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

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Abstract: Electrical control capacity or quality control capacity in electrical systems has always been very vital. However, the main attention should be focused on the characteristics of the supply voltage, especially in the modern era. A major constraint in the electrical structure is low voltage. Low voltage is a source of disturbance in the electrical system that affects the agility of related electrical equipment and can shorten the life of equipment, including battery components in DC energy systems such as solar panels. To anticipate the situation, low voltage circuit breaker hardware is used to protect batteries and DC devices from low voltage conditions, using a potentiometer as a voltage regulator, IC 7809 as a battery input voltage reducer, a switch to disconnect the battery, a power source, and a voltage display on the LCD screen and microcontroller control using Arduino Nano. The strategy applied can be a growth strategy or a research and development strategy. This approach is the foundation for planning and building the Moo voltage circuit breaker to protect batteries and DC devices. In the voltage test, Moo was able to disconnect the DC battery with ±99.795% accuracy. Standard tests for low voltage circuit breakers at 12 V and 24 V showed a difference of ±0.096 V and an error of ±0.554%.

Keywords: Arduino Nano; Battery; PLTS; Relay; Under Voltage

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1. Introduction

In a power system, it is important to pay attention to the quality of power supply. However, it is difficult to predict when and where the quality will degrade with certainty. The quality of electricity supply is affected by various factors, including disturbances to the power system. Electrical disturbances can affect or even damage equipment or electricity supply systems. One type of disturbance that often occurs is a voltage drop. If this type of disturbance occurs in electrical or electronic equipment and exceeds the nominal voltage tolerance limit, it can interfere with the performance of the equipment and even damage it. Low voltage disturbances, such as direct current disturbances, are also common in electrical systems. This voltage deficiency can have a negative impact on connected electrical devices, and can even shorten the life of these devices [1][2][3][4][5].

This previous research is relevant because it addresses the issue of undervoltage (which is another term for low voltage) in the context of a complex electrical network (a ship). It provides a foundation that undervoltage issues are a real problem and need to be addressed, even in different systems (ships vs. systems you might research). This research supports the importance of addressing low voltage issues to prevent disruptions to the system. The proposed research directly addresses the identified low-voltage issues. The proposed solution (Arduino control and monitoring system and UVLS) aims to mitigate the negative impact of low voltage. The previous research cited ([5]) provides context and scientific justification for the importance of addressing the low-voltage problem, albeit in a different context. In other words, the previous research strengthens the argument that the identified problem is valid and requires a solution. In summary, the proposed research builds a practical solution to the undervoltage problem that is supported by previous research that addresses the analysis and impact aspects of undervoltage.

Gunawan and Sahar's research (2024) made a new contribution through the development of an integrated protection and monitoring system for Arduino Due-based three-phase motors. This system uses easily available sensors, displays information through LCD, and most importantly, is able to control relays to automatically cut off electricity when a fault occurs. This approach offers a practical, economical, and effective solution to protect three-phase motors from damage due to overcurrent and abnormal voltage[3].

Only capable of controlling the relay to disconnect the power flow in case of a fault. The new contribution made is to disconnect the power supply to the DC load if the sensor detects a voltage drop below the configured voltage threshold, and the system will reactivate the relay when the voltage returns to normal.

2. Materials and Experiment Methods

In this study, to understand the low-voltage circuit breaker system for battery protection and DC load using Arduino Uno control, a control system analysis was conducted. The research stages include designing a battery low voltage circuit breaker control system, creating a block diagram of the control system, compiling a flow chart, designing a power supply, controlling relays, integrating indicator lights and LCD screens, running programs on the Arduino Nano microcontroller, and testing the integration of the Less Pressure Breaker system.

A. Blok Diagram Sistem

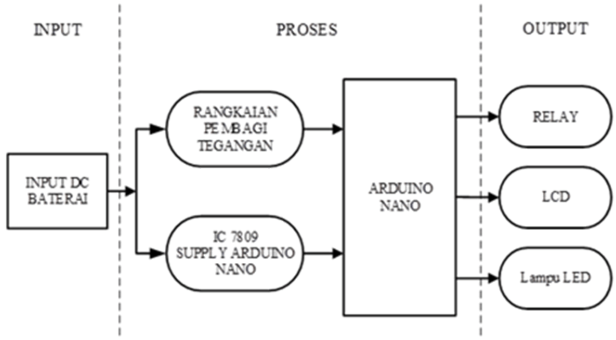


Figure 1. Block Diagram of the System

Figure 1 illustrates a system that uses a DC input battery as a power source for the Arduino Nano powered by a solar farm. There is a voltage divider circuit with 2 potentiometers as voltage reducers and sensors, which allows setting the battery voltage and reading it through the analog input pin (A0) of the Arduino Nano. IC 7809 is used to lower the battery input voltage before it is distributed to the Arduino Nano as the input voltage (Vin). The Arduino Nano serves as the control center and data processing for inputs and outputs. The relay output controls the connection between the battery and the DC load. The LCD is used as an interface to monitor the battery voltage and relay position. LED lights act as indicators to show the operational status of the low-voltage system equipment as well as to signal the off state of the low-voltage system.

B. Flowchart Sistem

In the diagram of figure 2, the steps are as follows:

1. Start by activating the circuit breaker system tool at the top.
2. Perform variable initialization by setting the LCD type and setting pin A0 as input and pins D2, D7, D8, and D9 as output.
3. Pin D8 is used to provide a HIGH signal, which signals the process of turning on the green LED as a signal that the device is operating.
4. Take voltage measurements using pin A0, especially for the process of reading the voltage coming from the output of the voltage divider circuit.
5. The voltage measurement results will be printed on the LCD, displaying the value of the voltage measurement results that have been read and processed by the Arduino Nano.
6. If the measured value is the same as the input voltage value setting, then run the D2 pin signal to HIGH / Relay 1 Normal mode, the D7 pin signal to HIGH / Relay 2 Normal mode, and the D8 pin signal to LOW mode / The red LED light will continue to light up.
7. End the process according to the steps already described.

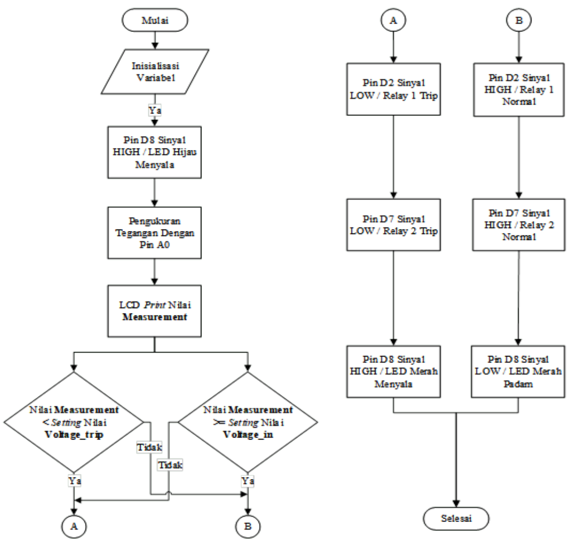


Figure 2. System Flowchart

C. Hardware Designing

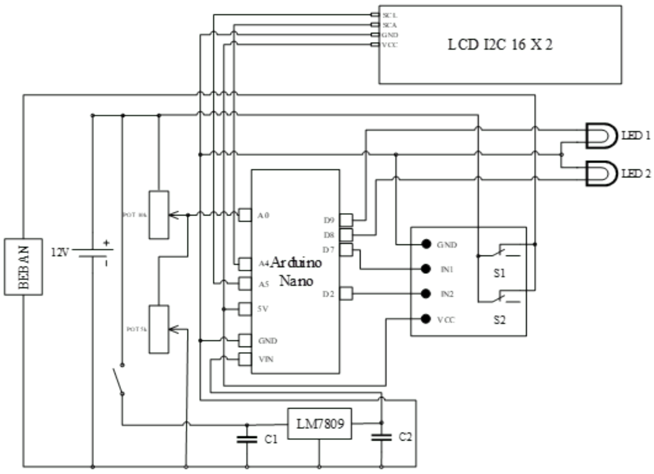


Figure 3. Control system circuit

In Figure Description 3, there is a system wiring circuit consisting of the following components:

1. When the switch connected to the battery is activated, current will flow through capacitor C1 and LM7809 regulator to capacitor C2 as input to pin 1 of the Arduino Nano.
2. Arduino Nano V3 is a microcontroller component used in this circuit.
3. Terminal X2 is the battery input terminal.
4. Pin A0 is connected to potentiometer pins 1 (R1) and 2 (R2).
5. Capacitors C1 and C2 serve to balance the input and output power of the LM7809 IC.
6. The positive terminal of the LM7809 IC is connected to the VIN pin of the Arduino Nano.
7. The negative terminal of the LM7809 IC is connected to GND on the Arduino Nano.
8. The D9 output pin of the Arduino Nano is connected to the LED indicator LED1.
9. The D8 output pin of the Arduino Nano is connected to the LED indicator LED2.
10. The D7 output pin of the Arduino Nano is connected to the dual-channel relay.
11. Pins A4, A5, GND, and VIN are connected to the 16 x 2 I2C LCD display.

D. Software Designing

The program in the Arduino IDE is a software editor that allows users to write programming code with algorithms that are already available. The following is a snippet of the script displayed on the Arduino IDE Figure 4:

1. Use of library for LCD with I2C and Wire library.
2. Setting the breakdown voltage as a reference to determine the minimum value of the voltage at which the relay will trip or the load will be disconnected.
3. Voltage adjustment as a parameter to determine the voltage value at which the relay will return to normal or the battery will be reconnected to the load.
4. Use of pinMode on pins 2, 7, 8, and 9 as outputs.

5. The use of pins 2 and 7 as relay controls that will turn off the load when a trip occurs. While pin 8 is used to turn on the red LED as a low voltage circuit breaker indicator (off), and pin 9 is used to turn on the green LED as a power-on indicator.

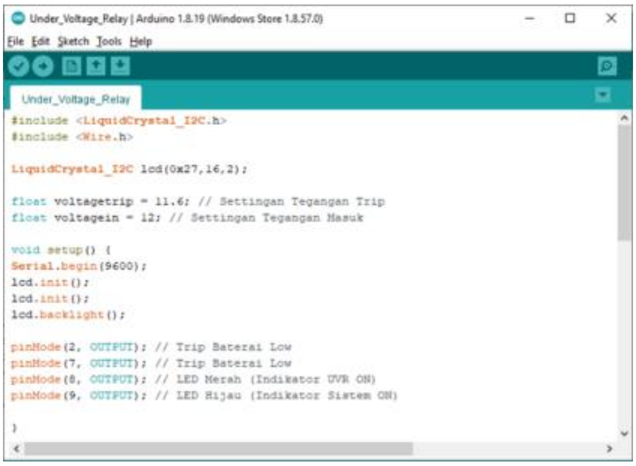


Figure 4. Undervoltage Breaker Program

3. Results and Discussion

In the design of this Undervoltage Breaker system, we use the Arduino Nano microcontroller to secure DC loads and batteries. Tests are carried out on tools with a low voltage breaker system to ensure the functionality of the system that has been made.

Figure 5. Results of the Undervoltage Breaker System Design

A. Testing the Arduino Nano supply

This test is carried out to determine whether the Arduino Nano can be booted using electrical power from the battery. The steps are as follows:

1. Connect V+ to terminal 2 and V- to terminal 3 using electrical power with a voltage between 11 to 35 VDC, which can come from a battery or PSU.
2. Turn on the Arduino by sliding the separation switch to the ON position.
3. Measure the output voltage of the Voltage Regulator IC LM7809 with a Multimeter to check if the voltage received by the Arduino Nano matches the recommended working voltage range, which is 7 to 12 V.

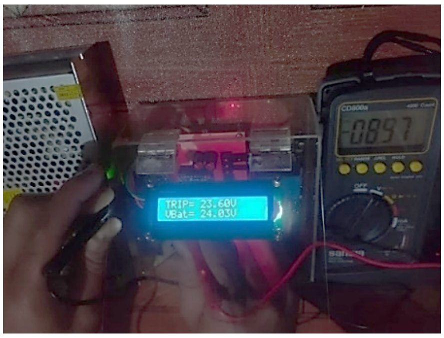


Figure 6. Testing the LM7809 IC as an Arduino Nano supply

The results of testing the LM7809 IC as a supply for the Arduino Nano have been recorded in Table 1. The measurement data shows a condition where the LM7809 IC provides power for part, not all, of the circuit breaker 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
Rata - rata	8,955

The data in Table 1 shows that the average voltage out of the LM 7809 IC is about 8.955 V, which is recommended as the input voltage for the Arduino Nano.

B. Voltage divider circuit testing

The purpose of this test is to verify if the output voltage of the voltage divider circuit matches the calculated resistance of the potentiometer. The first step is to connect terminals 1 and 3 of the battery source or PSU to V+ and V- of the voltage divider circuit. Next, set the resistance of potentiometers 1 and 2 to a ratio of 5:1 to test a 12-24 V voltage supply.

Then, use a multimeter to measure the voltage from the battery or PSU. Finally, record the value of the voltage entering pin A0, which is the output voltage of the voltage divider circuit.

Figure 7. Testing the voltage divider circuit

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

$$error \frac{Measurement\ Value}{Actual\ Value} x100\%$$

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

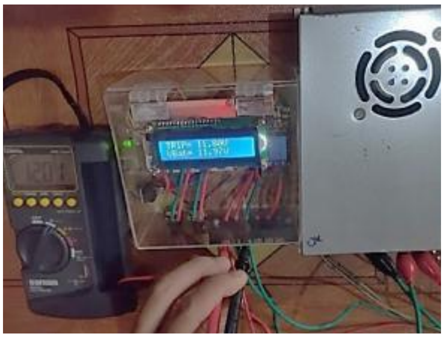
Pengujian Rangkaian Pembagi Tegangan				
Input (V)	Output		Selisih (V)	Error (%)
	Pengukuran (V)	Perhitungan (V)		
12	2	2	0	0
24	4	4	0	0

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

C. Testing Voltage Readings

This test aims to assess the ability of the circuit breaker to read the voltage accurately based on the given voltage conditions.

1. Connect the V+ and V- terminals of the battery or power source to terminals 1 and 3 connected to the voltage divider circuit.
2. Activate the Arduino Nano by sliding the breaker switch to the ON position.
3. Monitor the voltage reading on the battery or power supply displayed on the LCD screen.
4. Use a multimeter to measure the battery or power supply voltage to compare the low voltage circuit breaker readings.
5. The test results show a voltage of 12V.



Figur 8. Voltage value reading test with 12V PSU.

Test results and comparison of voltage reading data from a 12V PSU with a trip setting at 11.8V have been observed.

Table 3. Test results of voltage value readings with a 12V PSU

Nilai pembacaan tegangan Kurang				
UVR (V)	Multimeter (V)	Selisih (V)	Error (%)	Kondisi
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	
Rata - rata		0,032	0,270	

The test results in Table 3 show that the error rate of the voltage sensor readings tested using the 12V PSU is 0.27% on average, with an average difference of 0.032 V. This error in the detected value of the voltage reading can affect the accuracy of operating the voltage breaker.

The value errors recorded in Table 3 are very low, which indicates good results. Comparison with DC voltage sensors of the ACS712 and INA219 types shows a measurement tolerance of about 1%, making the test results very satisfactory.

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

Nilai pembacaan tegangan baterai (Kondisi Relay Normal)				
PTK (V)	Multimeter (V)	Selisih (V)	Error (%)	Kondisi
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 reflect the test results in a normal relay situation, with an average difference and error of 0.019 V and 0.151%. When there is a significant difference, this may result in a decrease in the accuracy of performing the voltage breaker function during a trip.

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

Nilai pembacaan tegangan baterai (Kondisi Trip)				
PTK (V)	Multimeter (V)	Selisih (V)	Error (%)	Kondisi
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	
Rata - rata		0,058	0,508	

The error increases to 0.058 V and 0.508%. A significant difference value can lead to a decrease in the accuracy of the voltage breaker execution when returning to normal.

Test results of 24 V voltage reading

Figur 9. Voltage value reading test with 24V PSU

In the test results, there is a comparison of the voltage value reading data when given a power supply from a 24V PSU with a trip setting at a voltage of 23.6V.

Tabel 6. Test results of voltage value readings with a 24V PSU

Nilai pembacaan tegangan baterai				
PTK (V)	Multimeter (V)	Selisih (V)	Error (%)	Kondisi
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	
Rata - rata		0,047	0,201	

The test results in Table 6 show that the reading error rate of the undervoltage sensor (PKT) tested using a 24V PSU is 0.201% with a difference in value of 0.047 V. As with the test with the 12V PSU, the test with the 24V PSU also gave equally good results, meeting the applicable measurement standards.

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

Nilai pembacaan tegangan baterai (Kondisi Relay Normal)				
PTK (V)	Multimeter (V)	Selisih (V)	Error (%)	Kondisi
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	
Rata - rata		0,017	0,065	

The test results in Table 7 show the test results under normal relay conditions, with an average difference and error value of 0.017 V and 0.065%. The existence of a significant difference value can result in a decrease in accuracy in the execution of the undervoltage breaker (PTK) to trip the relay.

Tabel 8. Test results with 24V PSU (Relay trip condition)

Nilai pembacaan tegangan baterai (Kondisi Relay Trip)				
PTK (V)	Multimeter (V)	Selisih (V)	Error (%)	Kondisi
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	
Rata - rata		0,118	0,516	

In Table 8, the test results show a significant difference in the condition of relay trip or under voltage set at 23.6V. This difference can be seen from the increase in the average difference and error to 0.118 V and 0.516%. If the difference in value is large enough, it can have an impact on the accuracy of the execution of the under voltage breaker (PTK) when returning to normal conditions.

D. Undervoltage breaker trip execution test

1. Connect the V+ and V- terminals of the battery source or PSU to terminals 1 and 3 connected to the voltage divider circuit.
2. Turn on the Arduino Nano by sliding 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 occurs due to under voltage.
4. Measuring the battery voltage using a Multimeter as a comparison of the voltage value when the trip is triggered to verify the reading by the voltage breaker.

Trip execution test results Under Voltage Breaker

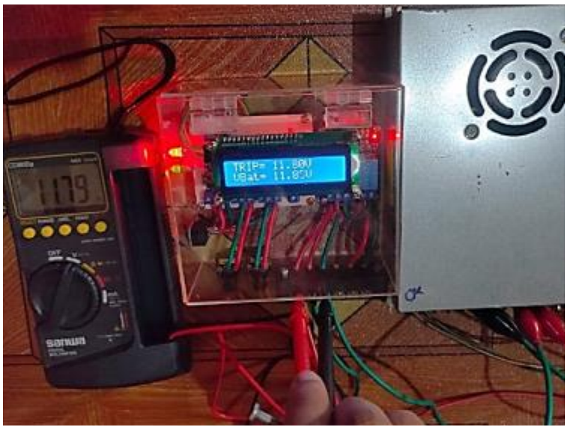


Figure 10. Undervoltage Breaker Trip Execution Testing

The following test results and comparisons were obtained:

Table 9. Trip execution testing results

Eksekusi Relay Trip				
Setting PTK Trip (V)	Multimeter (V)	Selisih (V)	Error (%)	Status Eksekusi
11,8	11,82	0,02	0,171	Berhasil
	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	
Rata - rata		0,024	0,205	

The tests in Table 9 show that the trip execution of the under voltage breaker is less accurate. It can be seen that in the case of under voltage, the under voltage breaker has an average difference and error of 0.024V and 0.205%, or reaches 99.795% of the expected value. Inaccuracy in the execution of the under-voltage breaker can cause problems to batteries and DC equipment. For example, if the undervoltage breaker activates before the voltage reaches the specified limit, this could result in inefficient use of the battery. Conversely, if the under-voltage breaker acts late after the voltage exceeds the specified limit, this can be detrimental to the battery and DC equipment due to under voltage.

Table 10. Re-entry execution test result

Eksekusi Kembali Normal				
Setting PTK Normal (V)	Multimeter (V)	Selisih (V)	Error (%)	Status Eksekusi
12	12.06	0.06	0.500	Berhasil
	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	
Rata - rata		0.096	0.554	

Results

The test in Table 10 shows the test results of the execution of the variable voltage breaker back to its normal position. It can be observed that the accuracy of the under-voltage breaker in executing the normalization of the under-voltage breaker is less when it is no longer in the under-voltage condition, where the setting for the under-voltage breaker to return to normal conditions can be found at 12 and 24 V values. The test results show the difference in execution accuracy between the normalization of the under voltage breaker and the execution of the under voltage breaker. The difference is documented in Table 10, with an average difference value of 0.096V and an average error of 0.554%.

Conclusion

From the test results on the Under Voltage Disconnect tool using the Arduino Nano Microcontroller, it was found that the tool successfully disconnects the load when it detects an under voltage condition with an accuracy rate of about ±99.8%. This ensures the protection of batteries and DC equipment from under voltage. In addition, the voltage reading value on this device showed an average difference of 0.032V in the test with a voltage supply of 12 Volts, and 0.047V in the test with a voltage supply of 24 Volts. The reading data can be displayed precisely on the LCD screen. In addition, the trip setting can be set in the LACK VOLTAGE REMOVER program with 99.795% ACCURACY OF THE SETTING TRIP VALUE.

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