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Under Voltage Relay System for Battery and DC Load Safety Using Arduino Nano

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ABSTRACT: The quality of the electric power supply in an electrical system is very necessary. One of the important things that need to be considered is the quality of the voltage supply. The disturbance in the electrical system is under voltage. Undervoltage is an electrical system disturbance that will affect the performance of connected electrical equipment and reduce the life of the equipment, including battery components in DC voltage source electrical systems such as solar power plants. To anticipate this occurrence, Under Voltage Relay equipment is needed which can be used to protect batteries and DC equipment from under voltage conditions by using a potentiometer as a voltage divider and IC 7809 to reduce the voltage from the battery input, Relays to disconnect the load, LCD for monitoring and using Arduino Nano microcontroller control. The method used is a development method or Research and Development. This method is used as a basis for designing and manufacturing Low Voltage Relay devices to protect batteries and DC equipment. From the results of the tests carried out, it can disconnect the DC load when detecting low voltage conditions with an accuracy of ± 99.795%. for the normalized execution test for under voltage relay at voltages of 12 V and 24 V, there is a difference value of ± 0.096V and an error of ± 0.554%.

KEYWORDS: Arduino Nano, Battery, Relay, Low Voltage

I. INTRODUCTION

In principle, in an electric power system, the thing that really needs to be considered is the quality of the electricity supply. But besides that, we cannot be sure when and where the quality decreases. The quality of the electricity supply is influenced by various factors, one of which is due to disturbances in the electrical system. The existence of disturbances in the electricity supply can affect and even damage equipment or an electric power system. One of the disturbances that occurs can be a decrease in electrical voltage (under voltage). If this kind of electrical disturbance is connected to electrical or electronic equipment and exceeds the nominal voltage tolerance limit, then it can interfere with the performance of these equipment or even damage it.

Under voltage disturbance is an electrical disturbance that often occurs in electric power systems including electricity with Direct Current. This under voltage disturbance has a negative impact on the connected electrical equipment and can reduce the life of the equipment.

To solve the problem of insufficient voltage interference that causes electrical equipment to malfunction by implementing an Arduino Uno control system and monitoring using a LCD to make it easier for users to obtain insufficient voltage information and disconnect the load connected to the battery.

II. LITERATURE STUDY

Here we authors conduct a literature study to get references from several previous studies regarding the manufacture of under voltage relay systems. Here are some previous studies on under voltage systems.

Ahmad Nur Pantoro, Sukir, Development of Trainer Kit for Electric Motor Installation with Over And Under Voltage Protection System in Vocational High School, to determine the performance and feasibility level of the Electric Motor Installation trainer kit as a learning program for the Electric Power Installation Engineering study program at SMK N 1 Pundong.

Arsyad et al, Design of Microcontroller-Based Over/Under Voltage Relay Control System on 220Vac Voltage Line, The design of this system uses an STM32F103C8T6 microcontroller with an actuator in the form of a relay.

F. Baskoro, et al, Making a Voltage Stabilizer Prototype to Overcome Over-Under Voltage Disturbance Based on Arduino Uno. The purpose of making this tool is to stabilize the normal voltage of 220V-225V based on Arduino UNO. This tool has a voltage limitation of Under voltage below 220V, Normal voltage 220V-225V, and Over voltage above 225V.

Bayu Choirawan, et al, Analyzing Undervoltage Disturbances in Ship Electrical Power Network Installations, discusses the main factors and efforts to overcome undervoltage problems at the electric power busbar. Load shedding testing uses the undervoltage load shedding (UVLS) method to manage the power system during low voltage conditions, prevent voltage instability and protect against potential damage to the electrical network.

D.N. Fitriyanah, et al, Battery Protection System Against Undervoltage and Overvoltage in Off-Grid Systems Photovoltaic. To secure electrical loads that are sensitive to damage, an overvoltage and undervoltage control system is made using an Arduino Mega microcontroller and relay actuators.

A. Gunawan, et al, Design of Overcurrent and Over/Under Voltage Protection and Monitoring System for Arduino-Based 3-Phase Motor, This protection system uses an ACS 712 sensor to measure current values and uses a voltage sensor for voltage values then uses Arduino Due as a microcontroller and LCD.

A. Hidayat, et al, Designing Undervoltage and Overvoltage Protection Systems in Simple Building Installations Based on the Internet of Things, Designing an Internet of Things-based voltage protection system that can protect household devices from voltage disturbances with an undervoltage tolerance of -10% and overvoltage of +5% of the 230 volt standard voltage.

K.M. Habsari, et al, Design of Charging and Battery Monitoring System in IoT-Based Power Plant.

This research aims to do charging and monitoring of batteries in real time using IoT technology integrated with thinger. io website. The result of this research is a charger with a non-inverting buck boost converter method.

S. Hidyatulloh, et al, Design of Monitoring and Protection System for Lithium Ion Batteries (Li-Ion) on Solar Panels. The scope of the research is the design of a monitoring system that can be seen through a 2x16 LCD that displays the amount of current and temperature and protection built based on the Arduino Uno microcontroller. The results of battery charge testing with 10 WP solar panels produce a total current in one day of 3.56Ah.

Li, Hao, et al, Design and fabrication of a novel MEMS relay with low actuation voltage. The experimental results show that the proposed MEMS relay has a low actuation voltage below 8 V and high performance, which is in good agreement with the simulation results.

Saleh, et al, Designing a home security system using a relay, with a home security system using this relay, the homeowner will get a warning from the house lights and alarm sound. Because if the security system is turned on by pressing the green push button, the relay will be active. And if the door of the house is open by 25-90 degrees, then all the house lights and alarms will change to position 1 or active.

Siti Saodah et al, Design of Low Voltage Protection System Module, Protection against various disturbances using contactors, using electromagnetic relays, static, and conventional safety such as melting fuses (Fuse), thermal overload relays (TOR), power Relays (MCB), leakage current safety (ELCB).

K. Widarsono et al, Relay Protection of Over Voltage, Under Voltage and Unbalance Voltage Magnitude Based on Visual Basic Using Arduino Mega, This research tries to solve the problem of over voltage, under voltage and unbalance voltage with a visual basic based voltage protection system.

Y. Yamato, et al, Analysis of Solar Module and Battery Requirements in Public Street Lighting Systems (PJU). The results obtained from planning the calculation of solar panel capacity and battery capacity obtained solar panel needs as many as 4 modules and battery needs as many as 4 50 Ah batteries or 2 100 Ah batteries.

Yusra Amrina et al, Analysis of Voltage Drop and Losses in the 20 kV Distribution System of Simpang Rima, To get the amount of voltage drop and power losses (looses) in the Simpang Rima extension, it is done using ETAP 12.6 software.

In some related research, the author concludes that the undervoltage disconnect system has been carried out in simulation and prototype modeling, but no one has maximized it with the DC load Relay system when detecting undervoltage conditions.

III. RESEARCH METHOD

To understand the under-voltage relay system for battery safety and DC load using Arduino Uno control, it is done by analyzing the control system. This research consists of a series of stages as follows:

design of the Control System for the battery under voltage relay, making the block diagram of the control system, preparing the flow chart, designing the power supply, relay driver, integration of Indicator Lights, LCD, making the Program on the Arduino Nano microcontroller and integrated testing of the under voltage relay system.

System Block Diagram

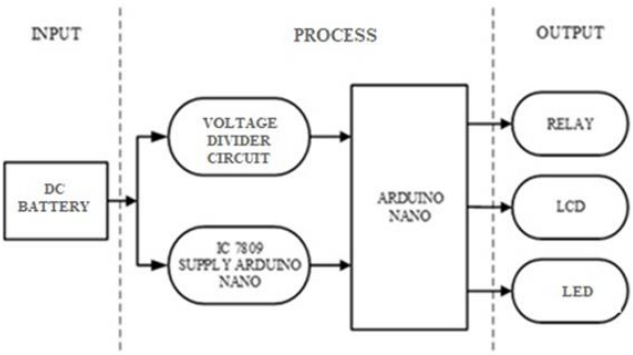

Figure 1. System Block Diagram

Image Caption 1:

- DC Battery input as an electrical power source for Arduino nano which has been charged with a PLTS source.

- Voltage divider circuit as a voltage reducer and sensor consisting of 2 potentiometers, which function so that the battery voltage can be adjusted and read via the analog input pin (A0) on the Arduino Nano.
- IC Voltage Regulator 7809 to reduce the input voltage from the battery so that it can be distributed to the Arduino Nano as input voltage (Vin).
- Arduino Nano as a control center and data processing center for input and output processes.
- Relay as output is a control process between the battery and the connected DC load.
- LCD as an interface for monitoring battery voltage conditions and relay conditions/positions.
- LED light as an indicator that the under voltage system equipment is active or indicators when the under voltage system is tripped.

IV. SYSTEMS DESIGN

The system design is depicted with a Flowchart and Control System Circuit in Figures 2 and 3 as follows.

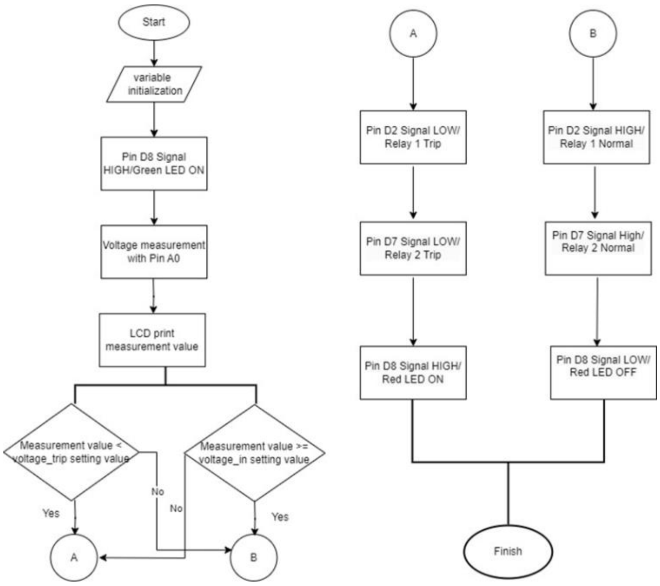

Figure 2. System Flowchart

Explanation of flowchart figure 2:

- Start, activate the Under Voltage Relay system tool.
- Variable initialization, setting the LCD type, pin A0 as input and pins D2, D7, D8, D9 as output.
- Pin D8 signals HIGH, which is the process of turning on the Green LED as an indicator that the equipment equipment is already in an active state.
- Voltage measurement with pin A0, namely the process of reading the voltage originating from the output of the voltage divider circuit.
- LCD Print Measurement value, displays the value of the voltage measurement results that have been read and processed by the Arduino Nano.
- If the Measurement Value < Setting voltage_trip Value, executes Pin D2 signal LOW / Relay 1 Trip, Pin D7 signal LOW / Relay 2 trip, Pin D8 signal HIGH / Red LED on
- If the measurement value is >= setting voltage_in value, execute Pin D2 signal HIGH / Relay 1 Normal, Pin D7 signal HIGH / Relay 2 Normal, Pin D8 signal LOW / Red LED Extinguished.
- Finish

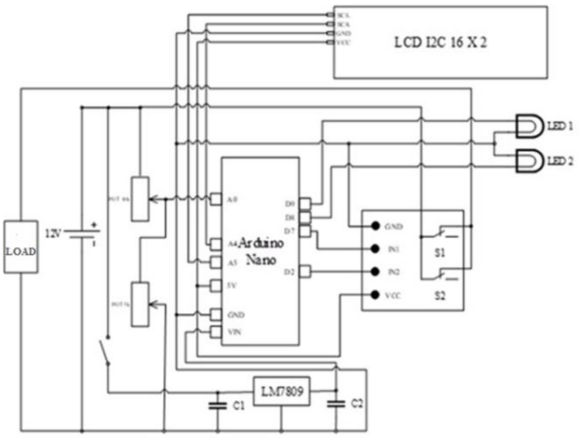

Figure 3. Control System Circuit

Figure 3 shows a System Flowchart that explains the flow of the leave application system in more detail.

Description of Figure 3. Control System Circuit :

- When the switch connected to the battery is turned on, current will flow from Capasitor C1 and the LM7809 Regulator to Capasitor C2 as input on pin1 on the Arduino Nano.
- Arduino Nano V3 is a component of the Arduino Nano microcontroller.
- Terminal X2 is the input terminal for the battery.
- Pin A0 is the terminal connected to potentiometer pins 1 (R1) and 2 (R2).
- Capacitors C1 and C2 are used to balance the input and output power of the LM 7809 IC.
- Terminal + IC LM7809 is connected to the VIN pin on the Arduino Nano.
- Terminal – IC LM7809 is connected to GND on the Arduino Nano.
- Output Pin D9 Arduino Nano is connected to the LED indicator LED1.
- Output Pin D8 Arduino Nano is connected to the LED indicator LED2.
- Output Pin D7 Arduino Nano is connected to a Dual Channel Relay.
- Pins A4 , A5 , GND and VIN are connected to I2C LCD 16 x 2.

V. RESULTS AND DISCUSSION

Results of designing a Low Voltage Relay system for protecting batteries and DC loads using the Arduino Nano microcontroller.

Figure 4. Design Results of Undervoltage Relay System

Testing tools with Arduino nano microcontroller-based under voltage relay system to test the system that has been made can work in accordance with what has been expected.

Arduino Nano supply testing

This test aims to determine whether the Arduino Nano device can boot with electrical power sourced from the battery.

1. Connect V+ to terminal 2 and V- to terminal 3 with electrical power ranging from 11 – 35 VDC, which can be supplied from the battery or PSU.
2. Turn on the Arduino by moving the disconnector switch position to the ON position.
3. Measure the output voltage of the LM7809 Voltage Regulator IC using a Multimeter to ensure the voltage received by the Arduino Nano is in accordance with the recommended working voltage of 7 - 12 V.

Figure 5. Testing the LM7809 IC as an Arduino Nano supply

The following are the results of testing the LM7809 IC as an Arduino Nano supply. The test result data in Table 1 is measurement data obtained under the condition that the LM7809 IC supplies the entire the under voltage relay components.

Table 1. Arduino Nano supply voltage test results

IC Voltage Regulator 7809	
Vin (V)	Vout (V)
11	8.9
12	8.96
13	8.96
22	8.95
24	8.97
26	8.99
Average	8,955

The data in Table 1 shows that the average voltage coming out of the LM 7809 IC is approximately 8.955 V, where this voltage value is the voltage value recommended as an Arduino Nano input.

Voltage divider circuit testing

This test aims to determine whether the voltage coming out of the voltage divider circuit is in accordance with the calculated resistance of the potentiometer.

1. Connect V+ and V- from the battery source or PSU to terminals 1 and 3 which are connected to the voltage divider circuit. .
2. Adjust the resistance of potentiometers 1 and 2 in a ratio of 5: 1 for testing supplies with a voltage of 12 – 24 V.
3. Measure battery or PSU voltage using a multimeter
4. Measure the value of the incoming voltage at pin A0, which is the output voltage from the voltage divider circuit.

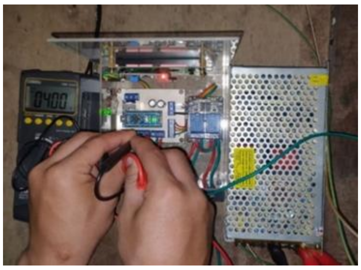

Figure 6. Testing the voltage divider circuit

After testing the voltage divider circuit, the following are the test results and comparison calculations of voltage value reading data. To calculate the percentage error value, you can use the following formula :

$$Error = \frac{\text{Actual Value} - \text{Measurement Value}}{\text{Actual Value}}\ x\ 100\%$$

Description :

Actual Value : Value obtained through calculation

Measurement Value : Measurement Value of Measuring Instrument

The following are the results of testing the output voltage of the voltage divider circuit.

Table 2. Voltage Divider Circuit Test Results

Voltage Divider Circuit Testing				
Input (V)	Outputs		Difference (V)	Errors (%)
	Measurement (V)	Calculation (V)		
12	2	2	0	0
24	4	4	0	0

The test results in Table 2. show that the output voltage of the voltage divider circuit is in accordance with the calculations carried out, as evidenced by the test results that have no error.

Voltage reading testing

This test aims to find out whether the voltage relay device is unable to take accurate voltage readings according to the existing voltage conditions.

1. Connect V+ and V- from the battery source or PSU to terminals 1 and 3 which are connected to the voltage divider circuit.
2. Turn on the Arduino Nano by moving the disconnector switch position to the ON position.
3. Monitor the reading of the voltage value on the battery or PSU which is displayed on the LCD.
4. Measure the battery or PSU voltage using a multimeter as a comparison for the low voltage Relay reading.
   Test results reading 12 V voltage

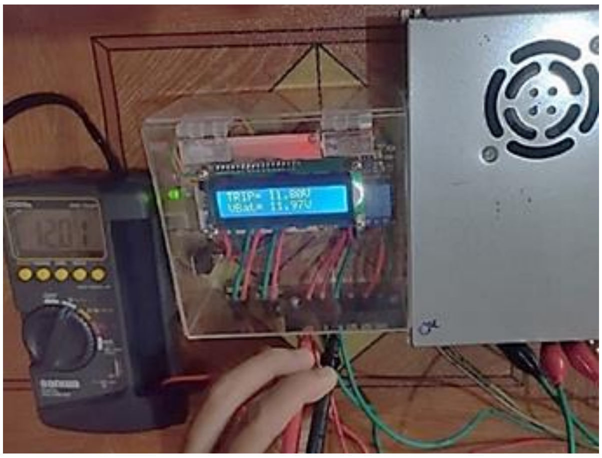

Figure 7. Testing voltage readings with a 12V PSU

The following are the results of testing and comparing the data reading of the voltage value supplied by the 12V PSU with the trip setting at a voltage of 11.8V.

Table 3. Test results for reading voltage values with a 12V PSU

Voltage reading value is Less				
UVR (V)	Multimeter (V)	Difference (V)	Errors (%)	Condition
13,18	13.2	0.02	0.152	Normal
13.01	13.01	0.00	0,000	
12.8	12.81	0.01	0.078	
12.59	12.62	0.03	0.238	
12.38	12.4	0.02	0.161	
12.17	12.2	0.03	0.246	
11.97	12.01	0.04	0.333	
11.82	11.82	0.00	0,000	
11.67	11.6	0.07	0.603	Trip
11.46	11.4	0.06	0.526	
11.25	11.2	0.05	0.446	
11.05	11	0.05	0.455	
Average		0.032	0.270	

The test results in Table 3. show that the error rate of the under voltage sensor reading tested using a 12V PSU is at an average of 0.27% with an average difference of 0.032 V. The error value obtained from the voltage reading results can have an impact on the accuracy of the execution of the undervoltage Relay.

The error values obtained in Table 3. are very small and this is a good result, when compared to DC voltage sensors type ACS712 and INA219 which have a measurement tolerance of approximately 1%.

Table 4. Test results with 12V PSU supply (Normal relay condition)

Baterry voltage reading value (Normal Relay Condition)				
UVR (V)	Multimeter (V)	Difference (V)	Errors (%)	Condition
13,18	13,2	0,02	0,152	Normal
13,01	13,01	0,00	0,000	
12,8	12,81	0,01	0,078	
12,59	12,62	0,03	0,238	
12,38	12,4	0,02	0,161	
12,17	12,2	0,03	0,246	
11,97	12,01	0,04	0,333	
11,82	11,82	0,00	0,000	
Rata - rata		0,019	0,151	

The test results in Table 4. are the test results under normal relay conditions, where the average difference and error values are at 0.019 V and 0.151%. A large difference value can have an impact on reducing the accuracy of the execution of the undervoltage Relay to trip.

Table 5. Test results with 12V PSU (relay trip condition)

Baterry voltage reading value (Trip Condition)				
UVR (V)	Multimeter (V)	Difference (V)	Error (%)	Condition
11,67	11,6	0,07	0,603	Trip
11,46	11,4	0,06	0,526	
11,25	11,2	0,05	0,446	
11,05	11	0,05	0,455	
Average		0,058	0,508	

While the test results in Table 5. are the test results in the condition of the relay trip or under voltage conditions set at 11.8V, it turns out that this causes the measurement to experience a difference where the average difference and error value increases to 0.058 V and 0.508%. A large difference value can have an impact on reducing the accuracy of the execution of the under voltage Relay when the execution returns to normal.

Test results reading 24 V voltage

Figure 8. Testing voltage value readings with a 24V PSU

The following are test results and data comparisons of reading voltage values supplied by a 24V PSU with a trip setting at 23.6V.

Table 6. Test results for reading voltage values with a 24V PSU

Battery voltage reading value				
UVT (V)	Multimeter (V)	Difference (V)	Errors (%)	Condition
28	28.01	0.01	0.036	Normal
27.49	27.5	0.01	0.036	
27.05	27.06	0.01	0.037	
26.49	26.51	0.02	0.075	
26	26.03	0.03	0.115	
25.5	25.51	0.01	0.039	
24.98	25	0.02	0.080	
24.52	24.53	0.01	0.041	
24	24.02	0.02	0.083	
23.59	23.49	0.10	0.426	Trip
23.17	23.03	0.14	0.608	
22.64	22.51	0.13	0.578	
22.13	22.03	0.10	0.454	
Average		0.047	0.201	

The test results in Table 6 show that the error level in the under voltage sensor (UVR) readings was tested using a 24V PSU. With an error value of 0.201% and a difference value of 0.047 V. Just like testing with a 12V PSU, it turns out that in testing with a 24V PSU the results obtained are just as good, so they meet existing measurement standards.

Table 7. Test results with 24V PSU (Normal relay condition)

Baterry voltage reading value (Normal Relay Condition)				
UVR (V)	Multimeter (V)	Difference (V)	Error (%)	Condition
28	28,01	0,01	0,036	Normal
27,49	27,5	0,01	0,036	
27,05	27,06	0,01	0,037	
26,49	26,51	0,02	0,075	
26	26,03	0,03	0,115	
25,5	25,51	0,01	0,039	
24,98	25	0,02	0,080	
24,51	24,53	0,02	0,082	
24	24,02	0,02	0,083	
Average		0,017	0,065	

The test results in Table 7 are the test results under normal relay conditions, where the average difference and error values are at 0.017 V and 0.065%. A large difference value can have an impact on reducing the accuracy of the execution of the under voltage relay (UVR) to trip.

Table 8. Test results with 24V PSU (relay trip condition)

Baterry Voltage Reading Value (Relay Trip Condition)				
UVR (V)	Multimeter (V)	Difference (V)	Error (%)	Condition
23,59	23,49	0,10	0,426	Trip
23,17	23,03	0,14	0,608	
22,64	22,51	0,13	0,578	
22,13	22,03	0,10	0,454	
Average		0,118	0,516	

The test results in Table 8 are test results in relay trip conditions or in under voltage conditions which are set at 23.6V. It turns out that this causes the measurements to experience differences where the average difference and error values increase to 0.118 V and 0.516%. If the difference value obtained is large enough, then this has the impact of reducing the accuracy of the Under Voltage Relay (UVR) execution when execution returns to normal.

Under Voltage Relay (UVR) trip execution test :

1. Connect V+ and V- from the battery source or PSU to terminals 1 and 3 which are connected to the voltage divider circuit.
2. Turn on the Arduino Nano by moving the position of the split switch to the ON position.
3. Monitoring the reading of the battery or PSU voltage value displayed on the LCD when a trip execution occurs due to under voltage.
4. Measure the battery voltage using a multimeter when a trip execution occurs as a comparison to the voltage value read by the voltage deficient relay.

Under Voltage Relay (UVR) trip execution test results :

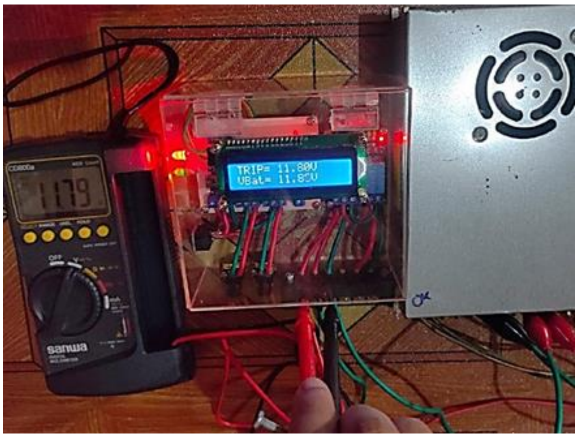

Figure 9. Low Voltage Relay Trip Execution Test

The following test results and comparisons were obtained:

Table 9. Trip execution test results

Relay Trip Execution				
UVR Trip Settings (V)	Multimeter (V)	Difference (V)	Errors (%)	Execution Status
11.8	11.82	0.02	0.171	Succeed
	11.83	0.03	0.256	
	11.83	0.03	0.256	
	11.84	0.04	0.342	
	11.82	0.02	0.171	
23.6	23.61	0.01	0.085	
	23.63	0.03	0.256	
	23.62	0.02	0.171	
	23.62	0.02	0.171	
	23.62	0.02	0.171	
Average		0.024	0.205	

The test results in Table 9. are the results of testing the execution of the trip of the under voltage relay, it can be seen that the accuracy of the under voltage relay in executing the trip when under voltage conditions with the average value of the difference and error at 0.024V and 0.205% or the execution of the undervoltage relay is at 99.795%.

The improper execution value of the under voltage relay can have an impact on batteries and DC equipment, if the execution of the under voltage relay works when the voltage has not reached the specified limit, it can certainly affect the use of batteries that are not maximized, otherwise if the execution of the under voltage relay works when the voltage has exceeded the specified limit, it can certainly adversely affect the battery and DC equipment because it is already under voltage.

Table 10. Return execution test results

Execution Returns to Normal				
Normal UVR Settings (V)	Multimeter (V)	Difference (V)	Errors (%)	Execution Status
12	12.06	0.06	0.500	Succeed
	12.08	0.08	0.667	
	12.06	0.06	0.500	
	12.07	0.07	0.583	
	12.1	0.1	0.833	
24	24.12	0.12	0.500	
	24.1	0.1	0.417	
	24.13	0.13	0.542	
	24.13	0.13	0.542	
	24.11	0.11	0.458	
Average		0.096	0.554	

The test results in Table 10 are the test results of the execution of the low voltage relay back to the normal position, it can be seen that the accuracy of the low voltage relay in executing the normalization of the low voltage relay when it is not in the under voltage condition, where the setting so that the low voltage relay can go to normal conditions is at a value of 12 and 24V. The test results of the normalization execution of the low voltage relay with the execution of the low voltage relay turned out to have a difference in execution accuracy, it can be seen in table 10, the difference value at an average value of 0.096V and an error at an average value of 0.554%.

VI. CONCLUSION

The test results carried out on the Lack of voltage relay tool using the Arduino Nano Microcontroller, it is obtained that:

The under voltage relay successfully disconnects the load when detecting under voltage conditions with an accuracy level of ± 99.8%. So that the under voltage relay can secure batteries and DC equipment from under voltage conditions and voltage reading values on the under voltage relay with an average difference value of 0.032V in testing with a 12 Volt voltage supply, for testing using a 24 Volt voltage supply, the results, with an average difference value, 0.047V. The reading data obtained can be displayed on the LCD accordingly. Trip settings can be set in the under voltage relay program with an accuracy of 99.795% of the specified trip value.

VII. ACKNOWLEDGMENTS

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