FOUNDATION EARTHING SYSTEM – ITS APPLICATION AND ELECTRICAL SAFETY CONSIDERATIONS

(Date received: 23.03.2023/Date accepted: 20.06.2023)

Toh Leong Soon[1*], Leong Kok Wah[2]

[1]*Aquarius Engineering Consultants Sdn. Bhd., 31 & 31A, Palma A/3, Seri Palma, Bandar Seri Botani, 31350 Ipoh, Perak, Malaysia*

[2]*Letrik Seri Pelangi, No. 5, Jalan Lip Seng Onn, Taman Ipoh, 31400 Ipoh, Perak, Malaysia*

**Corresponding author: aeceng238@gmail.com*

ABSTRACT

Foundation earthing system greatly reduces the resistance to ground as compared to driven earthing rods. Low resistance to ground is desirable to protect lives – it ensures automatic disconnection of power supply in the event of electrical fault. However, special attention must be given in the application of foundation earthing system to terrace houses and shop lots, where common ground slab steelwork is used throughout the entire row of houses or shop lots. This paper shows the field tests and findings of terrace houses with foundation earthing system, the requirements of the design and installation of foundation earthing system, and the importance of such installation to achieve low resistance to ground, to be able to operate the protective devices for supply disconnection during fault condition.

Keywords: Earth Loop Impedance, Earth Resistance, Equipotential Bonding, Foundation Earthing System, Residual Current Device

1.0 INTRODUCTION

In electrical installations, circuit breakers are used for overload and short circuit protection; and Residual Current Devices (RCDs) are used for leakage current protection. In Malaysia, RCDs shall be installed in accordance with Regulation 36(2), 36(3) and 36(4) of Electricity Regulations 1994. The following formula applies where RCD is used for protection by automatic disconnection of power supply in TT system:

$$R_A \times I_{\Delta n} \leq 50V \qquad (1)$$

where:

R_A is the sum of the resistances of the earth electrode and the protective conductor connecting it to the exposed-conductive-parts (in Ohms).

$I_{\Delta n}$ is the rated residual operating current of the RCD.

The electrical installation is depicted in Figure 1. The resistance of the installed earth electrode should be as low as practicable. A value exceeding 200 Ohms may not be stable [1].

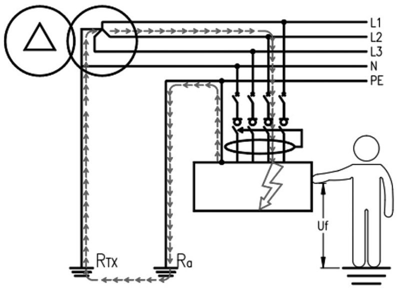

Figure 1: Electrical Installation with Automatic Disconnection of Supply for TT System

The common earth electrode used in electrical installation are:

a. Earthing rods

Earthing rods are vertically driven into the ground. The earthing rods may be copper or more commonly copper-jacketed steel core rods, with screw coupling to reach considerable depth and the desired resistance to ground value. Earth electrode using earthing rods is shown in Figure 2.

b. Foundation earthing system

Foundation steelwork in concrete is used as a readily available and effective earth electrode [2], [3], [4], [5]. The total electrode area formed by the underground steelwork of a structure provides a low resistance to ground value. Foundation earthing system, whereby the earth foundation steelwork is used as earth electrode, is shown in Figure 3.

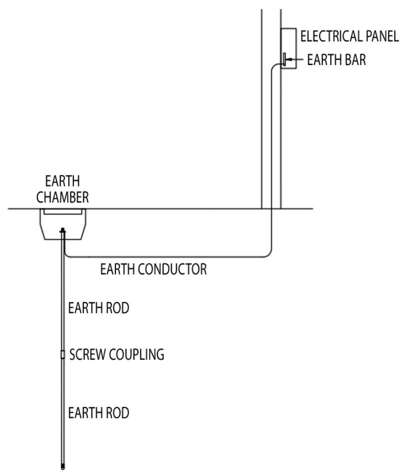

Figure 2: Earth Electrode using Earthing Rods

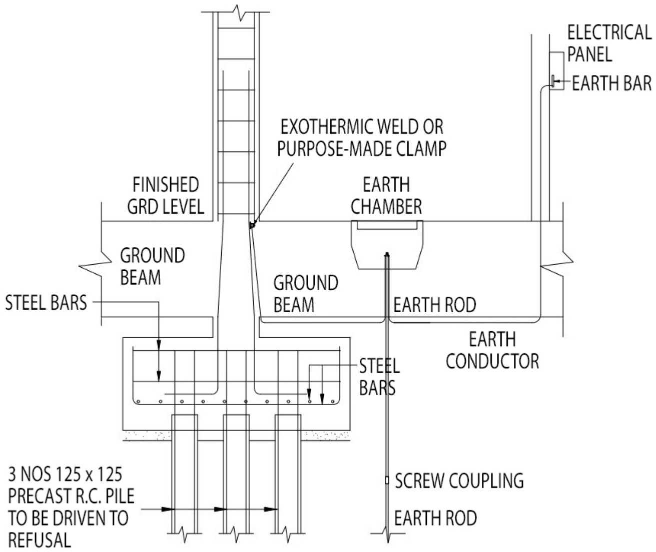

Figure 3: Foundation Earthing System

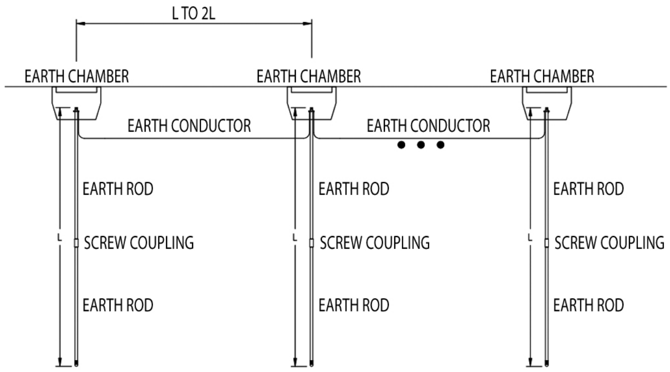

Figure 4: Earthing Rods Installed in Parallel

2.0 FOUNDATION EARTHING SYSTEM – ITS ADVANTAGES AND DISADVANTAGES

Low resistance to ground is essential for automatic disconnection of power supply and safety protection. The question is: what is the resistance to ground value to achieve? Various international and local standards were studied and compared. The recommended resistance to ground value by the various standards is summarised in Table 1.

In order to achieve low resistance to ground value, for instance in Malaysia, equal to or less than 10 Ohms, the earthing rods are installed in parallel, with mutual separation of L to 2L, where L is the driven depth of the earthing rods, as shown in Figure 4.

The effective resistance to ground can be calculated using the following formula:

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n} \tag{2}$$

where:
R_e is the effective resistance to ground (in Ohms).
n is the number of earthing rods installed.

Practically, there is space constraint to install earthing rods in parallel, especially for terrace houses and shop lots. Foundation earthing system provides the solution both technically and economically. The readily available foundation steelwork greatly reduces the resistance to ground value. However, special attention must be given in the application of foundation earthing system to terrace houses and shop lots, where common ground slab steelwork is used throughout the entire row of houses or shop lots.

Table 1: Recommended Resistance to Ground Value by Various Standards

Standard	Recommended resistance to ground value	Remarks
AS/NZS 3000 [6] (Australian/ New Zealand Standard)	Refer to Table 8.1	With reference to earth fault-loop impedance relating to operation of protective devices
BS 7430 [2](British Standard)	1 Ohm	With reference to earth resistance value obtainable with foundation structural steelwork
DIN 18014 [7] (German Standard)	Not stated	In Germany, there is an obligation to erect in every new building a foundation earth electrode according to National Standard DIN 18014
IEEE Std 80 (United States)	IEEE Std 80-2000 [8]: 1 to 5 Ohm	With reference to smaller distribution substations
	IEEE Std 80-2013 [9]: Not stated	Recommended resistance to ground value removed. Resistance value to be estimated by calculation formula.
SS 551 [10] (Singapore Standard)	1 Ohm	With reference to transformer star point earth
	100 Ohm	With reference to operation of RCD
MS IEC 60364-5-54 [5] (Malaysian Standard)	Not stated	-
MS 1936 [3] (Malaysian Standard)	10 Ohms	-
MS 1979 [4] (Malaysian Standard)	10 Ohms	-

In the event of faulty RCD in one of the houses or shop lots, if the fault current is too low for automatic disconnection of power supply by the circuit breaker or the cut-out fuse, the fault current may flow through the foundation earth to other houses or shop lots. The level of touch voltage generated by the fault current could be detrimental to the occupants of the house or shop lot with electrical fault, as well as the other houses or shop lots.

3.0 FIELD TESTS, FINDINGS AND DISCUSSION

To demonstrate the advantages and disadvantages of the foundation earthing system, field tests were carried out at a project site of terrace houses, where foundation earthing system is implemented. The following field tests were carried out:

a. Continuity test on the earth electrode from house to house
   i. Earthing rods without connection to foundation earth
   ii. Earthing rods with connection to foundation earth
b. Earth resistance test using 3-point fall-of-potential earth tester
   i. Earthing rods without connection to foundation earth
   ii. Earthing rods with connection to foundation earth
c. Earth loop impedance test using earth loop tester
   i. Earthing rods without connection to foundation earth
   ii. Earthing rods with connection to foundation earth
d. Simulation of fault condition
   In the event of faulty RCD in one of the houses, check and measure the fault current, the presence of potential touch voltage at the house with electrical fault and other houses, and the effectiveness of automatic disconnection of power supply by the 63A incoming circuit breaker or the 63A cut-out fuse.
   i. Earthing rods without connection to foundation earth
   ii. Earthing rods with connection to foundation earth

The results of the tests are shown in Table 2.

Some of the field test photographs can be found in Figure 5. The field tests and results are illustrated in Figure 6.

(a) Field test set with functional and faulty RCDs for simulation of fault condition

(b) Earth resistance test

(c) Earth loop impedance test - Earthing rods without connection to foundation earth

(d) Earth loop impedance test - Earthing rods with connection to foundation earth

Figure 5: Photographs of Field Tests

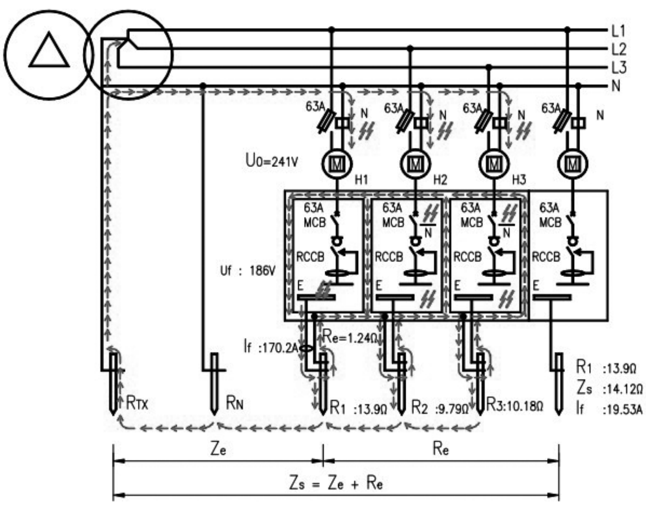

Figure 6: Field Tests and Results

It can be seen from the test results that the earth resistance of earthing rods without connection to foundation earth is generally higher. The earth resistance is greatly reduced with connection to foundation earth. Under the simulated fault condition, i.e. phase to earth fault, with faulty RCD in one of the houses, the fault current is 19.53A for earthing rods without connection to foundation earth (Z_s: 14.12 Ohm). The magnitude of the fault current is not sufficient to trip the 63A incoming circuit breaker. Under the similar fault condition, the fault current is 170.2A for earthing rods with connection to foundation earth (Z_s: 1.54 Ohm). The 63A incoming circuit breaker is tripped off.

For discussion purpose, assuming the effective resistance to ground value of a row of terrace houses or shop lots is 10 Ohm, and the incoming circuit breaker is of 63A. The fault current can be calculated using the following formula:

$$I_f = \frac{U_0}{Z_s} \quad (3)$$

$$I_f = \frac{U_0}{Z_e + R_e} \quad (4)$$

where:

I_f is the fault current
U_0 is the nominal phase to earth voltage
Z_s is the total earth loop impedance
Z_e is the external earth loop impedance
R_e is the effective resistance to ground of the installation

Assuming the external earth loop impedance is very low and negligible. In the event of phase to earth fault, with faulty RCD in one of the houses, the fault current will be:

$$I_f = \frac{U_0}{Z_e + R_e}$$

$$I_f = \frac{230V}{10\Omega}$$

$$I_f = 23A$$

Table 2: Field Test Results

No.	Tests	Results	Remarks
a	**Continuity test**		
i	Earthing rods without connection to foundation earth	H_1 - H_2: 462 Ohm H_1 - H_3: 486 Ohm	
ii	Earthing rods with connection to foundation earth	H_1 - H_2: 0.2 Ohm H_1 - H_3: 0.1 Ohm	
b	**Earth resistance test**		
i	Earthing rods without connection to foundation earth	R_1: 13.9 Ohm R_2: 9.79 Ohm R_3: 10.18 Ohm	
ii	Earthing rods with connection to foundation earth	R_e: 1.24 Ohm	
c	**Earth loop impedance test**		
i	Earthing rods without connection to foundation earth	Z_S: 14.12 Ohm	Prospective Fault Current (PFC): 17A
ii	Earthing rods with connection to foundation earth	Z_S: 1.54 Ohm	Prospective Fault Current (PFC): 157A
d	**Simulation of fault condition**		
i	Earthing rods without connection to foundation earth	I_f: 19.53A	- 63A incoming circuit breaker: no trip - Potential touch voltage at the house with electrical fault: 231.8V
ii	Earthing rods with connection to foundation earth	I_f: 170.2A	- 63A incoming circuit breaker: trip - Potential touch voltage at the house with electrical fault: 186V - Potential touch voltage at the other house: 185V

The magnitude of the fault current is not sufficient to trip the 63A incoming circuit breaker. The fault current will flow to other houses or shop lots through the foundation earth. The RCD of other houses or shop lots will not operate as the fault current is from external and thus not detected by the RCD. The touch voltage generated by the fault current may cause electrocution to the occupants of the house or shop lot with electrical fault, as well as the other houses or shop lots.

The above field tests and discussion show the importance of low resistance to ground in electrical installation, particularly where foundation earthing system is implemented. The required resistance to ground value should be checked against the electrical installation using the following formulas [11]:

$$Z_s = \frac{U_0}{Fusing\ Factor\ \times I_n} \tag{5}$$

where:

Z_s	is the total earth loop impedance
U_0	is the nominal phase to earth voltage
I_n	is the rated current of circuit breaker or fuse
Fusing factor	1.5 for circuit breaker, and 2.4 for fuse

$$Z_s = \frac{U_0}{1.5\ \times I_n \times Earth\ Fault\ setting} \tag{6}$$

where:

Z_s	is the total earth loop impedance
U_0	is the nominal phase to earth voltage
I_n	is the rated current of circuit breaker
Earth Fault Setting	is the percentage setting of earth fault relay, such as 5% and 10%

Formula (5) is used where the protective device is by means of circuit breaker or fuse. Formula (6) is used where the protective device is by means of circuit breaker and protection relay.

4.0 CONCLUSION AND RECOMMENDATIONS

Earth resistance of an electrical installation plays a vital role of safety protection to enable automatic disconnection of power supply in TT system. While foundation earthing system greatly reduces the resistance to ground, special attention must be given in its application, especially in terrace houses and shop lots, where common ground slab steelwork is used throughout the entire row of houses or shop lots. In the event of faulty RCD in one of the houses or shop lots, the magnitude of the fault current shall be sufficient to operate the incoming circuit breaker or cut-out fuse to disconnect the power supply. Otherwise, the fault current may flow through the foundation steels to other houses or shop lots. The level of touch voltage generated by the fault current could be detrimental to the occupants of the house or shop lot with electrical fault, as well as the other houses or shop lots.

Recommendations for the design and installation of foundation earthing system are:

i. Do not merely comply with the recommended resistance to ground value in the Standards. The required value could be lower. Check the required resistance to ground value using Formula (5) or (6) and implement accordingly.
ii. Proper bonding of earthing rods to foundation steel bars shall be ensured. This can be achieved by exothermic weld or purpose-made clamp. Continuity test should be carried out.

The recommended contact resistance is equal to or less than 0.2 Ohm.

iii. Special care should be given on corrosion and oxidation protection - foundation steel bars embedded in concrete provides good corrosion and oxidation protection.
iv. Measure earth loop impedance and Prospective Fault Current (PFC) using earth loop tester as verification of the installation.
v. Periodic inspection and testing. RCDs should be tested at least every 6 months to ensure they are functional.
vi. Design and installation of RCDs in series, with RCD at supply side, and RCDs at load side brand circuits, as per Annex A and Annex B of [4].

5.0 ACKNOWLEDGMENT

The authors wish to acknowledge the project owner for allowing the field tests and findings to be used for discussion in this paper. The authors also wish to thank the competent persons of Persatuan Kekompetenan Penjaga Jentera & Pendawai Elektrik Perak (PKPPE) who have contributed to the field tests, as well as Mr. Ng YT for the Computer Aided Design (CAD) drawing works. ■

LIST OF NOTATIONS

$I_{\Delta n}$ is the rated residual operating current of Residual Current Device
H_1 is the denotation for House 1 of the field tests
H_2 is the denotation for House 2 of the field tests
H_3 is the denotation for House 3 of the field tests
I_f is the fault current
I_n is the rated current of protective device
L is the driven length of earthing rods
R_1 is the resistance to ground for House 1 of the field tests
R_2 is the resistance to ground for House 2 of the field tests
R_3 is the resistance to ground for House 3 of the field tests
R_A is the sum of the resistances of the earth electrode and the protective conductor connecting it to the exposed-conductive-parts
R_a is the resistance of installation earth electrode
R_e is the effective resistance to ground
R_N is the resistance of the supply neutral of overhead poles
R_{Tx} is the resistance of substation transformer neutral earthing
S is the separation distance between earthing rods
U_f is the fault voltage
U_0 is the nominal phase to earth voltage
Z_e is the external earth loop impedance
Z_s is the total earth loop impedance

REFERENCES

[1] BS 7671: 2018 Requirements for Electrical Installations, IET Wiring Regulations Eighteenth Edition, The Institution of Engineering and Technology, pp 63-64, 2018.

[2] BS 7430: 2011+A1: 2015 Code of Practice for Protective Earthing of Electrical Installations, BSI Standards Publication, pp 43-46, August 2015.

[3] MS 1936: 2016 Electrical Installations of Buildings – Guide to MS IEC 60364, Department of Standards Malaysia, pp 49-50, 2016.

[4] MS 1979: 2015 Electrical Installations of Buildings – Code of Practice, Department of Standards Malaysia, p5, p21, 2015.

[5] MS IEC 60364-5-54: 2004 Electrical Installations of Buildings – Part 5-54: Selection and Erection of Electrical Equipment: Earthing Arrangements, Protective Conductors and Protective Bonding Conductors, Department of Standards Malaysia, p19, 2004.

[6] AS/NZS 3000: 2018 Electrical Installations (known as the Australian/New Zealand Wiring Rules), Australian/New Zealand Standard, p427, June 2018.

[7] DIN 18014: 2014 Foundation Earth Electrode – Planning, Execution and Documentation, German Standards, March 2014.

[8] IEEE Std 80-2000 IEEE Guide for Safety in AC Substation Grounding, The Institute of Electrical and Electronics Engineers, USA, p64, January 2000.

[9] IEEE Std 80-2013 IEEE Guide for Safety in AC Substation Grounding, The Institute of Electrical and Electronics Engineers, USA, p66, December 2013.

[10] SS 551: 2009 Code of Practice for Earthing, Singapore Standard, SPRING Singapore, p51, p71, 2009.

[11] Non-Domestic Electrical Installation Safety Code, Energy Commission, Malaysia, p57, 2016.

PROFILES

TOH LEONG SOON is a Professional Engineer with Practising Certificate (PEPC), Member of The Institution of Engineers, Malaysia (MIEM), Qualified Person of National Water Services Commission (SPAN QP), ASEAN Engineer, ASEAN Chartered Professional Engineer (ACPE), APEC Engineer and International Professional Engineer (Int.PE). He received his secondary education from High School Bukit Mertajam, Penang. He obtained his B.Eng (Hons.) and M.Eng from Universiti Teknologi Malaysia in 2003 and 2006 respectively. He has been working as a consulting engineer since 2007 and is currently a Director of a M&E engineering consultant firm in Perak, Malaysia. His area of expertise includes MV and LV electrical system, ELV system, Supervisory Control and Data Acquisition (SCADA) system, motor drives, renewable energy and energy efficiency projects, technical due diligence and building condition assessment.
Email: leongsoon.toh@gmail.com

LEONG KOK WAH is a registered competent chargeman and wireman, with more than 30 years' experience in electrical industry. He is currently a Technical Advisor and Honorary President of Persatuan Kekompetenan Penjaga Jentera & Pendawai Elektrik Perak (PKPPE).
Email address: wah630420@gmail.com