LIGHTNING PROTECTION AND EARTHING SYSTEM IN UNIVERSITI TEKNOLOGI PETRONAS

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ELECTRICAL & ELECTRONICS ENGINEERING
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by

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

UTP Lightning Protection and Earthing Systems has been a very interesting subject for the UTP Property Management and Maintenance Department (PMMD) of late. In the attempt of reviewing the system and also the understanding the actual design, reverse engineering is carried out. The level of safety of the university from lightning treat is unknown and is a subject of concern for UTP PMMD. The objective of this project will lead to analyze and verify original design and hence in-depth study on the UTP Lightning Protection and Earthing Systems. The project will be carried with obtaining documentations, carry out conceptual studies, site survey, literature review and then recommendation report. The results are shown in pictures and diagrams to enable clearer view of what has been found so far. By the end of this semester, a full report on UTP's Earthing System will be presented together with the simulation of the Earthing System Model.

ACKNOWLEDGEMENTS

I would like to reserve the highest gratitude to my supervisor, Dr. Taib bin Ibrahim for assisting me in the completion of this final year project. His guidance and tolerance has become a huge factor in enabling the success of this project.

Also I would like to thank Ir. M Fatimie Irzaq bin Khamis for assisting all my needs during the progression of the project. His guidance also helped me in improving my understanding of the Lightning Protection System in UTP.

Also there to assist me is Mr. Rohaizan from the Properties Management and Maintenance Department of UTP. He has been helpful in providing all available documents for this project.

Alongside that, I would like to thank all those who are directly and indirectly related in this project's involvement.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Lightning is a natural occurrence due to the atmospheric discharging of high voltage electricity. The strokes are random and have indefinite say of where it will strike next. An average bolt of negative lightning carries an electric current of 30 kiloamperes (kA), and transfers a charge of five coulombs and 500 MJ of energy. Large bolts of lightning can carry up to 120 kA and 350 coulombs [1]. These facts and figure is enough to describe that lightning stroke is uncertain and ultimately, dangerous. A single lightning stroke can cause serious damage to structures, assets, buildings, and even equipments within premises. It is also a danger to human being, causing many lives.

However, the danger pose by lightning strokes can be averted by lightning protection systems. This study is about lightning protection and earthing system installed within Universiti Teknologi PETRONAS (UTP). The two elements – lightning protection and earthing – make up into a set of system where lightning threats are being countered. Lightning strokes will be intercepted by the lightning protection devices. The intercepted lightning strokes are eventually currents and being flowed to safety by proper earthing systems. Connecting between both elements is the down-conductor, a crucial element which determines whether or not the whole protection system will work against lightning strokes.

1.2 Problem Statement

1.2.1 Problem Identification

Lightning protection and earthing system in UTP academic building has been designed and developed by contractor years back. However, the conceptual design is not determined. Hence, this prompted the proposal of carrying out a conceptual study on the system installed in the new buildings, particularly Building 22 and Building 23. The conceptual study includes verification of the design.

As-built drawings and basic documentations are available in the drawers of UTP PMMD. Installation details can be gathered from there. Generic information is available but how much is the lightning protection and earthing system working? How efficient is the protection offered by the system? Does it cover enough the areas between buildings and properties? Is UTP really safe from lightning threat?

1.2.2 Significant of Project

The aim of this project is to be able to find answers to the questions above. By using the reverse engineering, original design and system implemented into as-built designs are tracked back, identified and track backed. This project can achieve safety improvement as the PMMD is looking to review whether or not replacement or upgrade for the lightning protection is needed. As relevant to the academic side, these are the basic knowledge in Electrical Engineering in most industries; safety of equipments, buildings, and the people. It is important to know the system used for earthing where grounding of lightning current is one type of many.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The objectives are listed as below:

i) To analyze the original design of the lightning protection and earthing system in UTP.

ii) To verify the original design of the lightning protection and earthing system in UTP with simulation and results.

iii) To do in-depth study regarding the best lightning protection and earthing system for UTP.

1.3.2 Scope of Study

The scope of study in general consists of 2 parts; earthing system and lightning protection system. Firstly, testing on earthing system used to ground the lightning current going through the protection system. Items such as the material conductivity, resistivity, current capacity and lifespan will be look into to determine the necessity to change the copper plate or any medium used for UTP earthing system. The method of grounding is also an area of focus for study of how conventional earthing system should look like.

The second part of the study will be about the lightning protection system. What type of lightning stroke is the lightning protection in UTP capable of protecting against? What is the system suits UTP environment most? Is there any problem in the design of the old system? Not only answering the above questions, this project is about in-depth studying of how the protection system works as they will be basic for protection system of electrical equipments against short circuit.

CHAPTER 2
LITERATURE REVIEW

2.1 Lightning Strike

Lightning strikes are formed of high voltage discharging of cells between two different medium. To be more specific, there are intracloud lightning, cloud-to-cloud lightning, and cloud-to-ground lightning, with the later as the subject focus relevant with this project [2].

Underneath cloud-to-ground lightning, there are two types of strikes in general; direct strike and indirect strike [3]. Direct lightning strike, as its name indicates, strikes directly towards the building, trees, human being, or anything else which is on the ground. The result of the strike differs, depending on what it hits. Direct strike on buildings without proper lightning, surge, and equipment protection will result in damage of electrical equipments and disruption in domestical power supply. Direct strike on human beings will mostly cause in death.

Indirect strike means the subject will only suffer the effect of the strike from other medium or objects. One of the types will be 'splash strike' from nearby object. This happens when lightning strikes on other object nearby a building, and then 'splash' to the building itself. The other indirect strike will be 'ground strike'. The lightning sometimes hits the ground nearby instead of the building. Still, the building will receive the lightning effect, which is the surge and also the Electromagnetic Pulse (EMP) effect to the building's internal wiring system.

2.2 Earthing

Grounding is actually connecting to a common point which is connected back to the electrical source [4]. There are two types of grounding in general; connected to earth and not connected to earth. The grounding method or connecting to earth is called earthing. It is very common for structures and buildings which are on the ground. Grounding which does not requires earth also exist. A very good example would be the grounding system of an airplane.

The conventional building grounding structure is simply shown in the diagram below:

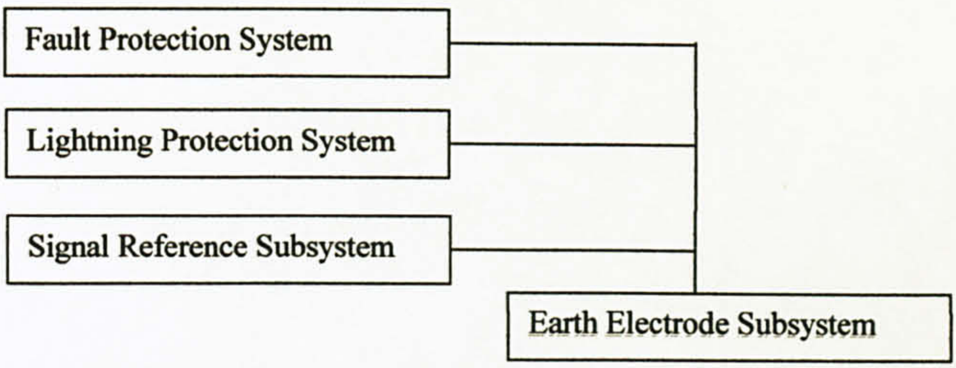

Figure 1 Building Grounding System

The several crucial functions of grounding are:

i) Personnel safety
ii) Equipment and building protection
iii) Electrical noise reduction

2.2.1 Personnel Safety

The primary motive of grounding is eventually to protect people. The foremost undesired hazard to occur onto a certain personnel is shock hazard. The current from the lightning must be ensured that it is insufficient to cause shock hazard. To achieve this, there should be low impedance grounding and bonding between metallic equipments and other conductive objects.

2.2.2 Equipment and Building Protection

The secondary reason is to protect equipments and structures from unintentional contact with high current, for example lightning strike. Electrical equipments especially in crucial industries are expensive and failing to protect them will cause in efficiency turbulence and drop of production which leads to financial loss. Protection of building similarly needs the low impedance grounding and bonding between conductors available in the building.

2.2.3 Electrical Noise Reduction

Noise is of course among one of the most undesired disturbance in electrical equipments especially the ones with direct application of signal processing .The aim of reducing the electrical noise would be to ensure the three points below:

i) The impedance between the signal ground points throughout the building is minimized.

ii) The voltage potentials between interconnected equipment are minimized.

iii) The effects of electrical and magnetic field coupling are minimized.

2.2.4 Types of Grounding

There are several types of groundings:

i) Power system grounding
ii) Bonding
iii) Grounding electrical equipment
iv) Lightning protection
v) Protection of electronic equipment

2.3 Types of Earthing

There are three types of earthing systems in general; TN network, TT network, and IT network [5].

2.3.1 TN Network

This type of connection is where the generator is connected directly to earth. On the same earth connection to the generator/transformer, the electrical device is also connected. The general view of the TN network can be seen as below:

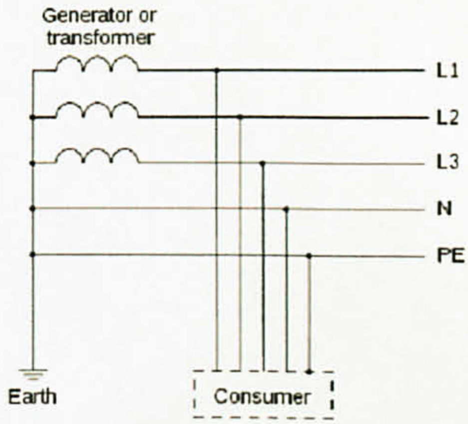

Figure 2 TN Network

2.3.2 TT Network

The TT Network is where the electrical device is connected directly to earth, independent of the generator-earth connection. The benefit of this network is that it is interference-free earthing. This type of earthing is often the first choice in telecommunications as it can differentiate the frequency noises coming through the neutral wires.

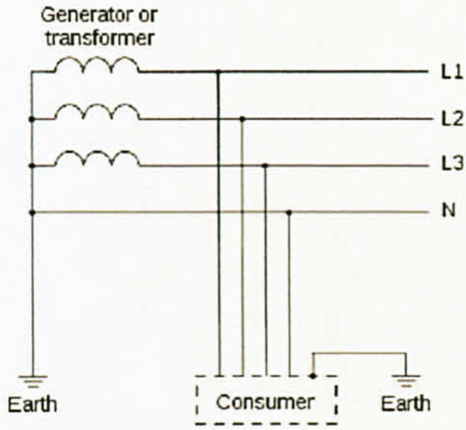

Figure 3 TT Network

2.3.3 IT Network

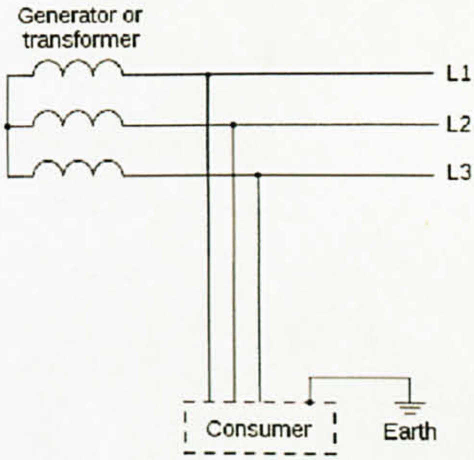

Figure 4 IT Network

As for the IT network, the generator or any supply it has does not have any connection to earth. Instead, the electrical device is connected to the earth. The earthing system in the new academic building utilizes this IT network.

2.4 Overall Lightning Protection and Earthing System

The whole of Lightning Protection and Earthing System is divided into three main parts; air terminals, down-conductor, and grounding system [6].

2.4.1 Air Terminal

For the air terminal part, the design can be based on the theories of continuum [4]. The below shows the application of the theories of continuum where it decides the shape of the air terminal:

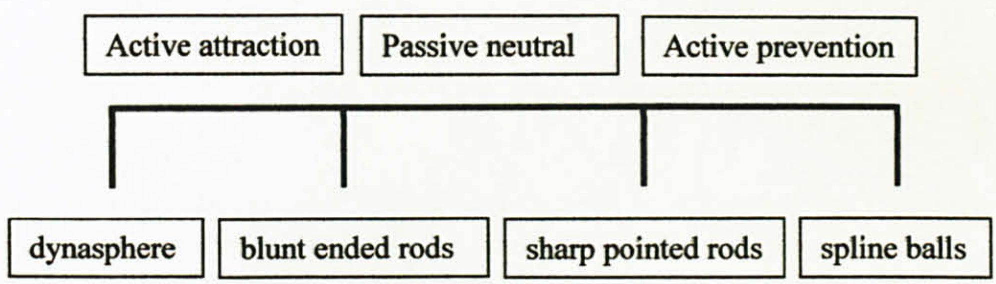

Figure 5 Theories of Continuum in Air Terminal Design

The commonalities of the three approaches mentioned are listed as below:

i) The air terminal or strike termination device must be positioned so that it is the highest point on the structure.

ii) The lightning protection system must be solidly and permanently grounded. Poor or high resistance connections to ground are the leading cause of lightning system failure for each one of these systems.

The active attraction system uses the theory of attracting the lightning to a known and preferred point, therefore protecting the nearby non-preferred points. The common method is using the air terminal to intercept the lightning down stroke leader and flow it to the ground.

The passive neutral system is done by placing the conductors to the places where lightning are most likely to strike should a strike occurs. It is called neutral as it is neither attractive nor unattractive to the lightning.

The active prevention systems will use the design to prevent the propagation of a direct stroke of lightning. There 2 theories in the prevention; the 'bleed off' and the sharp points on the prevention devices.

2.5 Lightning Protection Design

There are few methods in the design stage of a certain lightning protection system; Faraday Cage, Cone of Protection, Empirical Curve, and our focus in this project, the Rolling Sphere Method. Rolling Sphere Method is actually a sub chapter of Electrogeometric Method (EGM). There are other main methods as well depending on the design structure of each lightning protection system

EGM uses the concept of attractive effect of the air terminal device is a function of a striking distance which is determine by lightning amplitude [7]. A point on a structure equidistant from the striking distance is likely to receive a lightning strike.

2.5.1 Rolling Sphere Method

The Rolling Sphere Method is a method which calculates the area of protection by the lightning poles [7].

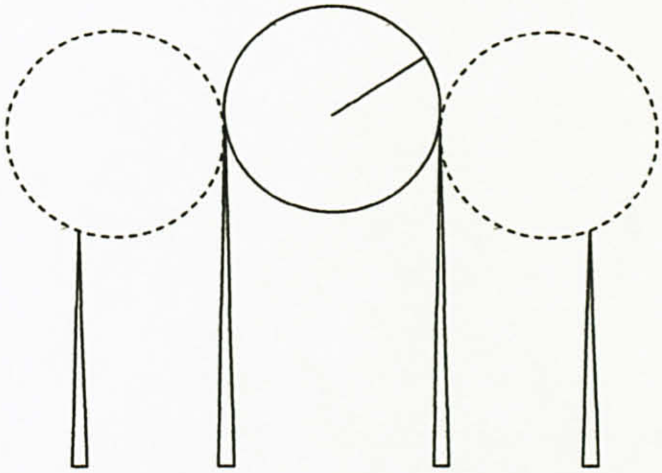

Figure 6 Rolling Sphere Method Over Poles

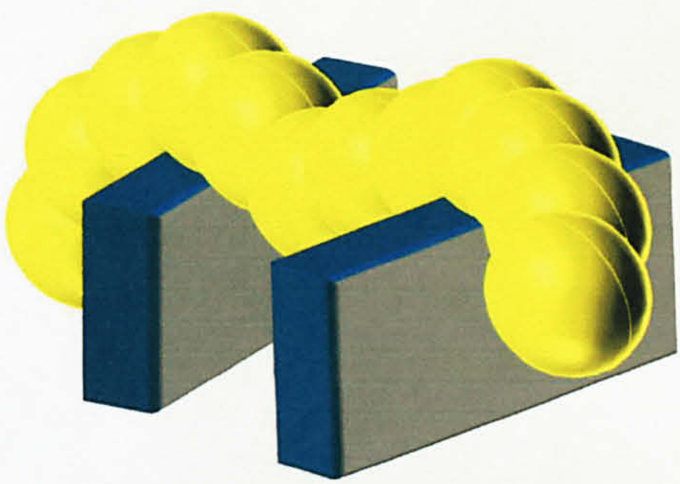

Figure 7 Rolling Sphere Method Over Buildings

In order to calculate the area of protection base on Rolling Sphere method, there are few elements needed to be obtained:

- surge impedance
- allowable stroke current
- striking distance

Surge Impedance

In order to calculate surge impedance Z_S, the below equation is used:

$$R_C \ln\left(\frac{2h}{R_C}\right) - \frac{V_C}{E_0} = 0$$

$$Z_S = 60\sqrt{\ln\left(\frac{2h}{R_C}\right)\ln\left(\frac{2h}{r}\right)} \quad \text{..........[7]}$$

Where,

R_C = corona radius

r = radius of the conductor

h = average height of conductor

V_C = basic impulse level

E_0 = limiting corona gradient, 1500 kV/m

Stroke Current

In order to calculate stroke current I_S, the below equation is used:

$$I_S = \frac{2.2(V_S)}{Z_S} \quad \text{..........[7]}$$

Striking Distance

In order to calculate stroke current S_m, the below equation is used:

$$S_m = 8kI^{0.65} \text{...........[7]}$$

Where,

$k = 1.0$; ground or wires

$k = 1.2$; lightning mass

I = stroke current

Sphere Radius

In order to calculate sphere radius R_d, the below equation is used:

$$R_a = 2.83H^{0.4}I^{0.63} \text{...........[9]}$$

Where,

H = building height

I = stroke current

The above diagram shows the main method used in carrying out this project. Currently, completion of flow has reached the third step, which is site survey and field works. Another half of the field works will resume in the second phase of Final Year Project (FYP).

3.2 Tools and Equipment Required

Below are the list of tool and equipments used so far for obtaining data and results for studies and field works.

i) Resistance Meter for continuity and conductivity test.

ii) Very long single core wire to connect between the air terminal end and the earth pit end.

3.3 Tracing of Electrical Circuit and Drawings

The few drawings type to be obtained are as below:

i) roof plan for earthing in academic buildings

ii) detail physical drawing of the earthing system

iii) installation details of the earthing system

iv) detail circuit of the earthing system

I had tried to get the drawings with collaboration with Ir. Al Fatimie and Mr. Rohaizan from the PMMD electrical section. The sight checking of the earthing system is limited due to limited access to certain places where the system is hidden. The location of the earth pit as found. Also, the rooftop is visited for the verification of the lightning protection system design.

3.4 Continuity Check

Continuity check is to check whether there is connectivity between two points of a conductor. It can be done by having the first point at the upper end of the air terminal and the second point at the end of the copper plate connecting to the copper bond in the earth pit. Connecting both points with resistance meter will enable the testing for continuity with the continuity test function. The 'beep' will signifies that there is continuity and the copper plate is working perfectly.

Also, the test can be done on random two points of the rooftop, as the protection system for Building 22 and Building 23 is using the aluminum roof connected to the copper plate. Similarly, the 'beep' will signifies that the aluminum is a good conductor and current can flow through it.

3.5 Resistivity Check

After checking that there is continuity in the system, resistivity test should be conducted. This is to see if the lightning protection is working properly. The theory is simple; high resistivity will result low conductivity of current, hence making the current harder to flow through the conductor and to be grounded to earth. Therefore, low resistivity will indicate a very good lightning protection system.

Also on the same resistance meter, the resistivity between the same two points is measured. The IEEE standards had stated that the best resistance value would be 5.0 ohms or less [8]. This test will tell if the lightning protection system in UTP in working properly of not.

The diagram below show the connection circuit for both tests:

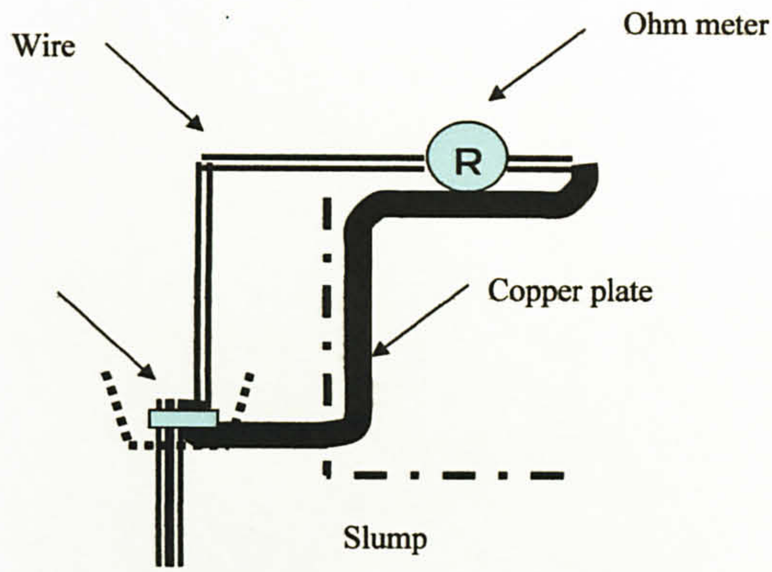

Figure 9 Circuit for Continuity Test

3.6 Feasibility Report

There will be 2 parts in general for the feasibility studies:

Feasibility Study on Existing System

i) Existing Lightning Protection in UTP

ii) Existing Earthing Systems in UTP

iii) Existing Load (Lightning Rate) in UTP

Assessment and Comparison

i) Technical assessment

ii) Economical benefit

iii) HSE benefit

CHAPTER 4
RESULT AND DISCUSSION

4.1 Documentation

The basic documentation has been gathered. The drawings obtained are very useful. Please refer to *Appendix A Electrical Drawings* for future details and reference.

4.2 Site Survey

Some of the field work will be on getting to see the lightning protection. From the drawing gained, the tracing work can be done. However, some difficulty has occurred while locating the earth pit which contains the copper rod. This is due to the accuracy problem of the drawings given. The locations of certain earth pits are not found.

Figure 10 Overall View of An Earth Pit

Figure 11 “EARTH ROD” Labeled On the Earth Pit Cover

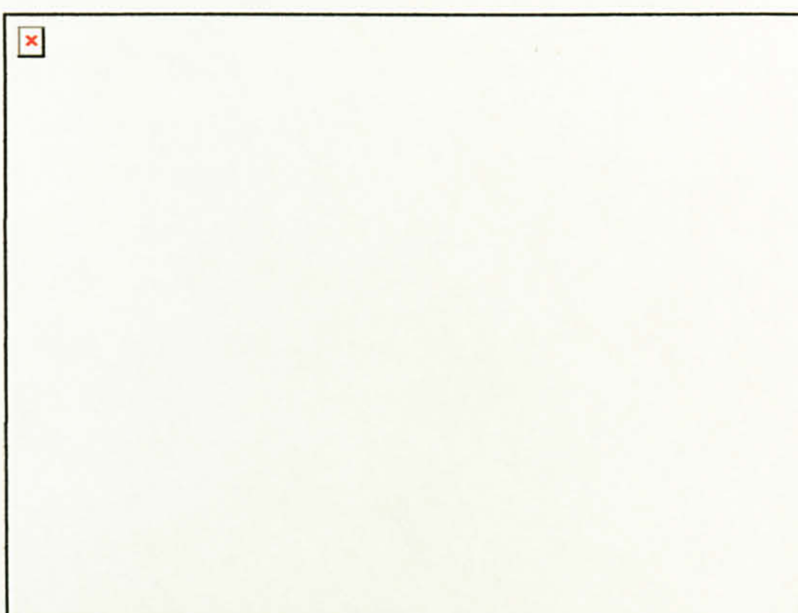

Figure 12 Inner View of The Earth Pit

Figure 13 Copper Tape (right) Clamped To Copper Rod (left)

Maintenance work has been done by the PMMD Electrical team to ensure all the earth pits are located and viewable. The maintenance project has been smooth and all the earth pits can now be clearly spotted.

4.3 Test Results

There are 2 tests done; continuity check and resistivity check. These tests are done to verify whether or not the current UTP lightning protection system is working or not. The test results are satisfactory, signifies that the current design is working properly.

4.3.1 Continuity Check

Table 1 Continuity Check

Conductor	Copper Plate	Aluminum roof
Resistance meter response	Beep	Beep

The result in the table shows that both subject of testing has continuity. Hence, both allow current to flow through. Due to the danger and potent risk available during the field work, the result above is limited to only Building 22.

4.3.2 Resistivity Check

Table 2 Resistivity Check

Conductor	Copper Plate	Aluminium Roof
Point 1	13 ohm	0.02 ohm
Point 2	10.2 ohm	0.05 ohm
Point 3	12.3 ohm	-
Point 4	9.6 ohm	-

The tabulated result shows that the resistivity of the copper plate and aluminum roof. It indicates that the resistance is quite low for both subject and hence, proves that the lightning protection and earthing system in Building 22 and Building 23 is functioning.

Figure 14 Copper Plate Resistivity Point 1

Figure 15 Copper Plate Resistivity Point 2

4.4 Design Verification

The verification includes checking of whether the design is following the standards set for industrial Lightning Protection Systems. The progresses are recorded as below:

Table 3 Design Verification

Item	Standard	Measured	Status
Thickness of aluminium roof	Minimum 15.9mm (0.625 inch)	Average 16.2mm	Pass
Resistivity of aluminium roof	Maximum 5 ohm	Average 0.035 ohm	Pass
Resistivity of downconductor	Maximum 5 ohm	Average 4.375 ohm	Pass
Distance of rod to exterior footing of building	In between 0.6-1.8 m (2-6 feet)	Average 0.84m	Pass

Rolling Sphere Method Calculations

Building height = 40m

Building length = 40m

Building width = 20m

Distant between 2 buildings = 20m

Radius of the Sphere is calculated as below,

$$R_a = 2.83H^{0.4}I^{0.63}$$
$$20m = 2.83(40)^{0.4}I^{0.63}$$
$$I^{0.63} = 1.6159kA$$
$$I = 2.142kA$$

Protection level is of level 1, which is 20m radius and minimum lightning peak value is 3 kA according to IEC 62305-2 [10]. Protection angle is from 70° to 25°, getting lesser with distance going further from the air termination system [11]. Also, objects located within the radius influences the equivalent collective area, which is the area of protection.

$$A_e = LW + 6H(L+W) + 9\pi H^2$$
$$A_e = (40)(20) + 6(40)(40+20) + 9\pi(40)^2$$
$$A_e = 60438.9342m^2$$

Based on the calculation, the design is according to the IEC standard and the radius of the rolling sphere is 20m which can detect stroke current of 2.142 kA.

Rolling Sphere Method Modeling

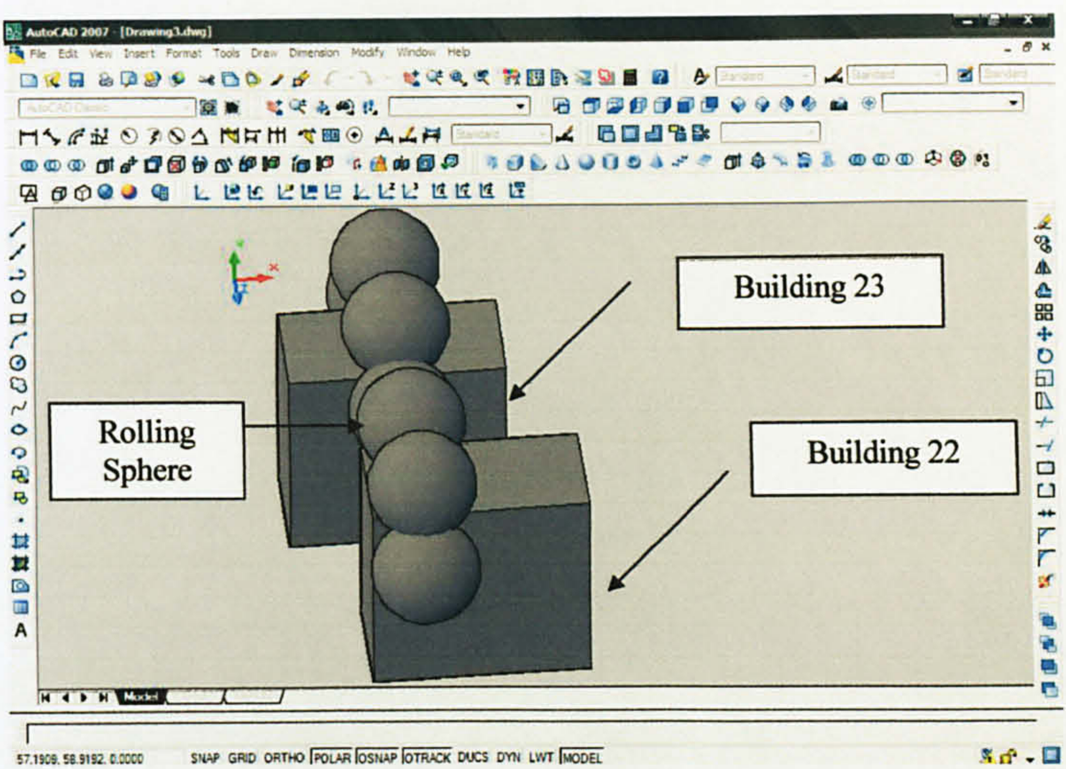

Figure 16 Rolling Sphere Method Side View

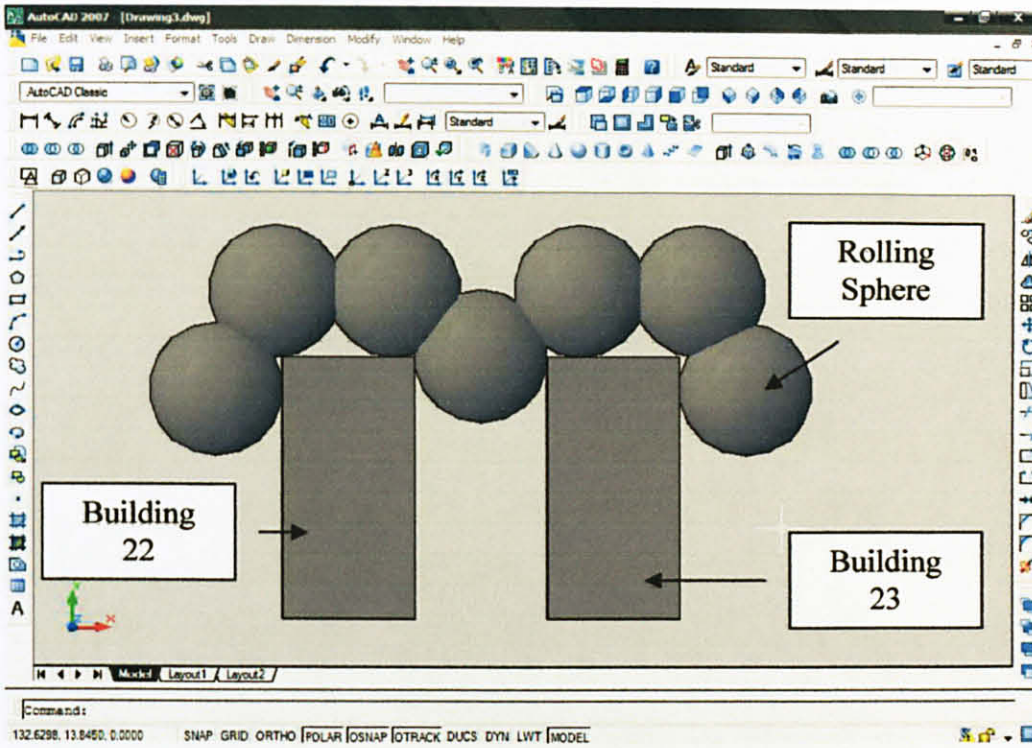

Figure 17 Rolling Sphere Method Front View

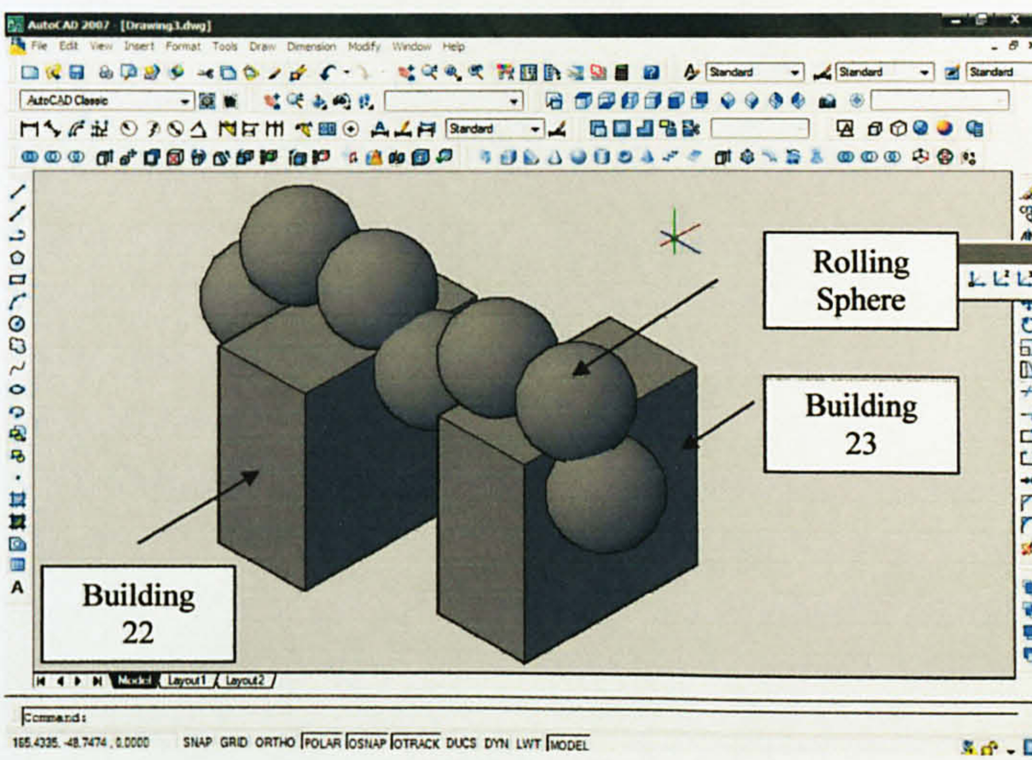

Figure 16 Rolling Sphere Method Isometric View

4.5 Feasibility Study on Existing System

4.5.1 Existing Lightning Protection in UTP

The existing Design of the lightning protection in UTP covers the sports complex, recreation park, old academic buildings, residential hostel, guess houses and the largest area – Chancellor Complex and new academic buildings. The details of the lightning protection in the academic buildings can be seen in "22 Roof Plan" in the attachments. The design has 6 copper plates attached to the aluminium roof going down to the earth pit. The system works with the lightning current dissipated to the ground via the nearest point of the copper plate. Strategic placement of the copper plates allows the LPS to covers the whole rooftop, keeping the building safe.

4.5.2 Existing Earthing System in UTP

The design of the earthing system can be seen in the drawing Detail 'A' in the attachments. It has a 25mm x 3mm copper plate as the core of the down-conductor with 32mm conduit. The whole down-conductor is situated inside the building together with the rain water pipe, hidden from human view.

4.5.3 Existing Load in UTP

For the LPS, the load is the lightning strike itself. Lightning strokes ranges from 0.1kA to 50kA in current measurement [10]. We also needed to know the frequency of lightning occurring in Tronoh and likelihood of the strikes onto building in this area.

Average Lightning Frequency	= 24 per year
Likelihood of Building Strike	= 0.01

4.6 Assessment and Comparison

Assessments and comparisons are done to see the whether or not to implement the LPS.

4.6.1 Technical Assessment

Studies had been done to find out the standards needed to be met to declare a lightning protection system is functioning in excellent condition. The results are as shown, according to the IEC standards.

Table 4 Technical Standards

Item	Standard
Thickness of aluminium roof	Minimum 15.9mm (0.625 inch)
Resistivity of aluminium roof	Maximum 5 ohm
Resistivity of downconductor	Maximum 5 ohm
Resistivity of junctions	Maximum 1m ohm
Resistivity of earth rod to ground	Maximum 20 ohm
Distance of rod to exterior footing of building	In between 0.6-1.8 m (2-6 feet)
Depth of earthing rod	Minimum 3.05m (10 feet)

4.6.2 Economical Benefit

To see whether we benefit from the implementation of the system or not, we can calculate it base on the payback period.

Estimated Total Loss = RM 500,000 (Repair Fee per Building)

The implementation cost includes installation and engineering costs, obtained by surveys among companies providing installation services in Malaysia.

$$implementationCost = MaterialCost + InstallationCost$$
$$implementationCost = RM200{,}000 + RM500{,}000$$
$$implementationCost = RM700{,}000$$

Payback period is the payback period of the installation of the system in years to obtain the money spent. Implementation of the LPS system is seen as a form of investment here.

$$Payback = implementationCost \div EstimatedTotalLoss$$
$$Payback = RM700{,}000 \div RM300{,}000$$
$$Payback = 2.33 years$$

4.6.3 HSE Benefit

Among the few considerations in HSE issues are the potential benefit and average recoups time. Potential benefit is the gain from installing the LPS system if when an incident which causes lived occurs. Below calculations are made in estimations of one personal with severe injuries.

$$PotentialBenefit = PotentialSeverity \times Frequency \times Likelihood$$
$$PotentialBenefit = RM1{,}000{,}000(MedicalCost) \times 24 \times 0.01$$
$$PotentialBenefit = RM240{,}000$$

Average recoups time is the 'recovery' time over the years if an incident has really occurred.

$$Average\,\mathrm{Re}\,coupsTime = implementationCost \div PotentialBenefit$$
$$Average\,\mathrm{Re}\,coupsTime = RM700{,}000 \div RM240{,}000$$
$$Average\,\mathrm{Re}\,coupsTime = 2.9167\,years$$

CHAPTER 5
CONCLUSION

Getting into knowing the earthing system and lightning protection throughout UTP is a lot harder than it seems as there are limited information and limited field work due to exposure to risk and hazards. The reverse engineering is not an easy process due to this reason. A lot of knowledge has been done to accomplish the first objective which is to analyze the original design of the lightning protection and earthing system in UTP. Lightning Protection System is often neglected and not taught in the basic for engineers even tough it should be the core knowledge for power systems. Suggestion is that this knowledge is implemented in the academic syllabus as well to increase awareness among engineers. This knowledge is very crucial as safety as always become a major concern in power systems industrial applications.

Verification has been done and though not in-depth, UTP lightning protection and earthing system has been working well, reducing to zero lightning incidents ever since its takeover from Universiti Sains Malaysia 15 years back. Base on tests and data obtained, UTP's New Academic Building design can be seen as safe from lightning threat for years to come as the system is tested to be functioning well. This fulfills the second objective of this project, to verify the original design of the lightning protection and earthing system in UTP with simulation and results. In-depth testings can be done with appropriate equipments and with the right knowledge. Recommendation on improvising the current design can be done by first looking into the ground resistivity and earth rod design.

The current design is not the latest as it is installed many years back. However, it is not necessary to spend more to keep in track with the latest design as long as the existing system is able to keep us safe. Changes are only needed when the system is found not working. To do that, routine inspection and maintenance are needed. The procedure must be carried out accordingly and complying all the standards and in this case, IEC standards. Safety measure should be taken during the whole inspection process as lightning has been quite frequent in UTP in recent years.

In completing the third objective of this project, which is to do in-depth study regarding the best lightning protection and earthing system for UTP, the best system is already here itself – UTP Lightning Protection and Earthing System.

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