DESIGN, DYNAMIC MODELING AND ANALYSIS OF AN ON-GRID PHOTOVOLTAIC SYSTEM FOR A HOUSE IN LAHORE, PAKISTAN

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INTRODUCTION

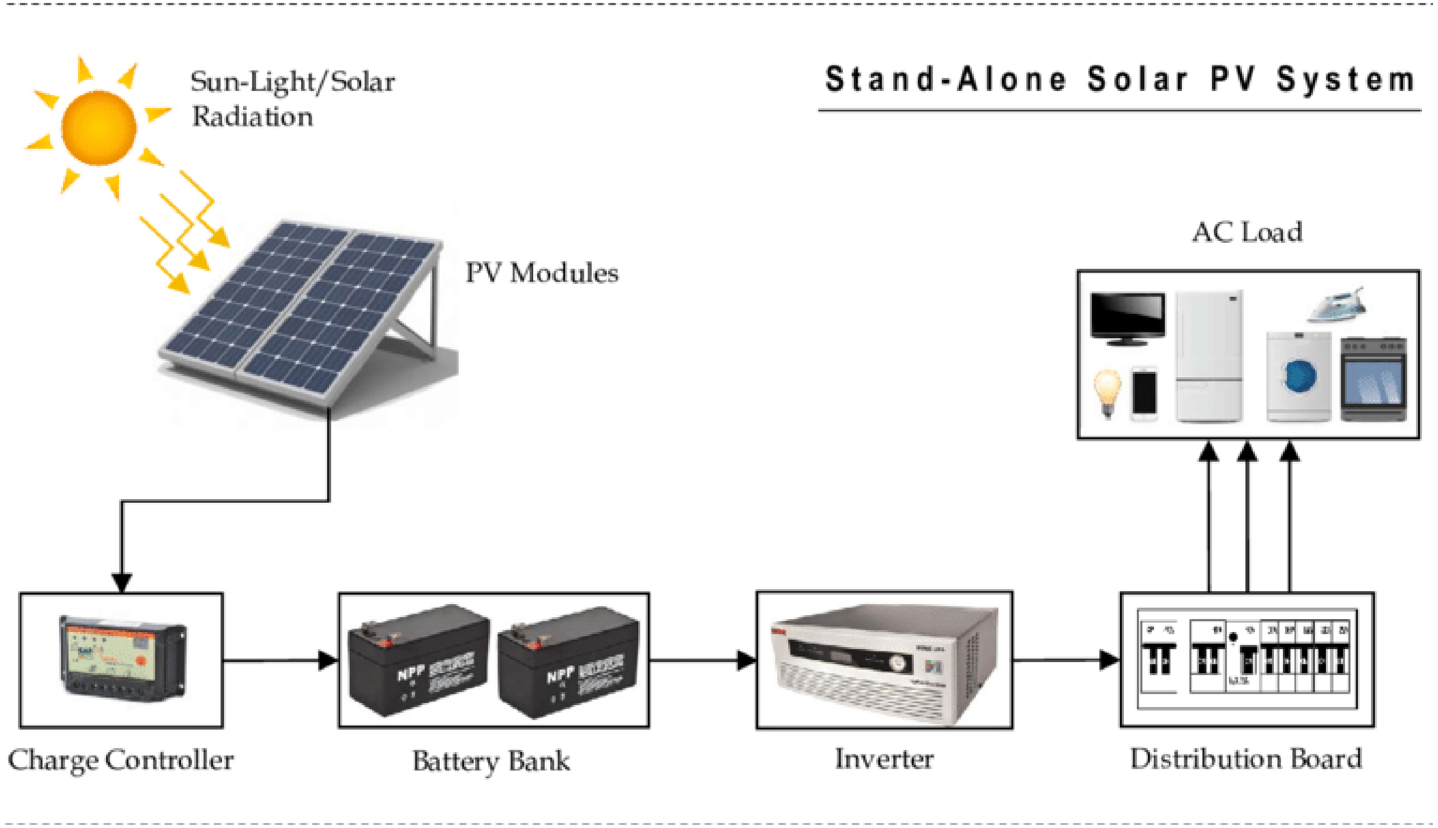
INTRODUCTION

- Solar energy, as a renewable resource, has gained considerable attention due to its potential to provide sustainable and clean electricity.
- With the ever-increasing concerns regarding global warming and the depletion of fossil fuels, the adoption of solar photovoltaic (PV) systems has become more prevalent.
- Solar energy is seen as a viable alternative to conventional energy sources, which are associated with pollution and carbon emissions.
- Lahore faces power shortages and load shedding due to a strained grid.
- Solar PV systems offer a solution, but optimal design and data monitoring are crucial.
- This study aims to design, analyze, and test a grid-tied solar system for a Lahore residence.

STAND ALONE PV SYSTEM

- Stand-alone PV systems operate independently of the public electricity grid.
- **Components of a PV System:**

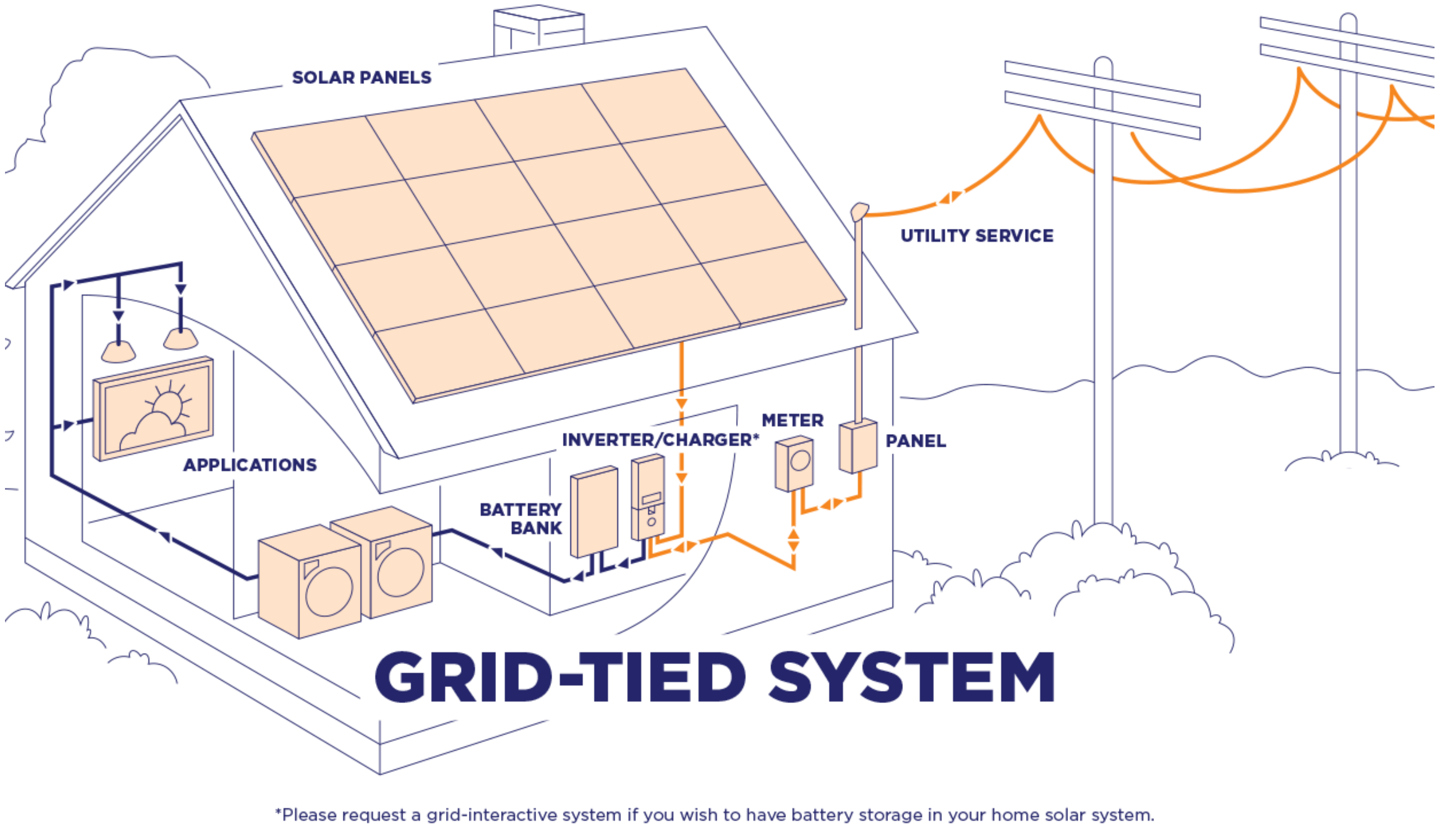
- Solar Panels
- Charge Controller
- Battery Bank
- Inverter
- Load



GRID-TIED PV SYSTEM

- Grid-tied PV systems are connected to the public electricity grid..
- **Components of a Grid-tied PV System:**

- Solar Panels
- Inverter
- Net Metering System
- Connection to the Grid
- Load



LITERATURE REVIEW

Area of Focus	Key Findings	References
Solar Energy Systems in Pakistan	• Significant potential for solar energy due to high solar irradiance. • Adoption is limited by infrastructure and policy issues.	[1] [2] [4]
Stand-Alone PV Systems	• Stand-alone systems operate independently of the grid. • Optimal system design is crucial for off-grid applications.	[15] [17]
Grid-Tied PV Systems	• Grid-tied systems offer flexibility and net metering benefits. • Stability and efficiency depend on control strategies and grid management.	[11] [12] [14] [13]
Hybrid Renewable Energy Systems	• Combining solar with other sources can increase efficiency and reduce costs. • Suitable for both residential and industrial applications.	[5] [7] [16]
Net Metering and Grid Integration	• Net metering is important for grid-tied systems and effective grid management. • Policies and regulations significantly affect solar adoption.	[6] [8]
Data Acquisition and Monitoring	• Real-time monitoring is essential for efficient solar PV system operation. • Innovations in low-cost and IoT-based monitoring systems contribute to improved performance.	[21] [22] [23] [24] [25] [26] [27]
MATLAB/Simulink-Based Modeling	• Provides valuable tools for simulating and analyzing grid-connected PV systems. • Useful for exploring control strategies and system behavior.	[18] [19] [20]

PROBLEM STATEMENT

- Lahore, Pakistan, is a growing city experiencing frequent power shortages and load shedding due to a strained power grid.

- **Challenges:**
  - Frequent power outages disrupt daily life and business operations.
  - Grid-tied solar systems require careful design to ensure optimal integration and performance.
  - A reliable data logging system is needed for monitoring and identifying system issues early.

- This calls for:
  - **Optimal Design:** Creating a grid-tied solar system that addresses the unique needs of Lahore.
  - **Efficient Energy Management:** Managing energy flow to reduce load shedding and outages.
  - **Performance Monitoring:** Developing a data logging system for continuous performance tracking.

AIM & RESEARCH OBJECTIVES

To design and analyze a grid-tied solar system for a residential setting in Lahore, addressing power shortages and ensuring efficient grid integration.

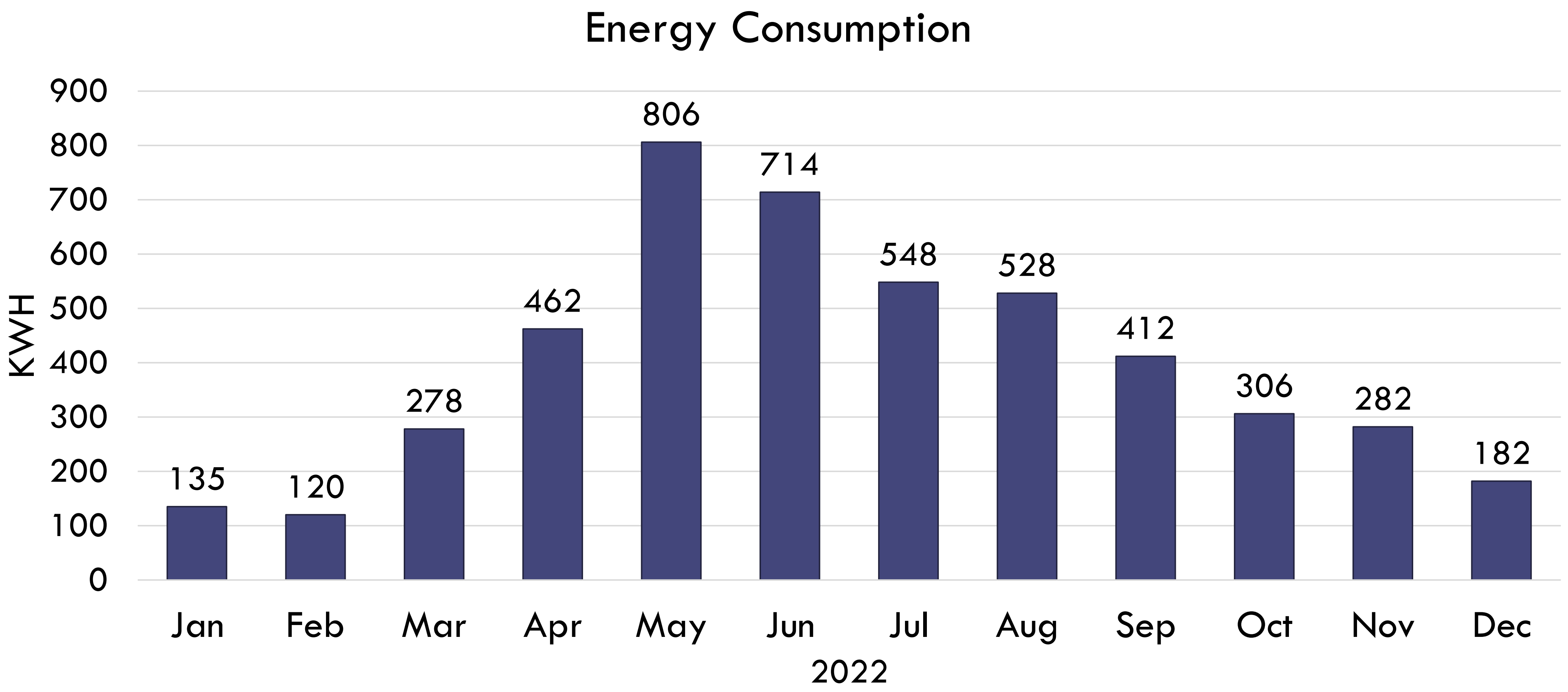
- Design and Analyze a Solar System for a Residential Setting in Lahore, Pakistan.
- Model and Simulate a Grid-Tied System using simulation tools to model a three-phase photovoltaic system, testing different scenarios and grid conditions.
- Develop a Data Logging System to monitor solar system performance, providing insights into efficiency and early detection of potential issues.

DESIGN AND ANALYSIS OF AN ON-GRID SOLAR SYSTEM FOR A HOUSE IN LAHORE, PAKISTAN

SITE LOCATION

- Site Location on Google Maps (Latitude: 31.5481, Longitude: 74.3916).
- The site selected for this research is a house in Lahore.
- House is in Askari X housing society, Lahore and the total rooftop area of this house is 1680 ft2.
- This house is made of bricks with a flat rooftop.
- Seven family members are living in this house including three kids and four adults

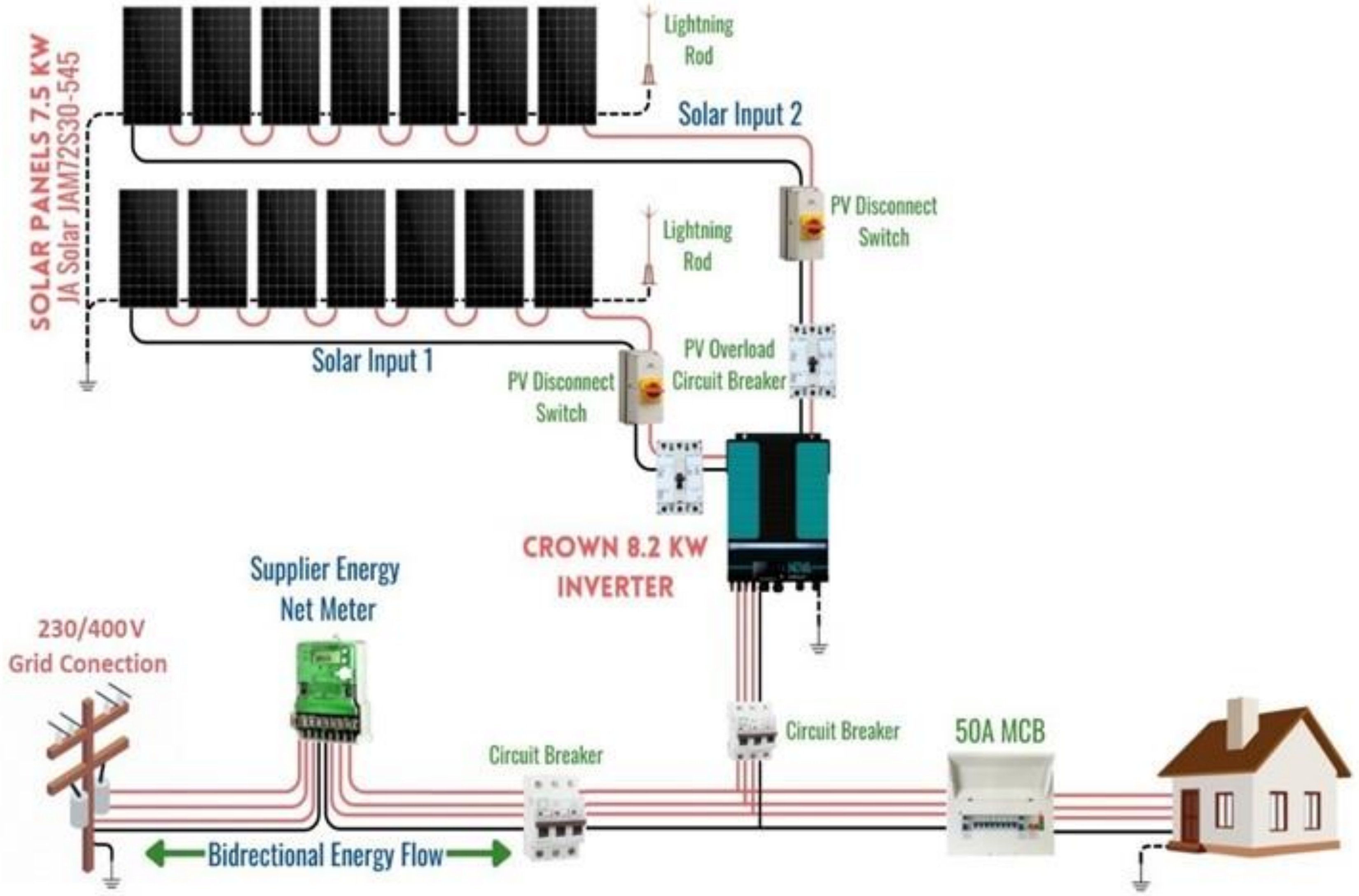
ELECTRIC ENERGY CONSUMPTION OF THE HOUSE IN 2022



ELECTRIC ENERGY CONSUMPTION OF THE HOUSE IN 2022

Sr. No	Appliances	Load (Watt)	Qty	Total Load (Watt)
1	Ceiling fan	60	7	420 W
2	LED light	10	16	160 W
3	Refrigerator	400	1	400 W
4	LED TV	350	1	350 W
5	Air Conditioner	1250	2	2,500 W
6	Microwave	1200	1	1,200 W
7	Laptop	100	1	100 W
8	Modem	20	1	20 W
	Total			**5,150 W**

SYSTEM LAYOUT



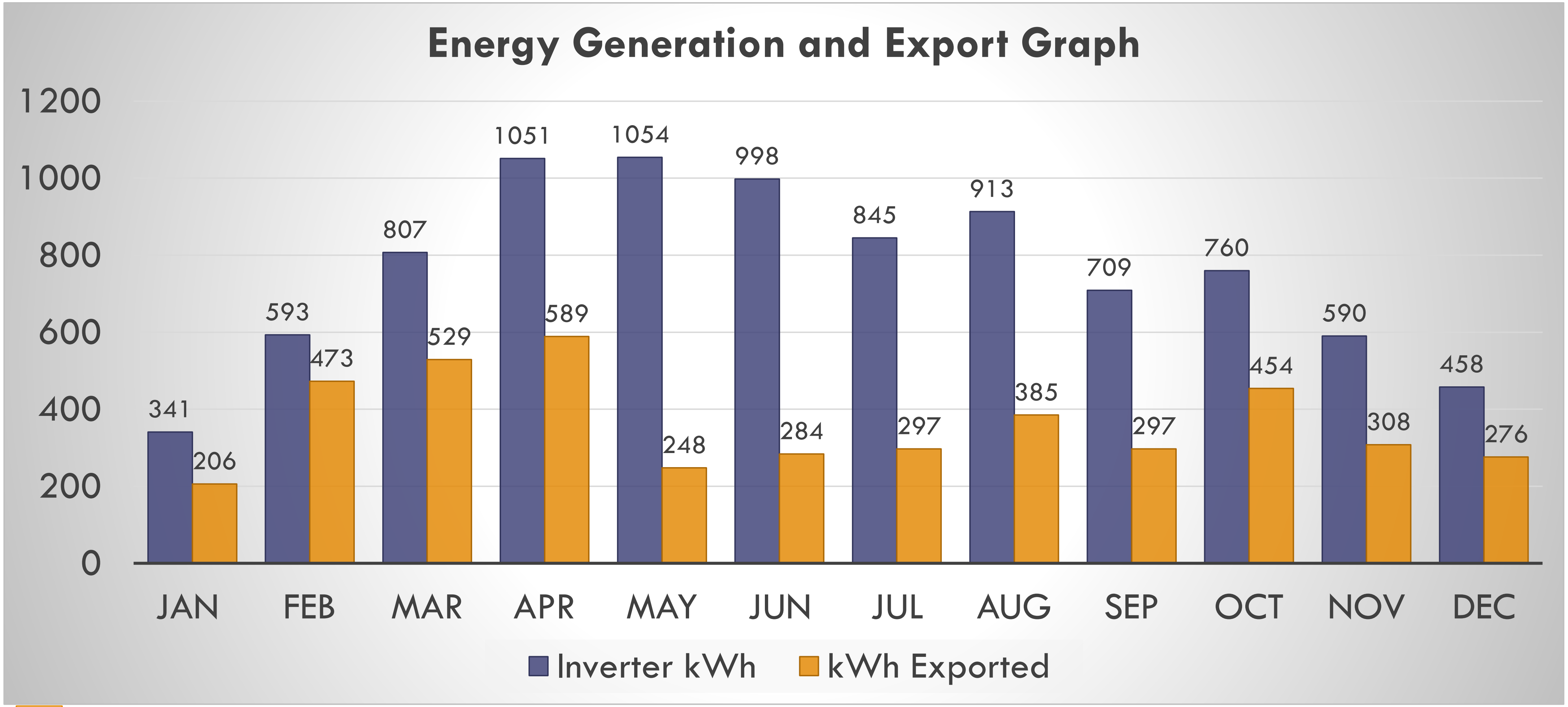
ELECTRICAL SPECIFICATION OF SOLAR PANEL

Type	Rating
Maximum Power (Pmax)	545 W
Open Circuit Voltage (Voc)	49.75 VDC
Maximum Power Voltage (Vmp)	41.80 VDC
Short Circuit Current (Isc)	13.93 A
Maximum Power Current (Imp)	13.04 A
Module Efficiency	21.10%
Power Tolerance	0 – 5W
Temperature Coefficient of Isc (α_Isc)	-0.045% °C
Temperature Coefficient of Voc (β_Isc)	-0.275% °C
Temperature Coefficient of Pmax (γ_Isc)	-0.350% °C

ELECTRICAL SPECIFICATION OF INVERTER

Type	Rating
Rated Output Power	8200VA/8200W
Rated Voltage	230 VAC
Frequency range	50Hz/60Hz Auto sense
Surge Power	16000VA
Peak Efficiency	93%
Maximum PV Array	12000W (6000W X 2)
MPPT Range	90 - 450 VDC
Maximum PV Array Voc	500 VDC
Maximum Solar Charging Current	150A
Operating Temperature	10 °C – 50 °C

ELECTRIC ENERGY CONSUMPTION OF THE HOUSE IN 2022

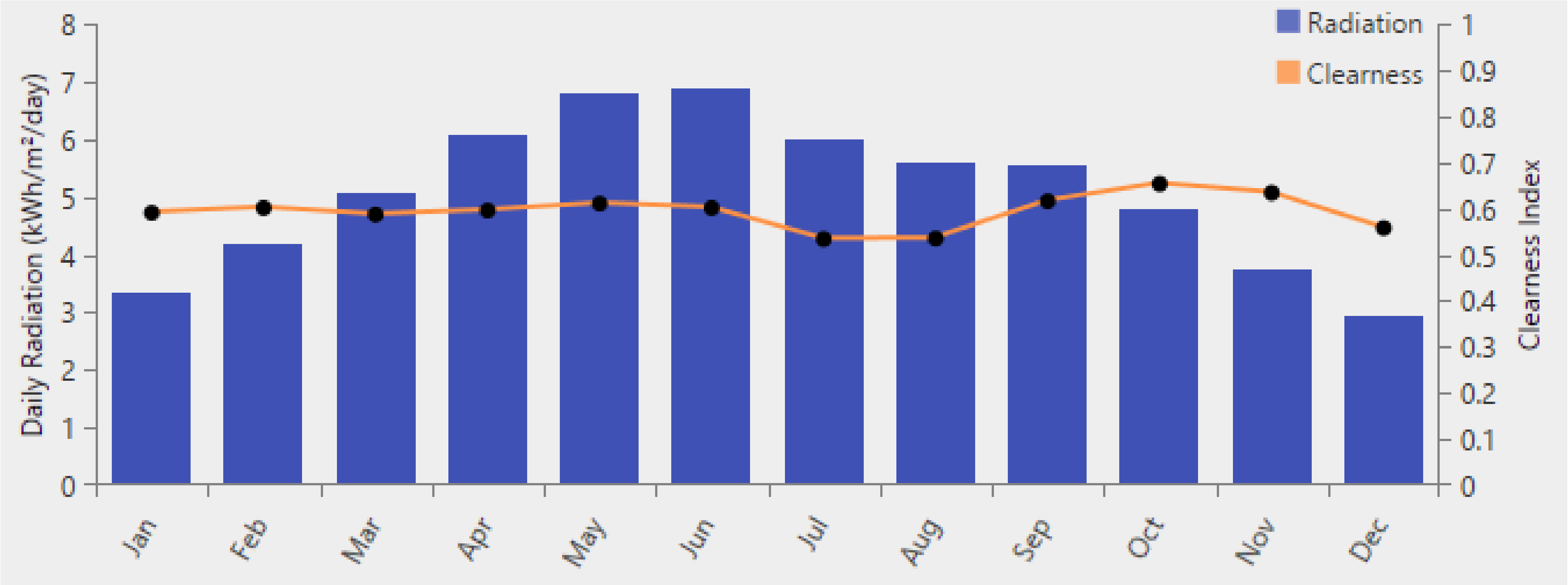


SYSTEM PERFORMANCE ANALYSIS

- **System Advisor Model (SAM)**
  - A comprehensive software for performance and financial analysis of solar PV systems.
  - Provides a 25-year return on investment estimate based on weather data and system details.
  - Capable of modeling various solar energy systems, including rooftop PV and battery storage.
- **REopt**
  - A techno-economic analysis platform by NREL for energy systems optimization.
  - Evaluates energy savings, resilience, and emissions reductions.
  - Offers portfolio analysis, system sizing, and dispatch strategies to meet energy goals.
- **HOMER Pro**
  - A versatile tool for energy system analysis and optimization, focusing on renewable energy and microgrids. Assists in finding cost-effective and environmentally friendly energy solutions.
  - Utilizes online solar irradiance and temperature data to simulate system performance.
  - Models grid-tied PV systems and can suggest optimal energy combinations.

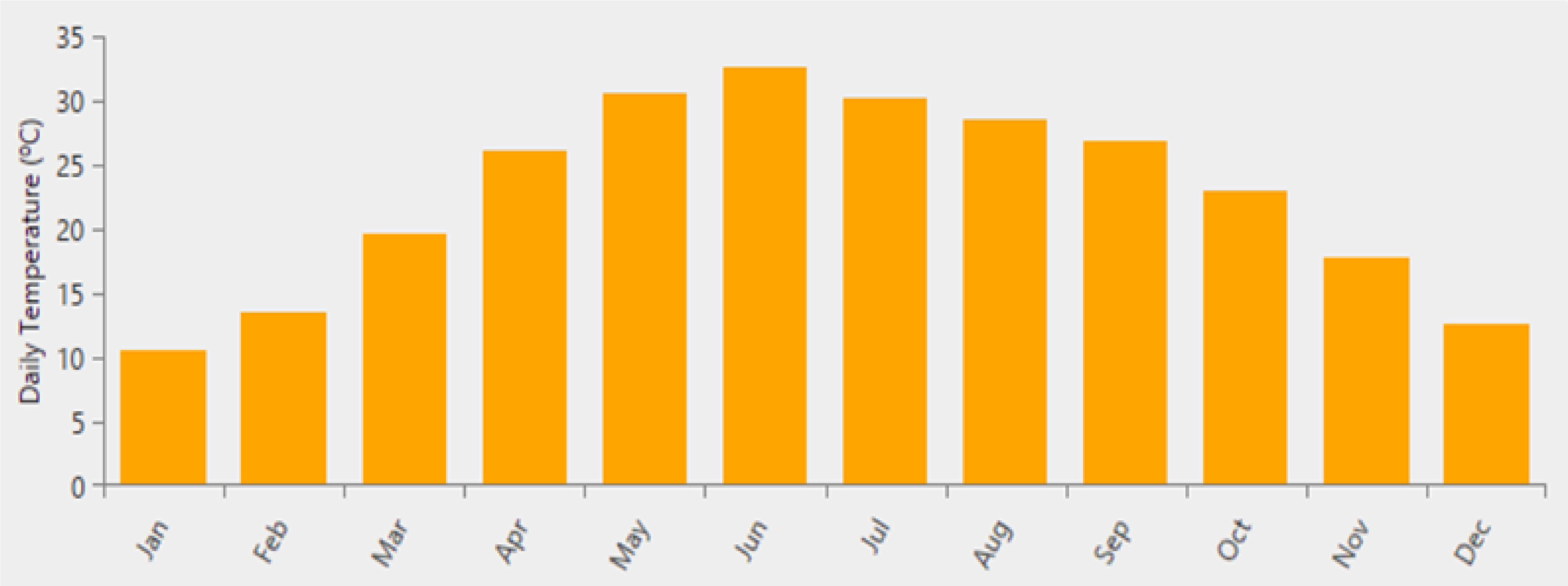
RESULTS (SAM)

Monthly Global Irradiance of Site.



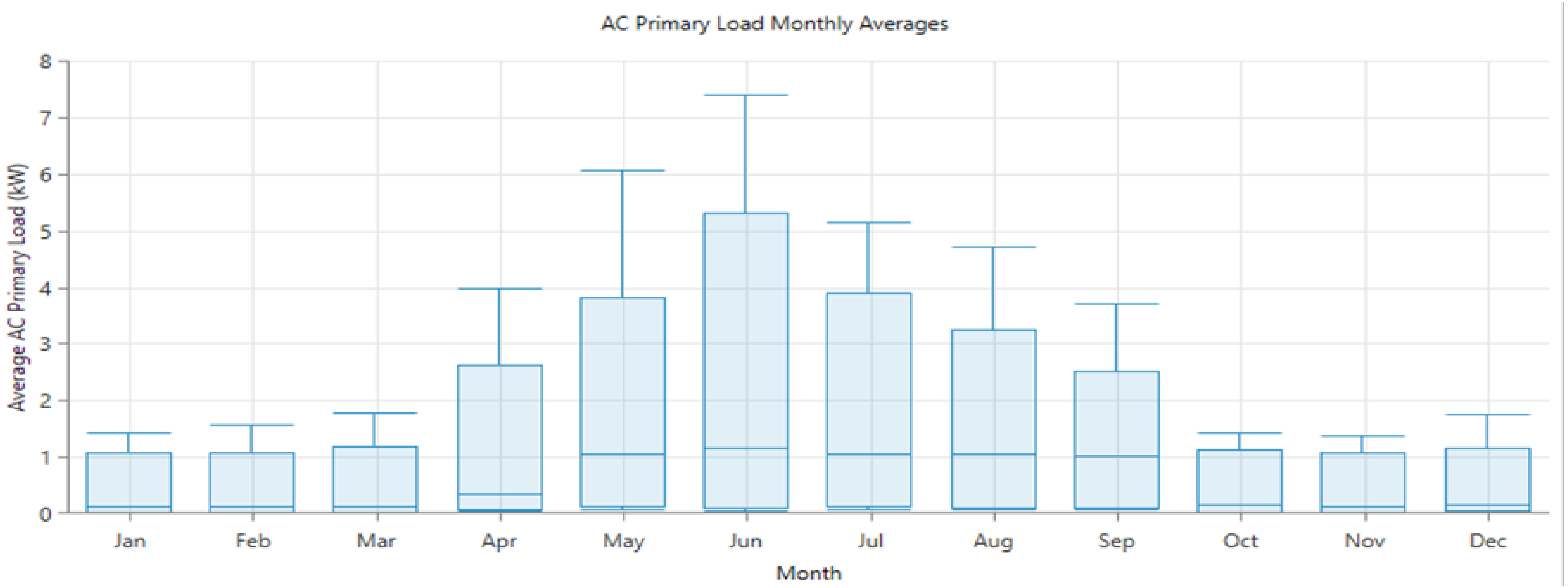
RESULTS (SAM)

Dry Bulb Temperature of Site



RESULTS (SAM)

Monthly energy production of installed solar PV system



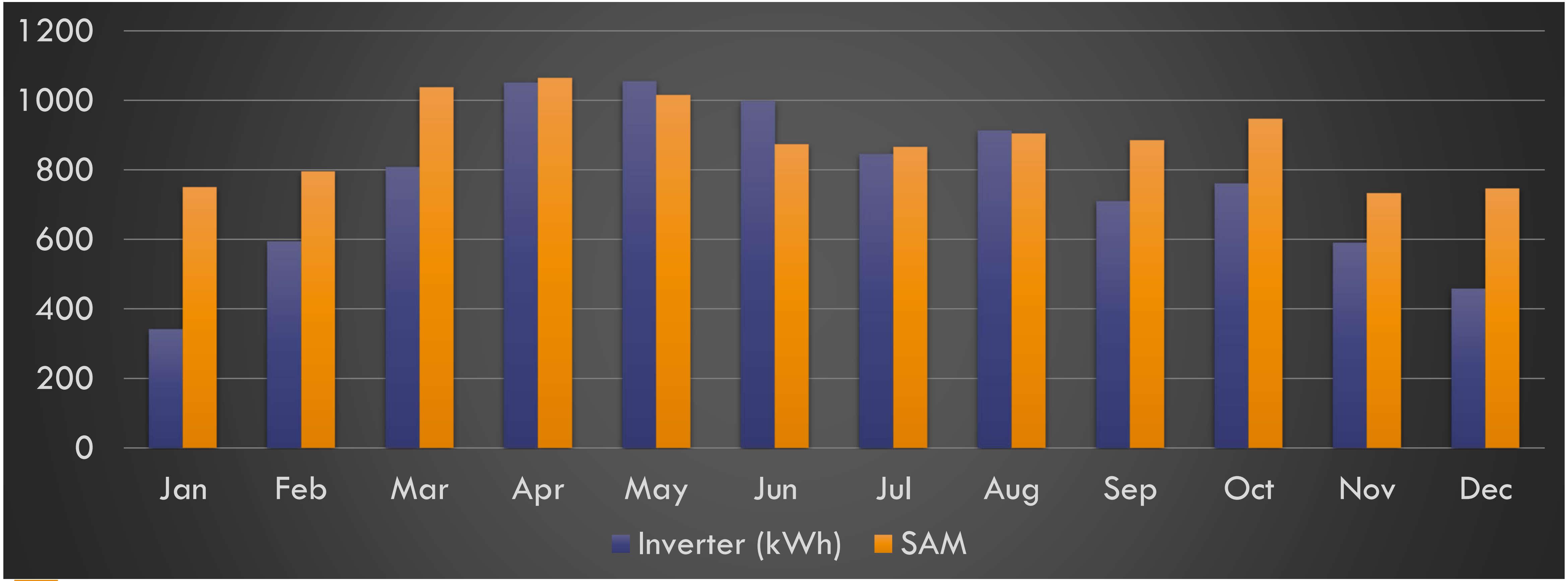
RESULTS

System Summary Chart

Metric	Value
Annual AC Energy in year 1	10,620 kWh
DC Capacity factor in Year 1	15.9 %
Energy Yield in Year 1	1,392 kWh/kW
Performance ratio in year 1	0.73
PPA Price in Year 1	9.00 ¢/kWh
PPA Price escalation	0.50 %/kWh
LLPA Levelized PPA Price Nominal	9.49 ¢/kWh
LLPA Levelized PPA Price Real	7.04 ¢/kWh
LCOE Levelized cost of Energy Nominal	3.78 ¢/kWh
LCOE Levelized cost of Energy Real	2.81 ¢/kWh
NPV Net present value	$ 10,574
IRR Internal rate of return	18.41 %
Year IRR is achieved	10
IRR at end of project	21.95 %
Net capital cost	$ 4,752
Equity	$ 4,752
Size of debt	$0.00
Minimum DSCR	inf

RESULTS (SAM)

Comparison Chart of Inverter Output and SAM Results



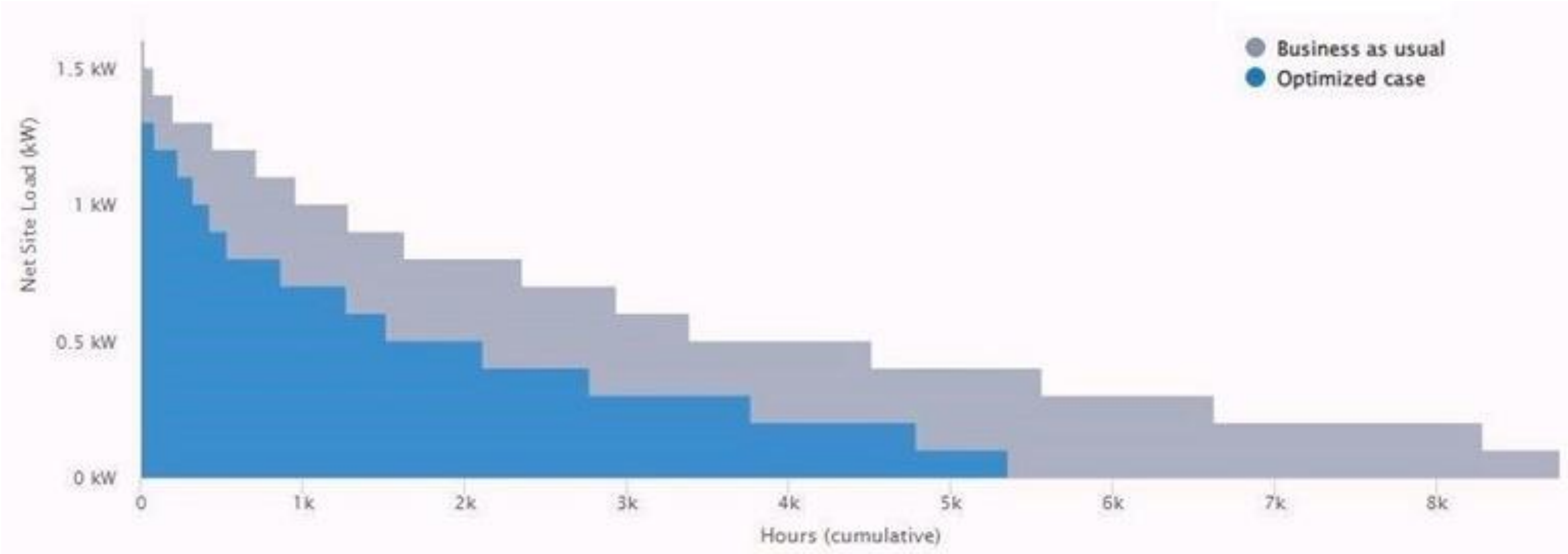
RESULTS (REOPT)

Daily Power Analysis

Year

RESULTS (REOPT)

Net Load Duration

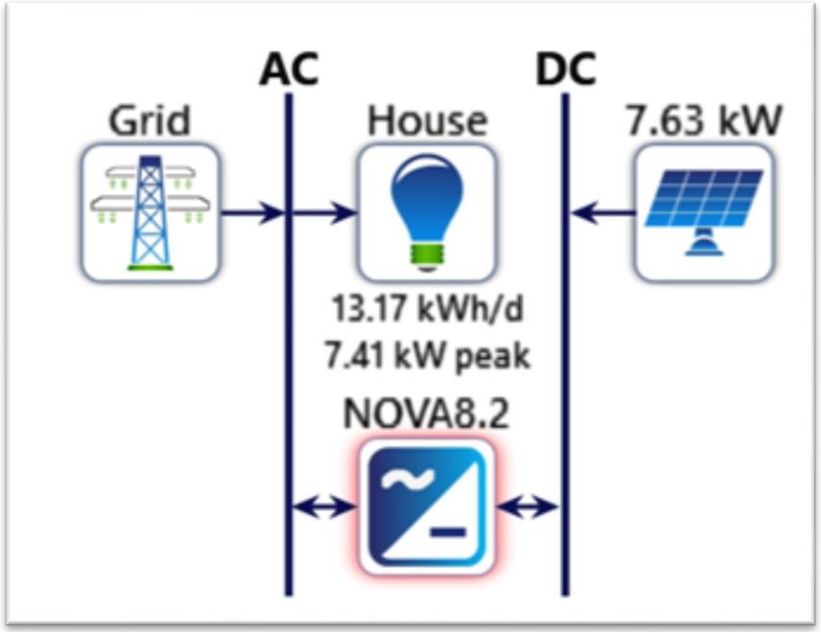


RESULTS (REOPT) “FINANCIAL ANALYSIS OF SITE”

	Business As Usual	Financial	Difference
System Size			
PV Size	0 kW	7 kW	7 kW
Energy Production and Fuel Use			
Annual Average PV Energy Production	0 kW	8,813 kW	8,813 kW
Average Annual Energy Supplied from Grid	4,770 kW	2,410 kW	-2,2360 kW
Renewable Energy Metrics			
Annual Renewable Electricity (% of electricity consumption)	0%	100%	100%
Year 1 Utility Electricity Cost – Before Tax			
Utility Energy Cost	$1,192	$982	-$210
Utility Demand Cost	$20	$19	-$1
Total Year 1 Utility Cost – Before Tax	$1,213	$1,001	-$211
Life Cycle Cost Breakdown			
Technology Capital Costs + Replacements, After Incentives	N/A	$7,400	$7,400
O&M Costs	$0	$1,850	$1,850
Total Utility Electricity Cost	$38,026	$31,395	$6,632

RESULTS (HOMER PRO)

System Structure & Cost Summary of Selected System



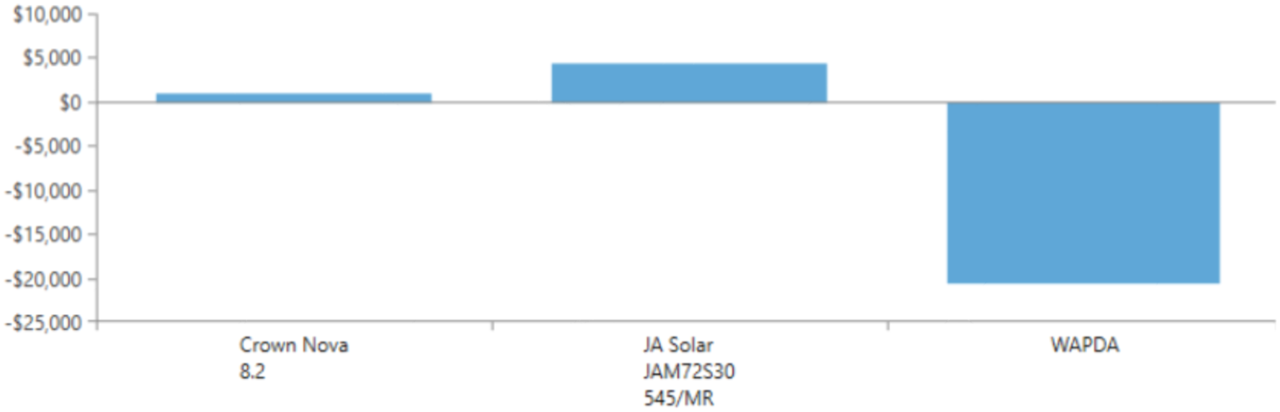
System Architecture: WAPDA (15.0 kW)
JA Solar JAM72S30 545/MR (7.63 kW) HOMER Cycle Charging
Crown Nova 8.2 (8.20 kW)

Total NPC:	-$15,046.67
Levelized COE:	-$0.03184
Operating Cost:	-$695.05

ost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | JA Solar JAM72S30 545/MR | WAPDA | Crown Nova 8.2 | Emissions

Cost Type
Net Present
Annualized

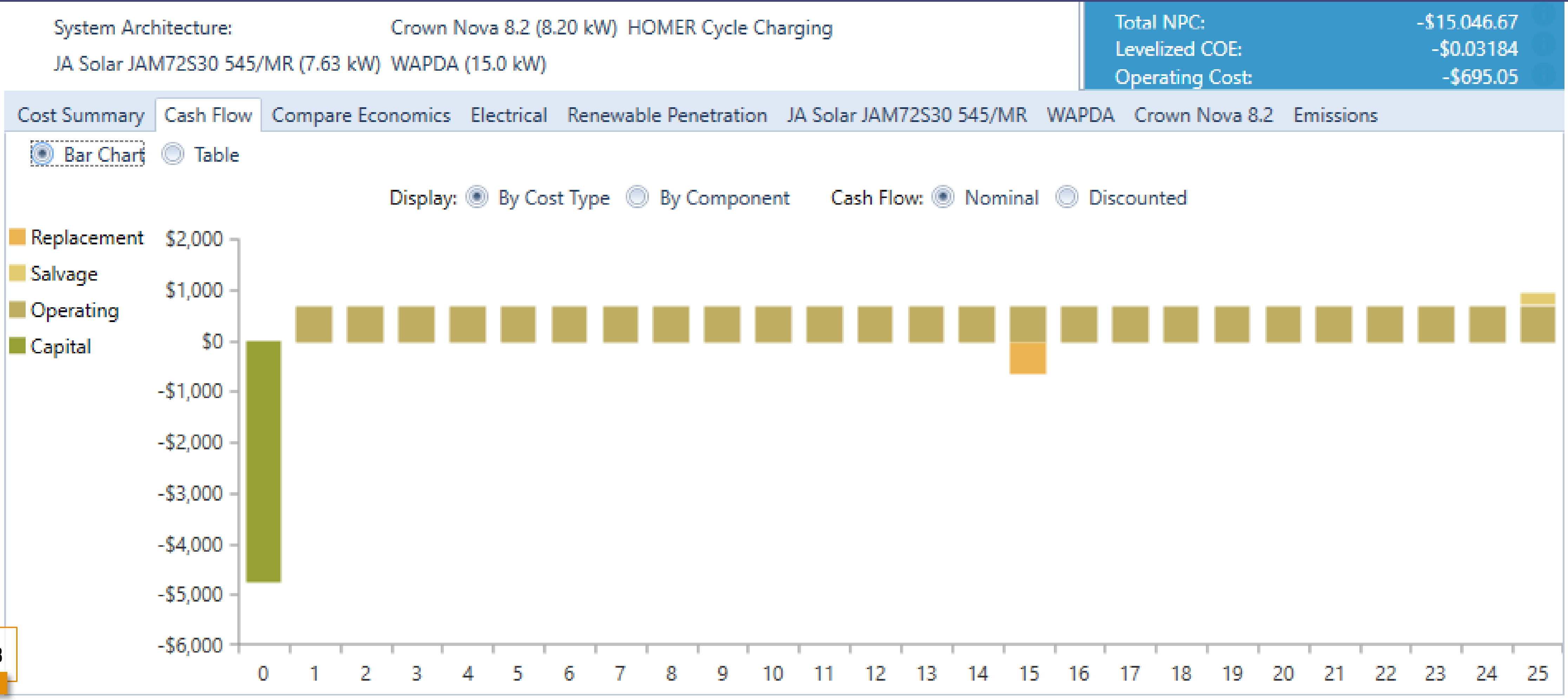
Categorize
By Component
By Cost Type



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Crown Nova 8.2	$650.00	$754.63	$0.00	$0.00	-$277.86	$1,126.77
JA Solar JAM72S30 545/MR	$4,130.00	$0.00	$399.36	$0.00	$0.00	$4,529.36
WAPDA	$0.00	$0.00	-$20,702.80	$0.00	$0.00	-$20,702.80
System	$4,780.00	$754.63	-$20,303.44	$0.00	-$277.86	-$15,046.67

RESULTS (HOMER PRO)

Projected Cash Flow for 25 Years



RESULTS (HOMER PRO)

Monthly Electric Production

System Architecture: WAPDA (15.0 kW)
JA Solar JAM72S30 545/MR (7.63 kW) HOMER Cycle Charging
Crown Nova 8.2 (8.20 kW)

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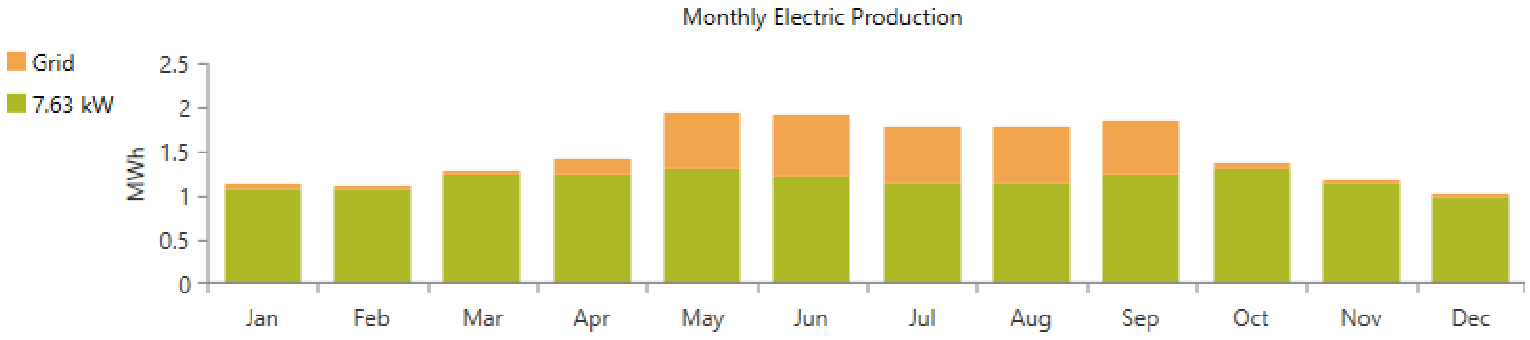
Emissions
Cost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | JA Solar JAM72S30 545/MR | WAPDA | Crown Nova 8.2

Production	kWh/yr	%
JA Solar JAM72S30 545/MR	14,058	79.2
Grid Purchases	3,693	20.8
Total	17,752	100

Consumption	kWh/yr	%
AC Primary Load	4,807	29.0
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	11,757	71.0
Total	16,564	100

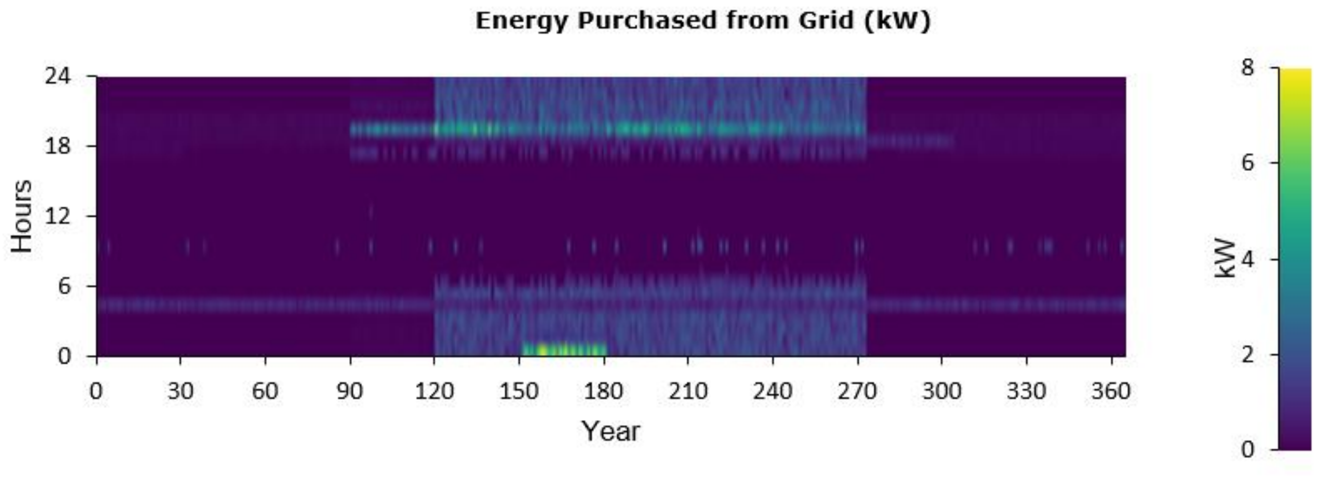
Quantity	kWh/yr	%
Excess Electricity	219	1.23
Unmet Electric Load	0	0
Capacity Shortage	0	0

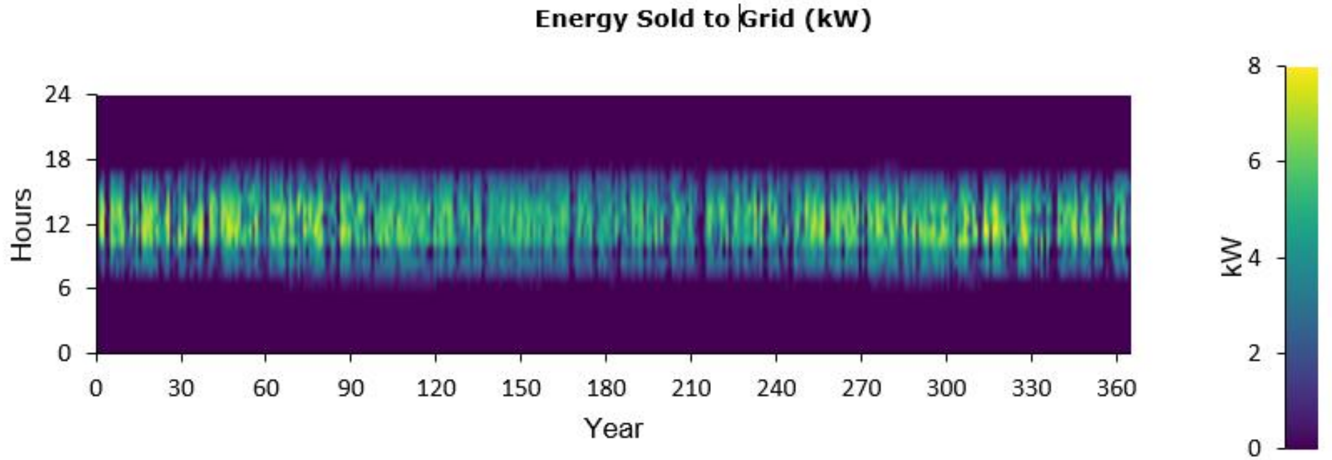
Quantity	Value	Units
Renewable Fraction	77.7	%
Max. Renew. Penetration	108	%



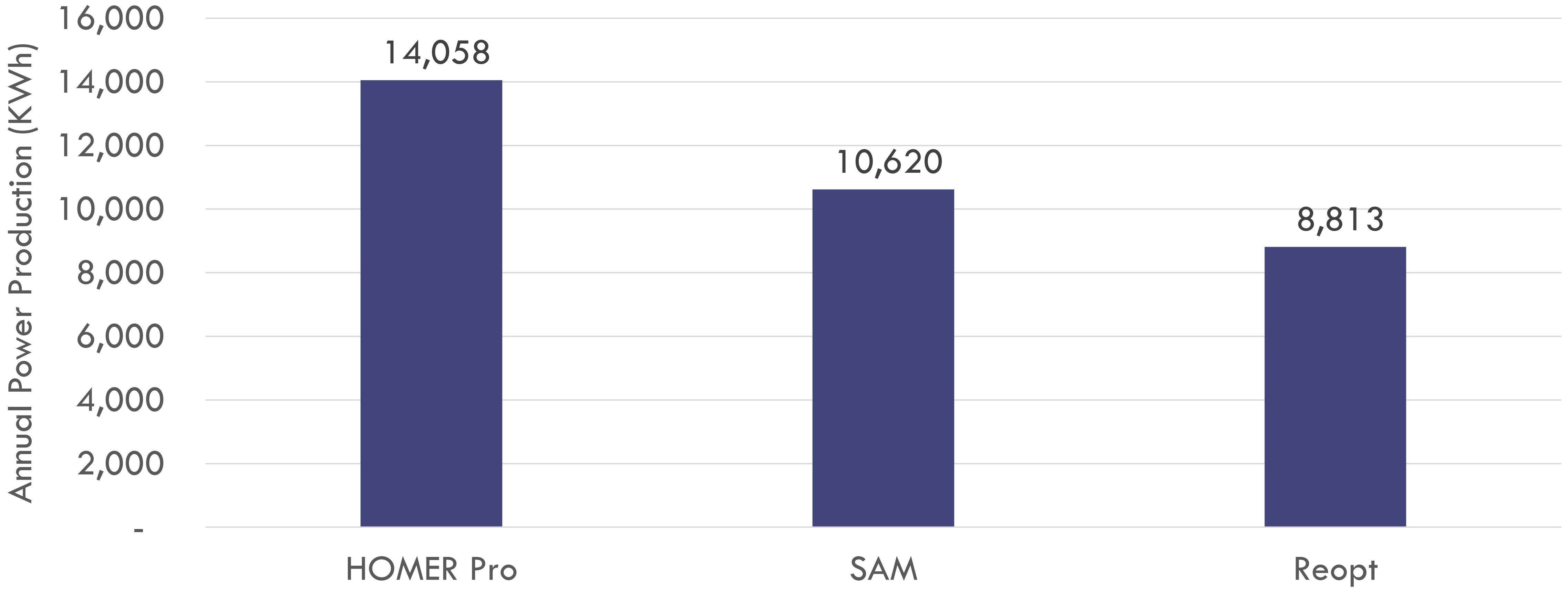
RESULTS (HOMER PRO)

Power Grid Import and Export graphs





COMPARISON OF THE ANALYSIS DONE BY THE THREE SOFTWARE

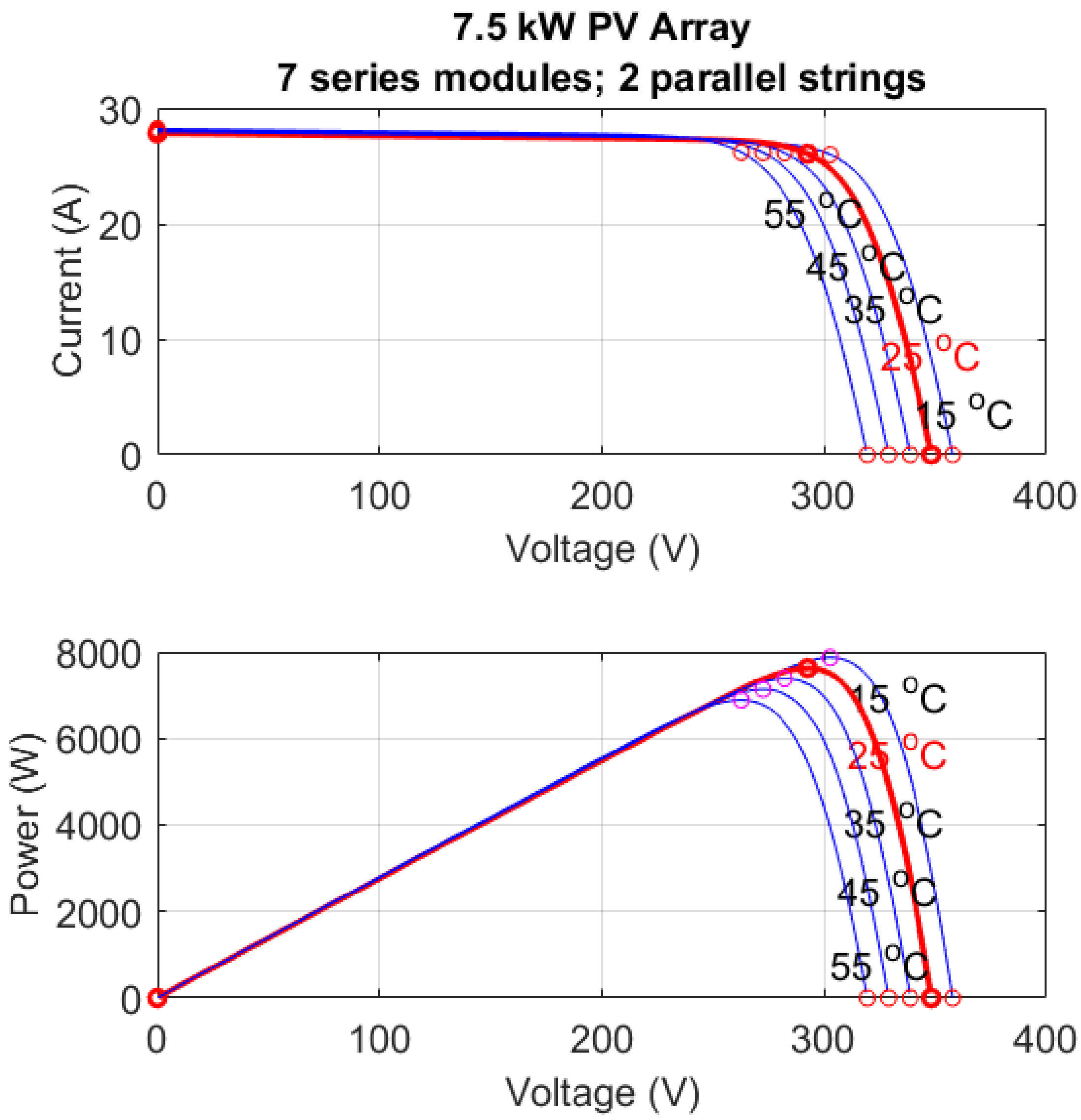


MODELING AND SIMULATION OF GRID-TIED THREE-PHASE PV SYSTEM IN LAHORE, PAKISTAN

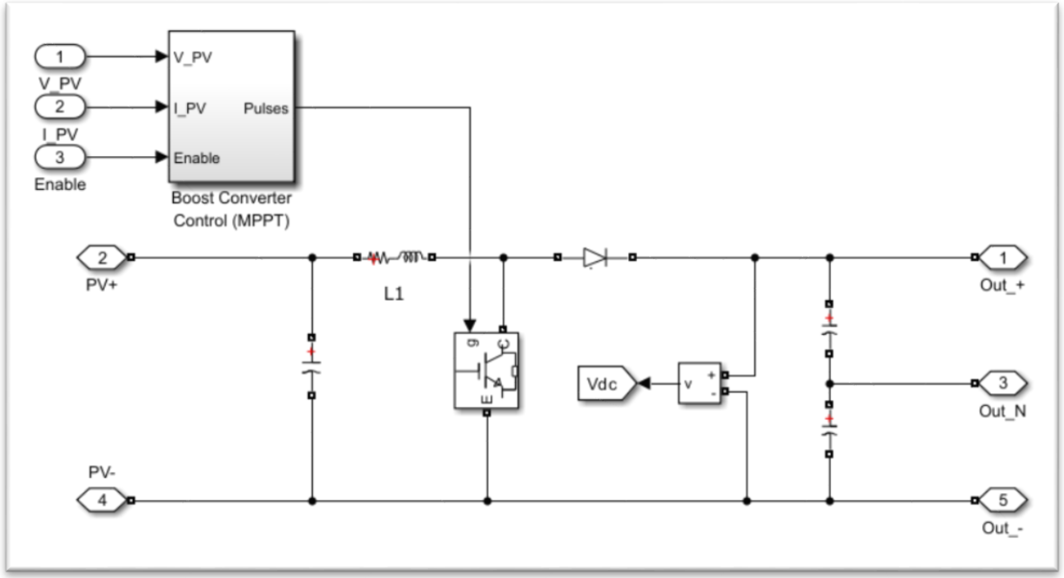
MATLAB/SIMULINK FOR GRID-TIED PV SYSTEM MODELING

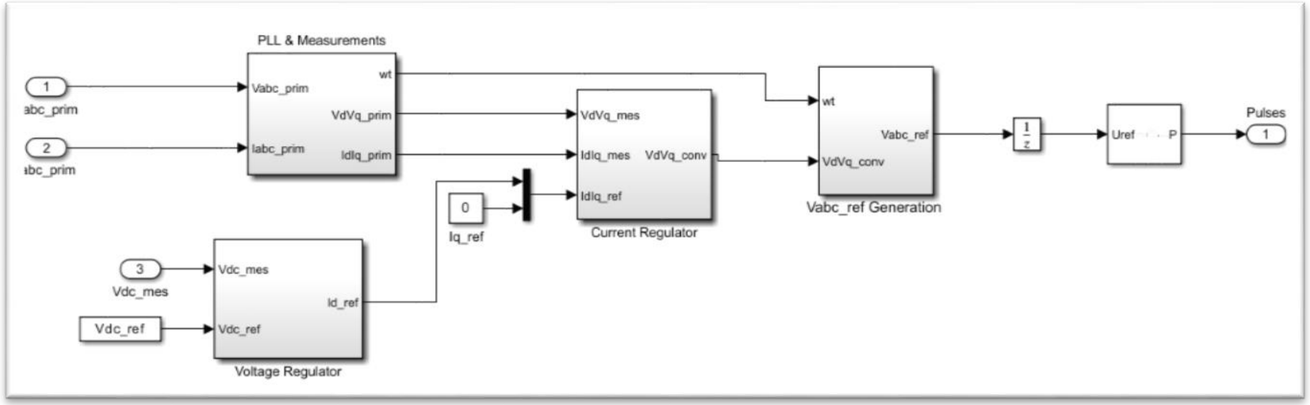
- **MATLAB/SIMULINK:**
  - Provides a versatile and powerful platform for system modeling.
  - Seamlessly integrates mathematical modeling with dynamic simulation.
  - Ideal for complex systems like solar inverters and grid-tied solar systems.
- **Focus of Investigation:**
  - Development of a comprehensive model for a grid-tied PV system.
  - The model captures the architecture and constituent parts, reflecting real-world dynamics.
- **Model Structure and Approach:**
  - Encompasses key components: photovoltaic array, power electronics, control mechanisms, and grid interactions.
  - Modular design allows for detailed examination and adaptability.
  - The system is broken down into subcomponents, each represented by mathematical equations and algorithms.

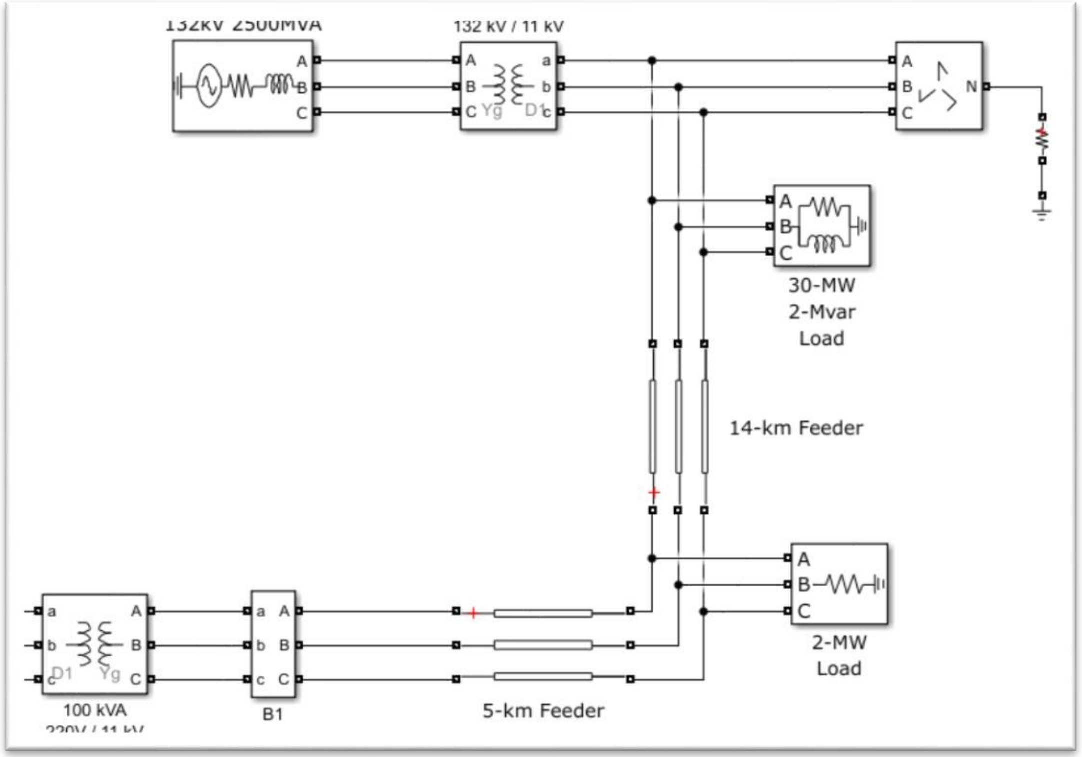
I-V AND P-V CURVES OF THE PV ARRAY



DC-DC CONVERTER, 3-PHASE INVERTER, & GRID







RESULTS

Scenarios Explored

- **Grid Disconnected with Constant Irradiance:**
  - Simulates the system's behavior when the grid is offline, demonstrating the PV array's ability to meet load demands independently.
- **Grid Connected with Varying Irradiance:**
  - Examines net metering and the system's dynamic response to changing irradiance levels.
- **Grid Connected with Realistic Irradiance and Temperature:**
  - Mimics the day and night cycle with temperature consistency to evaluate the system's adaptability to real-world conditions.

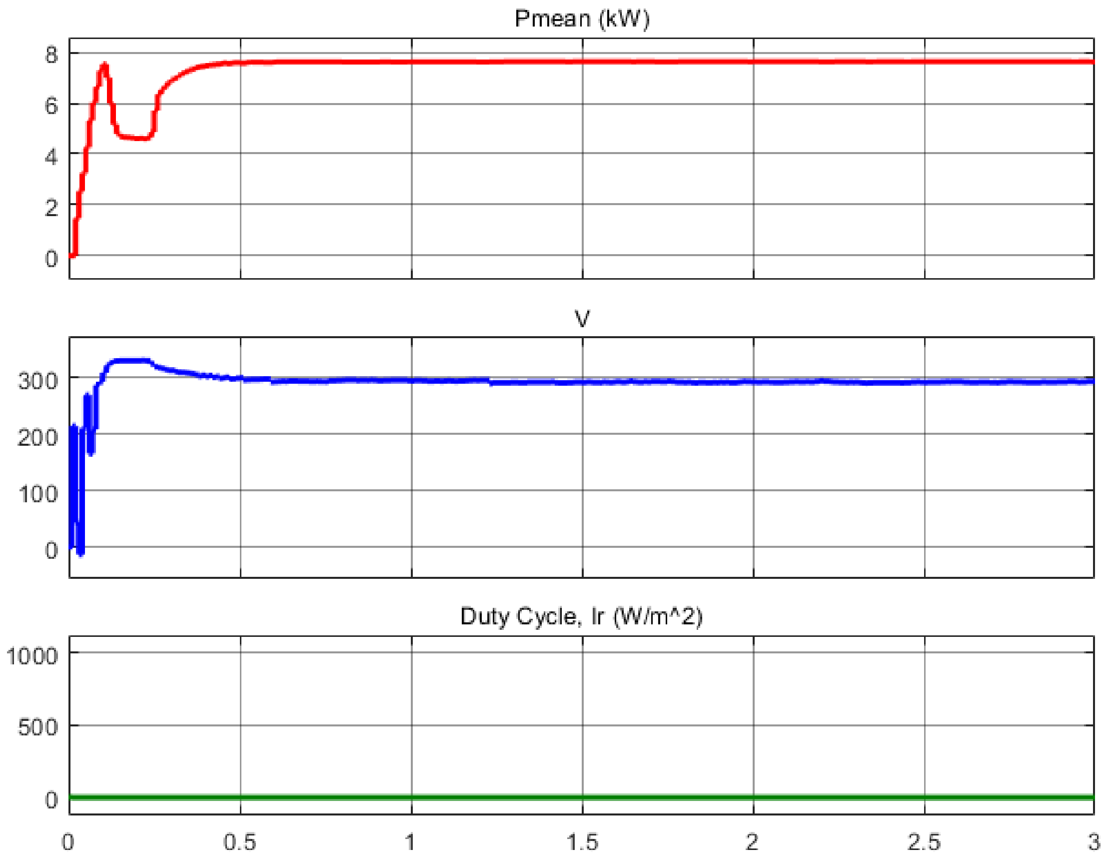
RESULTS (GRID DISCONNECTED WITH CONSTANT IRRADIANCE)

Simulation Overview:

- The grid is disconnected, and the 7.5 kW PV array meets the 5.1 kW load demand.
- Voltage remains stable at 300V, indicating the PV array's self-sufficiency.

Key Results:

- The PV array generates sufficient power without grid support.
- The simulation demonstrates the robustness of the system in a standalone scenario.



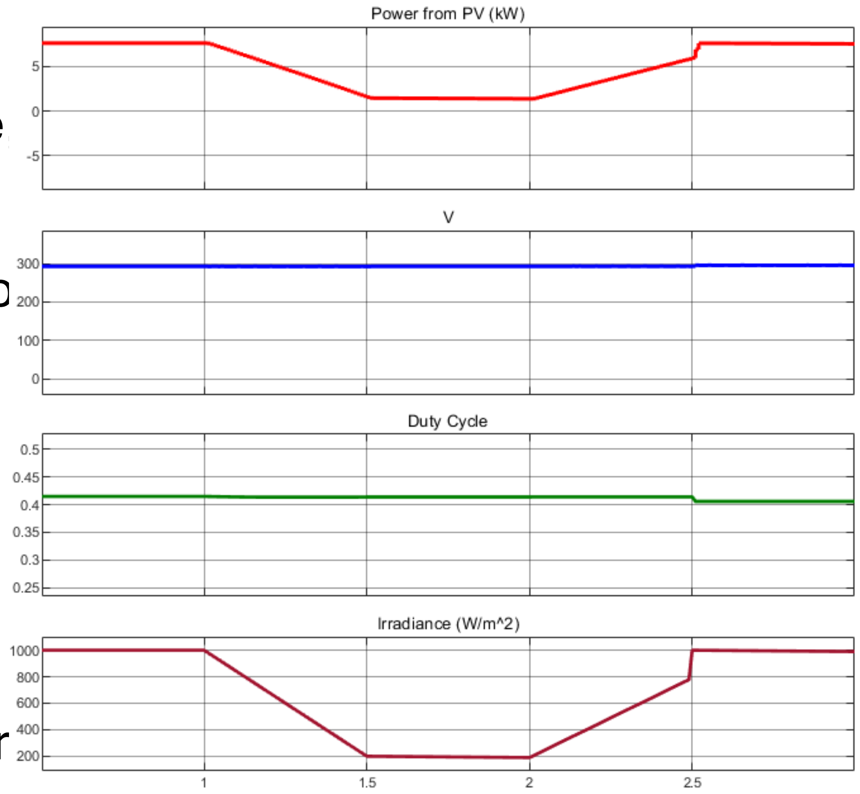
RESULTS (GRID-CONNECTED SCENARIO WITH VARYING IRRADIANCE)

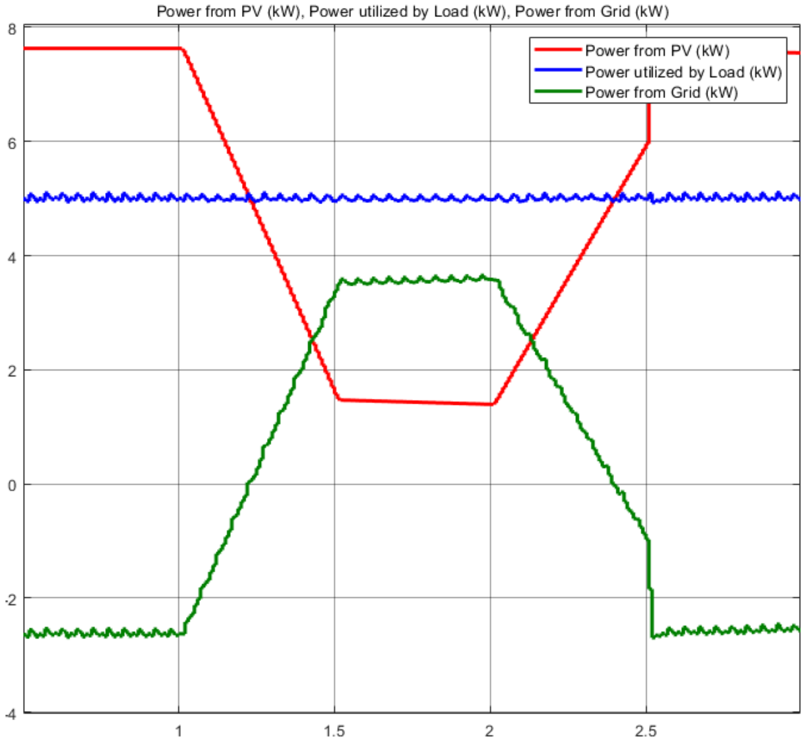
Simulation Overview:

- The PV array is connected to the grid with varying irradiance allowing for net metering.
- The excess power generated by the PV array is fed back into the grid.

Key Results:

- The system adapts to varying irradiance levels, exporting power to the grid during high irradiance periods.
- Under reduced irradiance, the system draws additional power from the grid to meet the load.





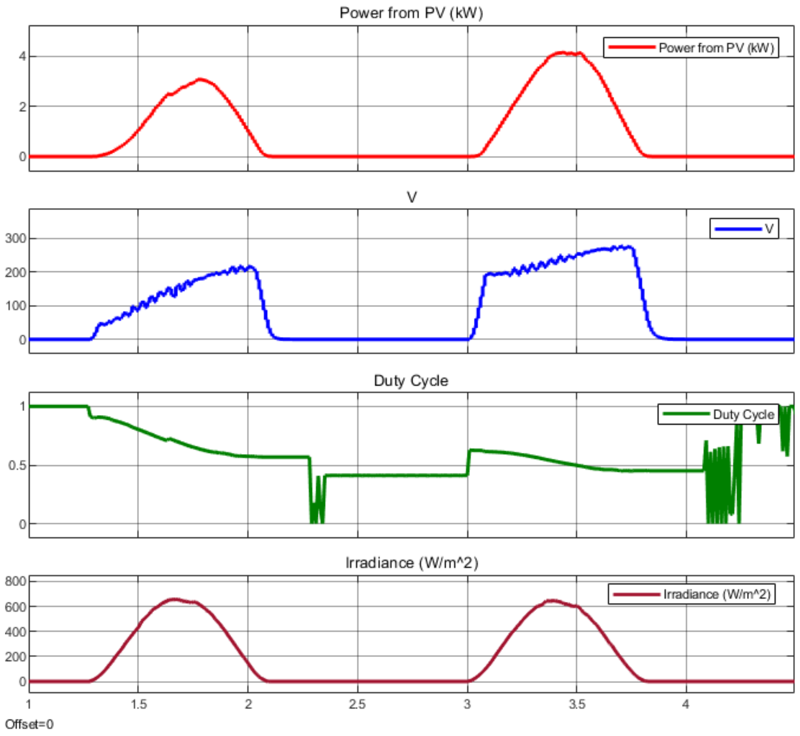
RESULTS (GRID CONNECTED WITH REALISTIC IRRADIANCE AND TEMPERATURE)

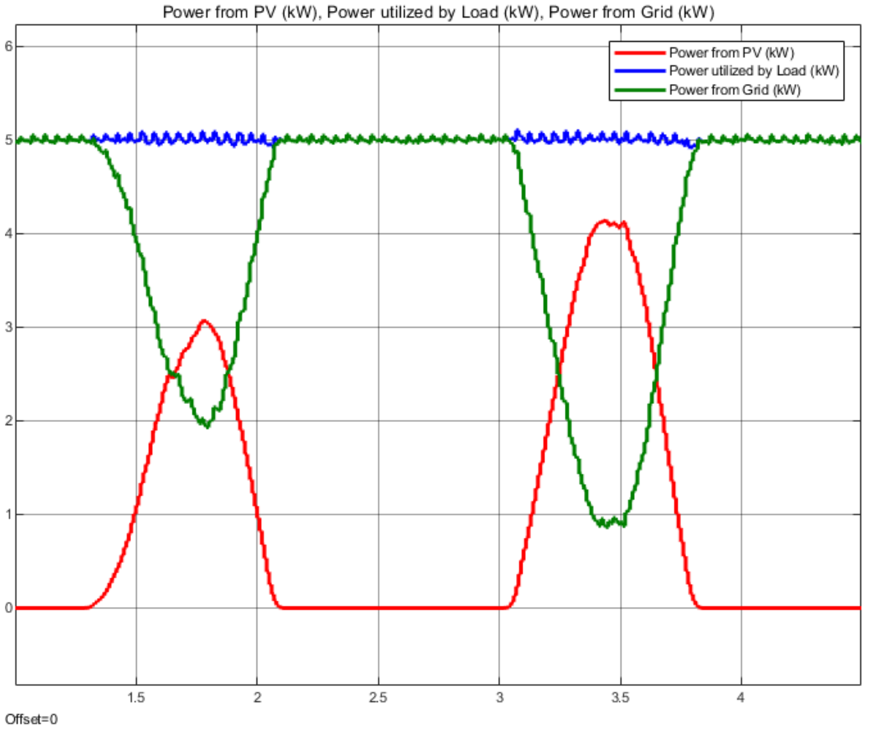
Simulation Overview:

- The simulation incorporates realistic irradiance patterns, simulating the day and night cycle.
- The temperature is kept constant at 25°C for consistency.

Key Results:

- The model accurately represents the varying power output from the PV system throughout the day.
- The simulation captures the real-world behavior of the system, reflecting the impact of changing sunlight intensity.



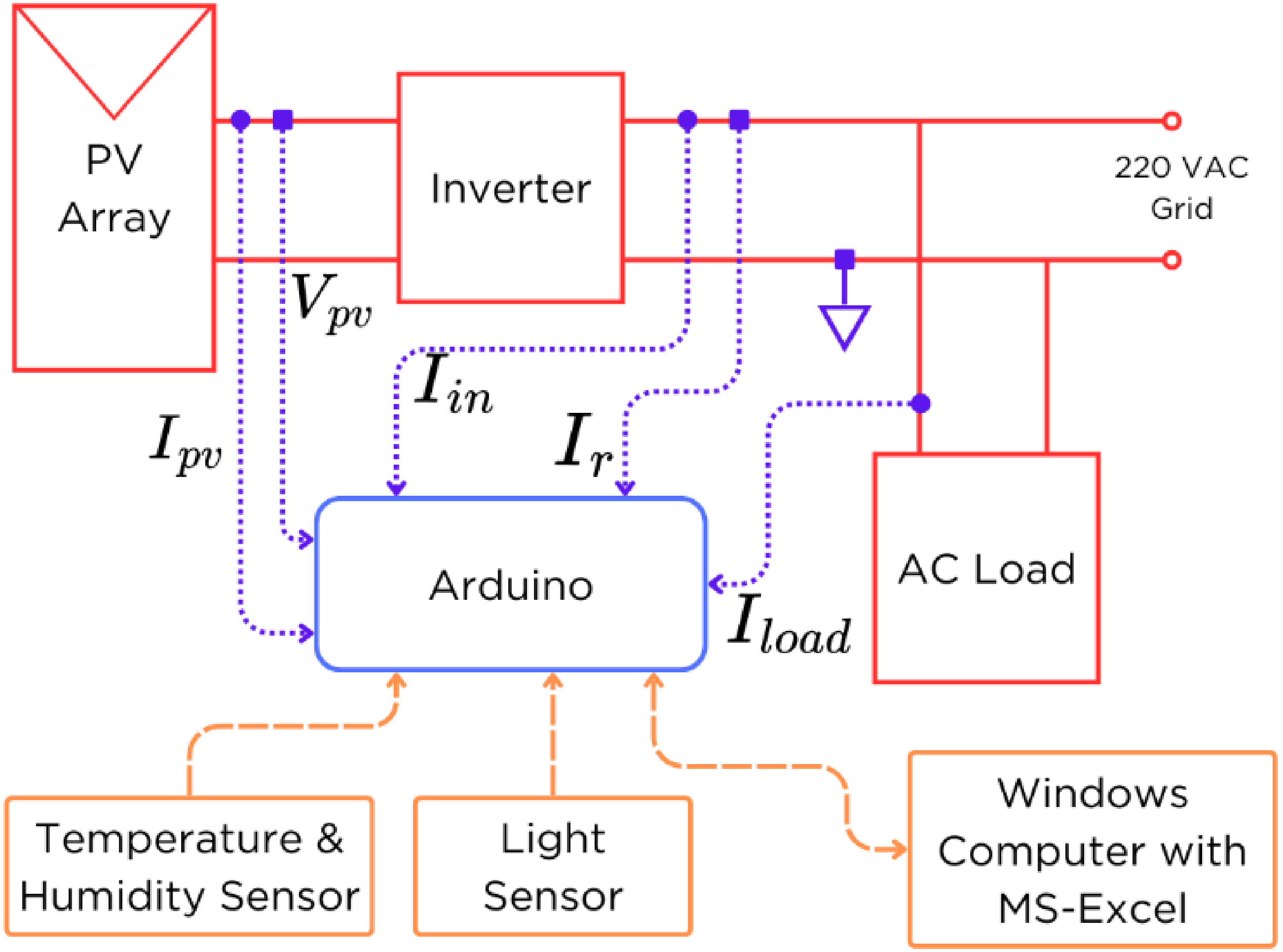


DEVELOPMENT AND EVALUATION OF AN ARDUINO-BASED DATA LOGGING SYSTEM INTEGRATED WITH MICROSOFT EXCEL FOR MONITORING ON-GRID PHOTOVOLTAIC SYSTEMS

ARDUINO-BASED DATA LOGGING SYSTEM FOR PV SYSTEMS

- An Arduino-based data logging system designed for on-grid photovoltaic (PV) systems.
- The system is integrated with Microsoft Excel for data storage and analysis.
- Arduino reads analog signals from voltage and current sensors placed between the PV array, inverter, load, and grid.
- Additional sensors measure temperature, humidity, and solar irradiance.
- The Arduino is connected to a Windows computer via USB, where Microsoft Excel stores and analyzes the data.
- The Arduino transmits voltage, current, and calculated values like power, irradiance, and temperature to Excel at regular intervals.
- MS Excel serves as the data analysis platform, enabling detailed performance evaluation of the on-grid PV system.

BLOCK DIAGRAM OF THE PROPOSED METHODOLOGY



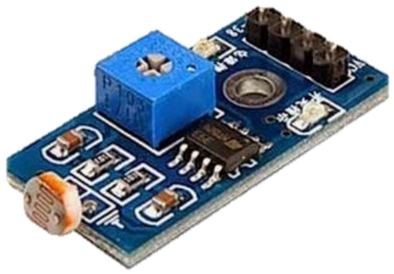
HARDWARE DESIGN FOR ON-GRID PV SYSTEM DATA LOGGING

Arduino Uno Microcontroller

- Central processing unit for data logging.
- Interfaces with sensors, collects data, and communicates with external devices like Microsoft Excel.
- Features ample digital and analog input/output pins, allowing integration with multiple sensors and peripherals.

ARDUINO-BASED DATA LOGGING SYSTEM FOR PV SYSTEMS

Integrated Sensors



LDR Module

Temperature and humidity sensor

Voltage Sensor

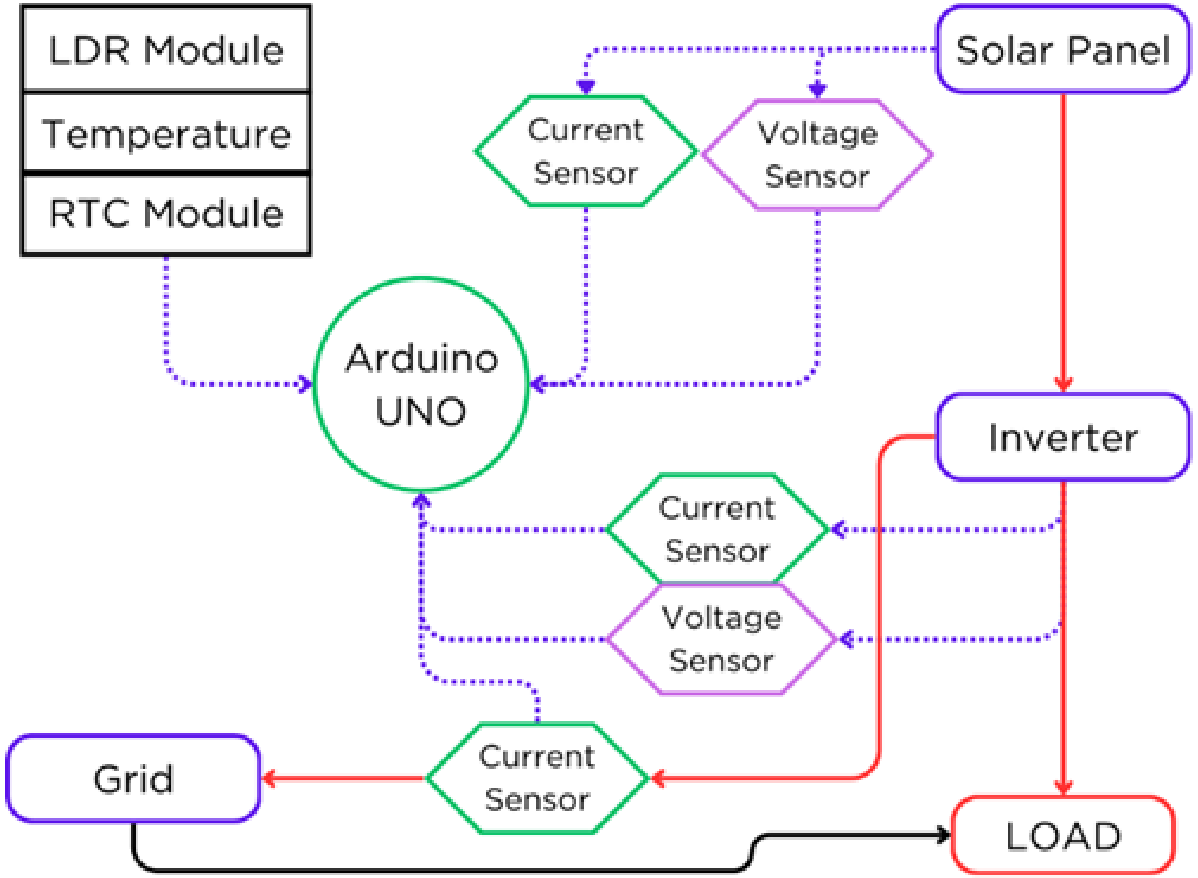
Current Sensor

RTC Module

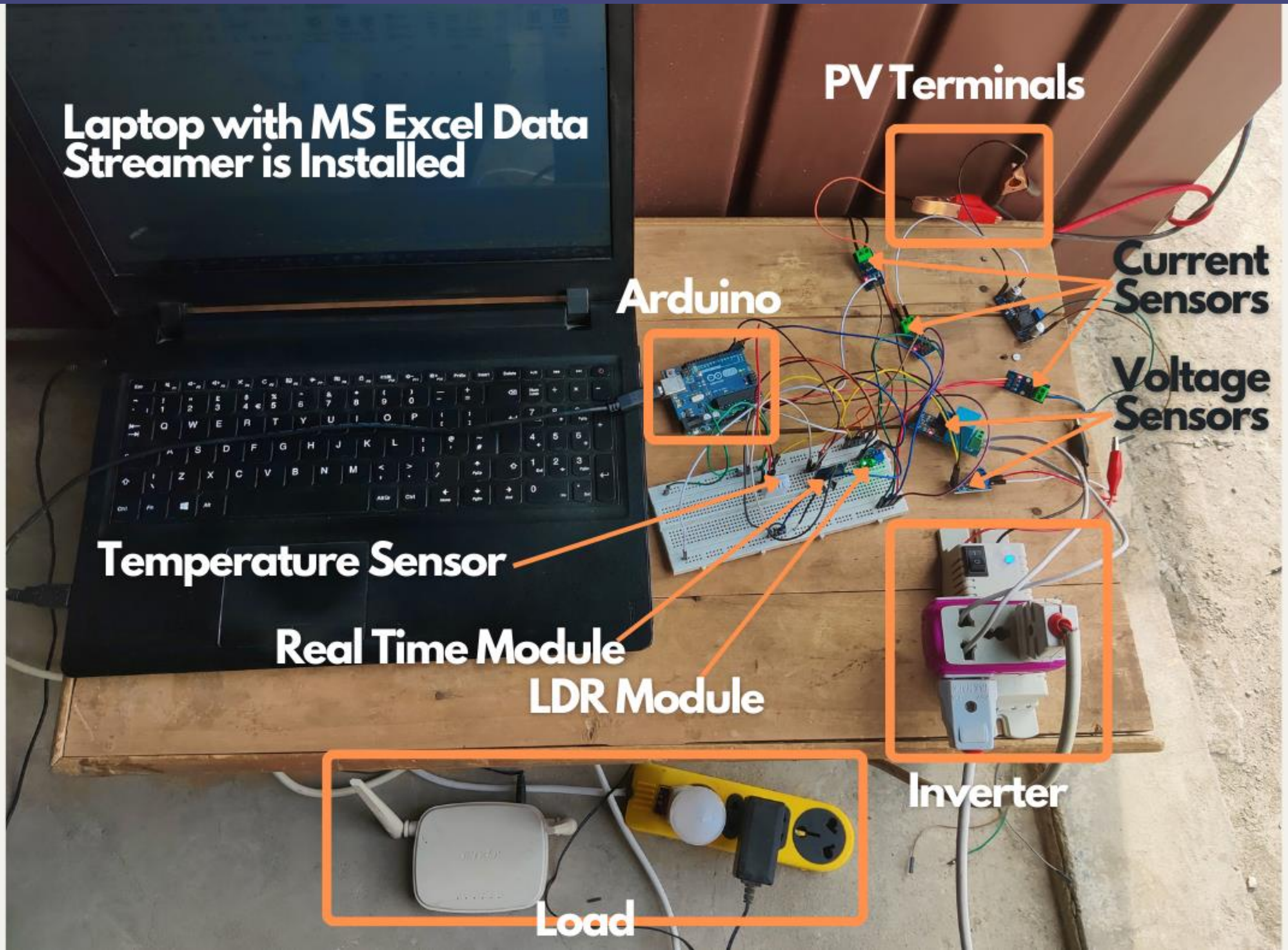
HARDWARE DESIGN FOR ON-GRID PV SYSTEM DATA LOGGING

Block Diagram

- Overall block diagram of the proposed study.
- The red and black lines illustrate the power flow.
- Blue dotted lines shows the connection of sensors with Arduino.



EXPERIMENTAL SETUP



SOFTWARE IMPLEMENTATION FOR DATA LOGGING SYSTEM

Arduino Programming:

- The Arduino IDE is used to create firmware for the Arduino Uno microcontroller.
- Firmware functions: sensor initialization, data collection, data formatting, and establishing serial communication with Microsoft Excel via USB.

Sensor Integration:

- Analog sensors (e.g., LDR, DC voltage sensor, current sensors) use analogRead() to collect sensor values.
- Digital sensors (e.g., DHT22 for temperature and humidity) require specific libraries for communication and data retrieval.

Serial Communication:

- The Arduino Uno communicates with Microsoft Excel through USB.
- Serial.print() is used to transmit data packets containing sensor readings and timestamps to Excel.

SOFTWARE IMPLEMENTATION FOR DATA LOGGING SYSTEM

Microsoft Excel Configuration:

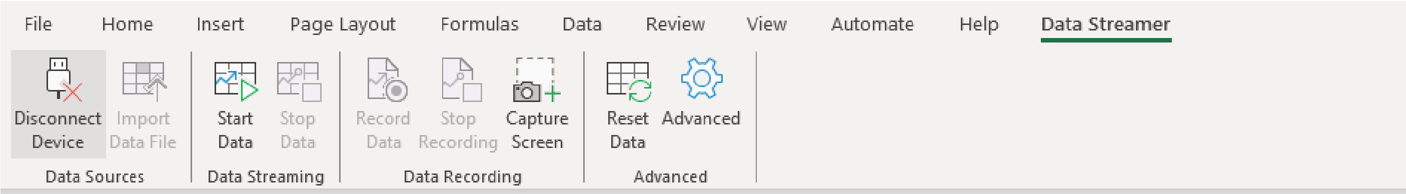
- The MS Data Streamer add-in is installed to receive and log data from the Arduino Uno.
- Data Streamer settings include serial port selection and data format (e.g., CSV).

Data Logging and Visualization:

- Data is logged to designated Excel cells, enabling real-time monitoring of PV system performance.
- Excel's charting and graphing tools are used to visualize sensor data, including solar irradiance, temperature, voltage, and current levels.

RESULTS

Realtime data logging in MS Excel.11 channels were used to log all the



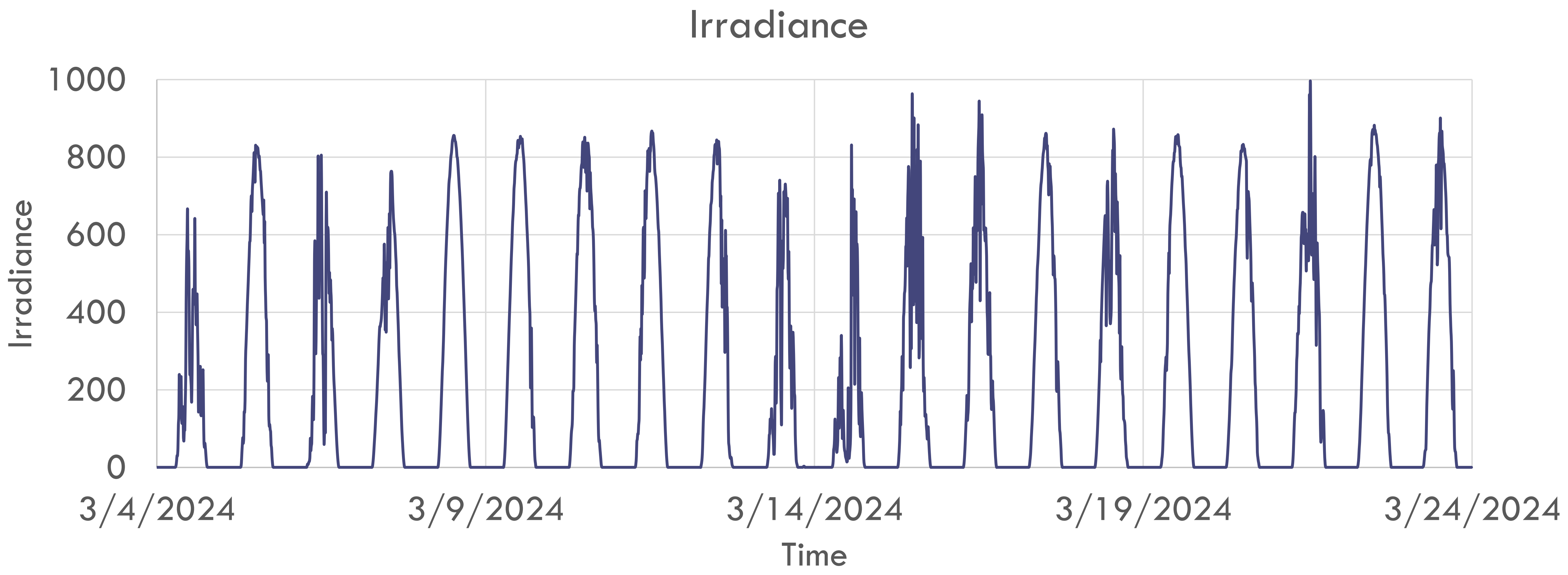
	A	B	C	D	E	F	G	H	I	J	K	L	M
3	Current Data												
4	TIME	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CH11	CH12
5	0:37:16.11	/1/2 10:45	352	25.5	20.49	222.2	0.15	0.05	0.1	3.15	12	22.22	
6	Historical Data												
7	TIME	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CH11	CH12
8	0:37:01.94	/1/2 10:44	955	25.5	16.87	219.8	0.15	0.05	0.1	2.61	12	21.98	
9	0:37:02.96	/1/2 10:44	957	25.5	16.86	222.5	0.15	0.05	0.1	2.59	12	22.25	
10	0:37:03.98	/1/2 10:44	955	25.5	16.87	221.8	0.15	0.05	0.1	2.6	12	22.18	
11	0:37:04.98	/1/2 10:44	957	25.5	16.86	222.3	0.15	0.05	0.1	2.6	12	22.23	
12	0:37:05.98	/1/2 10:44	957	25.5	16.86	218	0.16	0.06	0.1	2.61	12	21.8	
13	0:37:07.00	/1/2 10:44	851	25.5	17.49	221.6	0.15	0.05	0.1	2.7	12	22.16	
14	0:37:08.02	/1/2 10:45	377	25.5	20.34	221.2	0.15	0.05	0.1	3.14	12	22.12	
15	0:37:09.02	/1/2 10:45	371	25.5	20.37	219.2	0.15	0.05	0.1	3.15	12	21.92	
16	0:37:10.04	/1/2 10:45	370	25.5	20.38	219.5	0.15	0.05	0.1	3.15	12	21.95	
17	0:37:11.04	/1/2 10:45	370	25.5	20.38	219.2	0.15	0.05	0.1	3.15	12	21.92	
18	0:37:12.06	/1/2 10:45	131	25.5	21.81	222.2	0.15	0.05	0.1	3.36	12	22.22	
19	0:37:13.08	/1/2 10:45	132	25.6	21.81	217.7	0.16	0.06	0.1	3.38	12	21.77	
20	0:37:14.08	/1/2 10:45	146	25.6	21.72	219.1	0.15	0.05	0.1	3.36	12	21.91	
21	0:37:15.10	/1/2 10:45	110	25.5	21.04	218.5	0.15	0.05	0.1	3.4	12	21.85	

RESULTS (DATA COLLECTED FROM SENSORS)

Time	I	T	V(PV)	I(PV)	V(AC)	I(Inv)	I(Grid)	P(DC)	P(Inv)	P(Grid)
10:00	337.9	12.1	9.54	0.726	215	0.032	0.022	7.48	6.73	4.90
10:10	329.4	12.2	9.31	0.732	214	0.032	0.022	7.36	6.62	4.99
10:20	335.6	12.6	9.50	0.756	210	0.034	0.020	7.90	7.27	4.47
10:30	362.4	13.1	10.2	0.786	226	0.036	0.018	8.97	8.25	4.12
10:40	404.2	13.8	11.5	0.828	214	0.045	0.009	10.2	9.26	2.19
10:50	404	14.3	11.5	0.858	226	0.044	0.010	10.8	9.90	2.36
11:00	401.4	15.2	11.5	0.912	221	0.048	0.007	11.3	10.06	1.54
11:10	418.8	15.3	12.0	0.918	222	0.050	0.004	12.2	11.14	1.06
11:20	431.5	15.4	12.3	0.924	220	0.052	0.002	12.4	11.10	0.55
11:30	440.2	15.5	12.6	0.93	212	0.055	0.00	12.6	11.30	-0.20
11:40	440.1	16.1	12.6	0.966	218	0.056	0.00	13.4	12.25	-0.35
11:50	465.2	16.4	13.4	0.984	225	0.059	0.00	14.5	13.21	-0.90
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

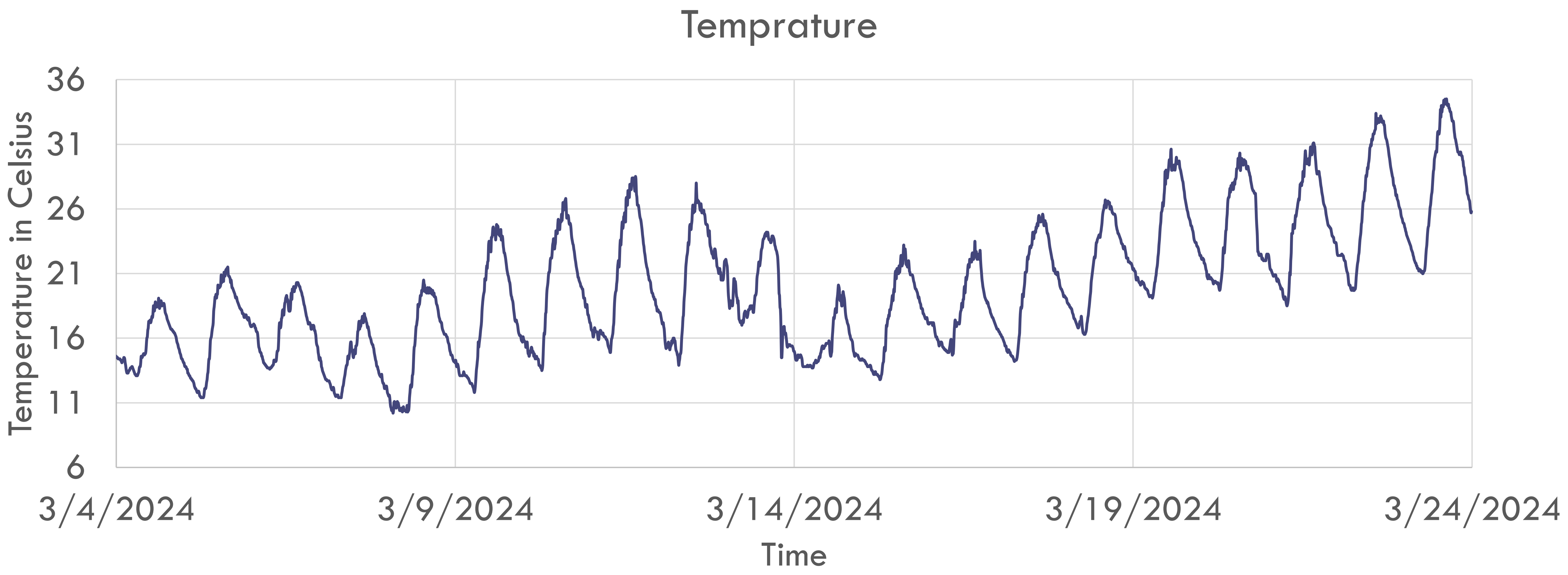
RESULTS

Irradiance Logged During The Experimental Setup



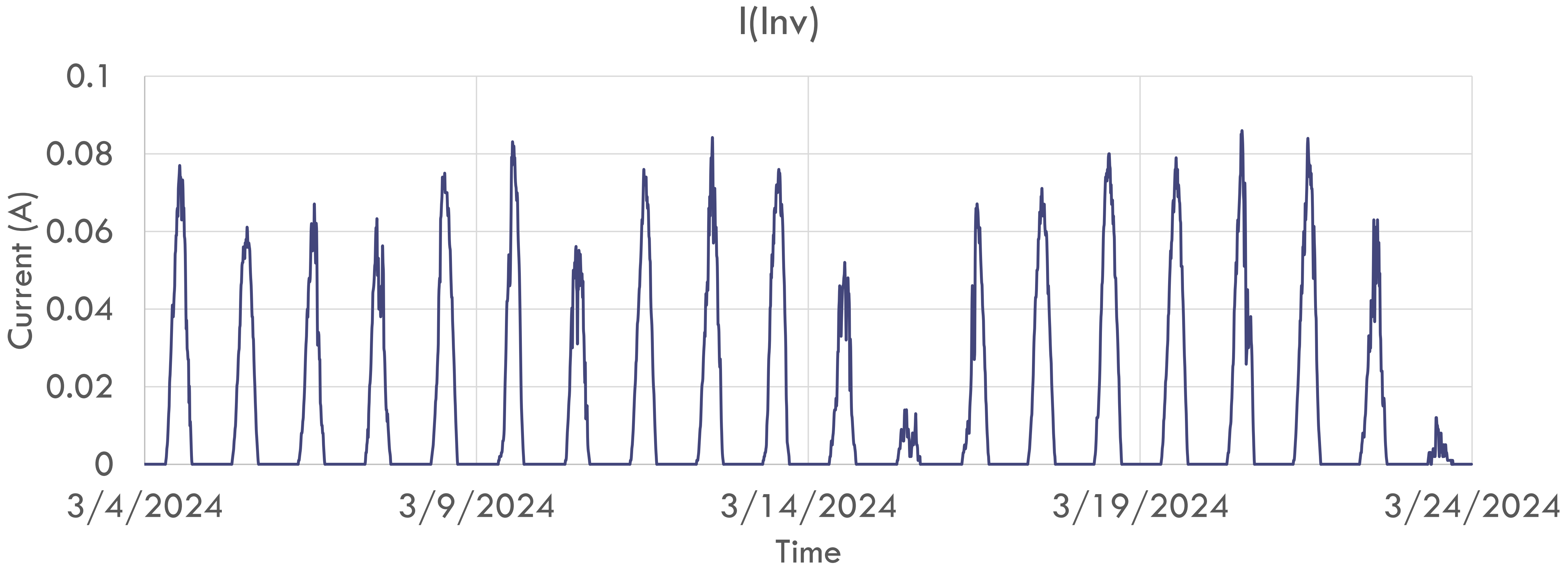
RESULTS

Temperature Measured During The Experimental Setup Recordings



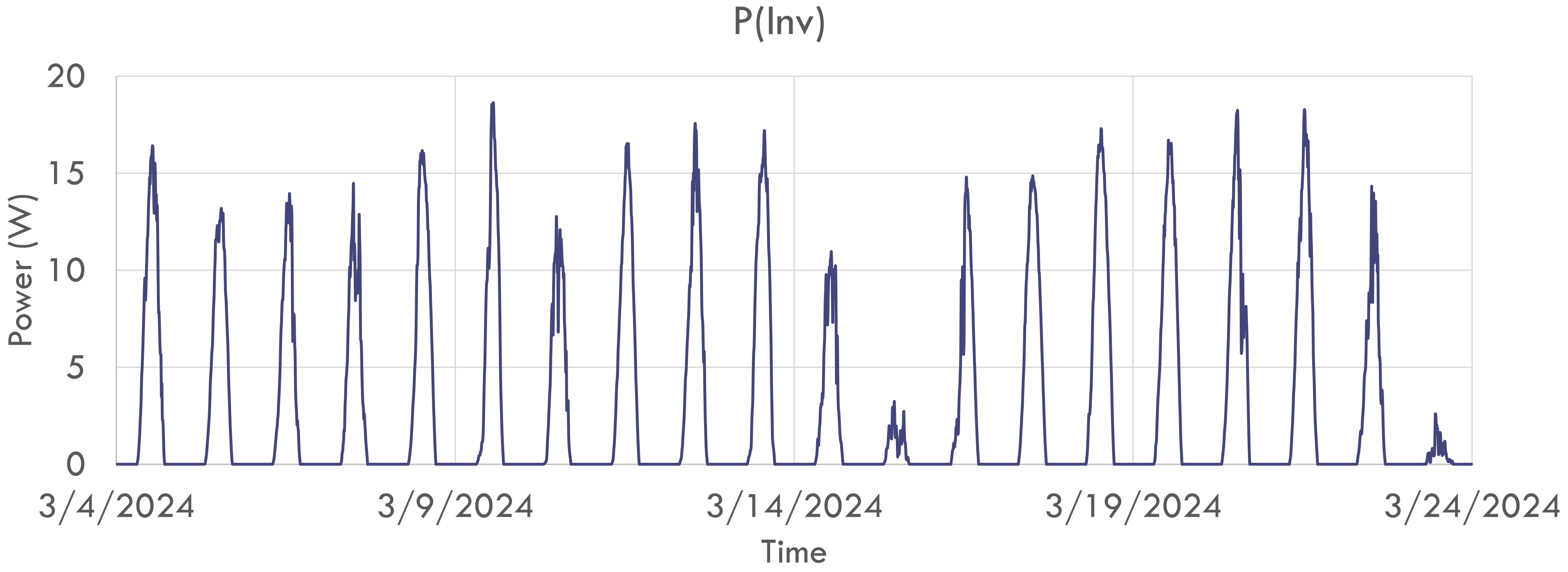
RESULTS

Inverter Current Measured Using Current Sensor.



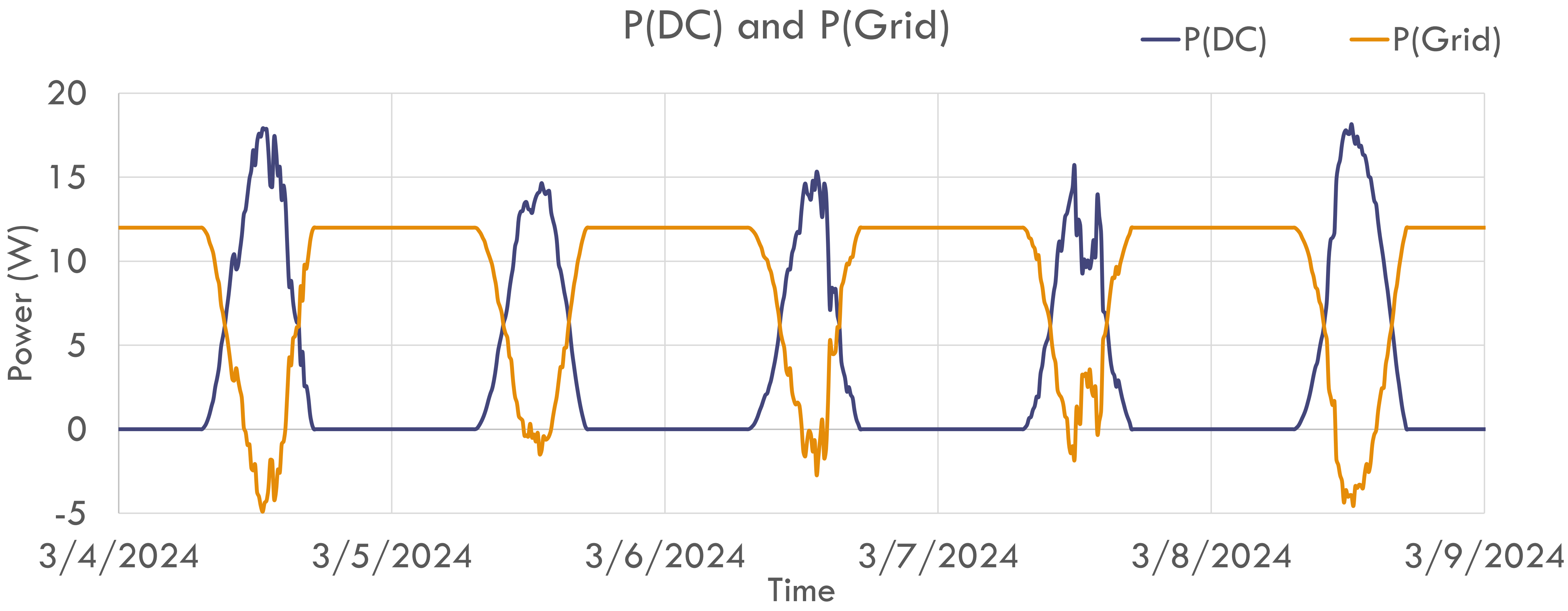
RESULTS

Output Power Calculated Using Inverter Voltage And Inverter Current



RESULTS

Power Provided By PV And Grid During Day And Night Sessions For First 5 D



EXPERIMENTAL FINDINGS

Experimental Results:

- The system provides accurate measurements of various parameters, including solar irradiance, temperature, voltage, and current levels.
- Real-time analysis and visualization are achieved through integration with Microsoft Excel.

Strengths of the System:

- Versatility and ease of use.
- Compatibility with Microsoft Excel for data logging and analysis.
- Cost-effective solution for real-time monitoring.

CONCLUSIONS, LIMITATIONS & FUTURE WORKS

KEY FINDINGS

Design and Implementation:

- Successfully designed a grid-tied solar system for a residential house in Lahore.
- Ensured compatibility with the existing power grid despite frequent outages and load shedding.
- Design considerations included meeting peak energy usage and allowing for net metering to return excess energy to the grid.

Performance Analysis and Simulations:

- Conducted simulations using System Advisor Model (SAM) and HOMER Pro to validate system performance.
- The system generated a substantial portion of the household's energy requirements, reducing grid dependence.
- Enabled net metering, providing potential credits for surplus energy fed back into the grid.

Development of Data Logging Systems:

- Introduced a cost-effective data logging system for real-time monitoring of key performance metrics.
- The system enabled early detection of issues, preventive maintenance, and optimization.
- Data collected over time provided insights into trends and informed future design and maintenance practices.

LIMITATIONS

Scope and Scale:

- The study focused on a single residential installation, limiting the generalizability to larger-scale systems or commercial applications.

Environmental Variability:

- Simulations were based on typical weather patterns in Lahore, not accounting for extreme events or climate change impacts.

Long-Term Performance Data:

- Real-time data monitoring was achieved, but a longer-term study is needed to fully understand system durability and reliability.

FUTURE WORK

Expansion to Diverse Installations:

- Future studies could include a variety of residential, commercial, and industrial solar installations in different regions to offer broader insights.

Advanced Control Strategies:

- Research into advanced control mechanisms like adaptive control, machine learning, and fuzzy logic could enhance stability and efficiency.

Integration of Hybrid Systems:

- Explore combining solar energy with other renewable sources like wind or biomass for more resilient hybrid systems.

Comprehensive Monitoring and Data Analysis:

- Conduct a longer-term study to monitor system performance, degradation over time, and maintenance needs.

LIST OF PUBLICATIONS

- **Akhtar, M.U.**, Iqbal, M.T. (2024). Design and Analysis of an On-Grid Solar System for a House in Lahore, Pakistan. *Jordon Journal of Electrical Engineering (JJEE)*. The paper is reviewed, accepted by the Journal, and in press to be published soon.

- **Akhtar, M.U.**, Iqbal, M.T. (2024). Modeling and Simulation of Grid-Tied Three- Phase PV System in Lahore, Pakistan. *European Journal of Electrical Engineering and Computer Science (EJECE).* The paper is reviewed, accepted by the Journal, and published in Volume-8, Issue-1, Feb.2024.

- **Akhtar, M.U.**, Iqbal, M.T. (2024). Development and Evaluation of an Arduino-Based Data Logging System Integrated with Microsoft Excel for Monitoring On-Grid Photovoltaic Systems. *European Journal of Electrical Engineering and Computer Science (EJECE)*. The paper is reviewed, accepted by the Journal, and in press to be published soon.

ANY QUESTIONS?