Analysis of the INA219 Sensor System and Voltage Divider on a Calibrate Multimeter

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Abstract: This research focuses on the study of uncertainty in current and voltage measurements based on the Internet of Things (IoT) using the NodeMCU ESP8266 microcontroller. The primary objective is to design a power meter that incorporates a current sensor, specifically the INA219 module, and a voltage sensor utilizing a microcontroller-based voltage divider circuit. Additionally, the study aims to evaluate the validity of the measurement results obtained from the developed instrument. The research methodology comprises three main stages: hardware design, software development, and system testing. Testing involves analyzing the uncertainty and error values associated with the current and voltage measurement data. The findings reveal that the accuracy of the sensors yields a percentage uncertainty of 3.49% for voltage measurements and 0.65% for current measurements when utilizing a 100 Ω resistor. Furthermore, variations in test loads using a 300 Ω resistor resulted in a percentage uncertainty of 2.99% for voltage measurements and 2.16% for current measurements.

Keywords: Current; voltage; microcontroller; uncertainty

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http://dx.doi.org/10.12962/j24604682.v20i2.21600

I. INTRODUCTION

The increasing energy demand in densely populated areas has made access to electricity crucial for modern life. Electricity plays an essential role in daily activities and has become indispensable with the advancement of electronic technology [1, 2]. The generation and distribution of electrical energy are made possible by the movement of electric charge through conductors, which creates electric current. This flow of electric charge can be monitored using current sensors, which measure electrical consumption and provide analog signals to regulate and control power usage [3].

Given the importance of effectively managing electrical energy consumption, a system for monitoring current and voltage is essential. Current sensors play a vital role in various applications, including measuring voltage and current in hybrid solar panel systems using Arduino Uno, monitoring current and voltage in three-phase transformers, and integrating current and voltage sensors into IoT-based solar power systems [4].

Building on these existing applications, this research focuses on designing a current and voltage measurement system. The system utilizes a voltage sensor to measure the power supply, a relay to act as a power switch, and an INA219 sensor to measure DC current and voltage accurately. This approach aims to provide a reliable and efficient tool for monitoring and controlling electrical energy usage, addressing the growing need for energy management in todays technological landscape.

Based on the aforementioned description, this research focuses on designing a current and voltage measurement system by utilizing a voltage sensor to measure the power source, a relay to act as a switch, and the INA219 sensor to measure DC current and voltage accurately. The novelty of this research lies in integrating these components into a single, efficient system for real-time monitoring of electrical parameters, which can be applied to various energy systems, such as solar power installations or hybrid energy systems.

A. INA219 sensor

The INA219 sensor is a module that can monitor voltage and current in a network. It is supported by an I2C interface. This device is capable of monitoring shunt voltage and supply bus voltage with a soft conversion and filtering time. The INA219 sensor has a maximum input gain of ± 320 mV, allowing it to measure currents up to ± 3.2 A. Its 12-bit ADC provides an internal data resolution of 0.8 mA within the 3.2 A range. With internal amplification set to a minimum value of div8, the maximum current measurable is ± 400 mA, with a resolution of 0.1 mA. The INA219 can identify shunt voltages from 0 to 26 V.

In Fig. 1, the INA219 features I/O data pins, a clock pin, analog input pins (A0 and A1), Vin+, Vin, ground, and supply voltage. The IN+ and IN- pins serve as the positive and negative input pins for the shunt voltage, with the positive pin connected to the shunt resistor and the negative pin connected to ground. The SCL and SDA pins represent the serial bus clock line and the serial bus data line, respectively.

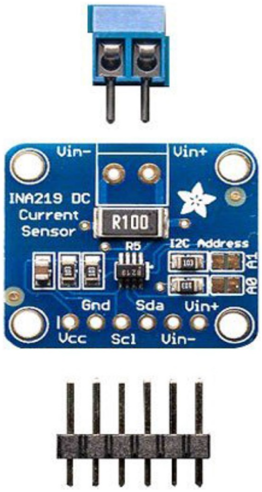

FIG. 1: INA219 sensor [5].

FIG. 2: Splitter sensor module pinout voltage [6]

B. Voltage Sensor

Common voltage sensors utilize voltage divider circuits. The voltage divider sensor applies Kirchhoff's Voltage Law (KVL) and is arranged in a series configuration. The principle of operation of this network is to reduce the voltage across two connected resistors in series, which are then connected in parallel with the voltage source to be measured, resulting in a reduced voltage. The decrease in voltage is a consequence of the reduction throughout the network and can be measured at the junction where the two resistors meet. Therefore, this series voltage divider is often referred to as an analog measurement without direct connection to the source. The network module for the voltage divider is illustrated in Fig. 2.

Component main from voltage sensor module are two resistors, namely a 7.5 Ω resistor and a 30 Ω resistor. Module input voltage This is 0-25 V and the output is 0-5 V. Principle Work network This is network divider voltage, as shown in Fig. 3.

Based on Fig. 3, the sensor will read voltage big, divide VCC voltage becomes 5x more small, for example VCC 25 V then output network the is 5 V. When maximum voltage Work Arduino is 5V, then No OK give VCC voltage on the voltage circuit /sensor the above 25 V, because the output of voltage sensor circuit the will exceeding 5 V is possible result Arduino damaged. Voltage output produced by the circuit the delivered in form Eq. (1):

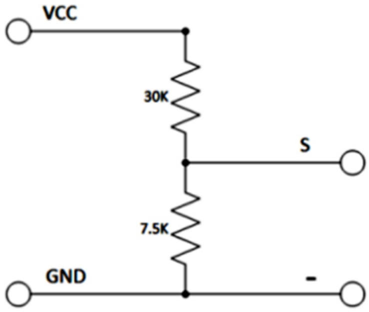

FIG. 3: Network divider voltage on the voltage sensor module.

$$V_{out} = \frac{V_{in} \times R_2}{R_1 + R_2} \tag{1}$$

C. Calibration

Calibration is action verification for ensure that accuracy tool measuring in accordance with the design. Calibration process usually done with compare connected standards with standard national or international and materials existing reference certified [7]. By general, calibration is the process for adjust the output or indication from device gauge to match with standard used in accuracy certain [8].

II. RESEARCH METHODS

The voltage and current sensor circuit is illustrated in Fig. 4. The INA219 sensor is connected to the NodeMCU using digital interfaces D1 and D2. The interface is presented to the user through a built-in LCD that utilizes I2C synchronous serial communication to display measurable values on the screen. Meanwhile, the voltage sensor employs a voltage divider module, with the S pin connected to A0, and the + and - pins connected to VCC and GND on the NodeMCU ESP8266, respectively.

The schematic of the voltage divider module is shown in Fig. 2. To analyze the comparison of prototype current sensors and voltage sensors with standard instruments, systematic calculations are carried out following the formulation [9]:

1. Average

$$\bar{x} = \frac{x_1 + x_2 + x_3 + x_4}{n} \tag{2}$$

2. Standard deviation

$$SD = \sqrt{\frac{\Sigma(\bar{x} - x_i)^2}{n-1}} \tag{3}$$

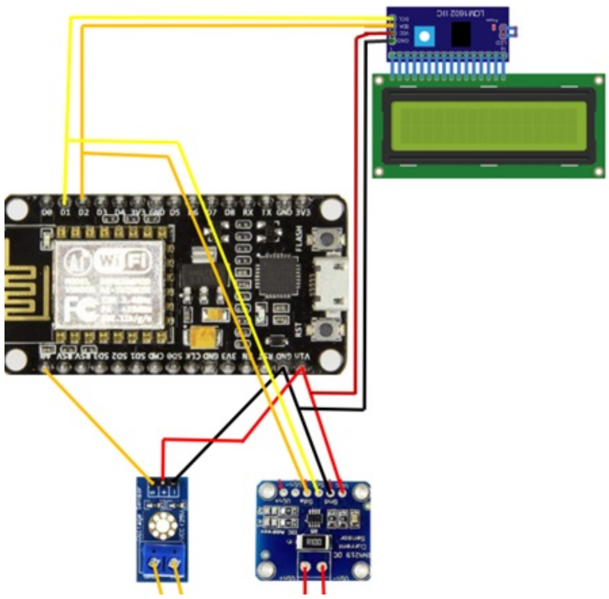

FIG. 4: Voltage and current sensor circuit.

3. Error value

$$Error = |Test - Standard| \quad (4)$$

4. Uncertainty relative (KR)

$$KR = \frac{\text{Test - Standard}}{Standard} \times 100\% \quad (5)$$

The circuit consists of an INA219 current sensor, a voltage divider, and an ESP8266 microcontroller. The INA219 measures both current and voltage on the high side of the load, connected between the positive power supply and the load itself. It communicates with the ESP8266 via the I2C interface, with the SDA and SCL pins connected to GPIO 4 and GPIO 5, respectively. Meanwhile, the voltage divider reduces a higher input voltage to a safe level that can be read by the analog pin (A0) of the ESP8266. The ESP8266 powers both the INA219 and the voltage divider while processing the sensor data.

During operation, the INA219 measures the current flowing through the load and the bus voltage across it. The voltage divider scales down any higher voltages for the ESP8266 to read through its ADC. The ESP8266 collects data from both the INA219 and the voltage divider.

III. RESULTS AND DISCUSSION

A. Test Results of Voltage Sensor Characteristics

The purpose of voltage sensor testing is to measure the voltage flowing through a load. The voltage sensor operates based on the principle of a voltage divider, which consists of two resistors connected in series. This arrangement generates a reference voltage at the connection point of the resistors. The voltage reference for the sensor is limited to a maximum of +5V DC to ensure compatibility with the microcontroller. The measured voltage is then converted from an analog signal to a binary format.

To determine the stability of the voltage sensor, hysteresis testing is required. This method involves measuring the voltage during both increasing and decreasing voltage conditions. The stability of the voltage sensor can be observed from the hysteresis curve shown in Fig. 5.

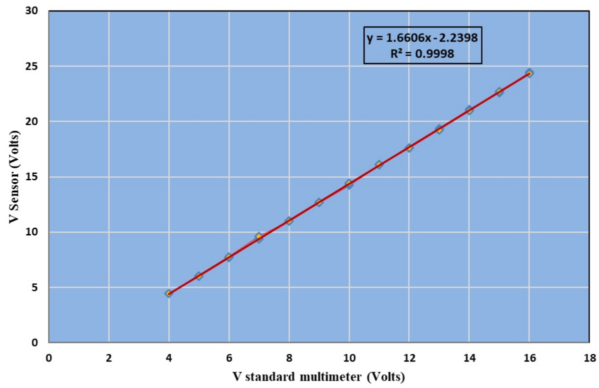

FIG. 5: Results data testing voltage sensor hysteresis.

Visually curve hysteresis Fig. 5 does not looks curve his hysteresis because difference results measurement moment voltage raised and lowered very little. Results data testing hysteresis in the voltage sensor (Fig. 5) is analyzed use equality linear regression. Function from analysis this linear regression, for predict and measure in a way accurate influence One variable X (independent / predictor) against another variable Y (no free / response) [10]. Analysis regression on testing This use method regression simple because only use One variable free. Result of analysis voltage sensor regression This form a equality regression namely y = 1.6606x - 2.2398 with coefficient determination R^2 = 0.9998. Coefficient value this used for measure strength connection between predictor variable x and response y. The value R^2 = 0.9998 means that, the relationship between the independent variable / predictor x is the voltage data from sensors with variable bound /response y (multimeter data) is very strong, with percentage 99.98%. Change voltage in the characteristic test The INA129 sensor voltage is very small ($< 1\%$) can be influenced by several factor among them resistance external, fluctuation source Power input electricity, temperature operations, and interference electromagnetic [11].

B. Test Results of Current Sensor Characteristics

Current sensor built for monitoring current output results injection from network source current . Current sensor testing with use multimeter as calibrator and power supply as source the voltage. Testing done with source voltage 12 V DC. Data collection for testing calibration done with variation load re-

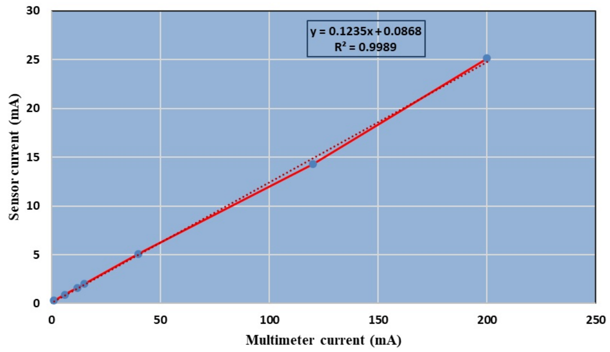

FIG. 6: Test Results of Current Sensor Characteristics.

sistors of 60, 100, 300, 800, 1000, 2000, and 10000 Ω. Each test load is assembled in a way series. Test results shown in form graph in Fig. 6.

Based on Fig. 6, results from analysis voltage sensor regression This form a equality regression namely $y = 0.1235x + 0.0868$ with coefficient determination $R^2 = 0.9989$. This value show that 99.89% variable free / predictor x can explain / explain variable not free / response y and 0.11% explained by the variable other. Deviation mark characteristics current electricity on this INA129 sensor caused because changes conductivity electricity, permeability magnetic, on components or the system being measured, is likely variation burden inductive, and capacitive sensors are measured [12, 13].

C. Calibration of Voltage Sensors and Current Sensors

To determine the accuracy of the measurement results, the data obtained from the sensor circuit's data acquisition is validated using a multimeter as a calibrator. The testing is conducted with a 30V DC power supply, which allows for a range of possible voltage changes. The test data obtained is then processed using Microsoft Office Excel and analyzed using linear regression to derive the linear equations depicted in Fig. 5 and Fig. 6. These linear equations are incorporated into the Arduino IDE program sketch, after which the program is executed to conduct further testing and collect measurement data. The results of the measurements are expected to closely align with the actual values when compared to the calibrated multimeter standards.

D. Calculation of Uncertainty in Current and Voltage Sensor Measurements

After calibrating each sensor, testing is conducted on the current and voltage measurements compared to a calibrated standard multimeter, specifically the Sanwa brand. The generated data is then used to calculate the uncertainty. The results of these calculations are presented in Tables I and Tables II.

Based on Table I and Table II, sensor data were collected using two variations of load tests, each performed with three repetitions. The loads used were two resistors, 100 Ω and 330 Ω, both of which were verified against a standard multimeter. The testing results yielded an average voltage of 6.1 V and a current of 0.062 A for the 100 Ω resistor load. In contrast, the 300 resistor load resulted in a voltage of 12.3 V and a current of 0.036 A. These data were further compared with the readings from the standard multimeter to calculate the correction values. A negative correction value (-) indicates that the measurements from the sensor prototype need to be reduced by this correction value. Conversely, a positive correction value (+) suggests that the measurements need to be increased by this value.

TABLE I: Test results of current and voltage sensors on 100 Ω resistors.

Data	V (mV)	I (mA)	R (Ohms)	Error	%KR
1	6089.65	61.82	98.5	1.5	1.5
2	6086.83	61.99	98.2	1.8	1.8
3	6092.48	61.87	98.47	1.53	1.53
4	6262.2	62.03	100.95	0.95	0.95
5	6132.08	61.99	98.93	1.07	1.07
6	6103.8	62.03	98.39	1.61	1.61
Average	6127.84	61.95	98.91	1.09	1.09
Deviation standard			0.94		

TABLE II: Test results of current and voltage sensors on 330 Ω resistors.

Data	V (mV)	I (mA)	R (Ohms)	Error	%KR
1	12272.97	35.44	346.27	16.27	4.93
2	12287.12	35.46	346.52	16.52	5.01
3	12258.83	36.07	339.82	9.82	2.98
4	12360.66	36.04	342.95	12.95	3.92
5	12434.21	36.27	342.83	12.83	3.89
6	12400.26	36.43	340.38	10.38	3.15
Average	12335.68	35.95	343.13	13,13	3.98
Deviation standard			2.58		

The magnitude of the correction value can be influenced by various factors, including the standard instruments used as references and the environmental conditions during testing. Additionally, the accuracy of the measurements may be affected by factors such as the duration of use during testing, the age of the instrument, observation uncertainties, and other physical parameters that may not comply with the expected standards. Based on the uncertainty measurement results, it can be observed that the sensor tested with a 100 Ω resistor load exhibited an average uncertainty percentage of 1.09%, while the sensor tested with a 300 Ω resistor load showed an uncertainty percentage of 3.98%.

IV. CONCLUSION

The results of the sensor test show that the uncertainty value of the accuracy of the voltage sensor and current sensor measurements by 100 Ω resistor load is 3.49% and 0.65%, respectively. Furthermore, in the test by 300 Ω resistor load for the voltage sensor and current sensor measurements, the measurement uncertainty percentage is 2.99% and 2.16%, respectively.

[1] A. Tanveer, and Z. Dongdong, ”A Critical Review of Comparative Global Historical Energy Consumption and Future Demand: The Story Told So Far . Energy Reports”, Guangxi University, 2020, November Vol 6. https://doi.org/10.1016/j.egyr.2020.07.020

[2] L. Zhibin, *et al.*, ”Research On Optimization of Energy Storage Regulation Model Considering WindSolar and Multi-Energy Complementary Intermittent Energy Interconnection”, Energy Reports, North China Institute of Aerospace Engineering, vol. 7, 2022, https://doi.org/10.1016/j.egyr.2022.05.062

[3] I. Hudati, A.P. Aji, and S. Nurrahma, ”Kendali Posisi Motor DC dengan Menggunakan Kendali PID”, Jurnal Listrik, Instrumentasi, dan Elektronika Terapan, vol.2, no.2, pp. 25-30, 2021, https://doi.org/10.22146/juliet.v2i2.71148

[4] S. Anwar, *et al.*, ”Measurement PZEM-004T Based Electrical Energy”, Proceedings of the National Seminar Lhokseumawe State Polytechnic, vol. 3, no. 1, 2019.

[5] Y. Cheddadi, *et al.*, ”Design and Implementation of an Intelligent Low-Cost IOT Solution for Energy Monitoring of Photovoltaic Station”, SN Applied Sciences, vol. 2, no. 1165, 2020, https://doi.org/10.1007/s42452-020-2997-4

[6] Voltage Sensor Module, https://components101.com/sensors/voltage-sensor-module.

[7] Anonymous, ”Guide to The Expression of Uncertainly in Measurement (JCGM-GUM)” Part 6, Developing and Using Mesurement Models, 2020.

[8] A.S. Morris, ”Measurement and instrumentation principles” (3rd ed.), Elsevier, 2001.

[9] N.M. Rosanti , D.T. Rahardjo, DT, and D. Harjunowibowo, ”Pengembangan Alat Ukur Suhu Contact Less Thermogun Berbasis IOT Menggunakan Aplikasi BLYNK Sebagai Alat Ukur Suhu Di Era Covid-19”, Jurnal Materi dan Pembelajaran Fisika, vol. 12, no. 1, hal. 35-45, 2022.

[10] S.A. Sandjojo, I. Setiawan, T. Andromeda, ”Implentasi Kontrol Arus pada Inverter Satu Fasa menggunakan DSPIC30F4011 dengan Metode KOntrol Hiterisis”, Journal Transient, vol. 7, no. 1, hal. 327-333, 2018.

[11] A. Fitri, M.W. Kasrani, and Arwin, ”Perancangan Sistem Regulator pada Lampu Emergency menggunakan Arduino UNO”, Jurnal Teknik Elektro Uniba, vol. 3, no. 2, hal. 7-12, 2019.

[12] H.N. Isnianto, E. Puspitaningrun, ”Monitoring Tegangan, Arus, Dan Daya Secara Real Time untuk Perbaikan Faktor Daya Secara Otomatispada Jaringan Listrik Satu Fase Berbasis Arduino”, Jurnal Nasional Teknologi Terapan, vol. 2, no. 1, hal. 31-36, 2018.

[13] Y. Esye, and S. Lesmana, ”Analisa Perbaikan Faktor Daya Sistem Kelistrikan”, Jurnal Sains and Teknologi Fakultas Teknik Universitas Darma Persada, vol. 11, no. 1, hal. 104113, 2021