Simple I-V acquisition module with high side current sensing principle for real time photovoltaic measurement

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Abstract. This work presents a data acquisition module for measurement of current voltage (I-V) characteristic of photovoltaic module based on INA219 sensor Adafruit integrated with the Atmega328 Microcontroller. The module can be used to measure the photovoltaic DC current precisely, which is controlled using a developed software interface as a data logger display. The sensor works based on the principle of high side currents sensing consists of sense and load resistor to accommodate four sensors of 3 Amps in the maximum voltage range up to 26V. The measurement result in real-time is depicted in graphical form using visual studio software. Calibration and linearity tests result an error of of 0.76% and 0.572% for currents and voltages respectively. The result of linearity test shows a value of R = 0.98 for current and voltage of PV module compare to the calibrator.

1. Introduction
The energy demand in the world significantly increased energy source, especially green energy obtained from solar energy using photovoltaic (PV) modules. The advantages of this photovoltaic systems are quiet and visually unobtrusive, easy to use, practical and also has fairly high efficiency, especially for the tropic regions. The performance of the PV module can be attributed to the current-voltage characteristic (I-V curve) of output factors, for instance short circuit current (Isc), open-circuit voltage (Voc) and maximum power (Pmax) directly [1,2]. Precise data measurements must be done in short time intervals of less than 1 minute due to unstable solar intensity, which has an impact on the maximum power output of the PV module at low intensity [3]. Therefore, an electronic device that can acquire data parameters in real-time is needed. Some researchers have characterized the PV module performance electronically, but still have drawbacks such as non-linear sensor output [4], the percentage of error between the current sensor and calibrator is still above 1%, the error reading the current value, and is done manually [5].

This paper presents an electronic data module for real-time I-V data acquisition in intervals of less than 1 minute based on the INA219 current sensor with 1% accuracy. INA219 current sensor works based on the principle of high side current sense with a built-in load resistor, which is directly connected to ground and is not damage the sensor or any other device safe in the case of a short circuit that happened [6]. The sensor electronic circuit has been designed integrated with the Atmega328 Microcontroller and a software interface used as a high-precision data logger display for DC currents.
2. Method

2.1. Electronic System

The INA219 sensor has a digital amplifier with an I2C serial protocol for two-wire interface and SMBus-Compatible interfaces for serial communication standard which is specifically designed to send and receive data. The I2C system involves Serial Clock (SCL) and Serial Data (SDA) channels that carry data information between I2C and Microcontroller. Figure 1 shows two analog inputs INA219, VIN+, and VIN– connected to the shunt resistors supplied separately from voltages 3V up to 5.5V, which can detect the bus voltage from 0 to 26V. INA219 is able to detect changes in current passing through the shunt resistor, as well as the voltage connected to ground from VIN– as a bus voltage parameter [6].

Figure 1. INA219 sensor electronic circuit

The PV module output was coupled with the INA219 input using 1Ω 10W current divider resistor to prevent the current passing through the INA219 module not being overloaded. The maximum input current INA219 is 3 Amps for a Shunt Resistor of 0.1Ω and 1% tolerance connected in series between the PV module and the load resistance. A 100Ω wire-wound Rheostat was used as an external load for the current and voltage readings of the PV module. The block diagram of the PV module I-V data acquisition system is depicted in figure 2. INA219 calculates the current flowing from the PV module through the "Current Shunt" by measuring the differential voltage drop on the shunt resistor, and then the PV current can be calculated based on Ohm's law.

Figure 2. Block diagram of an I-V curve PV module acquisition system

The internal ADC converts analog voltages to digital values stored in binary representations using the Shunt Voltage Register of a 12-bit ADC, which means it can resolve analog voltages to 4096 discrete digital values. Range can be extended using PGA in front of the ADC which is configured by a factor of 1, 2, 4, and 8 representing an effective range of ±40mV, ±80mV, ±160mV, and ±320mV respectively.
2.2. High Side Current Sense Measurement Principle

High side current sense has been used in a very wide range of applications such as over current protection. Figure 3 shows the high side current sense circuit scheme using the shunt resistor (R\text{shunt}) positioned between the bus voltages and the load resistance of the system. It is formed differential voltage proportional to the magnitude of the load current, which is then amplified to produce a single output voltage.

![Figure 3. High side current sense series](image)

High side current sense is not interfere the ground disturbances, since the ground noise arises in the case of interacting between circuits system and the load. This can be eliminated by giving a shunt resistor to the top of the load resistance.

![Figure 4. Developed I-V module based on INA 219 current sensor](image)

Figure 4 shows the developed I-V module based on INA219 with high side current sense. This online data acquisition system was developed with an INA219 sensor that can measure currents up to 10A / 50V through I2C communication with a high degree of precision. Data collection measurements are carried out quickly < 1 minute so that the data is not influenced by variations in temperature and solar intensity [2].
2.3. Interfacing
The software displays data from the acquisition of PV modules in the form of real time graphics designed using visual studio software. The data obtained can be directly stored in the form of text and images via the save button available on the monitoring interface.

![Figure 5. Interface monitoring of PV modules in real time](image)

The interface receives analog data from the microcontroller in the form of float (decimal) data which is then converted into a data string (char), as the serial port line is open every 1 second.

3. Results and Discussion

3.1. Calibration
The INA219 current and voltage sensors were calibrated using standard laboratory multimeter Fluke 15B+ to compare the measurement results between the calibrator and the developed module, as well as the module performance such as the sensor sensitivity performance, accuracy of reading values, signal linearization and data validation.

![Figure 6. Current and voltage calibration curves on the INA219 sensor](image)

These factors are very important and affect the performance of the measurement system. Linearity, accuracy and sensitivity tests aim to see the accuracy of the current and voltage readings between the INA219 sensor and calibrator. Figure 6a presents the sensor validation test produces from a measured current of the INA219 sensor-based electronic module which shows a linear correlation with R-square of 0.98 and results in an error value of 0.76%. The effective current value of INA219 can be measured from 10mA up to 3A. For the voltage measurement in Fig 6b, the INA219 sensor produces results
with a very good linearity with an error value of 0.572% with effective voltage values between 0V-26V.

3.2. Rapid I-V Measurement of Photovoltaic Module

Current and voltage measurements from PV modules using the INA219 sensor electronic module are carried out rapid and real time under normal light conditions. Figure 7 depicts the measurement results of the I-V curve of the Hooray MCP-2 (100 WP) Polycrystalline Silicon PV module with the load resistance varying between 0-100 Ω and surface temperature of PV at 35°C. The maximum current that can be measured reaches 1 A under normal conditions. I-V curve extraction is very important to find out the internal parasitic value which is a parameter of module performance. In [6], the measurements of the I-V curve under direct illumination to characterise the performance of the polycrystalline PV module based on lambert-W function has been taken.

![Figure 7. Measurement of PV module I-V curves in real-time](image)

Table 1. I-V curve parameter for PV characterization.

| No | Parameter                  | Unit | Value  |
|----|----------------------------|------|--------|
| 1  | Open circuit voltage, Voc  | V    | 19.58  |
| 2  | Short circuit current, Isc | A    | 2.314  |
| 3  | Voltage at Pmax, Vmp       | V    | 14.51  |
| 4  | Current at Pmax, Imp       | A    | 2.153  |

This measurement has been carried out at the output current of the PV module ≥ 3A by modifying the shunt resistor to be a smaller value for a larger current measurement scale. However, this can imply a shunt load resistor in the form of excessive heat dissipation, so a shunt resistor with greater power is needed to anticipate an increase in temperature.

4. Conclusion

Current and voltage data acquisition systems using the INA219 sensor with the high side current sense measurement principle have been successfully made. The linearity and sensor validation tests are performed by calibrating the current and voltage values using a Fluke 189 multimeter with an average error of 0.76% and 0.572%, respectively. The range of effective current values INA219 that can be
measured is 10mA-3A with a shunt resistor 0.1 Ω, while the voltage has a measurement range of 0V-26V which is very accurate and sensitive to measure the output generated by the PV module marked by a linearity test which has a value of R = 0.98 for current and voltage.

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