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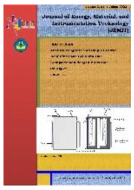

Prototype of a Digital Measuring Device Based on Atmega 328P for Measuring Current, Voltage, Electrical Power, and RLC Components

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Abstract

Research on digital measuring device prototypes has developed over the past few years. However, there are still challenges in measuring current, voltage, electrical power, and RLC component parameters accurately. This research aims to design a digital system to measure electrical quantities such as current, voltage, resistance, inductance, and capacitance using Atmega 328P. Data retrieval is done by implementing the system as a whole, namely the AC and DC electrical measurement system and the measurement of RLC components. The results showed that the system can measure and display the result of measuring current, voltage, electric power, and RLC components correctly. The accuracy percentage for the components measuring instrument on the resistor test is 99.35%, the error is 0.65%, and the precision is 99.87%. In the inductor test measurement, the percentage value of accuracy is 94.11%, the error is 5.89%, and the precision is 96.77%. In the capacitor test measurement, the accuracy percentage is 98.03%, the error is 1.97%, and the precision is 98.65%. On the DC voltage sensor, the accuracy percentage is 97.31%, error 2.69%, and precision 99.77%.

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Abstrak

Penelitian mengenai prototipe alat ukur digital telah berkembang dalam beberapa tahun terakhir. Namun, dalam proses pengukuran arus, tegangan, daya listrik, serta pengukuran komponen RLC, masih terdapat kendala dalam mengukur parameter yang dihasilkan. Pada penelitian ini telah direalisasikan prototype alat ukur digital berbasis atmega 328P untuk aplikasi pengukuran arus, tegangan dan daya listrik serta pengukuran komponen RLC. Tujuan penelitian adalah merancang sistem digital untuk mengukur besaran listrik seperti arus, tegangan daya listrik, resistansi, induktansi dan kapasitansi menggunakan atmega 328P. pengambilan data dilakukan dengan mengimplemetasikan sistem secara keseluruhan yakni pada sistem pengukuran listrik AC dan DC, serta pengukuran komponen RLC. Hasil penelitian menunjukan sistem dapat mengukur dan dapat menampilkan hasil pengukuran arus, tegangan, daya listrik serta pengukuran komponen RLC dengan baik. Nilai persentase akurasi untuk alat pengukur komponen pada uji resistor sebesar 93,35%, error sebesar 0,65% dan presisi sebesar 99,87%. Pada pengukuran uji induktor nilai persentase akurasi sebesar 94,11%, error sebesar 1,97% dan presisi sebesar 98,65%. Pada sensor tegangan DC persentase akurasi sebesar 97,31% error sebesar 2,69% dan presisi sebesar 99,77%.

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Introduction

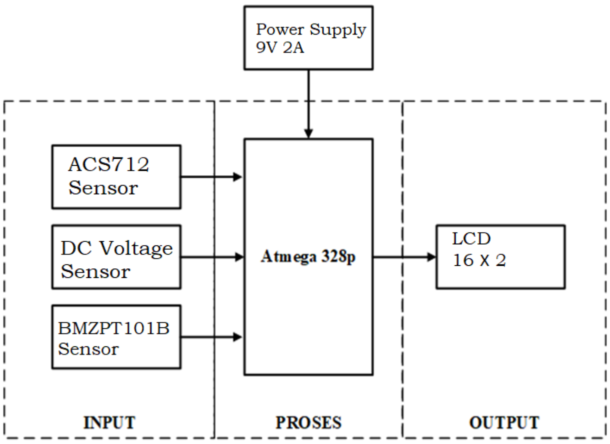
One of the physics problem-solving areas focused on is the electrical matrix. One of the most critical goals in learning physics is to explain natural phenomena and lead students to understand in depth the basic concepts of physics, one of which is electrical material (Galili & Goinbarg, 2005). Electrical material is one of the branches of physics that emphasizes a qualitative approach because the ability of students to understand and analyze circuits is the most crucial part of learning electrical science. Therefore, electrical material is a problem for students who need practical explanations of microscopic phenomena in practice need a tool that can digitally measure the amount of electricity (Hutagalung & Melda, 2018). Based on the findings of several previous studies, it is shown that many students still have difficulty to understanding physics material related to the concept of electric circuits (Jufri et al., 2014). This research will use a prototype digital measuring instrument based on ATMega 328P to apply AC/DC, voltage, and electric power and measure the electricity of the resistor, inductor, and capacitor (RLC) components. The research conducted has shown that many students still struggle to understand why the concept of current differs between series and parallel circuits. This confusion makes it difficult for them to relate electric current, voltage, and resistance in series and parallel circuits, also known as the concept of Ohm's Law. (Stetetzer et al., 2013).

2. Methods

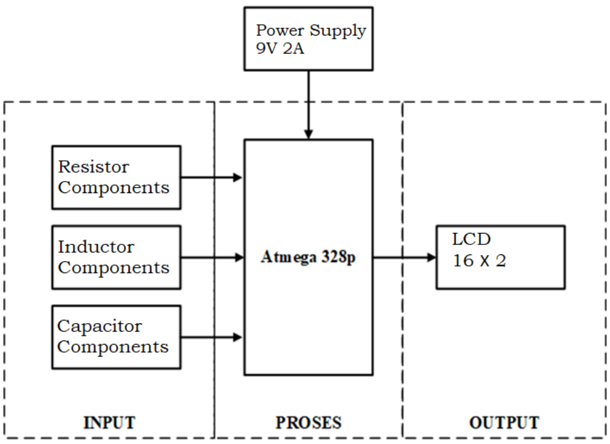
The tools and materials used in this research are PCB fiber, PCB drill, tin, solder, plastic box, Atmega 328P, ACS712 sensor, ZMPT101B sensor, DC voltage sensor, 9V 2A power supply, 16x2 type LCD, DC step-down module, digital multimeter XL830L type, Neco Soe brand lamp and adjustable power supply.

2.1. System Planning

In the design of the instrumentation system for measuring AC and DC voltage and electric power, the ATMega 328P microcontroller is used. This system also measures resistor, inductor, and capacitor (RLC) components. The microcontroller is programmed with the Arduino UNO bootloader. The system design to be made is shown in the block diagram in **Figure 1**.



(a)



(b)

Figure 1. Block diagram (a) AC and DC, voltage, and power measurement instrumentation, (b) RLC component measurement instrumentation

The measurement parameters conducted encompass both AC and DC current, voltage, and electric power. A series of systems built include reading input parameters, processing, and displaying measurement results on a 16x2 character LCD. At the parameter reading stage, the ACS712 sensor, DC Voltage sensor, and ZMPT101B sensor read the physical parameters and convert them into electrical quantities in analog signals. Furthermore, the analog signal is converted into a digital signal using the ATMega 328P processor. The digital value of the conversion result will be displayed on a 16x2 character LCD. The instrumentation system for measuring RLC components in this study has measured the values of resistors, inductors, and capacitors. The measurement is carried out in three stages, namely the input stage, where the readings of the values of resistors, inductors, and capacitors with physical quantities are converted into analog signals. Furthermore, the analog signal is converted into a digital signal by the ATMega 328P microcontroller for the processing stage. The last stage is the output, which plays a role in displaying the results of data processing that can be seen on the 16x2 character LCD screen.

Design instrumentation systems for measuring current, voltage, and AC and DC electrical power, as well as instrumentation systems for measuring RLC components.

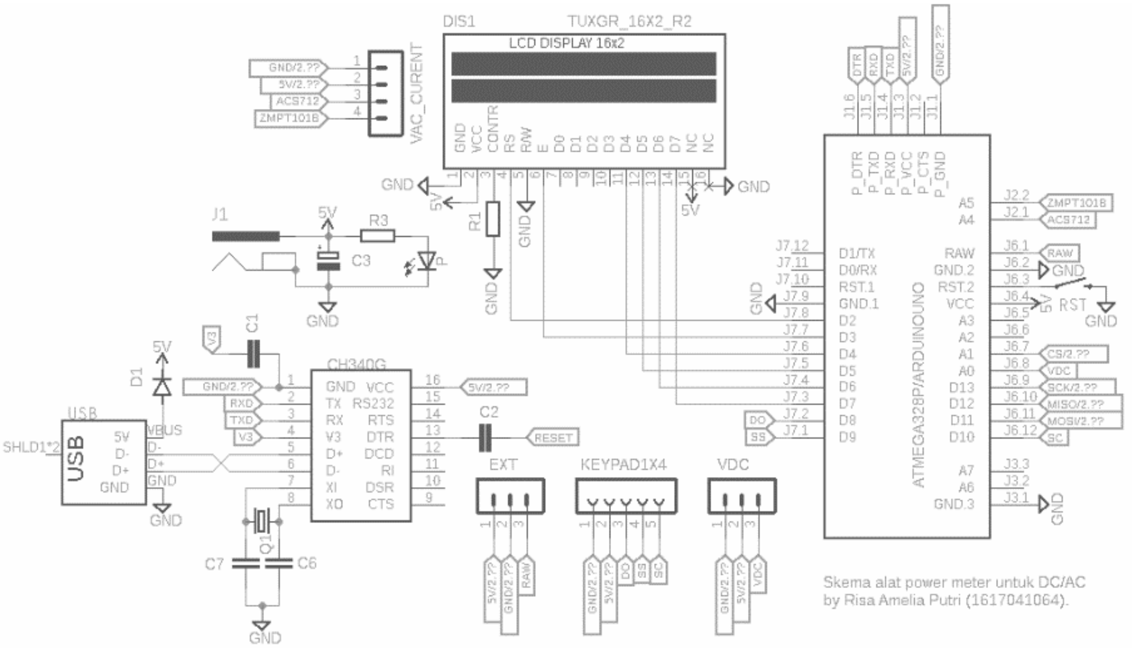


Figure 2. Schematic of the AC and DC power instrumentation system circuit.

This system uses 12 ATMega 328P microcontrollers and two power pins, namely VCC and GND. Then, the 3 ATMega 328P analog pins used include pins A0, A4, and A5. Pin A0 is used to read data from the DC voltage sensor. Meanwhile, pin A4 is the pin used to read input data from the ACS712 sensor. Pin A5 is used to read input data from the ZMPT101B sensor. Meanwhile, the three digital pins used for 1x4 keypad communication with the ATMega 328P microcontroller are D8, D9, and D10. As for the 16x2 character LCD, six digital pins are used, namely pins D2, D3, D4, D5, D6, and D7.

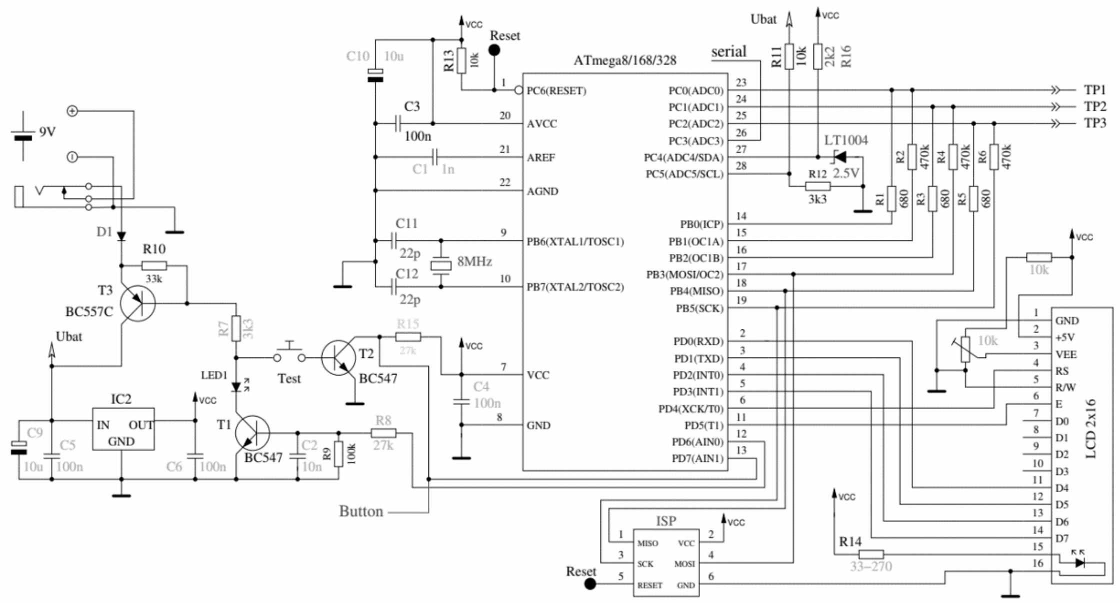


Figure 3. Circuit diagram of the RLC component measuring instrumentation system

This system is a 16x2 character LCD connected to 6 pins on the ATMega 328P microcontroller, namely PD0, PD1, PD2, PD3, PD4 and PD5. There is also a protection circuit from the test point input before the ATMega 328P microcontroller by adding a relay and diode.

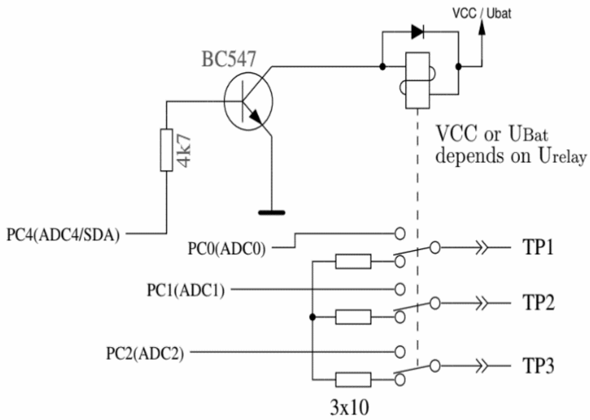


Figure 4. Protection circuit on the RLC component measurement system

The protection circuit protects capacitor components that still carry the remaining voltage when measuring. Therefore, it is better to discharge the voltage by connecting the two legs (short) for capacitor measurements. The RLC component measurement system can also perform frequency measurements connected to the PD4 (XCK/T0) ATMega 328P microcontroller. The TP4 pin is used as a frequency input pin or the one that reads f on the PCB board.

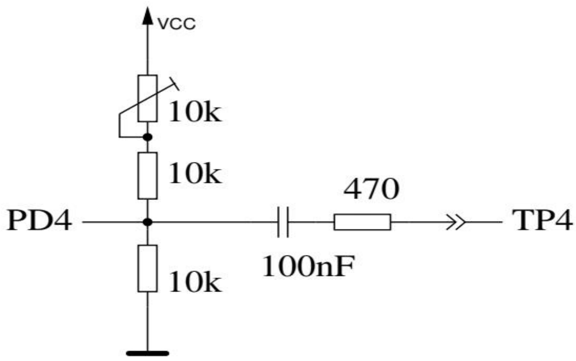


Figure 5. Frequency measurement circuit schematic

Meanwhile, to make the RLC component measurement instrumentation system easier to use, a control circuit using a rotary encoder facilitates the selection of the menus provided. The rotary encoder is connected to pins PD1 and PD3 on the ATMega 328P microcontroller.

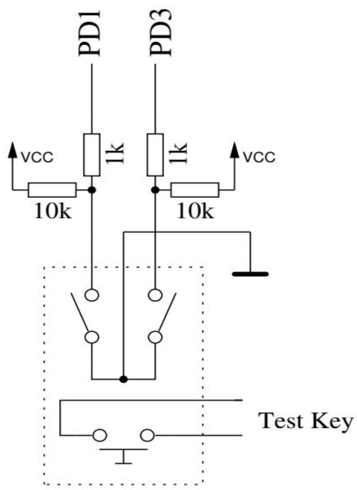


Figure 6. Control circuit schematic using a rotary encoder

The controller program for the ATMega 328P microcontroller was made using Arduino IDE software version 1.8.10. control programs are designed to perform three main tasks. The first task is to program a menu using the 1x4 keypad as an option to select measurements in two modes, namely AC or DC. The second task is to read the electrical parameters from the three sensors and convert them into digital values by the ATMega 328P microcontroller as a processor. Three measured physical parameters will be assigned on the 16x2 character LCD screen. The instrumentation system will be tested to measure component quantities so that the measurement results follow each component value. The component measurement mechanism is repeated three times on the resistor, inductor, and capacitor components. Suppose the readings get measurement results that do not match the component values before carrying out the test or measurement. In that case, the calibration process should be carried out by selecting the calibration menu and following the instructions on the screen. 16x2 character LCD. The monitoring instrumentation system that has been designed is then tested so that the sensor measurement results are by the calibrated instrument. Three parameters are tested: electric current, voltage, and electric power. Sensor testing is done by comparing the measurement results of the AC and DC electrical measurement instrumentation system with a calibrated instrument, namely the XL830L type digital multimeter. The electric current and voltage measurement mechanism is carried out three times on DC lamp loads and RLC circuit loads arranged in series or parallel.

3. Results and Discussions

Hardware has been realized, namely the AC and DC electrical power instrumentation system, with the results shown in **Figure 7**.

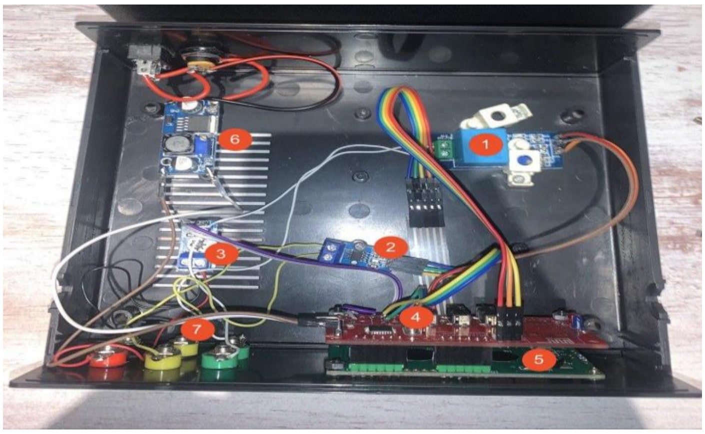


Figure 7. Overall Realization

3.1. Test Results of the RLC Measuring Instrument System on Resistor Components

The results of the measured resistance values are compared with the accuracy of the resistance values in the sample resistors shown in **Figure 8**.

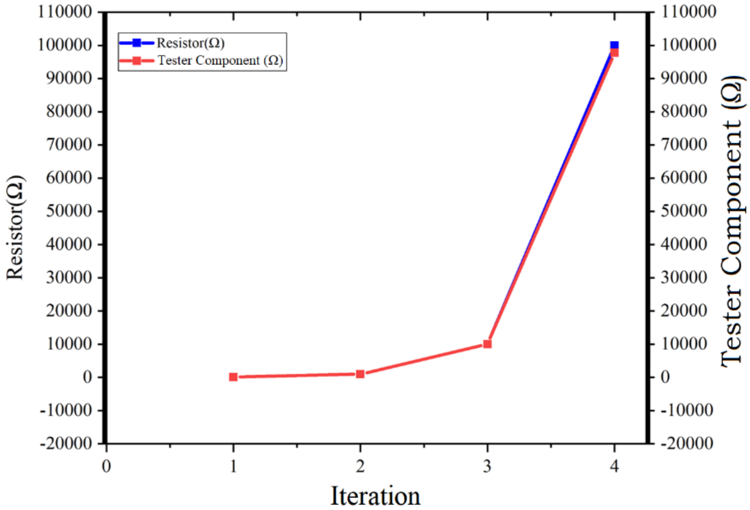


Figure 8. Graph of testing the measured resistance value (Ω) against the sample resistor value (Ω)

The test results of the measured resistance value against the sample resistor value show that the linearity value obtained by R^2 is 0.96, and the R^2 value is the level of conformity of the line equation obtained to the variation of the data with a value range of 0-1. If the value of R^2 gets closer to 1, then the equation of the line obtained is by the variation of the data [5]. The average error obtained is 0.65%, so the percentage of the average value of the measured resistance value reading accuracy is 99.35%. The smaller the percentage of error generated and the more excellent the accuracy produced, the better the tool's performance [6]. If the value of R2 gets closer to 1, then the equation of the line obtained is determined by the variation of the data [7].

The high precision value obtained from this research is 99.87%. The higher the precision value, the more precise the measurement [8]. It shows that the RLC measuring instrument has good accuracy and precision and can be applied to measure the magnitude of the resistor component.

3.2. Testing the RLC Measuring Instrument System on Inductor Components

Figure 9 shows the measured inductance value compared with the determination of the inductance value on the inductor sample.

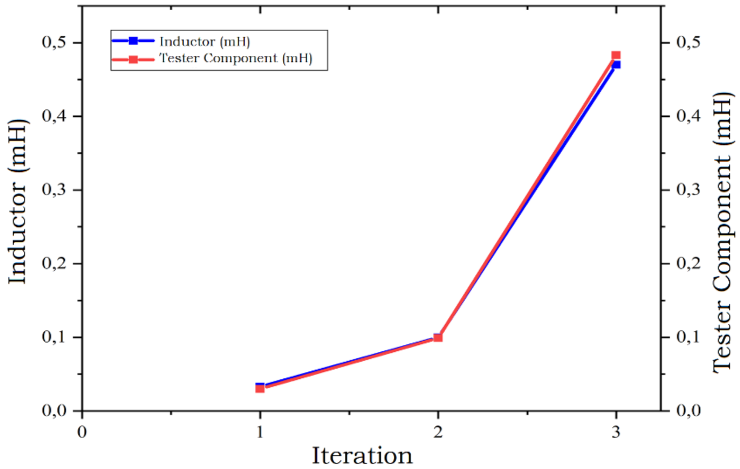


Figure 9. Graph of testing the measured inductance value (mH) against the sample inductor value (mH)

The test results of the measured inductance value against the sample inductor value show that the linearity value obtained by R^2 is 1. Meanwhile, the average error obtained is 5.89%, so the percentage of the average value of the measured inductance reading accuracy is 94.11%. The average precision percentage value is 96.77%. It shows that the RLC measuring instrument has good accuracy and precision and can be applied to measure the magnitude of the inductor component.

3.3. Test Results of RLC Measuring Instruments on Capacitor Components

Figure 10 shows the measured capacitance value compared with the determination of the capacitance value on the sample capacitor.

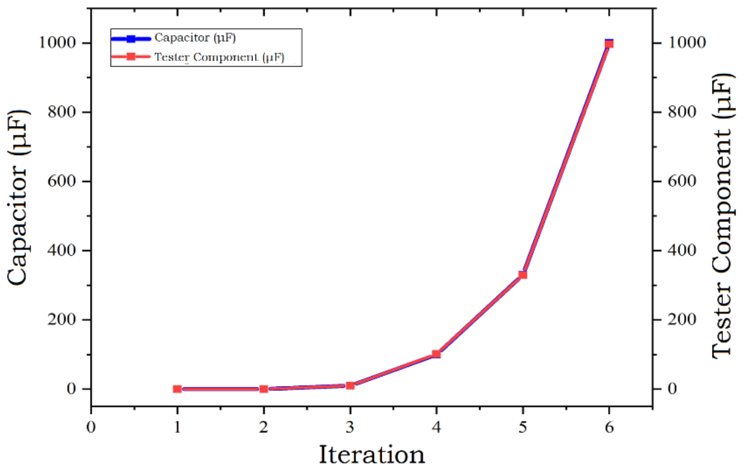


Figure 10. Graph of testing the value of the measured capacitance (uF) against the sample value of the capacitor (uF)

The test results of the measured capacitance value against the sample capacitor value show that the linearity value obtained by R^2 is 0.95. Meanwhile, the average error obtained from the calculation results is 1.97%, so the percentage of the average value of the measured capacitance value reading accuracy is 98.03%. The average precision percentage value is 98.65%. It shows that the RLC measuring instrument has good accuracy and precision and can be applied to measure the magnitude of the inductor component.

3.4. DC Sensor Test Results

A DC voltage sensor will be implemented to measure DC voltage in series and parallel circuits that use DC lamps as a load. The testing mechanism in this study is to connect the red banana socket (+) and the black banana socket (-) using a probe. DC voltage sensor testing is done by providing an input voltage from an adjustable power supply (PSU) as a voltage source with an output of 0 to 36 Volts.

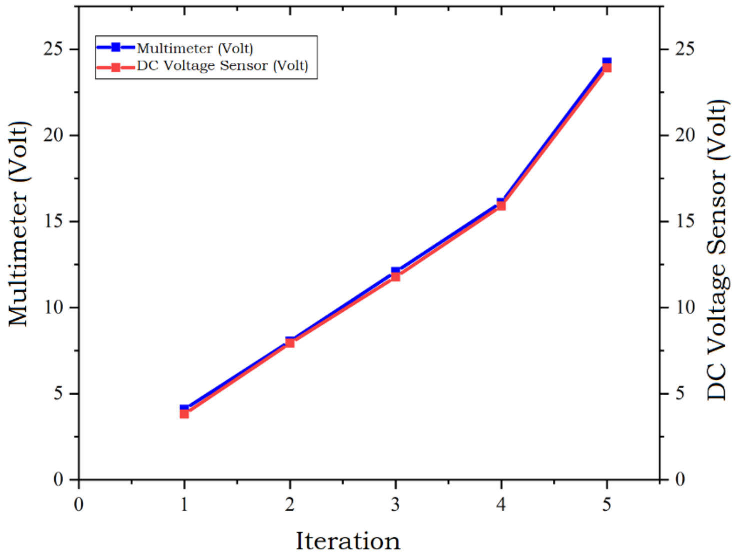


Figure 11. DC voltage sensor test graph against a multimeter

The test results of the DC voltage sensor measurement against the multimeter, shown in **Figure 11**, indicate a linearity value with an R^2 of 0.97. Meanwhile, the average error obtained from the calculation results is 2.69%, so the percentage of the average value of the measured DC voltage sensor reading accuracy is 97.31%. Furthermore, the average precision percentage value is 99.78%. It shows that the DC voltage sensor has good accuracy and precision and can be applied to measure the DC voltage.

Table 1. DC voltage sensor measurement data at series lamp load

Load Measuring Point	**DC Voltage Sensor (volt)**
DC Lamp (ab)	11.74
DC Lamp (bc)	11.79
DC Lamp (ac)	24.00

The results of these calculations obtained a total voltage of 23.53 Volts. When compared with the measurement results of the DC voltage sensor at points a-c (overall load), a measurement of 24.00 Volts was obtained.

Table 2. DC voltage sensor measurement data on parallel lamp loads

Load Measuring Point	**DC Voltage Sensor (volt)**
PSU output (ab)	11.65
DC Lamp (cd)	11.65
DC Lamp (ef)	11.65

From the results of these measurements, a total voltage calculation (Vtotal) was also performed manually to obtain a total voltage of 11.65 Volts.

3.5. ACS712 Sensor Test Results

The ACS712 sensor will measure AC and DC currents in series and parallel circuits using DC lamps and RLC circuits as loads. It has been tested in these circuits for three repetitions using DC and RLC lamps as loads. The test results are in **Table 3**.

Table 3. Electrical current test data on the ACS712 sensor

Test Load	**Sensor ACS712 (ampere)**			**Multimeter (ampere)**		
	1	**2**	**3**	**1**	**2**	**3**
Series DC lamp	0.15	0.10	0.15	0.12	0.12	0.12
Parallel DC lamp	0.24	0.19	0.24	0.24	0.24	0.24
RLC Series	0.08	0.07	0.07	0.06	0.06	0.06
RLC Parallel	1.65	1.72	1.62	1.45	1.45	1.45

3.6. ZMPT101B Sensor Test Results

The ZMPT101B sensor in this study measures AC voltage parameters. Therefore. it will be implemented to measure AC voltage in series and parallel RLC circuits as loads. The measurement results obtained show that the voltage obtained is 11.04 Volts in the resistor component. 5.83 volts in the inductor component. 6.54 Volts in the capacitor component. and 11.52 volts in the series RLC circuit.

Table 4. ZMPT101B sensor measurement data at series RLC load

Load Measuring Point	Sensor ZMPT101B (volt)
Resistor 10 Kohm (ab)	11.04
Inductor 100 uH (bc)	5.38
capacitor 100 uF (cd)	6.54
Overall load (ad)	11.52

From the measurement results of the ZMPT101B sensor on a series RLC load. a manual total voltage calculation (Vtotal) was also calculated to obtain a total voltage calculation of 11.12 Volts. In addition. the measurement of the ZMPT101B sensor on a parallel RLC load is also manually calculated by calculating the total voltage (Vtotal). The calculation results obtain a total voltage of 6.15 Volts. The measurement results show that the voltage obtained is 6.16 Volts in the resistor component. the inductor component is 6.18 Volts. the capacitor component is 6.67 Volts. and the measured voltage in the parallel RLC circuit is 11.46 Volts.

Table 5. ZMPT101B sensor measurement data at parallel RLC load

Load Measuring Point	Sensor ZMPT101B (volt)
Transformer output (ab)	11.51
Resistor 10 Kohm (cd)	6.16
Inductor 100 uH (ef)	6.18
capacitor 100 uF (gh)	6.76

3.7. Results of DC Electric Measurement Implementation

The system that has been realized is measuring DC electricity with the PSU as the primary source of electricity in a series circuit requiring a voltage source of ± 24 volts to use DC lamp loads. The result of reading the implementation of the DC measurement system series circuit that appears on the 16x2 character LCD screen is a voltage of 23.85 Volts. current of 0.15 Ampere. and electric power of 3.49 Watt. The system that has been realized is measuring DC electricity using the PSU as the primary source of electricity in a parallel circuit. The required voltage source is ± 12 Volts to use DC lamp loads. The reading results of the parallel circuit implementation of the DC measurement system that appears on the 16x2 character LCD screen are 11.68 Volts. a current of 0.24 Ampere. and an electric power of 2.84 watts.

Table 6. Measurement results of electrical measurement systems on DC lamp loads

Load	Current (A)	Voltage (V)	Power (W)
Series DC lamp	0.15	23.85	3.49
Parallel DC lamp	0.24	11.68	2.84

3.8. Results of RLC Component Measurement Implementation

The measurement of the resistor component of 10KΩ. the inductor of 100uH. and the capacitor of 100uF has been carried out using the RLC component measurement instrumentation system. The result of the implementation of measuring the 10KΩ resistor value. which is read by the RLC component measurement system. is 10.08KΩ. Then measure the value of the inductor quantity with the instrumentation system for measuring the RLC component; the result of the implementation of measuring the 10uH inductor value is 0.11mH. or if it is converted to uH. the inductor value is ±110uH. After measuring the value of the capacitor using the RLC component measurement instrumentation system. the results from the implementation of measuring the 100uF capacitor value obtained a result of 102uF. The conclusion from the measurement results of the three components can be said that the RLC component measurement instrument system can function adequately to read the resistor. inductor. and capacitor values obtained close to the actual value.

3.9. Results of AC Electrical Measurement Implementation

The system that has been realized is measuring AC electricity with a transformer as the primary source of electricity in a series RLC circuit that requires a voltage source of ± 12 Volts—implementation of resistor voltage measurement (V resistor) on the RLC component as a load. The results of the AC measurement system readings that appear on the 16x2 character LCD screen are a voltage of 2.19 Volts. a current of 0.08 Ampere. and an electrical power of 0.16 watts. The implementation of measuring the inductor voltage (V inductor) in a series circuit uses an RLC component as a load. Furthermore. the results of the AC measurement system readings that appear on the 16x2 character LCD screen are 2.86 Volts. a current of 0.07 Ampere. and an electrical power of 0.18 watts.

The following is the implementation of measuring capacitor voltage (v capacitor) in a series circuit using an RLC component as a load. The results of the AC measurement system readings that appear on the 16x2 character LCD screen are 2.86 Volts. a current of 0.07 Ampere. and an electrical power of 0.18 watts.

The two systems that have been realized are AC power measurements with a transformer as the primary source of electricity in a parallel RLC circuit that requires a voltage source of ± 12 Volts—implementation of resistor voltage measurement (V resistor) on the RLC component as a load. The results of the AC measurement system readings that appear on the 16x2 character LCD screen are 3.25 Volts. a current of 1.59 Ampere. and an electric power of 5.18 watts. The next step has been to realize the voltage measurement on the inductor component (v inductor) in a parallel RLC circuit. The AC measurement system reading results on the 16x2 character LCD screen are 3.21 Volts. a current of 1.65 Ampere. and an electric power of 5.30 watts. Furthermore. the voltage measurement on the capacitor component (V capacitor) in a parallel RLC circuit was realized. The AC measurement system reading results on the 16x2 character LCD screen are 3.46 Volts. the current is 1.61 Ampere. and the electric power is 5.57 watts.

4. Conclusions

Based on the measurements. observations. and testing results in this study. the following conclusions were obtained: the DC voltage sensor in this study can measure the voltage from the 0 Volt to 24 Volt DC range. The ACS712 sensor in this study can be applied to measure the amount of current flowing in AC and DC circuits. The ZMPT101B sensor in this study can be applied to measure AC voltage from the 0 Volt - 250 Volt AC range. The percentage of component measurement accuracy in the resistor test is 99.35%. with an average error percentage of 0.65%. At the same time. the percentage of precision obtained is 99.87%. The percentage of accuracy of the component measurement tool in the inductor test is 94.11%. with an average error percentage of 5.89%. In contrast. the percentage of precision obtained is 96.77%. The percentage of accuracy of the component measurement tool in the capacitor test is 98.03%. with an average error percentage of 1.97%. In comparison. the percentage of precision obtained is 98.65%. The percentage accuracy of the DC voltage sensor is 97.31%. with an average error percentage of 2.69%. At the same time. the percentage of precision obtained is 99.77%. The calculation results of the total voltage (Vtotal) compared to the peak-to-peak voltage (Vpp) of the oscilloscope at a series RLC load obtained a percentage difference of 7.33%. while in a parallel RLC load. the percentage difference was 48.75%.

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