

Design and Implementation of Grounding Resistance Control System Using Water Pump Actuator and Real-Time Monitoring Sensors

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Abstract – Grounding system performance is strongly influenced by soil moisture and temperature, which can vary significantly due to environmental conditions. The lack of real-time monitoring may cause grounding resistance to exceed safety limits, particularly during dry seasons. This study aims to design and evaluate a microcontroller-based grounding resistance control system capable of maintaining resistance below 5 Ω through real-time monitoring and automatic soil conditioning. An experimental method was applied at an active grounding installation in the Multi Integra Building, Rawamangun, Jakarta, representing tropical soil conditions with variable moisture content. The proposed system integrates soil moisture and temperature sensors, a microcontroller, and a water pump actuator operating in a closed-loop control scheme. Grounding resistance measurements were conducted before and after automated irrigation and validated using an earth resistance tester. The results show a clear inverse relationship between soil moisture and grounding resistance. Initial dry soil conditions produced an average grounding resistance of 6.095 Ω . After controlled irrigation, soil moisture increased to approximately 63.5% and soil temperature decreased, resulting in a significant reduction of grounding resistance to an average of 0.707 Ω . These findings confirm that active soil moisture control effectively stabilizes grounding performance and enhances electrical safety.

Keywords: Grounding system, grounding resistance, soil moisture, real-time monitoring, microcontroller, electrical safety



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I. INTRODUCTION

Grounding systems play a critical role in electrical installations by safely dissipating leakage currents, voltage surges, and lightning strikes into the earth. The effectiveness of a grounding system is primarily determined by soil resistance, which must remain low and stable to ensure electrical safety. According to

applicable standards such as PUIL 2011 and SNI 03-7015-2004, grounding resistance should not exceed 5 Ω for general installations and must be lower for sensitive facilities, including hospitals and data centers.

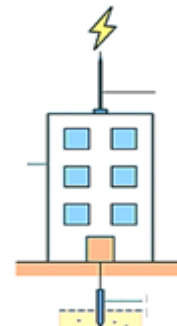


Figure 1. Franklin Rod-Type Lightning Protection Method

Despite strict regulatory requirements, grounding performance is commonly assessed only during installation or periodic inspections. This practice creates a vulnerability, as soil conditions—particularly moisture and temperature—can change significantly over time. During dry seasons, reduced soil moisture increases soil resistivity, potentially causing grounding resistance to exceed safe limits without immediate detection. This condition poses a risk to both equipment and personnel.

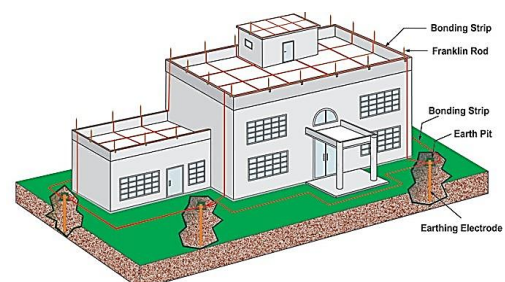


Figure 2. Faraday Cage-Type Lightning Protection Method

Previous studies have confirmed that soil moisture and temperature have a strong influence on grounding resistance. However, most existing mitigation methods, such as chemical soil treatment or the use of multiple electrodes, are static in nature and unable to respond dynamically to environmental changes. Recent developments in microcontroller and sensor technologies have enabled real-time monitoring of soil parameters, yet most studies remain limited to monitoring functions without integrating active control mechanisms. The typical resistivity ranges of various soil types relevant to grounding system performance are summarized in Table 1.

Table 1. Soil Type and Soil Resistivity

No.	Soil Type	Soil Resistivity (Ω)
1	Rocky Soil	3000
2	Dry Gravel	1000
3	Wet Gravel	500
4	Wet Sand	200
5	Agricultural Soil	100
6	Swamp Soil	30

This study addresses that gap by proposing a grounding resistance control system that combines real-time monitoring with automated soil moisture regulation using a water pump actuator. Unlike earlier works that focus solely on data acquisition, the proposed system operates in a closed-loop configuration, allowing direct intervention when soil conditions deviate from optimal levels.

The main contribution of this research lies in demonstrating the effectiveness of integrating environmental sensors, a microcontroller, and an actuator to actively stabilize grounding resistance under changing soil conditions.

This study is limited to experimental evaluation at a single grounding installation under tropical soil conditions, focusing on soil moisture and temperature as control parameters, without incorporating wireless communication or long-term seasonal analysis.

I. METHOD

A. Research Method and Experimental Design

This study employed an experimental research method using a laboratory–field simulation approach to design, implement, and evaluate an automated grounding resistance control system. The experiment focused on observing changes in soil moisture, soil temperature, and grounding resistance before and after the activation of an automatic irrigation mechanism controlled by a microcontroller.

The experimental approach was selected to enable direct measurement of system performance under real grounding conditions, as well as to assess the effectiveness of closed-loop soil moisture control in maintaining grounding resistance within acceptable safety limits.

B. Experimental Location and Object of Study

The experiment was conducted at an operational grounding installation in the Multi Integra Building, Rawamangun, Jakarta. The location represents tropical soil conditions with non-uniform soil structure and significant moisture variation, particularly during dry periods. The grounding electrode was installed at standard depth in natural soil without chemical additives, allowing the system response to be evaluated under realistic environmental conditions.

C. System Architecture

The proposed system consists of four main subsystems:

- Sensing subsystem, comprising soil moisture and temperature sensors;
- Processing subsystem, using an Arduino Uno R3 microcontroller;
- Actuation subsystem, consisting of a relay module and a water pump;
- Monitoring subsystem, utilizing an LCD display for real-time visualization.

All subsystems are integrated into a closed-loop control configuration, where sensor measurements continuously influence actuator operation. The overall system architecture and interconnection between components are illustrated in Figure 3, which presents the hardware circuit wiring diagram.

D. Hardware Components and Sensor Specifications

The main hardware components used in this study include an Arduino Uno R3 microcontroller, two YL-69 soil moisture sensors, one DS18B20 soil temperature sensor, a 5 V relay module, a mini water pump, and a 128×64 LCD display.

The specifications of the sensors are summarized as follows:

- YL-69 Soil Moisture Sensor: analog output (0–5 V), relative moisture range 0–100%, connected to the 10-bit ADC of the Arduino Uno for soil moisture detection around the grounding electrode.
- DS18B20 Temperature Sensor: digital 1-Wire interface, measurement range $-55\text{ }^{\circ}\text{C}$ to $+125\text{ }^{\circ}\text{C}$, accuracy $\pm 0.5\text{ }^{\circ}\text{C}$ within $-10\text{ }^{\circ}\text{C}$ to $+85\text{ }^{\circ}\text{C}$, used to monitor soil temperature variation.

E. Sensor Calibration

Prior to experimental testing, all sensors were calibrated to ensure data reliability. Soil moisture sensors were calibrated using three reference conditions—dry soil, moist soil, and saturated soil—with validation performed using a VT-05 soil moisture tester. The DS18B20 temperature sensor was calibrated by comparison with a calibrated digital thermometer under steady-state conditions.

Calibration accuracy was evaluated using percentage error analysis, and only sensors with measurement errors below 5% were used in the experiment.

F. Control System Strategy

The control system applies a threshold-based closed-loop control algorithm implemented on the microcontroller. Soil moisture is defined as the primary control variable, while soil temperature functions as a supporting parameter.

The control logic operates as follows:

- When soil moisture falls below 30%, the microcontroller activates the relay to turn on the water pump.
- Irrigation continues until soil moisture reaches the target range of approximately 60–65%.
- Once the upper threshold is reached, the pump is automatically deactivated.

This mechanism enables adaptive regulation of soil conditions without manual intervention and ensures stable grounding resistance over time.

G. Experimental Procedure

The experimental procedure was conducted sequentially as follows:

- Installation of soil moisture and temperature sensors around the grounding electrode at equal depth and spacing.
- Initial measurement of soil moisture, soil temperature, and grounding resistance under dry soil conditions.
- Activation of the automatic control system.
- Controlled irrigation using water flow rates ranging from 5 to 50 L/min.
- Data collection at 3-minute intervals over a total duration of 30 minutes.
- Final grounding resistance measurement after soil conditions stabilized.

H. Testing Parameters

The parameters evaluated during the experiment include:

- Soil moisture (%)
- Soil temperature (°C)
- Grounding resistance (Ω)
- Water flow rate (L/min)
- System response time (minutes)

I. Data Analysis

Grounding resistance was measured using an earth resistance tester and compared with sensor-based measurements. The experimental data were analyzed descriptively and comparatively to evaluate system performance before and after irrigation, focusing on the relationship between soil moisture variation and grounding resistance reduction.

II. RESULTS AND DISCUSSION

Prior to activating the automatic control system, manual measurements were performed to establish the initial soil conditions. These measurements represent the baseline values of soil moisture, soil temperature, and grounding resistance before the control mechanism was applied. The results of the manual measurements are presented in Table 2.

Table 2.. Manual Measurement of Initial Conditions

Manual Measurement Results				
Measurement	Time (Minutes)	Manual Soil Temperature (°C)	Soil Moisture Value (%)	Grounding Resistance Value (Ω)
1	3	35	25	5,93
2	6	35	25	6,59
3	9	34	27	6
4	12	35	25	7,31
5	15	35	20	6,87
6	18	35	27	6
7	21	35	25	5,25
8	24	34	20	5,3
9	27	34	20	5,7
10	30	35	20	6
Average		34,7	23,4	6,095

A. Experimental Results

The experimental tests were conducted to evaluate the relationship between soil moisture, soil temperature, and grounding resistance under controlled conditions. Data were collected periodically at fixed intervals during system operation. The primary parameters observed included soil moisture percentage (%), soil temperature (°C), and grounding resistance (Ω).

The experimental results indicate that a decrease in soil moisture consistently leads to an increase in grounding resistance. Conversely, when the automatic control system activated the water pump and increased soil moisture around the grounding electrode, the grounding resistance decreased and returned to values below the recommended threshold of 5 Ω . This behavior confirms the dominant influence of soil moisture on grounding performance. The relationship between soil moisture variation and grounding resistance during the experimental test is illustrated in Figure 3.

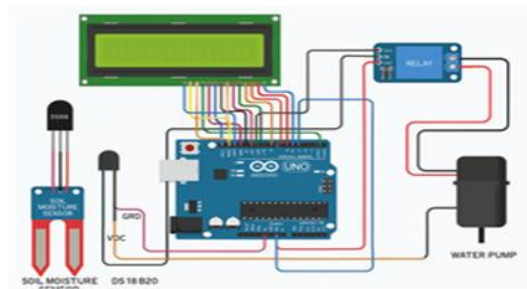


Figure 3. Hardware Circuit Wiring Diagram

The measured values of soil moisture, soil temperature, and grounding resistance obtained during the experiment are presented in Table 3.

Table 3. Experimental measurement results

Manual Measurement Results				
Measurement	Time (Minutes)	Manual Soil Temperature (°C)	Soil Moisture Value (%)	Grounding Resistance Value (Ω)
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Average		34,7	23,4	6,095

B. Statistical Analysis

To strengthen the interpretation of the experimental results, descriptive statistical analysis was applied to the collected data. The statistical parameters evaluated included the mean, minimum, maximum, and standard deviation of soil moisture, soil temperature, and grounding resistance.

Furthermore, a correlation analysis was conducted to examine the relationship between soil moisture and grounding resistance. The analysis revealed a strong negative correlation, indicating that increases in soil moisture are associated with reductions in grounding resistance. This finding is consistent with soil conductivity theory and previously reported studies, which emphasize moisture as a key factor affecting soil resistivity. A statistical summary of the experimental data, including mean, minimum, maximum, and standard deviation values, is shown in Table 4.

Table 4. Descriptive statistical analysis of experimental data

Manual Measurement Results				
Measure ment	Soil Condition	Soil Temperature Value (°C)	Soil Moisture Value (%)	
			Sensor 1	Sensor 2
1	Dry	35	25	23
2	Dry	35	25	24
3	Dry	34	25	24
4	Dry	35	22	22
5	Dry	35	20	23
6	Dry	35	24	25
7	Dry	35	25	24
8	Dry	34	20	21
9	Dry	34	21	22
10	Dry	35	20	21
Average		34,7	22,7	22,9

C. Control System Performance Evaluation

The performance of the proposed control system was evaluated based on its ability to respond to environmental changes and maintain grounding resistance within safe limits. Several performance indicators were considered:

a. System response time

The system was able to detect a decrease in soil moisture and activate the water pump automatically shortly after the predefined threshold was reached.

b. Grounding resistance stability

After actuator activation, the grounding resistance showed a stable decreasing trend and remained below the standard limit.

c. Effectiveness of closed-loop control

The closed-loop configuration proved more effective than passive grounding methods, as it enabled real-time adjustment of soil conditions without manual intervention.

However, the applied control strategy is still based on a simple on-off control mechanism, which may cause minor fluctuations around the threshold value. The performance evaluation of the proposed control system under different soil conditions is summarized in Table 5.

Table 5. LCD Measurement of Final Conditions

LCD Measurement Results						
Measure ment	Time (Minutes)	Flow (L/Min)	Soil Condition	Soil Temperature Value (°C)	Soil Moisture Value (%)	
					Sensor 1	Sensor 2
1	3	5	Normal	28,5	69	66
2	6	10	Normal	28,6	69	66
3	9	15	Wet	28,6	69	65
4	12	20	Wet	28,5	69	65
5	15	25	Wet	28,5	69	65
6	18	30	Wet	28,4	68	64
7	21	35	Wet	28,4	68	64
8	24	40	Wet	28,4	68	63
9	27	45	Wet	28,4	62	55
10	30	50	Wet	28,4	62	57
Average				28,47	67,3	63

D. Discussion and Comparison with Previous Studies

The results of this study confirm that soil moisture is a critical parameter influencing grounding resistance. Unlike most previous studies that focus solely on monitoring soil parameters, this research demonstrates that integrating an active control mechanism significantly enhances grounding system reliability.

Compared to conventional static methods such as chemical soil treatment or additional grounding electrodes, the proposed system offers adaptive control that responds directly to environmental changes. This adaptive capability represents a practical improvement over passive grounding approaches. A comparison between this study and related previous works is provided in Table 6.

Table 6. Final Measurement Results

Final Measurement Results of Manual Instrument, Microcontroller, and Earth Tester								
Measurement	Time (Minutes)	Flow (L/Min)	Soil Temperature Value (°C)		Soil Moisture Value (%)			Resistance Value (Ω) Earth Tester
			Manual	DS18B20	VT-05	Sensor 1	Sensor 2	
1	3	5	12	28.5	70	69	66	3.72
2	6	10	32	28.6	70	69	66	2.35
3	9	15	31	28.6	65	69	65	0.14
4	12	20	30	28.5	65	69	65	0.14
5	15	25	30	28.5	65	69	65	0.13
6	18	30	29	28.4	60	68	64	0.13
7	21	35	29	28.4	60	68	64	0.12
8	24	40	28	28.4	60	68	63	0.12
9	27	45	28	28.4	60	62	55	0.11
10	30	50	28	28.4	60	62	57	0.11
Average			29.7	28.47	63.5	67.3	63	0.707

E. Research Limitations

Despite the promising results, several limitations of this study should be acknowledged:

- The experiments were conducted at a single grounding location and on a specific soil type, limiting the generalizability of the results.
- The control system employs a basic on-off control strategy and does not incorporate advanced control techniques such as PID or fuzzy logic.
- Long-term performance and seasonal variations were not evaluated.
- The system was not integrated with wireless communication for remote monitoring.

F. Implications and Future Work

Future research should focus on testing the system under different soil types and climatic conditions, implementing more advanced control algorithms, conducting long-term evaluations, and integrating wireless communication to enable remote monitoring. These improvements would further enhance the applicability of the proposed system within smart and adaptive electrical protection framework.

III. CONCLUSION

This research successfully designed and implemented a grounding resistance control system that integrates real-time environmental monitoring with an automatic water pump actuator controlled by an Arduino Uno R3 microcontroller. The experimental results confirm that the proposed system is capable of maintaining favorable soil conditions around the grounding electrode. After actuator activation, soil moisture increased significantly while soil temperature decreased, leading to a substantial reduction in grounding resistance from an average of 6.095 Ω to 0.707 Ω , well below the maximum threshold of 5 Ω recommended by applicable standards.

The observed inverse relationship between soil moisture and grounding resistance is consistent with established grounding theory, reinforcing the critical role of soil water content in electrical conductivity. Beyond confirming theoretical expectations, this study demonstrates that active, closed-loop control provides a more reliable solution than conventional passive grounding approaches, which are unable to adapt to dynamic environmental changes.

Despite these promising results, this study has several limitations. The experimental evaluation was conducted at a single location with a specific soil type, and the control strategy was limited to a basic on-off mechanism. In addition, long-term performance under seasonal variations and extreme environmental conditions was not investigated, and the system was not integrated with wireless communication for remote monitoring.

From a practical perspective, the proposed system offers a feasible solution for maintaining grounding performance in electrical installations exposed to fluctuating soil conditions, such as substations, industrial facilities, lightning protection systems, and critical infrastructures in tropical or arid regions. The low-cost hardware configuration and straightforward implementation make the system suitable for real-world deployment, particularly in locations where routine manual inspection is difficult.

The scientific contribution of this study lies in demonstrating the effectiveness of integrating environmental sensing, microcontroller-based decision logic, and active soil conditioning into a unified grounding resistance control system. This work extends previous research that focused primarily on monitoring by introducing an adaptive control approach capable of directly stabilizing grounding performance.

Future research should focus on evaluating the system across different soil types and climatic conditions, implementing advanced control

algorithms such as PID or fuzzy logic, conducting long-term field testing, and integrating IoT-based communication to enable remote supervision and data-driven optimization of grounding systems.

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