DESIGN AND DEVELOPMENT OF AN FLC - BASED GROUND GRID INTEGRITY TESTING EQUIPMENT FOR SOTERO H. LAUREL (SHL) BLDG. OF LYCEUM OF THE PHILIPPINES UNIVERSITY – LAGUNA (LPU – L)

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ABSTRACT

This study provides a distinctive approach in assessing the integrity of a grounding system for it uses an advanced technique by constructing an equipment that is capable of determining the integrity of the grounding system of an institutional building. In this study, the proponents make use of the concepts of fuzzy logic in the assessment of the ground grid integrity test of LPU-L SHL bldg. It can be classify as Highly Acceptable (HA), Considerably Acceptable (CA), Just Acceptable (JA), Poor (P) and Critical (C). The input parameters include grounding conductor (conductivity), earth resistivity (Ω-^{o}C) and grounding electrode (Ω -mm). The parameters in the model are acquired through the use of standards prescribed by the Philippine Electrical Code (PEC) and the Institute of Electrical and Electronics Engineering (IEEE). This study aims to provide a mathematical model to assess the integrity of the grounding system of the SHL bldg., design a fuzzy-based system, simulate and verify the effectiveness of the results. The proponents preferred to use the triangular membership functions and Sugeno-style of fuzzy inference systems.

Keywords: *fuzzy logic; ground grid integrity; Sugeno-style; Matlab Fuzzy Logic Toolbox.*

INTRODUCTION

The effectiveness of Electrical system design and wiring of an institutional building depends on the reliability of its components. This includes proper functions of protective devices (such as fuses, circuit breakers and contactors for motors), proper insulation of conductors and also its grounding system. There are drawbacks and issues in electrical safety. This includes but not limited to electrical ground faults, short circuit currents, lightning and other transients often do occur in an institutional building. In this regard, issues of electrical safety when servicing electrical equipment has acquired growing importance. By establishing the new principles and methods of protection, taking into account advances in science and practice of electrical safety are only some of the ways to improve electrical safety conditions [1].

A properly designed, installed and maintained grounding system is very important for a safe and effective electrical system in an institution. The most important reason for effective grounding is to protect people. Second, is to include protection of structures and equipment for unintentional contact with energized lines. This also ensures the maximum safety for electrical system faults [1].

It is important to keep in mind that the requirements contained in the Institute of Electronics and Electrical Engineers (IEEE) codes or any codes that can be used as a standard for electrical system design constitute minimum electrical installation requirements.

These minimum requirements cannot ensure that the equipment will perform satisfactorily. For this reason, electrical practitioners often require additional grounding components. One of these consists of a copper conductor that is directly connected to earth and installed in the perimeter of the building. The steel building columns and some non – current carrying metallic frame of electrical equipment or some electrical part of the system are connected to this copper conductor to complete the grounding system [2].

There are many factors in determining the overall integrity of the grounding system. The voltage drop, resistance and the continuity and the earth resistance can significantly impact the overall resistance of the grounding system. The moisture content, mineral content, soil type, soil contaminants and any other related factors determine the overall resistivity of the earth. To properly design a grounding system, the earth resistivity must be measured and also must be in a good condition to establish a low resistive grounding [1].

The testing and evaluation of the integrity of the grounding system to determine its actual condition is the first step in the process to correct problems. The study is focused on creation of a new approach towards establishing condition monitoring for grounding integrity. Considerable benefits such as time and labor reduction for the grounding devices investigation with increase of accuracy of failures location can be achieved by using this proposed technique.

Lyceum of the Philippines University – Laguna (LPU-L) itself consists of high voltage apparatus, switchgear equipment and any other equipment that involves electricity. It is necessary to hand over normal and safe operating condition to all people inside the institution. In due course, it is important for LPU-L to provide an effective and reliable grounding system. One reason for increased risk during electrical fault or short circuit condition is due to ineffective integrity of the grounding devices.

In this study, the proponents will use the concepts and principles of fuzzy logic in simulation of the ground grid integrity test. The factors and parameters to be considered for classifying the integrity of the grounding system include the grounding conductor (conductivity), earth resistance (Ω-^{o}C) and the grounding electrode (Ω -mm).

The parameters will be categorized as Very Good (VG), Good (G), Satisfactory (S), Poor (P) and Critical (C). The proponents will use triangular membership functions for its input and output parameters and it would employ the Sugeno style of fuzzy inference system. The proponents would verify the results using Matlab Fuzzy Logic Toolbox and it will be compared to derived formulas in Excel. This study will be simulated purely mathematical.

Objectives of the Study

The prime objective of this study is to design and develop an equipment that is capable of determining the integrity of the electrical grounding system of Lyceum of the

Philippines – Laguna, Sotero H. Laurel Culinary Arts Building and clearly identifies the weak points and discontinuities.

Specifically, this study aims to:

a) Understand the importance of a grounding system and how it affects the electrical system of an institutional building;

b) Design and develop an equipment that will measure the grounding conductor resistance, grounding electrode resistance and earth resistance;

c) Asses using Fuzzy – Logic MatLab Toolbox Kit that the installation and the parameters of the grounding system will meet the basic requirement of the National Electrical Code, Philippine Electrical Code and IEEE Code.

REVIEW OF RELATED LITERATURE

The proponents gathered several references that provided them with different ideas, thoughts and knowledge for developing the ground grid integrity test. By these studies, the proponents managed to come up with a concrete knowledge of developing new ideas that will contribute well to the study.

Table 2.1 Tabular Charts of Related Studies

Title	Description	Hardware	Software Used	Test Method Used
Ground Grid Integrity	This article tackles about the testing of the integrity of the ground grid through resistance test and how it is being done.	Grid Tester that is capable of injecting high current	N/A	Resistance Test
Importance of High Speed Fault Clearing	This paper describes the impact of having a high speed fault clearing of protective devices.	N/A	N/A	N/A
Fuzzy Logic Control of Water Quality Monitoring and Surveillance for Aquatic Life Preservation in Taal Lake	This paper shows how the fuzzy logic can be used in assessing the quality of water in Taal Lake Batangas. The proposed system was implemented using MatLab Fuzzy Logic Toolbox and Excel VB Macro Program.	N/A	N/A	N/A
Substation Grounding	This paper describes the appropriate design of substation grounding.	N/A	N/A	N/A
Investigating Grounding Grid Integrity Based on the Current Injection Method	This paper shows a method that can be used in testing the ground grid integrity through injecting high amount of current.	Current injection generator through the use of Op-Amp (OPA549)	N/A	Current Injection Method
Analysis of a Steel Grounding System	In this paper, a thorough analysis of the performance of a large grounding system made of steel instead of copper conductors buried in a low soil resistivity was discussed.	Steel Conductors	N/A	Fall-of-Potential Method
Application of Electromagnetic Field Theory to Measure Correct Grounding System Impedance	This paper shows a technique in measuring the ground impedances that minimizes the effects of inductive coupling, conductive coupling and power line grounding.	N/A	HIFREQ	Fall-of-Potential Method
Mathematical Modeling for Assessing Integrity of Power Systems Grounding Devices	This paper introduces a new technique to monitor the operating conditions of a grounding device of high voltage equipment and systems without any diggings and forced tripping through evaluation of the magnetic field distribution along the current-carrying horizontal element when it has been deteriorated.	N/A	N/A	Mathematical Modeling through the use of the use of the principles of Biot-Savart Law
Substation Ground Grid Continuity D.C High Current Test Method	This paper introduces a method of testing the ground grid through the use DC high current test method by injecting a 300 amperes DC through the ground grid and measuring the voltage drop.	N/A	Current Injection Generator	DC high Current Test
Ground Grid Integrity testing Using MEGGER Model GTS-300 as Implemented by the National Grid Corporation of the Philippines-Calamba	This paper describes the theory of operation and process of testing the transmission substation ground grid owned and operated by NGCP through the use of MEGGER Model GTS-300	MEGGER Model GTS-300	N/A	Injection of a substantial amount of current

Synthesis

Based on the review of related literature, it can be summarized that ground grid integrity test is vital in maintaining the effectiveness and reliability of the grounding system. The principles behind the operation of grounding system and how it affects the overall performance of an electrical system were discussed. In order to maintain an effective grounding system, an assessment of its integrity should be done to ensure that it can still operate properly especially upon the occurrence of a fault or short circuit. Therefore, testing and assessing the ground grid integrity was made possible through several ways. This can be seen above in which different techniques was employed. Injecting AC inputs were usually done in testing the integrity of the grounding system. Technology has a big impact in the modernization of ground grid integrity testing methods. Advanced electronics, programmable equipment and computer simulation techniques became a trend in today's era as they have more precise measurements and results rather than the usual methods which require much data inputs.

Table 2.1 below tabulates the comparison of related literature on the basis of the following parameters: a.) Description of the study, b.) Hardware, c.) Software Used. D.) Test of Method Used.

It can be seen that the test of the grounding integrity is usually done in a substation. For this reason, the proponents decided to conduct the test in an institutional building since it is not yet been established in a structure outside the substation. In addition, the proponents will design an equipment that will test the grounding for the given research area using point-to-point method. It is also proved that this is the first time to test the integrity of the grounding system of an institutional building. Also, the proponents decided to use MatLab Fuzzy Logic Toolbox Kit for the Assessment of the integrity of the grounding system.

FUZZY RULE BASED SYSTEM

There are fuzzy rules constructed to assess the integrity of the grounding system such as Highly Acceptable (HA), Considerably Acceptable (CA), Just Acceptable (JA), Poor (P) and Critical (C).

A hierarchical structure was constructed for the simulation of the grounding system, *Refer to figure 3.1.* The second level characterizes the grounding conductor integrity, earth resistance and the grounding electrode to obtain an acceptable grounding system for monitoring and surveillance purposes. The last hierarchical level characterizes the integrity of the grounding system. The following are the sample rules stored at three different hierarchical levels of structure:

If the Grounding Conductor Resistance is<poor> and the Earth Resistance is<very good> the Grounding Electrode Resistance is<good>

Then the Ground Grid Integrity is<JA>

If the Grounding Conductor Resistance is<good> and the Earth Resistance is<very good> the Grounding Electrode Resistance is<very good>

Then the Ground Grid Integrity is<CA>

If the Grounding Conductor Resistance is<critical> and the Earth Resistance is<poor> the Grounding Electrode Resistance is<good>

Then the Ground Grid Integrity is<P>

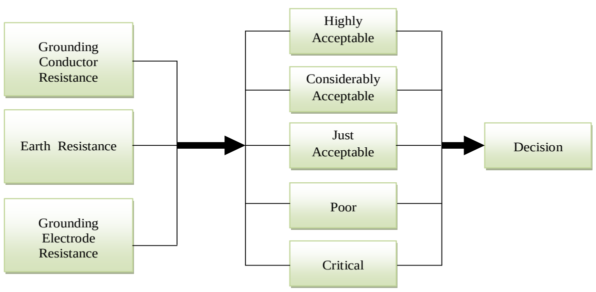


Figure 3.1 Hierarchical Structure for the simulation of the integrity of the grounding system.

The proponents have used the basic process of designing the fuzzy logic for the assessment of the integrity of the grounding system as shown in Figure 2.2. The process consists of five steps. For the first process involving the formulation of the problem the inputs to the fuzzy controller are the Grounding Conductor Resistance, Earth Resistance and the Grounding Electrode Resistance. The variable is scored and sent to the ground grid integrity assessment. The preceding step is by selecting the fuzzy inference rule. This method relies on by trial and error. The inference rule is selected based on the degree of match. The input values are averaged to fit linguistic terms. The proponents used triangular function in defining membership function. In this step involves determining the position and the shapes of the membership function as the factors in determining the performance of the fuzzy logic. The next is by performing fuzzy inference based on inference method. In this method the efficiency of the final control surface is determined by the inference and deffuzzification methods. Lastly is by selecting a deffuzification method to assess the integrity of the grounding system. In this case, deffuzification is done by calculating the center of gravity and the output is produced through averaging technique.

In this study the proponents used Sugeno style over Mamdami method because of only those constant values will vary unlike in Mamdami method the membership functions will also varied. Therefore Mamdami method will be more complicated than the Sugeno Style.

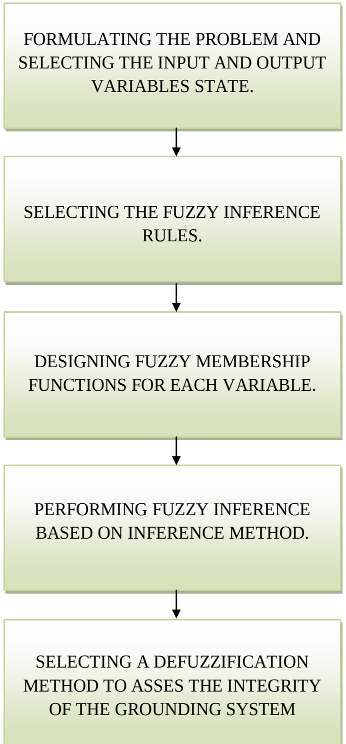


Figure 2.2 Design of Fuzzy Logic for the Assessment of the Ground Grid Integrity

RESEARCH PROCESS

In chase of a successful upshot of this study, developmental method was employed by the proponents as their basis of their procedures which predominantly intend to achieve the set of objectives to solve the stated problems. Aforementioned to the system's advancement, this study also comprise of the design of the system, where planning, problem definition and setting up of the objectives were involved.

The study also comprises of the testing and valuation of the system as the proponents used experimental method in testing the system's operation. Set of experiments were conducted to tabulate successful and abortive results. To depict the system development life cycle, the proponents have used flowcharts and block diagrams to clearly understand the process.

The design of the entire system goes behind the procedures below:

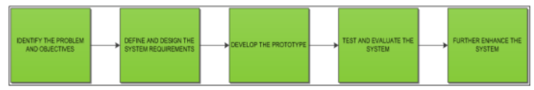
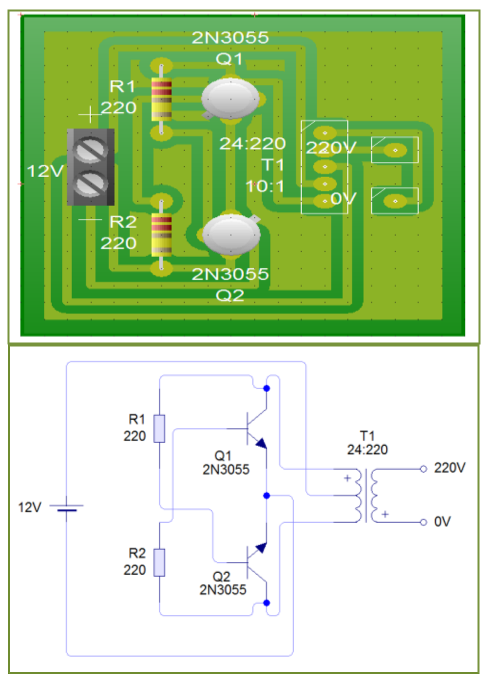


Figure 4.1 Research Process Block Diagram

Figure 4.1 shows the sequential process of the system. It depicts the system's developmental process which serves as a guide by the proponents in putting up the project.

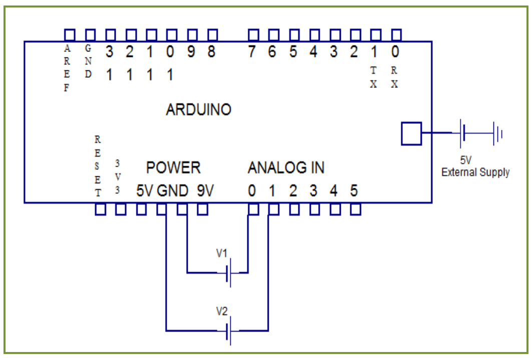
Prototype Components

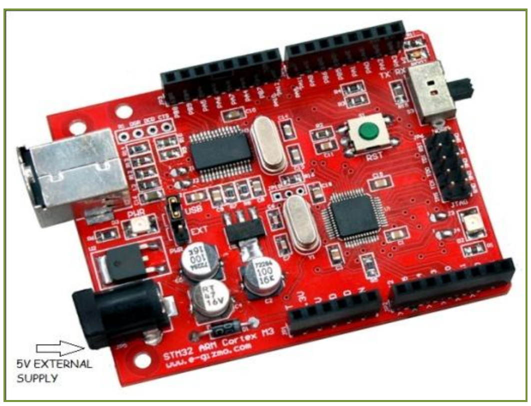
Power Inverter



Power inverter is an electrical device that converts direct current (DC) to alternating current (AC). The circuit main components comprise of a 12V/12Ah dc source which will serve as the main power source of the system, two 2N3055 NPN transistors that act as the switching part and connected in a push-pull configuration which will generate a square wave that will be fed in the step up transformer to amplify the voltage.

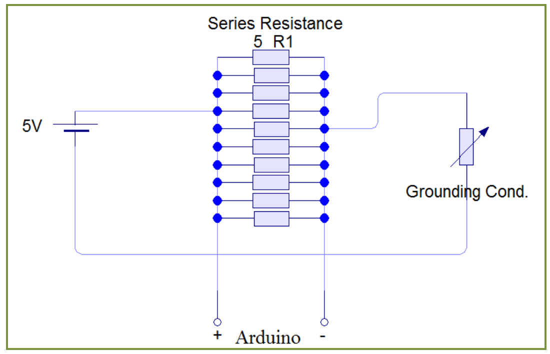
Arduino Microcontroller

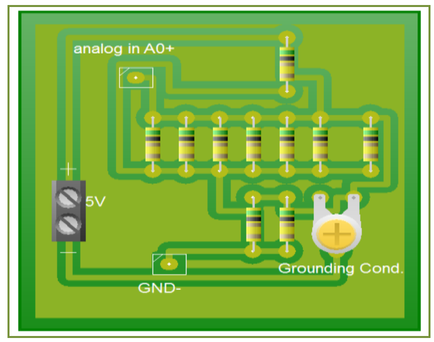




Arduino Microcontroller is an open-source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board. It will serve as the brain of the system for it manipulates and executes the algorithm and converts the measured analog input into its equivalent digital output.

Voltage Divider Circuit





The voltage divider circuit will serve as the circuit for measuring the resistance of the given parameters using voltage divider theorem and the equations below:

Eq. 1
$$V_{Arduino} = \frac{R_1}{R_1 + R_{parameter}} \, x \, E_{source}$$

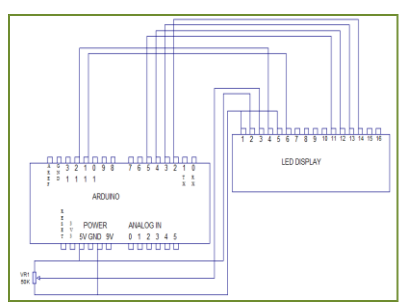
$$(V_{Arduino})(R_1 + R_{parameter}) = R_1 E_{source}$$

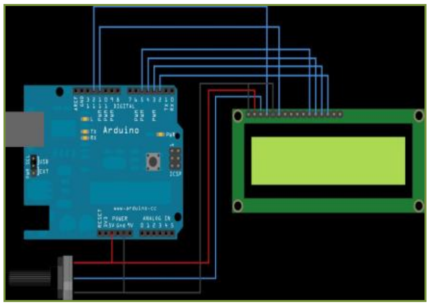
$$V_{Arduino} R_1 + V_{Arduino} R_{parameter} = R_1 E_{source}$$

$$V_{Arduino} R_{parameter} = R_1 E_{source} + V_{Arduino} R_1$$

Eq. 2
$$R_{parameter} = \frac{R_1 E_{source} + V_{Arduino} R_1}{V_{Arduino}}$$

LED Display





The LED display will be the output indicator of the system. The digital output coming from the arduino microcontroller will be displayed and viewed in the LED display.

MatLab Fuzzy Logic Toolbox

The linguistic variables are commonly used instead of numerical variables in fuzzy logic system. Fuzzification is the process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number or fuzzy variable). The perception, experience and the general knowledge of the system behavior serve as the derivation that will act as the control rules that relate the fuzzy output to the fuzzy inputs. In this study, the proponents make use of the averaging technique in deriving its membership functions. The rule table for the designed fuzzy logic system for ground grid integrity assessment is given in Table 3.1

Table 4.1Fuzzy Associative Memory (FAM) Matrix for Ground Grid Integrity Assessment

Count	Weight	Grounding Conductor	Earth resistivity	Grounding Electrode	Ground Grid Integrity (Classified Value)	Ground Grid integrity (Linguistic Class)
0	w1	5	5	5	5.00	HA
1	w2	5	5	4	4.68	CA
2	w3	5	5	3	4.36	CA
3	w4	5	5	2	4.05	CA
4	w5	5	5	1	3.73	JA
5	w6	5	4	5	4.77	CA
6	w7	5	4	4	4.45	CA
7	w8	5	4	3	4.14	CA
8	w9	5	4	2	3.82	JA
9	w10	5	4	1	3.50	JA
10	w11	5	3	5	4.55	CA

From the combination of the input parameters such as grounding conductor, earth resistance and grounding electrode, 125 fuzzy rule bases were able to formulate. The triangular figures of the associated function of this arrangement presume that for any particular input there is only one dominant fuzzy subset. The linguistic variables are converted into a numerical variable.

Creating, editing and observing the fuzzy inference system makes use of five primary Graphical User Interfaces (GUIs). It comprise of Fuzzy Inference System (FIS) Editor, Membership Function Editor, Rule Editor, Rule Viewer and Surface Viewer. If changes were made to the FIS of one of the toolbox, the effect can be seen in other GUIs since it is dynamically connected with each other. In addition to these five primary GUIs, the toolbox includes the graphical ANFIS Editor GUI, which is used for building and analyzing Sugeno-types adaptive neural fuzzy inference systems [3].

The method used in this study for Matlab Fuzzy Logic Toolbox simulation is the Sugeno or Takagi-Sugeno-Kang of fuzzy inference that was introduced in 1985 and it is similar to Mamdani method in many respects. The first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator are exactly the same. Sugeno output membership functions are either linear or constant unlike the Mamdami. In this paper, the proponents think about the use of constants as output membership functions [3].

EXPERIMENTS AND ANALYSIS OF RESULTS

The experimentation was done methodically as discussed in the block diagram in the previous chapter (*Figure 4.1*). The results obtained from the experimentation will prove the system's effectiveness and consistency.

Earth Resistance Measurement

The earth resistance of a single spike, of diameter and length buried to earth with a soil resistivity can be calculated as follows:

$$R_g = \frac{\rho}{2\pi L}[\ln\left(\frac{8L}{d}\right) - 1]$$

Ea.

Where: Soil resistivity of the soil in ohm – meter (Ωm)

L Buried length of the rod in meter (m)

d diameter of the rod in meter (m)

The proponents conducted a parallel test of measuring earth resistance by using a 10 centimeter (0.1 meter) in length, 3.5 square millimeters ($2.11\text{x}10^{-3}$ meter in diameter) copper rod supposing that the rod is the actual grounding rod buried.

$$R_g = \frac{\rho}{2\pi L}[\ln\left(\frac{8L}{d}\right) - 1] \qquad \textit{Eq. 4}$$

$$R_g = \frac{120\Omega m}{2\pi(0.1m)}[\ln\left(\frac{8(0.1m)}{0.00211m}\right) - 1]$$

$$R_g = \frac{120\Omega m}{2\pi(0.1m)}[\ln(378.966) - 1]$$

$$R_g = 190.985\Omega[\ln(378.966) - 1]$$

$$R_g = 190.985\Omega[5.937 - 1]$$

$$R_g = 190.985\Omega[4.937]$$

$$R_g = 942.978\Omega$$

Table 5.1 Tabulated Results

No. of trials	Measured value	Theoretical value	Percentage error
Trial 1	843. 33 ohms	942.978 ohms	10.567%
Trial 2	1019 ohms	942.978 ohms	8.062%
Trial 3	848.33 ohms	942.978 ohms	10.037%
Trial 4	848.33 ohms	942.978 ohms	10.037%
Trial 5	726.43 ohms	942.978 ohms	22.964%

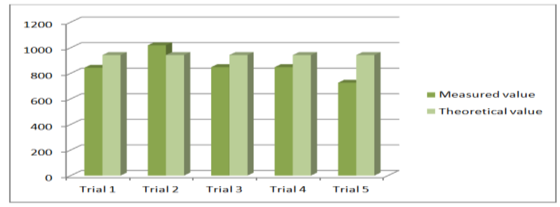


Figure 5.1 Graphical Representations of Results

Grounding Conductor and Electrode Measurement

The value of the grounding conductor resistance can be obtained using the formula formulated George Simon Ohm known as the Laws of Resistance:

$$R_c = \frac{\rho L}{A} \qquad \textit{Eq. 5}$$

Where: Conductor resistivity in ohm – meter (Ωm)

L Length of the conductor in meter (m)

A Area of the conductor in square meter (m^2)

The proponents made a computation parallel for the test procedure conducted to measure the resistance of the grounding conductor to prove and to assure the accuracy of the equipment for the measurement of the grounding conductor resistance using a 3 meter copper conductor with a $5.18868 \text{ x } 10^{-7}$ m^2 area.

$$R_c = 0.0971\Omega$$

$$R_c = \frac{\rho L}{A}$$

$$R_c = \frac{(1.68\ x\ 10^{-8}\Omega m)(3m)}{5.18868\ x\ 10^{-7}\ m^2}$$

In addition to test the accuracy of the equipment, the proponents also conducted a test using a carbon type resistor with a value of 150 ohms ±5% tolerance.

Table 5.2 Tabulated Results

No. of trials	Measured value	Theoretical value	Percentage error
Trial 1	0.06 ohms	0.0971 ohms	38.14%
Trial 2	0.13 ohms	0.0971 ohms	34.02%
Trial 3	0.17ohms	0.0971 ohms	38.14%
Trial 4	0.13 ohms	0.0971 ohms	75.26%
Trial 5	0.05ohms	0.0971 ohms	48.45%

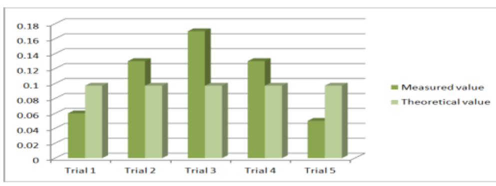


Figure 5.2 Graphical Representation of Results

Table 5.3 Tabulated Results

No. of trials	Measured value	Theoretical value	Percentage error
Trial 1	150.15 ohms	150 ohms	0.1%
Trial 2	145.59 ohms	150 ohms	2.94%
Trial 3	155ohms	150 ohms	3.33%
Trial 4	137.22 ohms	150 ohms	8.52%
Trial 5	150.10 ohms	150 ohms	0.067%

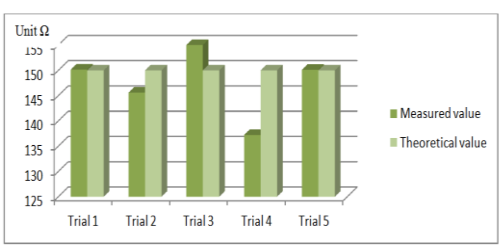


Figure 5.3 Graphical Representation of Results

The proponents have used the rule editor (Figure 5.4) and rule viewer (Figure 5.5) for ground grid integrity testing using Matlab fuzzy logic toolbox. It is where the FAM matrix of 125 rules is plugged in. The proponents conducted 10 tests to determine the reliability of the fuzzy system for each linguistic classification. Table 5.4 shows the simulation results, which classifies the integrity of the grounding system as Highly Acceptable, Considerably Acceptable, Just Acceptable, Poor or Critical. Based from the results obtained, it could be analyzed that there is a perfect correlation between fuzzy system for, PEC and IEEE standards for ground grid integrity test as shown in Table 5.5.

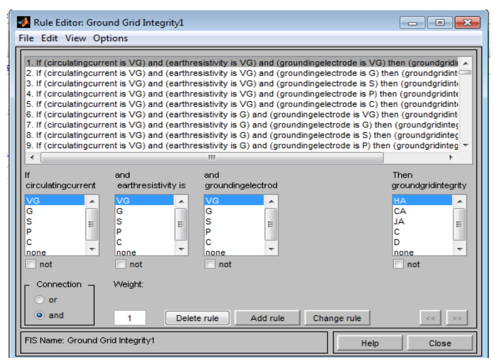


Figure 5.4 Rule Viewer for Ground Grid Integrity Assessment

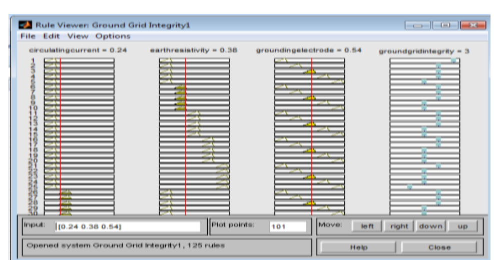


Figure 5.2 Rule Viewer for Ground Grid Integrity Assessment

Table 5.4Testing Results usingMatLab Fuzzy Logic Toolbox

Trials	Board Predictive Assessment Input Parameters		Input Values (Normalized)	Crisp Output (Matlab Fuzzy Logic Toolbox)	Linguistic Classification
1	Ground Grid Integrity	Grounding Conductor	0.24	3	Just Acceptable
		Earth Resistivity	0.38		
		Grounding Electrode	0.54		
2	Ground Grid Integrity	Grounding Conductor	0.36	4	Considerably Acceptable
		Earth Resistivity	0.54		
		Grounding Electrode	0.19		
3	Ground Grid Integrity	Grounding Conductor	0.11	3	Just Acceptable
		Earth Resistivity	0.78		
		Grounding Electrode	0.88		
4	Ground Grid Integrity	Grounding Conductor	0.57	2	Poor
		Earth Resistivity	0.66		
		Grounding Electrode	0.92		
5	Ground Grid Integrity	Grounding Conductor	0.16	4	Considerably Acceptable
		Earth Resistivity	0.19		
		Grounding Electrode	0.35		
6	Ground Grid Integrity	Grounding Conductor	0.87	1	Critical
		Earth Resistivity	0.72		
		Grounding Electrode	0.69		
7	Ground Grid Integrity	Grounding Conductor	0.52	3	Just Acceptable
		Earth Resistivity	0.08		
		Grounding Electrode	0.75		
8	Ground Grid Integrity	Grounding Conductor	0.17	5	Highly Acceptable
		Earth Resistivity	0.19		
		Grounding Electrode	0.19		
9	Ground Grid Integrity	Grounding Conductor	0.38	3	Just Acceptable
		Earth Resistivity	0.78		
		Grounding Electrode	0.27		
10	Ground Grid Integrity	Grounding Conductor	0.32	2	Poor
		Earth Resistivity	0.76		
		Grounding Electrode	0.67		

Table 5.5 Verification of Fuzzy based results with PEC/IEEE Standards

Trials	Parameters		Actual Input Values	PEC standards	IEEE standards	PEC/IEEE standards	Linguistic classification (fuzzy system for ground)		Linguistic classification (fuzzy system for ground)		%	
1	Grounding Conductor	Voltage Drop	0.011 V/ft	N/A	0.03 V/ft	4 - Good	VG	Good	HA	CA	20	45.45
		Resistance	1.22mΩ/ft	955.34 μΩ/ft - 2.626mΩ/ft	N/A	4 - Good					30	
		Watts-Loss	353mW/ft	342mW/ft - 942.08 mW/ft	N/A	4 - Good					20	
		Continuity	short	short	short	5 - Very Good					30	
	Earth Resistance	Soil Resistance	3.88Ω	N/A	5Ω	3 - Satisfactory	S		JA		40	22.73
		Soil Temperature	M	N/A	N/A	4 - Good					40	
		Moisture Content	38%	N/A	N/A	2 - Poor					20	
	Grounding Electrode	Depth	369mm	750 mm	N/A	3 - Satisfactory	G		CA		28.57	31.82
		Electrode Resistance	7.42Ω	25Ω	N/A	4 - Good					42.86	
		Spacing	1850mm	1800 mm	N/A	5 - Very Good					28.57	
2	Grounding Conductor	Voltage Drop	0.053 V/ft	N/A	0.03 V/ft	2 - Poor	VG	Good	HA	CA	20	45.45
		Resistance	0.983mΩ/ft	955.34 μΩ/ft	N/A	4 - Good					30	
		Watts-Loss	236mW/ft	942.08 mW/ft	N/A	5 - Very Good					20	
		Continuity	short	short	short	5 - Very Good					30	
	Earth Resistance	Soil Resistance	0.9Ω	N/A	5Ω	5 - Very Good	G		CA		40	22.73
		Soil Temperature	M	N/A	N/A	4 - Good					40	
		Moisture Content	8%	N/A	N/A	1 - Critical					20	
	Grounding Electrode	Depth	203mm	750 mm	N/A	2 - Poor	S		JA		28.57	31.82
		Electrode Resistance	18.6Ω	25Ω	N/A	3 - Satisfactory					42.86	
		Spacing	1389mm	1800 mm	N/A	4 - Good					28.57	

CONCLUSION

The contribution of this study is a tangible procedure in determining the effectiveness of the integrity of the grounding system. Developed in this thesis is an FLC based equipment that is capable of determining the integrity of the grounding system of LPU-L SHL bldg. The proponents had developed the ground grid integrity testing equipment by injecting a substantial amount of direct current into the grounding system and measuring its important parameters. The equipment has the capability to assess and classify the condition of the grounding system and if it can still operate properly in normal and anomalous conditions especially upon the occurrence of a fault.

The assessment of the grounding system was done through the use of the concepts of fuzzy logic. Averaging technique was employed in deriving its membership functions. From the combination of the input parameters such as grounding conductor resistance, earth resistance and grounding electrode resistance, 125 fuzzy rule bases were able to formulate.The triangular figures of the associated function of this arrangement presume that for any particular input there is only one dominant fuzzy subset. The linguistic variables are converted into a numerical variable. The proponents think about the use of constants as output membership functions.

It has been verified experimentally from theoretical studies and actual data analysis as supported by the data above to prove the effectiveness of the results. It can be seen that ground grid integrity test is working as it should be, considering that it established a perfect correlation between theoretical and the actual values that had been obtained.

The proponents were able to establish a distinctive approach towards the unsophisticated way of assessing the integrity of the grounding system that will present a cheaper and quicker method which will also apply most likely to the improvement and development of maintaining an effective and reliable grounding system.

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FUZZY LOGIC ALGORITHM CONSTRUCTION

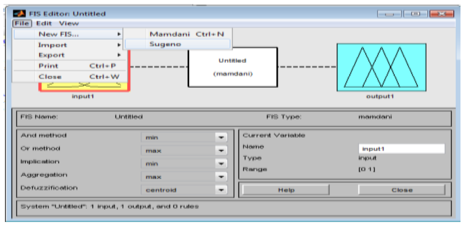

Figure 9.1Making a Sugeno file.

STEP 1:

Specify, create FIS editor by specifying the fuzzy inference system (mamdani or sugeno style) and save it as "Ground Grid Integrity". (See Figure 9.1)

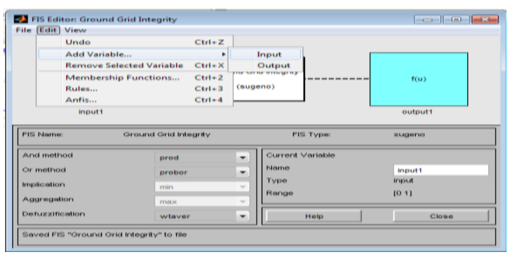

Figure 9.2Adding variables for input twice.

STEP 2:

Go to edit, add variable (Input) two (2) times. (See Figure 9.2)

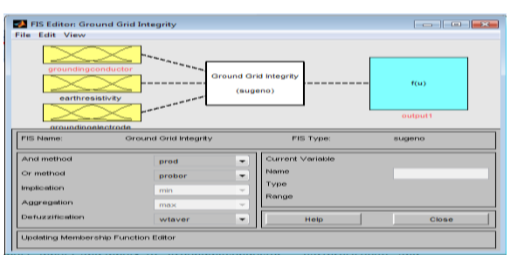

Figure 9.3Naming the inputs "groundingconductor", "earthresistivity" and "groundingelectrodes".

STEP 3:

Change input1, input2 and input3 to "groundingconductor", "earthresistivity" and "groundingelectrodes" respectively. (See Figure 9.3)

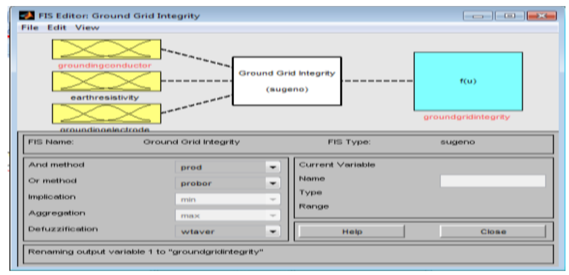

Figure 9.4 Naming the output "groundgridintegrity".

STEP 4:

Change the output1 and named it to "groundgridintegty". (See Figure 9.4)

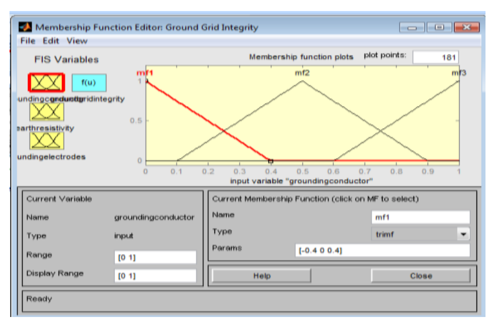

Figure 9.5 Different functions display namely mf1, mf2 and mf3.

STEP 5:

Double click the "groundingconductor" in the input and you will see different membership functions namely mf1, mf2 and mf3. (See Figure 9.5)

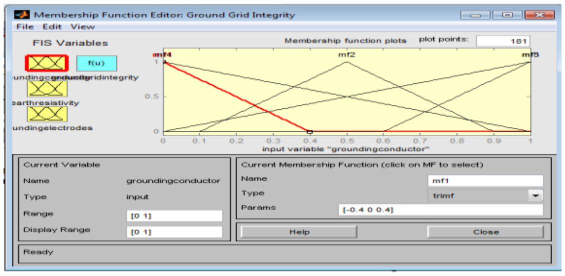

Figure 9.6Additional of 5 MF's.

STEP 6:

Go to edit, add MFs, choose 2 and click ok to have 5 MF's. (See Figure 9.6)

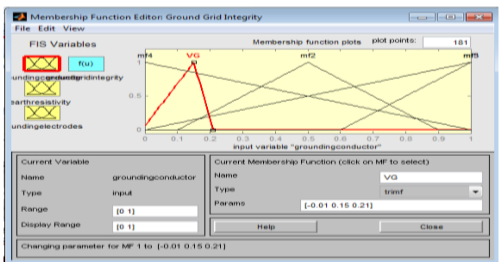

Figure 9.7 Changing mf1 to its specific parameters.

STEP 7:

Go to mf1 and specify the parameters [-0.01 0.15 0.21], change the name of mf1 to "VG" (Very Good). (See Figure 9.7)

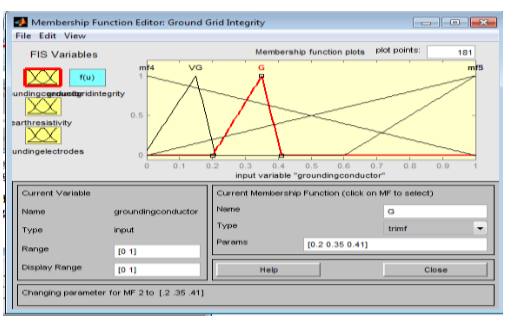

Figure 9.8 Changing mf2 to its specific parameters.parameters.

STEP 8:

Go to mf2 and specify the parameters [0.2 0.35 0.41], change the name of mf2 to "G" (Good). (See Figure 9.8)

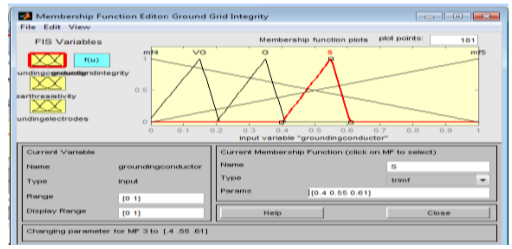

Figure 9.9: Changing mf3 to its specific parameters.parameters.parameters.

STEP 9:

Go to mf3 and specify the parameters [0.4 0.55 0.61], change the name of mf3 to "S" (Satisfactory). (See Figure 9.9)

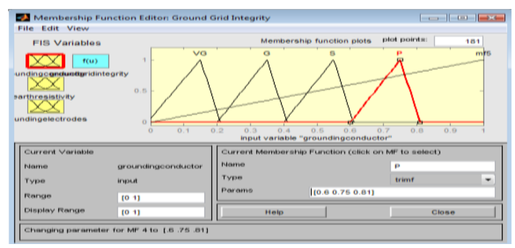

Figure 9.10Changing mf4 to its specific parameters.

STEP 10:

Go to mf4 and specify the parameters [0.6 0.75 0.81], change the name of mf4 to "P" (Poor). (See Figure 9.10)

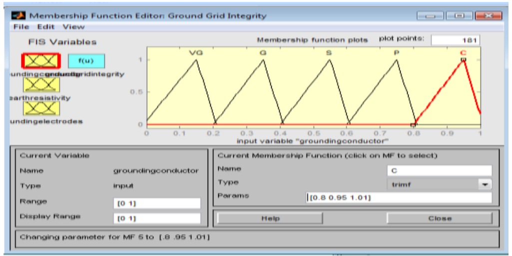

Figure 9.11Changing mf5 to its specific parameters.

STEP 11:

Go to mf5 and specify the parameters [0.8 0.95 1.01], change the name of mf5 to “C” (Critical). (See Figure 9.11)

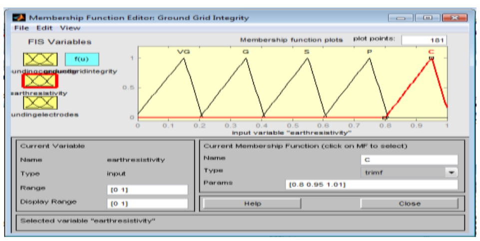

Figure 9.12Changing “earthresistivity” specifications and parameters.

STEP 12:

Click the “earthresistivity” and repeat the process from STEP 6 to STEP 11. (See Figure 9.12)

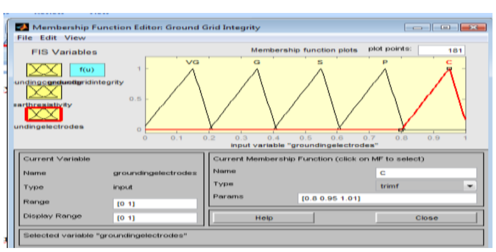

Figure 9.13Changing “groundingelectrodes” specifications and parameters.

STEP 13:

Click the “groundingelectrodes” and repeat the process from STEP 6 to STEP 11. (See Figure 9.13)

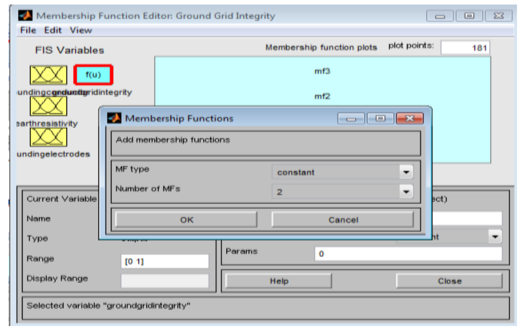

Figure 9.14Additional for MFs for 5 MFs Output.

STEP 14:

Click the “groundgridintegrity”, click edit then add MFs then choose 2 and click OK. (See Figure 9.14)

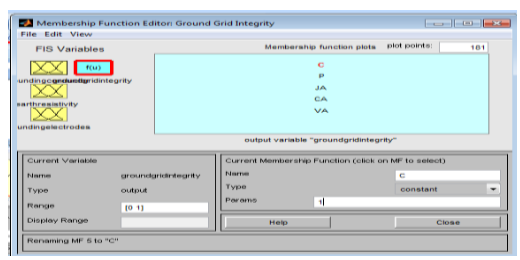

Figure 9.15Changing the Names and Parameters.

STEP 15:

Change the name of mf1, mf2, mf3, mf4 and mf5 to “HA”(Highly Acceptable), “CA”(Considerably Acceptable), “JA”(Just Acceptable), “P”(Poor) and “C”(Critical) respectively and change also the parameters from mf1, mf2, mf3, mf4 and mf5 to “5”, “4”, “3”, “2” and “1” respectively. (See Figure 9.15)