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# Ground Grid Integrity Testing Using Matlab Fuzzy Logic Toolbox

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**ABSTRACT**

In this study, the proponents make use of the concepts of fuzzy logic in simulating the ground grid integrity test of LPU-L SHL bldg. 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

## 1. 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 (Switzer, 1999).

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 (Switzer, 1999).

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 practioners 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 (Surbrook and Althouse, 2008).

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 (Switzer, 1999).

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.

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 ($\Omega$-$^{o}$C) and the grounding electrode ($\Omega$ -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.

## 2. 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 2.1.* 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 Voltage Drop is<good> and the Resistance is<good> the Watts – Loss is<satisfactory> and the Continuity is<very good>*
***Then the Grounding Conductor is<good>***

*If the Soil Resistance is<poor>, the Soil temperature is<very good> and the moisture content is<very good>*
***Then the Earth Resistance is<satisfactory>***

*If the Depth is<poor>, the Electrode Resistance is<critical> and the spacing is<very good>*
***Then the Grounding Electrode is<poor>***

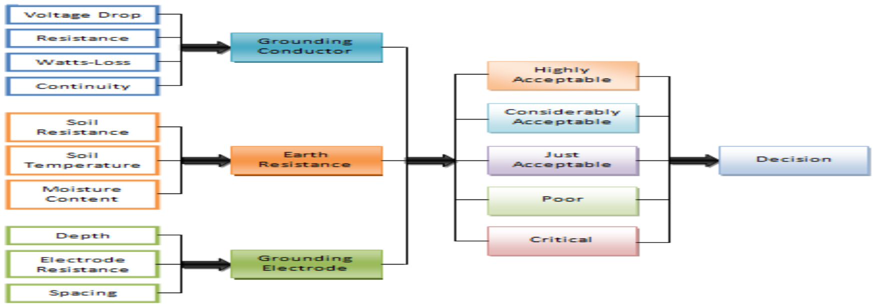


**Figure 2.1:** *Hierarchical Structure for the simulation of the integrity of the grounding system.*

The proponents constructed a precedence graph that can be used in analyzing the sequence of the tasks performed by the operators in line with the simulation of the integrity of the grounding system. Figure 2.2 shows a precedence graph with three major tasks and ten minor tasks to assess the integrity of the grounding system. Table 2.1 represents the standards for the simulation of the assessment for the integrity of the grounding system.

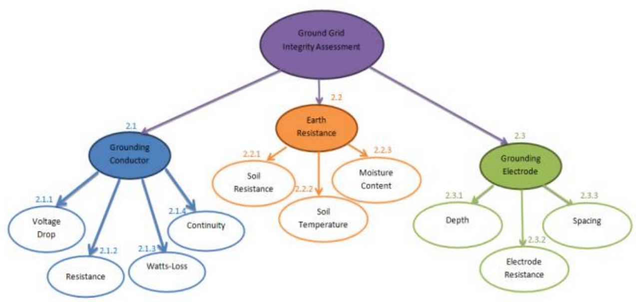


**Figure 2.2:** *Precedence for the simulation of the assessment for the integrity of the grounding system*

**Table 2.1:** *Standards used for the simulation of the assessment for the integrity of the grounding system*

| GROUNDING CONDUCTOR (CONDUCTIVITY) | | | | | |
|---|---|---|---|---|---|
| ADJECTIVAL RATING | VERY GOOD | GOOD | SATISFACTORY | POOR | CRITICAL |
| Voltage Drop (0.03 Volts / Feet) | 0 to 0.01 | 0.01 to 0.02 | 0.02 to 0.04 | 0.04 to 0.06 | 0.06 to 1.0 |
| Resistance (0.955mΩ - 2.626mΩ per Feet for Copper conductors) | 0 to 0.955mΩ | 0.955 mΩ to 1.3728 mΩ | 1.3728 mΩ to 1.7905 mΩ | 2.208 mΩ to 2.626 mΩ | >2.626 mΩ |
| Watts – Loss (342.726mW - 942.408mW per Feet) | 0 to 324.726 | 342.726 to 492.6465 | 492.6465 to 642.567 | 642.567 to 792.4875 | >792.4875 |
| Continuity | Short | ----- | ----- | ----- | Open |
| EARTH RESISTANCE ( OHM – °C) | | | | | |
| ADJECTIVAL RATING | VERY GOOD | GOOD | SATISFACTORY | POOR | CRITICAL |
| Soil resistance (Ω) | 0 to 1.25 | 1.25 to 2.5 | 2.5 to 3.75 | 3.75 to 5 | >5 |
| Soil Temperature | HIGH TEMP. | MODERATE TEMP. | LOW TEMP. | VERY LOW TEMP. | BELOW FREEZING POINT |
| Moisture Content | 80% - 100% | 60% - 80% | 40% - 60% | 20% - 40% | 0% - 20% |
| GROUNDING ELECTRODE(Rod and Pipe Electrodes) (OHM - MM) | | | | | |
| ADJECTIVAL RATING | VERY GOOD | GOOD | SATISFACTORY | POOR | CRITICAL |
| Depth (mm, Rod and Pipe Electrodes) | >750 | 562.5 to 750 | 375 to 562.5 | 187.5 to 375 | 0 to 187.5 |
| Electrode Resistance | 0 to 6.25 | 6.25 to 12.5 | 12.5 to 18.75 | 18.75 to 25 | >25 |
| Spacing (mm) | >1800 | 1350 to 1800 | 900 to 1350 | 450 to 900 | 0 to 450 |

## 3. 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 3.1**: *Fuzzy 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 (Caldo, 2013).

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 Mamdani (Caldo, 2013). In this paper, the proponents think about the use of constants as output membership functions

### 3.1 Derivation of Input to the Fuzzy Sets

In this paper, the proponents derived inputs for the fuzzy sets Grounding Conductor, Earth Resistance and Grounding Electrode. The grounding conductor has a factor of 45.45%. They have used 20%, 30%, 20% and 30% factors for Voltage drop, Resistance, Watts – loss and Continuity respectively. The Resistance and Continuity have higher percent contribution considering that they are critical parameters of the grounding system. The Earth Resistance has a factor of 22.73%. They have used 40%, 40% and 20% factors for Soil Resistance, Soil Temperature and Moisture Content respectively. Finally, the Grounding Electrode has a factor of 31.82%. They have used 28.57%, 42.86% and 28.57% factor for Depth, Electrode Resistance and Spacing. Each factor being derived was based from the importance of each parameter in a grounding system as noted by PEC and IEEE standards.

## 4. DATA AND RESULTS

In presenting the data and results of the study, the proponents have used the rule editor (Figure 5.1) and rule viewer (Figure 5.2) 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 5.1 shows the simulation results, which classifies the integrity of the grounding system as Highy 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 5.2.

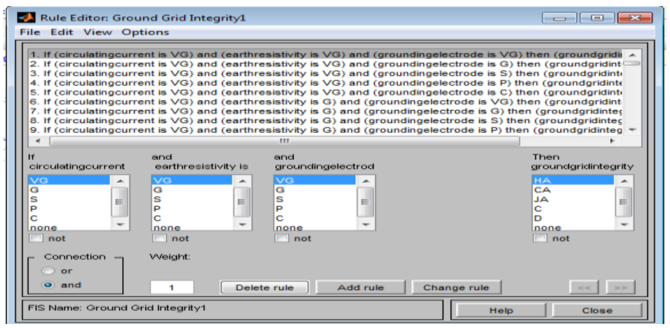


**Figure 5.1**: *Rule Editor for Ground Grid Integrity*

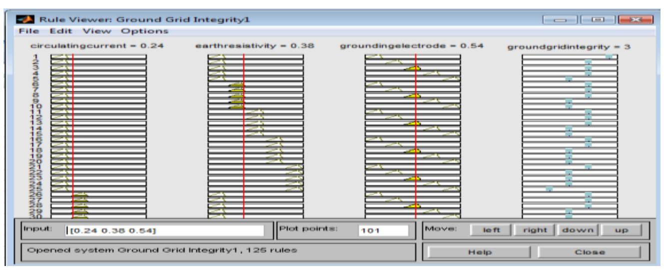


**Figure 5.2**: *Rule Viewer for Ground Grid Integrity*

**Table 5.1**: *Testing Results using MatLab Fuzzy Logic*

| 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 5.2**: *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 | |

## 5. CONCLUSIONS

This paper introduces a tangible tool, which could be possibly used in determining the effectiveness of the integrity of the grounding system. The proposed method was implemented systematically using Matlab Fuzzy Logic Toolbox and it showed that fuzzy-based system for ground grid integrity test is simple, available, reliable and effective. The constructed fuzzy logic algorithm was verified experimentally through successful tests.

The proponents were able to establish a distinctive approach towards unsophisticated way of assessing the integrity of the grounding system, which would apply to low voltage dc application. It presents a cheaper and quicker method, which will also apply most likely to the improvement, development and maintenance of an effective and reliable grounding system for institutional buildings.


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