, can be calculated with the use of simple equations.[1,5]. The mutual ground resistance between the grid and the feet will depend on the location of the feet. At the point where a person is exposed to the maximum touch voltage, the mutual ground resistance, R_m can be determined from the mesh voltage and the total voltage rise (I_gR_g) of the grid.

$$R_m = (I_gR_g-E_m)/I_g \tag{18}$$

Simplified equations are available to determine E_m.[1,6]. R_m in practical cases may be 60% to 90% of R_g.[7].

MODEL TESTS

To verify the Thevenin approach as applied to the calculations of the ground resistance of the feet, analog model tests were conducted in a water tank. The effective ground resistance of one foot was measured. This value was compared with the calculated value of the effective ground resistance obtained from the measurement of ground resistance of the foot when the grid was present, R_{fg}; ground resistance of the grid, R_g; and the mutual ground resistance between the grid and the foot, R_m. At a scale of 1:10 one foot was modelled by a 2.84x0.57 cm rectangular plate. The following two widely different types of models of the grid were tested.

1. Plate model - 30x30 cm aluminum plate.
2. Loop model - 24x15 cm one mesh rectangular grid made with 20 AWG wire.

Because of the limitation of the size of the water tank available for testing, larger models of the grids that would represent the practical systems could not be used. However for verification of the Thevenin approach, the models selected are considered adequate.

The model of the grid was suspended horizontally at different depths and the plate representing the foot was placed horizontally on the surface of water. The foot was placed where the maximum touch voltage would occur. In the case of the plate it was placed above the edge of the plate and in the case of the loop it was placed above the center of the loop.

The test circuit is given in Figure 4. Model of the foot and one model of the grid were placed in position and the following tests were conducted:

1. The grid and the foot were connected in parallel and energized. The following quantities were measured.
    - (a) Current through the grid, I_g.
    - (b) Current through the foot, I_f.
    - (c) Voltage of the grid and the foot with respect to the tank, V.
2. The foot was disconnected from the supply and only the grid was energized. No significant change in the current through the grid or in the voltage of the grid with respect to the tank was noticed. The following quantity was measured.
    - (a) Voltage of the foot with respect to the tank, V_{f0}.
3. Only the foot was energized and the following quantities were measured.
    - (a) Current through the foot, I_{fg}.
    - (b) Voltage of the foot with respect to the tank, V_{fg}.

From these measurements the following quantities were calculated.

Ground resistance of the foot with unenergized grid present.

$$R_{fg} = V_{fg}/I_{fg} \tag{19}$$

Ground resistance of the grid.

$$R_g = V/I_g \tag{20}$$

Mutual ground resistance of the grid and the foot.

$$R_m = V_{f0}/I_g \tag{21}$$

Touch voltage. $V_t = V-V_{f0}$ (22)

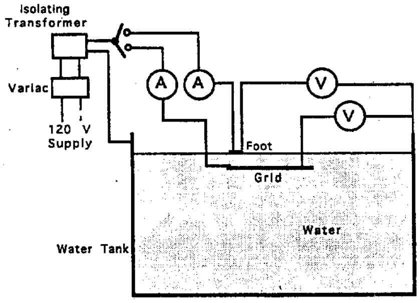

Figure 4 - Analog test setup.

Effective ground resistance of the foot, R_{fe}

Measured value, V_t/I_f

Calculated value, $R_{fg}+R_g-2R_m$

Table I gives the test data and the results for the two models of the grid. Measured and calculated values of the effective ground resistance of the foot are very close. It verifies that the effective ground resistance is, for all practical purposes, the ground resistance between the feet and the grounding grid of the station.

PRACTICAL SITUATIONS

Equation (16) gives the effective ground resistance of the feet for calculating the current that would go through the body of a person exposed to the touch voltage in a high voltage switchyard. Application of this equation is not convenient as the parameters used in this equation depend on the location of the feet and the geometry of the grounding system of the station. Equation (4) which is derived without consideration of the proximity between the feet and the presence of the grounding grid in the switchyard, is convenient to use. In a little different form it has been recommended in IEEE Standard 80.[1].

For the usual high voltage switchyards the value of the ground resistance of the feet obtained from equation (4) is very close to the effective ground resistance given by equation (16). The per unit difference, ε, in the values obtained from equations (4) and (16) is

$$\varepsilon = \frac{R_{2fpe} - R_{2fp}}{R_{2fpe}} = 1 - \frac{1}{\alpha\beta + (R_g - 2R_m)/R_{2fp}} \tag{23}$$

Table I - Analog model test data and results

Resistivity of water = 53 ohm-m.
Ground resistance of the isolated foot, R_f = 1583 ohms.

S.No.	Item	I	II	III	IV	V
(1)	Type of grid:	Plate	Plate	Plate	Loop	Loop
(2)	H, cm.:	12	5	2	5	2
(3)	I_g, mA.:	1010	988	894	494	304
(4)	I_f, mA.:	9.02	6.23	5.74	12.8	8.7
(5)	V, volts:	51.5	59.3	60.8	55.8	38.1
(6)	V_{f0}, volts:	37.4	50.4	53.6	36.1	24.6
(7)	I_{fg}, mA.:	10.5	11.2	12.4	12.2	12.8
(8)	V_{fg}, volts:	16.6	16.5	16.1	19.3	20.2
(9)	R_{fg}, ohms,: (8)/(7)	1581	1473	1298	1582	1578
(10)	R_g, ohms,: (5)/(3)	51	60	68	113	125
(11)	R_m, ohms,: (6)/(3)	37	51	60	73	81
(12)	V_t, volts,: (5)-(6)	14.1	8.9	7.2	19.7	13.5
(13)	R_{fe}, ohms,					
	Measured,: (12)/(4)	1563	1429	1254	1539	1552
	Calculated,: (9)+(10)-2(11)	1558	1431	1246	1547	1543

The ground resistance of the grid and the mutual ground resistance between the grid and the feet are both usually less than 1% of the ground resistance of the feet. Therefore, equation (23) can be simplified to

$$\varepsilon = 1 - 1/(\alpha\beta) \tag{24}$$

Table II gives the value of ε in percent for a few representative values of H, ρ_s/ρ, G(Y) and d. Positive value of ε shows that the value obtained from equation (4) is less than that obtained from equation (16). The error in using equation (4) in this case is on the safe side. This error is not likely to exceed 12%. When ε is negative, the error in using equation (4) is not on the safe side. This can happen only under conditions which are not normally encountered in practice. These conditions are:

(a) Depth of the grid is less than 0.3 m.
(b) Ratio ρ_s/ρ is less than 2.
(c) Ground resistance of the station ground and the mutual ground resistance between the feet and the grid are not negligible as compared to the ground resistance of the feet given by equation (4).

Equation (4) is easy to use. In practical cases it gives slightly lower value as compared to the value obtained from equation (16). The error is on the safe side and is small enough to be considered insignificant in grounding practice.

Table II - Difference in equations (4) and (16)

H, cm	d, cm	ρ_s/ρ	G(Y)	ε, %
20	40	2	.85	1.1
20	70	2	.85	-3.9
20	40	10	.70	9.0
20	70	10	.70	4.4
20	40	100	.65	11.1
20	70	100	.65	6.5
30	40	2	.85	4.7
30	70	2	.85	-0.1
40	40	2	.85	6.5
40	70	2	.85	1.7
40	40	10	.70	10.2
40	70	10	.70	5.6
40	40	100	.65	11.2
40	70	100	.65	6.7
80	40	2	.85	9.0
80	70	2	.85	4.3
80	40	10	.70	10.7
80	70	10	.70	6.2
80	40	100	.65	11.2
80	70	100	.65	6.7

CONCLUSIONS

1. Current through the body of a person exposed to touch voltage in a high voltage switchyard is given by the touch voltage divided by the sum of the resistance of the body and the effective ground resistance of the feet. The effective ground resistance of the feet given by equation (16) is, for all practical purposes, the ground resistance between the feet and the grounding grid.

2. In practice under normal situations ground resistance of the feet obtained in its simple form as recommended in IEEE Standard 80 and given by equation (4) is very close to the effective ground resistance obtained with equation (16). Equation (4) is convenient and easy to apply. In most practical cases it gives slightly lower value as compared to the value obtained from equation (16). The error is on the safe side and is small enough to be ignored in grounding practice.

3. Unusual conditions under which equation (4) may give a higher value of the ground resistance of the feet as compared to the effective ground resistance have been identified and are given in the paper.

REFERENCES

[1] "IEEE guide for Safety in AC Substation Grounding", ANSI/IEEE Std. 80, 1986.

[2] F.P.Dawalibi, R.D.Southey, and R.S.Baishiki, "Validity of Conventional Approaches for Calculating Body Currents Resulting From Electric Shocks", IEEE Transactions on Power Delivery, vol.5, 1990, pp. 613-626.

[3] B.Thapar, V.Gerez, and P.Emmanuel, "Ground Resistance of the Foot in Substation Yards", IEEE/PES Winter 1992 Meeting.

[4] B.Thapar, V.Gerez, A.Balakrishnan, and D.A.Blank, "Finite Expression and Models for Footing Resistance in Substations, IEEE/PES Winter 1991 Meeting, Paper Number 91 WM 036-4 PWRD.

[5] B.Thapar, V.Gerez, A.Balakrishnan, and D.A.Blank, "Evaluation of Ground Resistance of a Grounding Grid of Any Shape", IEEE Transactions on Power Delivery, vol.6, 1991, pp. 640-645.

[6] B.Thapar, V.Gerez, A.Balakrishnan, and D.A.Blank, "Simplified Equations for Mesh and Step Voltages in an AC Substation", Ibid, pp. 601-606.

[7] E.B.Joy, N.Paik, T.E.Brewer, R.E.Wilson, R.P.Webb, and A.P.Meliopoulos, "Graphical Data for Ground Grid Analysis", IEEE Transactions on Power Apparatus and Systems, vol. PAS-102, 1983, pp. 3038-3048.

APPENDIX A
GROUND RESISTANCE OF THE FOOT IN PRESENCE OF A LARGE CONDUCTING PLATE

A human foot is usually represented by an equivalent circular plate. The foot can also be represented by an equivalent hemisphere. Ground resistance, R_f, of the equivalent hemisphere of radius b_1, on the surface of the soil of resistivity ρ_s is given by:

$$R_f = \rho_s/(2\pi b_1) \tag{A1}$$

Radiuses of the equivalent hemisphere and the equivalent plate, b_1 and b respectively are related by the following equation.

$$b_1 = 2b/\pi \tag{A2}$$

When a large horizontal, conducting plate is located at a depth H the ground resistance of the equivalent hemisphere, R_{fg}, can be determined with the use of the method of images and is given by:

$$R_{fg} = \frac{\rho_s}{2\pi}\left[\frac{1}{b_1} - \frac{1}{H}\left(1 - \frac{1}{2} + \frac{1}{3} - \frac{1}{4} + \frac{1}{5} \,.......\right)\right]$$

$$= \frac{\rho_s}{2\pi}\left[\frac{1}{b_1} - \frac{0.693}{H}\right] \tag{A3}$$

From equations (A1), (A2) and (A3)

$$R_{fg} = \beta \; R_f \tag{A4}$$

Where β (Grid proximity factor) $= 1 - 0.693(2b)/(\pi H)$ (A5)

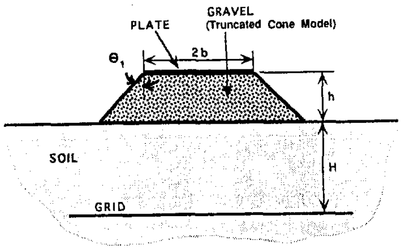

Figure B1 - Model of a foot on the gravel layer.

APPENDIX B
GROUND RESISTANCE OF THE FOOT ON GRAVEL IN THE PRESENCE OF A LARGE CONDUCTING PLATE

Figure B1 shows the equivalent model of a foot on the surface layer of the gravel overlaying a uniform soil. The foot is represented by a circular plate on a truncated cone representing the gravel layer.[4]. This cone has the same resistivity, ρ_s, as the gravel and its height, h, is equal to the thickness of the gravel layer. The radius at the top of the cone is equal to the equivalent radius of the foot, b. From the model the ground resistance of the foot, R_f, is determined by adding the resistance of the cone, R_c, and the resistance offered by the soil, R_s.

$$R_f = R_c + R_s = \frac{\rho_s}{4b} G(Y) \tag{B1}$$

$$R_c = \rho_s h / [\pi b (b + h \tan \theta_1)] \tag{B2}$$

The resistance offered by the soil is calculated by assuming the bottom of the cone to be a circular plate discharging current in the soil.

$$R_s = \rho / (4 b_s) \tag{B3}$$

Where $b_s = b + h \tan \theta_1$ (B4)

When a large metallic plate is introduced at a depth H as shown in Figure B1, it is assumed that it does not affect the cone representing the gravel. Therefore, R_c is not changed. The presence of the plate however changes the resistance offered by the soil from R_s to R_{sg}. From equations (A4) and (A5)

$$R_{sg} = R_s \left(1 - 0.693 \frac{2b_s}{\pi H}\right) \tag{B5}$$

The ground resistance of the foot in the presence of the plate is then given by

$$R_{fg} = R_c + R_{sg} \tag{B6}$$

From equations (B1) to (B6)

$$R_{fg} = \beta \; R_f$$

Where $\beta = [1 - 0.693 \frac{2b}{\pi H} \frac{\rho}{\rho_s} \frac{1}{G(Y)}]$ (B7)

Baldev Thapar (M'60, SM'62) was born in India on Sept. 1, 1930. He received the B.Sc.(Honours) degree from Banaras Hindu University, M.S. and Ph.D. degrees from Illinois Institute of Technology, in 1953, 1960 and 1963 respectively, all in electrical engineering. From 1953 to 1955 he was with Punjab Public Works Department, India, working in Power System Operation. In 1955 he joined the faculty of Punjab Engineering College, Chandigarh, India, where he was Professor, Electrical Engineering from 1966 to 1985. In 1985-86 he was a Visiting Professor at Louisiana State University. At present he is a Professor in the faculty of Electrical Engineering Department, Montana State University, Bozeman.

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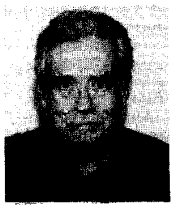

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Dr. Gerez is the author of several articles on system and power engineering and co-author of six electrical and system engineering textbooks widely used in Spanish speaking countries.

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