BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 416 (July 2023)

Microprocessor and Embedded Systems Laboratory

Final Project Report

Section: C2 Group: 05

Test Automation of MPPT Solar Charge Controller

Course Instructors:

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Signature of Instructor: ____

Academic Honesty Statement:

IMPORTANT! Please carefully read and sign the Academic Honesty Statement, below. <u>Type the student ID and name, and put your signature</u>. *You will not receive credit for this project experiment unless this statement is signed in the presence of your lab instructor.*

"In signing this statement, We hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, We will each receive a score of ZERO for this project and be subject to failure of this course."

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1 Abstract

This project focuses on the development and comprehensive testing of Maximum Power Point Tracking (MPPT) charge controllers for solar power systems. MPPT controllers play a crucial role in optimizing the efficiency of solar panels by dynamically adjusting their operating points to maximize power output. The abstract outlines various aspects of testing, including efficiency, dynamic performance, tracking accuracy, load handling capability, temperature performance, durability, reliability, communication interfaces, and safety features. Through systematic testing procedures, the project aims to ensure that MPPT charge controllers meet performance specifications, comply with safety standards, and demonstrate reliable operation in diverse environmental conditions. This research contributes to the advancement of renewable energy technology by enhancing the reliability and efficiency of solar power systems through robust MPPT charge controller design and testing methodologies.

2 Introduction

The advent of renewable energy sources, particularly solar power, has revolutionized the landscape of energy generation and distribution. Among the critical components driving the efficiency and reliability of solar photovoltaic systems are Maximum Power Point Tracking (MPPT) charge controllers. These controllers optimize the output of solar panels by continuously adjusting their operating points to extract maximum power from varying environmental conditions.

The "Test Automation of MPPT Solar Charge Controller" project addresses the pressing need for rigorous testing methodologies to ensure the performance, reliability, and safety of MPPT charge controllers. As solar energy continues to gain prominence as a viable alternative to traditional energy sources, the demand for robust testing solutions for MPPT controllers becomes increasingly imperative.

This project aims to develop an automated testing framework specifically tailored to evaluate the performance and functionality of MPPT charge controllers comprehensively. By leveraging automation technologies and advanced testing techniques, the project seeks to streamline the testing process, enhance accuracy, and expedite the identification of potential issues or anomalies.

The introduction of automation into the testing of MPPT charge controllers offers several significant advantages. Firstly, it enables rapid and repeatable testing procedures, ensuring consistent evaluation across various operating conditions and environmental factors. Secondly, automation facilitates scalability, allowing for efficient testing of multiple controller models or iterations simultaneously. Additionally, automated testing reduces the reliance on manual intervention, minimizing human error and enhancing overall testing efficiency.

Key objectives of the project include:

1. Designing and implementing a flexible and modular test automation framework tailored to the specific requirements of MPPT charge controller testing.
2. Integrating the automation framework with appropriate instrumentation and data acquisition systems to facilitate real-time monitoring and analysis of test results.
3. Validating the effectiveness and reliability of the automated testing framework through extensive testing across a range of simulated and real-world operating conditions.

By leveraging automation technologies and systematic testing methodologies, the "Test Automation of MPPT Solar Charge Controller" project aims to contribute to the advancement of renewable energy technology by ensuring the performance, reliability, and safety of critical components in solar power systems.

3 Design

3.1 Problem Formulation (PO(b))

3.1.1 Identification of Scope

Automated testing of MPPT charge controllers encompasses functional, performance, regression, compliance, fault handling, integration, scalability, and extensibility aspects. It verifies accurate MPPT operation under various environmental conditions, ensures compliance with industry standards and regulatory requirements, validates fault detection and error handling mechanisms, and facilitates seamless integration within photovoltaic systems. Automated testing plays a critical role in ensuring the reliability, efficiency, and compliance of MPPT charge controllers, contributing to the overall quality and effectiveness of renewable energy solutions.

3.1.2 Literature Review

1. García et al. (2019) proposed an Arduino-based MPPT charge controller testing system capable of assessing the performance and efficiency of MPPT algorithms under different environmental conditions. Their study demonstrated the feasibility of using Arduino microcontrollers for real-time data acquisition, monitoring, and control in MPPT charge controller testing setups.

2. In a similar vein, Li et al. (2020) presented a comprehensive review of automated testing techniques for MPPT charge controllers, highlighting the role of Arduino platforms in facilitating test automation. Their review encompassed various testing methodologies, including functional testing, performance evaluation, compliance testing, and fault detection, emphasizing the benefits of automation in enhancing testing efficiency and accuracy.

3. Khan et al. (2021) developed a novel Arduino-based MPPT charge controller testing framework incorporating machine learning algorithms for predictive analysis of MPPT performance. Their study demonstrated the potential of combining Arduino-based automation with advanced data analytics techniques to optimize MPPT operation and improve energy harvesting efficiency in solar photovoltaic systems.

4. In a recent study by Patel et al. (2023), the authors investigated the feasibility of utilizing Arduino microcontrollers for automating MPPT charge controller testing. Their research demonstrated the effectiveness of Arduino-based systems in streamlining testing processes and improving efficiency in renewable energy systems. By providing a low-cost and adaptable solution, the study contributes to the advancement of MPPT charge controller testing methodologies, offering practical insights for enhancing the performance and reliability of solar photovoltaic systems.

3.1.3 Formulation of Problem

This project basically requires the knowledge of basic current and voltage sensing by Arduino. The outcomes (P1, P3, P4, P5, P7) can be achieved on completing the project.

In this project we aimed to perform automation of the following MPPT charge controller tests:

1.Factory Preset Set Points:

After confirming the 2 features of the Charge controllers LVD, HVD and others, we can make decision that the factory preset set points are present for the particular battery to be used.

2.Labeling on Charge Controller Casing:

The rating of the MPPT charge controller should be printed on the charge controller casing. Labeling must be checked by the observer.

3. Maximum Drawn Self Current:

For this experiment, we have to keep load terminal and the panel terminal open. The battery terminal should be connected to the charge controller. In this situation we have to measure the current in the charge controller terminal. This current is the self-current of the charge controller. We have to compare the self-current with the maximum value of self current. The measured self current should be less than the maximum value of self current.

4. Input current Rating:

For this experiment , we have to calculate the panel short circuit current. Then we have to compare the input current rating of charge controller with 120% value of panel short circuit current. The input current rating should be 120% higher than the panel short circuit current.

5. Low Voltage Disconnect:

For this experiment, only the load end must be kept connected and the panel and battery ends must be kept open. A variable DC voltage must be applied to the panel end. By gradually decreasing the input voltage, we measure the voltage for which load current becomes zero

6. Reconnecting Voltage:

After disconnecting, we gradually increase the voltage and observe for which voltage value load current gains a significant value.

7. Battery High Voltage Disconnect:

This step is to determine whether overvoltage protection exists in the charge controller. At first, we apply a high voltage in the panel end (around 18V). If the same 18V appears at the battery end, then we conclude that no overvoltage protection exists in the charge controller. Otherwise, if some less voltage appears at the battery end (around 14V) then we can confirm protection exists.

8. Reverse Current Leakage Protection:

For this experiment, we short-connect the panel ends and keep the load terminals open. Some amount of voltage may be present in the battery terminals. If the current flowing through the panel terminals is less than 20A, we can confirm that reverse current leakage protection exists.

9. Short Circuit Protection Test:

For this test, the load terminals must be shorted. Since there is the possibility of a large amount of current flowing through the load terminals, the input current is reduced at the start of this test. We keep the panel end open, apply voltage at the battery terminals and then measure the current. If no or negligible current flows, we can confirm short circuit protection exists.

10. Efficiency Measurement:

For this test, we keep the PV terminals open and keep the battery load at 90%. We then calculate the efficiency of the controller by measuring the current and voltage at battery terminals and load terminals, both at battery charging and discharging state.

3.1.4 Analysis

The development and widespread adoption of solar photovoltaic systems have underscored the importance of efficient and reliable components, particularly Maximum Power Point Tracking (MPPT) charge controllers. These controllers play a pivotal role in optimizing the performance of solar panels by dynamically adjusting their operating points to extract maximum power from varying environmental conditions. However, ensuring the performance, reliability, and safety of MPPT charge controllers presents several challenges that necessitate a comprehensive problem analysis. In our task, we thoroughly tested it in various conditions to ensure proper reliability of this project.

3.2 Design Method (PO(a))

Components:

1. Current Sensor
2. Voltage Sensor
3. LEDs
4. Relay
5. Connector (25A)
6. Arduino Nano
7. MPPT Charge Controller
8. Variable Voltage Source
9. Battery
10. Load
11. 1 ohm power resistor

Methodology:

We connected all the terminals of panel, battery and load to necessary sensors to perform all the tests using necessary sensors. To run the tests, we connected two variable dc sources to both the panel and battery and used dc motors to control the voltage automatically for each test. Using the Arduino nano we wrote the required code to simulate different tests and then send the value to the LCD display.

3.3 Circuit Diagram

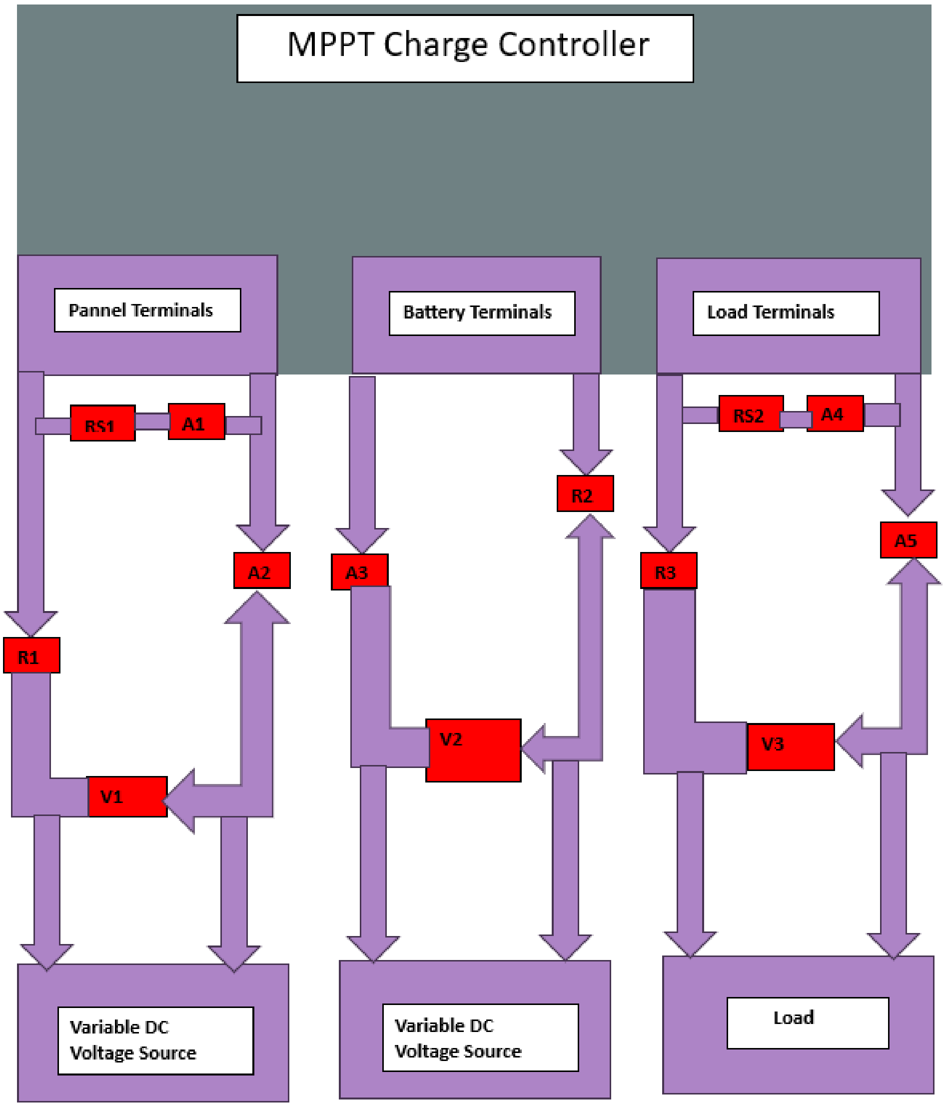


Figure: Circuit Diagram of the project

3.4 Full Source Code of Firmware

```
 #include <Wire.h>
#include <LiquidCrystal_I2C.h>

#define panel_relay 3
#define battery_relay 4
#define load_relay 5
#define v1_read A0
#define v2_read A1
#define v3_read A2
#define enA 9
#define in1 6
#define in2 7
#define enB 10
#define in3 8
#define in4 11

float voltage1;
float voltage2;
float voltage3;
const int pwmOutputA = 45;
const int pwmOutputB = 45;

const float VCC = 5.0;
const float factor = 4.78;

unsigned long startTime = 0;


LiquidCrystal_I2C lcd(0x27, 16, 4); //SDA - A4, SCL -
A5

void setup() {
      Serial.begin(9600);
      lcd.begin();
      pinMode(panel_relay,OUTPUT);
      pinMode(battery_relay,OUTPUT);
      pinMode(load_relay,OUTPUT);
      pinMode(v1_read,INPUT);
      pinMode(v2_read,INPUT);
      pinMode(v3_read,INPUT);
      pinMode(enA,OUTPUT);
      pinMode(in1,OUTPUT);
      pinMode(in2,OUTPUT);
      pinMode(enB,OUTPUT);
      pinMode(in3,OUTPUT);
      pinMode(in4,OUTPUT);

      lcd.clear();
      //lcd.backlight();
      lcd.setCursor(0,0);
      lcd.print("Enter a number:");

      while (Serial.available() == 0) {
      }

      //Serial.println("Low Voltage Disconnect");
      lcd.clear();
      lcd.setCursor(0,0);
      lcd.print("Experiment No.1:");
      lcd.setCursor(0,1);
      lcd.print("Low Voltage");
      lcd.setCursor(0,2);
      lcd.print("Disconnect");


      digitalWrite(panel_relay,LOW);
      digitalWrite(battery_relay,HIGH);
      digitalWrite(load_relay,HIGH);

      //Serial.println("Steadily lower the battery DC
voltage");
      delay(4500);
      //voltage3 =
(analogRead(v3_read)/1024.0)*(VCC*factor);

      startTime = millis();
      while ((millis()-startTime)<=3000){
        digitalWrite(in3, HIGH);
        digitalWrite(in4, LOW);
        analogWrite(enB, pwmOutputB);
        //delay(2500);
        //digitalWrite(in3, LOW);
        //digitalWrite(in4, LOW);

        //Serial.print("Voltage at load terminals: ");
        Serial.print(voltage3,3);
        voltage3 =
(analogRead(v3_read)/1024.0)*(VCC*factor);
        //Serial.print("Voltage at load terminals: ");
        Serial.print(voltage3,3);
        Serial.print(",");


        voltage2 =
(analogRead(v2_read)/1024.0)*(VCC*factor)-1.4;    //
read the current sensor value (0 - 1023)
        //Serial.print("Voltage at battery terminals:
");
        Serial.print(voltage2,3);
        Serial.print(",");

         voltage1 =
(analogRead(v1_read)/1024.0)*(VCC*factor);
         Serial.println(voltage1,3);


         lcd.clear();
         lcd.setCursor(0,0);
         lcd.print("V_panel: ");
         lcd.print(voltage1);
         lcd.print("V");
         lcd.setCursor(0,1);
         lcd.print("V_battery:");
         lcd.print(voltage2);
         lcd.print("V");
         lcd.setCursor(0,2);
         lcd.print("V_load: ");
         lcd.print(voltage3);
         lcd.print("V");
         //delay(1000);
      }
      digitalWrite(in3, LOW);
      digitalWrite(in4, LOW);

      float LVD = voltage2 ;
      //Serial.print("LVD is ");
      //Serial.print(LVD);
      //Serial.println("V");
      //Serial.println("       ");
      //Serial.println("       ");

      lcd.clear();
      lcd.setCursor(0,0);
      lcd.print("LVD = ");
      lcd.print(LVD);
      lcd.print("V");

      digitalWrite(panel_relay,LOW);
      digitalWrite(battery_relay,LOW);
      digitalWrite(load_relay,LOW);
      delay(10000);

      //Serial.println("Test for load disconnect");
      lcd.clear();
      lcd.setCursor(0,0);
      lcd.print("Experiment No.2:");
      lcd.setCursor(0,1);
      lcd.print("Test for");
      lcd.setCursor(0,2);
      lcd.print("Load Disconnect");

      digitalWrite(panel_relay,HIGH);
      digitalWrite(battery_relay,HIGH);
      digitalWrite(load_relay,HIGH);
      delay(1000);
      //Serial.println("Steadily increase the panel DC
voltage");
      lcd.clear();
      lcd.setCursor(0,0);
      lcd.print("Slowly increase");
      lcd.setCursor(0,1);
      lcd.print("Panel Voltage");
      delay(1000);

      startTime = millis();
      while((millis()-startTime)<=4000){
      digitalWrite(in3, LOW);
      digitalWrite(in4, HIGH);
      analogWrite(enB, pwmOutputB);
      //delay(5000);
      voltage3 =
(analogRead(v3_read)/1024.0)*(VCC*factor);
```

```
        Serial.print(",");


        voltage2 = 
(analogRead(v2_read)/1024.0)*(VCC*factor);    // read 
the current sensor value (0 - 1023)
        //Serial.print("Voltage at battery terminals: 
");
        Serial.print(voltage2,3);
        Serial.print(",");

         voltage1 = 
(analogRead(v1_read)/1024.0)*(VCC*factor);
         Serial.println(voltage1,3);


         lcd.clear();
         lcd.setCursor(0,0);
         lcd.print("V_panel: ");
         lcd.print(voltage1);
         lcd.print("V");
         lcd.setCursor(0,1);
         lcd.print("V_battery:");
         lcd.print(voltage2);
         lcd.print("V");
         lcd.setCursor(0,2);
```

Table: Source Code for the main program

4 Implementation

4.1 Description

To implement this project, we took help from a lab instructor. We used voltage and current sensors to do all the tasks. We used Arduino nano to perform all mathematical analysis and used conditions to see if the MPPT has all the required parameters. To automate the process, we used dc motors to rotate the nob of the voltage sources. So, the tests occurred one after another simultaneously.

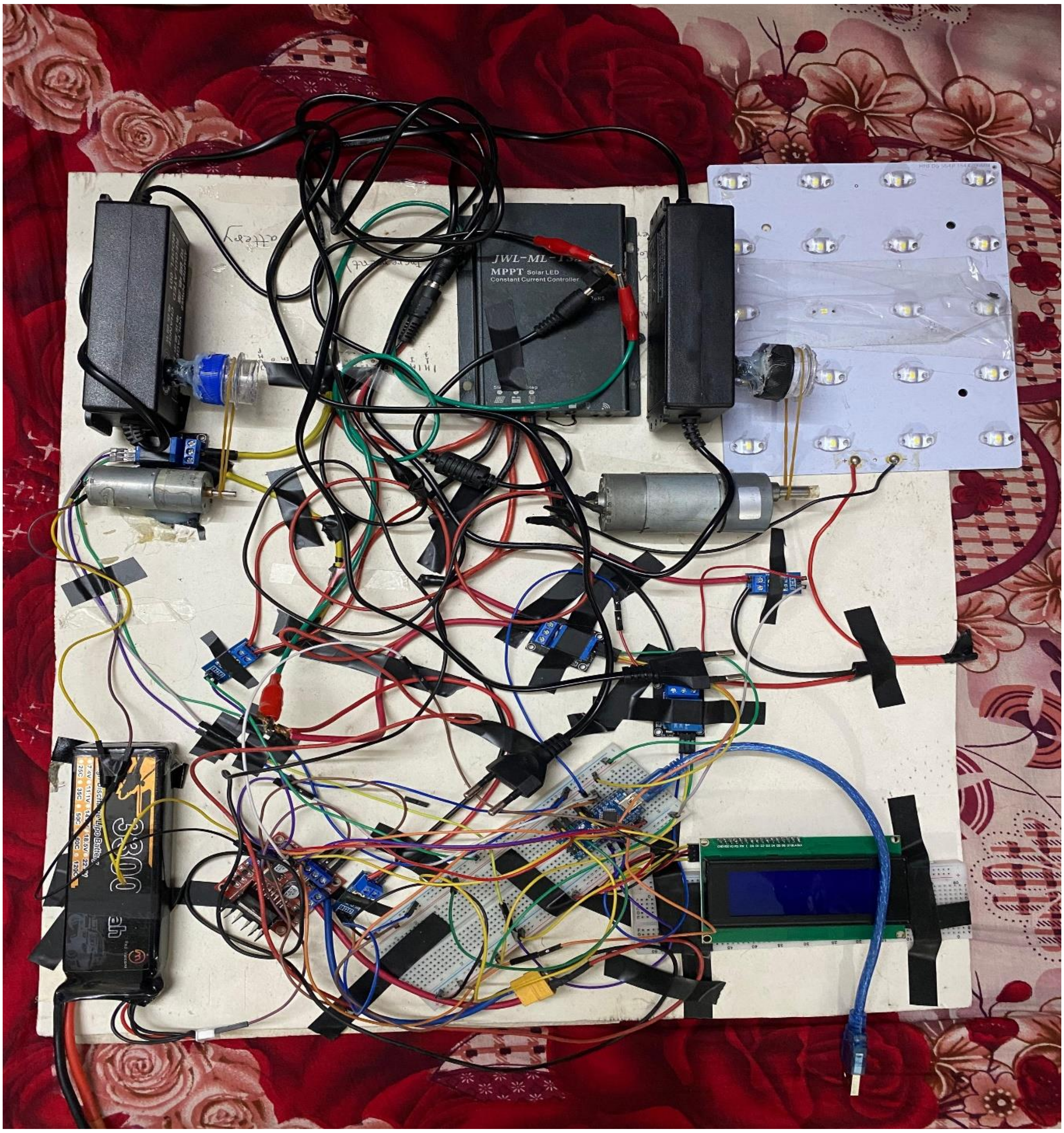


Fig: Our implemented project set-up

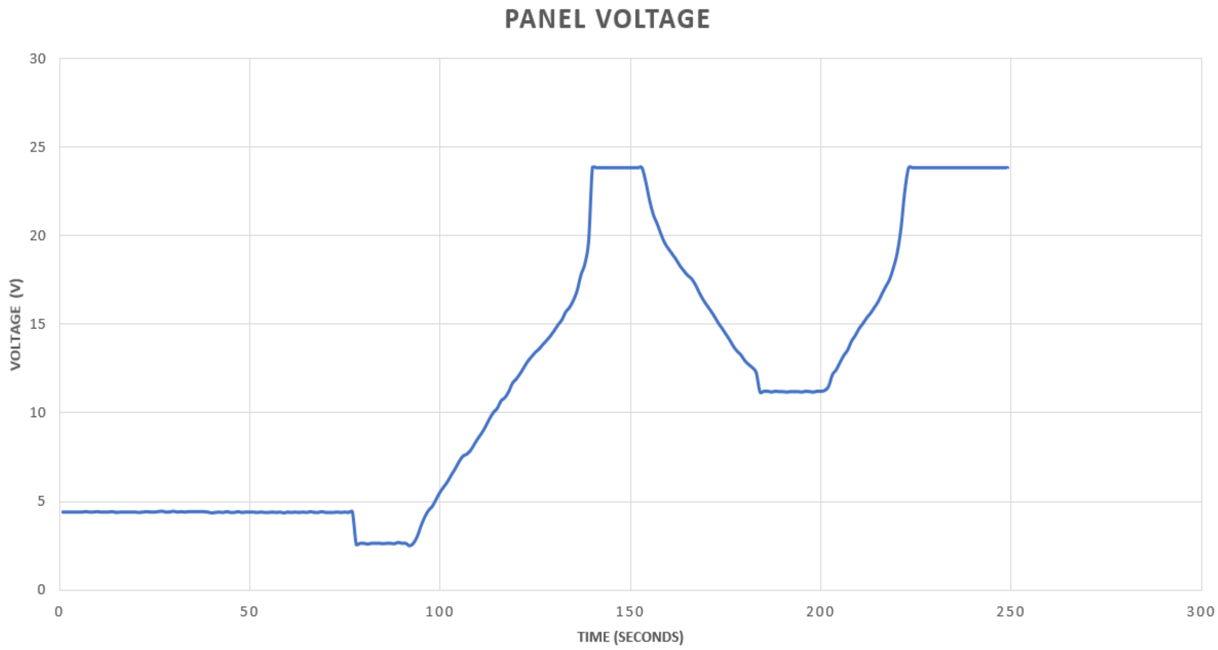
4.2 Experiment and Data Collection

We knew the parameters of the MPPT charge controller and so we sorted the tests accordingly to our needs and used the values to come to a decision whether the device was working properly or working within its specs. We performed the tests in accordance with all the preset values of the MPPT charge controller.

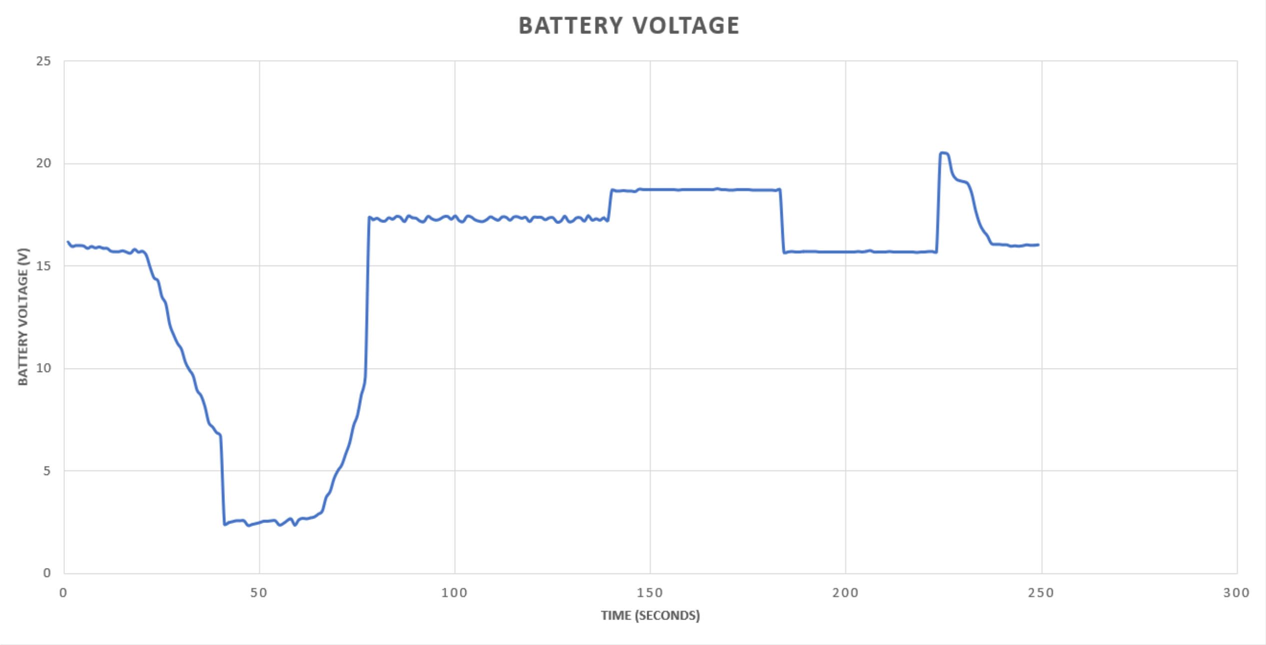
4.3 Data Analysis

Following are the plots of panel voltage, battery voltage and load voltage values recorded throughout our experiment:

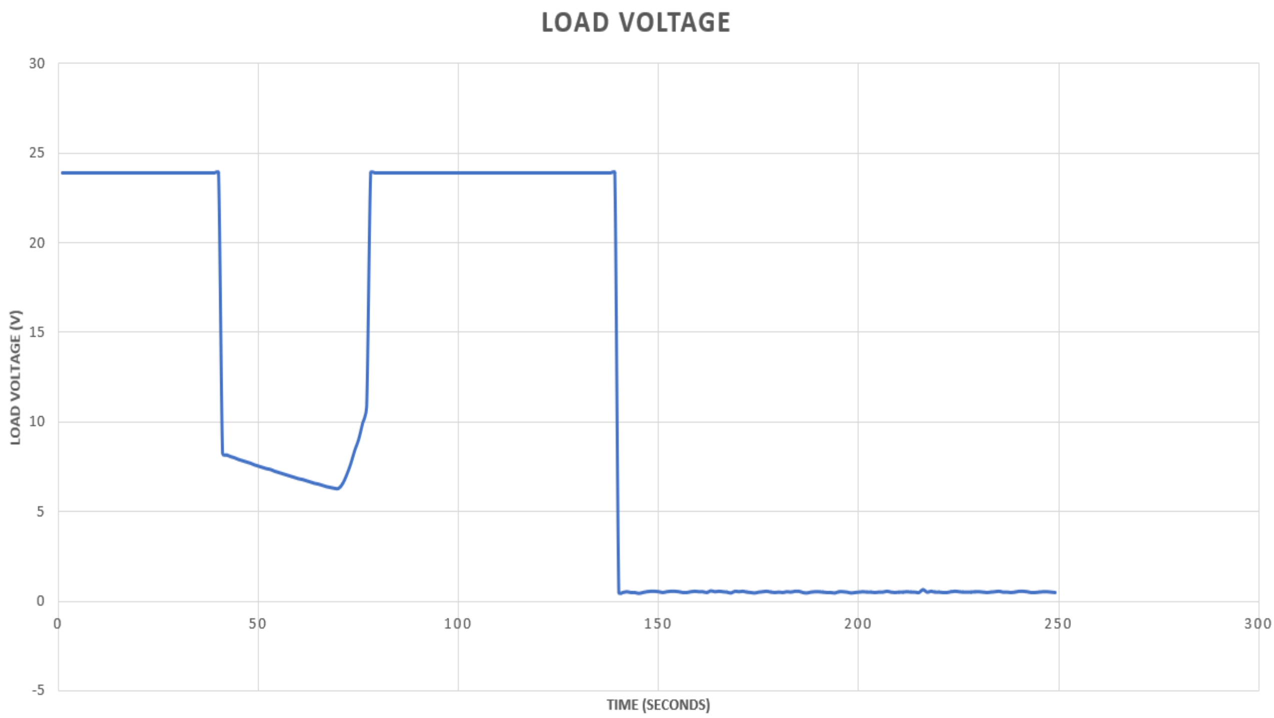
Panel Voltage:



Battery Voltage:



Load Voltage:



4.4 Results

After repeatedly performing tests on our project, we finally obtained the following results:

Low Voltage Disconnect (LVD) value: 6.65V

Reconnecting Voltage Value: 9.95V

Load Disconnect Voltage Value: 19.35V

High Voltage Protection : Sufficient protection does not exist in the charge controller

5 Design Analysis and Evaluation

5.1 Novelty

Our project is novel in the sense that we will automate the tests of an MPPT charge controller using Arduino microcontroller, which otherwise would have been performed manually in the BUET photovoltaics lab. This is both time and energy efficient.

Our project will leverage the use of precisely calibrated sensors that will enhance the accuracy of our project, ensuring the charge controller follows internationally set standards.

5.2 Design Considerations (PO(c))

5.2.1 Considerations to public health and safety

Our design is well within the safe limits of public health and safety. We designed the testing mechanism well so that there is almost no chance of any danger happening to the one testing or the MPPT charge controller itself.

5.2.2 Considerations to environment

The project has been assembled keeping the environment in check. This project aims to test MPPT controllers properly so that we may build a greener future with renewable energy.

5.2.3 Considerations to cultural and societal needs

This project can play an important role to build a better future filled with clean and reliable solar energy that can drive away many societal and cultural issues.

5.3 Limitations of Tools (PO(e))

This project uses various sensors extensively and so any small error in any sensor can hamper the whole goal of this project. These errors may cause faulty checks of MPPT charge controllers thus causing problems in reliability and wasting precious time. While doing the job, we tried our best to calibrate the sensors properly to ensure smooth, reliable and accurate performance of this project.

5.4 Impact Assessment (PO(f))

5.4.1 Assessment of Societal and Cultural Issues

By ensuring the performance, reliability, and safety of MPPT charge controllers, this project contributes to the accessibility of solar energy technologies. Reliable MPPT controllers enable more efficient utilization of solar power, potentially reducing energy costs for households, businesses, and communities. This increased accessibility to clean energy can help mitigate societal cultural issues.

5.4.2 Assessment of Health and Safety Issues

The deployment of solar energy systems facilitated by reliable MPPT charge controllers contributes to the reduction of air pollution and associated health risks. By displacing fossil fuel-based electricity generation, solar power helps to mitigate emissions of harmful pollutants such as particulate matter, nitrogen oxides, and sulfur dioxide, which are known to have adverse effects on respiratory health and cardiovascular function. Thus, this project can have a positive impact on health and safety.

5.4.3 Assessment of Legal Issues

The development and testing of MPPT charge controllers must adhere to relevant regulatory requirements and standards established by governmental agencies and industry organizations. Ensuring compliance with applicable regulations, such as safety standards, electromagnetic compatibility (EMC) directives, and product certification requirements, is essential to mitigate legal risks and ensure market acceptance of the controllers. This project meets all the required rules and regulations.

5.5 Sustainability and Environmental Impact Evaluation (PO(g))

The development of automated testing methodologies for MPPT charge controllers can improve resource efficiency by streamlining testing processes, reducing material consumption, and minimizing energy usage. Automation enables more efficient utilization of testing equipment and resources, thereby reducing waste and environmental impact associated with traditional manual testing methods.

In conclusion, the sustainability and environmental impact evaluation of this project highlights its potential to promote resource efficiency, energy savings, emission reduction, waste reduction and recycling, environmental compliance, and community engagement etc.

5.6 Ethical Issues (PO(h))

As the project involves automation and data collection for testing purposes, ethical considerations include safeguarding the privacy and security of sensitive data. Transparency about data collection practices, informed consent from stakeholders, and robust cybersecurity measures are essential to uphold ethical standards.

By addressing these ethical considerations thoughtfully and proactively, the project can uphold ethical standards, mitigate potential risks, and maximize its positive impact on society, the environment, and stakeholders involved in the development and deployment of MPPT charge controllers.

6 Reflection on Individual and Team work (PO(i))

6.1 Individual Contribution of Each Member

For the implementation of our project, ID 1906175 (Nayem Hasan) and ID 1906176 (Tanvir Rahman) worked with the hardware setup, i.e. the load connections and battery connections with MPPT controller and the overall setup.

ID 1906179 (Samiul Hossain) and ID 1906190 (Tousif Ansari) worked with Arduino and voltage sensing issues with the setup, GUI design, mainly the software portion of the project.

6.2 Mode of Team-Work

We planned to meet in person and online as needed. In the beginning, we held online meetings using teams where we shared ideas, spoke about project goals etc. For communication purposes and to discuss project-related files and ideas, we used a messenger group. We worked offline together and implemented the circuits. As we encountered challenges or obstacles during the project, we have engaged in collaborative problem-solving to find solutions.

7 Communication (PO(j))

7.1 Executive Summary

We're thrilled to announce a groundbreaking leap in solar technology with our latest project: Test Automation for MPPT Charge Controllers. This innovative initiative aims to streamline and enhance the performance testing process, ensuring top-notch efficiency and reliability in solar power systems. By automating tests, we're simplifying the complexity, making it accessible to everyone from tech enthusiasts to industry professionals. With this advancement, we're not just pushing boundaries; we're empowering communities to harness the full potential of renewable energy. Join us in shaping a greener, brighter future through technology that's easy for all to understand.

7.2 User Manual

Our test automation project of MPPT charge controller is very easy to use and simple to understand in the sense that all a user needs to do is to give a keyboard input and all the tests will be performed automatically by the Arduino microcontroller. After the code has been uploaded, the user has to give any input from the keyboard. Thereafter, the microcontroller will sequentially perform the experiments of **Low Voltage Disconnect**, **Reconnecting Voltage, Load Disconnect** and **High Voltage Protection**. At first our system's actuator (a DC motor in our case) will rotate the knob and reduce the battery terminal voltage. The microcontroller will record the voltage for which the load gets disconnected. That voltage is the **Load Disconnect Voltage (LVD).** Afterwards with a 10s delay, the next experiment will start. The actuator will then go on to increase the battery terminal voltage until the load gets connected again. The voltage at which this happens will be recorded and that will be our **Reconnecting Voltage.** Next the battery terminal voltage will be kept fixed and the panel terminal voltage will be increased with the help of another actuator. The voltage will go on increasing until a certain panel voltage will be reached for which the load gets disconnected. That voltage will be our **Load Disconnecting Voltage** and it will be recorded. Finally, our last experiment, **High Voltage Protection Test**, will be performed. For that the actuator will at first reduce the panel terminal voltage to its minimum value and then again gradually increase the voltage to its maximum value of around 25V. The battery terminal voltage will be recorded and observed during this time. If the battery terminal voltage does not go beyond 16V, it means that sufficient overvoltage protection exists in the charge controller. Otherwise, it means that the overvoltage protection system in the charge controller is not of satisfactory levels.

Project Management and Cost Analysis (PO(k))

7.3 Bill of Materials

Arduino Nano – 610

Wire – 40

Relay(2 pcs) – 150

Glue gun – 220

Battery (2 pcs)– 180

Glue stick – 30

Voltage sensor module -400

Current sensor module-1290

LCD display - 550

Total Cost– 3470 Tk

8 Future Work (PO(l))

This project has a lot of potential to be implemented on a large scale to test MPPT controllers swiftly and reliably. To improve this project, we may use digital voltage controllers that can be controlled by microprocessor for greater reliability rather than using dc motos. We can also create a system to send the necessary data found to a database for safe keeping. A PCB design can also be implemented to make this testing project easier to review and understand.

9 References

a) *https://youtu.be/M6QrJl6vfWg?si=AOHfDYHMk82KwIcB*
b) *https://www.researchgate.net/publication/362412213_Design_and_Analysis_of_MPPT_Charge_Controller*