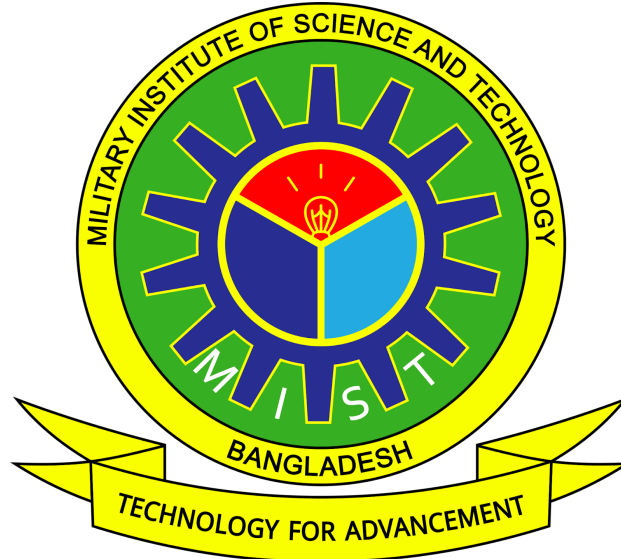# MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY

Department of Electrical Electronic and Communication Engineering

Open Ended Lab Project
EECE-314

AC ENERGY METER USING HALL EFFECT AND ARDUINO

GROUP-3

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Table of Contents

Abstract:

This study introduces a novel energy meter design that leverages the Hall Effect and an Arduino microcontroller. The Hall Effect, a fundamental physical principle, is utilized to measure the current flowing through a conductor by generating a voltage proportional to the magnetic field induced by the current. The resulting voltage signal is amplified and converted into a digital format using the Arduino's ADC. The digital data is then processed to calculate instantaneous power and total energy consumption. The proposed energy meter offers a highly accurate, reliable, and cost-effective solution for monitoring electrical energy usage in residential, commercial, and industrial settings. Furthermore, the Arduino-based design enables easy integration with other IoT devices and systems for advanced energy management and analysis.

The report begins by introducing the Hall effect and how it works in case of energy meters. It explains the working principle of the designed energy meter which involves the principle of Hall effect with the help of Arduino. The circuit's operation is analyzed in detail, including conversion from AC to pulsating DC using zener diodes and also smoothing the output using capacitor.

Furthermore, the report discusses the factors influencing the performance of the energy meter and how efficient it can be by using an arduino to it. It explores the advantages and limitations of using energy meters, including their accuracy, real time monitoring and maintenance.The report highlights the benefits and practical implementations of energy meters in these domains.

Introduction:

Energy monitoring is crucial for understanding power consumption patterns, optimizing energy usage, and reducing electricity costs in both residential and industrial settings. Traditional energy meters often lack advanced features such as real-time monitoring, data logging, and user-friendly interfaces. With the rise of smart home technologies and the increasing demand for energy efficiency, there is a growing need for affordable and accessible energy monitoring solutions

In this project, we propose the development of an AC energy meter using Arduino that employs Hall effect sensors to measure current. Hall effect sensors are advantageous because they provide non-invasive current measurement by detecting the magnetic field generated by current flow. This method enhances safety and accuracy, making it suitable for various applications. Additionally, the system utilizes an Analog-to-Digital Converter (ADC) integrated within the Arduino microcontroller to convert the analog signals from both current and voltage sensors into digital data. The ADC's 10-bit resolution allows for precise readings across a range of 0 to 5 volts, translating these values into usable digital outputs.

The integration of Hall effect sensors and ADC technology enables this project to showcase various aspects of electrical measurements, including real power (in watts), apparent power (in volt-amperes), RMS voltage (in volts), RMS current (in amperes), and power factor. By processing these measurements in real time, users can gain valuable insights into their energy consumption patterns and identify opportunities for optimization

Moreover, this Arduino-based energy meter serves as an educational tool for individuals interested in electronics and energy management. It provides hands-on experience in circuit design, programming, and data analysis while promoting awareness of energy consumption issues. The modular design allows for easy customization and expansion, enabling users to integrate additional features such as wireless communication for remote monitoring or data logging capabilities.

In summary, this paper presents a detailed methodology for designing and implementing an AC energy meter using Arduino technology. By leveraging Hall effect sensors for current measurement and ADC for analog data conversion, the proposed system offers a comprehensive solution for monitoring electrical energy consumption in residential and industrial applications. This project not only addresses the need for affordable energy monitoring solutions but also encourages further exploration in the field of energy efficiency.

Literature Review:

The Hall effect is the production of a potential difference (the Hall voltage) across an electrical conductor that is transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. It was discovered by Edwin Hall in 1879. Hall's discovery was initially met with skepticism and was not widely accepted until the early 20th century. However, as understanding of electromagnetic theory and semiconductor physics advanced, the Hall Effect gained recognition as a fundamental principle of electromagnetism. In the mid-20th century, advancements in semiconductor technology led to the development of more sensitive Hall sensors. These sensors began to find applications in various fields, including magnetic field measurement, current sensing, and position sensing. The 1960s and 1970s saw a significant increase in the use of Hall sensors in automotive applications, such as speedometers, anti-lock brake systems (ABS), and traction control systems. In the 1980s and 1990s, the development of integrated circuits incorporating Hall sensors further expanded their applications. Hall sensors were used in a variety of consumer electronics, including computer mice, joysticks, and proximity sensors. Today, Hall sensors continue to be an essential component in many modern electronic devices, with new applications emerging in fields such as renewable energy, robotics, and medical devices.

1. **Hall Effect based Energy Meters.** The technologic development level was increasing with new inventions of scientists like Galile Ferraris and Nikola Tesla. The AC-DC network contention between Thomas Edison and Nikola Tesla would determine the direction of the energy meters. In the 1920's, technologic studies about meter's connection protection and polyphase measurement increased. At 30's, the usage of energy meters were made with protective equipment like fuse and switches. In the ongoing years, energy meter structure has become today's condition according to network needs and additional requirements. Now, new energy meters are produced with a lot of technological methods like Rogowski, hall effect (current measurement), resistive and differential (voltage measurement).

2. **Arduino-Based Energy Meters.** Arduino microcontrollers have gained popularity in various electronic projects due to their ease of use and versatility. Several researchers have explored the

use of Arduino for energy metering applications and also presented a design that employed an Arduino to read analog voltage signals from a current sensor and calculate power consumption. They found that the Arduino-based energy meter provided accurate and cost-effective measurements.

Methodology:

The integration of the Hall Effect and Arduino in energy metering has been a relatively recent development, with significant progress made in the last decade. Early research and prototype development led to the emergence of open-source projects and commercial applications. The combination of Hall Effect and Arduino has enabled the development of IoT-enabled energy metering solutions and advancements in accuracy and reliability.

1. **Theory.**

   a. What is the Hall Effect? : The Hall Effect is a physical phenomenon where a voltage is generated across a conductor when it is placed in a magnetic field perpendicular to the current flowing through it. This voltage, known as the Hall voltage, is directly proportional to the magnetic field strength and the current. The following points briefly discuss about the working procedure of the Hall effect:

   i. **Current Flow:** When an electric current flows through a conductor, the moving electrons create a flow of charge.

   ii. **Magnetic Field:** If the conductor is exposed to a magnetic field that is perpendicular to the direction of current flow, the magnetic field exerts a force on the moving charges (due to Lorentz force).

   iii. **Charge Separation:** As a result of this force, electrons are deflected to one side of the conductor, creating a buildup of negative charge on one side and positive charge on the other.

   iv. **Hall Voltage:** This separation of charge generates a small voltage across the conductor, perpendicular to both the current and the magnetic field. This voltage is called Hall voltage and its magnitude is proportional to the strength of the magnetic field, the amount of current and the properties of materials. The mathematical representation of the Hall voltage can be expressed as:

   $$V_H = BI / (n \times e \times t)$$
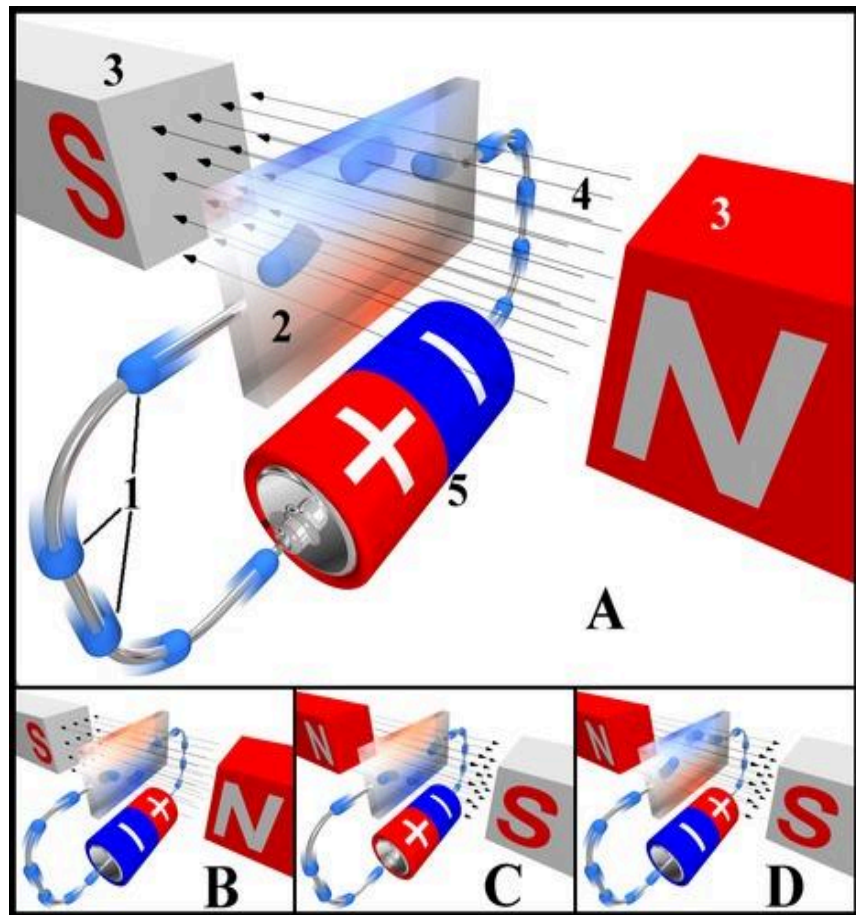
   where,

   B = Magnetic field strength

   I = Current through the conductor

   n = Charge carrier density

   t = Thickness of the conductor

Fig: Hall Effect

b. Hall Effect in the meter: In an energy meter, a Hall sensor is placed near a current-carrying conductor. The magnetic field generated by the current interacts with the Hall sensor, producing a Hall voltage. This voltage can be measured and used to determine the current flowing through the conductor.

c. Analog-to-Digital Conversion (ADC) Principle in Arduino: Arduino microcontrollers, like the ATmega328P found in the Arduino Uno, feature built-in Analog-to-Digital Converters (ADC) on certain analog input pins. These ADCs enable the board to interpret continuous analog signals, such as those from temperature sensors, light sensors, and other analog input devices.

   i. ADC Resolution: The Arduino's ADC has a 10-bit resolution, meaning it can distinguish 1024 different levels. The conversion is performed using a successive approximation ADC, which generates a digital representation of the input voltage in the form of a binary value. For a 10-bit ADC, the binary range is from 0 to 1023, corresponding to the input voltage range.

   For example, if the input voltage is 2.5V and the reference voltage is 5V,

ADC value= (2.5/ 5)x 1024.

The analog signal is sampled at discrete intervals during conversion. The frequency at which the analog is sampled is determined by the **ADC clock speed**. For an ATmega328P microcontroller, the ADC operates at a default clock speed of 125 kHz. With a 13-cycle conversion time, the conversion rate is approximately **9600 samples per second (SPS).**

ii. Reference Voltage (V_ref): The reference voltage determines the range of the input voltage the ADC can read. In Arduino, the default reference voltage is 5V, but it can be adjusted to 3.3V or an external reference voltage using the analogReference() function.

$$ADC\ Value = (Input\ /\ VoltageVref) \times 1023$$
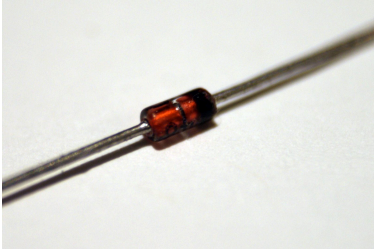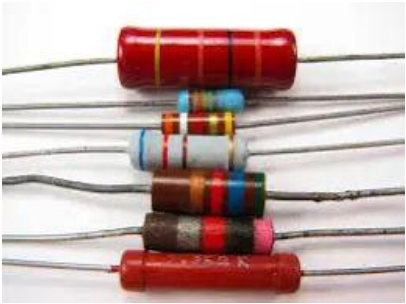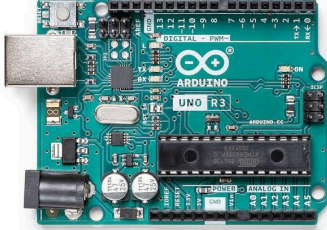
iii. ADC Operation Stages:

- **Sampling:** The analog signal is captured at a particular instant.
- **Hold:** The sampled signal is held constant during conversion to avoid fluctuations.
- **Quantization:** The signal is mapped to one of the 1024 possible values corresponding to different voltage levels.
- **Encoding:** The quantized value is encoded into a digital number representing the input signal.

iv. Non-Linearities and Errors:
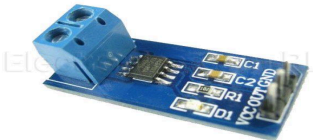
Practical ADCs exhibit non-ideal behavior due to factors such as error non-linearity, quantization, thermal noise. These errors can lead to a slight deviation from the theoretical ADC output, though for most applications, the error is negligible.

- **Quantization Error:** Due to finite resolution, the actual voltage input will be approximated to the nearest discrete value, leading to small errors.
- **Differential Non-Linearity (DNL):** This occurs when the step sizes between successive digital output values are not uniform.
- **Integral Non-Linearity (INL):** It refers to the deviation of the actual output from the ideal ADC output across the range of input voltages.

2. Components.

Name of Components	Figure
Diode	
Zener Diode	
Capacitor	
Resistor	
Arduino Uno	

LCD Display	
ACS 712 Module	
AC Voltmeter	
AC Ammeter	

3. Circuit.

4. Circuit description & Flowchart.

a. Components and their Functions:

i. **Resistors:** These resistors form the voltage divider circuit. Their values determine the voltage reduction ratio**.** They also limit current and adjust voltage levels.
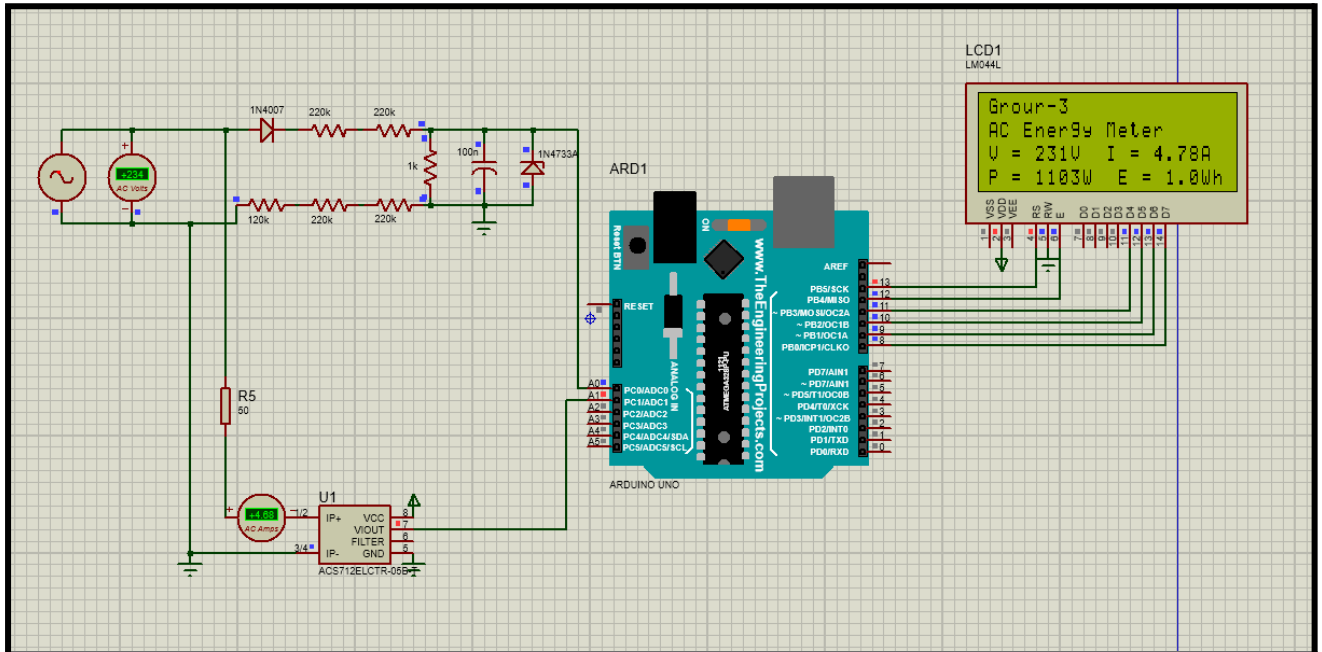
ii. **Diodes (1N4007, 1N4733):** These diodes are used for rectification and to provide protection against reverse voltage and ensure that the voltage divider circuit functions correctly with AC input.

iii. **Capacitors (C1):** These capacitors are used to filter out high-frequency noise from the AC voltage or to smooth out voltage signals and stabilize them.

iv. **ACS712 Current Sensor:** This sensor measures the AC current flowing through the load and generates a voltage proportional to the current.

v. **Arduino Uno:** The microcontroller reads the analog values from the voltage divider and current sensor, performs calculations to determine power consumption and displays the results on an LCD. Several analog and digital pins are used for interfacing with the sensors and LCD display.

vi. **LCD(Liquid Crystal Display):** This display is used to show the measured values of voltage, current, power and energy consumption.

b. Circuit Operation:

  i. **Current Measurement:** The ACS712 current sensor senses the AC current flowing through the load and provides analog signal proportional to the current. The current sensor is connected in series with the load and its output is fed to an analog pin of the Arduino.

  ii. **Voltage Measurement:** The voltage is stepped down using a resistor network to bring the high AC voltage to a measurable range for the Arduino. The rectified signal is fed to the Arduino for analog to digital conversion.

  iii. **Calculations:** The Arduino Uno uses the amplified current signal and the measured voltage to calculate the power($P=V \times I$) and energy consumption ($E = P \times t$).

c. **Flowchart:**

Voltage	Current
AC INPUT	AC INPUT
↓	↓
RECTIFY	HALL EFFECT
↓	↓
VOLTAGE DIVIDER	INPUT VOLTAGE
↓	↓
ARDUINO ADC	ARDUINO ADC
↓	↓
DISPLAY	DISPLAY
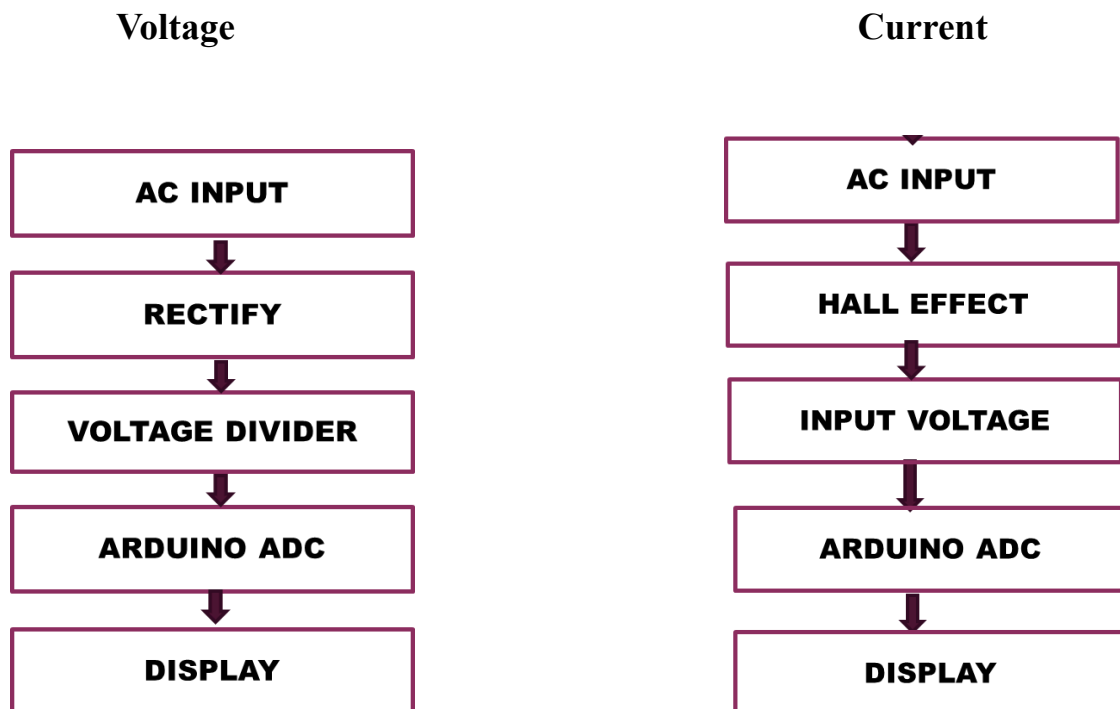
5. **Arduino Code.**

```arduino
#include <LiquidCrystal.h>
LiquidCrystal lcd(13, 12, 11, 10, 9, 8);



void setup()
{
  lcd.begin(20, 4); // set up the LCD's number of columns and rows:
  lcd.setCursor(0,0);
  lcd.print("Grour-3");
  lcd.setCursor(0,1);
  lcd.print("AC Energy Meter");
}

unsigned int get_max() {
  unsigned int max_v = 0;
  for(int i = 0; i < 100; i++) {
    unsigned int r = analogRead(A0);  // read from analog channel 3 (A3)
    if(max_v < r) {
      max_v = r;
    }
    delayMicroseconds(200);
  }
  return max_v;
}

void loop()
{



  uint32_t Vrms = get_max();
  Vrms = Vrms * 1100/1023;
  Vrms /= sqrt(2);
  Vrms*=2.017; // calibration factor



  lcd.setCursor(0,2);
  lcd.print("V = ");
  lcd.print(Vrms);
  lcd.print("V  ");

// this part is for RMS current
```

```
const float sensitivity = 185;   // Sensitivity (100mV per Amp for ACS712-20A)
const int offsetvoltage = 2568;

unsigned int temp=0;
float max = 0;
for(int i=0;i<500;i++)
{
 temp = analogRead(A1);
 if(temp>max)
 {
  max = temp;
 }
}
float ADCvalue = max;
double eVoltage = (ADCvalue / 1024.0) * 5000; // Gets you mV
double Current = ((eVoltage - offsetvoltage) / sensitivity);
Current = ( Current ) / ( sqrt(2) );



lcd.print("I = ");
lcd.print(Current,2);
lcd.print("A       "); //unit for the current to be measured

//*********************** Measure Power ****************************************
int Power = (Vrms * Current);

lcd.setCursor(0,3);
lcd.print("P = ");
lcd.print(Power);
lcd.print("W  "); //unit for the current to be measured



long milisec = millis(); // calculate time in milliseconds
long time=milisec/1000; // convert milliseconds to seconds

float Energy = (Power*time)/3600; //Watt-sec is again convert to Watt-Hr by dividing 1hr(3600sec)

lcd.print("E = ");
lcd.print(Energy,1);
lcd.print("Wh   ");

delay(200);

}
```
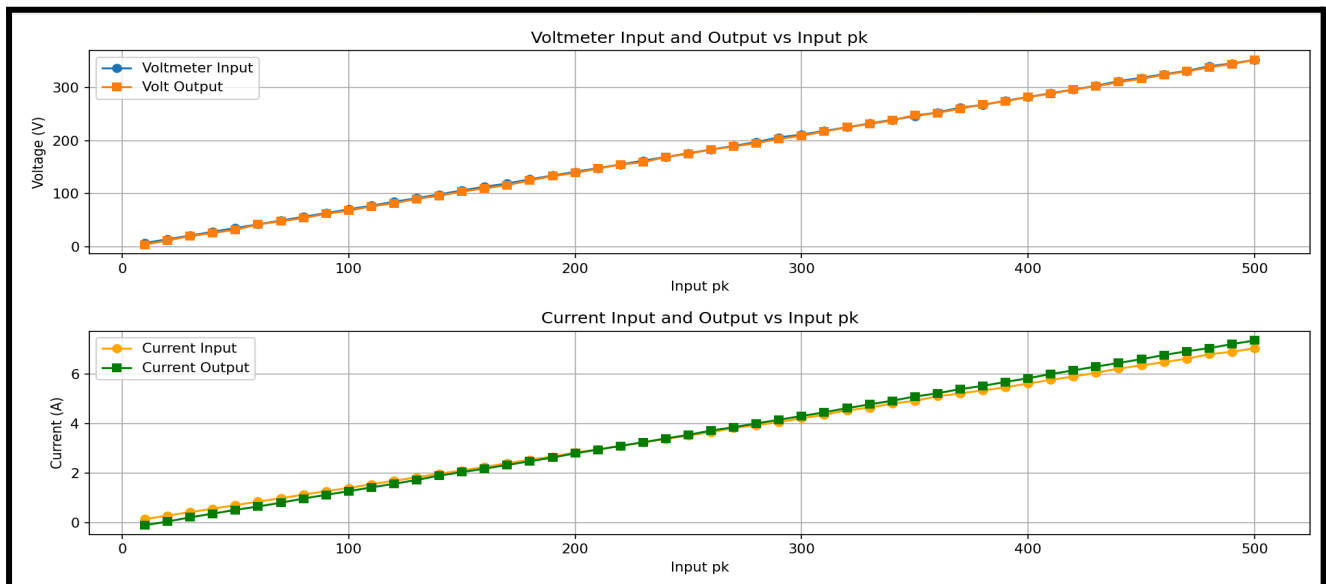
Analysis:

1. Data Table.

We collected a comprehensive dataset to evaluate the performance and accuracy of the AC energy meter system. The data includes measurements for **input pk(input in alternator)**, **voltmeter input (voltmeter i/p)**, **Arduino voltage output (volt o/p)**, **current input (current i/p)**, and **Arduino current output (current o/p)**, along with the corresponding percentage errors for both voltage and current. A total of **50** data points were recorded, covering a wide range of input pk values. The **voltage error** and **current error** were calculated to assess the accuracy of the system's voltage and current measurements. This dataset enables a detailed analysis of the system's performance under different conditions, providing insights into its efficiency and identifying trends in measurement errors across varying input levels.

2. Data Table Link.
https://docs.google.com/spreadsheets/d/1ig5mclctYOHtFKLmmUfbBQBCLy0dGB0MCh5fQZr3oo4/edit?usp=sharing

3. Graph.
The graph is generated from a python script

Result and Findings:

1. Accuracy.

In this dataset, the accuracy of the measurements is evaluated by comparing the input and output values for both voltage and current, followed by the calculation of the error percentage. The dataset includes columns for **voltmeter input (voltmeter i/p)**, **voltmeter output (volt o/p)**, **current input (current i/p)**, and **current output (current o/p)**, as well as the respective **error percentages**. Percentage of error in voltage is 2.52203 % and error in current is 11.5303 %.

a. Voltage Accuracy.

The input and output voltage values are provided across various points of input pk. The **voltage error** is calculated by comparing the output voltage against the input voltage and determining the percentage difference. A consistent deviation is seen in the data, with errors ranging from a few percent to higher percentages, indicating possible calibration issues or losses in the system. As the input pk increases, the error tends to fluctuate but generally shows higher error percentages at higher input values, which could suggest non-linearity in the system's voltage response.

b..Current Accuracy.

Similarly, the current input and output are compared. The **current error** is calculated in a manner similar to the voltage error. The dataset suggests significant discrepancies between the input and output current, particularly more at lower and higher input pk levels. These large errors could be attributed to losses in energy conversion or measurement inaccuracies at lower currents, which are common in many practical energy meters due to noise and resolution limitations.

2. Error Trends:

At lower values of input pk, the error percentages are notably higher, especially for current. This could imply that the system's accuracy is compromised at low operating conditions, possibly due to issues like sensor sensitivity or power factor corrections.

At higher values of input pk, the system exhibits better stability in voltage, but the current accuracy still shows notable deviations, possibly due to power losses or internal inefficiencies.

Comparison:

While all types of energy meters measure energy consumption, AC energy meters offer more functionality and precision tailored for specific applications. Comparison between a typical energy meter and an AC energy meter is as follows:

A. A typical energy meter measures total energy consumption (usually in   kilowatt-hours, kWh) for residential or commercial use where an AC Energy Meter is Specifically designed to measure alternating current (AC) energy consumption and can provide more detailed metrics (like power factor, current, and voltage).

B. A typical energy meter can be analog (mechanical) or digital and AC energy meters are typically digital, offering features like real-time monitoring and data logging.

C. A typical energy meter used in various settings, including residential, commercial, and industrial where AC energy meters are used in precise energy management such as industrial plants and commercial buildings.

D. A typical energy meter is generally accurate for measuring total consumption but may not provide detailed data on usage patterns where AC meters are more precise in measuring parameters related to AC power, including phase and frequency variations.

E. A typical energy meter is generally lower in cost, especially for basic models but AC meters are often more expensive due to advanced features and capabilities.

F. AC energy meters can measure additional parameters, while typical energy meters focus solely on total energy consumed.

G. AC meters often utilize advanced digital technology for enhanced accuracy and monitoring that is totally absent in typical ones.

1. **Advantages.** AC energy meters come with different advantages and that are really noteworthy to choose in our day to day life. Some advantages are as follows:

   a. **Accuracy:** Provides precise measurements of energy consumption, ensuring fair billing and effective monitoring.

   b. **Real-Time Monitoring:**Many modern meters offer real-time data, allowing users to track usage patterns and make informed decisions.

   c. **Cost Savings:**By identifying high energy consumption, users can take steps to reduce usage, leading to lower electricity bills.

   d. **Energy Efficiency:**Helps identify inefficient appliances or systems, promoting energy-saving practices.

   e. **Data Logging:**Some meters can store previous data, enabling analysis of energy trends over time.

   f. **Demand Management:**Assists utilities in managing load and balancing supply, which enhances grid reliability.

   g. **User-Friendly Interfaces:**AC energy meters come with digital displays and mobile app integration for easy access to data.

   h. **Sustainability:**Encourages energy conservation, contributing to environmental sustainability goals.

i. **Remote Monitoring:**Advanced models enable remote readings, reducing the need for manual checks and increasing operational efficiency.

j. **Integration with Smart Grids:**Compatible with smart grid technologies, facilitating enhanced energy management and automation.

2. <u>Disadvantages.</u> While AC energy meter offers several benefits, it also comes with certain disadvantages:

a. **Cost:** The initial cost of designing, developing, and implementing an AC energy meter project can be significant, especially if high-precision components are required.

b. **Complexity:** AC energy metering involves complex calculations and measurements, requiring specialized knowledge and skills. This can increase development time and the potential for errors.

c. **Calibration:** Ensuring the accuracy of an AC energy meter is crucial. Calibration procedures can be time-consuming and require specialized equipment.

d. **Interference:** External factors like electromagnetic interference, voltage fluctuations, and harmonics can affect the accuracy of AC energy meter measurements. This can lead to inaccurate readings and potential billing errors.

e. **Security:** If an AC energy meter project involves wireless communication or remote access, it may be vulnerable to security threats like hacking or data breaches.

f. **Maintenance:** AC energy meters may require regular maintenance, including calibration, component replacement, and software updates. This can add to the ongoing costs and complexity of the project.

g. **Environmental Impact:** The manufacturing and disposal of electronic components used in AC energy meters can have environmental implications. Careful consideration should be given to the sustainability of the project.

h. **Limited Versatility:** AC energy meters are designed for specific applications and may not be easily adaptable to other energy measurement needs.

i. It is important to carefully evaluate these disadvantages before embarking on an AC energy meter project to ensure that the potential benefits outweigh the challenges.

<u>Conclusion</u>

The AC energy meter project using Arduino demonstrates an effective way to measure and monitor electrical energy consumption. By integrating components such as current and voltage sensors, the system can accurately calculate power usage in real-time. The Arduino processes this data and can display it via an LCD or send it to a connected device for further analysis.Despite the promising results, there are still challenges to be addressed in the development of Hall Effect-based energy meters using

Arduino. One of the main concerns is the accuracy of the measurements, which can be affected by factors such as noise, temperature variations, and calibration errors. Future research should focus on improving the accuracy and reliability of these meters. Additionally, exploring the integration of energy meters with smart grid technologies and IoT platforms can provide valuable insights into energy consumption patterns and enable more efficient energy management.

Project Link: https://github.com/pretom-das/AC-Energymeter-Arduino.git