Design and Implementation of an Optimized Solar Home System for Urban Areas using Bifacial Photovoltaic Panel

By

Tanvir Mahmud Mahim
19121012
Adnan Miah
19121056
Begum Fatema Tuz Zohra
19121027
Sahha Munzer
19121101

A Final Year Design Project submitted to the Department of f Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical & Electronic Engineering

ATC Panel Member:

Chair- Tasfin Mahmud, Lecturer, Department of EEE, BRAC University
Member- Md. Rakibul Hasan, Lecturer, Department of EEE, BRAC University
Member- Md. Mehedi Hasan Shawon, Lecturer, Department of EEE, BRAC
Department of Electrical and Electronic Engineering
Brac University
January 2023

Declaration

It is hereby declared that

1. The Final Year Design Project submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

Student's Full Name & Signature:

Tanvir Mahmud Mahim 19121012	**Adnan Miah** 19121056
Begum Fatema Tuz Zohra 19121027	**Sahha Munzer** 19121101

Approval

The Final Year Design Project titled "Design and Implementation of an Optimized Solar Home System for Urban Areas using Bifacial Photovoltaic Panel" submitted by

1. Tanvir Mahmud Mahim (19121012)
2. Adnan Miah (19121056)
3. Begum Fatema Tuz Zohra (19121027)
4. Sahha Munzer (19121101)

of Fall, 2022 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical & Electronic Engineering on 25th January 2023.

Examining Committee:

Academic Technical Committee:
(Chair)

____
Tasfin Mahmud
Lecturer, Dept. of EEE
BRAC University

Final Year Design Project Coordination Committee:
(Chair)

____
Dr. Abu S.M. Mohsin
Assistant Professor, Dept. of EEE
BRAC University

Department Chair:

____
Dr. Md. Mosaddequr Rahman
Professor and Chairperson, Dept. of EEE
BRAC University

Ethics Statement

The 'Design and Implementation of an Optimized Solar Home System for Urban Areas Using Bifacial Photovoltaic Panel' project is devoted to moral and ethical principles. When designing, developing, and deploying our system, we adhered to the IEEE standards for ethical considerations as well as the suggestions of our eminent ATC panel's chair and members. When collecting and utilizing data, we place a strong emphasis on security, privacy, and transparency, and we respect the rights of individuals and communities influenced by the system. We encourage the use of renewable energy sources to reduce environmental impacts. We appreciate the chair and members of our ATC panel's valuable feedback and direction in ensuring that the project adheres to these ethical standards.

Abstract

This study offers a PV system consisting of bifacial PV modules with a single-axis tracking mechanism to address the energy requirements of residential buildings. A customized net metering system is also implemented to monitor the system's power flow. In addition, the proposed system is referred to as a Hybrid Bidirectional Grid-tied system with a single-axis tracking. Furthermore, due to the unavailability of bifacial PV panels and the high cost of the module, a cheaper alternative utilizing two monofacial PV panels was developed. This innovative module was known as a custom-made bifacial PV. Moreover, the experimental setting compared the custom-made bifacial PV to the monofacial PV of identical dimensions. During a one-month period of data gathering, it was found that custom-made bifacial PV were around 20% more efficient than monofacial PV. Moreover, during midday, the efficiency of custom-made bifacial PV was as much as 40% higher than that of monofacial PV.

Keywords: Bifacial Photovoltaic, Monofacial Photovoltaic, Custom-made Net-meter, Single-axis Tracking System

Dedication

This Final Year Design Project is a tribute to our devoted parents, who helped shape who we are today through nurturing us, being there for us whenever we needed them, and providing us with unwavering love and kindness.

Acknowledgement

All gratitude belongs to the Almighty Allah, who enabled us to accomplish our Final Year Design Project on schedule and without encountering any major obstacles. We would like to express our sincere appreciation to our esteemed supervisor, Dr. A. H. M. Abdur Rahim Professor of BRAC University and Tasfin Mahmud Lecturer BRAC University, for their unparalleled guidance and for his ongoing encouragement and support throughout the thesis study. We owe him a huge gratitude note for his tireless efforts, professionalism, and invaluable advice, all of which prepared the way for the successful completion of this Final Year Design Project work.

Table of Contents

Declaration ii
Approval iii
Ethics Statement iv
Abstract v
Dedication vi
Acknowledgement vii
Table of Contents viii
List of Tables xii
List of Figures xiii
List of Acronyms xvi
Chapter 1: Introduction 1
1.1 Introduction 1
1.2 Problem Statement 1
1.3 Background Study and Literature Review 1
1.4 Relevance to current and future Industry 2
1.5 Objectives, Scope, Requirements, Specification and Constraints 3
1.5.1 Objectives and Scope 3
1.5.2 Requirements [Functional and Non-functional] 3
1.5.3 Specifications 6
1.5.4 Constraints 6
1.6 Applicable compliance, standards, and codes 6
1.7 Systematic Overview/summary of the proposed project 7
1.8 Conclusion 8
Chapter 2: Project Design Approach 9
2.1 Introduction 9
2.2 Identify multiple design approach 9
2.2.1 Design 1 9
2.2.2 Design 2 10
2.2.3 Design 3 10
2.3 Describe multiple design approach 11
2.3.1 Design 1 11
2.3.2 Design 2 11
2.3.3 Design 3 11
2.4 Analysis of multiple design approach 11
2.5 Conclusion 12
Chapter 3: Use of Modern Engineering and IT Tool 13
3.1 Introduction 13

3.2 Select appropriate engineering and IT tools 13
3.2.1 Comparison of PVsyst. Homer Pro, PVPlanner and RETscreen 13
3.2.2 Comparison of MATLAB Simulink, LabVIEW and Scilab Xcos 14
3.3 Use of modern engineering and IT tools 15
3.3.1 PVsyst 15
3.3.2 MATLAB Simulink 16
3.4 Conclusion 17
Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution 18
4.1 Introduction 18
4.2 Optimization of multiple design approach 18
4.2.1 Design 1 18
4.2.1 Design 2 24
4.2.2 Design 3 31
4.3 Identify optimal design approach 38
4.3.1 Comparing the multiple design approaches 38
4.3.2 Comparison with Mono-facial and Bifacial hybrid system 38
4.4 Performance evaluation of developed solution 40
4.4.1 System Validation of the developed solution 40
4.4.2 Sun detection algorithm 46
4.4.3 The tracking system 49
4.5 Conclusion 54
Chapter 5: Completion of Final Design and Validation 55
5.1 Introduction 55
5.2 Completion of final design 55
5.2.1 Subsystem 1: Solar Utility System (SUS) 55
5.2.2 Subsystem 2: Netmetering System (NS) 56
5.2.3 Subsystem 3: Single Axis Tracking System (SATS) 58
5.2.4 Complete System diagram 59
5.2.5 Net-meter diagram 61
5.3 Evaluate the solution to meet desired need 61
5.3.1 Weather parameters 62
5.3.2 PV panels parameters 63
5.4 Problems faced and troubleshooting 65
5.4.1 Drawback of PZM sensor 65
5.4.2 Custom made net-meter 66
5.4.3 Issue with the relay 66
5.4.4 Power management for the system 66
5.4.5 Issue with barometric sensor 67
5.4.6 Wire problem 67

5.5 Conclusion ... 68
Chapter 6: Impact Analysis and Project Sustainability ... 69
6.1 Introduction ... 69
6.2 Assess the impact of solution ... 69
6.3 Evaluate the sustainability ... 70
6.4 Conclusion ... 71
Chapter 7: Engineering Project Management ... 72
7.1 Introduction ... 72
7.2 Define, plan and manage engineering project ... 72
7.2.1 FYDP 400C plan ... 72
7.2.2 Complete Project plan ... 73
7.3 Evaluate project progress ... 73
7.4 Conclusion ... 74
Chapter 8: Economical Analysis ... 75
8.1 Introduction ... 75
8.2 Economic analysis ... 75
8.2.1 Design 1 ... 75
8.2.2 Design 2 ... 77
8.2.3 Design 3 ... 79
8.2.4 Prototype ... 81
8.3 Cost benefit analysis ... 82
8.3.1 Design 1 ... 82
8.3.2 Design 2 ... 83
8.3.3 Design 3 ... 83
8.4 Evaluation economic and financial aspects ... 84
8.5 Conclusion ... 84
Chapter 9: Ethics and Professional Responsibilities ... 86
9.1 Introduction ... 86
9.2 Identification of ethical issues and professional responsibilities ... 86
9.3 Application of ethical issues and professional responsibilities ... 86
9.4 Conclusion ... 87
Chapter 10: Conclusion and Future Work ... 88
10.1 Project summary ... 88
10.1.1 Simulation summary ... 88
10.1.2 Prototype summary ... 89
10.2 Future work ... 90
Chapter 11: Identification of Complex Engineering Problems and Activities ... 92
11.1 Attributes of Complex Engineering Problems (EP) ... 92
11.2 Reasoning how the project address selected attribute (EP) ... 92

11.3 Attributes of Complex Engineering Activities (EA) ... 92
11.4 Reasoning how the project address selected attribute (EA) ... 93
References ... 94
Appendix ... 96
I. Arduino mega and ESP8266 connections ... 96
II. Arduino mega and ESP8266 code ... 96
Arduino mega code ... 96
Esp8266 code ... 104
III. Arduino uno connections ... 108
IV. Arduino uno code ... 108

List of Tables

TABLE I. Total daily energy usage of home appliances ... 3
TABLE II. Specifications of all the components we will use in our project ... 6
TABLE III. compliance, Standards and Codes ... 6
TABLE IV. Comparison of PVsyst, Homer Pro, PV Planner and RETscreen ... 13
TABLE V. Comparison of Simulink, LabVIEW and Scilab Xcos ... 14
TABLE VI. System production and economic evaluation of design 1 ... 20
TABLE VII. Operation parameters, shed parameters and electrical effects of design 2 ... 25
TABLE VIII. Daily irradiance on ground and sky ... 27
TABLE IX. System production and economic evaluation of design 2 ... 28
TABLE X. Operation, tracker and ground parameters; daily irradiance on ground and sky ... 32
TABLE XI. System production and economic evaluation of design 3 ... 34
TABLE XII. Comparison of the three design approaches ... 38
TABLE XIII. Comparison of mono-facial and bifacial based hybrid system ... 40
TABLE XIV. Impact analysis of the developed solution ... 69
TABLE XV. Swot analysis ... 70
TABLE XVI. Sustainability of the developed design ... 70
TABLE XVII. Allocated persons, starting and ending dates for FYDP 400C tasks ... 72
TABLE XVIII. Allocated persons, starting and ending dates for FYDP 400 [P_D_C] ... 73
TABLE XIX. Total budget of Design 1 ... 75
TABLE XX. Maintenance costs of design 1 ... 75
TABLE XXI. Financial Analysis of design 1 ... 76
TABLE XXII. Total budget of Design 2 ... 77
TABLE XXIII. Maintenance costs of design 2 ... 77
TABLE XXIV. Financial Analysis of design 2 ... 78
TABLE XXV. Total costs of design 3 ... 79
TABLE XXVI. Maintenance costs of design 3 ... 79
TABLE XXVII. Financial Analysis of design 3 ... 81
TABLE XXVIII. Prototype budget ... 81
TABLE XXIX. Comparison of financial summary for design 1, 2 and 3 ... 84
TABLE XXX. Ethical consideration for the design ... 86
TABLE XXXI. Design summary ... 88
TABLE XXXII. System's lifecycle CO2 emission ... 89
TABLE XXXIII. Total power generation from the prototype system ... 89
TABLE XXXIV. Prototype summary ... 90

List of Figures

Fig. 1. Hourly use of household consumption per day 3
Fig. 2. Array voltage sizing of the PV Panels 4
Fig. 3. Site plan [location requirement] 5
Fig. 4. System flow diagram 7
Fig. 5. Standalone system (fixed axis tiled) 9
Fig. 6. Hybrid Bidirectional Grid connected system (mutual shading – fixed axis tilted) 10
Fig. 7. Hybrid Bidirectional Grid connected system (single axis tracking system) 10
Fig. 8. Use of PVsyst in the project 16
Fig. 9. Use of MATLAB Simulink in the project 17
Fig. 10. Perspective of PV-field and surrounding shading scene 18
Fig. 11. Tilt type fixed axis of 23 degrees 19
Fig. 12. Yearly optimization of the fixed tiled plane 19
Fig. 13. Iso-shedding diagram 20
Fig. 14. Normalized productions (per installed KW-p) 21
Fig. 15. Monthly performance ratio 22
Fig. 16. Loss diagram of standalone system [Sankey diagram] with fixed axis tilt 23
Fig. 17. Perspective of PV-field and surrounding shading scene 24
Fig. 18. Mutual shading-tilt type fixed axis of 23 degrees 24
Fig. 19. Optimization of mutual shading 25
Fig. 20. Mutual shading factor 26
Fig. 21. Iso-shedding diagram 26
Fig. 22. Hourly irradiance [mutual shading] 27
Fig. 23. Normalized productions (per installed KW-p) 28
Fig. 24. Monthly performance ratio 29
Fig. 25. Loss diagram of hybrid system [Sankey diagram] with mutual shading 30
Fig. 26. Perspective of PV-field and surrounding shading scene 31
Fig. 27. Horizontal tracking system and tracking angle limits 31
Fig. 28. Distance to panel above planted surface 32
Fig. 29. Hourly irradiance [single axis tracking] 33
Fig. 30. Iso-shedding diagram 34
Fig. 31. Normalized productions (per installed KW-p) 35
Fig. 32. Performance ratio 36
Fig. 33. Loss diagram of hybrid system [Sankey diagram] with single axis tracking 37
Fig. 34. Mono-facial PV panel-based hybrid system's data 38
Fig. 35. Sankey diagram of Mono-facial PV panel-based Hybrid system 39
Fig. 36. Over all Simulink Diagram PV system 41

Fig. 37. PV system setup....41
Fig. 38. Irradiance pattern....41
Fig. 39. Block diagrams under Solar Panel system block in Simulink....42
Fig. 40. Boost converter....42
Fig. 41. Charge controller....43
Fig. 42. Buck converter inside the charge controller....43
Fig. 43. Battery bank....44
Fig. 44. Inverter....44
Fig. 45. Comparison of supplied output voltage Home and Grid....45
Fig. 46. Waveform validation....45
Fig. 47. Sunny day and cloudy day power data of one year [on average from last 5 years]....46
Fig. 48. Spectral analysis of the sunny day cloudy day power....47
Fig. 49. Algorithm for sunny detection....48
Fig. 50. Sunny detection....48
Fig. 51. Panel equation of motion implemented in Simulink....49
Fig. 52. Position scope panels velocity increasing with time with positive torque....49
Fig. 53. Position scope panels velocity decreasing with time with negative torque....50
Fig. 54. Motor equation [DC motor]....50
Fig. 55. Sun position and panel position....51
Fig. 56. Testing the controller with real data [sun position data]....52
Fig. 57. Sun position data....52
Fig. 58. Controller tracking the sun....52
Fig. 59. System block diagram of power generation [custom function block]....53
Fig. 60. Power generated from the system [scaled version]....53
Fig. 61. Flowchart of subsystem 1....55
Fig. 62. Flowchart of subsystem 2....56
Fig. 63. Custom made net-meter a) outside of net-meter b) inside of net-meter....56
Fig. 64. Condition 1 validation....57
Fig. 65. Condition 2 validation....57
Fig. 66. Condition 3 validation....57
Fig. 67. Flowchart of subsystem 3....58
Fig. 68. Images of protype system, a) single axis tracking setup b) connectors of the main board including sensors and solar panel 1 [bifacial] and 2 [monofacial] c) connectors of the control board form tracking system and d) LDR sensor connection design....58
Fig. 69. System connection diagram....59
Fig. 70. Net-meter connection diagram....61
Fig. 71. Per minute data of various collected temperature [30-day average]....62
Fig. 72. Per minute data of air humidity and pressure [30-day average]....63

Fig. 73. Generated power at per minute rate from sunrise to sunset [30-day average]........................ 63
Fig. 74. Efficiency at per minute rate from sunrise to sunset [30-day average] 64
Fig. 75. AC current and voltage sensor [for system power flow measurement].................................. 66
Fig. 76. Relay: a) malfunctioning relay and b) replaced relay 66
Fig. 77. Buck converter: a) supplying power to Arduino mega and connect sensors, modules b) supplying power to Arduino uno, sensors and motor drivers. 67
Fig. 78. BMP180 sensor... 67
Fig. 79. Wire: a) narrow wire b) solar DC wire 68
Fig. 80. Gantt chart [EEE400_C].. 72
Fig. 81. Gantt chart [1-year plan].. 73
Fig. 82. Income allocation for standalone system.. 82
Fig. 83. Income allocation grid tied system [mutual shedding]... 83
Fig. 84. Income allocation hybrid grid tied system [single axis tracking] 83
Fig. 85. Saved CO2 Emission vs. Time 88
Fig. 86. Weekly energy generation of the protype system [one month period].................................... 90
Fig. 87. Arduino mega and ESP8266 port connections 96
Fig. 88. Arduino uno port connections 108

List of Acronyms

EPP: Efficiency of PV panels 74

NS: Netmetering System........ 66

SATS: Single Axis Tracking System........ 68

SUS: Solar Utility System 65

Chapter 1: Introduction

1.1 Introduction

Solar energy is one of the best renewable energy sources to produce emission-free electricity to maintain a net zero emission balance. An exponential growth has been noticed over last few decades in solar panel installations. Solar home systems are far more financially sustainable than domestic power for urban areas and households with moderate financial states. Based on incident irradiation, PV panels can be of two types, i) Monofacial and ii) Bifacial. The most promising PV module advancement today is bifacial Technology. The structure of bifacial is unlike the structure of the mono facial panel. Monofacial are mainly glass-back sheet type and energy collected only from front side. On the other hand, bifacial PV panels are of glass-glass and glass-back sheet types and energy is collected from both front and rear side which is the main attraction of bifacial PV panel. Bifacial PV panels can absorb irradiation from its both front and rear sides whereas the mono facial PV panel can only collect photons from its front side. Currently, monofacial PV panels are dominating the market but bifacial PV panels have the ability to attract interest and by estimated 2030 the share in PV market will rise up to 30% [1]. The cost of solar panels has been falling over the last several decades, and on the other hand, the cost of electricity from utility grids has been progressively rising, which has led to an increase in solar panel installations worldwide. A solar home system could be beneficial to urban businesses, and to fulfill household electricity needs. Rooftop solar home system installation is more preferable to the people in many ways, including full-price and installment purchases.

1.2 Problem Statement

It is necessary to explain conventional testing procedures since bifacial modules cannot be evaluated in the same way as monofacial modules. However, the photovoltaic sector is interested in this technology due to the potential benefit. The technology behind bifacial panels is not new, but their popularity is. White back sheet against glass are the primary structural and material differences between monofacial and bifacial PERC (Passivated Emitter and Rear Cell.) modules, and the industry is growing more confident in the long-term performance of bifacials. Another crucial point is that if bifacial module prices fall further, so will the output increase needed to offset higher upfront costs. Although bifacials' annual output growth is often estimated to be between 6% and 10%, the upfront costs might only ask for a much smaller percentage [2]. Since bifacial solar panels produce more energy annually than monofacial solar panels, the percentage of energy generation that increases as albedo increases is higher.

1.3 Background Study and Literature Review

Solar home systems can be a more effective alternative to conventional electricity because only 4.2 million out of 25 million households have access to it [3]. According to the weather and energy demand, researchers are currently attempting to improve the efficiency of solar powered energy systems utilizing various forms of tracking systems [4]. It appears that improved solar system tracking results in increased electricity production [5]. There are several tracking systems, including single-axis and dual-axis solar trackers, that are available to increase the efficiency of photovoltaic modules [4]. It is crucial to emphasize the potential for combining these technologies to increase the technical and financial viability of photovoltaic facilities. According to the findings, the bifacial gain ranges from 3.78% to 8.16%, the monofacial panels using tracker gain ranges from 13.40% to 18.20, and the bifacial modules and trackers ranges from 19.39% to 27.39 [6]. According to recent studies, using bifacial PV modules can increase annual PV energy production by up to 20% [7]. Additional benefits of bifacial PV panels include lower operating temperatures, higher open circuit voltage, and less parasitic infrared radiation absorption from the majority of solar cells, which reduces recombination losses [8], [9]. When the surface has a greater albedo value, the power derivation of monofacial and bifacial PERC (Passivated Emitter and Rear Cell) PV modules rises. Bifacial PV panels absorb solar light in both side cells to produce a higher energy density [8]. Albedo value can boost output energy by 30% if it is increased to between 0.25 and 0.5 and varied with an elevation of 1 meter [10]. Bifacial PV modules have an energy yield percentage that is 6% higher and can rise to 10% because photons that are dispersed and reflected off the ground and other surfaces are collected. Bifacial PV modules can increase energy generation by between 10 and 30 percent [11]. In the photovoltaic thermal (PVT) solar system, PV panels may convert sunlight into electrical and thermal energy at the same time [12]–[20]. The front and backside efficiency are determined by the bi-faciality index, and bifacial gain is the power generated by bifacial PV modules [21]. Bi-faciality index is a technique used to assess the effectiveness of both front and rear side efficiencies [8]. The efficiency of the PV module is determined by a number of elements, including solar irradiation absorption rate, PV array sizing, reliability analysis, panel degradation, ambient temperature, thermal and electrical behavior, and albedo value. These criteria indicate that bifacial PV modules are more effective than monofacial PV modules [22]. A monofacial PV module needs a larger area to produce the same amount of electricity as a bifacial PV panel [7], [23]. According to study, the yearly energy collection rate of bifacial PV modules attached to a sun tracker is 80% higher than that of a monofacial panel that is fixed [24]. In reality, utilizing a single or double axis solar tracker has an impact on bifacial gain and albedo value, and it produces more energy that can be converted into thermal and electrical energy [24], [25]. According to observations, bifacial solar panels provide more energy annually than monofacial solar panels [9]. This long-term electrical and thermal performance of bifacial PV system design is generating interest [26]. The external surface of a ventilated exterior made of solar modules has a dual purpose: it reduces the building's warming while also generating energy from renewable sources [27].

1.4 Relevance to current and future Industry

Bifacial modules, which date back to the 1960s, are one of the most established advancements in solar panel technology. It is also one of the most recent innovations to catch on. But many professionals assert that it is currently on course to become the newest trend to sweep the solar sector and will soon become the norm [28]. Bifacial solar market size was estimated at US$ 3.37 billion in 2021, and from 2022 to 2027, total revenue is anticipated to increase by 16%, or roughly US$ 8.20 billion. Monocrystalline solar panels would see the quickest Compound Annual Growth Rate of 19.61% over the projection period. The highest efficiency levels, which are typically between 15% and 20%, are found in this solar panels. Bifacial Solar Panel/Bifacial Solar Module is anticipated to expand at a Compound Annual Growth Rate of 18.71 percent in the Commercial sector over the course of the projected period (2022-2027). Due to a rise in the commercial sector's demand for electricity at peak times. In the commercial sector, a system with bifacial panels and solar trackers generated 27% more solar energy than a comparable-sized system with conventional panels [29]. In late 2019, 224 MW, the largest bifacial plant to date, was finished. It is anticipated that growth will continue. Bifacial modules will make up 17% of the global market for solar panels in 2024, predicts Wood Mackenzie Consultancy [28]. The unpredictable power production of a bifacial solar panel is its biggest drawback. It is very reliant on the substrate that supports the modules. Additionally, the mounting structure differs from that of a typical module. For the intended output, the installer must utilize the correct mounting arrangement. For optimal performance, these panels must be installed at a specific height and angle [30]. Numerous large-scale solar projects have been and are still being constructed using bifacial solar modules. These bifacial installations show how this technology has become more popular around the world. These notable developments are listed below: An 870-acre solar farm was finished in 2021 at Robins Air Force Base in Georgia to power the base. One of the biggest solar projects in Texas will be completed in 2021 with the Taygete Energy Project in Pecos, Texas, which will have 344 MW of solar power. A 224 MW power generation project in Mitchell County, Georgia, was started by LONGi in 2019. The power generation facility will be the biggest "bifacial plus tracker" project in the country [31]. The next big innovation in solar energy is being praised as bifacial solar panels. Bifacial panels appear destined to gain popularity in the solar industry as they produce more electricity. The industry is now still having trouble controlling the variables that go into estimating the output of bifacial modules as well as the costs associated with maximizing the power these modules provide. But as data and technology advance, these challenges are being gradually solved.

1.5 Objectives, Scope, Requirements, Specification and Constraints

1.5.1 Objectives and Scope

Our main objective in this project is:

- Solar home system design.
- Analyzing the system with collected data for an optimized system.
- Data validation.
- Performance study.
- Analyzing a cost-effective way of a solar home system.
- Monitoring the solar home system for safety analysis.

The scope of this project is:

- Providing electricity to an urban house-hold equipment.
- Use of zero-emission power generating source (such as Photovoltaic system).
- Using a rooftop solar system.
- Use of bifacial Solar Panel to increase efficiency of the system.
- Lessening the power demand over national-grid.
- Self-dependent power generation.
- Monitoring of the energy usage to mitigate excess use of electricity.

1.5.2 Requirements [Functional and Non-functional]

a. Functional requirements

❖ Load and energy requirements:

Here we have set the load and energy requirement for an average user of our proposed solar home system. Here an average user has lamps (LED or Fluo), TV/ PC/ Mobile, Domestic appliances, Fridge/ Deep-freeze and we are assuming standby consumers to be 24hr [standby means while no one is at home some electrical appliances might get left on for the entire 24hr such as light bulbs or any other necessary appliance etc.]: -

TABLE I. TOTAL DAILY ENERGY USAGE OF HOME APPLIANCES

Appliance	Use [Hour/day]	Quantity	Power (W)	Energy (W/day)
Lamps (LED or fluo)	4	6	10 W/lamp	240
TV/ PC/Mobile	3	1	75 W/app	225
Domestic appliances	3	3	200 W/app	1800
Fridge/ Deep-freeze	24	1	0.8 KW/day	799
Stand-by consumers	24	-	-	144
Total daily energy				**3208 W-h/day**

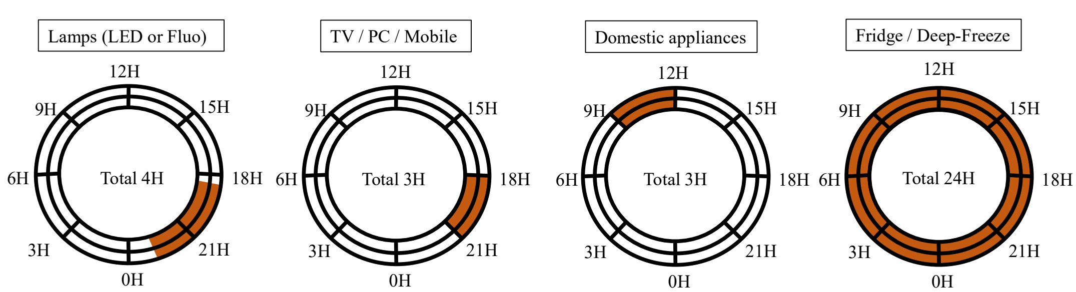


Fig. 1. Hourly use of household consumption per day

Here Fig. 1 illustrates the amount of time an appliance is being under usage by the owner throughout a 24-hour time window.

❖ Inverter:

Inverter rating for this kind of user requirement should be 1.3 KW-ac with an operating voltage of 22-48 volts. And Pnom ratio is = 1.12 (DC-AC).

❖ Battery size and charging current:

Battery rating would be 12V/ 100Ah and the number of units would be required is 4 unit. Max charge power is 1.1 KW-DC. Maximum efficiency would be 97 percent. The stored energy from the four unit will be 3.8 KW-h. The battery packs characteristics would be voltage = 48V and nominal capacity = 100Ah and the ambient temperature of the battery should maintain around 20 degrees Celsius.

❖ Renewable energy source:

Photovoltaic panel (PV) is required. Here we are using Bifacial PV module and one panel would have nominal power = 350 Wp. The number of PV module is required for this project is 4 and the Nominal (STC) is 1400Wp. The module area is approximately $8m^2$.

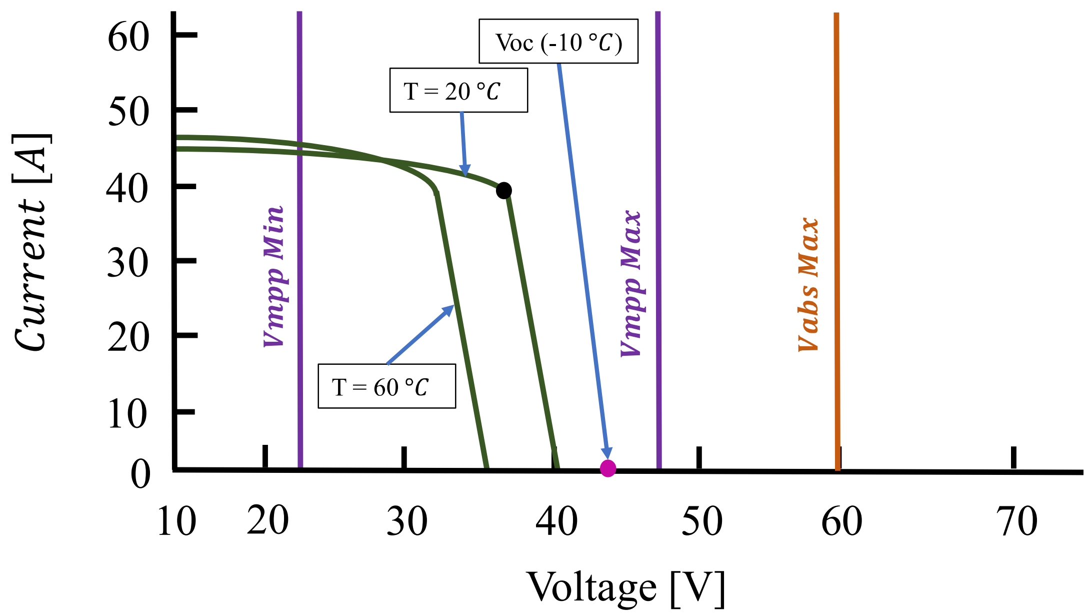


Fig. 2. Array voltage sizing of the PV Panels

Here, form Fig. 2, it can be observed that the bifacial panel we are using can operate in the temperature range of 60 $°C$ to 20 $°C$ but for example if the temperature is at an extreme situation such -10 $°C$, then the PV module won't function properly. From the graph we can observe that at V_{mpp} maximum the current is minimum and at V_{mpp} minimum the current is maximum.

❖ Location requirement:

The location requirements are the followings

- We will install the solar home system on a building's rooftop which is a 7 storied building which has longitude 27.2046° N and latitude 77.4977° E.
- Sunlight reaches the site easily from early morning till 5 pm.
- The roof has an 18m-by-18m dimension and has adequate availability of rainwater pipe and vent pipe to prevent water from getting stuck in the rainy season, the vent pipe is for the junk and waste items to be ventilated.

- In Fig. 3, the shady and non-shady regions are identified.

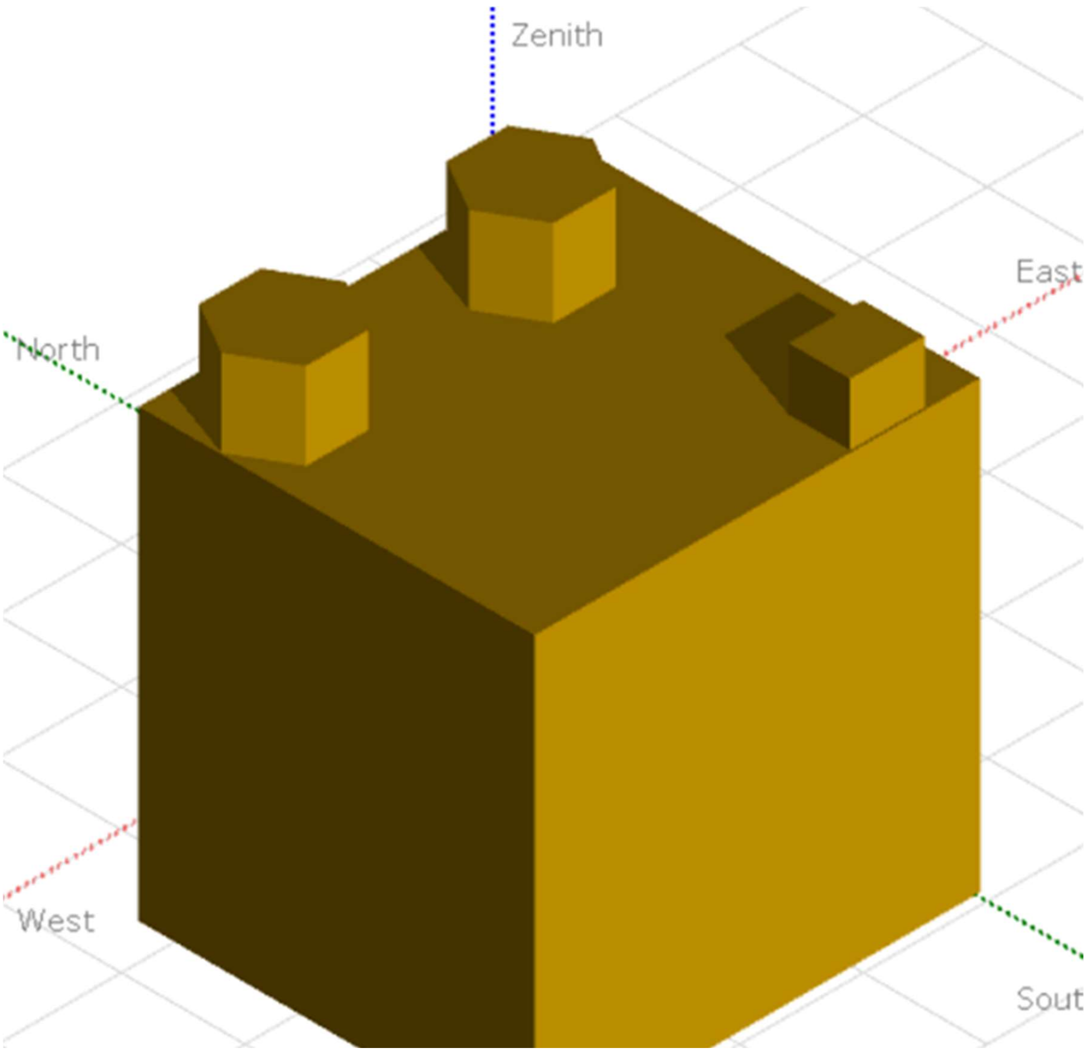


Fig. 3. Site plan [location requirement]

- Design of a charge controller that matches the PV array and battery voltages. We have chosen operating mode of the charge controller in direct coupling mode. The controller type is universal direct controller with Voltage 24V and current ranges from (64A – 27A)
- Plain and smooth surface at the bottom of the PV module.

b. Non-Functional requirements

The following are the technical and non-technical contains of the project, regardless of these constraints there maybe unexpected constrains that may come ahead while the project is implemented

- Monitoring the solar home system for safety analysis.
- PV installations must be operating for many years with little maintenance after their initial set-up.
- The system must be efficient to produce maximum electric power.
- To have a white-colored wall around the site to get better light irradiance.

1.5.3 Specifications

TABLE II. SPECIFICATIONS OF ALL THE COMPONENTS WE WILL USE IN OUR PROJECT

Sub-system	System specification	System Component
Photovoltaic Module	Si-mono (350W-p, Voc (-10 degree) =44.1V, Vmpp (60 degree) = 28.8V)	4 photovoltaic panels [350watt*4 = 1400W-p]
Charge Controller	DC-DC (Universal direct charge controller) (24V, [64A-27A])	MOSFET, Diode, Relay
Tracking System	Here with respect to the designs [two in our case] in the second design we will need two trackers.	LDR sensor, resistors, microcontroller, actuators
Monitoring	Temperature range (24deg – 30deg), Barometric pressure range (101,325 Pa - 100,000 Pa) Dust particle measurement (PM2.5 [particulate matter 2.5])	Temperature sensor, barometric pressure sensor, dust particle sensor, microcontroller

1.5.4 Constraints

- The availability of each and every component required for the project, is a technical constraint.
- One of the biggest roadblocks is the lack of bifacial PV modules in Bangladesh.
- Many people don't know how to properly maintain their existing Photovoltaic panels.
- Poor maintenance is also a factor in the general public's lack of knowledge about solar home systems.
- Producer and customer restrictions include a lack of promotion, a bad economy, and client unawareness.
- Improper site selection for solar panel configurations is another major source of energy output degradation.
- Dependence on weather conditions.

1.6 Applicable compliance, standards, and codes

The applicable compliance, standards and codes that this project will abide by are in the following TABLE III. The name and purpose of the specific conducts are described in the TABLE III.

TABLE III. COMPLIANCE, STANDARDS AND CODES

Code	Name	Purpose
ISO 9060:2018	(Solar energy) Specification and classification of instruments for measuring hemispherical solar and direct solar radiation	We will follow this code to observe the atmosphere, where the system will be installed and will also observe the solar radiation.
ISO 9060:2018	(Solar energy) Reference solar spectral irradiance at the ground at different receiving conditions — Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5	We will follow this code to observe the solar irradiance level at the site the system will be installed.
IEC TS 63217:2021	Utility-interconnected photovoltaic inverters - Test procedure for over voltage ride-through measurements	We will follow this code to properly use the inverter for safer interfacing.
IEC TS 62727:2012	Photovoltaic systems - Specification for solar trackers	We will follow this code to have a proper interfacing over the individual components of the tracking system in the solar powered system.

1.7 Systematic Overview/summary of the proposed project

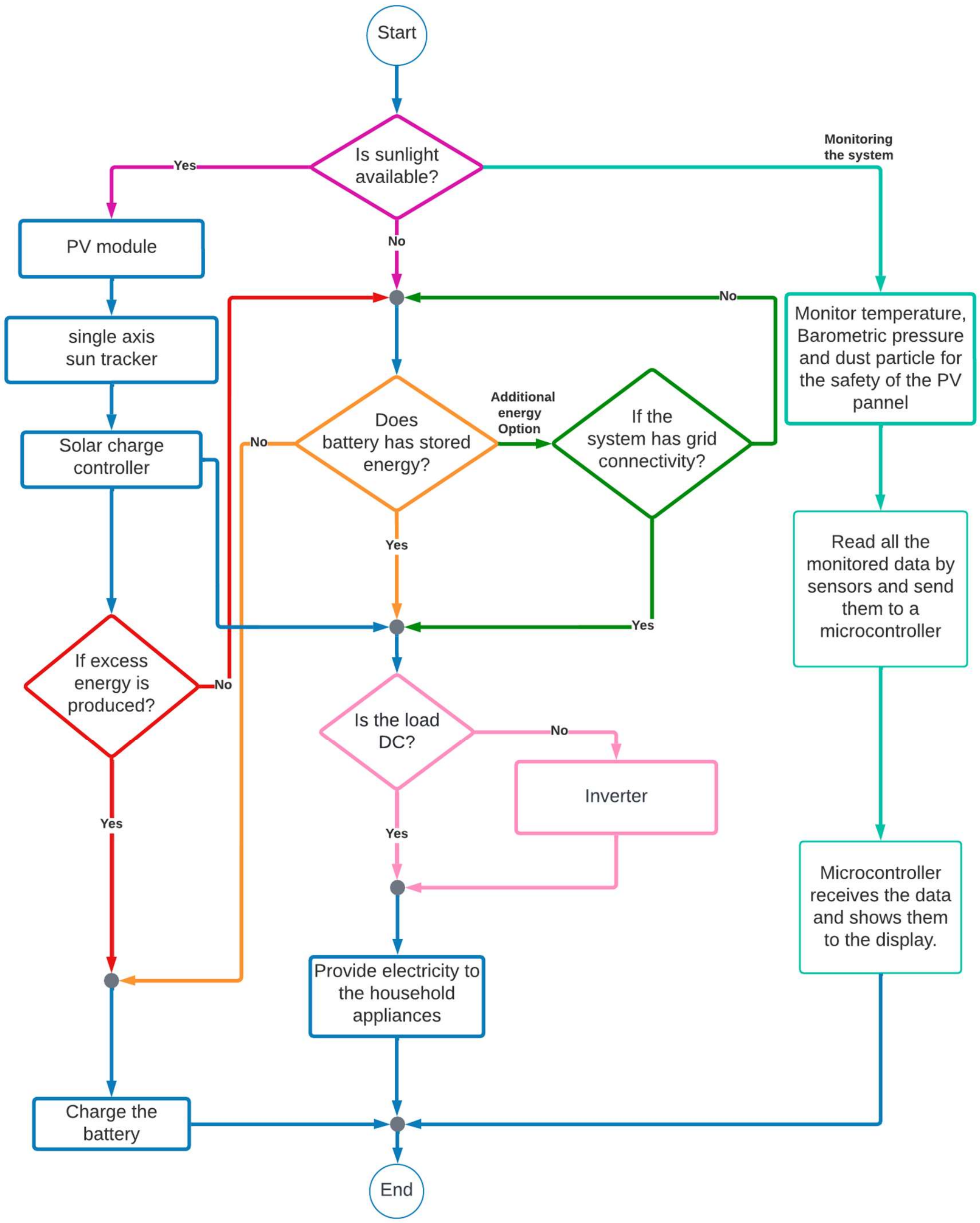


Fig. 4. System flow diagram

Solar system is an advanced technology to convert the solar energy to electrical energy. When sunlight falls into the PV panels, this solar energy converts to electrical energy and get stored in the batteries. Solar charge controllers are also used to control the charge capacity of these batteries. To distribute this electricity to the electrical appliances, it is needed to convert AC current since the appliances uses AC electricity. Inverters easily convert this DC current to AC current. Firstly, the system makes decisions based on whether or not sunlight is available. If the weather is sunny enough, the PV module will be activated and collect sunlight radiation and convert it into electrical energy. Since, we are proposing Bifacial PV panel solar system sunlight will be collected by both front and rear side cells. We will use a sun tracking system because the position of the sun is not constant. The single axis sun tracker will help in tracking the position of the sun. This generated electrical energy will be used to charge the battery. The solar charge controller will ensure that the batteries are not overcharged, ensuring battery longevity. If sunlight is not available and sufficient energy is not produced by battery, another decision will be made regarding whether the battery has stored sufficient energy or not. Furthermore, the system will determine whether or not the system is connected to the grid. If the system is not connected to the power grid, it will go back to determine whether the battery is sufficiently charged. If the battery has stored enough energy and the system is grid-connected, the current generated by the solar panels will be transmitted to the DC load to power household appliances. If an alternating current (AC) load is connected to the system, AC current will be converted to the DC current by transporting current to inverter before distributing power to electrical appliances. Temperature, barometric pressure, and dust particle for the safety of the PV panel will be monitored from collecting sunlight to providing electricity to household appliances. Finally, the monitored data will be read and evaluated by sensors before being transferred to microcontrollers for display.

1.8 Conclusion

Bifacial PV system is an innovative technology capable of competing with conventional power generation. Solar irradiance collection by both front and rear side is the main feature of Bifacial PV module. Observing the evaluation of energy generation rate, this is predictable that Bifacial PV solar system will be more reliable than monofacial PV solar system. Nowadays, this technology is one of the most researchable projects. Since bifacial PV panels are more efficient and benefited than mono-facial PV panels, there is a huge opportunity to strengthen the solar PV market. In this study, an optimized and financially efficient Bifacial PV panel based solar home system has been proposed for urban areas. Due to some structural changes has made Bifacial PV panel system more efficient than mono-facial PV system. Moreover, a graphical simulation based Bifacial PV solar system has also been shown to implement the system properly in hardware. Proper database, tools and simulation will result in an efficient Bifacial PV solar system. The proposed solar home system will benefit the urban population by reducing the electricity demand dependent on the national grid. Analyzing the power characteristics and the installation cost, this system will provide electricity to the home appliances for an ideal case. We expect Bifacial PV panel solar home system will increase people's attention.

Chapter 2: Project Design Approach

2.1 Introduction

The objective is to design a rooftop solar home system. There are many designs of the system that can be implemented. However, the system must be efficient, reliable, cost- effective and must supply adequate amount of power according to the user's demand. A solar home system is self-dependent. It is 100% carbon neutral because it generates energy by converting solar energy into useful electrical energy. As, the sun does not always shine, plan for a backup energy supplier have to be taken in mind that, will assist in case when the system is unable to provide sufficient power to the load. Since, most household appliances uses Alternating Current, but Photovoltaic panels generates Direct Current, it is compulsory to use an inverter that will supply AC power to the house hold electrical. Tracking system containing motors, microprocessors and sensors could be installed that would make the PV panels follow the sun's path to further boost up the efficiency of the total system. Monitoring system could also be added into the solar home system for safety analysis and for keeping track of energy usage, to reduce over use of electricity.

2.2 Identify multiple design approach

2.2.1 Design 1

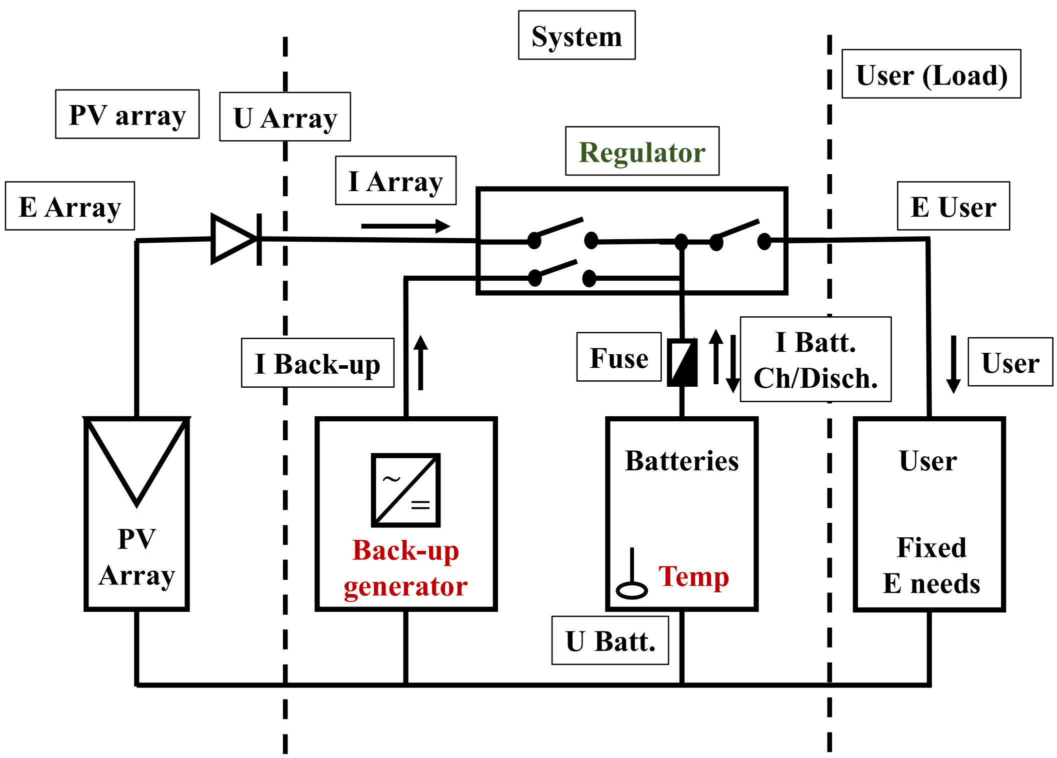


Fig. 5. Standalone system (fixed axis tiled)

Fig. 5, illustrates a standalone system and fixed axis tilted PV setup is used as utility grid for the user. The PV panels are Bifacial PV panels.

2.2.2 Design 2

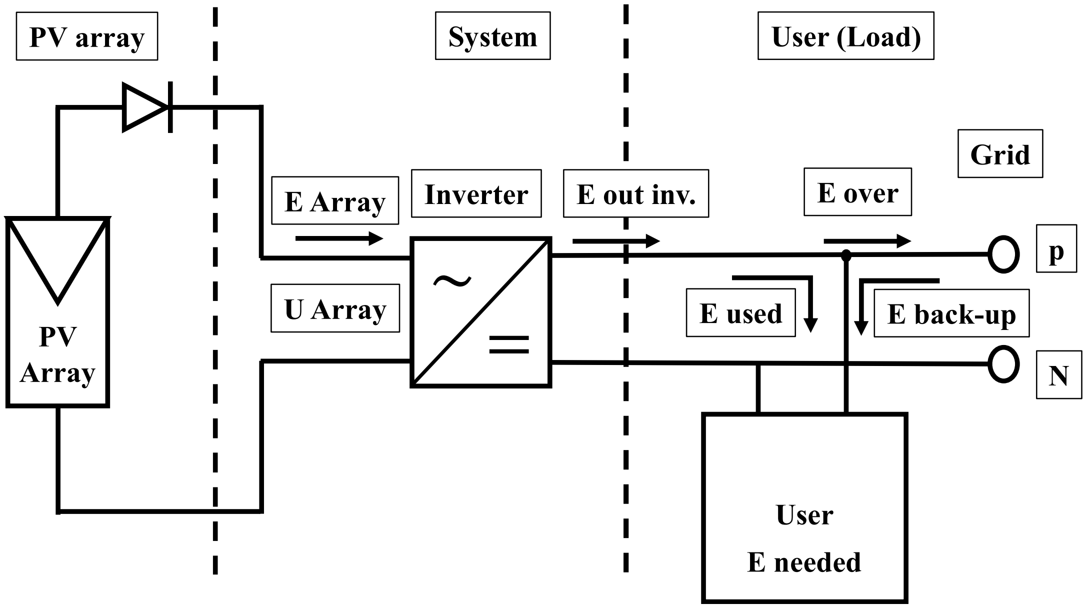


Fig. 6. Hybrid Bidirectional Grid connected system (mutual shading – fixed axis tilted)

Fig. 6, illustrates a grid tied hybrid system and fixed axis tilted PV setup is used as utility grid for the user. The PV panels are Bifacial PV panels.

2.2.3 Design 3

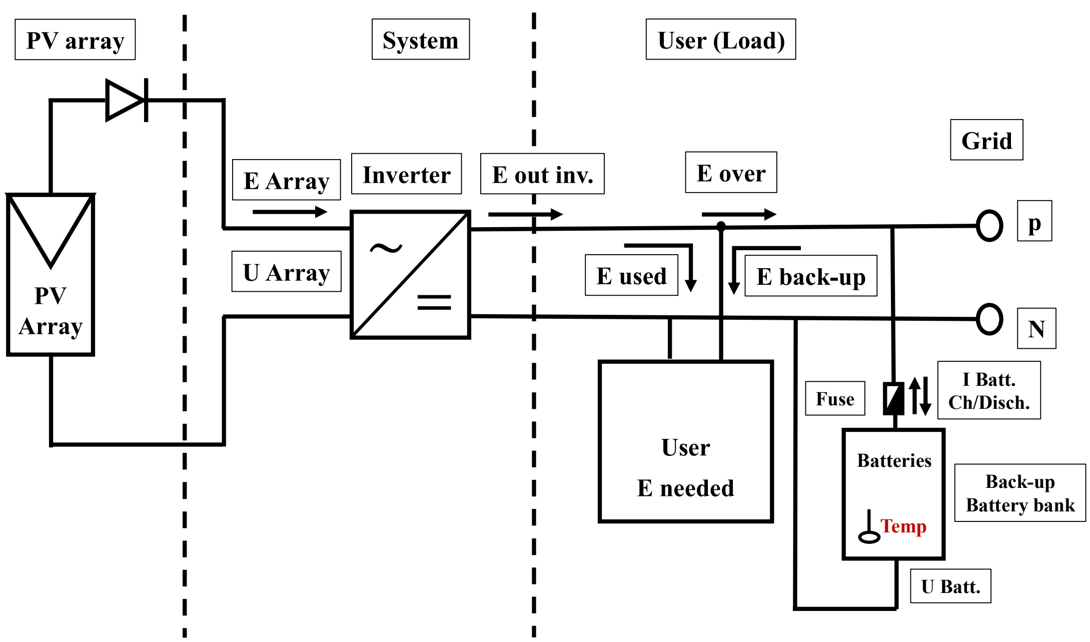


Fig. 7. Hybrid Bidirectional Grid connected system (single axis tracking system)

Fig. 7, illustrates a grid tied hybrid system and single axis tracking system PV setup is used as utility grid for the user. The PV panels are Bifacial PV panels.

2.3 Describe multiple design approach

2.3.1 Design 1

In Design Approach 1, we constructed a standalone system consists of three sub-systems: PV array, system and the user (load). In the system part, there is a regulator that regulates the non-constant output voltages produced by the PV array. The system also has a back-up generator to supply power to the load when there is no energy generation by the PV panels. It also has batteries to store excess energy produced by the PV array, and use that energy later when the energy production is less than consumption. We used a fixed axis tilt of 22.8^0 by calculating the longitudinal, latitudinal and altitudinal values of our location.

2.3.2 Design 2

In Design Approach 2, we built a hybrid bidirectional grid connected system which also has three sub-system parts like our first approach. This system is connected to the grid and will provide power to the grid when excess energy is generated by the PV panels and also consume energy from grid and feed the load when the system is not producing sufficient energy. The user's load is connected to both the grid and the inverter. Here, we used an inverter to convert the output DC voltage from the PV arrays to usable AC voltage for AC loads.

2.3.3 Design 3

In Design Approach 3, being similar to our second design expect, with the addition of a single axis tracking system. The single axis tracking system will keep track of sun's direction and would make the PV system capture maximum energy, as much as possible. Here, inverter and backup battery banks have been connected to the system to store the excess energy produced, for later usage, when energy generation is not sufficient for load. This system will also provide power to the grid when excess energy is generated and also feed energy to load from the grid if the stored charge in the battery runs out.

2.4 Analysis of multiple design approach

All of the three multiple design systems operate differently from one another, although the way they produce and supply power to home is quite similar. PV panels do not generate energy when there is no sunlight. But when there is lot of sunlight, the panels can generate more energy than required. This extra energy could be store in the battery bank which can be used later at night when there is no sunlight. However, battery bank also has a limited capacity and has chances of run out of stored charge after heavy usages of electricity, which usually peaks during evening and night times. Also, battery bank that has very high storage capacity and can supply uninterrupted power are very expensive to buy and maintain. To avoid such complication, a backup generator could be connected in the standalone system, but this also has its disadvantages as generator needs fuels such as diesel to run, which of course emits carbon dioxide. This is a direct conflict to one of our main goals that is to design an emission free energy producer for home. On top of that the price of petroleum in the international spot market does not stay stable and fluctuates a lot. If diesel is expensive, this would put a huge burden on the customers if they want continuous energy supply. Theoretically, the standalone system can work in the desired way but practical assumptions tell us that the system operation would not be as feasible, both technically and economically. The Hybrid Bidirectional Grid connected system could completely omit the complicacy of the backup generators, however, the system will not be an independent system like the Standalone system. Dependency on the grid electricity would be a factor to look for. But the unpredictable expenses on generator fuel and carbon emission would not be an issue anymore. In Hybrid Bidirectional Grid connected system when the panels are not generating enough power at absence of the sun, electricity from the grid could be taken in and use via the system-grid. Also, when the system is generating more power, some of the extra power after consumptions could be sent back to the grid like a miniature power station. The customer could profit from the national power grid company if they could sell more power than they buy. Design 2 and Design 3, both are Hybrid Bidirectional Grid connected system, but design 2 uses fixed axis tilted panels and design 3 has single axis tracking system attached to the panels. It is certain that panels with tracking system to identify sun tracks are capable of producing more energy from sunlight than panels that are tilted at a fixed axis. A battery could also be added to further increasing reliability and feasibility of the system. The panels in multiple design approach 3 with the support of trackers, should able to generate higher maximum energy than the panels of design 2 and design 1 and with the aid of battery bank, the more extra energy could be stored for later usage during night. This would make the system less dependent on the grid electricity during insufficient energy production of the system. The user could possibly profit more from selling power as the buying from the grid could be minimized because of the backup supply from battery bank. In case when the battery charge runs empty, the grid connected to the system could provide power to the loads. After assuming all possible practical outcomes, analyzing all of the three design approaches, we can declare, hypothetically that our design approach 3 is the best and most optimized design in terms of reliability, feasibility, maintainability and economically.

2.5 Conclusion

Although we have made a proposition that design 3 is the most optimized design, further investigation needs to be performed to proof and strengthen our claim. From the three proposed designs, output data will be collected from them and their working principles and performance will be studied. For the precision of the data, the systems have to be run and operate in the same environmental condition over and over many times. The data will be validated and any anonymous data shall be ignored. The data will be thoroughly analyzed and compared. After comparing the results, the most appropriate and most optimized system design will be selected for the solar home system considering their efficiency, usability, reliability cost effectiveness and impact.

Chapter 3: Use of Modern Engineering and IT Tool

3.1 Introduction

The use of modern engineering and IT tool is very significant for the project. Since, the project is about PV panels and using them to build a solar home system, we have identified some of the IT tools on how to use them to get our desired output. The name of the IT tools is given below:

- PVsyst
- Homer Pro
- PVPlanner
- RETscreen

For the study, sizing, and data analysis of full PV systems, there is a PC software program called PVsyst. It covers grid-connected, standalone, pumping, and DC-grid (public transportation) PV systems and has vast information on meters and PV system parts in addition to generic tools for solar energy. The HOMER Pro microgrid software from HOMER Energy is the industry standard for maximizing microgrid designs across all industries, from grid-connected campuses and military posts to village electricity and island utilities. When planning and optimizing photovoltaic (PV) systems, the online simulation tool PVPlanner uses high-performance algorithms, climate and geographic data with high temporal and spatial resolution. The RETScreen Software is intelligent decision support software that enables stakeholders to quickly identify, evaluate, optimize, and monitor the performance of clean energy investments throughout the course of the full project life cycle. We have also identified some other IT tools for output waveforms for our project, these are:

- MATLAB Simulink
- LabVIEW
- Scilab Xcos

Simulink is a block diagram environment for model-based design and multidomain simulation. It provides continuous testing and verification of embedded systems, simulation, automatic code creation, and system-level design. For modeling and simulating dynamic systems, Simulink offers a graphical editor, adaptable block libraries, and solvers. Because of its integration with MATLAB, you may export simulation results for additional analysis and include MATLAB algorithms into models. With both continuous and discrete models, the Scilab tool Xcos is used to model and simulate hybrid dynamic systems. It also enables the simulation of systems regulated by both explicit and implicit equations (causal simulation) (causal simulation). By linking the blocks to one another, the graphical editor in Xcos makes it simple to represent models as block diagrams. National Instruments' LabVIEW is a platform and development environment for a visual programming language. LabVIEW is an acronym for Laboratory Virtual Instrumentation Engineering Workbench. The name of the graphical language is "G." LabVIEW is frequently used for data gathering, instrument control, and industrial automation on a variety of platforms, including Microsoft Windows, several flavors of UNIX, Linux, and Mac OS X. LabVIEW was first made available for the Apple Macintosh in 1986. Version 2011 of LabVIEW is the most recent release.

3.2 Select appropriate engineering and IT tools

3.2.1 Comparison of PVsyst. Homer Pro, PVPlanner and RETscreen

TABLE IV. COMPARISON OF PVSYST, HOMER PRO, PV PLANNER AND RETSCREEN

PVsyst	Homer Pro	PVPlanner	RETscreen
Is for PV system design and simulation worldwide. The	Is a micro-grid optimization software, comes with	It is a cloud-based software and claims	It is an Excel-based clean energy project analysis software tool

developers claim this software is designed to be also used by students	Simulation, Optimization and Sensitivity Analysis tools	their data is highly accurate	determine the technical and financial viability of potential renewable energy, energy efficiency and co-generation projects. Student Friendly
Quick estimation of production at project planning stage, detailed study, sizing, hourly estimation. Generates a comprehensive simulation report	Not specifically designed for Solar PV. Does not do shading analysis. PV electricity generation report is less comprehensive due to limited information on weather data and module data. Many loss factors during PV power generation are not added to calculation	Accurate satellite data allows user to make estimation of solar radiation and PV power potential of a location. It is only available as an online version, so an internet connection is mandatory	Consisting of a macro enabled spreadsheet that has all the formulae in place to calculate various sorts of energy sources and allows user to calculate PV power generation based on location, do cost analysis and determine project feasibility
Allows high level of control of various factors. Simulates most parameters that are required by PV system designers	Schematic View is useful. Not intuitive and too many parameters to be added manually	Interface is neat and intuitive but the performance could be affected by internet connectivity	Fairly easy to use and has options to choose from drop down lists. There is not much scope of modifying values and percentages
Thousands of modules and inverter models. Can also input user defined data	Can import module data. Only 8 modules (including 1 generic) and 8 (including 1 generic) inverters are included in the program	Long term annual and monthly average data is included in the basic package. There is no option of importing other data types like NASA, Meteonorm, SAM	Comes with limited number of modules but not inverters. There is no scope for adding custom module or inverter data
Cost: USD 1,351/BDT 128,500 Unlimited Version	Cost: USD 4,200/BDT 399,000 Annually	Cost: USD 3,600/BDT 342,000 PER YEAR	Free of cost

PVsyst:

PVsyst is a well-known software through which various real-life parameters of the solar plant is considered compared to other solar powered simulation environments. Through PVsyst we can define the tracking system PV panels setup, consider shading factor to the site that the panels will be planted. We can also draw a visual representation of the site where the system will function through PVsyst. Economic evaluation of the project can also be done through PVsyst.

3.2.2 Comparison of MATLAB Simulink, LabVIEW and Scilab Xcos

TABLE V. COMPARISON OF SIMULINK, LABVIEW AND SCILAB XCOS

MATLAB Simulink	LabVIEW	Scilab Xcos
It is a computing language for control algorithm development and simulation	Is mainly a graphical programming language for visualization and parameter tuning for remote operation	Is a tool dedicated to the modeling and simulation of hybrid dynamic systems including both continuous and discrete models
Simulink is great for implementing control algorithms and embedded applications	In LabVIEW, we can face difficulties while designing control algorithms as graphical programming	Control algorithms can be implemented to some extend in Xcos

MATLAB Simulink mainly provides mathematical/numerical and technical computing environment	LabVIEW is a system design platform that allows data acquisition, test automation, instrument control and embedded system design	Scilab Xcos also allows simulating systems governed by explicit equations (causal simulation) and implicit equations (acausal simulation)
Designing in Simulink is simple and does not require sophisticated software and hardware. It comes free with MATLAB	LabVIEW requires hardware interfacing and other software. It is not free	Designing is similar to Simulink. Xcos is free and comes with Scilab
Is used for simulations and has extensive libraries that contain higher-level functions	LabVIEW is used where a functional and intuitive GUI or interaction with hardware is required	Its libraries have some important predefined components for simulations
$2,350.00/ BDT 223,250 Perpetual license	$2,771.00/ BDT 263,245 Per Year	Free and open source

MATLAB Simulink:

MATLAB Simulink is a programming platform designed specifically for engineers and scientists to analyze and design systems and products that transform our world. The core of MATLAB is the matrix-based MATLAB language, which enables the most organic expression of computer mathematics. For a variety of applications in industry and academia, including deep learning and machine learning, signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology, millions of engineers and scientists around the world use MATLAB. Learning is possible whether we are a rookie or an expert because MATLAB is made for the way we think and the work we do.

3.3 Use of modern engineering and IT tools

3.3.1 PVsyst

PVsyst is the software that shall be used for the simulation purpose of the power calculation and PV array sizing depending on the requirement of an average user. PVsyst is a well-known software through which various real-life parameters of the solar plant is considered compared to other solar powered simulation environments. Through PVsyst we can define the tracking system PV panels setup, consider shading factor to the site that the panels will be planted. Moreover, a visual representation can also be drawn for the site where the system will function through PVsyst. Economic evaluation of the project can also be done through PVsyst. Besides, PVsyst software can also produce more detailed and elaborated reports than the others. This software is more realistic and student friendly. This software is mainly designed to deal with PV system components databases and solar energy tools. Also, a greater number of modules in PVsyst compared to the other software and it allows high level of control of various elements. However, most parameters used in solar installation and for data reading are calculated precisely by PVsyst which is the important reason of using PVsyst software. PVsyst is exemplary software to optimize the solar PV designs. Mostly, solar plant designers prefer this software over other software without hesitation. There are also some other notable software used to calculate solar parameters such as Homer Pro, PVPlanner, RETscreen but PVsyst is the most preferable and easier to use. Although, RETscreen is free of cost, we still choose PVsyst which is cheaper than the other two software. Moreover, PVsyst also has wide varieties of features some of which are not present in other simulation applications. To explain and design an optimized PV system, especially Bifacial PV system, PVsyst can be the best option. In the following Fig. 8, depicts one of the usages of the software in this project.

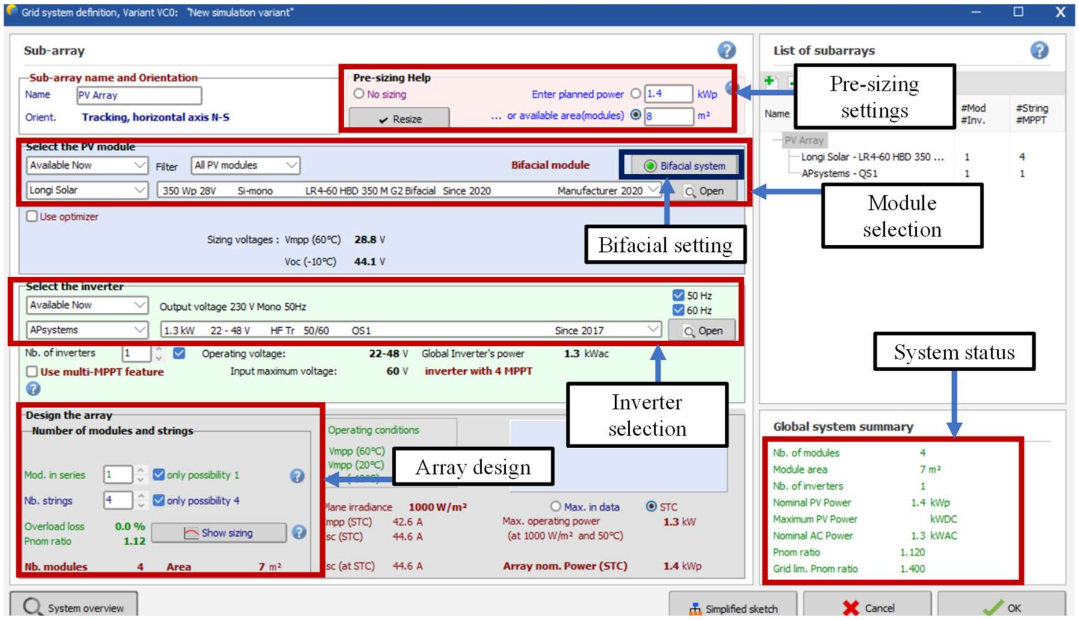


Fig. 8. Use of PVsyst in the project

The Fig. 8, illustrates a screenshot of the simulation software, PVsyst used in the project. From the screenshot it can be clearly seen the different aspects of the system that we are trying to design, can be changed here such as pre-sizing settings, bifacial settings, module and inverter selection, array design and system status. Here, in system status, under global system summary, the number of modules used is 4 and the module area is $7m^2$. Nominal PV power is 1.4kWp. From module selection option, we can choose the name and type of PV module that we want to use which also shows the sizing voltages at two different temperatures (-10° and 60° C). This also has a bifacial setting for tuning the bi-facial features of the PV module. In pre-sizing setting, we can enter the amount of planned PV power which is 1.4kWp as clearly shown. PVsyst also allow us to choose and configure the inverter we want to use from select the inverter option, and change different parameters of the inverter. Lastly the array design option from where we can select the numbers of PV module and modify their connections. We can also see the other parameters like, area, plane irradiance, different current, voltage and power values.

3.3.2 MATLAB Simulink

MATLAB Simulink is a widely used software in many industries. MATLAB Simulink is used in this project over other simulator because of its superior control of the components from library. In Simulink, using this software, components can be customized, for example changing PV arrays' cell type, module type, maximum power output, I-V characteristics, series-parallel connection and other aspects which are not possible in LabVIEW and Scilab Xcos. This makes working with Simulink much easier than the other software. Besides, Simulink can also simulate systems that resemble a real-world practical system making the simulation more realistic. Since, its component library is quite rich, designing any system for various parameters is quite easy with MATLAB Simulink. However, using this software solar plant blocks can be designed perfectly. Through MATLAB graphs and charts can be generated. Using MATLAB Simulink, the whole PV system of the project can be built, containing PV cells, battery, loads and other components and run the system under various situations and environment to individually determine the working principles and behaviors of the whole system and sub-systems. This simulation platform gives the opportunity to explain, design and check the outcome of solar system design in a graphical view. Another important advantage of this software is not complex; rather the installation requirements of this software are also very simple. In the following Fig. 9, depicts one of the usages of the software in this project.

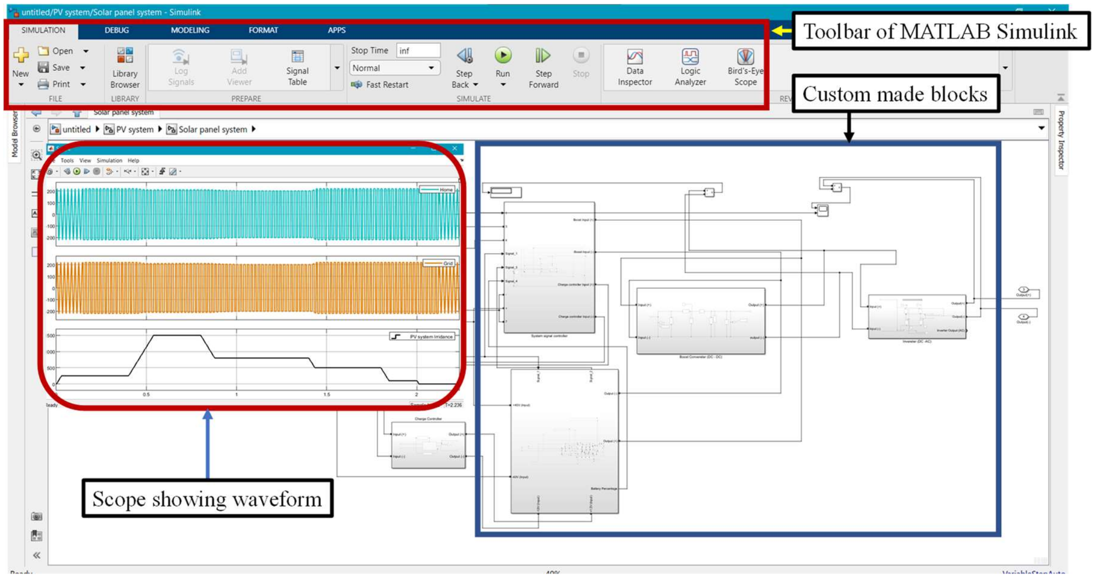


Fig. 9. Use of MATLAB Simulink in the project

The Fig. 9, illustrates a screenshot of the software, MATLAB Simulink, used in the project to design the circuit level system. Here, it is clearly noticeable the two different parts of the Simulink software: the toolbar, from where icons of variety of tools, functions and options can be found and implemented and the blank white platform, where different blocks can be connected and run in the environment to simulate the system. In the toolbar, there are icons named 'Open', 'New', 'Save' which are for opening, saving and creating new simulation files, respectively. We can also set the stop time of the simulation in the 'Stop Time' option by inputting a number. From the 'library browser' icon, we can search and select different build in blocks to place in the white platform and make connections among them to create and resemble a real time system. The 'Run' icon when selected will run the system designed in the Simulink environment, which would produce different kinds of data and outputs relative to the system. Some custom-made blocks in the white platform, where all are connected to each other can be seen here, from which each blocks contains many other different kinds of interconnected build in blocks, all together to create a huge system. The scope shows the input and output of the system, representing the data as a graphical illustration.

3.4 Conclusion

Bifacial PV solar system is one of the most interesting researchable projects nowadays. Different companies are initiating further researches to improvise this high technology. Modelling and simulation of Bifacial PV module is the primary step to build an efficient Bifacial PV solar system. Simulation platforms help to design these simulating models using different parameters and modules. Some important parameters such as solar irradiance, I-V characteristics of solar panels, power- voltage-current ratio, temperature, resistances, open-circuit voltage, short-circuit current etc. are calculated by simulations before hardware implementation. Moreover, MATLAB Simulink and PVsyst type software is student friendly that is why simulating designs are easier and affordable. These softwares also represent the simulation in realistic and graphical method, so comprehending the simulations are spontaneous. To develop the future bifacial solar PV industry, modelling and simulation of solar PV panels will be major key point. In this paper, MATLAB Simulink and PVsyst software-based simulations have been discussed. Some other software's Homer Pro, PVPlanner, RETscreen and LabVIEW, Scilab Xcos are also used to design and deals with solar PV system tools but MATLAB Simulink and PVsyst are more applicable for our undergraduate solar PV system designing. The outcomes of the graphical simulation and the analyzed data have been observed properly before implementing in hardware.

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution

4.1 Introduction

An engineering complex problem may have multiple types of solutions so does this project. As the project is a solar home system design, thus we have picked out three multiple design approaches. In all of our design approaches, a Bifacial PV panel has been used, and then the output and results were compared to observe which one is the optimal solution for the project. For comparison of all the three multiple design approaches, an iso-shedding diagram, normalized energy production bar chart, monthly performance ratio chart, Sankey diagram, and economic valuation was used. Firstly, an iso-shedding diagram depicts the path of the sun over the course of 24 hours and shows us at what time of the day the energy production is maximum and minimum. It also informs us about the value of albedo and attenuation for diffuse. The shading losses can also be figured out from the iso-shedding diagram. Secondly, the normalized energy production chart shows the energy supplied to the user on monthly basis. Furthermore, it conveys information about unused energy, collection losses, and system losses. Thirdly, the monthly ratio performance chart displays us the energy supplied to users and energy loss. Additionally, the Sankey diagram provides us with detailed documentation of the efficiency, mismatch losses, the total energy produced, energy directly used, energy stored, and some other factors. Finally, an economic valuation is also shown of all three designs to analyze which design approach is cost-effective. Thus, by analyzing all these aspects and calculations the optimal solution to this project can be found.

4.2 Optimization of multiple design approach

4.2.1 Design 1

The site planning of design approach 1 is illustrated in Fig. 10.

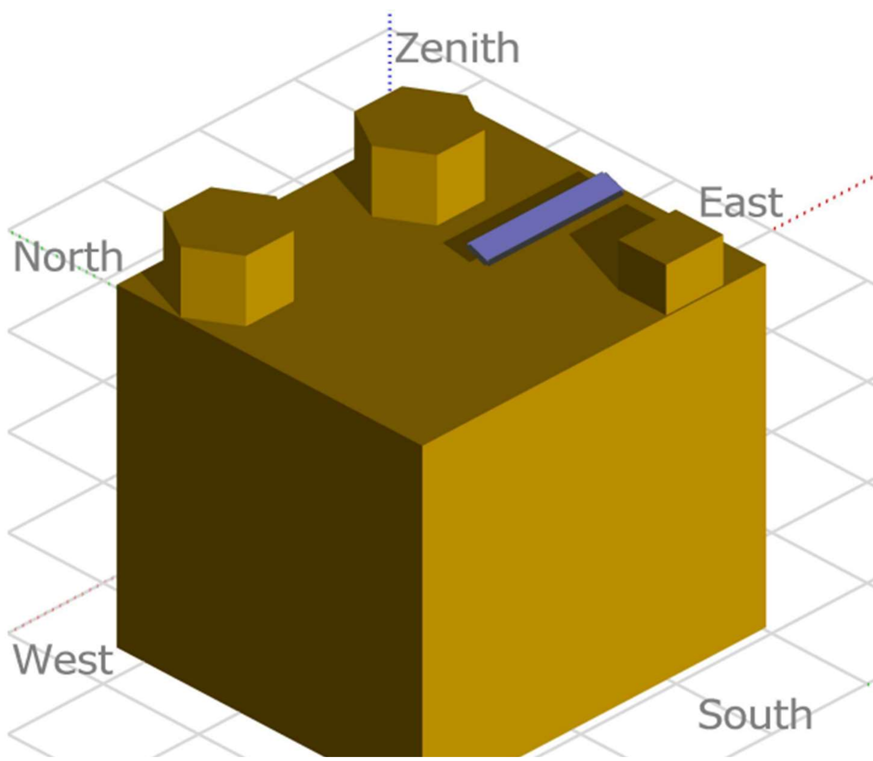


Fig. 10. Perspective of PV-field and surrounding shading scene

Here, we have chosen a design of PV array in a 1-by-4 single array. We have chosen a fixed tilted plane for our standalone design. Tilt angle = 22.8 degrees.

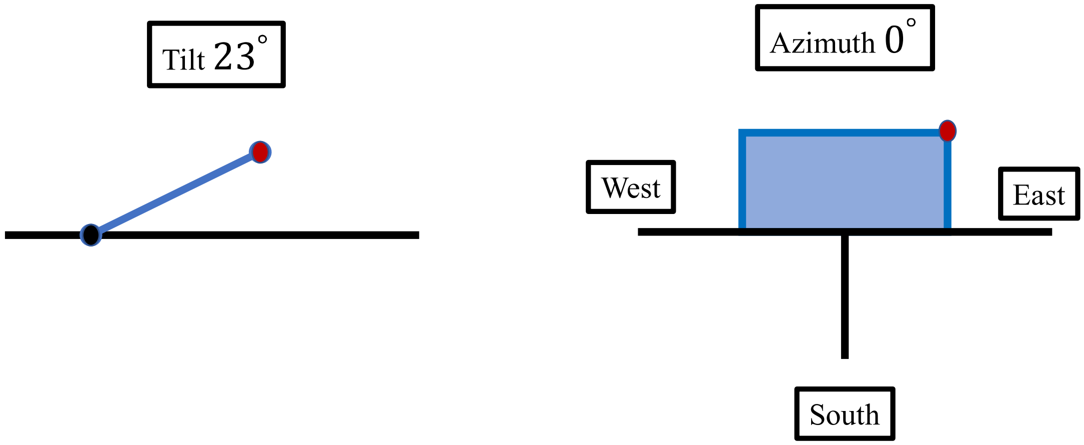


Fig. 11. Tilt type fixed axis of 23 degrees

Fig. 11, depicts the tilt and azimuth of design 1 [standalone system], 23 degrees is the optimized angle for the fixed axis tilted PV system. The tilt angle is chosen approximately 23^0 by calculating the longitudinal, latitudinal and altitudinal values of the geographical location. The value of azimuth angle is taken as 0^0. The PV array will be facing will be facing the west as the tilt angle will be 23^0 from east. Therefore, it can be seen in the above figure that, how the PV panel will be fixed according to the west, east and south in the standalone system.

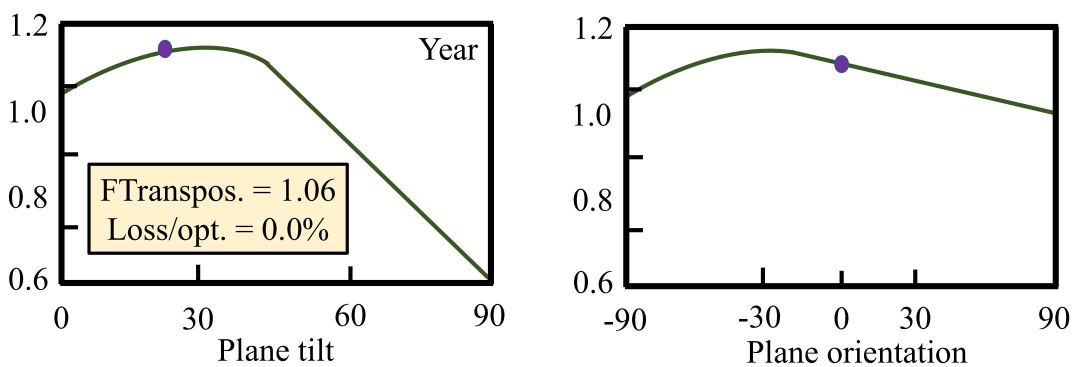


Fig. 12. Yearly optimization of the fixed tiled plane

Here, the yearly optimization of the fixed tilted plane is shown in Fig. 12, which illustrates the optimized tilt angle consideration according to the geographical place [Mohakhali] and the plane orientation for best outcome [solar energy to electrical energy by bifacial PV in standalone fixed axis system]. Considerably, over a certain period of time or yearly the transposition factor is 1.06. The loss of optimization is zero percent. The Global radiation on the plane of PV array will be at a considerable rate as the angle is fixed at 23^0. The energy produced by this design approach will also be lower as compared to other two design approaches. The main reason for this is the fixed tilt angle, as the sun's path changes over the course of 24 hours so the fixed tilt angle will restrict the PV array from consuming the maximum energy. If any solar axis tracker is used, then the PV array would be able to locate the direction of sun and thus can produce maximum energy. As a result, this design approach will not provide the maximum efficiency but it will be much less expensive as no solar tracker is used. Therefore, usage of solar trackers in any of our design approach will boost our efficiency.

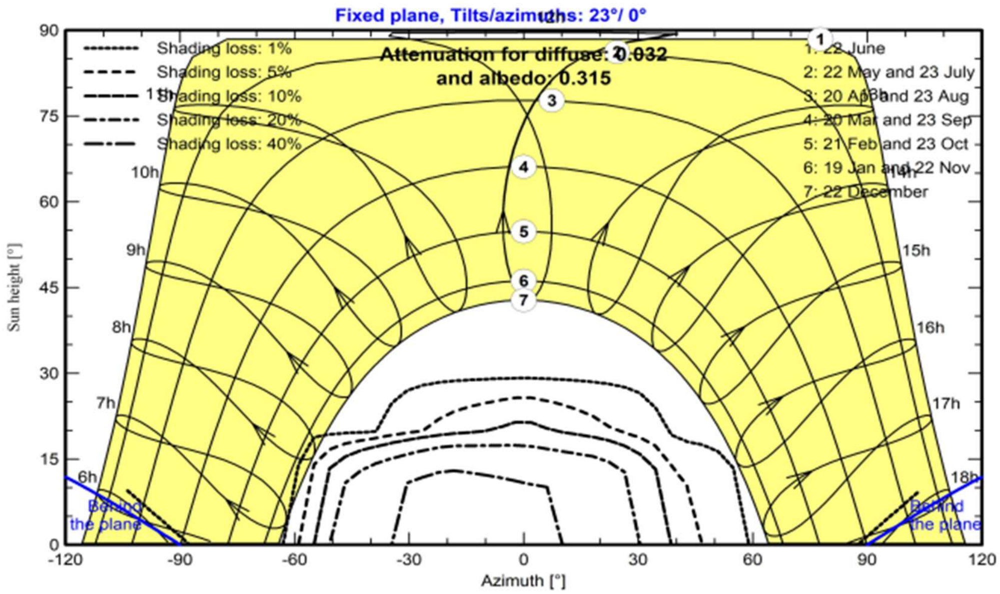


Fig. 13. Iso-shedding diagram

Fig. 13, illustrates the iso-shedding diagram according to azimuth and suns position for the PV panels tilt angle optimization. With this diagram we can minimize the shading losses due to suns position or panels position. Here we can see from the iso-shedding diagram that before 6am and after 6:30pm the panels are slightly behind shadows. Attenuation for diffuse 0.032 and albedo for the site for this design is 0.315.

- <u>Main results</u>

TABLE VI. SYSTEM PRODUCTION AND ECONOMIC EVALUATION OF DESIGN 1

System production	**Economic evaluation**	
Available energy = 1650 KW-h/ year Used energy = 1168 KW-h/ year Excess (unused) = 463 KW-h/ year Specific production = 1179 KW-h/ KW-p/ year Performance ratio = 51.35%	Total investment = **105932** Tk Specific = **76** Tk/ W-p Annuities = **2478** Tk Run costs = **791** Tk Payback period = **11** years Energy cost = **4** Tk/ KW-h	***The battery life time will be approximately 8.6 years for the system design.***

The produced energy of the first design approach is 1650 KW-h/year. Around 1168 KW-h/year is used energy and the rest of the produced energy is unused. The performance ratio of this design approach is 51.35%. As the specific production per year stands at 1179KW-h/KW-p, so the performance ratio will stand at that point. An economic evaluation is also done to analyze if this design approach is cost-effective than the other two design approaches or not. A total investment of Tk. 105932 is made. Out of this cost, specific production sits at Tk.76/W-p, the amount of annuities values at Tk.2478. The payback period of this design approach is roughly around 11 years. In this case, the energy production cost charges at Tk.4/KW-h. The cost of per KW-h energy is quite economic but the efficiency is relatively lower. By this economic valuation and analyzing the system production, the efficiency of each design approach can be evaluated. Lastly, it can be viewed that the battery lifetime is approximately at 8.6 years.

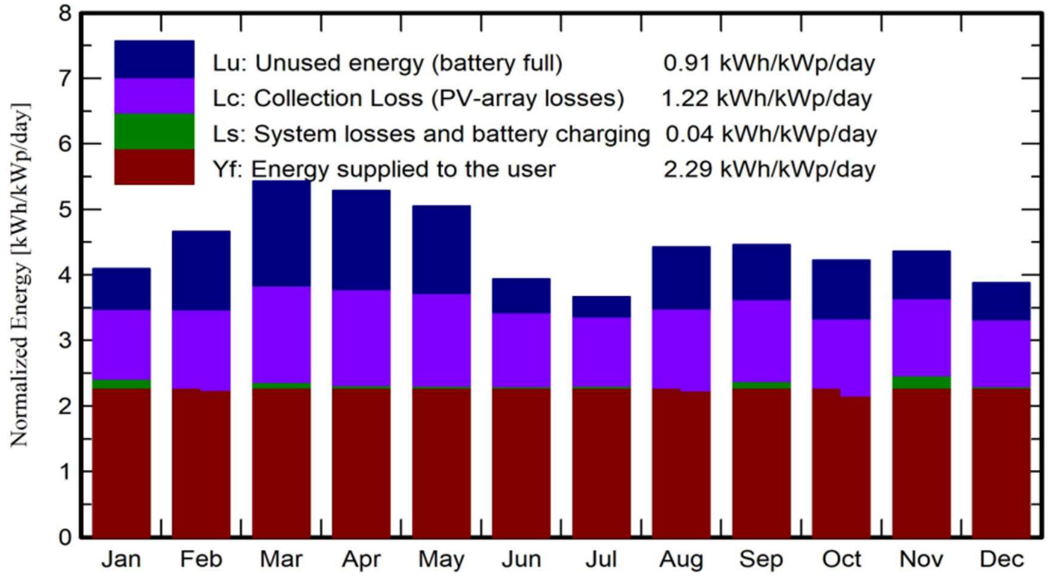


Fig. 14. Normalized productions (per installed KW-p)

Fig. 14, shows that the energy supplied to the user on a monthly basis is denoted by the brown bar. The magenta and dark blue bar both denotes the losses of the system. Therefore, from the graph we can find the average value over a year is:

Energy supplied to the user $\boldsymbol{Y_f} =$ 2.29 KW-h/ KW-p / day

Total system loss = (collection loss + unused energy + System losses)

= (0.91+1.22+0.04)

= **2.17** KW-h/ KW-p/ day

$\boldsymbol{Y_r} =$ **(**Total system loss + Energy supplied to the user)

= 2.17+2.29 = **4.46** KW-h/ KW-p / day

From this we can calculate the average performance ratio:

Average yearly Performance ratio = $\frac{Energy\ supplied\ to\ the\ user}{\boldsymbol{Y_r}} = \frac{\boldsymbol{Y_f}}{\boldsymbol{Y_r}} = \frac{2.29}{4.46} = 0.514$

Therefore, the average yearly performance ratio of the system is = 51.4%

Figure 14 is a column chart that illustrates the Normalized Energy production in per installed KW-p, for every month of a year. In January, the Normalized Energy production is 4kWh which slowly rises to 4.5 in February. In March it peaks at 5.5kWh then slowly decreasing in the next coming two months. From May to June, there is a sudden drop from 5 to less than 4kWh and then in July it further falls down to 3.5kWh at its lowest. This is due to the sky staying mostly cloudy during the monsoon season at that period. Later, from August till November, the Normalized Energy production elevates and remains steady at around 4.5kWp and then again falling down to 3.9KWp in December when it is foggy in winter season. In conclusion, we can say that the yearly Normalized Energy production remains in the range of 3.5 to 5.5kWp. Also from the column chart, the average yearly energy supplied to the user is 2.29 kWh/kWp/day, system and battery charging loss is 0.04 kWh/kWp/day, PV-array loss is 1.22 kWh/kWp/day and unused energy is 0.91 kWh/kWp/day.

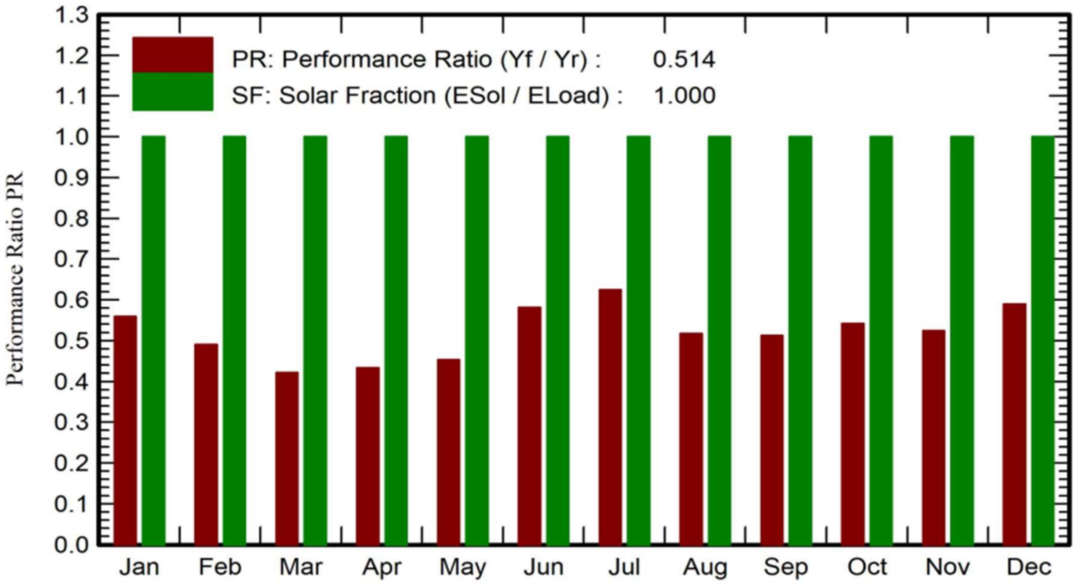


Fig. 15. Monthly performance ratio

Figure 15 illustrates a column chart which represents the monthly performance ratio PR of twelve months of a year. The green bar represents the Solar Fraction SF which remains constant at performance value of 1.0 throughout the year. The maroon bars are the average yearly performance ratio PR that changes with different months. The average yearly performance ratio of this system is roughly around 51.4%. Generally, the performance ratio is the ratio of energy supplied to the user to the total energy loss and energy supplied to user. From the above graph, the Solar Fraction (SF) rests at 1.0 where the performance ratio increases or decreases according to the time of the year. In the beginning of the year, in January, the performance ratio starts off approximately around 0.56. This value of performance ratio is assumed to be a moderate value. A slight decline is visible in next month of the year. The performance ratio declines to 0.48 in February. Moving on, a further fall in the performance ratio is observed in the month of March. The lowest value of performance ratio can be seen in the month of March which is 0.42 over the whole year. In the following month, April, a slight inclination can be seen in the performance ratio. A further more inclination in the performance ratio can also be observed in the next month following April. Respectively, the value of performance ratio in the months of April and May are 0.44 and 0.46. Sudden, rise in the performance ratio is visible in the months of June and July. In the month of June, the performance ratio climbs to 0.58 and a performance ratio of 0.62 is recorded in July. A highest performance ratio is recorded in the month of July. As it is visible from the graph, the performance ratio is highest for July comparing to any other months of the year. Gradually, the performance ratio drops down to 0.52 in the month of August and September. Over the period of these two months, the performance ratio stands at 0.52. In October, again a prone to inclination in the value of performance ratio is noticeable. Additionally, the value of performance ratio noticed in the month of October is 0.54. Furthermore, a modest shrink in the performance ratio is noted in the month of November where the performance ratio is 0.52. Finally, in the last month of the year, December, the performance ratio hits 0.60 where we can observe a sharp inclination from 0.52 from previous month. A number of fluctuations can be observed from the above performance ratio graph. Initially, the graph starts at 0.56 from the month of January, then it starts to decline until the March. However, it starts to rise again from May to July. There is no fluctuation noticed in August and September. In spite of these frequent fluctuations, the performance ratio stays in a range from 0.42 to 0.62. Approaching to the later part of the year, a maximum value of 0.60 is recorded in December. The highest performance ratio is taken in the month of July which is 0.62. In comparison to other months of the year, July gives the maximum performance ratio for this system. On the other hand, the lowest performance ratio recorded was in the month of March which is 0.42. In the final analysis, it is visible that fluctuations in the performance ratio are very marginal and don’t have any drastic changes.

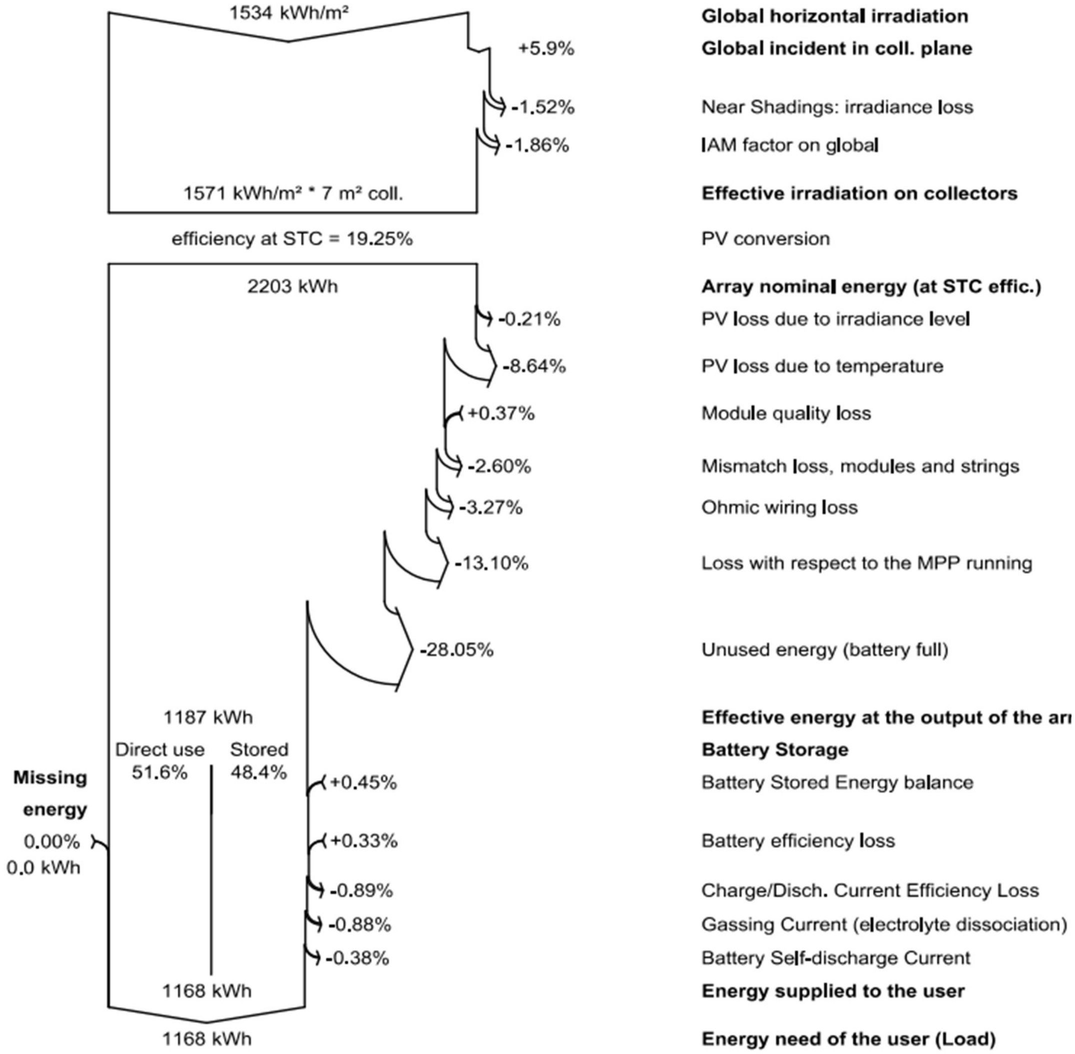


Fig. 16. Loss diagram of standalone system [Sankey diagram] with fixed axis tilt

From Fig. 16, the Sankey diagram illustrates the input and output energy of our PV system, taking in all the different kinds of loss within the system. The global irradiation at our location where the PV system is installed is 1534 KW-h/m^2. This irradiance will be incident into panels will area 7 m2. So, the total energy that will fall on the panel is 1534×7 kWh. After considering all the loss factors, such as near shadings loss and irradiance loss which stands at 1.52% combinedly. Consequently, the global incident in coll. plane is 5.9%, thus, the energy that will be generated by the PV panels is 2203KW-h. The efficiency of the system is 19.25%. Again, considering all the loss factors due to irradiance level is roughly around 0.21% where due to temperature is 8.64%. Furthermore, the module quality loss stands at 0.37%, along miss match loss 2.60% and ohmic wiring loss, the loss percentages are 2.60% and 3.27% respectively. Moreover, the unused energy percentage reported at 28.05% and loss due to MPP running recorded is 13.01%. Therefore, the effective energy at the output of the array battery storage is 1187 KW-h. Out of that energy 51.6% is being used directly by the user and 48.4% is being stored. However, there are some other loss factors as well which mainly includes battery losses. Now considering other battery loss like the battery efficiency loss (0.45%), current efficiency loss (0.33%), electrolyte dissociation (0.88%), battery self-discharge current (0.38%), the final energy that the user receives (load) is 1168 KW-h. Therefore, with just efficiency at 19.25%, the energy supplied to the user is 1168KW-h so an increase in efficiency will boost up the energy production of the system.

4.2.1 Design 2

The site planning of design approach 2 is illustrated in Fig. 17.

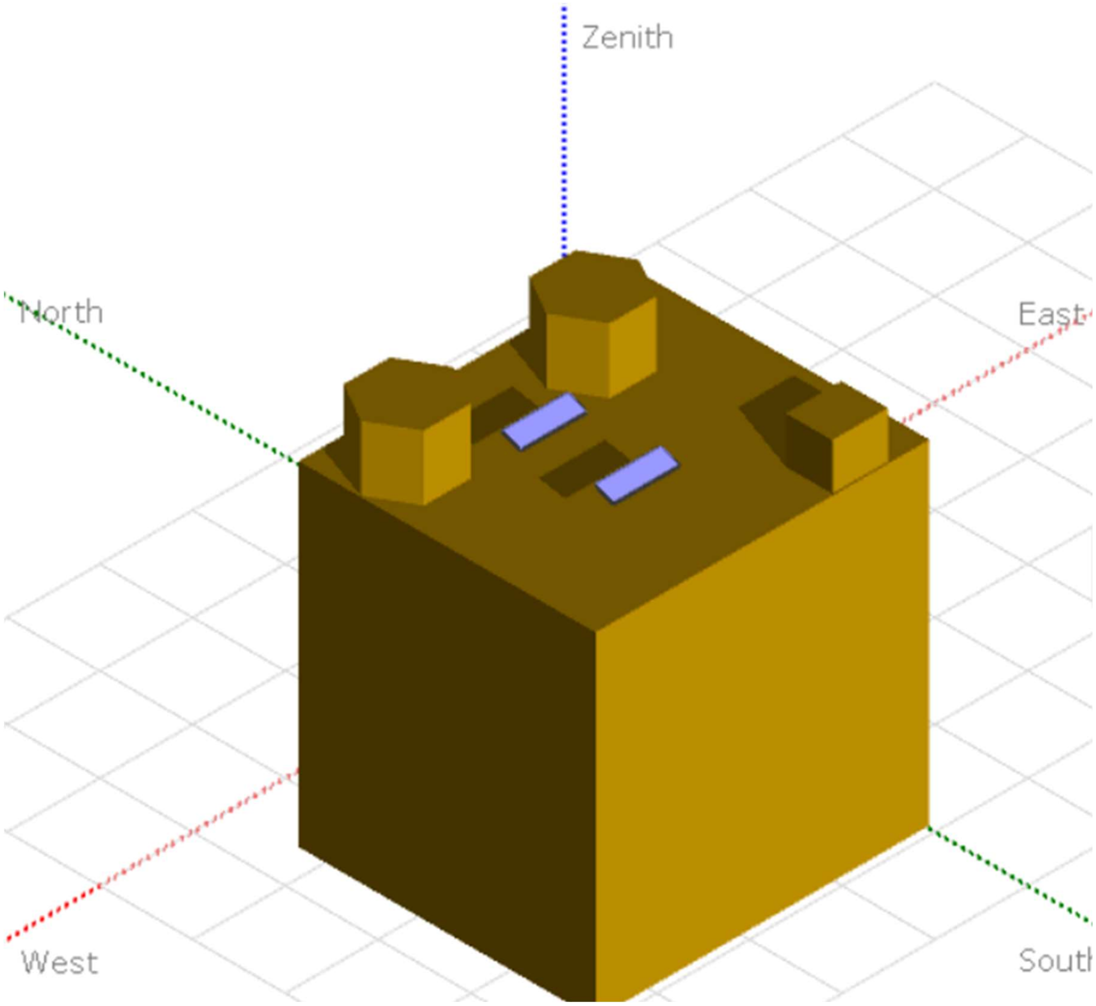


Fig. 17. Perspective of PV-field and surrounding shading scene

Here, we have chosen a design of PV array in a 2-by-2 array and we have considered mutual shading of the bifacial panels.

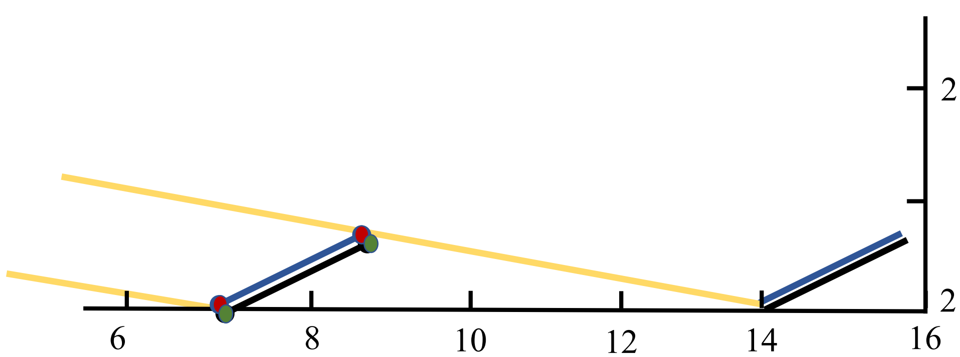


Fig. 18. Mutual shading-tilt type fixed axis of 23 degrees

Fig. 18. depicts, mutual shading scene, the shading limit angle is 8.7 degrees and the ground coverage ratio = 0.29.

TABLE VII. OPERATION PARAMETERS, SHED PARAMETERS AND ELECTRICAL EFFECTS OF DESIGN 2

Operation parameters	Shed parameters	Electrical effect
Plane tilt = 22.8 degrees Azimuth = 0.0 Number of sheds = 2	Pitch = **7**m Column Band width = **2**m Top inactive band = **0.02**m Bottom inactive band = **0.02**m Ground coverage ratio = **28.6**%	Number of modules in width = **2** Module row width = **1**m Width of one PV cell = **15.6**cm

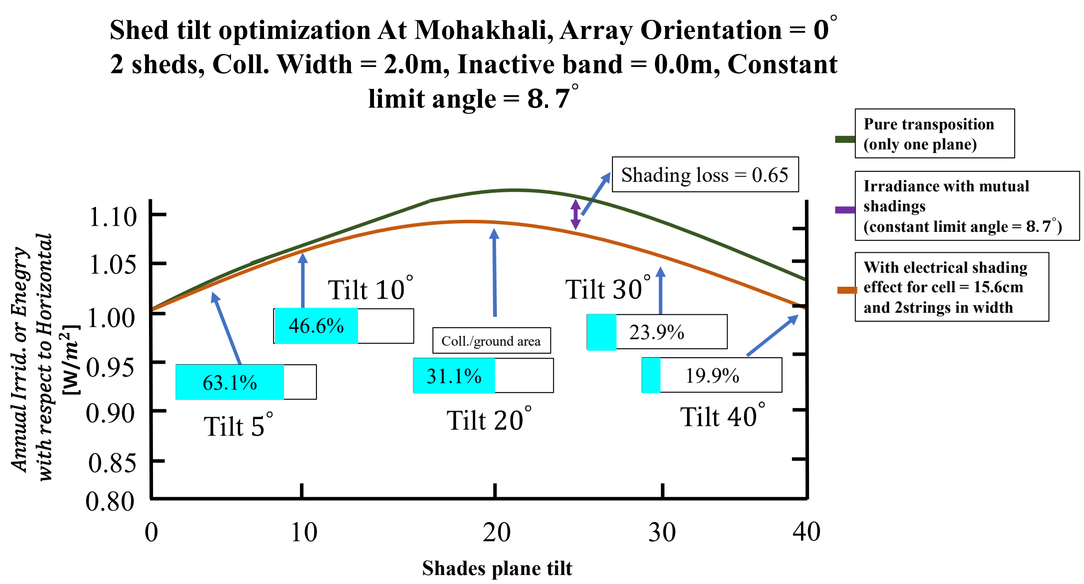


Fig. 19. Optimization of mutual shading

This graphical Fig. 19, is about the optimization of mutual shading of proposed solar PV system. From simulation result we got, array orientation for shed tilt optimization at Mohakhali is 0° for 2 sheds, column width is 2m and constant limit angle is 8.7°. This graph relates the annual irradiance with respect to horizontal and shades plane tilt angle. Column per ground area has also been indicated in this graph. Column band width is the width of the modules regardless of angle. We can see that column per ground area changes due to the variation of tilt angle. Here, green curve is for pure transposition of one plane and orange curve is for the case of electrical shading effect for cell. At first, for one plane transposition annual irradiance value starts to increase very slowly for tilting the shades plane 0° to 23°. We got the optimal tilt angle approximately 23° which is shown in the graph. However, when tilting angle increases more than 23°, the annual irradiance value for one plane transposition falls gradually. In the contrary, annual irradiance value also rises gradually from 1 W/m2, for the case of 15.6 cm and 2s strings in width-based shaded planes with electrical shading effect. Approximately by tilting 18°, we get the highest annual irradiance value, 1.075 W/m2 and after increasing tilting angle more and more only decrease the value. Moreover, we can observe the column per ground area has been fluctuated from 63.1% to 46.6% after tilting planes 5° to 10°. This column per ground area drops when the tilting angle increases more. By tilting 20°, 30° and 40° we can see this column per ground area value decreases 31.1%, 23.9% and 19.9% respectively. Lastly, from this graph we can see the irradiance with natural shadings for constant limit angle 8.7°, denoted by violet line. Therefore, the gap between two curves indicates the shading loss and this shading loss value, 0.65 is quite low.

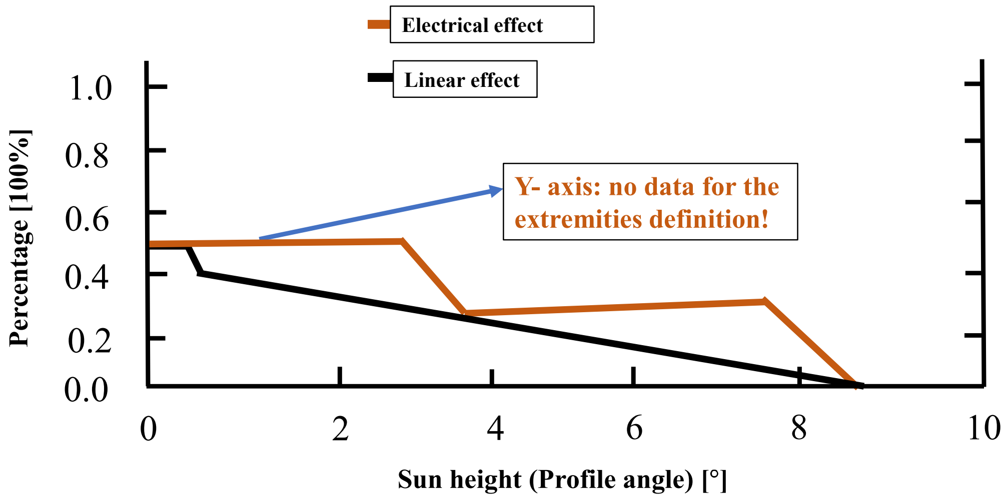


Fig. 20. Mutual shading factor

This graph in Fig. 20, shows the electrical and linear effect measurement percentages over sun height (profile angle). Here, the black line and the orange line indicate linear effect and electrical effect measurement respectively and this measured data are scaled to 100%. Firstly, electrical effect slightly increases till sun profile is angle at 3°. Tilting the angle from 3° to 3.8°, there causes a sudden decrease of the percentage value from 0.52 to 0.3. At sun profile angle 3.8°, the percentage value of electrical effect again rises from 0.3 to 0.35. Another rapid decrease in percentage value is observed when the sun profile angle tilts from 7.5° to 8.8°. On the other hand, linear effect remains steady at first and after tilting the sun profile angle slightly, a sudden fall of percentage value from 0.5 to 0.4 is observed. Furthermore, tilting sun profile angle only causes gradually drop of the percentage value. Therefore, this graph mainly explains the relationship between electrical effects and linear effects.

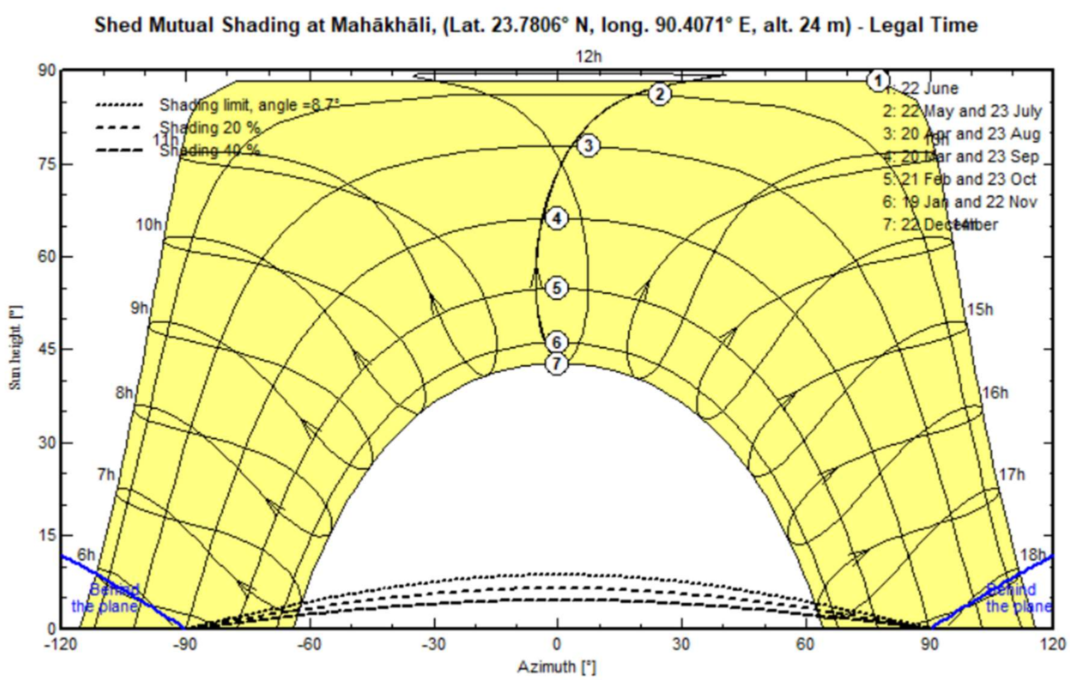


Fig. 21. Iso-shedding diagram

Fig. 21, illustrates the iso-shedding diagram that before 6:30 am and after 6:30pm the panels are slightly behind shadows.

TABLE VIII. DAILY IRRADIANCE ON GROUND AND SKY

Irradiance on ground	Daily irradiations for clear sky
Profile angle = 0.0 degrees Diffuse fraction on ground = 71.4% Global fraction on ground = 0	Beam clear sky = **4.6** KW-h/ m^2 Diffuse clear sky = **2.5** KW-h/ m^2 Beam fraction on ground = **74.6%** Diffuse fraction on ground = **71.4%** Global fraction on ground = **73.5%**

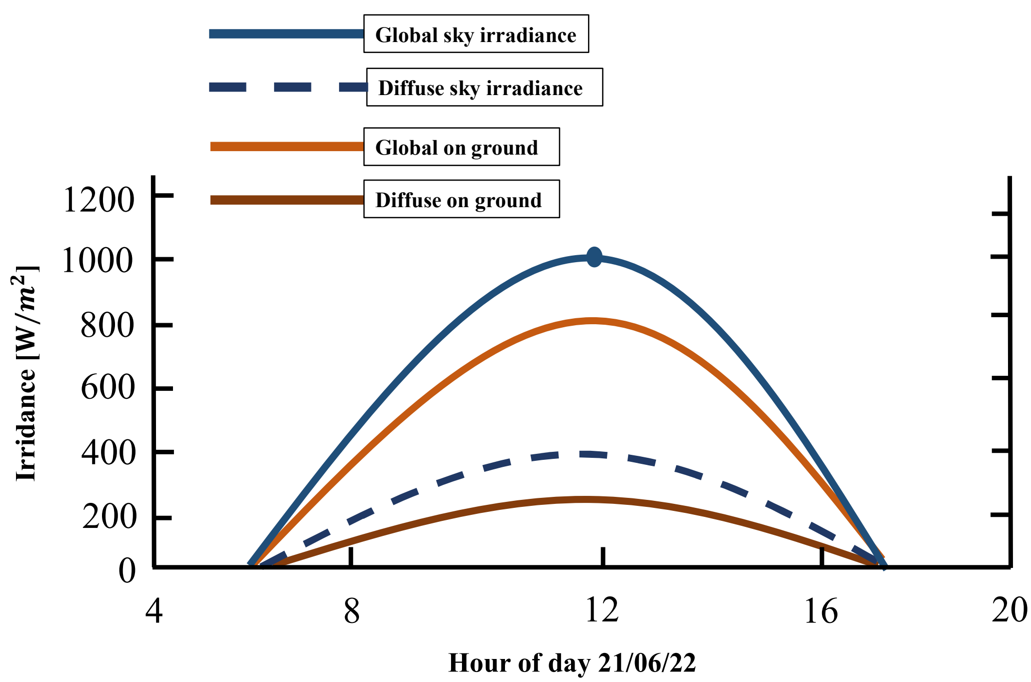


Fig. 22. Hourly irradiance [mutual shading]

Fig.22. is the graphical representation of hourly irradiance of our proposed bifacial solar PV system. This graph mainly shows the solar irradiance rate over different hours of a day for four cases. Irradiance of the solar radiation incident on horizontal surfaces is called Global horizontal irradiance. It actually consists of diffuse irradiance and ground-reflected radiation. Diffuse irradiation is the amount of sunlight (integrated over time) falling on the surface of the earth, which is scattered by air molecules or atmospheric particles. From this graph, we can see that hourly irradiance rate gradually increases from 6 AM to 12 PM and after 12 PM to 6 PM this rate decreases steadily. At 12 PM solar irradiance rate is highest in all four cases. Here, Blue line denotes the global sky irradiance which is the outer curve of this graph. At 12 PM when the sun is directly overhead, the global sky irradiance value is the highest, 1000W/m^2. The diffuse sky irradiance rate is quite lower than the global sky irradiance rate. In case of diffuse sky irradiance, 400 W/m^2 is the highest value at 12 PM which is denoted by the dotted line. On the other hand, global on ground is another irradiance rate which is shown by the orange curve. From 6 AM the irradiance rate increases till 12 PM and at that time the highest value of this curve is 800 W/m^2, after this irradiance rate slowly drops. Lastly, the lower irradiance curve is for diffuse on ground which is indicated by the brown line. Around 200 W/m^2 is the peak value of this curve at 12 PM and compare to other irradiance curve this is the lowest value. In conclusion, this irradiance vs time graph gives a clear idea of distribution of power of specific area.

- <u>Main results</u>

TABLE IX. SYSTEM PRODUCTION AND ECONOMIC EVALUATION OF DESIGN 2

System production	Economic evaluation	
Produced energy = 1959 KW-h/ year Used energy = 1171 KW-h/ year Specific production = 1400 KW-h/ KW-p/ year Performance ratio = 82.76%	Total investment = **122228** Tk Specific = **87.3** Tk/ W-p Annuities = **2892** Tk Run costs = **2282** Tk Payback period = **6.1** years Energy cost = **7** Tk/ KW-h	***The battery life time will be approximately 10 years for the system design.***

The produced energy of design approach two is 1959 KW-h per year. Out of that, the used energy is 1171 KW-h/year. At the same time, the specific production lies at 1400KW-h/KW-p/year. Furthermore, the performance ratio rises to 82.76%. With an economic valuation, how cost-effective the design approach will be known. The total investment stands at Tk.122228 where energy per KW-h costs at Tk.7. The payback period is 6.1 years. Finally, the battery lifetime is approximately 10 years to last for.

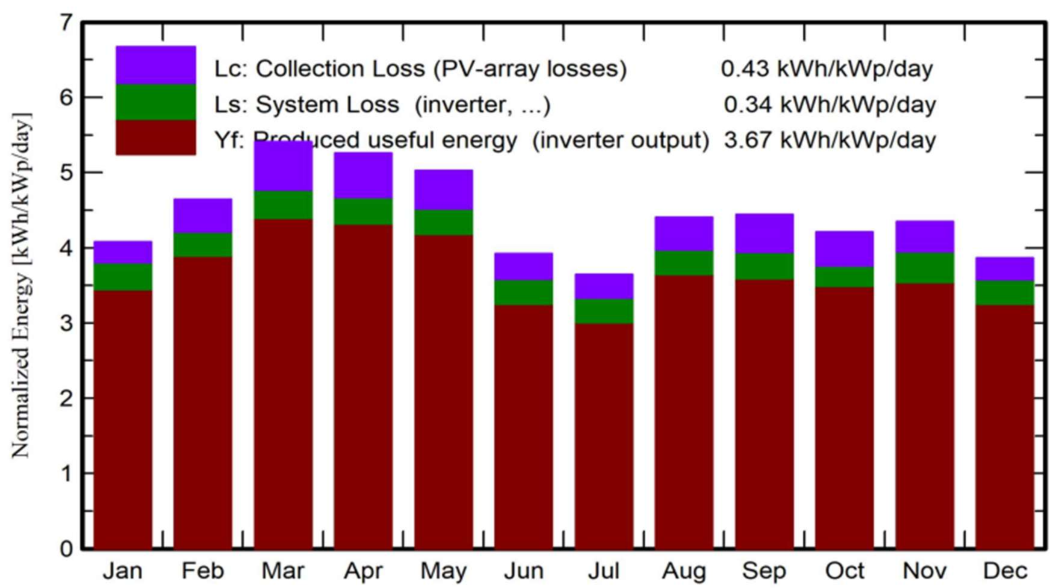


Fig. 23. Normalized productions (per installed KW-p)

Here Fig. 23, illustrates that the energy supplied to the user on a monthly basis is denoted by the brown bar. The magenta and dark blue bar both denotes the losses of the system. Therefore, from the graph we can find the average value over a year is:

Produced useful energy $\boldsymbol{Y_f} =$ **3.67** KW-h/ KW-p / day

Total system loss = (collection loss + System losses)
= (0.43+.34)
= 0.77 KW-h/ KW-p/ day

$\boldsymbol{Y_r} =$ **(**Total system loss + Energy supplied to the user)

= 0.77+3.67 = **4.44** KW-h/ KW-p / day

From this we can calculate the average performance ratio:

Average yearly Performance ratio = $\frac{Energy\ supplied\ to\ the\ user}{\boldsymbol{Y_r}} = \frac{\boldsymbol{Y_f}}{\boldsymbol{Y_r}} = \frac{3.67}{4.44} = 0.82655$

Therefore, the average yearly performance ratio of the system is = 82.76%

Figure 23 is a column chart which demonstrates the Normalized Energy Production of design 2, in kWh per installed kWp per day, for every month of a year. The column chart has three colors, brown which denotes the useful energy output from the inverter, blue which describes the collection losses from PV arrays and magenta which is the system loss, in inverter and other components. The system loss remains constant at 0.34kWh/kWp/day throughout the year as shown in the chart. The average collection loss and produced useful energy is 0.43kWh/kWp/day and 3.67kWh/kWp/day respectively. However, throughout the year, these values fluctuate. From January, the value of collection loss rises from 0.20kWh/kWp/day to peak at 0.65kWh/kWp/day on March. This then gradually decreases to 0.60kWh/kWp/day and 0.50kWh/kWp/day in the next two months consecutively. In June the value reaches 0.30kWh/kWp/day and then further falls to 0.25kWh/kWp/day in July. The collection loss recorded in August is at around 0.40kWh and stays steady at this number for the following four months till November, and then again falls to 0.20kWh/kWp/day in December. Produced useful energy follows a similar pattern in the chart. At first, in January, the useful energy values is 3.5kWh/kWp/day, rises to 4.5kWh/kWp/day in March and then gradually decreases to 4.25kWh/kWp/day and 4.00kWh/kWp/day in April and May respectively. In June, the values plummet to 3.20 kWh/kWp/day and further go down to 3.00kWh/kWp/day in July. August, September, October and November the useful energy recorded in theses months is around 3.5kWh/kWp/day and finally in December it falls again to 3.20 kWh/kWp/day

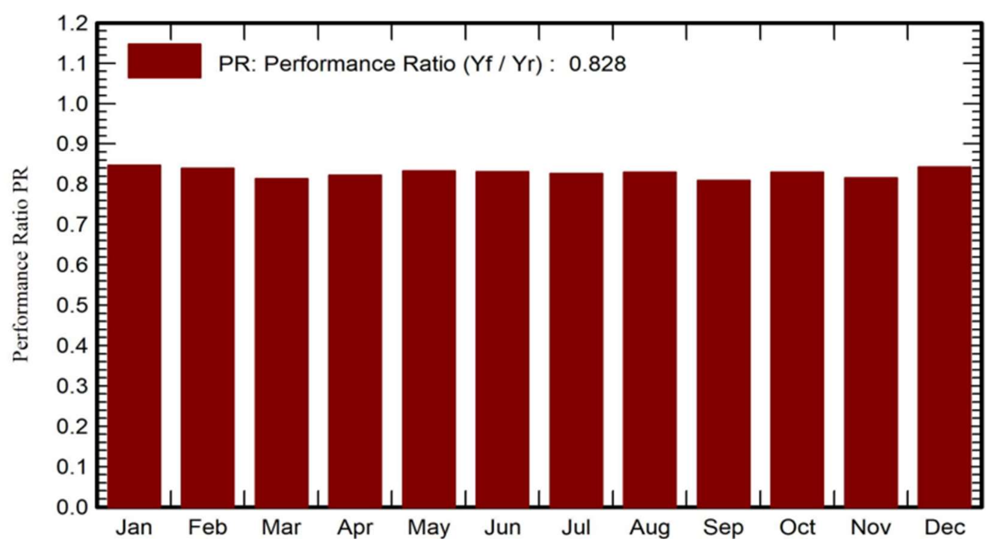


Fig. 24. Monthly performance ratio

Figure 24 illustrates a bar chart which describes the Performance Ratio PR of design 2 for all the months in a year. From above, the total system loss (0.77kW-h/ KW-p/ day) and Yr (4.44 KW-h/ KW-p / day) of design 2 is calculated and using them, the average performance ratio is found to be 82.76%. From the Monthly Performance ratio chart, the Average Performance ratio is 0.828 or 82.8%. This value is very close to the calculated value, with insignificant difference. Since, it can be said that the two values match, this further validates the calculated value.

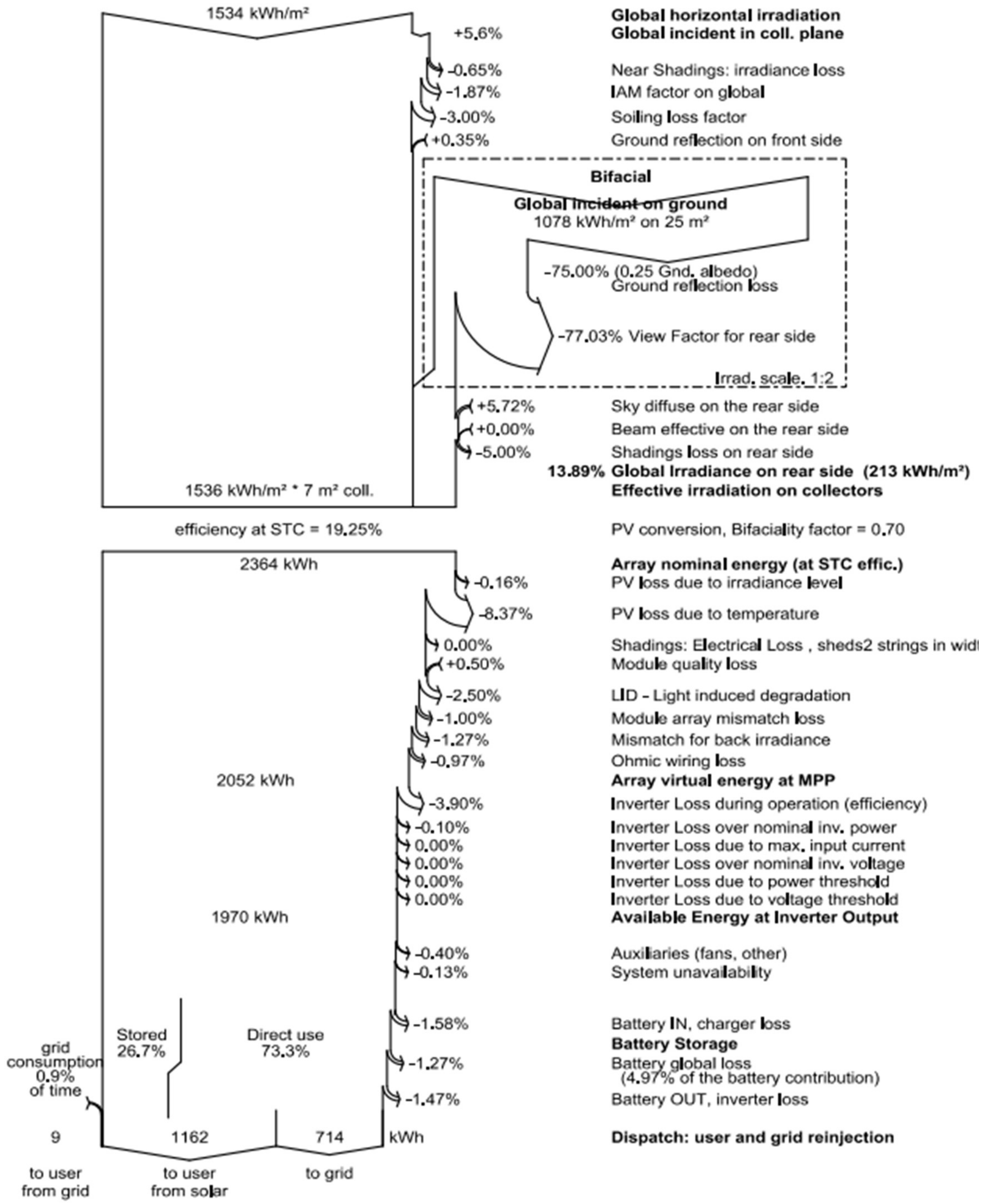


Fig. 25. Loss diagram of hybrid system [Sankey diagram] with mutual shading

Here, from Fig. 25, the Sankey diagram we can see that global irradiation at our location where the PV system is installed is 1534 KW-h/m^2. After considering all the loss factors the energy that will be generated by the PV panels is 2364 KW-h again considering all the loss factors due to temperature, module quality loss, ohmic wiring loss etc. the effective energy at the input of the inverter is 2052 KW-h, after that some inverter losses occur and then at the output of the inverter the energy received is 1970 out of this energy 73.3% is in direct use and 26.7% is stored. The grid consumption from this design approach is 0.9% which eventually leads to 9 kW-h coming from the grid to the user and 1162 KW-h is injected to the user from the PV system, furthermore, 714 KW-h is being reinjected to the grid from the PV system.

4.2.2 Design 3

The site planning of design approach 2 is illustrated in Fig. 26.

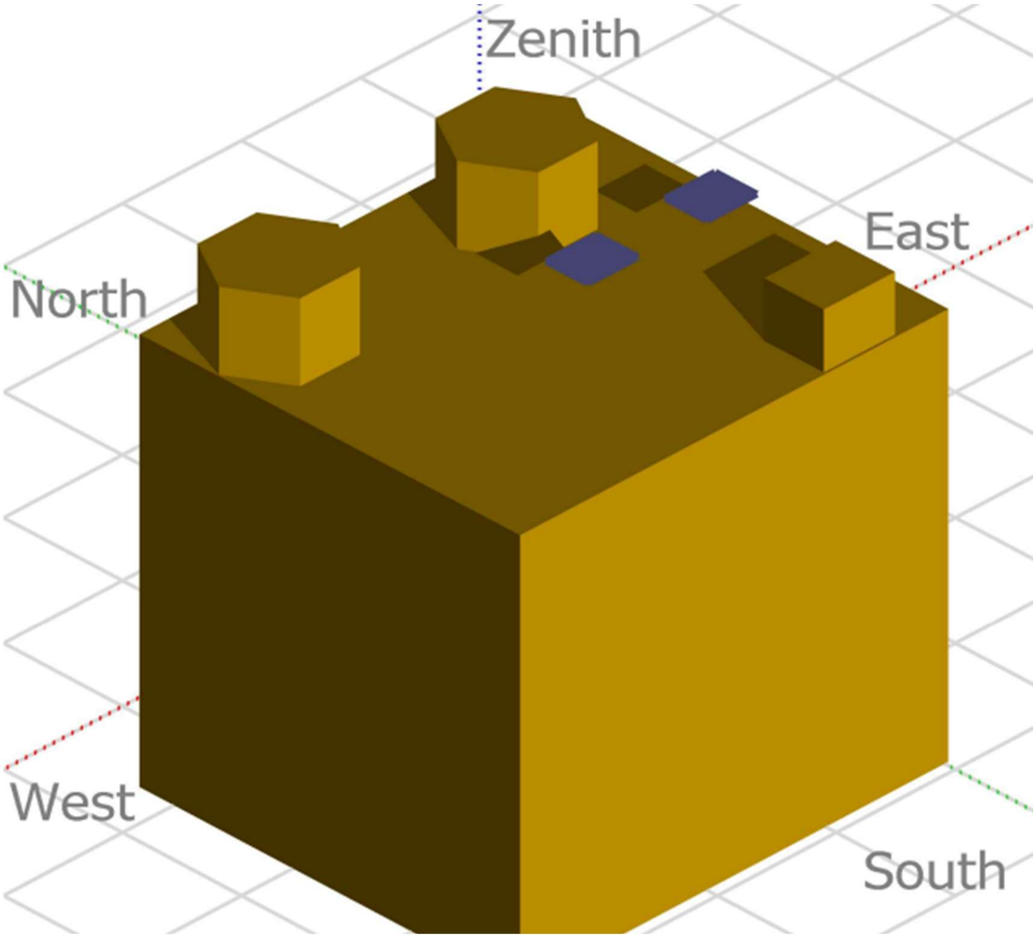


Fig. 26. Perspective of PV-field and surrounding shading scene

Here, we have used tracking horizontal axis, N-S. Also, in this design approach we have chosen two horizontal trackers and the setup for the PV plane is two array of PV table with 2-by-1 array.\

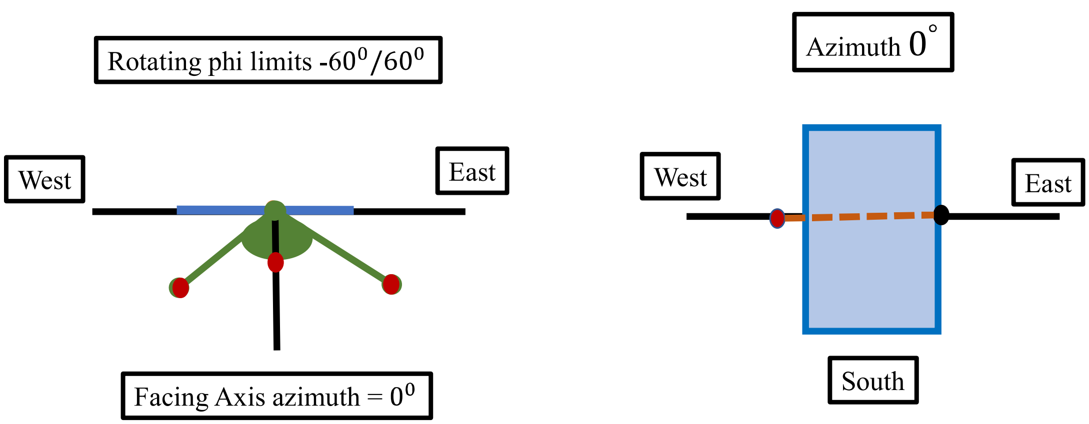


Fig. 27. Horizontal tracking system and tracking angle limits

Fig. 27 illustrates the setup for single axis tracking system for design 3 and rotating angle is form - $60^0/60^0$ for the bifacial PV panels that shall be mounted.

TABLE X. OPERATION, TRACKER AND GROUND PARAMETERS; DAILY IRRADIANCE ON GROUND AND SKY

Operation parameters	**Trackers and ground parameter**	**Irradiance on ground**	**Daily irradiations for clear sky**
Axis azimuth = 0 Phi min = -60 degrees Phi max = 60 degrees	Pitch = **5**m Shed total width = **2.1**m Profile angle = **-90** degrees Height above ground = **2.1**m Ground albedo = **0.25**	Phi angle (without limits) = **0.1** degrees Beam clear sky = **644** W/m^2 Global fraction on ground = **72.8%**	Beam clear sky = **4.6** KW-h//m^2 Diffuse clear sky = **2.5**KW-h/ /m^2 Beam fraction on ground = **47.5%** Diffuse fraction on ground = **58.5%** Global fraction on ground = **53.5%**

In this design, we have calculated Axis azimuth and maximum-minimum Phi angle as Operational parameters. Axis azimuth is 0 and Phi angle is maximum 60° to minimum -60°. For Trackers and ground parameters, our calculated pith value is 5m and total shed width is 2.1m. Moreover, for -90° profile angle and 2.1m distance between tracker and ground, ground albedo value is 0.25. From simulation results we got, without limits the Phi angle is 0.1° in case of irradiance on ground. Irradiance for beams in clear sky is 644 W/m2. Besides, the Global fraction on ground has been measured about 72.8%. On the other hand, the daily irradiations have also simulated through software. Beam clear sky is 4.6 KWh/m2 and Diffuse clear sky irradiance is 2.5KWh/ /m2 we found from simulation. Furthermore, Beam fraction on ground, Diffuse fraction on ground and Global fraction on ground are also included in Daily irradiations parameters calculation. According to simulation, Beam fraction on ground irradiance is about 47.5% and Diffuse fraction on ground is about 58.5% whereas Global fraction on ground has been calculated around 53.5%.

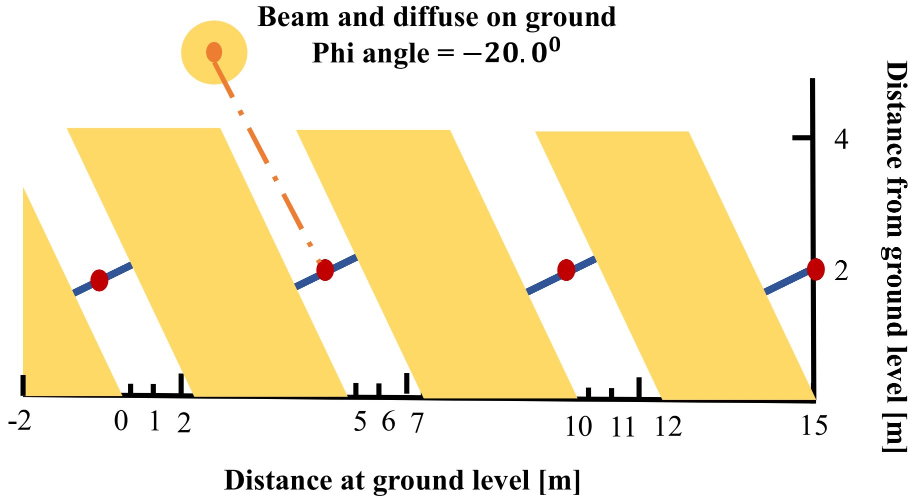


Fig. 28. Distance to panel above planted surface

Fig.28 gives an idea about the distance to panel above planted surface in a graphical method. Besides, this graph shows a relation between the beam directly falling on the surface and diffused sunlight on ground or reflected sunlight from the ground. From our simulation result, we found the phi angle (reflected sunlight angle) to be approximately -20°. This graph is characterized by the panel distance from ground (panel height from ground) against the panel distance at ground level. However, distance between two adjacent panels is 3m. Moreover, this graph is showing the incident and reflected sun beams between two side-by-side panels at a height of 2 meters from ground. Since we are proposing Bifacial PV solar system, front side cells will collect sunlight directly from the sun whereas rear side cells will collect from scattered and diffused reflected sunlight from the ground and surroundings.

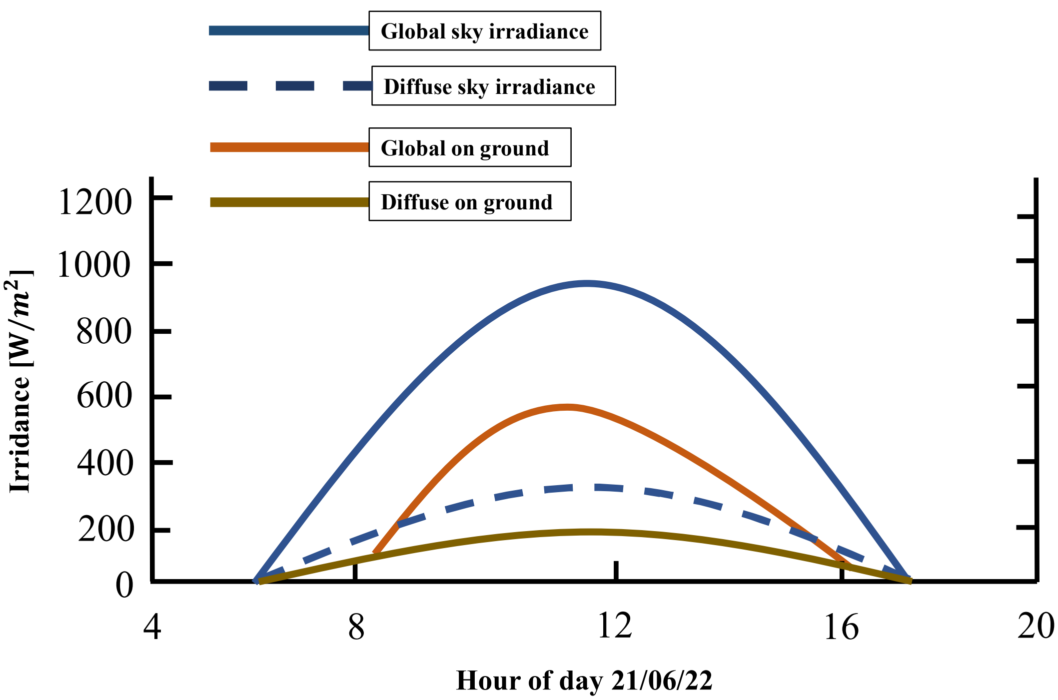


Fig. 29. Hourly irradiance [single axis tracking]

Fig.29 is the graphical representation of hourly irradiance rate after using single axis tracking system. Single axis tracking system has been used to tack the sun's position. Moreover, under bright, sunny situations with the longest direct solar irradiance period, single axis tracking system was found to be highly efficient. The primary focus of this graph is the sun irradiance rate for four scenarios throughout different hours of the day. The blue curve represents the trend of global sky irradiation. Between 6 AM and 11 AM, the irradiation rate progressively increases. At around 11 AM its irradiance rate reaches a maximum value of 900 W/m^2. Irradiance rate declines slowly from 11 AM to 6PM. The dotted line shows that the diffuse sky irradiance starts to dramatically increase between 6 AM and 11 AM. As in the chart above, the irradiance rate steadily decreases after 11 AM, reaching a maximum of 300 W/m2 at 11 AM. Consequently, the orange curve depicts the global on-ground irradiance rate and its irradiance value increases from approximately 8 AM to 11 AM. At 11 AM, the irradiance rate reaches its peak value, which is 800 W/m2. Henceforth, a decrease in irradiance value occurs with increased time. Lastly, the lower irradiance curve is for diffuse on ground which is indicated by the brown line. At 11 AM, this curve reaches at the highest irradiance value of approximately 200 W/m2, which is the lowest compared to other irradiance curves. In conclusion, single axis tracking system tracks the direct solar ray exposure; this causes generating more energy and increases the efficiency of solar PV system.

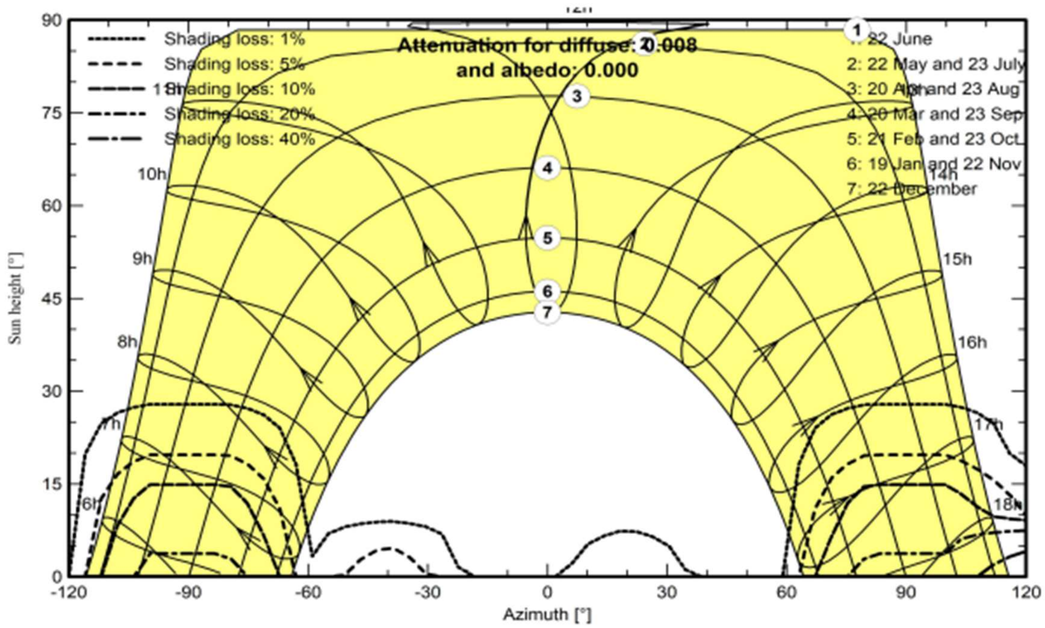


Fig. 30. Iso-shedding diagram

Here, from Fig. 30, we can see from the iso-shedding diagram that before 7:30am and after 6:30pm the panels are slightly behind shadows. Attenuation for diffuse 0.008 and albedo for the site for this design is 0.

➢ <u>Main results</u>

TABLE XI. SYSTEM PRODUCTION AND ECONOMIC EVALUATION OF DESIGN 3

System production	Economic evaluation	
Produced energy = 2180 KW-h/ year Used energy = 1171 KW-h/ year Specific production = 1557 KW-h/ KW-p/ year Performance ratio = 82.27%	Total investment = **131963** Tk Specific = **94** Tk/ W-p Annuities = **3087** Tk Run costs = **2373** Tk Payback period = **6** years Energy cost = **6** Tk/ KW-h	***The battery life time will be approximately 10 years for the system design.***

The produced energy of design approach three is 2180 KW-h per year. Out of that, the used energy is 1171 KW-h/year. At the same time, the specific production lies at 1557 KW-h/KW-p/year. Furthermore, the performance ratio rises to 82.27%. With an economic valuation, how cost-effective the design approach will be known. The total investment stands at Tk.131963 where energy per KW-h costs at Tk.6. The payback period is 6 years. Finally, the battery lifetime is approximately 10 years to last for.

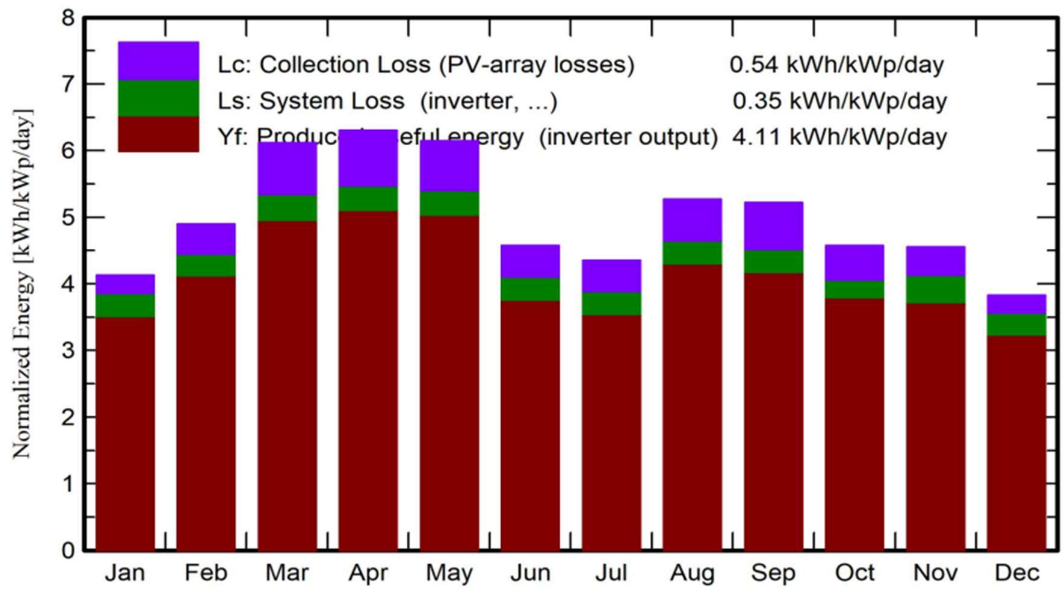


Fig. 31. Normalized productions (per installed KW-p)

Here we can see from the graph that the energy supplied to the user on a monthly basis is denoted by the brown bar. The magenta and dark blue bar both denotes the losses of the system. Therefore, from the graph we can find the average value over a year is:

Produced useful energy $\boldsymbol{Y_f} =$ 4.11 KW-h/ KW-p / day

Total system loss = (collection loss + System losses)
= (0.54+.35)
= **0.89** KW-h/ KW-p/ day

$\boldsymbol{Y_r} =$ **(**Total system loss + Energy supplied to the user)
= 0.89+4.11 = **5** KW-h/ KW-p / day

From this we can calculate the average performance ratio:

Average yearly Performance ratio = $\frac{Energy\ supplied\ to\ the\ user}{\boldsymbol{Y_r}} = \frac{\boldsymbol{Y_f}}{\boldsymbol{Y_r}} = \frac{4.11}{5} = 0.8222$

Therefore, the average yearly performance ratio of the system is = 82.22%

Figure 31 is a column chart which describes the Normalized Energy Production of design 3, in kWh per installed kWp per day, for every month of a year. The system loss remains constant at 0.35kWh/kWp/day throughout the year as shown in the chart. The average collection loss and produced useful energy is 0.54kWh/kWp/day and 4.11kWh/kWp/day respectively. These values fluctuate. From January, the value of collection loss rises from 0.25kWh/kWp/day to peak at 0.70kWh/kWp/day on March. The values are 0.65kWh/kWp/day and 0.60kWh/kWp/day in the next two months consecutively. In June the value reaches 0.40kWh/kWp/day and then further falls to 0.35kWh/kWp/day in July. The collection loss recorded in August is at around 0.55kWh and stays steady at this number in September also. In October and November this number is around 0.35kWh/kWp/day and in December it falls back to 0.25kWh/kWp/day. Produced useful energy follows a similar pattern in the chart. At first, in January, the useful energy values is 3.5kWh/kWp/day, increases to 5.0kWh/kWp/day in April.

In June, the number declines to 3.70 kWh/kWp/day and further go down to 3.50kWh/kWp/day in July. In August and September, it is around 4.25kWh/kWp/day, decreases to 3.75kWh/kWp/day October and November, later falls to 3.25kWh/kWp/day in the month of December.

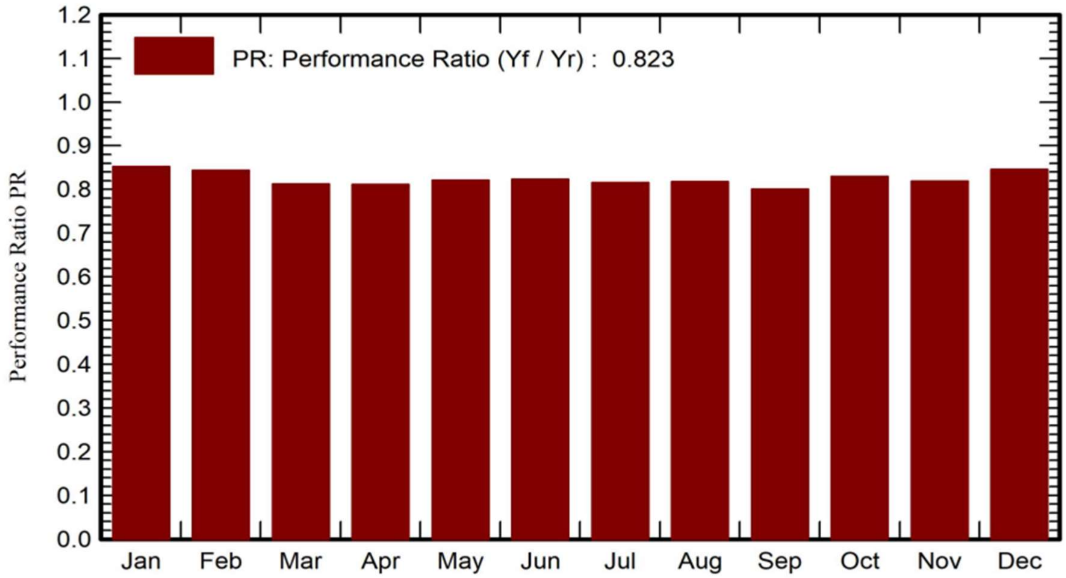


Fig. 32. Performance ratio

Figure 32 illustrates a bar chart which shows the Performance Ratio (PR) for design 3 for all the months in a year. The average yearly performance ratio of third design approach system is roughly around 0.823. Generally, the performance ratio is the ratio of energy supplied to the user to the total energy loss and energy supplied to user. From above, the total system loss (0.89kW-h/ KW-p/ day) and Yr (5.00KW-h/ KW-p / day) of design 3 is evaluated and using them, the average performance ratio is found to be 82.22%. In the beginning of the year, in January, the performance ratio starts off approximately around 0.84. This value of performance ratio is assumed to be a moderate value. A slight decline is visible in next month of the year. The performance ratio declines to 0.83 in February. Moving on, a further fall in the performance ratio is observed in the month of March. The value of performance ratio can be seen in the month of March is 0.82. In the following month, April, no changes can be seen in the performance ratio. Again, an inclination in the performance ratio can also be observed in the next month following April. Respectively, the value of performance ratio in the months of May and June are 0.825 and 0.824. Suddenly, a slight decline in the performance ratio is visible in the months of July and August. In the month of July, the performance ratio slides to 0.82 and the performance ratio recorded in August is also 0.82. Gradually, the performance ratio drops down to 0.81 in the month of September and again rises in October. Over the period of these two months, the performance ratio stands at 0.81 and 0.83 respectively. In November, again a prone to declination in the value of performance ratio is noticeable. Furthermore, a modest shrink in the performance ratio is noted in the month of November where the performance ratio is 0.82. Finally, in the last month of the year, December, the performance ratio hits 0.83 again. A number of fluctuations can be observed from the above performance ratio graph. Initially, the graph starts at 0.84 from the month of January, then it starts to decline until the March. However, it starts to rise again from May to July. There is no fluctuation noticed in March and April and also May and June. In spite of these frequent fluctuations, the performance ratio stays in a range from 0.81 to 0.84. Starting the first part of the year, a maximum value of 0.84 is recorded in January. In comparison to other months of the year, January gives the maximum performance ratio for this system. On the other hand, the lowest performance ratio recorded was in the month of September which is 0.81. In the final analysis, it is visible that fluctuations in the performance ratio are very marginal and do not have any drastic changes.

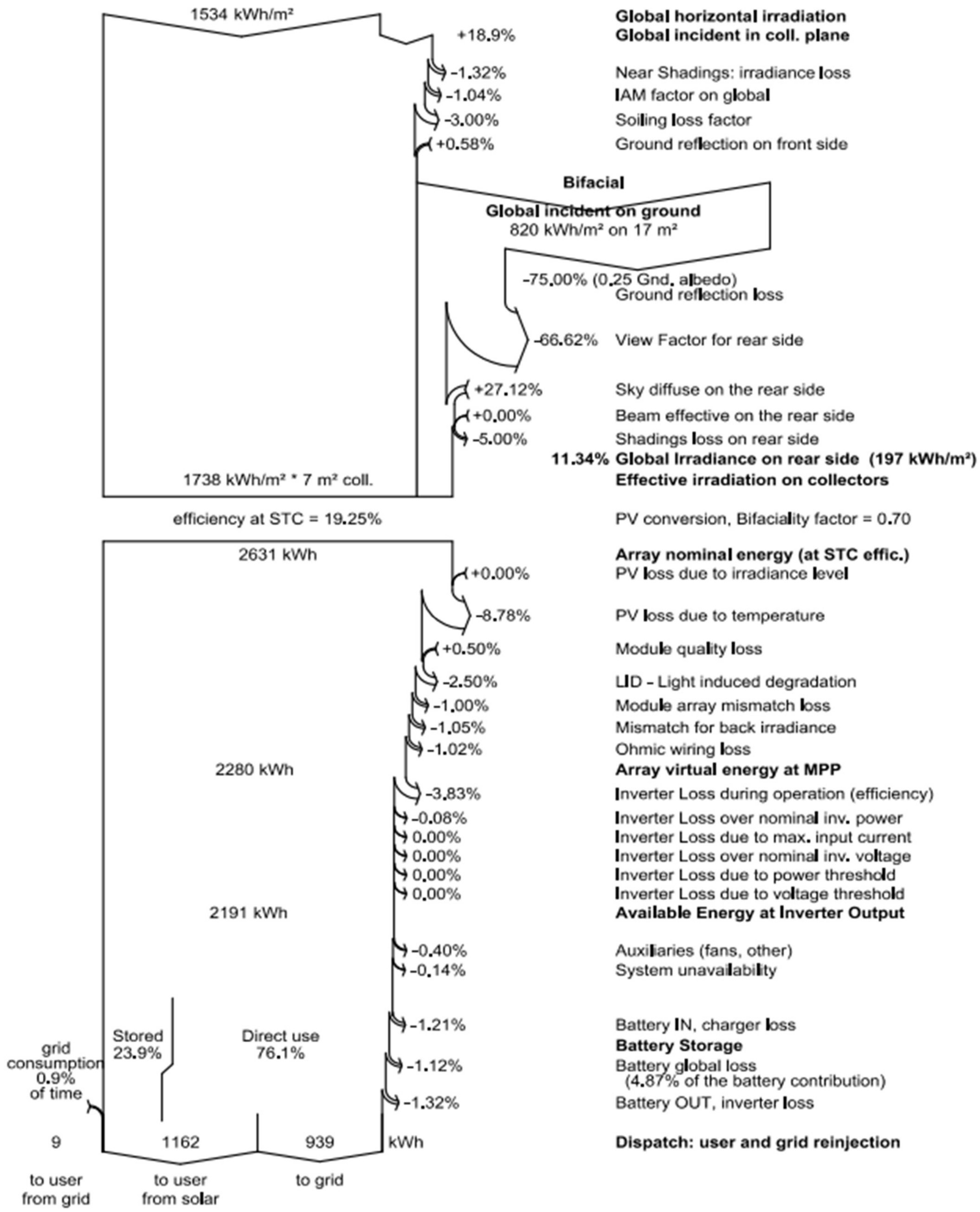


Fig. 33. Loss diagram of hybrid system [Sankey diagram] with single axis tracking

Here, Fig. 33, illustrates the Sankey diagram, we can see that global irradiation at our location where the PV system is installed is 1534 KW-h/m^2. After considering all the loss factors and the efficiency of the PV panels, the energy that will be generated by the PV panels is 2631 KW-h again considering all the loss factors due to temperature, module quality loss, ohmic wiring loss etc. The effective energy at the input of the inverter is 2280 KW-h. Again, taking all the inverter losses that occurs, then at the output of the inverter the energy received is 2191 KW-h, out of this energy 76.1% is in direct use and 23.9% is stored in the battery bank. Here 9 kW-h is coming from the grid to the user and 1162 KW-h is injected to the user from the PV system, 939 KW-h is being reinjected to the grid from the PV system. To conclude, this Sankey diagram proves that design 3 produces and send to the grid more energy than design 1 and design 2.

4.3 Identify optimal design approach

4.3.1 Comparing the multiple design approaches

TABLE XII. COMPARISON OF THE THREE DESIGN APPROACHES

Design1	Design2	Design3
Results overview System production = **1650KW-h/year** Used energy = **1168KW-h/ year** The output energy of the Sankey diagram after considering all the losses = **1168 KW-h**	***Results overview*** Produced energy = **1959 KW-h/ year** Used energy = **1171 KW-h/ year** From the Sankey diagram, we can see that, **1162 KW-h** energy is being used by the user out of which **26.7%** is stored. **714KW-h** energy is being injected to the grid **9KW-h** is being drawn from the grid	***Results overview*** Produced energy = **2180 KW-h/year** Used energy = **1171 KW-h/ year** From the Sankey diagram, we can see that, **1162 KW-h** energy is being used by the user and out of which **23.9%** is being stored. **939 KW-h** energy is being injected to the grid 9KW-h is being drawn from the grid

By this comparison in Table XIL, we can clearly observe that design 2 and 3 are far superior than design 1 and among design 2 and design 3, the last design which is design 3 is much more optimized compared to the other two design. As we can verify that design 3 which is a hybrid system with bifacial PV modules being used as the solar panels, we can now compare our optimized design which is the third design to a mono-facial PV panel with tracker hybrid system just show how efficient and optimized design 3 is compared to the nowadays used mono-facial PV panel-based system.

4.3.2 Comparison with Mono-facial and Bifacial hybrid system

If we simulate the mono-facial PV panel-based hybrid system we can get every aspect of the general mono-facial PV panel-based hybrid systems data. Some of the important data that we can get for this are:

System production = 2070 KW-h/ year
Used energy = 1168KW-H/ year
Performance ratio = 77.04%

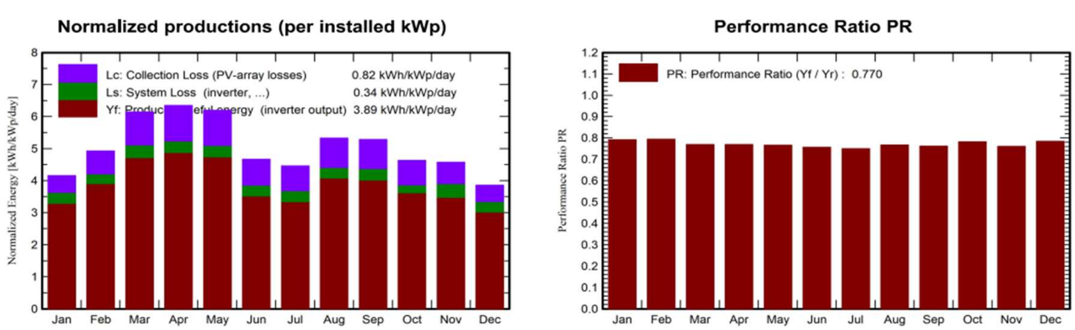


Fig. 34. Mono-facial PV panel-based hybrid system's data

Figure 34 is an illustration of two bar charts representing the monthly Normalized productions (per installed kWp) and Performance Ratio of the hybrid system based upon Mono-facial PV panel in a year.

From the first chart, it can be observed that the average system loss is 0.34kWh/kWp/day and the average production useful energy of the whole year is 3.89kWh/kWp/day although in every month, the useful energy changes drastically. The useful energy which are denoted by the brown bars, follows a similar trend like the Bifacial PV panel-based hybrid system with the only differences are that the height or the values at each month are smaller. The average collection loss of the 12 months records at 0.82kWh/kWp/day which is very high, almost double of the Bifacial PV panel-based hybrid system that we determined earlier. In the month of March, April and May, the collection loss is as high as 1kWh/kWp/day. From June to November, this value stands in the range of around 0.60 to 0.80kWh/kWp/day and in January, February and December the loss value is around 0.5kWh/kWp/day The average Performance Ratio stands at 0.770 or 77% which is almost same as the Performance Ratio of 77.04% stated above the charts, indicating that both the values are correct and validates each other.

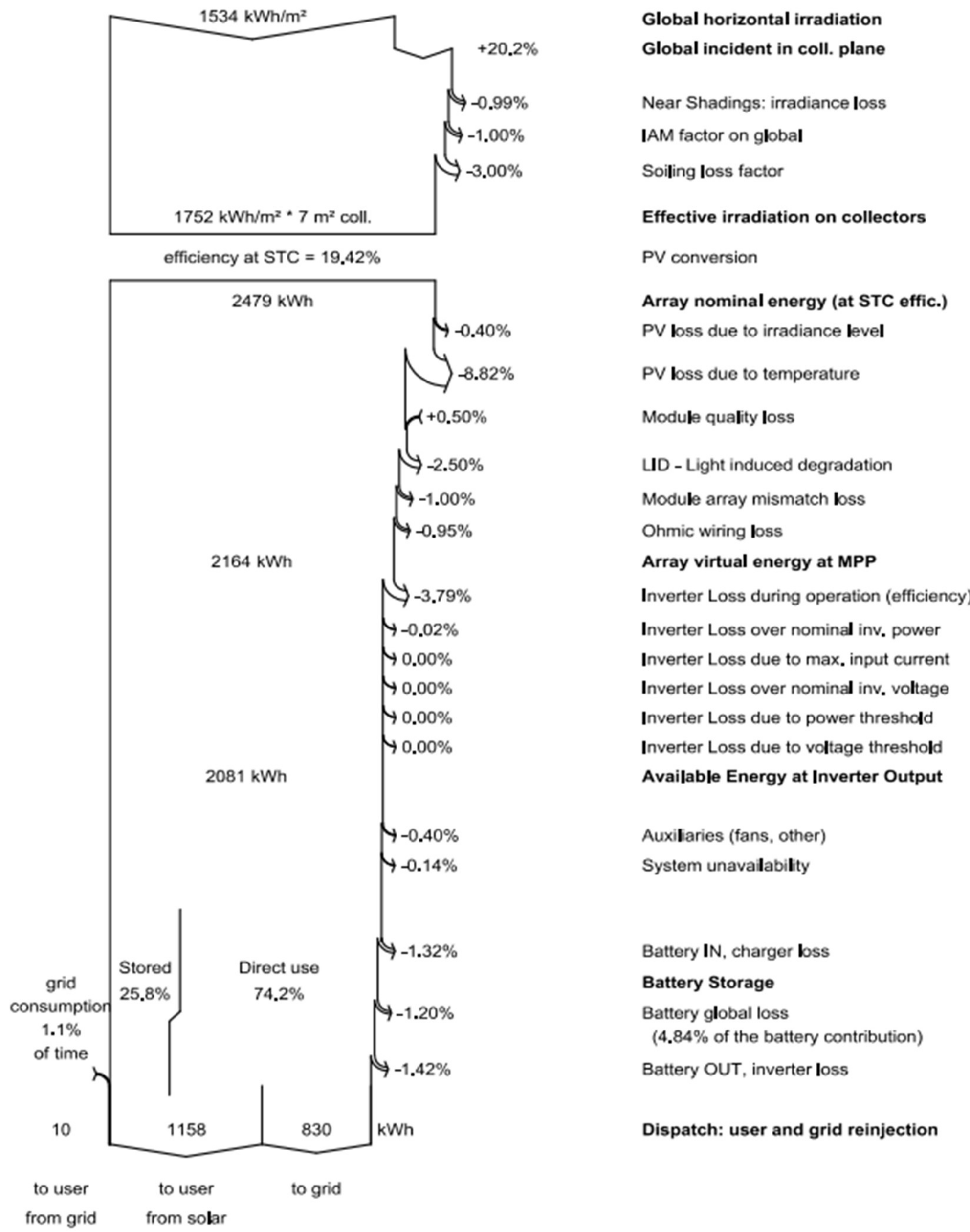


Fig. 35. Sankey diagram of Mono-facial PV panel-based Hybrid system

From Fig. 35, the Sankey diagram illustrates the input and output energy of our PV system, taking in all the different kinds of loss within the system. The global irradiation at our location where the PV system is installed is 1534 KW-h/m^2. This irradiance will be incident into panels will area 7 m2. So, the total energy that will fall on the panel is 1534×7 kWh. After considering all the loss factors, such as near shadings loss and irradiance loss which stands at 0.99% combinedly. Consequently, the global incident in coll. plane is 20.2%, thus, the energy that will be generated by the PV panels is 2479KW-h. The efficiency of the system is 19.42%. Again, considering all the loss factors due to irradiance level is roughly around 0.40% where due to temperature is 8.82%. Furthermore, the module quality loss stands at 0.50%, along miss match loss and ohmic wiring loss, the loss percentages are 1.00% and 0.95% respectively. Moreover, loss due to MPP running recorded is 3.79%. Therefore, the effective energy at the output of the array battery storage is 2081 KW-h. Out of that energy, 74.2% is being used directly by the user and 25.8% is being stored. However, there are some other loss factors as well which mainly includes battery losses. Now considering other battery loss like the battery charger loss (1.32%), inverter loss (1.42%), battery global loss (1.20%), the final energy that the user receives (load) is 1158 KW-h, 830 KW-h to grid and 10 KW-h from grid to user.

TABLE XIII. COMPARISON OF MONO-FACIAL AND BIFACIAL BASED HYBRID SYSTEM

Bifacial PV panel-based hybrid system yearly basis	**Mono-facial PV panel-based hybrid system yearly basis**
Results overview	***Results overview***
Produced energy = **2180 KW-h/year**	Produced energy = **2070 KW-h/ year**
Used energy = **1171 KW-h/ year**	Used energy = **1168 KW-h/year**
Performance ratio = **82%**	Performance ratio = **77%**
From the Sankey diagram, we can see that, **1162 KW-h** energy is being used by the user and out of which **23.9%** is being stored.	From the Sankey diagram we can see that, **1158 KW-h** energy is being used by the user out of which **25.8%** is being stored.
939 KW-h energy is being injected to the grid	**830 KW-h** energy is being injected to the grid
9 KW-h is being drawn from the grid	**10 KW-h** is being drawn from the grid

We know that if a plant has a performance ratio less than 75% then it's not a good plant. But here both the system has a higher performance ratio than an average plant but we can clearly see from Table XIIL, that the Hybrid system with Bifacial PV panel-system is much more optimized and beneficial according to the data we have provided.

4.4 Performance evaluation of developed solution

4.4.1 System Validation of the developed solution

Since we have validated that design 3 is the best approach among all the design's now, we will simulate design 3's some aspects that can be simulated using Simulink. Here, we have set a constant value for controlling the system. Continuous powergui block uses variable step solver method in Simulink. However, we have drawn an embedded PV system from which irradiance and output voltage will be provided.

Fig. 36 depicts, ac voltage source and output voltage are connected to a sensor. Output of this sensor is connected to both grid and home appliances. Lastly, to show and compare the graphs we have added a scope. In MATLAB Simulink we tried to design an optimized PV system design. We also have collected data based on this Simulink design.

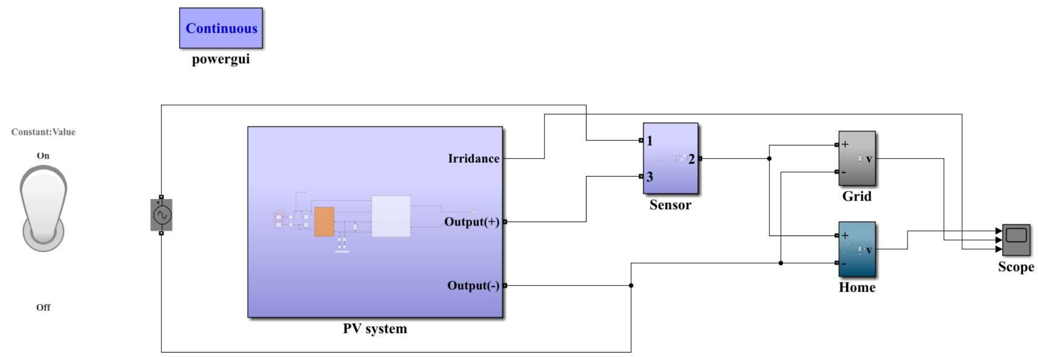


Fig. 36. Over all Simulink Diagram PV system

In this Fig. 36, we can see the ac voltage source is providing grid voltage if needed and the PV system is mainly providing voltage to the home and grid connected at the far-right sight of the Fig. 36.

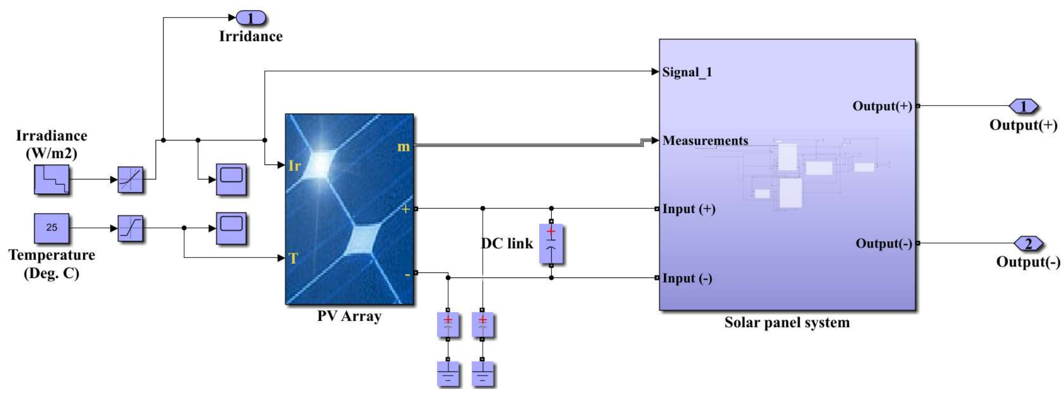


Fig. 37. PV system setup

In Fig. 37, we can see that DC link capacitor has been added in order to minimize the ripples of the voltage signal that is being generated by the PV panel setup. We have designed the PV panel in such a way that it can match the bifacial PV panel's criteria's [the model and the system design we have mentioned in the Design 3's specification of PV module]. Also, we have used stray capacitances so that the parasitic capacitances of the PV modules get dispatched.

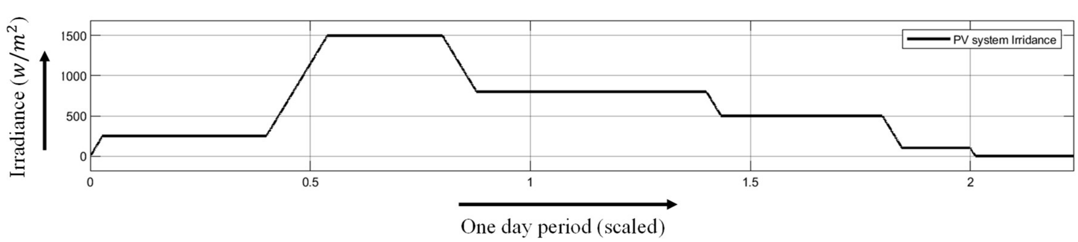


Fig. 38. Irradiance pattern

Irradiance pattern illustrated in Fig.38 is chosen for simulation and a fixed 25 degrees of temperature is being fed into the PV modules block in the simulation environment. Fig.38, is a simulated graphical representation of irradiance changes over different period of a day (scaled). This black line indicates the PV system irradiance rate. Different period of a day has been scaled in this graph to measure and show the fluctuation rate precisely. X- axis denotes the scaled day period and Y- axis denotes the irradiance values. We can observe an increase and decrease in the values of irradiance over scaled time.

This graph shows an increased irradiance rate about 250 W//m^2 at the first day period. This value remains stable for a long time after the increase. Around 0.375 to 0.6, the irradiance value again increases steeply from 250 W//m^2 to 1500 W//m^2. After reaching at 1500 W/m2, the irradiance rate again stays constant for a short period. Since then, the irradiance value does not increase any more but is seen to decrease gradually. A sudden drop-in irradiance rate is observed at around 0.7 to 0.875 and at 750 W//m^2 this value stays unchanged. Furthermore, irradiance rate decreases slightly and reaches at 500 W//m^2. Again, irradiance rate stays constant and then declines at 100 W/m^2. Lastly, irradiance rate value gradually decreases to zero.

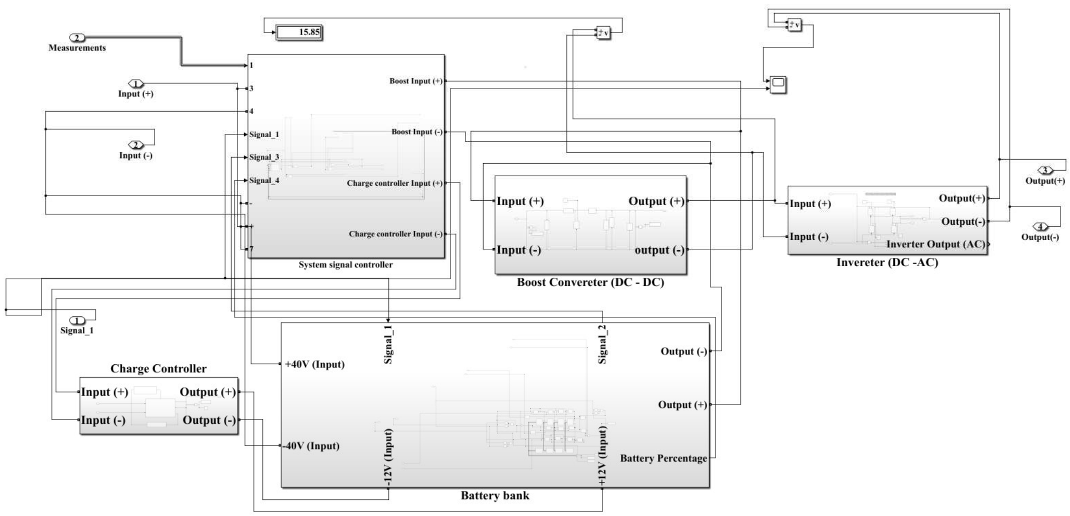


Fig. 39. Block diagrams under Solar Panel system block in Simulink

In this Fig. 39, we can see all the components that are under the block diagram of Solar Panel system. Here we can see the battery bank, charge controller boost converter and the inverter as well. The system functions as follows:

- When the irradiance level is more than 700 the system will run on direct irradiance converted into 220V voltage signal and sent to home and grid in parallel. At this time if the battery bank capacity is less than 10 percent then the battery bank will get charged.
- When the irradiance is less than 700 then the system will check if the battery bank voltage is greater than 10 percent of its full capacity. If it is then the battery banks stored voltage will be fed through the boost converter and through the inverter, then from the inverter output goring to the home and grid

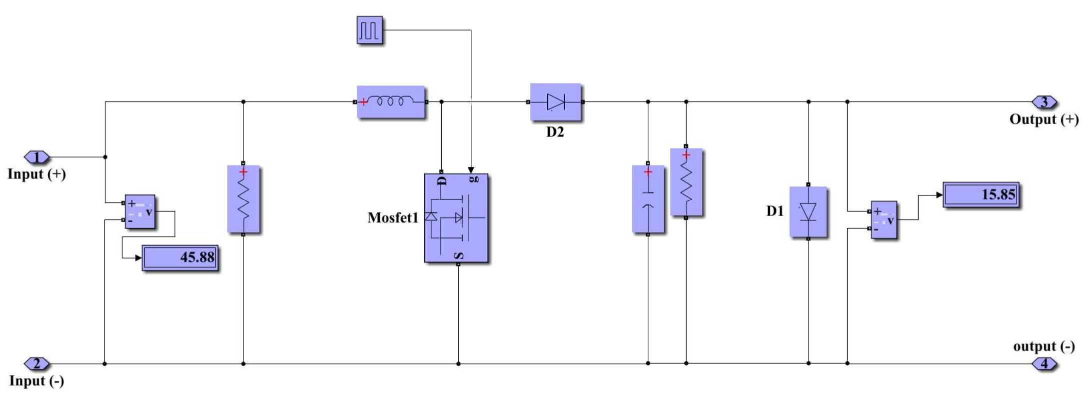


Fig. 40. Boost converter

Here in Fig. 40, we can see the diagram of the boost converter. This boost converter boosts 40 volts to 220 volts [approximately]. Here we have used a voltage regulator in order to get a constant 220 volts at the output of the boost converter and a resistance at the input side of the boost converter so that the inductor does not get open circuited during the sensors signals causing the boost converter to be open circuited.

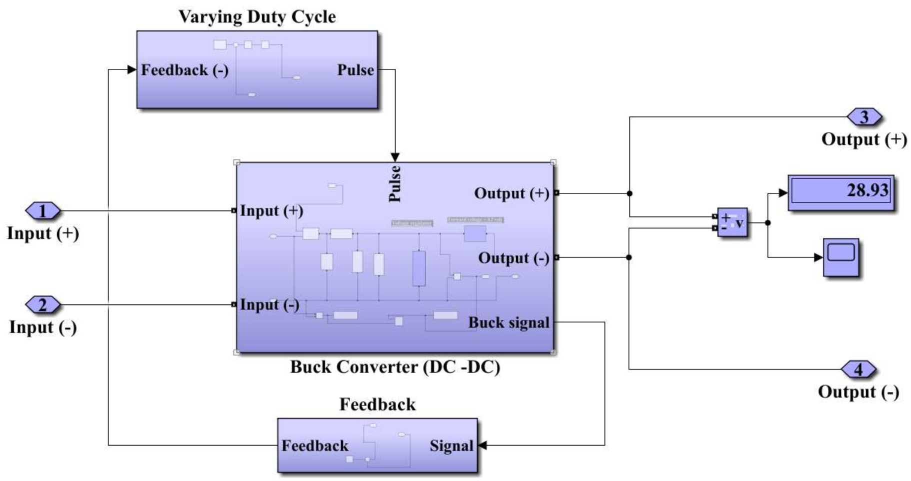


Fig. 41. Charge controller

In Fig. 41, we can see the charge controller is having a design of closed loop negative feedback with the help of a buck converter. Inside a solar charge controller, a buck converter is used to step down the voltage which eventually prevents the battery from overcharging.

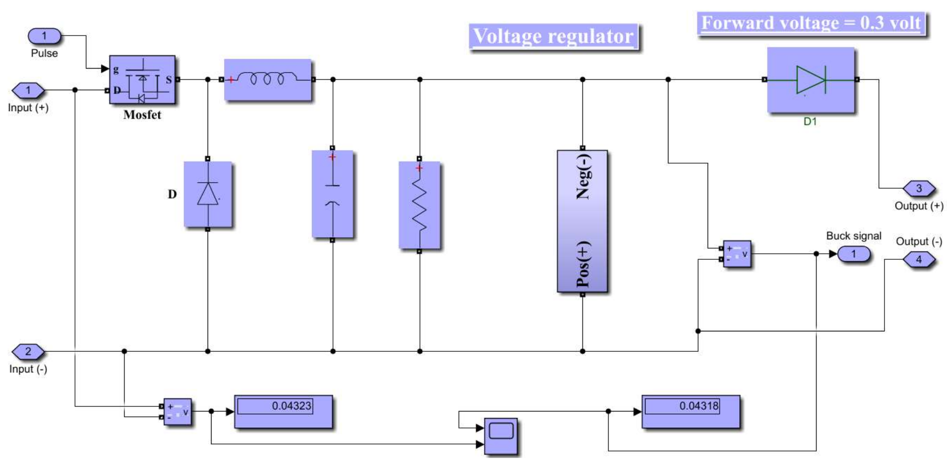


Fig. 42. Buck converter inside the charge controller

The buck converter inside the charge controller is bucking down the voltage to 12 volts constant as its feedback controlled buck converter. In the case of buck converters, the fixed dc input signal is converted into a different, lower value, dc signal at the output. This indicates that it is built to have an output dc signal with a lower magnitude than the applied input. Here, a pulse is added to input voltage is connected to the MOSFET. Pulse generator produces this pulse to control this MOSFET to buck or decrease the voltage. Resistance, diode, capacitor, conductor is connected to MOSFET, before connecting these to voltage regulator. Voltage regulator is used to control the voltage limit so that the system does not damage. Moreover, a forward voltage of 0.3V is also applied to another diode to the show the output voltage. We have also connected another input signal with another voltmeter and display to display the input signal values. To show the graphs we have connected a scope and to compare the displayed data of input signal and voltage regulator produced value we have added a buck signal to the voltmeter at voltage regulator.

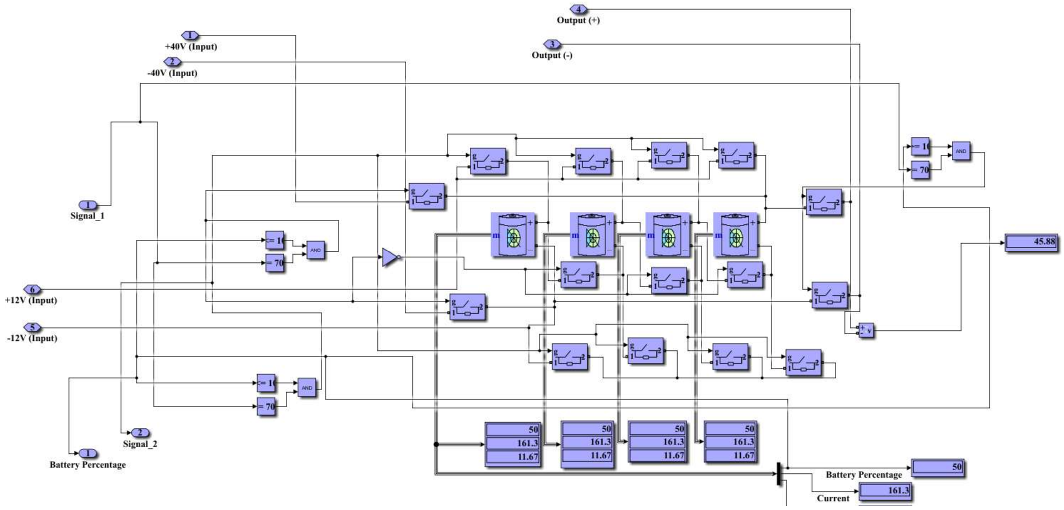


Fig. 43. Battery bank

In figure 43 we can see the designed battery bank the battery banks rating is 48volts 100Ah, and we have designed the battery bank in such a way that when the solar irradiance is less than 700 and the battery percentage is less than 10 percent the battery [as the battery bank consists of four 12volts battery in series] we are charging them is parallel as the voltage generated by the solar modules are not close to 40 volts. This low irradiance charging is happening from the solar modules, through the charge controller and to the battery. But when the solar irradiance can produce 40V and battery percentage is less than 10 percent the battery bank is in series and [four 12V battery banks are in series connection resulting is 48 volts at the output] and gets charged through the PV modules and at the battery bank at this moment will get charged and discharged at the same time.

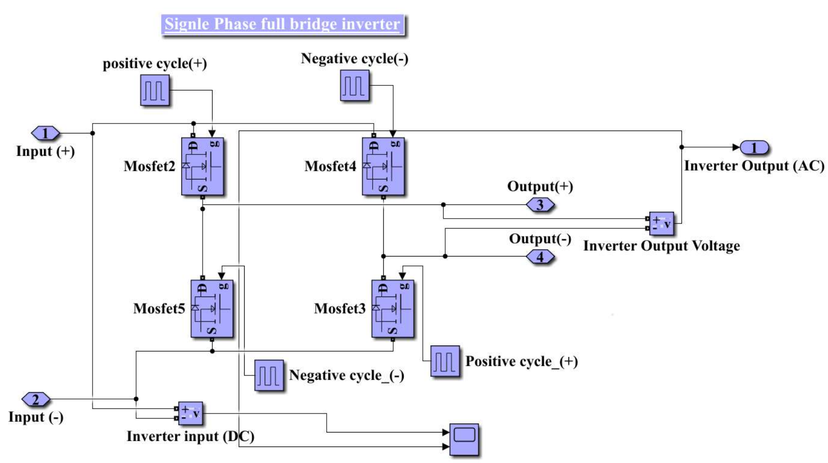


Fig. 44. Inverter

Here Fig. 44, is the inverter for the system. It illustrates a single-phase full bridge inverter system that takes input voltage from PV panels as DC, converts this DC into AC and gives output as useful AC voltage. There are four MOSFETS, Mosfet2, Mosfet3, Mosfet4, Mosfet5 in which Mosfet2 and Mosfet3 is connected to positive cycle pulse generator, turns on only for positive cycle of AC voltage and Mosfet4 and Mosfet5 is connected to negative cycle pulse generator, which turns on only for the negative cycle of AC voltage. The Drain of Mosfet2 and 4 are both connected to the positive terminal of DC input and the Drain of Mosfet3 and 5 are both connected to the negative terminal of the input. The positive terminal of the AC output is attached to the Source of Mosfet2 and Drain of Mosfet5 and the negative terminal of the output is attached to the Source of Mosfet4 and Drain of Mosfet5.

Now to have a clear visualization the figure below will be a comparison which will help us to visualize how this design is providing the output voltage.

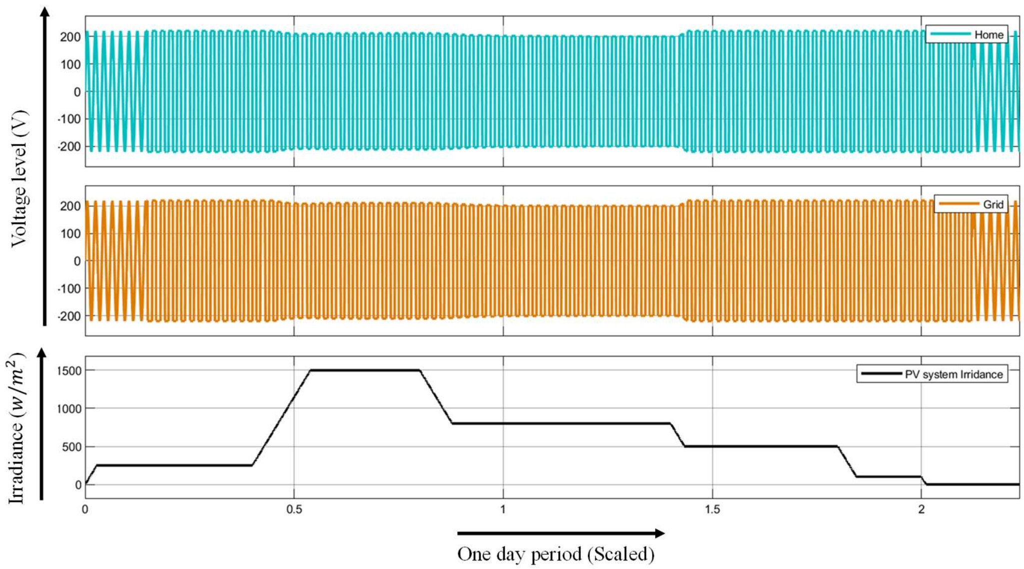


Fig. 45. Comparison of supplied output voltage Home and Grid

Here when the pure sine wave is visible at the output voltage of home and grid it is to visualize the condition that there is no voltage stored at the battery bank and also there is no sun irradiance available. Also, the pulsating DC is to visualize the wave form generated by the PV system and feeding to the home and the grid simultaneously. Here, one thing to notice is that at the time of low irradiance, the PV module generates a bit low but approximately 215 volts stable pulsating DC, when the stored voltage of the battery bank is being converted by the boost converter.

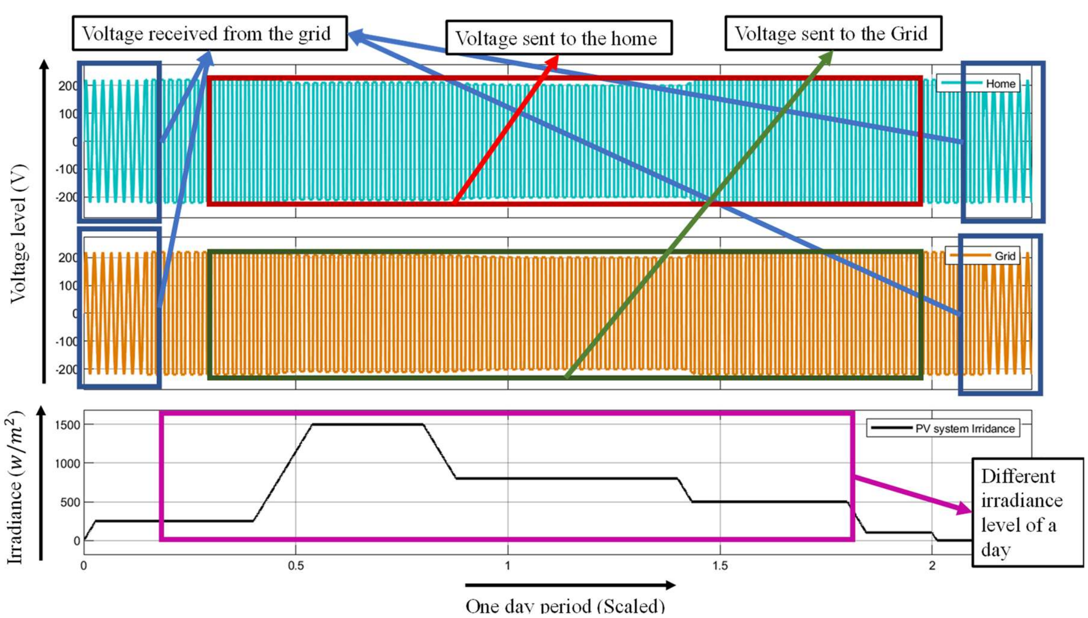


Fig. 46. Waveform validation

Here the sine wave from the graph refers to voltage received from the grid [grid is contributing] and pulsating dc waveform is referring to PV panel's generated power to home and grid [when PV panel or stored energy in the battery bank is in action]. The third graph is for different irradiance level of a day. This graph illustrates the voltage level over a day period. From 1st fig and 2nd, we can see, blue shaded areas are indicating voltage received from the grid. This portion's sine curve frequency is slightly lower compared to voltage sent to the grid and home. We can observe voltage sent to grid and home sine curve portion is very compressed due to higher frequency. Peak to peak voltage in both cases is 400V. On the other hand, 3rd graph the irradiance vs different period of a day. We can observe increase and decrease in the values of irradiance over scaled time. This graph shows an increased irradiance rate about 250 W/m2 at the first day period. This value remains stable for a long time after the increase. Around 0.375 to 0.6, the irradiance value again increases steeply from 250 W/m2 to 1500 W/m2. After reaching at 1500 W/m2, the irradiance rate again stays constant for a short period. Since then, the irradiance value does not increase any more but is seen to decrease gradually. A sudden drop-in irradiance rate is observed at around 0.7 to 0.875 and at 750 W/m2 this value stays unchanged. Furthermore, irradiance rate decreases slightly and reaches at 500 W/m^2. Again, irradiance rate stays constant and then declines at 100 W/m2. Lastly, irradiance rate value gradually decreases to zero.

4.4.2 Sun detection algorithm

We used Simulink to process a signal from the sensor and performed:

- Spectral analysis to explore the signal
- Design and build digital filters as part of a signal processing algorithm
- Performance evaluation
- C code generation that can be embedded into real time hardware

Power measurement array [sunnyDay and cloudyDay] of the location we selected to plant the system [we took this data from weather forecast website for Mohakhali area]. The data is sampled at every 15 minutes that means we get 96 samples per day.

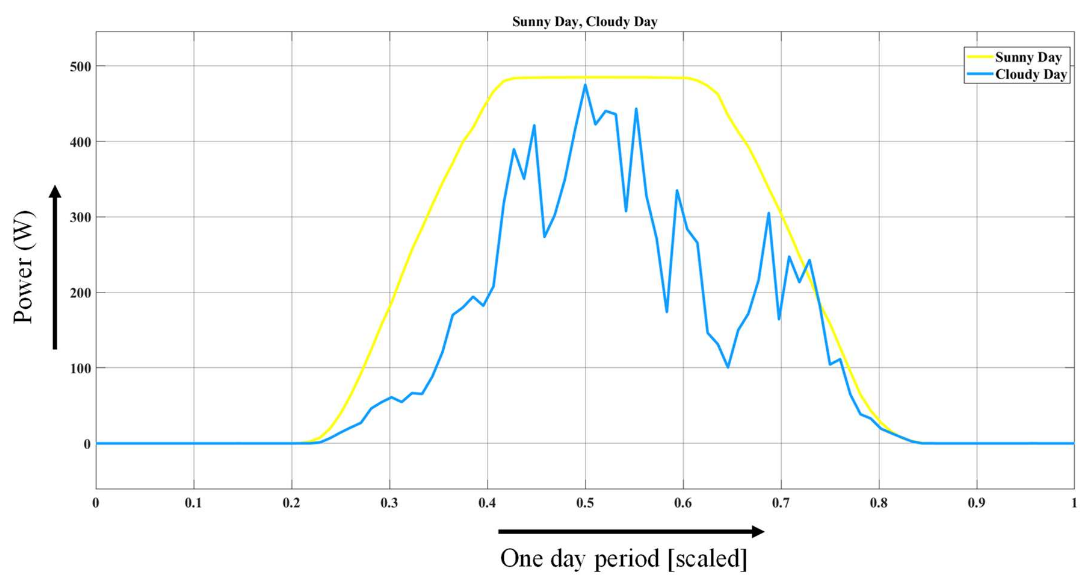


Fig. 47. Sunny day and cloudy day power data of one year [on average from last 5 years]

Fig.47 illustrates how power production rate changes over different period of a day. Period of a day has been scaled in this graph. Here the yellow line is for sunny day and the blue line shows that the cloudy day produces less power and also has many short time variations as the clouds pass over the solar array. We can use spectral analysis which helps measure the frequency content of each signal. In a sunny day, panels produce more power and that is why power generation rate is the highest value. This rate gradually increases over time and decreases at a certain time. From this graph, we can observe that, at Mohakhali area power production rate reaches up to approximately 500W in case of sunny day. In the contrary, power does not generate early in the day and after certain time this power production rate usually fluctuates in case of cloudy day. Power produces rate grows higher in the middle of the day. Finally, this power production rate declines at the end of the day which is indicated in this graph.

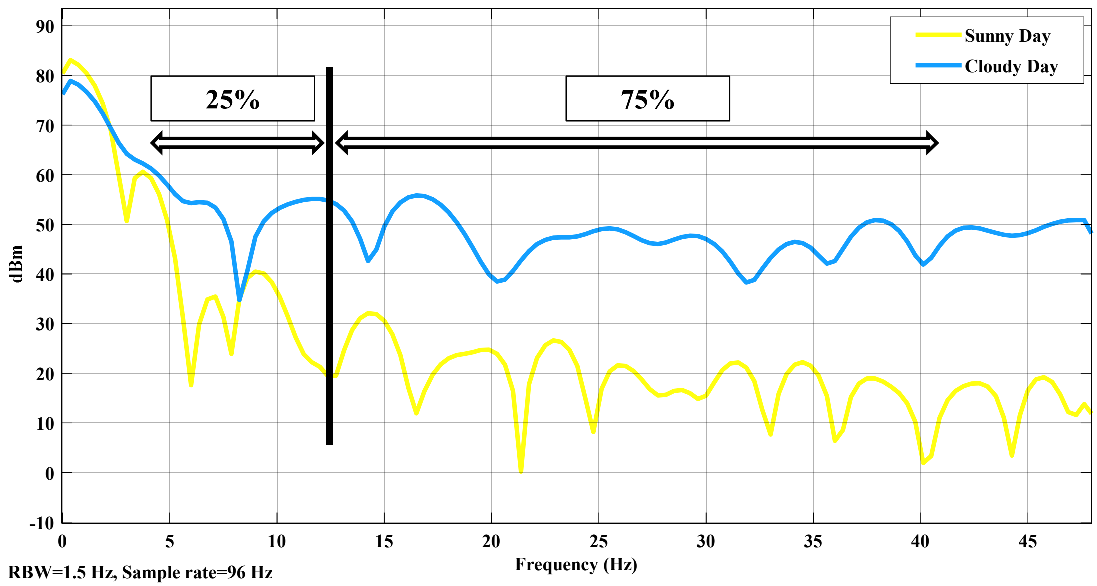


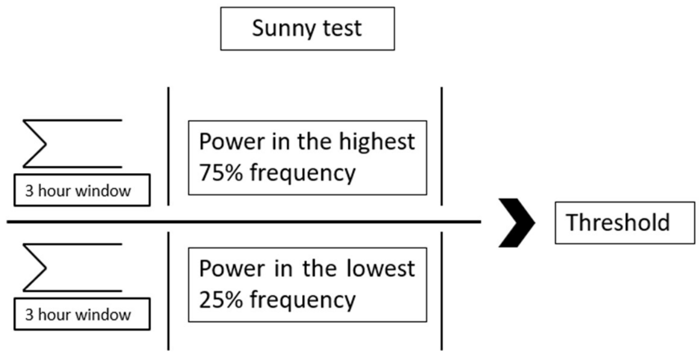
Fig. 48. Spectral analysis of the sunny day cloudy day power

Here, looking at the x axis is the frequency value and y axis shows us how much power is in our signal at a given frequency although the default time unit in seconds, we are actually measuring time in days so the x axis is not cycles per seconds or hertz's. The RBW (resolution bandwidth) for this simulation is 1.5Hz and sample rate is considered to be 96Hz. We see that the low frequency content is about the same for both days but the cloudy one has way more high frequency content this is because of the short time variation in the time domain. We can decide whether it is sunny or cloudy comparing the power and the higher frequencies to some threshold, however the panels produce more power in the summer and less in the winter which means the threshold would have to change throughout the year. If we normalize the high frequency power by the power and lower frequencies, we can use a fixed threshold. Now by computing the ratio of the total power in the top 75 %. Of the frequencies to the total power in the bottom 25% of frequencies. By building digital filters we can separate low and high frequencies.

Ratio of total power = (top 75 %. Of the frequencies / bottom 25% of frequencies)

Low pass filter for the low frequency content and high pass filter for the high frequency content were required. Here Chebyshev type 2 IIR filter and set the filter order to 4 ha been used. Here the low pass filter introduces a delay of three samples and the high pass filter introduces a delay of one so some delay blocks are need to be added to make sure that the signals are aligned. A three-hour window, has been chosen, which is just 12 measurements to store the filters output over time.

Here, sunny test in a diagram is illustrated below. The data were taken for this test for the sum of 3 hours window time. For this short time Frequencies can be varied easily. By comparing the power and higher frequency, we can determine whether it is sunny or cloudy. A ratio of power by comparing the top 75% of the higher frequency with the bottom 25% of frequency has been done. To fix the threshold this ratio has been calculated. The positive value has been taken of both these frequencies so that a precise value is achievable.



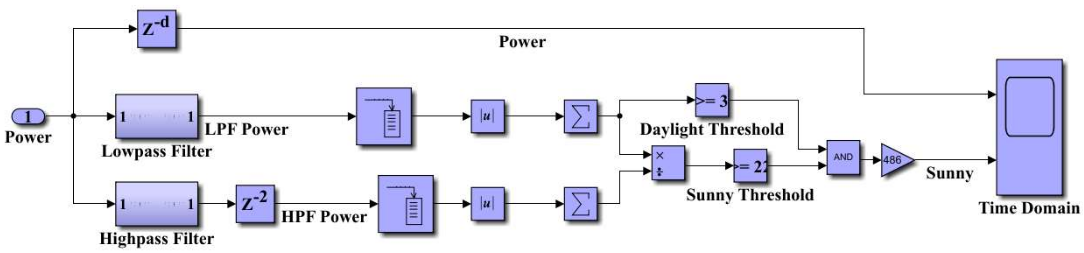


Fig. 49. Algorithm for sunny detection

Here we used threshold for sunny and daylight since only sunny threshold will cause false detection of sun at night times as well.

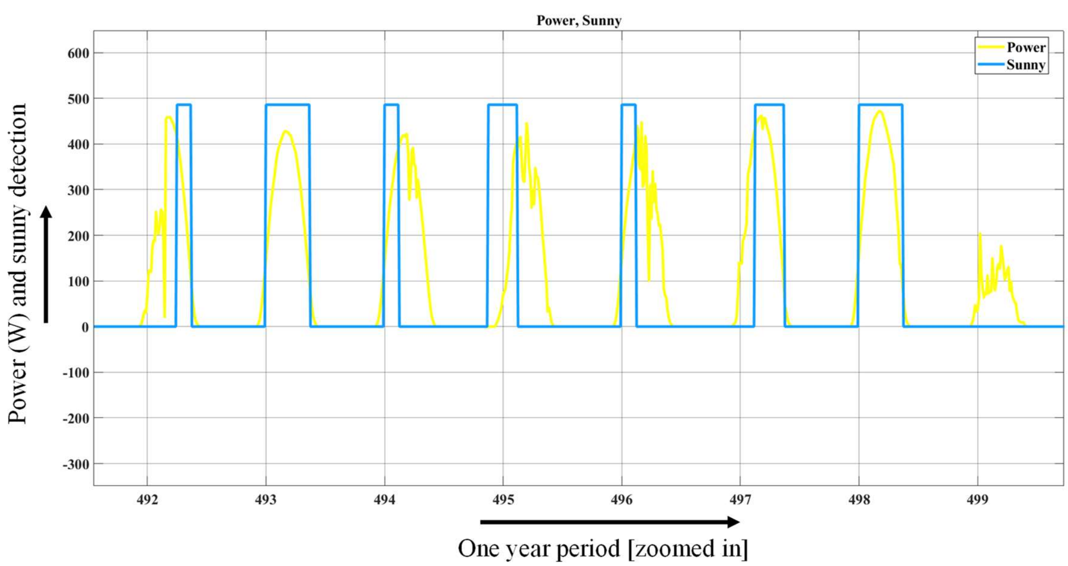


Fig. 50. Sunny detection

By generating code for the above system, we can deploy the code into embedded system for this case ESP 8266 board is used. Fig.50 graphically represents the power production rate under sunny detection condition gradually increases or decreases over a year period. Here, the blue line denotes the sunny detection and yellow line denotes the power production rate. Power production rate actually varies on different time of a year. Power production rate fluctuates, only when sunny detection condition is applicable. Approximately 450W power is the highest produced power and around 150W is the lowest power produced over a year.

4.4.3 The tracking system

Here the physical system consists of a panel and a motor.

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}(T - K_d\frac{d\theta}{dt}) \quad (1)$$

Here in Equation 1,
$T = Torque,$
$\frac{d\theta}{dt} = damping\ term,$
$K_d = Gain,$
$J = Inertia$

This is the panel's equation of motion. We can find out how to model the equation of motion for the solar panel rotating about its central post. Constant torque is applied to the panel. We will model the equation in Simulink and by-Simulink blocks like integrator to get the velocity and to insert torque we will use initially constant block it will be replaced with the motor later.

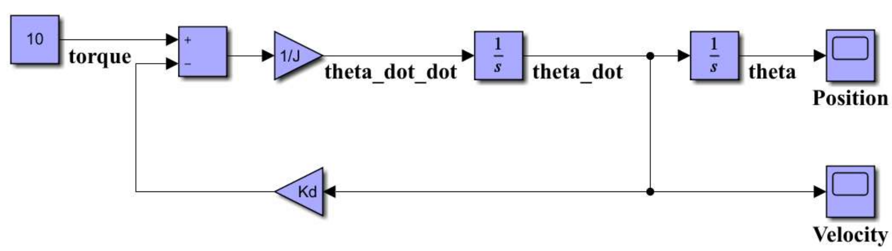


Fig. 51. Panel equation of motion implemented in Simulink

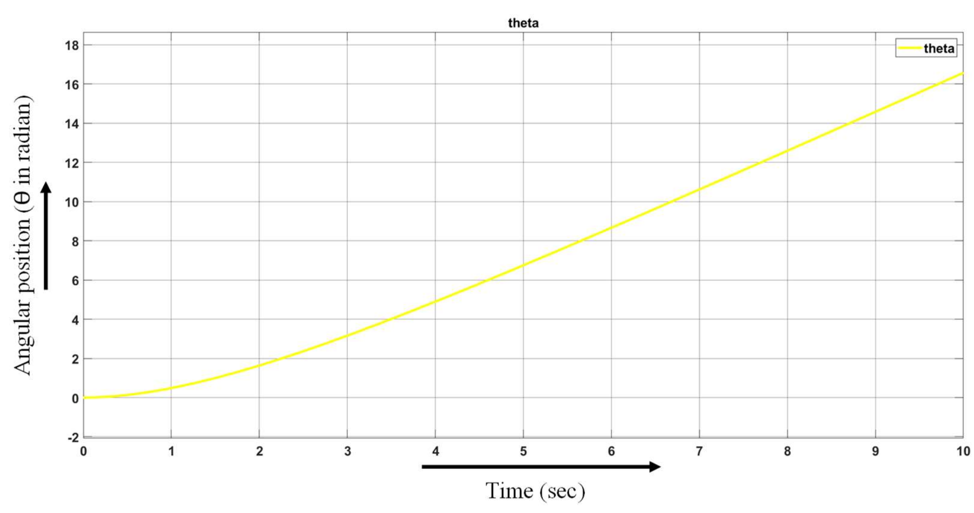


Fig. 52. Position scope panels velocity increasing with time with positive torque

In Fig. 52, it is illustrated that with respect to time the angular position of the panel is rising with a positive constant torque. But if the angular torque is negative then the angular position of the panel will decrease as shown in Fig. 53.

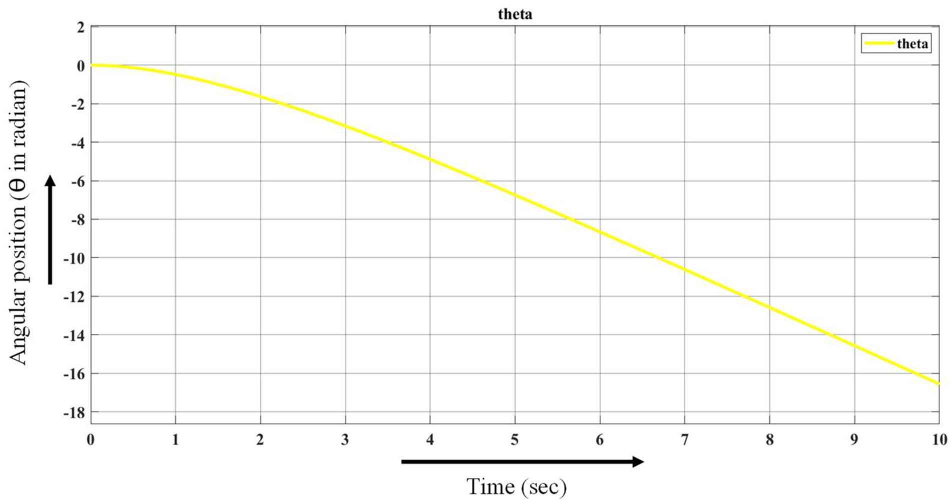


Fig. 53. Position scope panels velocity decreasing with time with negative torque

Now we can make a subsystem for the panel holding all these things inside a subsystem block. Similarly, we can build the motor equation into Simulink,

$$\frac{di}{dt} = \frac{1}{L}(V - K_g K_f \frac{d\theta}{dt} - R_i) \tag{2}$$

$$T = K_g K_t i \tag{3}$$

In Equation 2 and 3,

$\frac{di}{dt} = change\ in\ armature\ current$

$L = armature\ inductance$

$V = applied\ armature\ voltage$

$K_f K_g = gear\ constant$

$\frac{d\theta}{dt} = \ \ damping\ term$

$R_i =$ "$electric\ friction$" $that\ tends\ to\ improve\ the\ stability\ of\ the\ motor.$

$T = troque$

$K_g K_t i = gear\ constant\ and\ integartor\ constant\ multiplied\ with\ current$

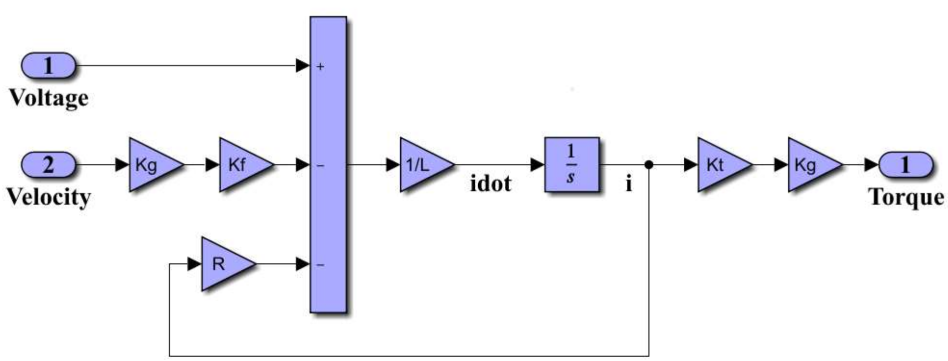


Fig. 54. Motor equation [DC motor]

We have designed our panel and motor in Simulink for the tracking system and now we need a controller to the correct voltage so that the panel tracks the sun. We want the panel pointing at the sun so that the difference is the error. We will add a controller that applies a voltage to the motor to make that error as small as possible and if the sun moves the controller will react accordingly to keep the panel pointing at the sun.

At the design stage of the controller, we will use a unit set block as sun position data for now and then update it later. Here we will use PID controller [proportional, derivative and integral] because the control output is some function of the error the integral error and the derivative error. Here we need PI controller because the D term helps response to quick changes which we do not need because the sun moves steadily across the sky. There are two gains to adjust. One for the proportional term and another for the integral term., these effect the controller's response. We will set the proportional gain to 240 and the integral gain to 180 to see how the controller performs. Generally, the position of the sun will be detected using sensors and if the panels are not facing in the direction of the sun, they must turn to that direction. The position of the sun and the direction at which the panels are facing will be compare. If there is a miss match, an error in position will be send to the PI controller that will provide a voltage to the motor. As there is input voltage, the motor will continuously to rotate and produce torque or velocity on the frame of the panel until the error is made zero or minimized to a certain acceptable value. The panels must rotate in that direction at which the error gets smaller. The panels always face the sun by the help of a rotating motor. In this way, by always facing in the direction of sun, the panels could produce maximum energy, increasing the output yield.

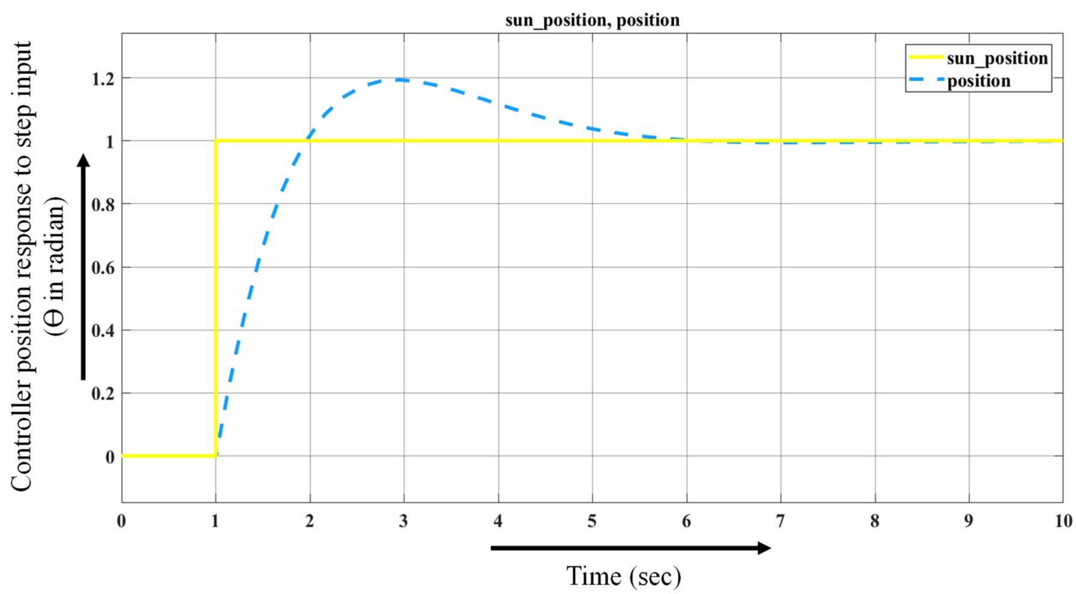


Fig. 55. Sun position and panel position

Now since the controller is ready [although it over shoots a litter but good enough for our implementation] we will now provide real data with supposition data, here we have 15 hours of data. This fig.55 shows controller position response to step input over 15 hours of time period. Here, blue line is for panel position and yellow line is for sun position. Sun position is indicating a step function graph, where at 1st second controller position was 0 radian and this position value increases steeply to 1 radian. Reaching there, this value becomes stable till whole time. On the other hand, panel position denoted by blue line, increases with time at first. At t=3s, peak controller position=1.2 radian is observed in this graph. Furthermore, by the increase of time from 3s to 6s, controller position declines slowly. From 6s to 10s we can see, this position value neither increases nor decreases, rather it become constant. Thus, we can see the sun position and the panel position is related to each other in terms of controller position over a certain time period.

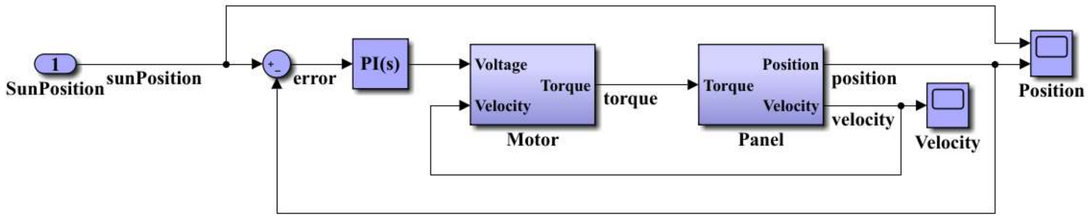


Fig. 56. Testing the controller with real data [sun position data]

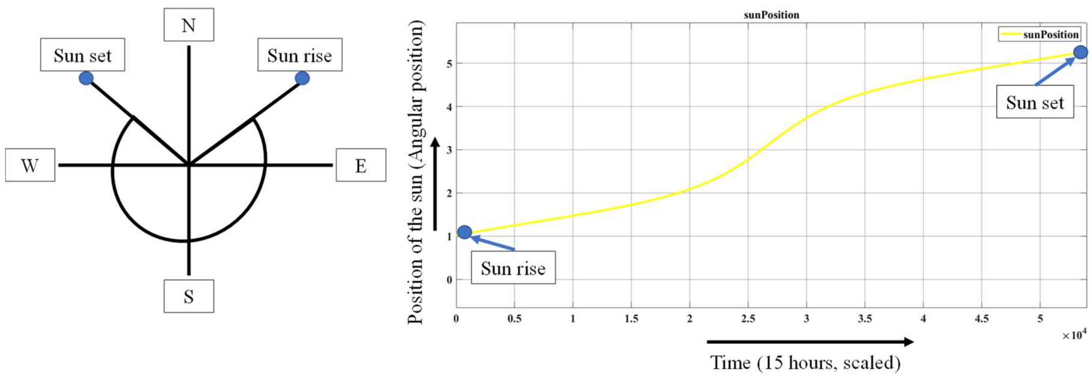


Fig. 57. Sun position data

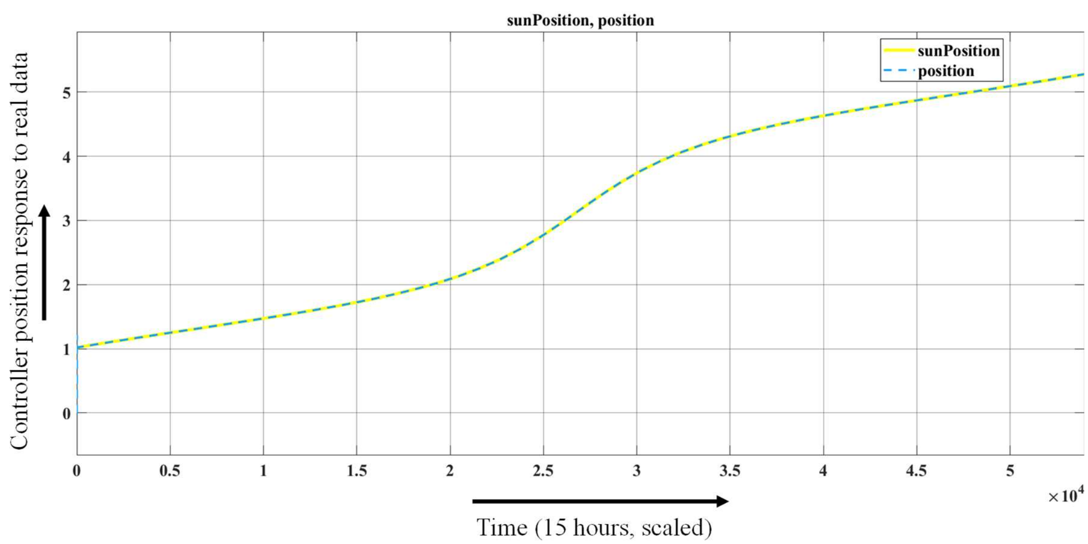


Fig. 58. Controller tracking the sun

From the graph we can see that the controller is tracking the sun quite efficiently. We can see that the sun rises in the north east at about 60 digress from due north and sets in the north west at about 300 degrees. Here the blue dotted line is the panel's position.

Power of the system is also calculated since the single axis trackers are used it is expected to have a better performance in terms of generated power from the panel. Here 15 hours data [real world data] is used for sun elevation and sun position and being inserted in the designed control system for the tracker.

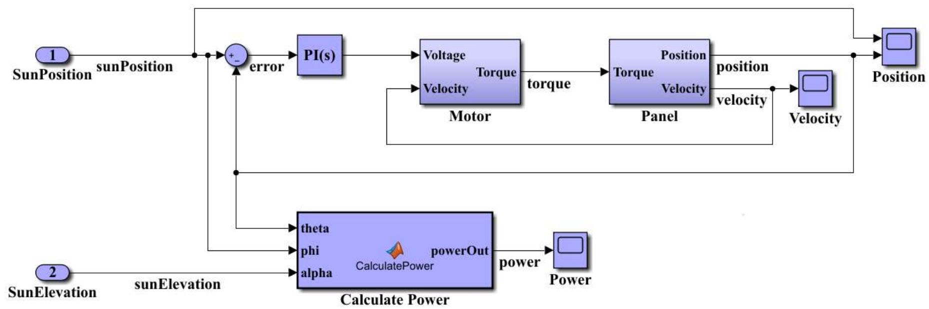


Fig. 59. System block diagram of power generation [custom function block]

Code for calculating power [custom function block]:

```
function powerOut = CalculatePower(theta, phi, alpha, A, beta)

% Calculate dot product of the incident sun and panel normal vectors
dot_prod = sin(beta)*sin(pi/2-alpha)*cos(theta-phi) ...
    + cos(beta)*cos(pi/2-alpha);

% Calculate the direct power
powerOut = 1.353*0.7.^(sin(alpha).^-0.678)*dot_prod*A*0.195*1000; % W

% Replace negative power values with zero (sun is behind the panel)
powerOut = max(powerOut,0);
```

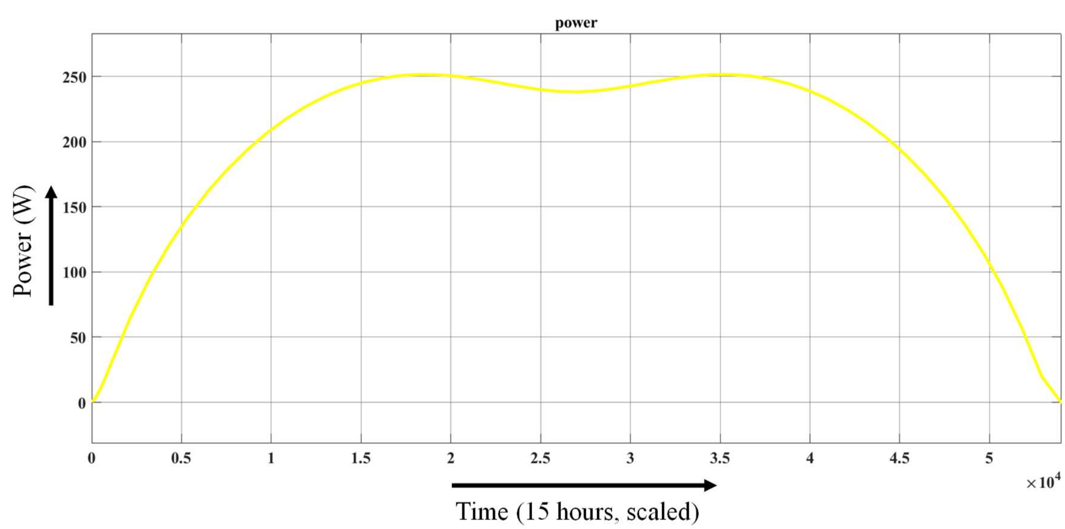


Fig. 60. Power generated from the system [scaled version]

Fig.60, is a simulated graph of this design which shows that how much power is generated from the system over 15 hours in a scaled version. This yellow curve is indicating the power generation rate. Power generation rate gradually increases up to 250W in 1st span of time. Next, we can see a slight decrease in the rate value for a short period. After this, the power generation rate reaches 250W again. Therefore, this rate value decreases from 250W to 0 at the last hours. This curve gives a clear idea of recent data calculated and collected from the simulation of this design.

4.5 Conclusion

Modern IT tools has become so advanced that complex systems can be designed in computer simulation software with given parameters which are assess to produce results immediately, that would usually take hours to evaluate and solve if done in the traditional way by hand. PVsyst, an IT tool has been using to model three designs for the proposed solar home system by carefully selecting location site, mutual shading from surrounding objects and structures are also included to make the simulation environment in PVsyst more realistic. In this software, it is possible to alter the latitude and the position of the sun in the simulation world to resemble our real world, thus enabling us to create a simulation environment like the way we want to. The three designs are modeled and run to produce different types of data in the form of diagrams like, charts, graph, Sankey diagram etc. which all are thoroughly analyzed and observed to find the best performer. It was found that the third design performed better and produced greater outcome values, comparatively than the other two designs. Subsequently, we used another IT tool, MATLAB, to design our optimized system, component by component to create many sub-systems that are all connected to each other to work together as a whole system. PV arrays, Charge controller, Battery bank, Inverter, Boost converter, sun tracker and other sub-systems all were designed and tuned to our requirements. In MATLAB, we can configure the PV panel input temperature and irradiance to change according to an average day temperature and sun irradiance. By doing this, we can proceed to design our system in such a way that it is adaptable to changes in the input, but able to function and provide constant, stable and steady output. Our system is also designed to provide maximum output yield possible, by taking advantage of sun tracking algorithm, to track the sun and face the panels in the sun direction. Thus, the PV arrays are able to generate maximum power. All this designing work was possible due to the availability of such powerful simulation software, without those, designing, calculating and testing would have been really difficult. We are really grateful that we are able to access such IT tools in this period of time which is making our work in the project really easy and elegant.

Chapter 5: Completion of Final Design and Validation

5.1 Introduction

The optimal solution of our project is chosen after analyzing all the outputs of multiple design approaches. To start with, as the system satisfies all the aspects and matches the outcomes as we expected. Therefore, our most efficient design approach is Hybrid Bidirectional Grid connected system with single axis tracking system. Moving on, the flowcharts explain how sub-systems of our third design approach works. One of the main attractions is the flowchart of our net-metering system as it is not available in the country so we built it from scratch. The following graphs also depicts the output as we expected and matches with our expectation from the project.

5.2 Completion of final design

5.2.1 Subsystem 1: Solar Utility System (SUS)

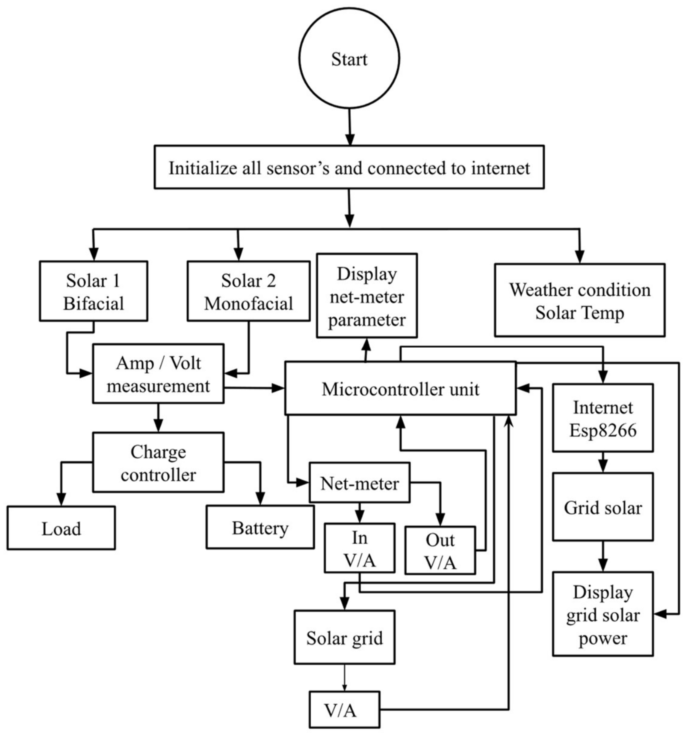


Fig. 61. Flowchart of subsystem 1

The Fig. 61, is the flowchart of subsystem 1, Solar Utility System and shows the working principle. At first, when this subsystem gets started, it gets connected to the internet and all the installed sensors begin to operate. The sensors will detect the condition of the weather and the temperature of the solar panels. The solar panels, both mono-facial and bifacial, orientate their position with the help of tracker motors by detecting the light direction. The current and voltage produced by the solar panels would be measured and then send to load and battery storage through charge controller. Current and voltage values from the charge controller then be send to the microcontroller unit and then to net-meter where it detects values of the input and output currents and voltages. These values would be shown in the displays along with the calculated input and output grid solar power. The values are sent to Solar grid and again to microcontroller for storing in SD-card. They are also uploaded to the Internet Esp8266 server with the help of the internet.

5.2.2 Subsystem 2: Netmetering System (NS)

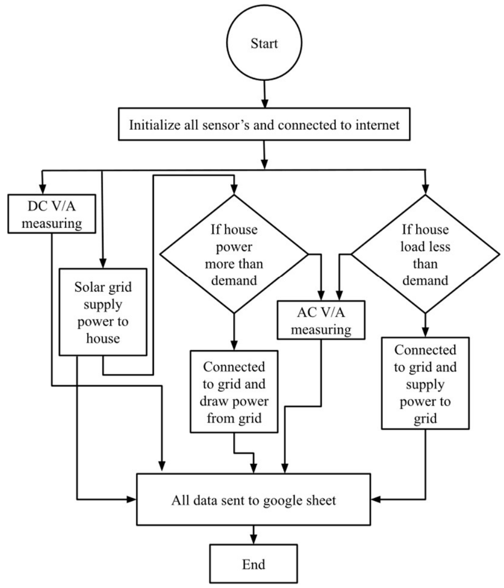
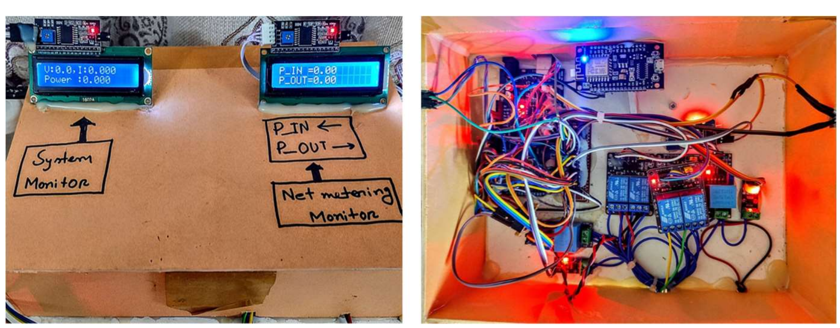


Fig. 62. Flowchart of subsystem 2

The Fig. 62, is the flowchart of subsystem 2, which is the net-metering system. All the sensors start to function after the starting of the subsystem and it gets connected to the internet. The solar grid starts to supply power to the house. If the house power is more than demand, the extra power is drawn from the grid. If the house load is less than produced power, power is sent to the connected grid. The DC, AC voltage and current measuring values in volts and amps along with the power produced by the Solar panels and the power drawn and send to the grid, all of those values go to the google sheet.

Moving on, three load conditions have been set up to visualize the function of netmetering. The three conditions are:

- Condition 1: If the household load is less than 4.5W, the solar utility grid will provide the necessary energy and send the remainder to the national grid.
- Condition 2: If the household load is between 4.5W and 9W, the solar utility grid will supply all of its energy to the household load.
- Condition 3: If the household load exceeds 9W, both the solar utility grid and the national grid will deliver energy to the household.



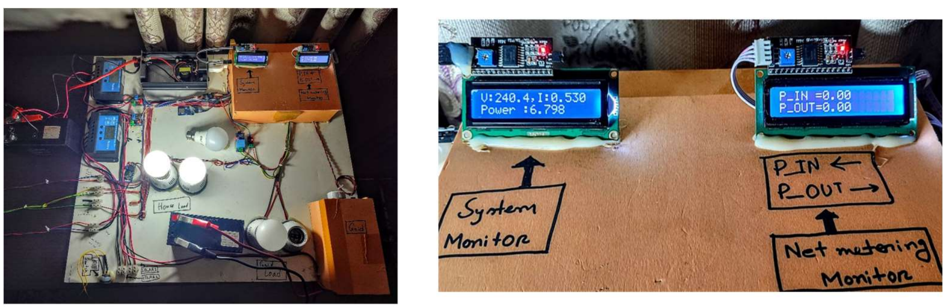
a. b.

Fig. 63. Custom made net-meter a) outside of net-meter b) inside of net-meter

a. b.

Fig. 64. Condition 1 validation

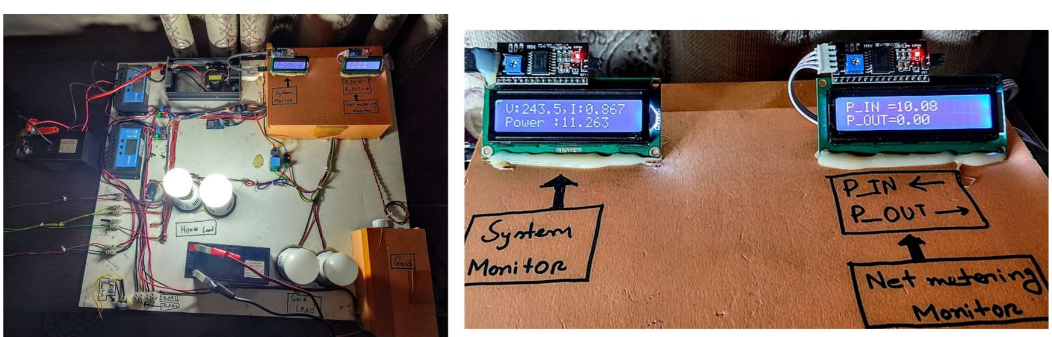
Fig. 64.a and Fig. 64.b, validates the load condition 1. It is visible on the LCD display [system monitor] that, condition 1 is met when the system power [household demands] is 4.254W, which is less than 4.8W. Therefore, P OUT = 14.19W indicates that the excess energy generated by the solar utility grid has been sent to the national grid, as confirmed by the LCD display [netmetering monitor]. As the extra energy has been sent to the national grid, from Fig. 63.a it can be observed that the grid load has been illuminated as well as the household load.



a. b.

Fig. 65. Condition 2 validation

Fig. 65.a and Fig.65.b, validates condition 2. The LCD display [system monitor] in Fig.65.b indicates that the household load consumption is 6.798W, which satisfies load condition 2 because the household load consumption falls within 4.8W and 11W. Consequently, Fig.65.b verifies that both P IN and P OUT are 0 from LCD display [netmetering monitor]. That indicates no power has been drawn from or sent to the grid, and the household load has been illuminated by the solar utility grid.



a. b.

Fig. 66. Condition 3 validation

Fig. 66.a and Fig.66.b validates condition 3. The system monitor in Fig. 66.b shows that the power consumption of the household load is 11.263W, satisfying condition 3 because the household load consumption is greater than 11W. Additionally, the netmetering monitor depicts that 10W of electricity was taken from the national grid. Meanwhile Fig.66.a, shows that the household load has been illuminated while the national grid and solar utility grid have been jointly meeting the household load consumption needs.

5.2.3 Subsystem 3: Single Axis Tracking System (SATS)

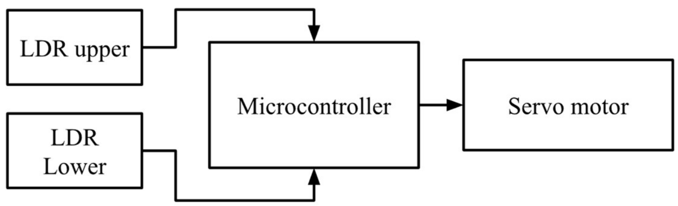


Fig. 67. Flowchart of subsystem 3

Conditions for tracking system:

As the panels will be installed facing east to west there are total 6 LDR sensors. Besides, 3 LDR sensors are at east side of the panel and the rest of the 3 LDR sensors are at West side of the panel.

- IF 3 LDR sensors of east side receives sunlight then the single axis tracking system will move from west to east until west side 3 LDR sensors receives sunlight simultaneously.
- If 3 LDR sensors of west side receives sun light then the single axis tracking system will move from east to west until east side 3 LDR sensors receives sunlight simultaneously.
- If none of the 6 LDR sensors receives sunlight then after 10 seconds the tracking system will go to its initial position which is also known as backtracking.

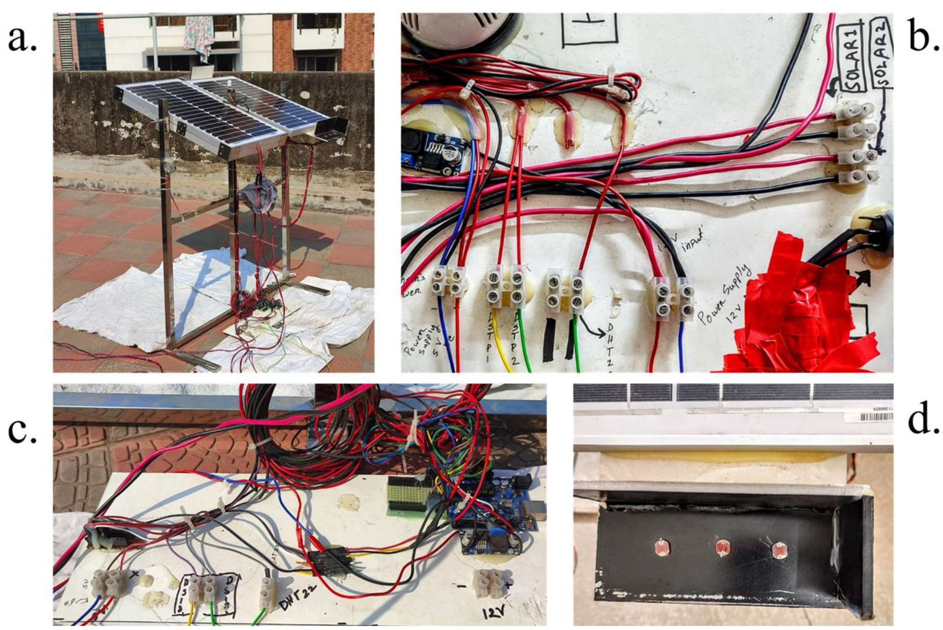


Fig. 68. Images of protype system, a) single axis tracking setup b) connectors of the main board including sensors and solar panel 1 [bifacial] and 2 [monofacial] c) connectors of the control board form tracking system and d) LDR sensor connection design

5.2.4 Complete System diagram

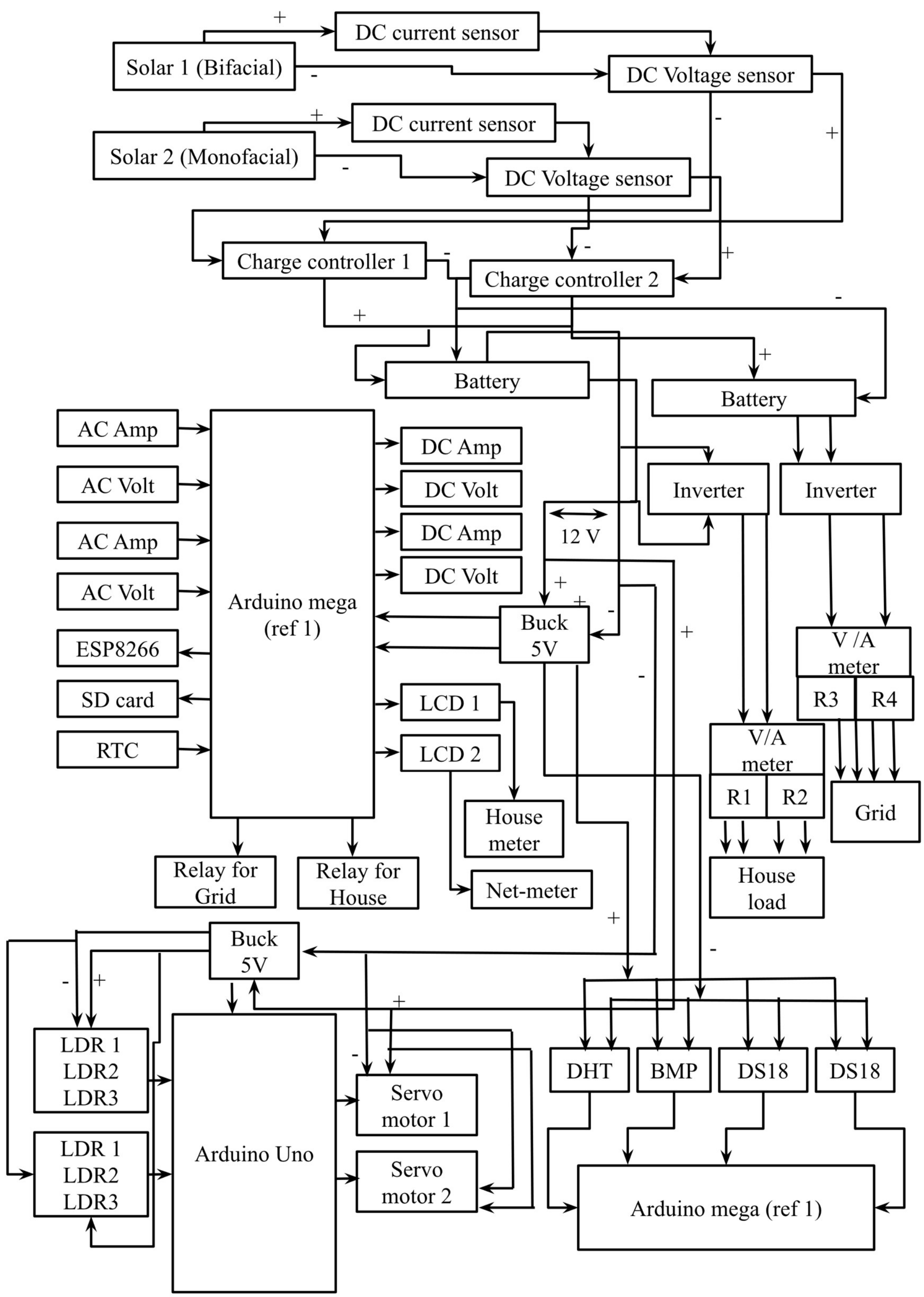


Fig. 69. System connection diagram

First of all, the prototype system has two PV module of similar voltage rating, one is bifacial and the other one is monofacial PV module. The bifacial PV module in the system is custom made. Besides, two monofacial PV module have been cascaded facing outward direction and they are connected in parallel connection to maintain both identical voltage rating. Secondly, both bifacial and monofacial PV panel are connected to the charge controller which is shown in Fig. 69. Afterwards, both the panel are connected in parallel. Additionally, four dc voltage and current sensors are connected to measure the power generated by individual PV panel. Moving on, the prototype system has two batteries. The battery connected to the solar utility grid, is giving a fixed 12V at the output of the solar utility system. On the other hand, the second battery is connected to a 12V to 220V ac inverter, which is referred as grid for the protype system. Meanwhile, to charge both the batteries, they are connected to the solar PV modules in a parallel connection. Thirdly, the battery referred for solar utility grid is connected to a 12V to 220V ac inverter, which is referred as grid tied inverter in this system. Afterwards, the solar utility grid's ac power is delivered to the load of the prototype system, referred as home load. Also, an ac voltage and current sensor is connected within the connection of grid tied inverter and home load to measure the power used by the house. Moreover, a custom-made net-meter is also developed in this system, which can be illustrated in Fig. 70. Besides, two LCD displays are included in the system to monitor the house power consumption and netmetering parameters respectively. Furthermore, to control the various parameters of the system an Arduino mega microcontroller and an ESP8266 is used. Arduino mega is the main control board of the system, controlling all the signals received by the sensors [ac voltage and current sensors and dc voltage, current sensors, RTC module, SD card module, relay module].

- AC voltage and current sensor: Measures ac power of the system and net-meter
- DC voltage and current sensor: Measures dc power of both the panels
- RTC module: Real time clock to keep track of date and specific time of recorded datasets
- SD card module: Stores per second data of all the collected parameters form the sensors
- Relay module: The system has 2- two channel relays for the netmetering system

Also, ESP8266 is used to present the data using WIFI over the cloud server to a google sheet. Additionally, all the data sets are also stored in a SD card, using a SD card module which allows to record all the data in a per second rate. Furthermore, all the sensors control unit is an Arduino uno microcontroller which is also controlling the tracking system of the PV module. Moving on, the sensors that are used in the system are:

- DHT22: Measures ambient temperature and humidity
- DS18B20: Measures body temperature of both the panels
- BMP180: Measures the barometric pressure of PV module surroundings
- LDR 20mm sensors: 6 LDR sensors are used which tracks the sun in single axis [East to West]
- ROB5GRHS3115: Servo motor for the tracking system

Furthermore, the whole system consists of two dc-dc buck converters to convert the 12V battery output to 5V. One converter is powering the Arduino mega microcontroller, relay module of the netmetering system. On the other hand, the second buck converter is providing 5V dc to Arduino uno microcontroller and sensors such as DHT22, DS18B20, BMP180, LDR sensors and servo motors.

Meanwhile, the system connection wires are divided in to two kinds. One of them is, jumper wire which is used for the microcontroller's connection. The other one is, 2 coils wire is also used for load connection. Second kind of wire is 2 core DC wire which can draw the max current of the PV modules.

5.2.5 Net-meter diagram

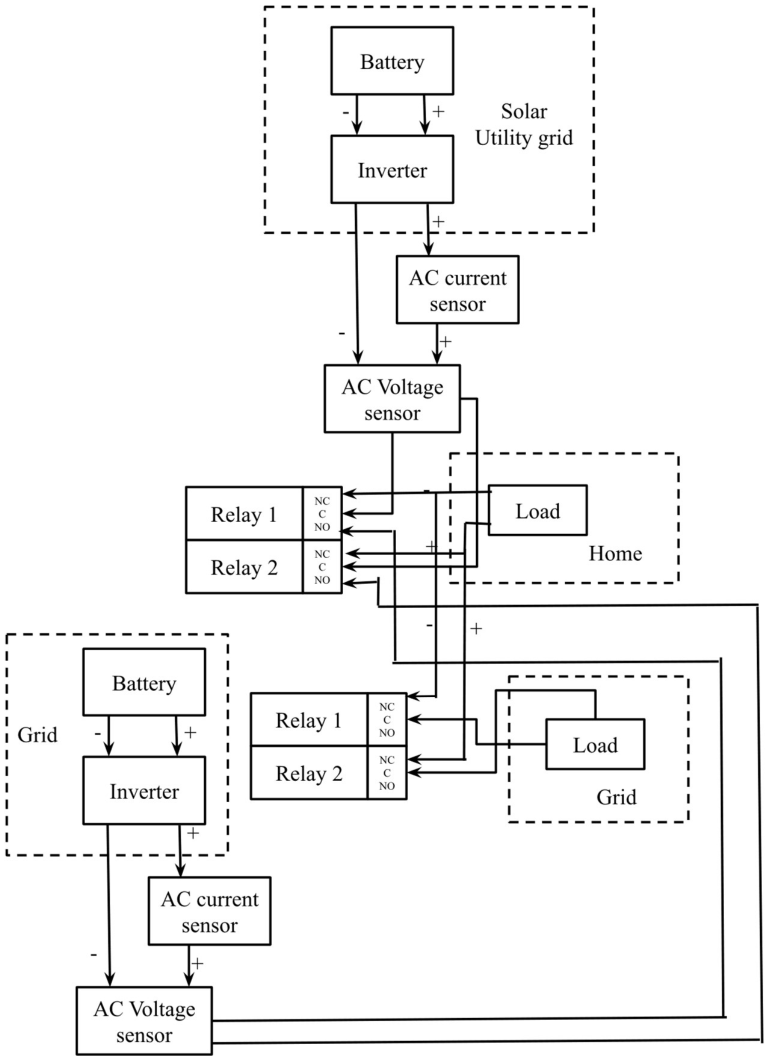


Fig. 70. Net-meter connection diagram

Fig. 70, illustrates the connection diagram of custom-made net-meter of the prototype system. The subsystem has couple of two-channel relay which can trip from common terminal to normally open terminal according to the condition controlled by a microcontroller. Moving on, house load is connected to both of the relay's normally closed terminal. Also, solar utility grid and national grid [referred by a battery and an inverter respectively] are connected in common terminal [solar utility grid] and normally closed terminal [national grid]. Furthermore, the grid load is connected to the second relay's common terminal.

5.3 Evaluate the solution to meet desired need

The prototype system was used for collecting one month data of parameters such as weather parameter, both the PV panel's various parameters. The weather parameter includes ambient temperature, bifacial PV panel's body temperature and monofacial PV panel's body temperature, humidity, barometric pressure. Besides, PV panels parameters are power of individual PV panel and efficiency of both the panel. Meanwhile, all the data were collected at a per minute rate from sunset to sunrise of a complete day. As there a was huge sets of [roughly 686-point data points] data polynomial regression was used to find the best fit curve for the scattered data points.

5.3.1 Weather parameters

A 30-day data collection [during the period of November 5th and December 4th, 2022] were conducted to record the surrounding weather parameter of the site where the prototype was planted. Besides, DHT22, DS18B20 sensors were used to collect the ambient temperature, humidity and PV panel's body temperature. Additionally, BMP180 sensor were used to collect the barometric pressure.

- Temperature

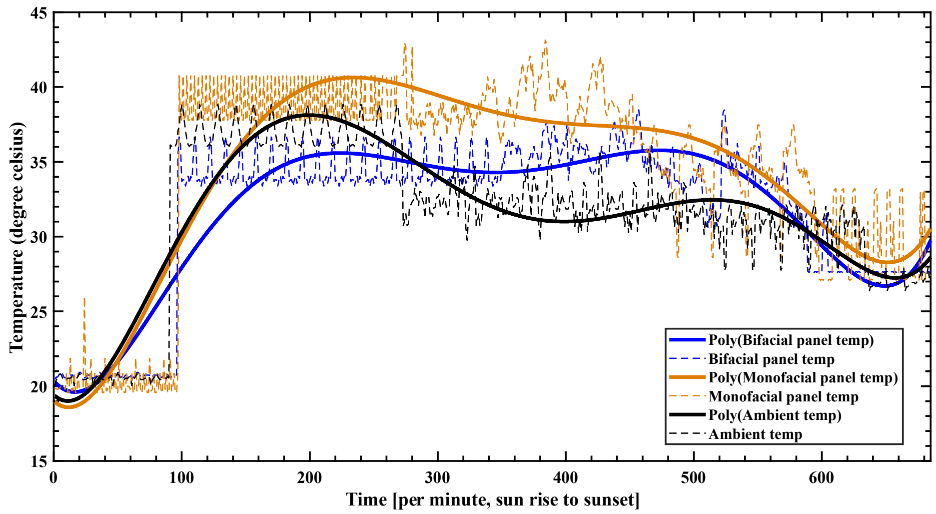


Fig. 71. Per minute data of various collected temperature [30-day average]

Fig. 71, shows the variation in ambient and PV panel body temperature respectively during sun rise to sunset for consecutive 30-day. Besides, the black, dark blue and orange dotted scattered plots in Fig. 71, are the raw data. Black, dark blue and orange solid lines are best fit lines found using polynomial regression. The polynomial regression equation and goodness of fit for each of the data sets are:

$$y = 4E^{-14}x^6 - 8E^{-11}x^5 + 6E^{-8}x^4 - 2E^{-5}x^3 + 0.0035x^2 - 0.065x + 18.867 \quad (4)$$

$$y = 4E^{-14}x^6 - 8E^{-11}x^5 + 6E^{-8}x^4 - 2E^{-5}x^3 + 0.0033x^2 - 0.0875x + 20.239 \quad (5)$$

$$y = 4E^{-14}x^6 - 9E^{-11}x^5 + 7E^{-8}x^4 - 3E^{-5}x^3 + 0.0037x^2 - 0.0655x + 19.287 \quad (6)$$

Eq. 4, 5 and 6 are 6th order polynomial regression for ambient and bifacial, monofacial PV panel's body temperature with a goodness of fit for each of the equation are 0.792, 0.8351 and 0.79 respectively.

Meanwhile, it can be observed from Fig. 71 that, bifacial PV panel's body temperature were consistently low compared to monofacial PV panel's body temperature. Besides, bifacial PV panel's body temperature were slightly above compared to ambient temperature. Additionally, monofacial PV panel's body temperature was comparatively higher than both bifacial PV panel's body temperature and ambient temperature. Moving on, Fig. 71, depicts that ambient and PV panel's body temperature were at its lowest value in the early morning. The temperature gradually increased for all the parameters as the day progressed. Noticeably, the temperature value for all the parameters reached its peak value just before noon. Later the temperature had a declining slope at a low rate until afternoon. As the evening approached the declining slope of all the temperature were at a higher rate than before.

- Humidity and Pressure

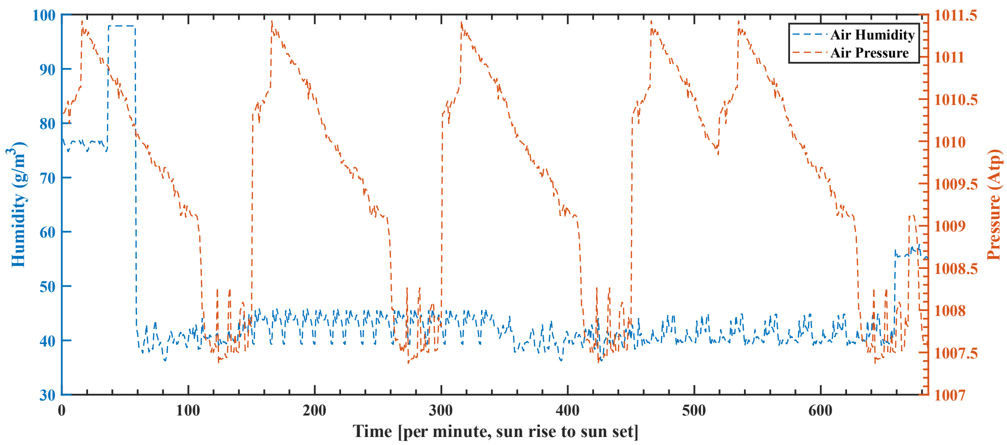


Fig. 72. Per minute data of air humidity and pressure [30-day average]

Fig. 72, illustrates the variation of air humidity and pressure from sunset to sunrise at a per minute rate. The dark orange and blue dotted scattered plot are the raw data that were collected for the span of one month. Firstly, blue dotted line [air humidity] has a high fluctuation at early morning. As the day progresses the humidity levels had minimal fluctuation throughout a day. At the end of the day the humidity levels had a slightly high fluctuation compared to the rest of the day excluding humidity fluctuation of early morning.

Moreover, Fig. 72, depicts barometric pressure levels [air pressure, orange dotted line]. From early morning to late evening the air pressure levels had very high fluctuations.

5.3.2 PV panels parameters

The PV panel parameters include a couple of things, they are power and efficiency for bifacial, monofacial PV panel. Besides, the data sets were collected at a per minute rate for the span of 30 days from sunrise to sunset [November 5th to December 4th, 2022]. Additionally, as there were a huge data sets of roughly 686 points for each day, polynomial regression is used for plotting the raw data sets for better observation of the PV panel's efficiency.

- Power generation

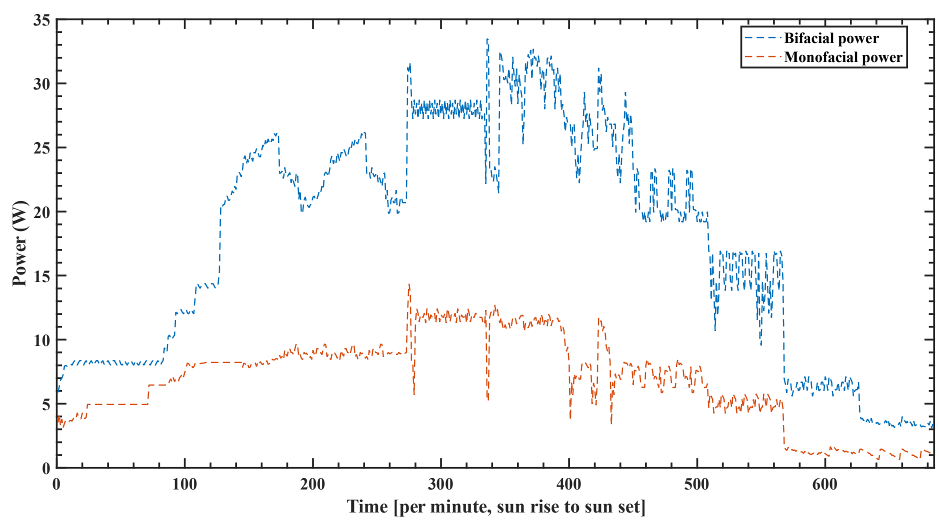


Fig. 73. Generated power at per minute rate from sunrise to sunset [30-day average]

Fig. 74, illustrates the raw data sets scatter plot of power generation by bifacial and monofacial PV panel at a per minute rate in a day. Firstly, at early morning and at late evening the power generation were the lowest as expected because the solar radiation is at its minimum since sun light cannot reach earth's surface. Secondly, as the day progresses starting from late mooring solar radiation increases resulting a steep increase in generated energy. Noticeably, the sharp fluctuations in both bifacial and monofacial PV panels power during noon to late evening is because of sudden cloud cover in the sky throughout a day. Besides, as the system has single axis tracking system to track the sun from east to west, there is a clear energy gain during the periods when solar radiation is at its maximum.

Meanwhile, Fig. 74, depicts that energy generated from bifacial PV panel is consistently higher than monofacial PV panel throughout a day. Furthermore, a total of power of 12202.126-watts was recorded, which was generated form bifacial PV panel at each day [30-day average]. On the other hand, a total power of 4692.0893-watts was recorded, which was generated from monofacial PV panel at each day [30-day average]. Finally, 7510.0366-watts extra energy was recorded, which bifacial PV panel produced per day compared to monofacial PV module.

- Efficiency of PV panels (EPP)

$$\eta = \frac{PV\ panel\ genrated\ power}{rated\ power} \times 100\% \tag{7}$$

$$\eta = \frac{PV\ panel\ genrated\ power}{34} \times 100\% \tag{8}$$

$$\eta = \frac{PV\ panel\ genrated\ power}{20} \times 100\% \tag{9}$$

Here, η = efficiency. Eq. 7 is the generalized formula for power efficiency measurement of PV panels. Eq. 8 and 9 are the power efficiency formula for bifacial and monofacial PV panels used in this protype system. The rated power that was calculated for bifacial PV panel in this prototype system is 34-watts. Similarly, the monofacial PV panel had a rated energy of 20-watts.

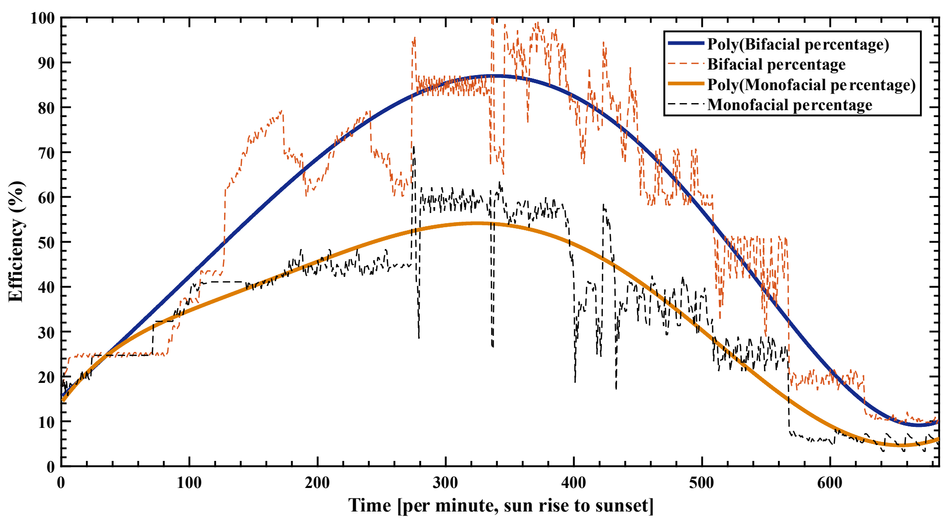


Fig. 74. Efficiency at per minute rate from sunrise to sunset [30-day average]

Fig. 75, shows the efficiency comparison of bifacial and monofacial PV panel in the prototype system. Eq. 8 and 9 were used to measure the efficiency of bifacial and monofacial PV panel respectively. The dark orange and black dotted scattered plots are raw data of bifacial and monofacial PV panels efficiency that were collected throughout a day, over the span of one month [November 5th to December 4th]. Besides, the solid dark blue land orange line is polynomial regression that provided the best fit curve for the respective datasets. The polynomial equation and goodness of fit for efficiency of PV panel are:

$$y = 7E^{-12}x^5 - 8E^{-9}x^4 + 1E^{-6}x^3 - 2E^{-5}x^2 + 0.2663x + 15.521 \quad (10)$$

$$y = -3E^{-14}x^6 + 6E^{-11}x^5 - 5E^{-8}x^4 + 2E^{-5}x^3 - 0.0034x^2 + 0.3951x + 16.058 \quad (11)$$

Eq. 10 and 11 are polynomial regression of bifacial and monofacial PV panels energy efficiency and goodness of fit of the equations are 0.9114 and 0.8916 respectively.

Moving on, at early morning and late evening the energy efficiency of both bifacial and monofacial PV panels were at its minimum. In contrary, the energy efficiency was at its maximum during the period of noon and until late afternoon. Furthermore, at late morning the energy efficiency of bifacial PV panel had a steep increasing slope until noon. On the other hand, during the same time period, monofacial PV panels energy efficiency also had a steep increasing slope, but the increasing rate of the slope were lower compared to bifacial PV panels energy efficiency curves slope. Besides, the high fluctuation in the raw data for energy efficiency of both PV panels were due to cloud cover in the sky. Moreover, at the opposite end of the day [from late afternoon to late evening] both bifacial and monofacial PV panels energy efficiency had a steep declining slope.

Meanwhile, it was found that bifacial PV panels energy efficiency were on average 19.7309% extra, compared to monofacial PV panel for a day [30-day average value]. Furthermore, Fig. 70 depicts that, during noon bifacial and monofacial PV panels energy efficiency was around 90% and 50% respectively. Thus, during noon bifacial PV panels energy efficiency was 40% higher compared to monofacial PV panels energy efficiency. Finally, from the data analysis it was found that bifacial PV and Monofacial PV panels average energy efficiency in a day at a per minute rate [for a 30-day average] were 53.97% and 34.248% respectively.

5.4 Problems faced and troubleshooting

During implementation phases of the prototype system, numerous challenges were found and corresponding troubleshooting were done to resolve the issue. Some of the challenges that were faced are: Drawback of PZM sensor, Custom made net-meter, Issue with the relay, Power management for the system, Issue with barometric sensor and Wire problem.

5.4.1 Drawback of PZM sensor

At the early phase of the prototype implementation PZM sensor were used to measure the system's AC power, voltage, current and power factor. But due to low durability of the current sensing coil in the PZM sensor, the coil got burnt and the sensor were not functional anymore. Although it a very accurate sensor to measure AC power and power factor, but due to its higher price an alternate option of AC current sensor and Voltage sensor were used to measure the systems AC power flow. Moreover, AC current sensor have its own drawbacks as well, which is it store a bit of current within it after being functional giving a small amount of false rating. Anyway, a higher priced and much better in quality of AC current sensor and voltage sensor will resolve the issue.

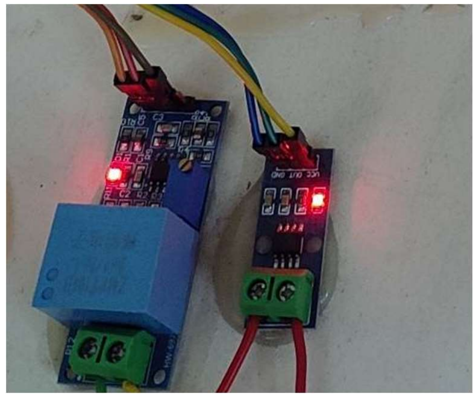


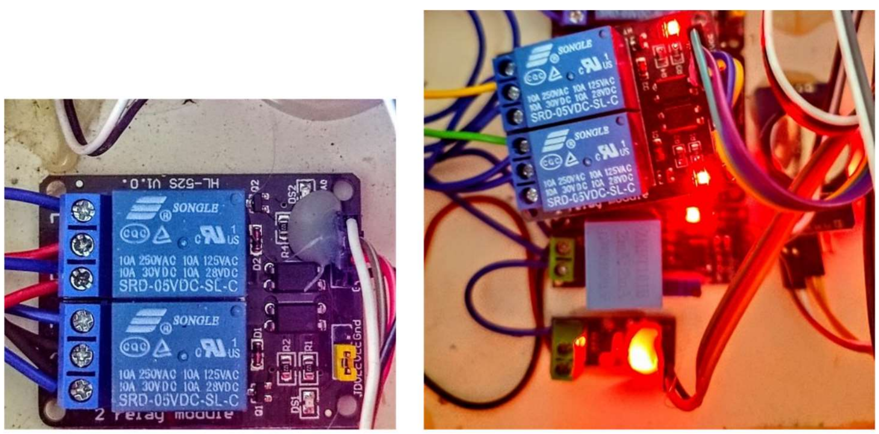
Fig. 75. AC current and voltage sensor [for system power flow measurement]

5.4.2 Custom made net-meter

For financial reasons, high price and availability a custom-made net-meter were used in the prototype system. Since cheaper components were used to build the net-meter as well as low accuracy AC current sensor and voltage sensor made the custom-made net-meter slightly inaccurate in reading inward and outward power from the solar grid utility system and national grid. To solve this a higher accuracy sensor which are costlier can be used to make it more accurate.

5.4.3 Issue with the relay

During the testing phase of the prototype system, one of the relays in the net-metering system malfunctioned and because of that one set of relays had to be changed. Normally relays are quite durable but due to over current surge during testing phase the relays' internal structure mal-functioned.

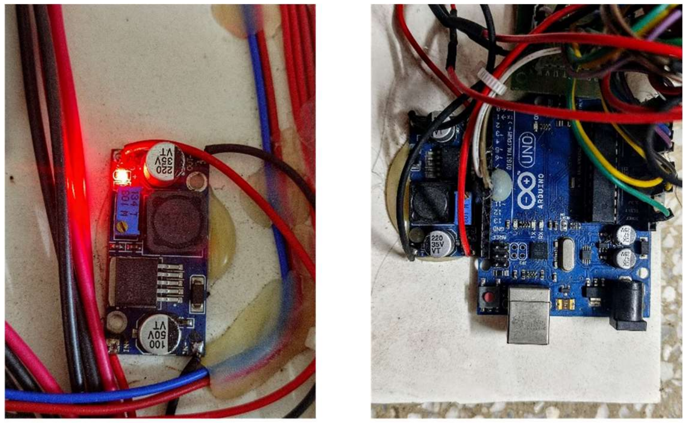


a. b.

Fig. 76. Relay: a) malfunctioning relay and b) replaced relay

5.4.4 Power management for the system

In the prototype system two buck converter were used to handle the power management system of the microcontrollers and sensors. At first one buck converter were used but it was not able to provide the sufficient current needed by the components connected to it. Therefore, two buck converters were needed to distribute the power needed withing the microcontrollers and sensors.



a. b.

Fig. 77. Buck converter: a) supplying power to Arduino mega and connect sensors, modules b) supplying power to Arduino uno, sensors and motor drivers.

5.4.5 Issue with barometric sensor

During the data collection phase barometric pressure sensor BMP180 which is and I2C protocol-based module and shares data using SCL (serial clock line) and SDL (serial data line) were having some issue. As the protype system had numerous sensors, BMP180 sensor were not synchronizing with the internal clock with other sensors. Due to this issue after the data collection phase ended to have a full functional working prototype, the BMP180 sensor had to be removed.

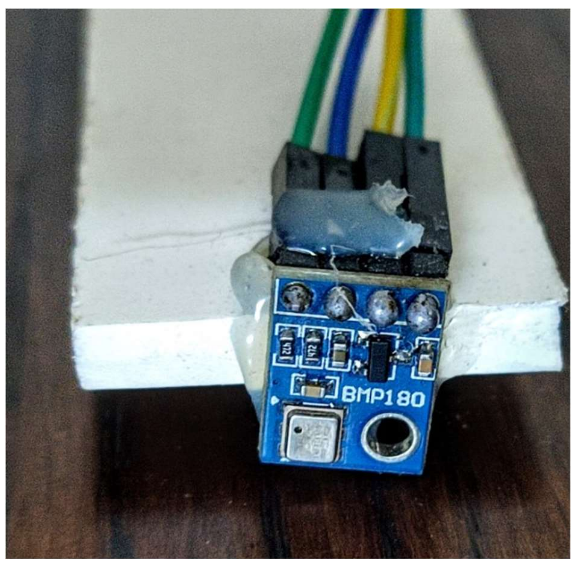
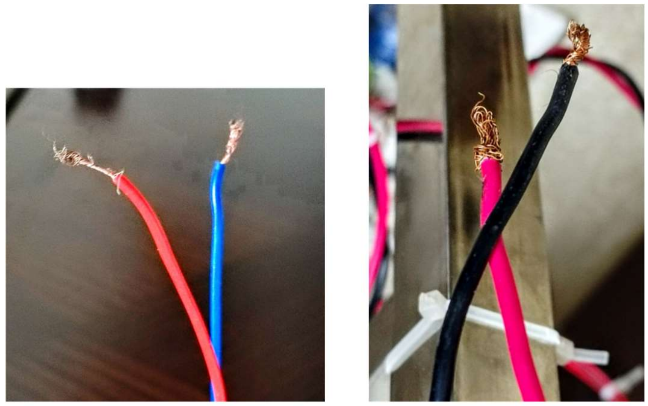


Fig. 78. BMP180 sensor

5.4.6 Wire problem

In the prototype system two kinds of wire were used. But at the beginning only one kind of wire was used and that is the narrow wire which can carry a current in the range of 1A. But as the rated current values of the PV panels in this prototype system were more than 1A. Therefore 2 by 1.2 (rm), 40/2 wire were used which had a max current rating of 10A to 11A. As the bifacial and monofacial PV panel could generate 2.3A and 1.17A respectively, the 40/2 wire could easily handle the current supply.



a. b.

Fig. 79. Wire: a) narrow wire b) solar DC wire

5.5 Conclusion

Through this prototype implementation we have evaluated and validated the efficacy of the Bifacial panels, observed the current-voltage -power characteristics and confirmed whether we will be able to meet up the energy demand according to the proposal. Since, Bifacial PV module is not available, we have customized Bifacial solar PV module by cascading two Monofacial PV panels in this prototype system. Three subsystems include this prototype system which is Solar Utility System, Net metering System and Single Axis Tracking System. Each subsystem has individual effects on this whole system. Solar utility system provides energy to the prototype system. Besides, Custom made net metering system enables this system to distribute power in home appliances and export surplus electricity to the grid. On the other hand, to improvise this system we have added single axis tracking system to track sun's position efficiently which enables to store more energy. After implementation of this system main goal was to determine and validate the PV panel parameters and one month data has been recorded for analysis of this prototype. These collected data has been used to monitor the performance of this prototype system by observing a number of weather parameters such as temperature, humidity and barometric pressure. Since the performance of two types of panels-Monofacial and Bifacial were observed in this system, most efficient panel was determined from the PV panel parameter data. Moreover, comparing the data sets of power and efficiency parameters, we can identify Bifacial PV module's efficiency and power generation rate is 19.722% and 7510.0366-watts higher than Monofacial PV module, respectively.

Chapter 6: Impact Analysis and Project Sustainability

6.1 Introduction

An engineering complex problem when comes with different approaches to the solution, it also arrives with some impact analysis and project sustainability. Without an impact analysis, the project would be incomplete as it analyzes what positive, and negative impacts or outcomes the project acquires. While doing an impact analysis, the first thing we should inspect that the impacts are positive or negative. Secondly, the negative or positive impact of the project must be categorized under the social, environmental, and economic impact. Besides this, a SWOT analysis must be carried out so that the sustainability of the project is examined. A SWOT analysis inspects the strength, weaknesses, opportunities, and threats of a project. Moreover, to detect the sustainability of the developed design, the environmental, social, and economic factor is further sub-categorized into both positive and negative impact. Therefore, after these all analyses we can assure the sustainability and impacts of the project.

6.2 Assess the impact of solution

TABLE XIV. IMPACT ANALYSIS OF THE DEVELOPED SOLUTION

<table>
<tr><th>Level</th><th>Social Impact</th><th>Environmental Impact</th><th>Economic Impact</th></tr>
<tr><td rowspan="4">Positive</td><td rowspan="2">Benefits of long-term promotions.</td><td>Environmental issues are being brought to the public's attention.</td><td>Spending (direct and indirect).</td></tr>
<tr><td rowspan="3">Area preservation for the long term.</td><td>The property's value has increased as a result of the redevelopment.</td></tr>
<tr><td>Pride in the community.</td><td rowspan="2">Increased trade and business opportunities.</td></tr>
<tr><td>Development of the community.</td></tr>
<tr><td rowspan="6">Negative</td><td>Infrastructure will not be used to its full potential in the future.</td><td>Short-term and long-term site/location damage.</td><td>The cost of an event's failure to the local and national economies.</td></tr>
<tr><td rowspan="2">Disruption of one's way of lifestyle.</td><td>Pollution and waste.</td><td>Product, service, and utility prices have been impacted.</td></tr>
<tr><td rowspan="4">Demand for energy and other natural resources has increased.</td><td rowspan="4">Wealth is distributed unequally.</td></tr>
<tr><td>Influence of the media.</td></tr>
<tr><td>Indifference and hostility in the community.</td></tr>
<tr><td>Security issues are more likely to arise.</td></tr>
</table>

The TABLE XIV describes the Impact Analysis of the Developed Solution, about the Positive and Negative Impacts in variety of sectors such as Social, Environment and Economic. To begin with, the Positive Social Impacts, it would develop the community and make the people feel proud when they start to embrace an idea that is new and advance, from which they could benefits in the long-run. One of the main Environmental Impact is that citizens would be highly aware of the current environmental issues and climate change, and how they can do their part to save the world. Also, site of this project, for a long period of time would be conserved for later other purpose usages or upgradation in the future. Increase in business opportunities and trade is an Economic Impact because local suppliers of items for the project, would profits from sales. Customers, who invests in the project would also benefits, in the long term, as they could become free from paying electricity bills. They could also increase their land value as a result of the property redevelopment. In contrast, the Negative Impacts are plenty. Under Negative Social Impacts, in future, it would halt the usage of infrastructure in the sites. Many people in the community would not accept the new idea and could try to influence the decisions of the ones who agreed up on, because many people are not comfortable bringing changes to their lifestyle. Security issues would arise and the media could also spread propaganda. The very thing that would save environment could also damage and pollute the environment especially when the panels become unusable and thrown away as unrecyclable wastes which cause land pollution. This damages the location and sites in the short and long run. Demand for energy and other natural resources has increased which also harms the environment. These are some of the Negative Environmental Impacts. Also, Negative Economic Impacts discuss that every people in the community does not have the same wealth and many people who cannot afford would be left out. As services, and utility prices have been impacted, local power distributor could lose customers and money. This could cost event's failure to the local and national economies.

6.3 Evaluate the sustainability

TABLE XV. SWOT ANALYSIS

Strength	Weakness	Opportunities	Threats (Risk)
Long-lasting power source with low operating costs.	Small scale of the renewable energy economy.	The increasing gap between energy and supply and demand.	Dominant position of fossil fuels.
Rich solar resources.	Short of foundation in the PV industrial sector.	Increasing worldwide awareness of climate change.	Potential ecological impacts associated with solar PV development.
Suitable application for distributed PV power systems.	Insufficient awareness of social and environmental benefits of solar PV.	Rapid decrease in PV prices around the world.	Discontinuity of energy policies.

We have evaluated the sustainability of Bifacial PV solar system from this SWOT analysis. Bifacial PV solar system has the advantage of lower operating cost and its long-lasting power source is the main strength. Moreover, rich solar resources and suitable application for distributed PV power systems will also strengthen Bifacial PV solar home system. Even though strength points are powerful enough, Bifacial PV solar system is not widely spread rather it is quite small scale of the renewable energy economy. Furthermore, the lack of foundation in the PV industrial sector and inadequate awareness of social and environmental benefits are additional weaknesses which we have enlisted. On the other hand, Bifacial PV solar system can face threat due to dominant position of fossil fuels, potential ecological impacts associated with solar PV development and discontinuity of energy policies. But at recent time, the increasing gap between energy and supply and demand may present the greatest opportunity in this regard. In addition, increasing worldwide awareness of climate change and rapid decrease in PV prices around the world are also urging to take this initiative. So, we are estimating if researching more in this field can bring a golden opportunity in this era.

TABLE XVI. SUSTAINABILITY OF THE DEVELOPED DESIGN

Factors	Sustainability		
	Impacts	***positive***	***negative***
Environmental	***Micro-environment***	On existing complexes or buildings, multipurpose and integrated usage (like rooftops, facades).	Higher initial expenses and changes in microclimate.
Social	***Infrastructure***	Transmission lines/grids are reduced.	Energy storage is required for continuous supply.
		Decentralized, low-density off-grid settings, including in underdeveloped countries.	
	Political	Import-free energy for the country.	Subsidies based on economic considerations, such as the fee-in tariff

			mechanism, which is uncontrolled and overestimated.
Economic	***Energy market***	Diversification and deregulation.	Irregular supply issues of the solar home system.

In Table XVI, the sustainability of the developed design is inspected. Firstly, the environmental, social, and economic factors are categorized into positive or negative impacts. As it is visible, all the factors possess both positive and negative impacts. Secondly, environmental factor contains micro-environment impacts that can be both positive and negative. Thirdly, the social factor can have an infrastructure impact and political impact which can be both negative and cheerful as well. Finally, the economic factor has only an energy market impact. Moving on, the positive micro-environmental impacts possess building the project on rooftops of high-rise buildings as it will save up much space. The positive impact of the infrastructure impacts is the grid lines are reduced along with that low-density off-grid settings are achieved. Furthermore, the positive impacts of political impact and energy market impact are import-free energy for the country and diversification and deregulation respectively. On the other hand, on the micro-environment factor, the higher initial expenses and changes in the micro-climate are one of the main negative impacts. Correspondingly, energy storage is also required which is a negative impact of social factors. Additionally, fee-in-tariff mechanisms and subsidies based on economic considerations also have a negative impact which falls under the political impact of social factors. Lastly, the irregular supply issues of the solar home system represent the negative impact of the economic factor.

6.4 Conclusion

This project has many positive and negative sides in the impacts it is going to bring to the community and its people. The sustainability of the project is also analyzed and the findings says there are many pros and cons present. SWOT analysis is also discussed about the project. However, the main goal is to provide uninterrupted clean energy to the customers that is both beneficial to the climate and the people. Many obstacles would always be present in the way when a new idea is going to be implemented, but such hardships should be overcome to achieve the greater goodness. The most important point to be taken in mind is that we should not inflict damage to the already damaged environment anymore, so any alternate way to approach is highly suggested. For example, a process of recycling the run-out lifetime of the Solar Module must be found so that they can be made reusable and does not go in the landfills. On top of that, if the project idea could be manufactured in large scale, the initial expenses could be greatly reduced, so that it becomes affordable to most of the people. The government could also help in reducing the tariffs of the goods. The technology of storing energy in battery is advancing at a rising pace, which makes it imminent that one day, our total energy grid would totally become dependent in renewable energy and storing energy, dumping the idea of old fashioned, dirty fossil fuel-based generation. So now would be a perfect time for the people to slowly shift to the clean, environment friendly renewable energy as both supplier and consumer.

Chapter 7: Engineering Project Management

7.1 Introduction

Coordination and implementation of any design and process is the most important thing to make an engineering project fruitful. Evaluating and analyzing data of a project is another skeleton of any project and for these a strategy and plan must be needed. Therefore, standard methodology, budget and cost management, approval of plan documentation are the pillars to convert a project into an extraordinary one. In addition to, team communication is a vital key point of any project management. We are proposing an innovative technology of solar industry where we intend to meet the energy demand in urban area households by reducing the installation cost and building an efficient Bifacial PV solar home system. To identify the goals of our project we also proposed a working plan before leading the research and development stage of projects. Project development depends on proper working plan and contingency plan. Moreover, detailed project plans and budget proposal and functional and non-functional requirements for the project are also included in an effective engineering project plan.

7.2 Define, plan and manage engineering project

7.2.1 FYDP 400C plan

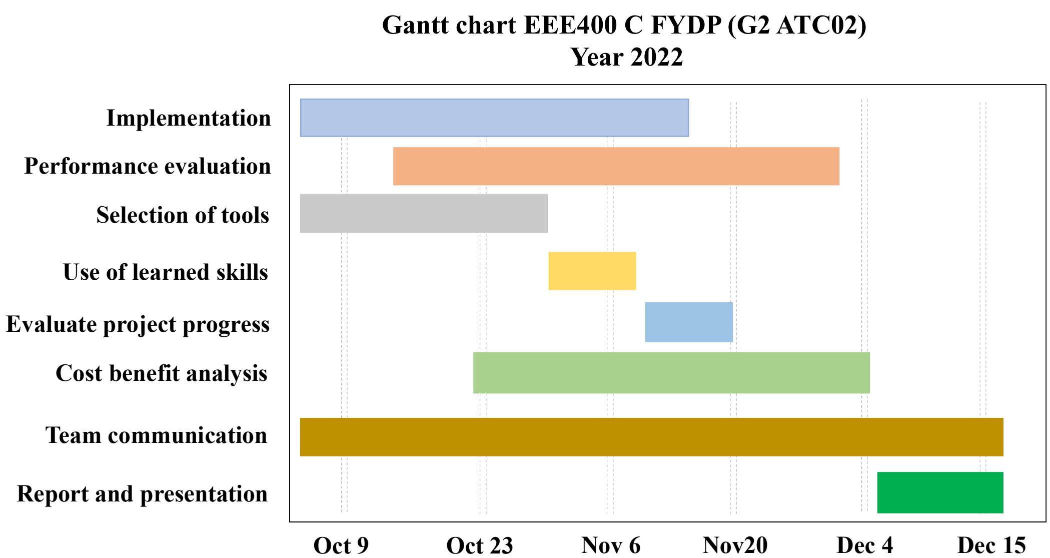


Fig. 80. Gantt chart [EEE400_C]

TABLE XVII. ALLOCATED PERSONS, STARTING AND ENDING DATES FOR FYDP 400C TASKS

TASK	START	END	Allocated persons
Implementation of selected design.	10/2	11/15	Tanvir Mahmud Mahim, Sahha Munzer
Performance evaluation of implemented design.	10/12	11/25	All the members
Selection of appropriate tools for implementation.	10/5	10/30	Adnan Miah, Begum Fatema Tuz Zohra
Use of learned knowledge and skills.	10/31	11/10	Adnan Miah, Begum Fatema Tuz Zohra
Evaluate project progress.	11/11	11/20	Tanvir Mahmud Mahim, Sahha Munzer
Cost benefit analysis and estimation.	10/21	12/5	All the members
Team communication	10/2	12/14	All the members
Report and presentation	12/5	12/14	All the members

7.2.2 Complete Project plan

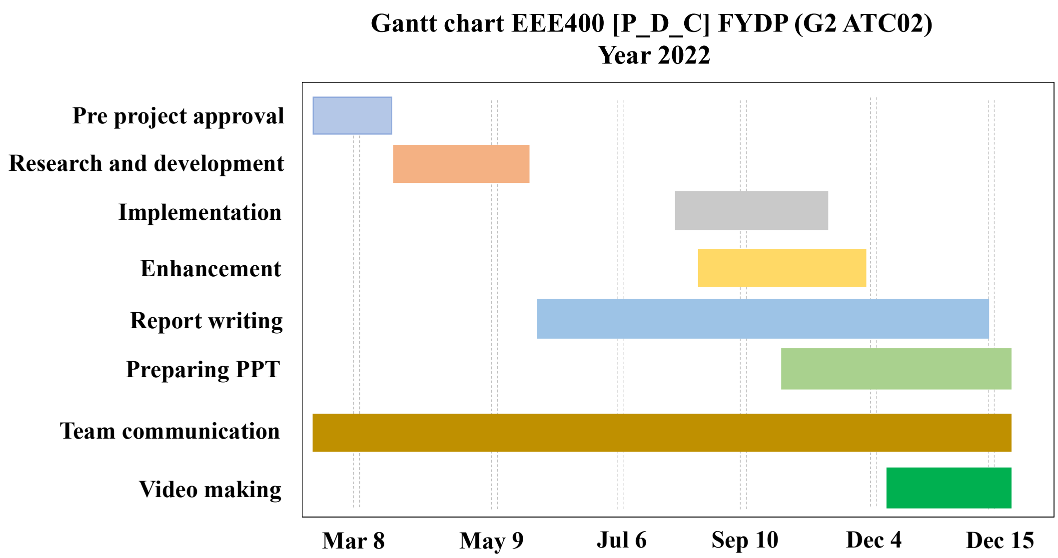


Fig. 81. Gantt chart [1-year plan]

TABLE XVIII. ALLOCATED PERSONS, STARTING AND ENDING DATES FOR FYDP 400 [P_D_C]

TASK	START	END	Allocated persons
pre-project approval	2/15	3/14	All members
Research and Development	3/15	5/14	All members
Implementation	10/2	11/15	Tanvir Mahmud Mahim, Adnan Miah
Enhancement	10/12	11/25	Sahha Munzer, Begum Fatema Tuz Zohra
Report writing	6/25	12/12	Tanvir Mahmud Mahim, Adnan Miah
Preparing PPT	10/30	12/14	Sahha Munzer, Begum Fatema Tuz Zohra
Team communication	2/15	12/14	All members
Video making	12/6	12/14	Tanvir Mahmud Mahim

7.3 Evaluate project progress

Figure 81 is a tentative Gantt chart of different tasks in EEE400 C FYDP. Figure 82 is a Gantt chart of the tasks in full one year of EEE400 P, D and C. Pre project Approval and Research and Development have been completed in EEE400 P and D. From both the charts throughout the project, Team Communication have been present among all the group members, for discussing and sharing problems, ideas, works and plans to proceed the project. Reports have been written in EEE400 P, D and C. Video made on the working prototype has been presented and final Report submitted at the end of the FYDP. These are some of the tasks along with Implementation that have been done in FYDP C in time, as preplanned according to the Gantt chart of figure 82. However, some extra works, have been considered in the EEE400 C that was not originally pre-planned in the Gantt chart of full one year. These extra tasks are Performance Evaluation, Selection of tools, Use of learned skills, Evaluate project progress and Cost benefit analysis. Also, Enhancement was removed from FYDP C. All these tasks were supposed to end by December 4th but we had to delay and extend this till December 15th including preparing PPT. Other than that, all the other works and task have been successfully completed within the proposed dates before deadline.

7.4 Conclusion

The Gantt chart of FYDP[P_D_C] overviews and sums up how we approached the project and how we concluded it. It explains the timeline of preparation, research and development, implementation, and also data analysis of the project. Moreover, the complete project plan depicts how we distributed the workload of the project. Additionally, while implementing the project several barriers were obstructing the timeline of the project but together, we overcame all the obstacles. One of the significant obstructions we faced was assembling the PV panels as Bifacial Panel, somehow, we managed to overcome that problem as well by using a steel structure for the panels. Therefore, managing the obstructions and problems we faced was tough but eventually, we stick to the feedback from the teachers and learned how to execute everything properly.

Chapter 8: Economical Analysis

8.1 Introduction

Evaluation of costs and benefits is essentially what economic analysis includes. In order to facilitate better resource allocation, it begins by evaluating projects according to their economic viability. It seeks to assess how a project would affect welfare. Generally, economic analysis involves three portions. Firstly, identifying and estimating investment-related costs. Secondly, identifying and estimating the advantages of a potential investment. Lastly, evaluating the investment's suitability by weighing costs and benefits. Economic analysis is one of the prime tasks to be executed when any project is commenced. Cost is a vital component to take into consideration in economic analysis. In economic analysis, we compared the costs and some other factors of our three design approaches. Here, in economic analysis, many factors lie such as financial analysis, depreciation, electricity sale, and return on investment. An extensive analysis of all these factors is completed to conclude the economic analysis. In this project, three design approaches have been shown and out of them only one design approach is selected to be the optimal solution. The design approach three is selected because of its cost-effectiveness and maximum efficiency. Through economic analysis, it can be verified which design approach three is the most cost-effective as it gives us more energy in the least value. Without an economic analysis, the best outcome from which design approach is achievable is quite tough to say. Economic analysis is useful for guiding policy decisions, but it cannot establish which policy option is the most efficient. To do so, the economic analysis, would need to possess all the knowledge on costs, advantages and other factors mentioned above that forbids market forces from substituting markets for the allocation of resources

8.2 Economic analysis

8.2.1 Design 1

- Installation costs:

TABLE XIX. TOTAL BUDGET OF DESIGN 1

Item	**Quantity [units]**	**Cost [Tk]**	**Total [Tk]**
PV modules			
LR4-60 HBD 350 M G2 Bifacial	4	20714	82856
Support for modules	4	2618	10473
Batteries	8	1657	13258
Controllers		2816	166
Total			**106763**
Depreciable asset			**106763**

- Maintenance:

TABLE XX. MAINTENANCE COSTS OF DESIGN 1

Item	**Total [Tk/ year]**
PV modules	
Cleaning	663
Total (OPEX)	663
Including inflation (1.5%)	797

- System summary:

Total installation cost = **106763** Tk

Operating costs (including inflation 1.5%/ year) = **797** Tk/year

Excess energy (battery full) = **463** KW-h/ year

Used solar energy = **1168** KW-h/ year

Used energy cost = **6** Tk/ KW-h

- Financial analysis:

Simulation period:

Project lifetime = 25 years

Start year = 2023

Income variation over time:

Inflation = 1.5% / year

Product variation (aging) = -0.5% / year

Discount rate = 1% / year

Depreciation:

Depreciable assets = 106763 Tk

Salvage value = 47351 Tk

Total redeemable = 59412 Tk

Depreciation period = 15 years

Financing:

Own funds = 53382 Tk

Loan 1– Redeemable with fixed annuity – 20 years = 17793 Tk; interest rate = 2%

Loan 2– Redeemable fixed amortization – 25 years = 17793 Tk; interest rate = 2%

Loan 3– Interest-only bullet loan – 25 years = 17793 Tk; interest rate = 2%

Electricity sale:

Feed-in tariff

Peak tariff = 13 Tk/ KW-h

Off-peak tariff = 9 Tk/KW-h

Return on investment:

Payback period = 11 years

Net present value = 113981 Tk

Return on investment = 106.8%

Paid dividends = 29554 Tk

- Detailed Economic Results (BDTK):

TABLE XXI. FINANCIAL ANALYSIS OF DESIGN 1

Year	Electricity sale	Loan principal	Loan interest	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Divid. 15.00 %	Cumul. profit
2023	13753	1446	1055	664	3965	8070	1614	8976	1346	-44545
2024	13684	1460	1025	673	3965	8021	1604	8921	1338	-35801
2025	13616	1475	997	684	3965	7971	1594	8867	1329	-27195
2026	13547	1491	967	694	3965	7921	1584	8811	1321	-18727
2027	13478	1506	937	704	3965	7872	1575	8756	1313	-10396
2028	13410	1521	906	714	3965	7823	1564	8701	1305	-2199
2029	13340	1538	877	725	3965	7774	1555	8645	1296	5864
2030	13271	1555	846	737	3965	7724	1545	8591	1288	1379
2031	13202	1571	814	748	3965	7676	1536	8534	1280	21600
2032	13133	1589	783	758	3965	7627	1525	8478	1271	29275

2033	13065	1606	751	770	3965	7579	1515	8422	1263	36824
2034	12996	1623	719	782	3965	7531	1506	8365	1255	44248
2035	12927	1642	687	794	3965	7483	1497	8309	1247	51549
2036	12859	1660	654	806	3965	7435	1487	8252	1238	58727
2037	12790	1680	621	818	3965	7388	1478	8195	1229	65786
2038	12721	1699	588	829	0	11305	2261	7345	1102	72050
2039	12652	1718	553	842	0	11258	2251	7287	1094	7820
2040	12584	1738	519	854	0	11175	2242	7229	1084	84246
2041	12515	1760	483	867	0	11163	2232	7171	1076	90183
2042	12446	1780	449	880	0	11117	2223	7113	1066	96012
2043	12377	712	414	893	0	11071	2215	8144	1222	102621
2044	12309	712	399	908	0	11003	2200	8089	1213	109120
2045	12240	712	385	921	0	10934	2187	8035	1205	115511
2046	12171	712	371	935	0	10867	2173	7980	1197	121797
2047	12103	18524	357	949	0	10798	2160	-9886	0	114088
Total	**323190**	**53432**	**17154**	**19948**	**59468**	**226619**	**45324**	**187332**	**29582**	**114088**

8.2.2 Design 2

- Installation costs:

TABLE XXII. TOTAL BUDGET OF DESIGN 2

Item	**Quantity [units]**	**Cost [Tk]**	**Total [Tk]**
PV modules			
LR4-60 HBD 350 M G2 Bifacial	4	20703	82856
Supports for modules	4	166	663
Inverters			
QS1	1	23581	23581
Batteries	4	3314	13257
Installation			
Global installation cost per inverter	1	2817	2817
Total			**123173**
Depreciable asset			**123173**

- Maintenance:

TABLE XXIII. MAINTENANCE COSTS OF DESIGN 2

Item	**Total [Tk/ year]**
PV modules	
Cleaning	663
Provision for battery replacement	1326
Total (OPEX)	1989
Including inflation (1.5%)	2299

- System summary:

Total installation cost = **123173** Tk
Operating costs (incl. inflation 1.5%/ year) = **2299** Tk/year
Used energy = **1162** KW-h/ year
Energy sold to the grid = **714** KW-h/year
Cost of produced energy = **7** Tk/KW-h

- Financial analysis:

Simulation period:

Project lifetime = 20 years
Start year = 2023

Income variation over time:

Inflation = 1.5% / year
Production variation (aging) = -0.5%/ year
Discount rate = 1%/ year

Income dependent expenses:

Income tax rate = 10%/ year
Other income tax = 10% /year
Dividends = 15%/ year

Depreciation:

Depreciable assets = 123173 Tk
Salvage value = 59183 Tk
Total redeemable = 61174 Tk
Depreciation period = 15 years

Financing:

Own funds = 66492 Tk
Loan 1– Redeemable with fixed annuity – 20 years = 22164 Tk; interest rate = 2%
Loan 2– Redeemable fixed amortization – 25 years = 22164 Tk; interest rate = 2%
Loan 3– Interest-only bullet loan – 25 years = 12354 Tk; interest rate = 2%

Electricity sale:

Feed-in tariff
Peak tariff = 13 Tk/ KW-h
Off-peak tariff = 9 Tk/KW-h
Duration of tariff warranty = 15 years
Annual connection tax = 1776 Tk/ KW-h
Annual tariff variation = +0.2%
Feed-in tariff decrease after warranty = 50%

Self-consumption:

Consumption tariff
Peak tariff = 13 Tk/ KW-h
Off-peak tariff = 9 Tk/KW-h
Tariff evolution = +0.8%/ year

Return on investment:

Payback period = 6.1 years
Net present value = 372772 Tk
Return on investment = 302.6%
Paid dividends = 5125 Tk

- Detailed Economic Results (BDTK):

TABLE XXIV. FINANCIAL ANALYSIS OF DESIGN 2

Year	Electricity sale	Loan principal	Loan interest	Run costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Divid. 15.00%	Self-cons. saving	Cumul. profit
2023	7524	1801	1117	1991	4082	333	66	2549	383	13727	-50447
2024	7496	1819	1081	2020	4082	312	63	2513	377	14825	-33450

2025	7467	1838	1045	2051	4082	289	58	2476	372	15924	-15590
2026	7439	1857	1008	2082	4082	267	53	2440	366	17022	3113
2027	7410	1876	970	2113	4082	244	49	2402	360	18121	22639
2028	7382	1896	934	2145	4082	222	44	2364	354	19219	42970
2029	7352	1916	896	2177	4082	198	39	2325	348	20317	64090
2030	7324	1936	857	2210	4082	175	36	2286	342	21415	85978
2031	7294	1957	819	2243	4082	152	31	2247	337	22513	108616
2032	7265	1979	780	2276	4082	127	25	2205	331	23612	131987
2033	7235	2000	739	2311	4082	103	20	2165	325	24699	156075
2034	7205	2023	699	2345	4082	78	15	2122	319	25808	180862
2035	7176	2045	659	2380	4082	53	11	2079	312	26907	206331
2036	7145	2069	619	2416	4082	28	6	2037	306	28004	232466
2037	7115	2093	577	2452	4082	4	1	1993	299	29102	259250
2038	2524	2116	536	2488	0	0	0	-2616	0	30201	282775
2039	2501	2141	493	2526	0	0	0	-2659	0	31299	306958
2040	2478	2166	450	2564	0	0	0	-2702	0	32398	331784
2041	2455	2192	406	2570	0	0	0	-2747	0	33496	357237
2042	2431	14585	363	2641	0	0	0	-15157	0	34593	373165
Total	**122219**	**56741**	**15045**	**46031**	**61238**	**2585**	**517**	**8323**	**5131**	**483213**	**373165**

8.2.3 Design 3

- Installation costs:

TABLE XXV. TOTAL COSTS OF DESIGN 3

Item	**Quantity [units]**	**Cost [Tk]**	**Total [Tk]**
PV modules			
LR4-60 HBD 350 M G2 Bifacial	4	20703	82856
Trackers	4	2618	104773
Inverters			
QS1	1	23581	23581
Batteries	4	3314	13257
Installation			
Global installation cost per module	4	704	2817
Total			**132983**
Depreciable asset			**130166**

- Maintenance:

TABLE XXVI. MAINTENANCE COSTS OF DESIGN 3

Item	**Total [Tk/ year]**
PV modules	
Cleaning	663
Provision for battery replacement	1326
Total (OPEX)	**1989**
Including inflation (1.5%)	**2299**

- System summary:

Total installation cost = **132983** Tk

Operating costs (incl. inflation 1.5%/ year) = **2299** Tk/year

Used energy = **1162** KW-h/ year

Energy sold to the grid = **939** KW-h/year

Cost of produced energy = **6** Tk/KW-h

- Financial analysis:

Simulation period:

Project lifetime = 25 years
Start year = 2023

Income variation over time:

Inflation = 1.5% / year
Production variation (aging) = -0.5%/ year
Discount rate = 1%/ year

Income dependent expenses:

Income tax rate = 10%/ year
Other income tax = 10% /year
Dividends = 15%/ year

Depreciation:

Depreciable assets = 130166 Tk
Salvage value = 59183 Tk
Total redeemable = 70984 Tk
Depreciation period = 15 years

Financing:

Own funds = 66492 Tk
Loan 1– Redeemable with fixed annuity – 20 years = 22164 Tk; interest rate = 2%
Loan 2– Redeemable fixed amortization – 25 years = 22164 Tk; interest rate = 2%
Loan 3– Interest-only bullet loan – 25 years = 22164 Tk; interest rate = 2%

Electricity sale:

Feed-in tariff

Peak tariff = 13 Tk/ KW-h
Off-peak tariff = 9 Tk/KW-h

Duration of tariff warranty = 15 years
Annual connection tax = 1776 Tk/ KW-h
Annual tariff variation = +0.2%
Feed-in tariff decrease after warranty = 50%

Self-consumption:

Consumption tariff

Peak tariff = 13 Tk/ KW-h
Off-peak tariff = 9 Tk/KW-h

Tariff evolution = +0.8%/ year

Return on investment:

Payback period = 6 years
Net present value = 548708 Tk
Return on investment = 412.6%
Paid dividends = 10137 Tk

➢ Detailed Economic Results (BDTK):

TABLE XXVII. FINANCIAL ANALYSIS OF DESIGN 3

year	Electricity sale	Loan principal	Loan interest	Run costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Self-cons. saving	Cumul. profit
2023	10406	1801	1314	1991	4737	2365	473	4828	724	13722
2024	10369	1819	1277	2020	4737	2334	467	4786	718	14821
2025	10332	1838	1241	2051	4737	2303	461	4742	711	15918
2026	10296	1857	1204	2082	4737	2273	455	4698	705	17016
2027	10258	1876	1167	2113	4737	2241	448	4654	698	18114
2028	10220	1896	1129	2145	4737	2209	442	4608	691	19212
2029	10182	1916	1091	2177	4737	2177	435	4563	685	20309
2030	10144	1936	1053	2210	4737	2145	429	4516	678	21406
2031	10106	1957	1014	2243	4737	2111	422	4469	671	22505
2032	10067	1979	975	2276	4737	2078	416	4421	664	23602
2033	10028	2000	936	2311	4737	2045	409	4372	656	24700
2034	9989	2023	896	2345	4737	2011	402	4324	648	25798
2035	9950	2045	855	2380	4737	1978	396	4273	641	26896
2036	9911	2069	815	2416	4737	1943	389	4223	634	27993
2037	9870	2093	774	2452	4737	1908	382	4171	626	29092
2038	3858	2116	731	2488	0	637	128	-1607	0	30189
2039	3827	2141	690	2526	0	611	122	-1652	0	31287
2040	3796	2166	646	2564	0	587	117	-1697	0	32385
2041	3766	2192	603	2602	0	560	113	-1743	0	33483
2042	3736	2218	559	2641	0	536	107	-1789	0	34580
2043	3705	887	514	2681	0	510	102	-480	0	35679
2044	3674	887	496	2722	0	456	91	-523	0	36776
2045	3645	887	479	2762	0	403	81	-565	0	37874
2046	3614	887	461	2803	0	348	70	-609	0	38971
2047	3583	23075	444	2846	0	294	59	-22840	0	40070
Total	**189333**	**66562**	**21370**	**59845**	**71059**	**37061**	**7413**	**34145**	**10147**	**672399**

8.2.4 Prototype

TABLE XXVIII. PROTOTYPE BUDGET

Component	Quantity	Per piece price (Tk)	Price(TK)
Arduino Mega	1 unit	2150	**2150**
Arduino uno	1 unit	1100	**1100**
12V 7.5 Amp battery	2 unit	1450	**2900**
Inverter 1000watt	2 unit	1390	**2780**
Charge controller	2 unit	480	**960**
LCD 16 by 2 I2C	2 unit	350	**700**
Relay 2 Channel	2 unit	170	**340**
ESP8266	1 unit	320	**320**
DS18B20	2 unit	290	**580**
DHT22	1 unit	350	**350**
RTC 3231	1 unit	340	**340**
SD card module	1 unit	220	**220**
SD card	1 unit	300	**300**

AC voltage sensor	3 unit	300	**900**
AC current sensor	3 unit	250	**750**
DC voltage sensor	2 unit	190	**380**
DC current sensor	2 unit	110	**220**
LDR sensor	10 unit	30	**300**
Buck converter	2 unit	90	**180**
BMP180	1 unit	200	**200**
2 core Solar BRB wire	15 yard	75	**1125**
Battery Charger	1 unit	1100	**1100**
Wire	3 coil	1000	**3000**
Jumper wire	4 set	95	**380**
Servo Motor (ROB5GRHS3115)	2 unit	2200	**4400**
Metal servo arm 25T	2 unit	120	**240**
Holder	4 unit	30	**120**
Light 5W	2 unit	150	**300**
Light 9W	2 unit	180	**360**
Panel Stand	-	8000	**8000**
Solar panels	3 unit	1000	**3000**
Board	-	1100	**1100**
Others	-	7950	**7950**
Total			**49545**

8.3 Cost benefit analysis

8.3.1 Design 1

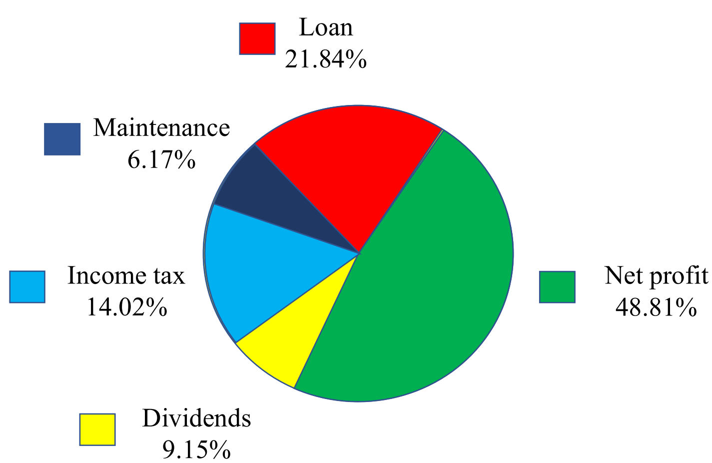


Fig. 82. Income allocation for standalone system

Here from Fig. 83, we can see the income allocation of design 1 in a pie chart and the net profit of design 1 is quite high but the energy produced in design 1 is very low compared to the other two proposed designs. Our 1st design approach is standalone system design and from this pie chart we can observe the income allocation of this system. Here, net profit, income tax, dividends, maintenance and loans are included in net income allocation. Firstly, the maximum portion of this pie chart is covered by net profit of the system. This net profit has a share of 48.81% shown in this chart. 21.84% is the 2nd highest income allocation percentage shown in this pie chart which is for loan. In addition to, income tax's share of income allocation is 14.02%. Furthermore, 9.15% of income allocation goes for dividends of this design. Finally, in this pie chart maintenance cost has 6.17% share which is the lowest value. This pie chart gives an overall idea about how much income is allocated for this design. In our simulation we have already analyzed this design; however, we are not able to produce as much power as with design 2 and 3.

8.3.2 Design 2

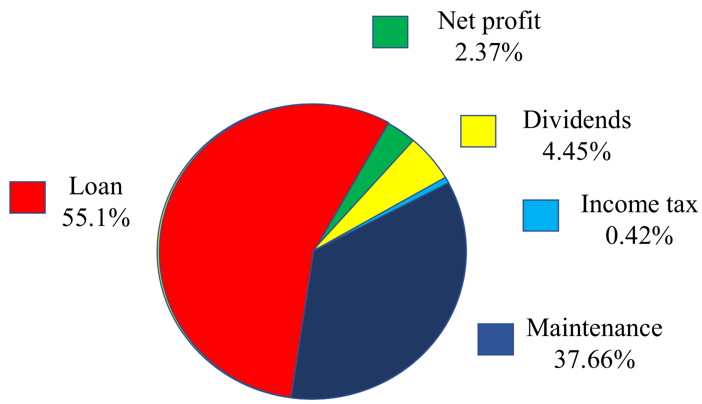


Fig. 83. Income allocation grid tied system [mutual shedding]

Here in Fig. 84, the income allocation of design 2 in a pie chart and the net profit of design 2 is the lowest among all the proposed designs. This pie chart illustrates the income allocation percentages of our grid tied system design. On the income allocation pie chart, Loan has the highest percentage. Around 55.1% is the loan share. Secondly, it is estimated that the percentage of income allocation to maintenance is 37.66%. Consequently, net profit, dividends and income tax represents very less proportion in income allocation. In terms of net income allocation, nearly 2.37% is allocated for net profit and 4.45% is allocated for dividends. According to this pie chart, income tax represents the lowest share at 0.42%. Although we can produce higher power from this design compared to the design 1, still from this income distribution pie chart we can see that this design has the lowest net profit percentage from the other two designs.

8.3.3 Design 3

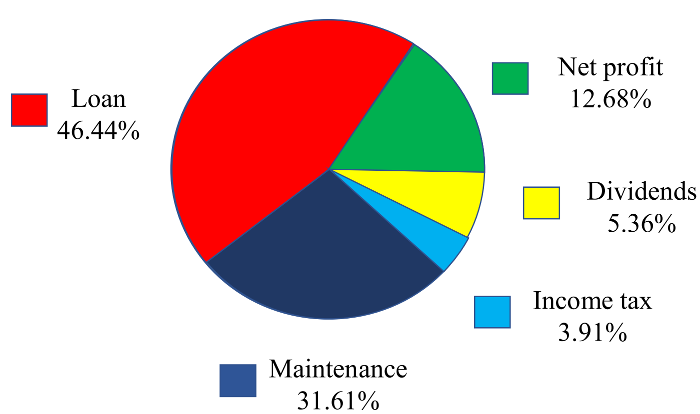


Fig. 84. Income allocation hybrid grid tied system [single axis tracking]

Here in Fig. 85, the income allocation of design 3 in a pie chart and the net profit of design 3 is the better than design 2 and among all the proposed designs design 3 has the highest energy production.

This pie chart states the income allocation for hybrid grid tied with single axis tracking system. We can see loan and maintenance cost of this system shares huge portion of income allocation of this system. Net profit, dividends and income tax percentages are comparatively lower than these. According to this pie chart, loan is occupying the largest allotment in income allocation like design 2. The loan proportion is roughly 46.44%. Next, 31.61% income is allocated for maintenance cost. Approximately 12.68% of net income is set aside for net profit. Furthermore, dividends and income tax are holding 5.36% and 3.91% shares respectively shown in this pie chart. This illustrated pie chart gives an overall idea about income allocation percentage of this design. Since we chose design 3 as our best design and proposing it, in future work this will be helpful for research works.

8.4 Evaluation economic and financial aspects

Here we can see that design 1 has the highest profitability but the worst optimization as mentioned earlier. Since design 2 and 3 are much more optimized than design 1 and between design 2 and design 3, design 3 is more optimized and financially profitable.

TABLE XXIX. COMPARISON OF FINANCIAL SUMMARY FOR DESIGN 1, 2 AND 3

Design1	Design2	Design3
Financial summary Installation costs = **76** TK/Wp Total yearly Cost = **3** Tk/ Wp/ year Used energy cost = **6** Tk/ KW-h Payback period = **11** years	***Financial summary*** Installation costs = **88** Tk/ Wp Total yearly cost = **4** Tk/ Wp/ year Cost of produced energy = **7** Tk/KW-h Payback period = **6.1** years	***Financial summary*** Installation costs = **95** Tk/ Wp Total yearly cost = **3** Tk/ Wp/ year Cost of produced energy = **5** Tk/KW-h Payback period = **5.8** years

From this comparison again we can see that design 3 which is a bifacial PV panel-based hybrid system is financially the best design among all the proposed designs. In the first design approach, the installation Wp cost is Tk.76 which eventually makes the total yearly cost Tk.3/Wp/year. The payback period of the first design approach is 11years and the used energy cost is Tk.6/KW-h. Comparing the second design approach with the first one, the installation cost increased to Tk.88/Wp as well as the total yearly cost to Tk.4/Wp/year. The payback period is also low compared to the first design approach. Moreover, the cost of produced energy is increased to Tk 7/KW-h. Lastly, in the third design approach the total yearly cost is reduced to Tk.3/Wp/year as well the cost of produced energy to Tk.5/KW-h. The payback period of the third design approach is also a bit less than the second design approach which is 5.8years.

8.5 Conclusion

In this chapter, Economical Analysis of all the three designs (1, 2 and 3) have been done. For each design, the total installation costs along with depreciable assets of all the required components and the maintenance expenditure budget have been calculated and determined. Financial analysis has been made for all the designs under which are the simulation period, income variation over time, depreciation, financing, electricity sale and return on investment all have been evaluated. However, in design 2 and 3, under financial analysis, self-consumption and income dependent expenses were the two extra criteria that have been considered in. A detailed economic result has been made by producing tables of financial analysis for each design from data after simulation that will generalize all the mentioned criteria. In this tables, financial values of the designs have been found in a period of 20 to 25 years starting from 2023. Electricity sale, Loans, running costs, Depreciation, Taxes, Profits and Dividends are determined for each year and the total of all these criteria have been calculated. All of these financial analyses were for the actual designs. The budget for the prototype that we are actually going to implement have been also included and a financial analysis for this design have been calculated from collected data after running. A summary of financial comparison of all the designs have been made. Here, we can observe that design 1 has the maximum profitability with the lowest installation cost among the three but, as was already indicated, it has the worst optimization. Between designs 2 and 3, design 3 is more optimal and profitable due to its superior optimization over designs 1 and 2. The energy production costs and total yearly costs of design 3 was found comparatively lesser than design 2 and design 1. It also has the smallest payback period of 5.8 years. Again, based on this analysis, it is clear that design 3, a hybrid system that is based on bifacial PV panels, is the most advantageous financially of all the three concepts of designs.

Chapter 9: Ethics and Professional Responsibilities

9.1 Introduction

While working on our project and implementing it, we must follow some ethics and professional responsibilities. These professional ethical principles serve as the foundation for professional codes of conduct, which specify the expected standards of conduct for a profession's members. They also aim to define what is expected of members of the profession and society. Codes of conduct are meant to provide as guides for the minimal acceptable standards of conduct in a professional setting. There are some universal ethical principles that apply across all professions, including: honesty, trustworthiness, loyalty, respect for others, adherence to the law, doing good and avoiding harm to others, accountability.

9.2 Identification of ethical issues and professional responsibilities

The ethical consideration is considered into three phases. The planning phase generally refers about the ethical issues and professional responsibilities when the project is under the condition of planning. While planning phase, many ethical issues need to be considered such as being responsive to the locals, balancing the risks and benefits, maintaining equilibrium and some other. The ethical consideration is being hindered if any of them misses out. Moving on, in the implementation phase, while starting the project the ethical issues and professional responsibilities need to taken is the autonomy and informed consent, privacy and confidentiality, standard of care and many more. Finally, in the post research phase, data ownership, benefit sharing, scalability and sustainability needs to be considered so that any aspects of the project is not obstructed.

9.3 Application of ethical issues and professional responsibilities

TABLE XXX. ETHICAL CONSIDERATION FOR THE DESIGN

Phases	Ethical considerations
Planning phase	Responsiveness to local needs and priorities: In terms of solar home systems in metropolitan locations, we will consider all of the priorities, whether passive or active, such as environmental and system-level component safety considerations, when implementing the system in the stakeholder given site. Equilibrium: We have to also manage balance among the project's different aspects and organize it properly. Study design: Study design is a framework, or a set of methods and procedures, for collecting and analyzing data on variables stated in a specific research problem. In this case, we must adhere to the designated system model design and data to build the system. Stakeholder and community engagement: We must also examine stakeholder and community involvement in the project, as well as how the initiative will influence both sectors. Balance between risk and benefits: In order to create an ideal system, we must examine all risk considerations in relation to the benefits.
Implementation phase	Autonomy and informed consent: While designing the system, we must also take into account the ethical considerations of system autonomy and stakeholders' demands. Privacy and confidentiality: With the approval of the stakeholder, we will also safeguard the privacy and confidentiality of the stakeholder as a top priority. Standard of care: We will also provide a high level of care to all parts of the project while it is being developed as well as after it has been completed. Ancillary care:

	Ancillary care refers to a wide range of diagnostic and support services supplied to assist workers in their tasks; in this case, we shall prioritize this ethical aspect. Community health system and empowerment: We will evaluate the community's ethical means of determining what impacts the solar home system has on this sector, as well as the ethical aspect of health empowerment.
Post-research phase	Dissemination of research findings: The dissemination of research findings is an important part of the research process since it allows other researchers, professionals, and the general public to benefit from it. We'll also share what we've learned and discovered along with the project. Data ownership: We will also take into account the ethical considerations of data ownership both during and after the project's implementation. Translating findings into public health action: We must consider public health factors while designing system designs, and we must also inform stakeholders of any safety consequences that have been ethically examined to offer them moral faith in the system's safety considerations after implementation. Scalability and sustainability: To ensure optimal scalability and sustainability, we will take all necessary steps once the solar home system is installed to ensure that the system has the fewest possible system failures and issues. Benefits sharing: Benefit-sharing is the practice of giving a portion of the benefits/profits obtained from the use of genetic resources or traditional knowledge to resource producers. This ethical concern will also be taken into account.

9.4 Conclusion

Engineering projects are planned by keeping ethical issues in mind. It is necessary to have an understanding of whether a project will be able to maintain ethical and professional integrity. Researchers and engineers are mainly guided by some set of rules and principals. As a part of our proposal of an optimized bifacial solar home system which is grid connected and specialized with single axis tracking system, we have planned ethical considerations accordingly. These ethical factors are distributed over the whole project validation time and post research time. We are planning to meet up energy demand of an ideal urban home by our proposed solar system so urban area people's responsiveness to local needs and their priorities is our first and foremost thing to consider. Bifacial solar home system is not that much known to people that is why this issue is our main ethical consideration in our planning phase. Moreover, balancing our project's different aspects, risks and benefits and stakeholder and community engagement are another some crucial factors which we are also regarding in our planning phase. On other hand, when we were implementing our system, we had to take into account some other important ethical factors such as autonomy and informed consent, privacy and confidentiality, standard of care, ancillary care and community health system and empowerment. We have ensured the support and diagnostic services provided to workers in the course of their duties while implementing our system. Stakeholder approval, their privacy and confidentiality was maintained properly. Though we were working with solar energy system we had to ensure the environmental and community health safety. Our system will not only provide more energy but also reduce the environmental pollution without emitting greenhouse gas and carbon. Besides, we have also set some rules for future research phase. Since we are proposing this system for our final year design project and we hope our system will need future research more to modify its efficiency, we will need these rules to guide in future. Dissemination of our research findings will allow other researchers to get benefitted from our project along with us. Data ownership of our project and translating our project findings into public health action will also be considered ensuring professional integrity. Scalability and sustainability of this system is the most cherished ethical factor to be considered. As long as we maintain this factor, we expect our project will benefit others surely. Lastly, ethical considerations not only help to guide in research but also balances the project accordingly.

Chapter 10: Conclusion and Future Work

10.1 Project summary

10.1.1 Simulation summary

As we have compared all the designs and proved that design 3 is the best among all the highlights of design 3 are.

TABLE XXXI. DESIGN SUMMARY

Bifacial PV panel-based hybrid system yearly basis	**Design3**
Results overview Produced energy = 2180 KW-h/year Used energy = 1171 KW-h/ year Performance ratio = 82% From the Sankey diagram, we can see that, 1162 KW-h energy is being used by the user and out of which 23.9% is being stored. 939 KW-h energy is being injected to the grid 9 KW-h is being drawn from the grid	***Financial summary*** Installation costs = **95** Tk/ Wp Total yearly cost = **3** Tk/ Wp/ year Cost of produced energy = **5** Tk/KW-h Payback period = **5.8** years

<u>CO2 emission balance</u>

Total = 28.9 tCO2

<u>Generated emissions:</u>

Total = 3.56 tCO_2

<u>Replaced Emissions:</u>

Total = 37.4 tCO_2

System production = 2135.42 KW-h/ year

Grid lifecycle emissions = 584 gCO_2/ KW-h (country: Bangladesh)

Lifetime = 30 years

Annual degradation = 1.0%

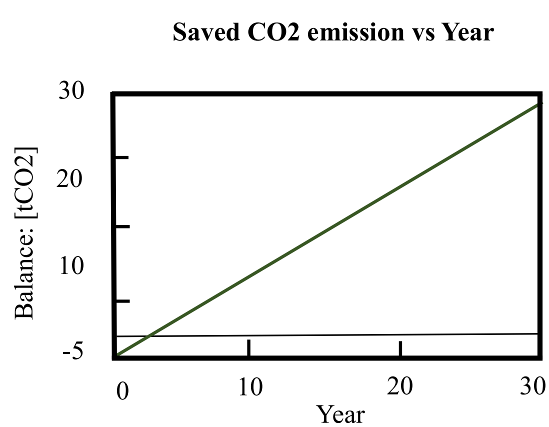


Fig. 85. Saved CO2 Emission vs. Time

In the above fig 86, the saved carbon emission vs time graph can be seen. The graph is quite self-explanatory as it shows how much of carbon emission is saved over a period of time. As we can observe, as the time increases the carbon emission saved is also increasing which makes the project more environment friendly. Over the period of 30 years, around $37.4tCO_2$ emission is saved.

System lifecycle emissions details

TABLE XXXII. SYSTEM'S LIFECYCLE CO2 EMISSION

Item	Least carbon emission (LCE)	Quantity	Subtotal [KgCO_2]
Modules	1713 kgCO_2/ KW-p	1.4 KW-p	2398
Supports	3.9 kgCO_2/ Kg	200kg	799
Inverters	386 kgCO_2/units	1.00 units	386

In the above table XXXI, the carbon emission of different components of the project is shown. To start with, from the modules, the least carbon emission is 1713kgCO_2 and the quantity of the modules is 1.4KW-p. Therefore, the total carbon emission from the modules, reaches to 2398kgCO_2. Furthermore, from the supports and other materials the carbon emission is 3.9kgCO2/kg. The quantity of the supports is 200kg which makes the total carbon emission to 799kgCO_2. Towards the end, the inverter also emits a good amount of carbon which is 386kgCO_2/unit. As the number of the inverter is only one, then the total carbon emission is 386kgCO_2. Therefore, the total carbon emission is shown which stands at 3583kgCO_2.

10.1.2 Prototype summary

TABLE XXXIII. TOTAL POWER GENERATION FROM THE PROTOTYPE SYSTEM

	Bifacial power (W)	Monofacial power (W)
day 1	11664.91	4251.571879
day 2	12692.41	4362.004879
day 3	12247.16	4311.851879
day 4	10959.36	3694.388879
day 5	9844.36	3881.307879
day 6	11890.02	5068.051879
day 7	13736.53	6599.571879
day 8	11958.52	4903.621879
day 9	12555.41	4255.681879
day 10	13719.91	4594.071879
day 11	13308.91	4267.326879
day 12	11205.96	3411.455879
day 13	12897.91	6991.571879
day 14	13651.41	4559.821879
day 15	12266.77	5503.571879
day 16	11958.52	4903.621879
day 17	11958.52	4903.621879
day 18	13651.41	4559.821879
day 19	13736.53	6599.571879
day 20	11205.96	3411.455879
day 21	11890.02	5068.051879
day 22	9844.36	3881.307879
day 23	10959.36	3694.388879
day 24	12247.16	4311.851879

day 25	12692.41	4362.004879
day 26	11664.91	4251.571879
day 27	12266.77	5503.571879
day 28	13736.53	6599.571879
day 29	10959.36	3694.388879
day 30	12692.41	4362.004879
total	**366063.78**	**140762.6814**

Bifacial and monofacial PV panel produced 366.06373 KW and 140.76268 KW energy over the span of 30-day data collection period. Bifacial PV panel produced 225.30105 KW extra energy for this period.

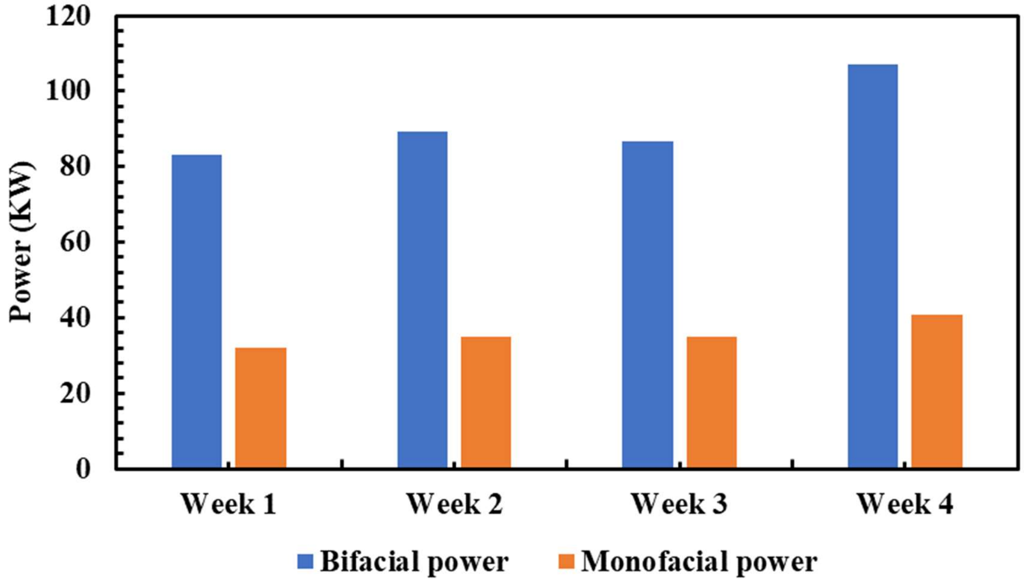


Fig. 86. Weekly energy generation of the protype system [one month period]

Fid. 87, illustrates weekly energy variation for both bifacial and monofacial PV panel. Also, it was found that bifacial PV panel consistently produced around 55.8153 KW extra energy per week compared to monofacial PV panel.

TABLE XXXIV. PROTOTYPE SUMMARY

	Bifacial PV panel	**Monofacial PV panel**
Power production rate	17.8133 watt/minute	6.8497 watt/minute
Daily power	12.202 KW	4.692 KW
Daily energy	3957.72969 KWh	1406.928638 KWh
Energy efficiency	53.979% per day	34.248% perday

10.2 Future work

The data sets that were collected for this protype system, which span within a 30day period of roughly 686 data point for each parameter per day can be used for a different purpose as a future work. For example, with the help of these data sets that were collected in this protype system, can be used to make a machine learning algorithm and predict the power of bifacial PV panel using the weather parameters that was collected in this protype as an input for the machine learning algorithm. A regression-based machine learning algorithm can be developed to predict the energy output of Bifacial PV panel.

Chapter 11: Identification of Complex Engineering Problems and Activities

11.1 Attributes of Complex Engineering Problems (EP)

	Attributes	Put tick (√) as appropriate	Description
P1	Depth of knowledge required	√	Depth knowledge of the software, knowledge about MOSFET, Buck Converter, Boost Converter, Inverter etc.
P2	Range of conflicting requirements	x	No range of conflicting requirements.
P3	Depth of analysis required	√	Depth analysis about Bifacial Panel, also the analysis of comparison mono facial and bifacial panel.
P4	Familiarity of issues	√	Unavailability of Bifacial panels in Bangladesh.
P5	Extent of applicable codes	√	We will follow the applicable codes that are mentioned in the project proposal.
P6	Extent of stakeholder involvement and needs	√	Government can be the biggest stakeholder of our project as it is producing renewable energy.
P7	Interdependence	√	All of our design approaches have coherence among themselves.

11.2 Reasoning how the project address selected attribute (EP)

The table at the top shows the different Attributes of Complex Engineering Problems that are present in our project. We have used our engineering knowledge about transistors, different types of converters, inverters etc. to configure and design them, using all kinds of engineering software tools to simulate and test them. For complex engineering problems and solutions, we have performed in-depth analysis and comparison on the efficiency of bifacial and mono-facial PV panels. The biggest issue in our project is the unavailability of Bifacial panels in Bangladesh's market, so due to budget constrain, we got creative and build a Bifacial panel using two mono-facial panels. We have strictly followed and respected the applicable codes while working on our project that are mentioned in the project proposal. Since we are working on a system that is emission free, the government could support us by investing in our proposal. All the design approaches that we have introduced could relate and resemble each other in system level as all of the designs provide the same functional outcomes, however performing in different ways from each other. Our project has no range of conflicting requirements.

11.3 Attributes of Complex Engineering Activities (EA)

	Attributes	Put tick (√) as appropriate	Description
A1	Range of resource	√	Inverter, battery bank, Bifacial PV panel, PVsyst, MATLAB Simulink, Grid connection etc.
A2	Level of interaction	√	Without high level of interaction and communication between us it will be hard to complete the project.
A3	Innovation	x	As far as we have progressed, we are not sure that our project has innovation.
A4	Consequences for society and the environment	√	There are many positive consequences and a few negative consequences. To name a positive consequence the project will provide self-dependent energy. No harm to environment as our project's goal is zero emission.
A5	Familiarity	√	Need to be acquainted with all the component such as Bifacial PV panel, Simulink, PVsyst, inverter, battery bank etc

11.4 Reasoning how the project address selected attribute (EA)

The table above is about the Attributes of Complex Engineering Activities that we have to followed while working on our project, such as range of resources, level of interaction, consequences for society and the environment and familiarity. We have put a cross mark on the innovation because as far we have progressed, we have studied many research papers, journals and reports related to our work that have been previously written and then design our system based on the ideas we have collected from those sources and implemented that in our project. Varieties of components and items such as inverter, battery bank, Bifacial PV panel and other hardware tools were used in the designing phase along with the computer simulation software for example, PVsyst, MATLAB Simulink, Grid connection. Communication and interaction among the members of the group was present till the end of the project for discussing and planning about the progression of project. We have also discussed problems related to our work with experienced technicians so that they can give their valuable feedbacks to us. There are both numerous beneficial effects and a few unfavorable ones. The project will offer independent energy, to mention one benefit. Our project aims for zero emissions, therefore there is no harm to the environment. Knowledge of every component is required, including Bifacial PV panels, Simulink, PVsyst, inverters, battery banks, etc.

References

[1] "International Technology Roadmap for Photovoltaic (ITRPV) - vdma.org - VDMA." https://www.vdma.org/international-technology-roadmap-photovoltaic (accessed Sep. 22, 2022).

[2] "LCOE of Monofacial vs Bifacial Modules: Are Bifacials Worth the Extra Cost? — Clean Energy Associates." https://www.cea3.com/cea-blog/lcoe-of-monofacial-vs-bifacial-modules-are-bifacials-worth-the-extra-cost (accessed Oct. 15, 2022).

[3] M. A. Hossain Mondal, "Economic viability of solar home systems: Case study of Bangladesh," *Renew Energy*, vol. 35, no. 6, pp. 1125–1129, Jun. 2010, doi: 10.1016/J.RENENE.2009.10.038.

[4] H. M. Fahad, A. Islam, M. Islam, M. F. Hasan, W. F. Brishty, and M. M. Rahman, "Comparative analysis of dual and single axis solar tracking system considering cloud cover," *International Conference on Energy and Power Engineering: Power for Progress, ICEPE 2019*, Mar. 2019, doi: 10.1109/CEPE.2019.8726646.

[5] O. López-Lapeña, M. T. Penella, and M. Gasulla, "A closed-loop maximum power point tracker for subwatt photovoltaic panels," *IEEE Transactions on Industrial Electronics*, vol. 59, no. 3, pp. 1588–1596, Mar. 2012, doi: 10.1109/TIE.2011.2161254.

[6] K. Barbosa de Melo, M. Kitayama da Silva, J. Lucas de Souza Silva, T. S. Costa, and M. G. Villalva, "Study of energy improvement with the insertion of bifacial modules and solar trackers in photovoltaic installations in Brazil," *Renewable Energy Focus*, vol. 41, pp. 179–187, Jun. 2022, doi: 10.1016/J.REF.2022.02.005.

[7] O. Ayadi, R. Shadid, A. Bani-Abdullah, M. Alrbai, M. Abu-Mualla, and N. A. Balah, "Experimental comparison between Monocrystalline, Polycrystalline, and Thin-film solar systems under sunny climatic conditions," *Energy Reports*, vol. 8, pp. 218–230, Nov. 2022, doi: 10.1016/J.EGYR.2022.06.121.

[8] G. Raina and S. Sinha, "A simulation study to evaluate and compare monofacial Vs bifacial PERC PV cells and the effect of albedo on bifacial performance," *undefined*, vol. 46, pp. 5242–5247, 2020, doi: 10.1016/J.MATPR.2020.08.632.

[9] A. A. Widayat, S. Ma'arif, K. D. Syahindra, A. F. Fauzi, and E. Adhi Setiawan, "Comparison and Optimization of Floating Bifacial and Monofacial Solar PV System in a Tropical Region," *2020 9th International Conference on Power Science and Engineering, ICPSE 2020*, pp. 66–70, Oct. 2020, doi: 10.1109/ICPSE51196.2020.9354374.

[10] C. D. Rodríguez-Gallegos, M. Bieri, O. Gandhi, J. P. Singh, T. Reindl, and S. K. Panda, "Monofacial vs bifacial Si-based PV modules: Which one is more cost-effective?," *Solar Energy*, vol. 176, pp. 412–438, Dec. 2018, doi: 10.1016/J.SOLENER.2018.10.012.

[11] H. P. Yin *et al.*, "Optical enhanced effects on the electrical performance and energy yield of bifacial PV modules," *Solar Energy*, vol. 217, pp. 245–252, Mar. 2021, doi: 10.1016/J.SOLENER.2021.02.004.

[12] A. Fudholi, M. Mustapha, I. Taslim, F. Aliyah, A. G. Koto, and K. Sopian, "Photovoltaic thermal (PVT) air collector with monofacial and bifacial solar cells: A review," *International Journal of Power Electronics and Drive Systems*, vol. 10, no. 4, pp. 2021–2028, Dec. 2019, doi: 10.11591/IJPEDS.V10.I4.2021-2028.

[13] N. S. Nazri *et al.*, "Energy economic analysis of photovoltaic–thermal-thermoelectric (PVT-TE) air collectors," *Renewable and Sustainable Energy Reviews*, vol. 92, pp. 187–197, Sep. 2018, doi: 10.1016/J.RSER.2018.04.061.

[14] M. Mustapha, A. Fudholi, C. H. Yen, M. H. Ruslan, and K. Sopian, "Review on Energy and Exergy Analysis of Air and Water Based Photovoltaic Thermal (PVT) Collector," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 9, no. 3, pp. 1367–1373, Sep. 2018, doi: 10.11591/IJPEDS.V9.I3.PP1367-1373.

[15] N. S. Nazri, A. Fudholi, M. H. Ruslan, and K. Sopian, "Mathematical modeling of photovoltaic thermal-thermoelectric (PVT-TE) air collector," *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 2, pp. 795–802, Jun. 2018, doi: 10.11591/IJPEDS.V9N2.PP795-802.

[16] N. S. Nazri, A. Fudholi, M. H. Ruslan, and K. Sopian, "Experimental Study of Photovoltaic Thermal-Thermoelectric (PVT-TE) Air Collector," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 9, no. 3, p. 1390, Sep. 2018, doi: 10.11591/IJPEDS.V9.I3.PP1390-1396.

[17] M. Zohri, N. Nurato, and A. Fudholi, "Photovoltaic Thermal (PVT) System with and Without Fins Collector: Theoretical Approach," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 8, no. 4, pp. 1756–1763, Dec. 2017, doi: 10.11591/IJPEDS.V8.I4.PP1756-1763.

[18] M. Zohri, Nurato, L. D. Bakti, and A. Fudholi, "Exergy Assessment of Photovoltaic Thermal with V-groove Collector Using Theoretical study," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 16, no. 2, pp. 550–557, Apr. 2018, doi: 10.12928/TELKOMNIKA.V16I2.8433.

[19] A. Fudholi and K. Sopian, "R&D of photovoltaic thermal (PVT) systems: An overview," *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 2, pp. 803–810, Jun. 2018, doi: 10.11591/IJPEDS.V9N2.PP803-810.

[20] "Collector efficiency of the double-pass solar air collectors with fins | Proceedings of the 9th WSEAS international conference on System science and simulation in engineering." https://dl.acm.org/doi/10.5555/1938907.1938978 (accessed Oct. 15, 2022).

[21] W. Muehleisen *et al.*, "Energy yield measurement of an elevated PV system on a white flat roof and a performance comparison of monofacial and bifacial modules," *Renew Energy*, vol. 170, pp. 613–619, Jun. 2021, doi: 10.1016/J.RENENE.2021.02.015.

[22] S. Bouguerra, M. R. Yaiche, A. Sangwongwanich, F. Blaabjerg, and E. Liivik, "Reliability Analysis and Energy Yield of String-Inverter Considering Monofacial and Bifacial Photovoltaic Panels," *2020 IEEE 11th International Symposium on Power Electronics for Distributed Generation Systems, PEDG 2020*, pp. 199–204, Sep. 2020, doi: 10.1109/PEDG48541.2020.9244425.

[23] W. Muehleisen *et al.*, "Energy yield measurement of an elevated PV system on a white flat roof and a performance comparison of monofacial and bifacial modules," *Renew Energy*, vol. 170, pp. 613–619, Jun. 2021, doi: 10.1016/j.renene.2021.02.015.

[24] "Bifacial Versus Monofacial Solar Panels: An Analysis – Bluestem." https://www.bluestemenergysolutions.com/bifacial-versus-monofacial-solar-panels-an-analysis/ (accessed Oct. 15, 2022).

[25] H. D. M. R. Perera and H. Wen, "Power generation and performance analysis of Bi-facial vs Mono-facial 10KW Photovoltaic power station," *2019 18th International Conference on Optical Communications and Networks, ICOCN 2019*, Aug. 2019, doi: 10.1109/ICOCN.2019.8934305.

[26] T. Katsaounis *et al.*, "Performance assessment of bifacial c-Si PV modules through device simulations and outdoor measurements," *Renew Energy*, vol. 143, pp. 1285–1298, Dec. 2019, doi: 10.1016/J.RENENE.2019.05.057.

[27] G. M. Tina, F. B. Scavo, S. Aneli, and A. Gagliano, "Assessment of the electrical and thermal performances of building integrated bifacial photovoltaic modules," *J Clean Prod*, vol. 313, p. 127906, Sep. 2021, doi: 10.1016/J.JCLEPRO.2021.127906.

[28] "Bifacial modules: The challenges and advantages – pv magazine International." https://www.pv-magazine.com/2020/08/19/bifacial-modules-the-challenges-and-advantages/ (accessed Oct. 17, 2022).

[29] "Bifacial Solar Market- Industry Analysis and Forecast (2022-2027)." https://www.maximizemarketresearch.com/market-report/bifacial-solar-market/147787/ (accessed Oct. 17, 2022).

[30] "Are Bifacial Solar Panels Worth It? Monofacial Vs. Bifacial Solar Cell." https://www.loomsolar.com/blogs/collections/bifacial-solar-panels (accessed Oct. 17, 2022).

[31] "Bifacial Solar Panels: Innovative, Eye-Catching, and Best of All, More Efficient." https://www.solarreviews.com/blog/bifacial-solar-panels (accessed Oct. 17, 2022).

Appendix

I. Arduino mega and ESP8266 connections

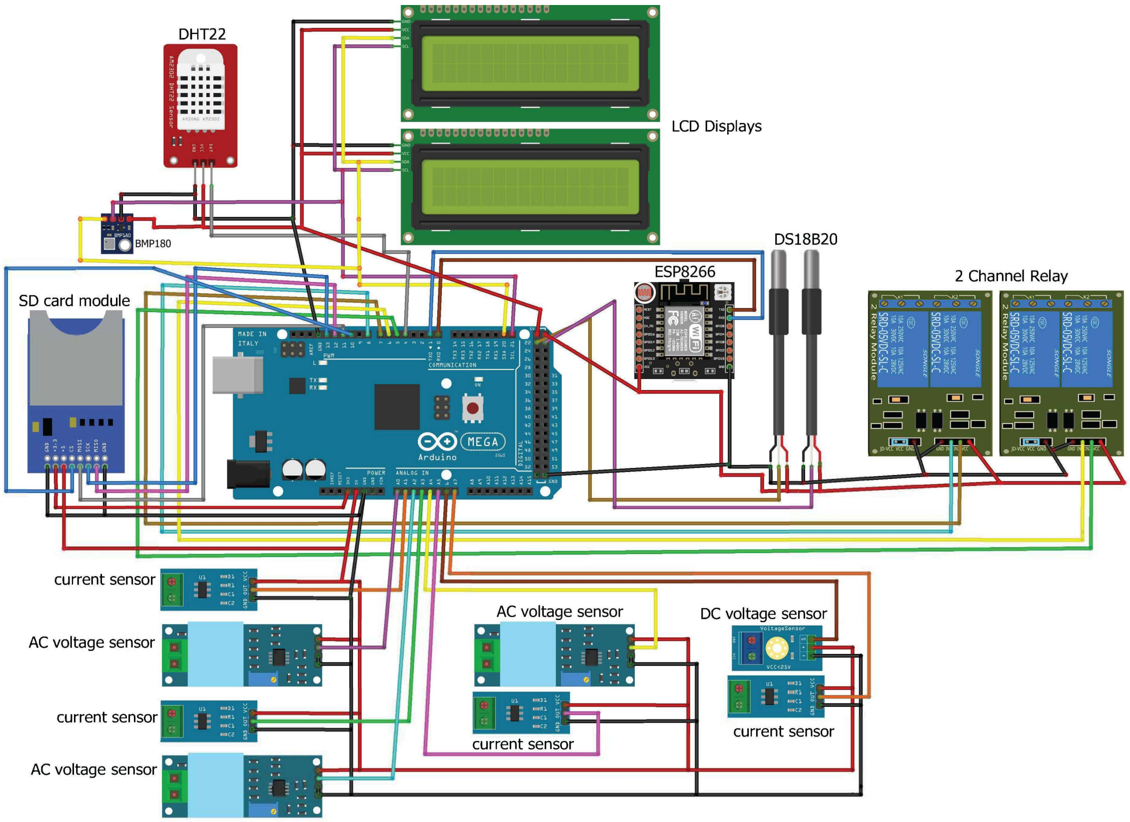


Fig. 87. Arduino mega and ESP8266 port connections

II. Arduino mega and ESP8266 code

Arduino mega code

```
#include <LiquidCrystal_I2C.h>
#include <PZEM004Tv30.h>                    // PZEM004Tv3 library
#include "TanvirLib.h"            // Include Tanvir Library
#include "DHT.h"
#include <SFE_BMP180.h>
#include <Wire.h>
#include <DS3232RTC.h>
#include <Streaming.h>
#include <SPI.h>
#include <SD.h>
#include <OneWire.h>
#include <DallasTemperature.h>
#include <Robojax_AllegroACS_Current_Sensor.h>

const int VIN      = A5; // define the Arduino pin A0 as voltage input (V in)
const float VCC    = 5;// supply voltage
const int MODEL    = 0;    // enter the model (see above list)
const int VIN1     = A7; // define the Arduino pin A0 as voltage input (V in)

Robojax_AllegroACS_Current_Sensor robojax(MODEL, VIN);
Robojax_AllegroACS_Current_Sensor robojax1(MODEL, VIN1);

#define ONE_WIRE_BUS 2
#define ONE_WIRE_BUS1 3
```

```
OneWire oneWire(ONE_WIRE_BUS);
OneWire oneWire1(ONE_WIRE_BUS1);

DallasTemperature sensors(&oneWire);
DallasTemperature sensors1(&oneWire1);

DS3232RTC myRTC;
SFE_BMP180 pressure;
File myFile;

#define ALTITUDE 943.7 // Altitude of Electropeak Co. in meters
#define VOLT_CAL 420

EnergyMonitor Tanvir1;              // Create an instance
EnergyMonitor Tanvir2;              // Create an instance
EnergyMonitor Tanvir3;              // Create an instance
LiquidCrystal_I2C lcd(0x27, 16, 2);
LiquidCrystal_I2C lcd1(0x26, 16, 2);

#define DHTPIN 8
#define DHTTYPE DHT22
#define vCal 1.006                            // voltage calibration coefficient(dafault=1.0)
#define iCal 0.9205                           // current calibration coefficient(dafault=1.0)

#define pzemRX   12                            // recieve data (connect to PZEM TX)
#define pzemTX   13                            // send data    (connect to PZEM RX)

DHT dht(DHTPIN, DHTTYPE);
PZEM004Tv30 pzem(pzemRX, pzemTX);             // Pin11 to TX, Pin12 to RX

unsigned int rangeTable[8] = {1, 2, 5, 10, 30, 60, 120, 300}; // time Inerval Table
int rangeNumber;
int timeToLog;
int previousMillis = 0;
int pp = 0;

float II, III;
float Vx, Ax, VAx, Wx, kWhx, PFx, Hzx, VARx; // measured value
char buff[8];                                 // character format buffer
unsigned int logInterval;                     // log interval

const int sensorIn = A0;
int mVperAmp = 66; // use 100 for 20A Modulec, 66 for 30A Module and 185  for 05A Module

double Voltage = 0;
double VRMS = 0;
double AmpsRMS = 0;
int supplyVoltage;

const int sensorIn1 = A2;
int mVperAmp1 = 66; // use 100 for 20A Modulec, 66 for 30A Module and 185  for 05A Module

double Voltage1 = 0;
double VRMS1 = 0;
double AmpsRMS1 = 0;
int supplyVoltage1, qqqq = 0;

const int sensorIn2 = A9;
int mVperAmp2 = 66; // use 100 for 20A Modulec, 66 for 30A Module and 185  for 05A Module

#define VOLT_CAL1 420
double Voltage2 = 0;
double VRMS2 = 0;
double AmpsRMS2 = 0;
int supplyVoltage2;
String Y, M, D, H, MM, S;

#define RELAY1_PIN 4
#define RELAY2_PIN 5
#define RELAY3_PIN 6
#define RELAY4_PIN 7

#define ANALOG_IN_PIN A4
#define ANALOG_IN_PIN1 A6
```

```
float adc_voltage = 0.0, adc_voltage1 = 0.0;
float in_voltage = 0.0, in_voltage1 = 0.0;
float R1 = 30000.0;
float R2 = 7500.0;
float ref_voltage = 5.0;
int adc_value = 0, adc_value1 = 0, asd = 0;
float Power_IN = 0, Power_OUT = 0;
float Power_S1 = 0, Power_S2 = 0;
float tempC , tempC1;
float pressure1, hh, tt;

void setup() {
  Serial.begin(9600);
  Serial1.begin(9600);
  pinMode(RELAY1_PIN, OUTPUT);
  pinMode(RELAY2_PIN, OUTPUT);
  pinMode(RELAY3_PIN, OUTPUT);
  pinMode(RELAY4_PIN, OUTPUT);

  digitalWrite(RELAY1_PIN, HIGH);
  digitalWrite(RELAY2_PIN, HIGH);
  digitalWrite(RELAY3_PIN, HIGH);
  digitalWrite(RELAY4_PIN, HIGH);

  lcd.init();
  lcd.backlight();
  lcd1.init();
  lcd1.backlight();

  rangeNumber = 4;
  if (rangeNumber > 7) {                         // abnormal range number will be
    rangeNumber = 0;                             // set to 0
  }
  logInterval = rangeTable[rangeNumber];

  dht.begin();
  Tanvir1.voltage(1, VOLT_CAL, 1.7);  // Voltage: input pin, calibration, phase_shift
  Tanvir2.voltage(3, VOLT_CAL, 1.7);  // Voltage: input pin, calibration, phase_shift
  Tanvir3.voltage(8, VOLT_CAL1, 1.7);  // Voltage: input pin, calibration, phase_shift

  if (pressure.begin())
    Serial.println("BMP180 init success");
  else
  {
    Serial.println("BMP180 init fail\n\n");
    Serial.println("Check connection");
    //    while (1);
  }
  myRTC.begin();
  setSyncProvider(myRTC.get);
  if (!SD.begin(53)) {
    Serial.println("initialization failed!");
  }

  sensors.begin();
  sensors1.begin();

  Serial.println();                              // start message
  Serial.println(F(" , PZEM-004V3 Power meter start V0.5"));
  Serial.println(F(" , sec, V(rms), I(rms), VA, W, PF, kWh, Hz, DI, DV"));
  Serial.flush();

  measure();                                     // get value from PZEM-004Tv3
  logPrint();                                    // data out serial port
}

void loop() {
  if ((Wx >= 9 || supplyVoltage2 < 50) && supplyVoltage > 180) {
    qqqq = 0;
    digitalWrite(RELAY1_PIN, LOW);
    digitalWrite(RELAY2_PIN, LOW);
    digitalWrite(RELAY3_PIN, HIGH);
    digitalWrite(RELAY4_PIN, HIGH);
  }
```

```
  else if (Wx < 4.5) {
    qqqq = 1;
    digitalWrite(RELAY1_PIN, HIGH);
    digitalWrite(RELAY2_PIN, HIGH);
    digitalWrite(RELAY3_PIN, LOW);
    digitalWrite(RELAY4_PIN, LOW);
  }
  else {
    qqqq = 2;
    digitalWrite(RELAY1_PIN, HIGH);
    digitalWrite(RELAY2_PIN, HIGH);
    digitalWrite(RELAY3_PIN, HIGH);
    digitalWrite(RELAY4_PIN, HIGH);
  }
  measure();                                    // get value from PZEM-004Tv3
  unsigned long currentMillis = millis();

  if (currentMillis - previousMillis >= 1000) {
    previousMillis = currentMillis;
    if (pp >= logInterval) {
      pp = 0;
      logPrint();
      Serial.println();
    }
    else {
      lcd.setCursor(0, 0);
      lcd.print("V:");
      lcd.print(Vx, 1);
      lcd.print(",I:");
      lcd.print(Ax, 3);
      lcd.print("         ");
      lcd.setCursor(0, 1);
      lcd.print("Power :");
      lcd.print(Wx, 3);
      lcd.print("             ");

      if (qqqq == 0) {
        Power_OUT = 0;
        lcd1.setCursor(0, 0);
        lcd1.print("P_IN =");
        lcd1.print(Power_IN);
        lcd1.print("        ");
        lcd1.setCursor(0, 1);
        lcd1.print("P_OUT=");
        lcd1.print(Power_OUT);
        lcd1.print("        ");
      }
      if (qqqq == 1) {
        Power_IN = 0;
        lcd1.setCursor(0, 0);
        lcd1.print("P_IN =");
        lcd1.print(Power_IN);
        lcd1.print("        ");
        lcd1.setCursor(0, 1);
        lcd1.print("P_OUT=");
        lcd1.print(Power_OUT);
        lcd1.print("        ");
      }
      if (qqqq == 2) {
        Power_IN = 0;
        Power_OUT = 0;
        lcd1.setCursor(0, 0);
        lcd1.print("P_IN =");
        lcd1.print(Power_IN);
        lcd1.print("        ");
        lcd1.setCursor(0, 1);
        lcd1.print("P_OUT=");
        lcd1.print(Power_OUT);
        lcd1.print("        ");
      }
      pp++;
    }
  }
}            // end of loop
```

```
void measure() {
  getpf();
  getpf1();
  getpf2();
  sensors.requestTemperatures();
  tempC = sensors.getTempCByIndex(0);
  sensors1.requestTemperatures();
  tempC1 = sensors1.getTempCByIndex(0);
  pressure1 = readPressure();

  hh = dht.readHumidity();
  tt = dht.readTemperature();

  if (isnan(hh) || isnan(tt)) {
    hh = 0;
    tt = 0;
  }

  adc_value = analogRead(ANALOG_IN_PIN);
  adc_voltage  = (adc_value * ref_voltage) / 1024.0;
  in_voltage = adc_voltage / (R2 / (R1 + R2)) ;

  II = robojax.getCurrentAverage(300);
  II = (II * 2);

  if (in_voltage < 2.50) {
    in_voltage = 0;
    II = 0;
  }

  Power_S1 = (in_voltage * II);

  adc_value1 = analogRead(ANALOG_IN_PIN1);
  adc_voltage1  = (adc_value1 * ref_voltage) / 1024.0;
  in_voltage1 = adc_voltage1 / (R2 / (R1 + R2)) ;

  III = robojax1.getCurrentAverage(300);
  III = (III * 2.5);
  if (in_voltage1 < 2.50) {
    in_voltage1 = 0;
    III =  0;
  }

  Power_S2 = (in_voltage1 * III);

  Vx = vCal * supplyVoltage2;                // voltage(apply calibration correction)
  Ax = iCal * AmpsRMS2;                // current(apply calibration correction)
  VAx = Vx * Ax;                             // calculate apparent power
  Wx = ((VAx ) / 18.732);          // effective power(Use the value after calibration correction)
  PFx = 0;                              // power factor
  kWhx = Wx / 1000;        // sum of energy(Use the value after calibration correction)
  Hzx = 50;                    // line frequency

  if (Vx >= 0) {
    asd = 1;
  }
  else {
    asd = 0;
  }
  printTime();
}

void logPrint() {                               // serial out for log
  static long t = 0;
  Serial.print(F(" , "));                       // this for the separator for terminal software
timestamp text
  Serial.print(t); Serial.print(F(", "));       // time in second
  Serial.print(Vx, 1); Serial.print(F(", "));   // voltage
  Serial.print(Ax, 3); Serial.print(F(", "));   // current amps
  Serial.print(VAx, 2); Serial.print(F(", "));  // VA value
  Serial.print(Wx, 1); Serial.print(F(", "));   // wattage
  Serial.print(PFx, 2); Serial.print(F(", "));  // powewr factor
  Serial.print(kWhx, 3); Serial.print(F(", ")); // totall energy
```

```
  Serial.print(Hzx, 1);  Serial.print(F(", ")); // frequency
  Serial.print(II, 3); Serial.print(F(", "));   // DC current
  Serial.print(in_voltage, 2);                            // voltage
  Serial.println();
  t += logInterval;                            // increment accumurate time

  String sms = "#" + String(Vx, 1) + "@" + String(Ax, 3) + "@" + String(VAx, 2) + "@" + String(Wx, 1)
+ "@" + String(PFx, 2) + "@" + String(kWhx, 3) + "@" + String(Hzx, 1) + "@" + String(pressure1) + "@"
+ String(hh) + "@" + String(tt) + "@" + String(Power_IN) + "@" + String(supplyVoltage) + "@" +
String(AmpsRMS) + "@" + String(Power_OUT) + "@" + String(supplyVoltage1) + "@" + String(AmpsRMS1) +
"@" + String(Power_S1) + "@" + String(in_voltage) + "@" + String(II) + "@" + String(tempC) + "@" +
String(Power_S2) + "@" + String(in_voltage1) + "@" + String(III) + "@" + String(tempC1) + "*";
  Serial1.println(sms);
  if (Vx >= 0) {
    Serial.println(sms);
  }
}

void getpf()
{
  Tanvir1.calcVI(25, 1000);        // Calculate all. No.of half wavelengths (crossings), time-out

  supplyVoltage   = Tanvir1.Vrms;             //extract Vrms into Variable

  Voltage = getVPP();
  VRMS = (Voltage / 2.0) * 0.707; //root 2 is 0.707
  AmpsRMS = (VRMS * 1000) / mVperAmp;
  if (supplyVoltage < 150)
  {
    supplyVoltage = 0;
    AmpsRMS = 0;
  }
  Power_IN = ((supplyVoltage * AmpsRMS) / 18.732);
}


float getVPP()
{
  float result;
  int readValue;
  int maxValue = 0;
  int minValue = 1024;

  uint32_t start_time = millis();
  while ((millis() - start_time) < 500)
  {
    readValue = analogRead(sensorIn);
    if (readValue > maxValue)
    {
      maxValue = readValue;
    }
    if (readValue < minValue)
    {
      minValue = readValue;
    }
  }
  result = ((maxValue - minValue) * 5.0) / 1024.0;
  return result;
}

void getpf1()
{
  Tanvir2.calcVI(25, 1000);        // Calculate all. No.of half wavelengths (crossings), time-out

  supplyVoltage1   = Tanvir2.Vrms;             //extract Vrms into Variable

  Voltage1 = getVPP1();
  VRMS1 = (Voltage1 / 2.0) * 0.707; //root 2 is 0.707
  AmpsRMS1 = (VRMS1 * 1000) / mVperAmp1;
  if (supplyVoltage1 < 150)
  {
    supplyVoltage1 = 0;
    AmpsRMS1 = 0;
  }
```

```
  Power_OUT = ((supplyVoltage1 * AmpsRMS1) / 18.732);
}


float getVPP1()
{
  float result;
  int readValue;
  int maxValue = 0;
  int minValue = 1024;

  uint32_t start_time = millis();
  while ((millis() - start_time) < 500)
  {
    readValue = analogRead(sensorIn1);
    if (readValue > maxValue)
    {
      maxValue = readValue;
    }
    if (readValue < minValue)
    {
      minValue = readValue;
    }
  }
  result = ((maxValue - minValue) * 5.0) / 1024.0;
  return result;
}

void getpf2()
{
  Tanvir3.calcVI(25, 1000);        // Calculate all. No.of half wavelengths (crossings), time-out

  supplyVoltage2   = Tanvir3.Vrms;             //extract Vrms into Variable
  Serial.println(supplyVoltage2);

  Voltage2 = getVPP2();
  VRMS2 = (Voltage2 / 2.0) * 0.707; //root 2 is 0.707
  AmpsRMS2 = (VRMS2 * 1000) / mVperAmp2;
  if (supplyVoltage2 < 150)
  {
    AmpsRMS2 = 0;
    supplyVoltage2 = 0;
  }
  //  Power_OUT = (supplyVoltage1 * AmpsRMS1);
}


float getVPP2()
{
  float result;
  int readValue;
  int maxValue = 0;
  int minValue = 1024;

  uint32_t start_time = millis();
  while ((millis() - start_time) < 500)
  {
    readValue = analogRead(sensorIn2);
    if (readValue > maxValue)
    {
      maxValue = readValue;
    }
    if (readValue < minValue)
    {
      minValue = readValue;
    }
  }
  result = ((maxValue - minValue) * 5.0) / 1024.0;
  return result;
}

// print time to Serial
void printTime() {
  static time_t tLast;
```

```
  time_t t;
  tmElements_t tm;

  t = now();
  D = printI00(day(t), '-');
  M = String(monthShortStr(month(t)));
  Y = String(year(t));
  H = printI00(hour(t), ':');
  MM = printI00(minute(t), ':');
  S =  printI00(second(t), ' ');
  //  Serial << D << M << '-' << Y << ' ' << H << MM << S;
  String PPPP = D + M + "-" + Y + "," + H + MM + S + "," + String(Vx, 1) + "," + String(Ax, 3) + "," +
String(VAx, 2) + "," + String(Wx, 1) + "," + String(PFx, 2) + "," + String(kWhx, 3) + "," +
String(Hzx, 1) + "," + String(pressure1) + "," + String(hh) + "," + String(tt) + "," +
String(Power_IN) + "," + String(supplyVoltage) + "," + String(AmpsRMS) + "," + String(Power_OUT) + ","
+ String(supplyVoltage1) + "," + String(AmpsRMS1) + ", , , ," + String(Power_S1) + "," +
String(in_voltage) + "," + String(II) + "," + String(tempC) + ", , , ," + String(Power_S2) + "," +
String(in_voltage1) + "," + String(III) + "," + String(tempC1);
  myFile = SD.open("DATA.csv", FILE_WRITE);
  if (myFile) {
    Serial.print("Writing to test.txt...");
    myFile.println(PPPP);
    myFile.close();
    Serial.println("done.");
  } else {
    Serial.println("error opening test.txt");
  }
}

String printI00(int val, char delim)
{
  String ASDFP;
  if (val < 10) ASDFP = "0" + String(val) + String(delim);
  else ASDFP = String(val) + String(delim);
  return ASDFP;
}


double readPressure()
{
  char status;
  double T, P, p0, a;
  status = pressure.startTemperature();
  if (status != 0)
  {
    delay(status);
    status = pressure.getTemperature(T);
    if (status != 0)
    {
      status = pressure.startPressure(3);
      if (status != 0)
      {
        delay(status);
        status = pressure.getPressure(P, T);
        if (status != 0)
        {
          return (P);
        }
        else Serial.println("error retrieving pressure measurement\n");
      }
      else Serial.println("error starting pressure measurement\n");
    }
    else Serial.println("error retrieving temperature measurement\n");
  }
  else Serial.println("error starting temperature measurement\n");
}
```

Esp8266 code

```
#include <WiFiManager.h>


#include <WiFiClientSecure.h>
String readString;
const char* host = "script.google.com";
const int httpsPort = 443;
WiFiClientSecure client;
String GAS_ID = "AKfycbyiIKCKyUhZlUIvGkPIO0DSCKNCc8SDjy48a1LU8QO4JGe_OQS6s4mtZrXsmdryCD_I";

char* esp_ssid = "NET METER BRAC";
char* esp_pass = "1234567890";

String smss, sms, sms1, sms2, sms3, sms4, sms5, sms6, sms7, sms8, sms9, sms10, sms11, sms12, sms13,
sms14, sms15, sms16, sms17, sms18, sms19, sms20, sms21, sms22, sms23, sms24;
int temp = 0, n = 0, k = 0, asd = 0;
int j = 0, jj = 0, jjj = 0, jjjj = 0, jjjjj = 0, jjjjjj = 0, jjjjjjj = 0, jjjjjjjj = 0, jjjjjjjjj = 0,
jjjjjjjjjj = 0, jjjjjjjjjjj = 0, jjjjjjjjjjjj = 0, jjjjjjjjjjjjj = 0, jjjjjjjjjjjjjj = 0,
jjjjjjjjjjjjjjj = 0, jjjjjjjjjjjjjjjj = 0, jjjjjjjjjjjjjjjjj = 0, jjjjjjjjjjjjjjjjjj = 0,
jjjjjjjjjjjjjjjjjjj = 0, jjjjjjjjjjjjjjjjjjjj = 0, jjjjjjjjjjjjjjjjjjjjj = 0, jjjjjjjjjjjjjjjjjjjjjj =
0, jjjjjjjjjjjjjjjjjjjjjjj = 0, jjjjjjjjjjjjjjjjjjjjjjjj = 0, jjjjjjjjjjjjjjjjjjjjjjjjj = 0;
char str[700], msg[700];

const int Erasing_button = 0;

void configModeCallback (WiFiManager *myWiFiManager) {
  Serial.println(WiFi.softAPIP());
  Serial.println(myWiFiManager->getConfigPortalSSID());
}

void setup() {
  Serial.begin(9600);
  pinMode(Erasing_button, INPUT);
  pinMode(D4, OUTPUT);

  for (uint8_t t = 4; t > 0; t--) {
    digitalWrite(D4, LOW);
    delay(500);
    Serial.println(t);
    digitalWrite(D4, HIGH);
    delay(500);
  }

  // Press and hold the button to erase all the credentials
  if (digitalRead(Erasing_button) == LOW)
  {
    WiFiManager wifiManager;
    wifiManager.resetSettings();
    ESP.restart();
    delay(1000);
  }

  WiFiManager wifiManager;
  wifiManager.setAPCallback(configModeCallback);
  if (!wifiManager.autoConnect(esp_ssid, esp_pass)) {
    Serial.println("failed to connect and hit timeout");
    ESP.restart();
    delay(1000);
  }
  Serial.println("connected...yeey :)");
  digitalWrite(D4, LOW);
  client.setInsecure();
}

void loop() {
  serialEvent();
}

void serialEvent()
{
  while (Serial.available())
```

```
{
  char ch = (char)Serial.read();
  str[n++] = ch;
  if (ch == '*')
  {
    temp = 1;
    break;
  }
}
if (temp == 1)
{
  for (int i = 0; i < n; i++) {
    if (str[i] == '#') {
      j = i;
    }

    if (str[i] == '@') {
      if (asd == 0) {
        jj = i;
        asd++;
      }
      else if (asd == 1) {
        jjj = i;
        asd++;
      }
      else if (asd == 2) {
        jjjj = i;
        asd++;
      }
      else if (asd == 3) {
        jjjjj = i;
        asd++;
      }
      else if (asd == 4) {
        jjjjjj = i;
        asd++;
      }
      else if (asd == 5) {
        jjjjjjj = i;
        asd++;
      }
      else if (asd == 6) {
        jjjjjjjj = i;
        asd++;
      }
      else if (asd == 7) {
        jjjjjjjjj = i;
        asd++;
      }
      else if (asd == 8) {
        jjjjjjjjjj = i;
        asd++;
      }
      else if (asd == 9) {
        jjjjjjjjjjj = i;
        asd++;
      }
      else if (asd == 10) {
        jjjjjjjjjjjj = i;
        asd++;
      }
      else if (asd == 11) {
        jjjjjjjjjjjjj = i;
        asd++;
      }
      else if (asd == 12) {
        jjjjjjjjjjjjjj = i;
        asd++;
      }
      else if (asd == 13) {
        jjjjjjjjjjjjjjj = i;
        asd++;
      }
      else if (asd == 14) {
```

```
      jjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 15) {
      jjjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 16) {
      jjjjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 17) {
      jjjjjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 18) {
      jjjjjjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 19) {
      jjjjjjjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 20) {
      jjjjjjjjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 21) {
      jjjjjjjjjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 22) {
      jjjjjjjjjjjjjjjjjjjjjjjj = i;
      asd++;
    }
    else if (asd == 23) {
      jjjjjjjjjjjjjjjjjjjjjjjjj = i;
      asd++;
    }
  }

  if (str[i] == '*')
  {
    k = i;
    break;
  }
}
int l = 0;
sms = String(str);
sms1 = sms.substring(j + 1, jj);
sms2 = sms.substring(jj + 1, jjj);
sms3 = sms.substring(jjj + 1, jjjj);
sms4 = sms.substring(jjjj + 1, jjjjj);
sms5 = sms.substring(jjjjj + 1, jjjjjj);
sms6 = sms.substring(jjjjjj + 1, jjjjjjj);
sms7 = sms.substring(jjjjjjj + 1, jjjjjjjj);
sms8 = sms.substring(jjjjjjjj + 1, jjjjjjjjj);
sms9 = sms.substring(jjjjjjjjj + 1, jjjjjjjjjj);
sms10 = sms.substring(jjjjjjjjjj + 1, jjjjjjjjjjj);
sms11 = sms.substring(jjjjjjjjjjj + 1, jjjjjjjjjjjj);
sms12 = sms.substring(jjjjjjjjjjjj + 1, jjjjjjjjjjjjj);
sms13 = sms.substring(jjjjjjjjjjjjj + 1, jjjjjjjjjjjjjj);
sms14 = sms.substring(jjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjj);
sms15 = sms.substring(jjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjj);
sms16 = sms.substring(jjjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjjj);
sms17 = sms.substring(jjjjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjjjj);
sms18 = sms.substring(jjjjjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjjjjj);
sms19 = sms.substring(jjjjjjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjjjjjj);
sms20 = sms.substring(jjjjjjjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjjjjjjj);
sms21 = sms.substring(jjjjjjjjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjjjjjjjj);
sms22 = sms.substring(jjjjjjjjjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjjjjjjjjj);
sms23 = sms.substring(jjjjjjjjjjjjjjjjjjjjjjj + 1, jjjjjjjjjjjjjjjjjjjjjjjj);
sms24 = sms.substring(jjjjjjjjjjjjjjjjjjjjjjjj + 1, k);
temp = 0;
```

```
    n = 0;
    asd = 0;
    Serial.print(sms1);
    Serial.print("\t");
    Serial.print(sms2);
    Serial.print("\t");
    Serial.print(sms3);
    Serial.print("\t");
    Serial.print(sms4);
    Serial.print("\t");
    Serial.print(sms5);
    Serial.print("\t");
    Serial.print(sms6);
    Serial.print("\t");
    Serial.print(sms7);
    Serial.print("\t");
    Serial.print(sms8);
    Serial.print("\t");
    Serial.print(sms9);
    Serial.print("\t");
    Serial.print(sms10);
    Serial.print("\t");
    Serial.print(sms11);
    Serial.print("\t");
    Serial.print(sms12);
    Serial.print("\t");
    Serial.print(sms13);
    Serial.print("\t");
    Serial.print(sms14);
    Serial.print("\t");
    Serial.print(sms15);
    Serial.print("\t");
    Serial.print(sms16);
    Serial.print("\t");
    Serial.print(sms17);
    Serial.print("\t");
    Serial.print(sms18);
    Serial.print("\t");
    Serial.print(sms19);
    Serial.print("\t");
    Serial.print(sms20);
    Serial.print("\t");
    Serial.print(sms21);
    Serial.print("\t");
    Serial.print(sms22);
    Serial.print("\t");
    Serial.print(sms23);
    Serial.print("\t");
    Serial.print(sms24);
    Serial.println();
    writing();
  }
}

void writing() {
  Serial.print("connecting to ");
  Serial.println(host);
  if (!client.connect(host, httpsPort)) {
    Serial.println("connection failed");
    return;
  }

  String url = "/macros/s/" + GAS_ID + "/exec?value1=" + sms1 + "&value2=" + sms2 + "&value3=" + sms3
+ "&value4=" + sms4 + "&value5=" + sms5 + "&value6=" + sms6 + "&value7=" + sms7 + "&value8=" + sms8 +
"&value9=" + sms9 + "&value10=" + sms10 + "&value11=" + sms11 + "&value12=" + sms12 + "&value13=" +
sms13 + "&value14=" + sms14 + "&value15=" + sms15 + "&value16=" + sms16 + "&value17=" + sms17 +
"&value18=" + sms18 + "&value19=" + sms19 + "&value20=" + sms20 + "&value21=" + sms21 + "&value22=" +
sms22 + "&value23=" + sms23 + "&value24=" + sms24;
  Serial.print("requesting URL: ");
  Serial.println(url);
  client.print(String("GET ") + url + " HTTP/1.1\r\n" +
               "Host: " + host + "\r\n" +
               "User-Agent: BuildFailureDetectorESP8266\r\n" +
               "Connection: close\r\n\r\n");
```

```
  Serial.println("request sent");
  while (client.connected()) {
    String line = client.readStringUntil('\n');
    if (line == "\r") {
      Serial.println("headers received");
      break;
    }
  }
  String line = client.readStringUntil('\n');
  if (line.startsWith("{\"state\":\"success\"")) {
    Serial.println("esp8266/Arduino CI successfull!");
  } else {
    Serial.println("esp8266/Arduino CI has failed");
  }
  Serial.println("reply was:");
  Serial.println("==========");
  Serial.println(line);
  Serial.println("==========");
  Serial.println("closing connection");
}
```

III. Arduino uno connections

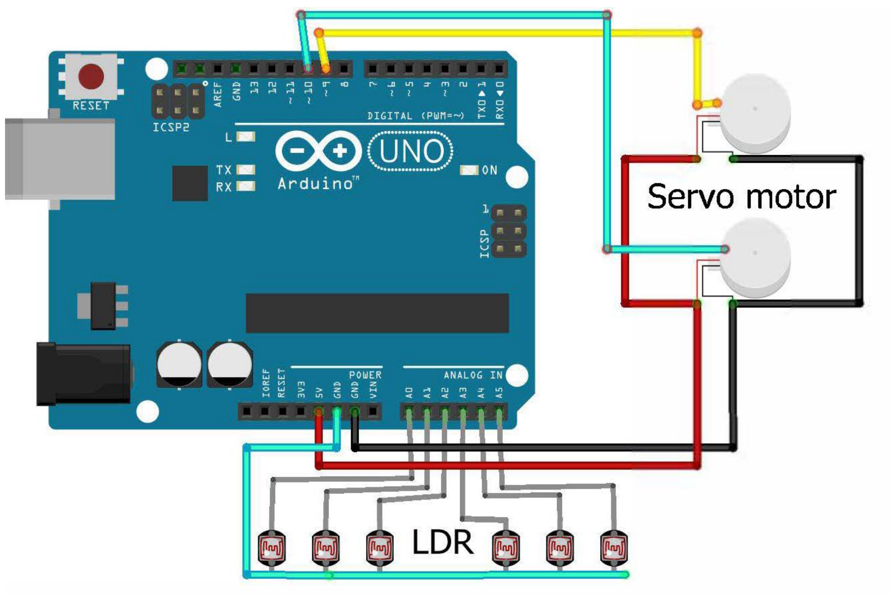


Fig. 88. Arduino uno port connections

IV. Arduino uno code

```
#include <Servo.h>

Servo myservo1;
Servo myservo2;

#define LDR1 A0
#define LDR2 A1
#define LDR3 A2
#define LDR4 A3
#define LDR5 A4
#define LDR6 A5

#define servo1 9
#define servo2 10

int pos = 0, qw = 0, angle1 = 0;
```

```
void setup() {
  Serial.begin(9600);
  pinMode(LDR1, INPUT);
  pinMode(LDR2, INPUT);
  pinMode(LDR3, INPUT);
  pinMode(LDR4, INPUT);
  pinMode(LDR5, INPUT);
  pinMode(LDR6, INPUT);
  Servo1_Control('=', angle1);
  delay(500);
}

void loop() {
  int LDR_OUT1 = analogRead(LDR1);
  int LDR_OUT2 = analogRead(LDR2);
  int LDR_OUT3 = analogRead(LDR3);
  int LDR_OUT4 = analogRead(LDR4);
  int LDR_OUT5 = analogRead(LDR5);
  int LDR_OUT6 = analogRead(LDR6);
  Serial.print(LDR_OUT1);
  Serial.print("\t");
  Serial.print(LDR_OUT2);
  Serial.print("\t");
  Serial.print(LDR_OUT3);
  Serial.print("\t");
  Serial.print(LDR_OUT4);
  Serial.print("\t");
  Serial.print(LDR_OUT5);
  Serial.print("\t");
  Serial.print(LDR_OUT6);
  Serial.print("\t");

  if(LDR_OUT1>650){LDR_OUT1 = 1;}else{LDR_OUT1 = 0;}
  if(LDR_OUT2>920){LDR_OUT2 = 1;}else{LDR_OUT2 = 0;}
  if(LDR_OUT3>550){LDR_OUT3 = 1;}else{LDR_OUT3 = 0;}
  if(LDR_OUT4>800){LDR_OUT4 = 1;}else{LDR_OUT4 = 0;}
  if(LDR_OUT5>700){LDR_OUT5 = 1;}else{LDR_OUT5 = 0;}
  if(LDR_OUT6>650){LDR_OUT6 = 1;}else{LDR_OUT6 = 0;}
  Serial.print(LDR_OUT1);
  Serial.print("\t");
  Serial.print(LDR_OUT2);
  Serial.print("\t");
  Serial.print(LDR_OUT3);
  Serial.print("\t");
  Serial.print(LDR_OUT4);
  Serial.print("\t");
  Serial.print(LDR_OUT5);
  Serial.print("\t");
  Serial.print(LDR_OUT6);
  if(LDR_OUT1 == 1 && LDR_OUT2 == 1 && LDR_OUT3 == 1 && LDR_OUT4 == 1 && LDR_OUT5 == 1 && LDR_OUT6 ==
1){
    Serial.print("\t");
    Serial.print("S");
    Servo1_Control('=', angle1);
    delay(2);
  }
  else if((LDR_OUT1 == 1 && LDR_OUT2 == 1 && LDR_OUT3 == 1) && ( LDR_OUT4 == 0 || LDR_OUT5 == 0 ||
LDR_OUT6 == 0)){
    Serial.print("\t");
    Serial.print("F");
    if (angle1 <= 0) {
      angle1 = 0;
      Servo1_Control('=', angle1);
    }
    else {
      Servo1_Control('-', angle1);
    }
    delay(2);
  }
  else if((LDR_OUT1 == 0 || LDR_OUT2 == 0 || LDR_OUT3 == 0) && ( LDR_OUT4 == 1 && LDR_OUT5 == 1 &&
LDR_OUT6 == 1)){
    Serial.print("\t");
    Serial.print("B");
    if (angle1 >= 180) {
```

```
      angle1 = 180;
      Servo1_Control('=', angle1);
    }
    else {
      Servo1_Control('+', angle1);
    }
    delay(2);
  }
  else if(LDR_OUT1 == 0 && LDR_OUT2 == 0 && LDR_OUT3 == 0 && LDR_OUT4 == 0 && LDR_OUT5 == 0 &&
LDR_OUT6 == 0){
    Serial.print("\t");
    Serial.print("SUN");
    angle1 = 0;
    Servo1_Control('=', angle1);
    delay(2);
  }
  Serial.println();
}

void Servo1_Control(char Status, int value1s)
{
  myservo1.attach(servo1);
  myservo2.attach(servo2);

  if (Status == '-') //open door
  {
    for (angle1; angle1 > value1s - 2; angle1--)
    {
      myservo1.write(angle1);
      myservo2.write(angle1);
    }
  }
  else if (Status == '+')
  {
    for (angle1; angle1 < value1s + 2; angle1++)
    {
      myservo1.write(angle1);
      myservo2.write(angle1);
    }
  }
  else if (Status == '=')
  {
    myservo1.write(angle1);
    myservo2.write(angle1);
  }
  //  delay(200);
  //  myservo1.detach();
  //  myservo2.detach();
}
```