Design of a PV System for a House in Pakistan and its open source Ultra-low power data logger and controller

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Presentation Outline

- Literature Review
- Research Objectives
- PV energy systems for domestic load
- Energy demand of a rural house in Pakistan
- Solar Resources available at selected site
- Design of PV energy system for rural house
- Annual energy output of designed system
- Cost comparison of commercial data-loggers
- Data-logging and control of designed system
- Self-power consumption of designed data-logger
- Results and Conclusion

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Literature Review

❑ Survey

- ➢ Type of Controller
- ➢ Type of Sensors
- ➢ Data extraction method
- ➢ Programming Software
- ➢ Monitoring Method
- ➢ Sampling frequency
- ➢ Database type

❑ Benchmark

- ✓ Hardware
- ✓ Logged parameters
- ✓ Monitoring Method

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Literature Review

Author	Controller	Logged Parameters	Monitoring Method
E. Mulyana [1]	Atmega328	I_{PV}, $V_{PV,}$ E_{PV}, V_B, I_L, E_L	PC
N. V Nehovski [2]	STM32	I_{PV}, $V_{PV,}$ E_{PV}, V_{AC}, I_L, E_L	Web, PC
V. Gupta [3]	Arduino UNO	I_{PV}, $V_{PV,}$ E_{PV}, V_{AC}, I_L, E_L, T, H	PC
López-Vargas [4]	Arduino UNO	I_{PV}, $V_{PV,}$ E_{PV}, V_{AC}, I_L, E_L,	PC
N. A. Othman [5]	Raspberry Pi	I_{PV}, $V_{PV,}$ E_{PV}, T	Web
Choi [6]	Raspberry Pi	I_{PV}, $V_{PV,}$ $E_{PV,}$ I_L, E_L	Mobile App

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Research Objectives

- Design of an Off-Grid Solar PV system design for a rural house in Pakistan
- Comparison of commercially available PV data-loggers
- Design of an open-source PV data-logger
- Ultra-low self-power consumption of designed PV data-logger
- User friendly and simple monitoring platform
- Easy data extraction from data-logger

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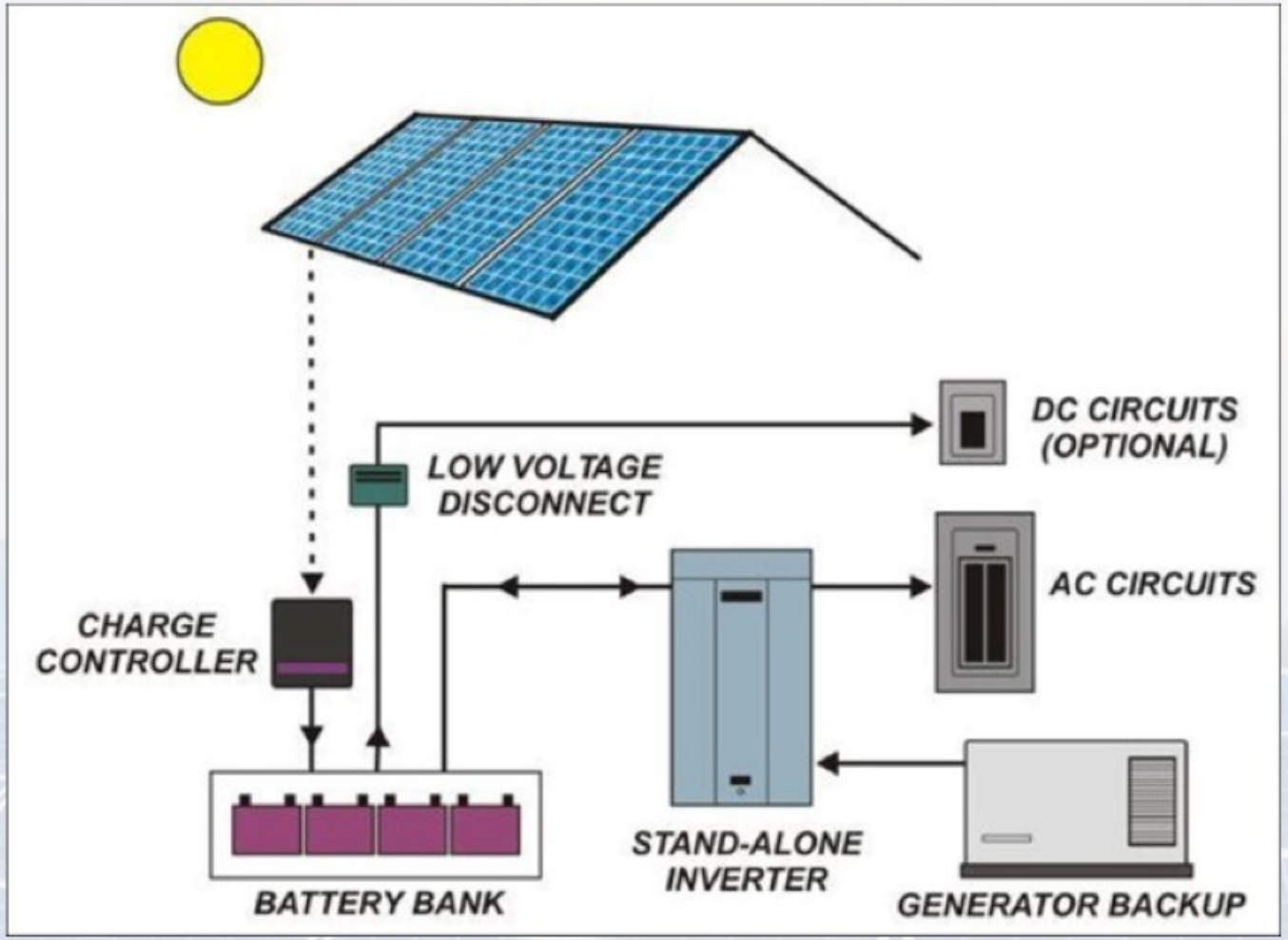
Domestic Solar Photovoltaic Systems

- Grid-tied PV system without battery
- Grid-tied PV system with battery
- Off-grid system



Off-Grid PV system

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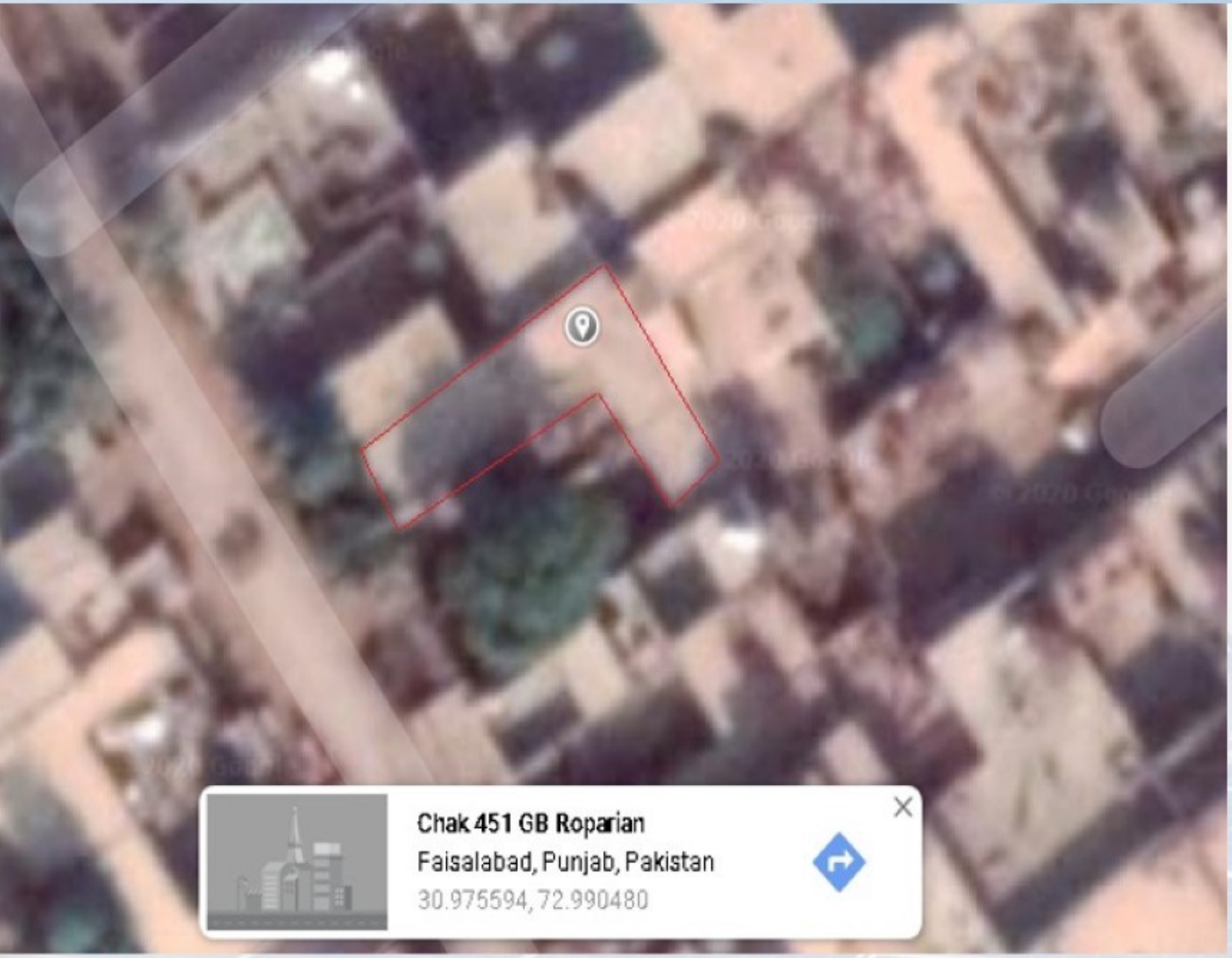
Site Specifications



- Available Area: 278 m^2
- Monthly Energy Demand: 40 kWh
- Solar Irradiance: 5.27 $kWh/m^2/day$
- Avg. Annual Temp: 24 C
- High load-shedding

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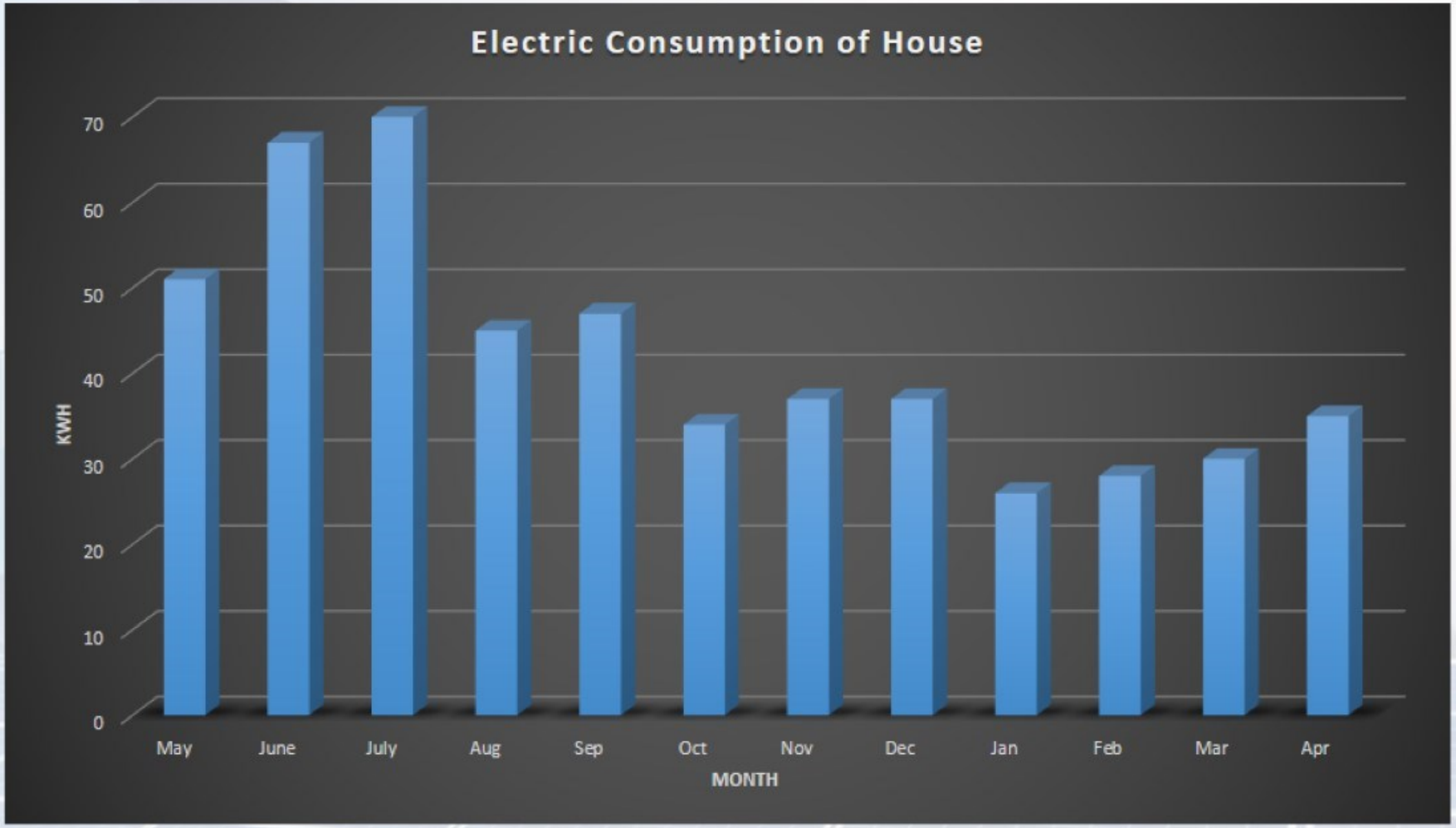
Energy demand of house



- Average Energy demand of the house is 40 kWh per month

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Solar resources of selected site

SOLAR GHI RESOURCE

Remove

Choose Data Source: Enter monthly averages | Import from a time series data file or the library

Download From Internet... | Import... | Import and Edit... | Library:

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.607	3.496
Feb	0.619	4.357
Mar	0.601	5.239
Apr	0.597	6.097
May	0.608	6.770
Jun	0.602	6.890
Jul	0.576	6.470
Aug	0.610	6.372
Sep	0.634	5.774
Oct	0.665	4.939
Nov	0.632	3.785
Dec	0.574	3.075

Annual Average (kWh/m²/day): 5.27

Downloaded at 6/25/2020 10:50:07 PM from:
National Renewable Energy Lab database.
National Solar Radiation Database
CellNumber: 321131
CellDimensions: 40km x 40km
CellMidpointLatitude: 31.046
CellMidpointLongitude: 72.799

Scaled Annual Average (kWh/m²/da 5.27 {..} Plot... Export...

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➢ Annual Average Solar GHI Resource of selected site are 5.27 kWh/m²/day

Annual Temperature graph of site

- Annual Average Temperature of selected site is 24 C

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Major components of designed off-grid PV system

- ❑Solar Photovoltaic (PV) panels (560 W)
- ❑PV Inverter (1 kW)
- ❑Battery Bank (250Ah, 24V)
- ❑Mounting frames for solar panels
- ❑PV combining boxes
- ❑Connection cables
- ❑Main protection and metering panel

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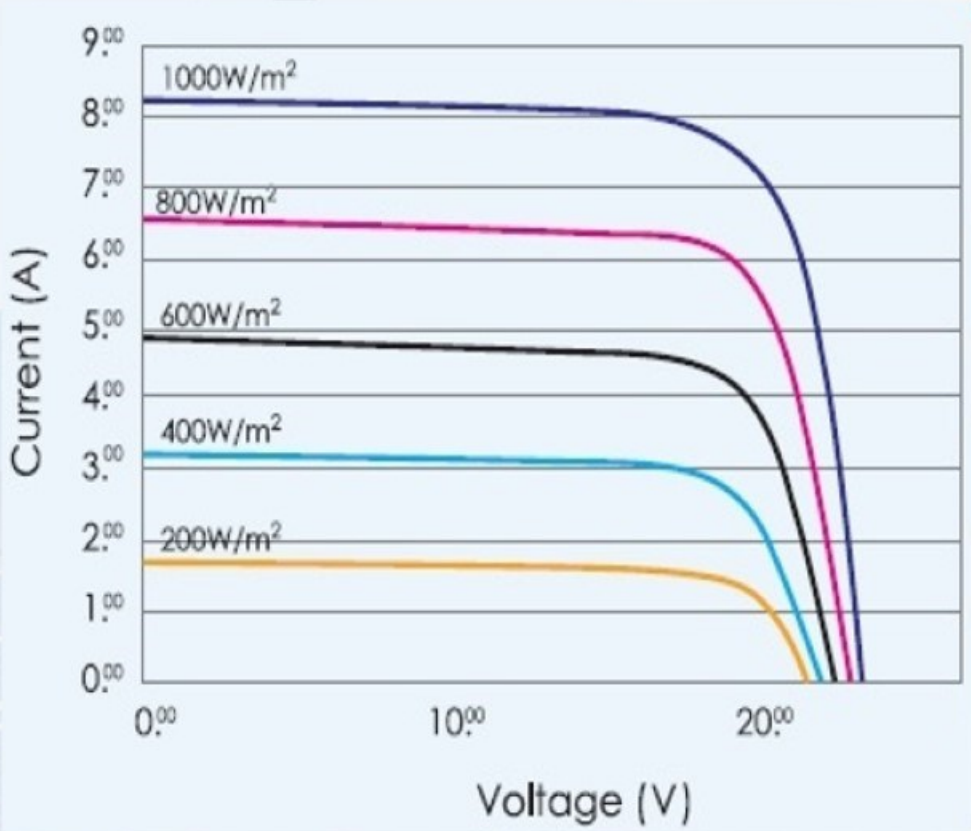
Technical Specifications of Solar Panels

- 4 Solar Panels of 140 w each



ELECTRICAL DATA @ STC	TSM-140 PC 20
Peak Power Watts-P_{MAX} (Wp)	140
Power Output Tolerance-P_{MAX} (%)	-3/+3
Maximum Power Voltage-V_{MP}(V)	17.9
Maximum Power Current-I_{MPP} (A)	7.83
Open Circuit Voltage-Voc (V)	22.3
Short Circuit Current-Isc (A)	8.30
Module Efficiency η_m (%)	13.9

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Technical Specifications of battery bank

- Narada AcmeG series 12NDF225 (2 batteries)
- AGM-Acid Valve-Regulated Lead Acid battery
- Patent Terminal sealing & front access
- Self-regulating pressure relief valve with flame arrester
- Terminal cover for insulation with flexible access
- Low self-discharge rate
- Comply with IEC, IEEE, UL, EN, CE standards, etc.
- Design life at 25°C (77°F): 12+ years

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Technical Specifications of Inverter

Sr.	Item	Specification
1	Max. PV Array Power	1200W
2	Rated Output Power	1000W
3	Maximum PV Array Open Circuit Voltage	55 VDC
4	MPPT Range @ Operating Voltage	15 VDC ~ 55 VDC
5	Nominal Output Voltage	230 VAC
6	Nominal Output Current	4.5 A
7	Power Factor	> 0.8
8	Maximum Conversion Efficiency (DC/AC)	93%
9	Frequency Range	50 Hz/60 Hz (Auto sensing)
10	Maximum Solar Input Current	40 A
11	Output Waveform	Pure sine wave
12	Efficiency (DC to AC battery)	93 %
13	Battery Voltage	24 VDC
14	Maximum battery Charge Current (Solar)	40 A

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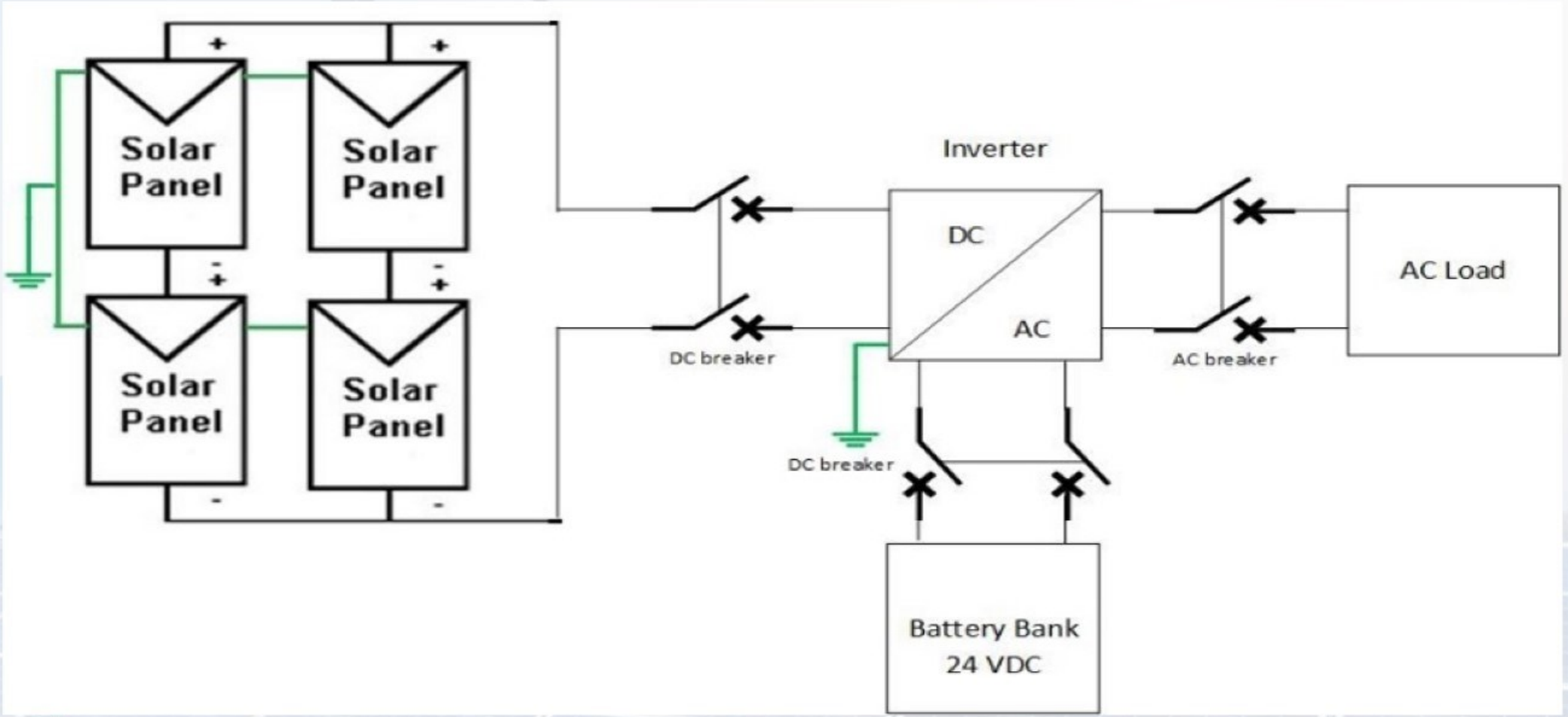
Layout of Designed System



Technical Specifications of Designed System

Sr.	Item	Specs
1	PV voltage	44.6 V_{oc}
2	PV current	15.66 A
3	Battery Voltage	24 V
4	Battery capacity	250 Ah
5	Battery Backup	2 days
6	Max output Power	1 KW

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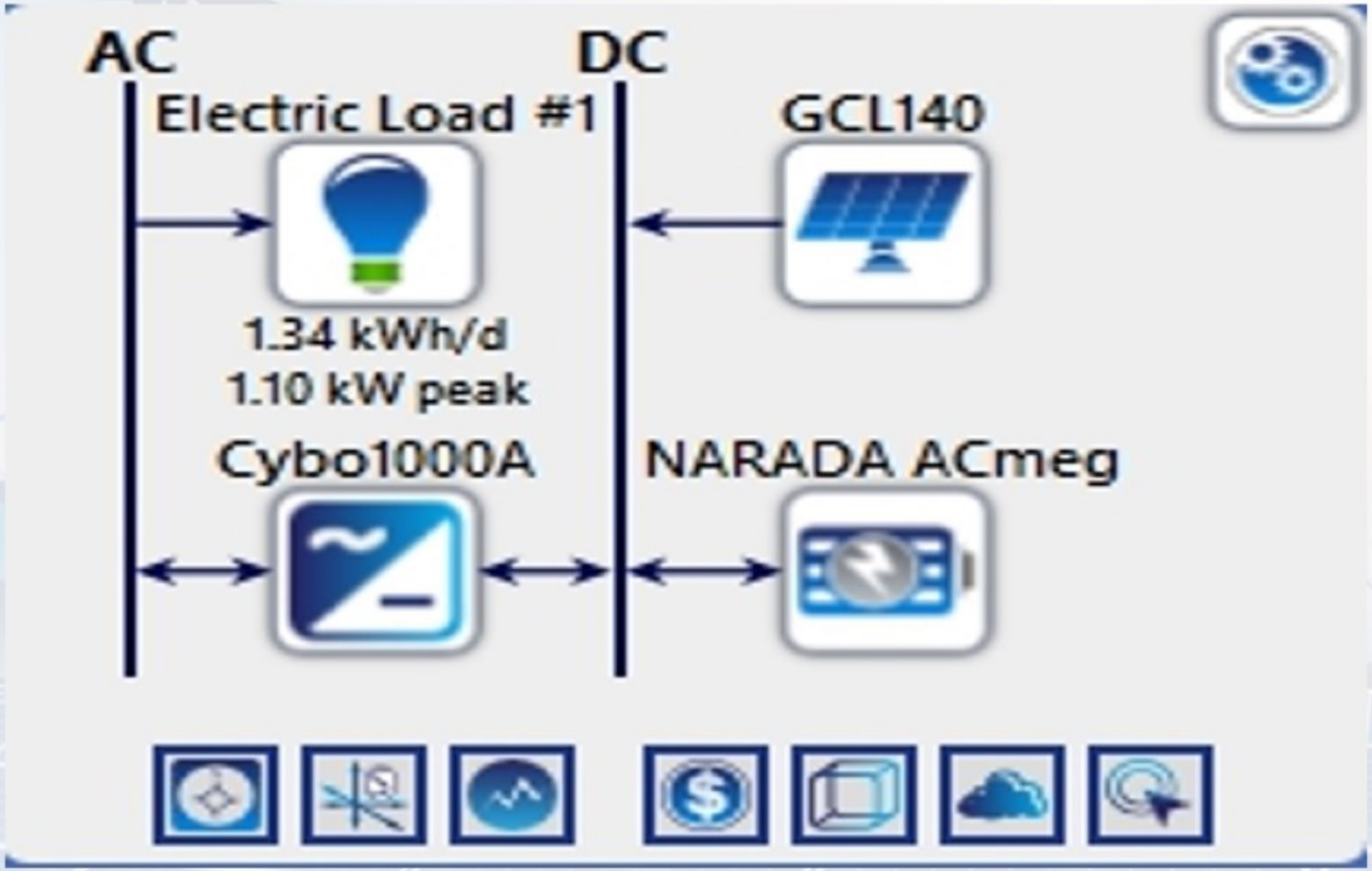
System Simulation



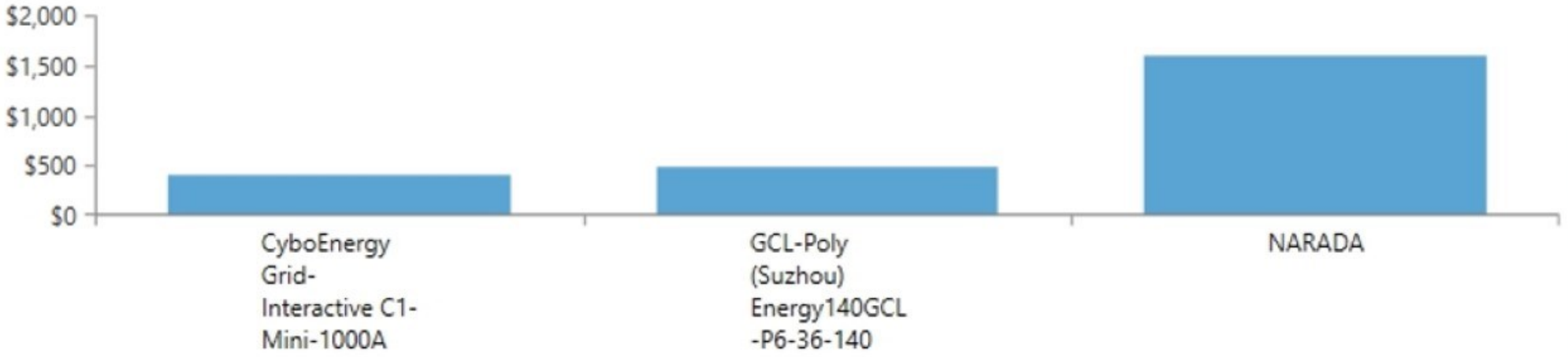
System design in Homer Pro

Cost of designed system

Cost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | NARADA | GCL-Poly (Suzhou) Energy140GCL-P6-36-140

Cost Type
- (•) Net Present
- ( ) Annualized

Categorize
- (•) By Component
- ( ) By Cost Type



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CyboEnergy Grid-Interactive C1-Mini-1000A	$203.91	$148.62	$65.90	$0.00	($20.15)	$398.28
GCL-Poly (Suzhou) Energy140GCL-P6-36-140	$285.00	$0.00	$204.68	$0.00	$0.00	$489.68
NARADA	$1,000.00	$369.16	$258.55	$0.00	($29.20)	$1,598.51
System	$1,488.91	$517.77	$529.13	$0.00	($49.35)	$2,486.47

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Annual PV Output Analysis of System

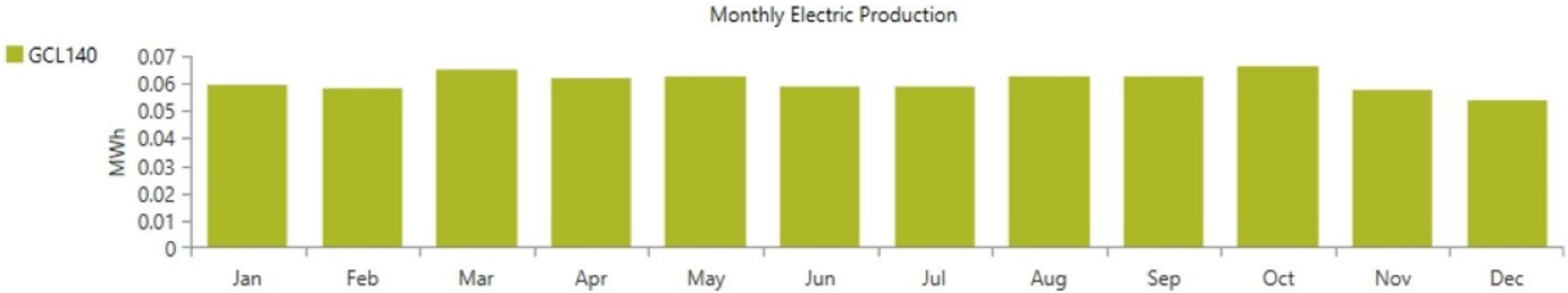
Cost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | NARADA | GCL-Poly (Suzhou) Energy140GCL-P6-36-140

Production	kWh/y
GCL-Poly (Suzhou) Energy140GCL-P6-36-140	729
Total	729

Consumption	kWh/yr	%
AC Primary Load	489	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	489	100

Quantity	kWh/yr	%
Excess Electricity	153	21.1
Unmet Electric Load	0.168	0.0344
Capacity Shortage	0.484	0.0990

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	5,497	%



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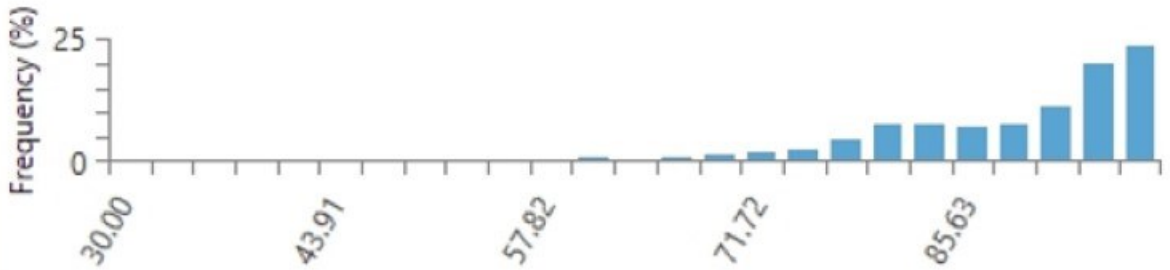
Battery Power Analysis of System

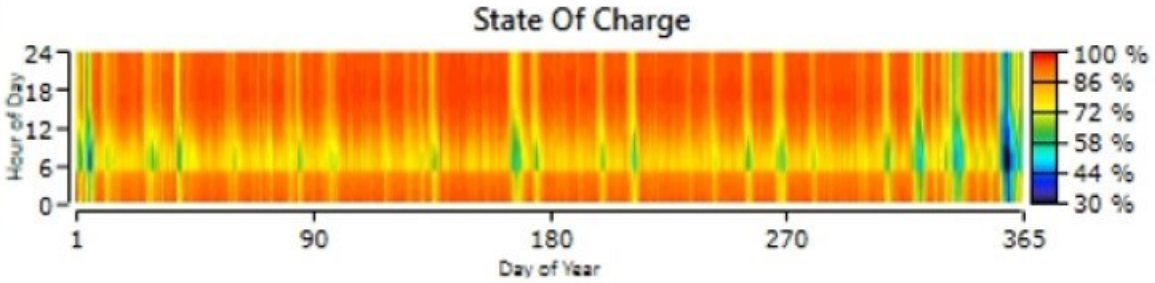
Cost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | NARADA | GCL-Poly (Suzhou) Energy140GCL-P6-36-140

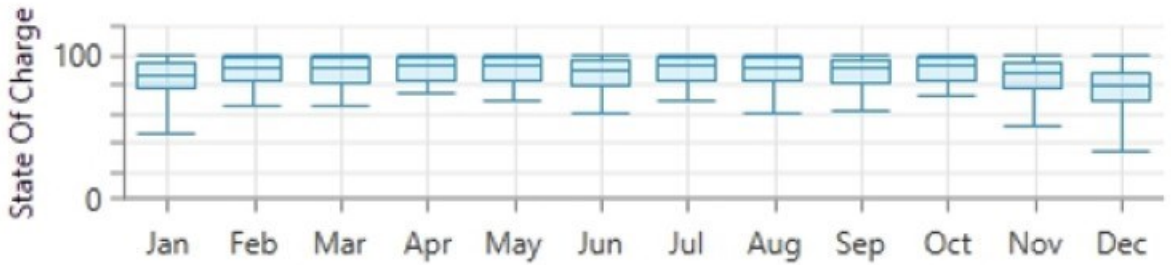
Quantity	Value	Units
Batteries	4.00	qty.
String Size	2.00	batteries
Strings in Parallel	2.00	strings
Bus Voltage	24.0	V

Quantity	Value	Units
Autonomy	85.0	hr
Storage Wear Cost	0.152	$/kWh
Nominal Capacity	6.78	kWh
Usable Nominal Capacity	4.75	kWh
Lifetime Throughput	5,702	kWh
Expected Life	13.5	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	455	kWh/yr
Energy Out	389	kWh/yr
Storage Depletion	2.32	kWh/yr
Losses	68.4	kWh/yr
Annual Throughput	421	kWh/yr







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Why need a data-logging and monitoring system

- Future improvements of PV system design fro specific locations
- Fault troubleshooting
- Panel cleaning schedule for different locations
- Performance analysis of PV system
- Sense the battery failure, better PV system's maintenance

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Commercial PV data-loggers

Sr.	Monitoring System	Manufacturer	Price
1	SmartPV monitoring system	ECO Eye	140 CAD
2	Geo Solo II PV	GEO	128 CAD
3	Intuition PV monitoring system	OWL	166 CAD
4	SolarFox Solar display system	SOLEDOS GmbH	180 CAD
5	SolarEdge PV monitoring system	SolarEdge	433 CAD
6	Tigo PV monitoring system	Tigo Energy	389 CAD
7	Enlighten PV monitoring system	Enphase	20 CAD/year

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Basic Components of designed PV data-logger

- ESP32-S2 microcontroller
- Memory card reader
- ACS712 current sensor (20A)
- Voltage sensor (Voltage divider)
- Light sensor (Light dependent resistor)

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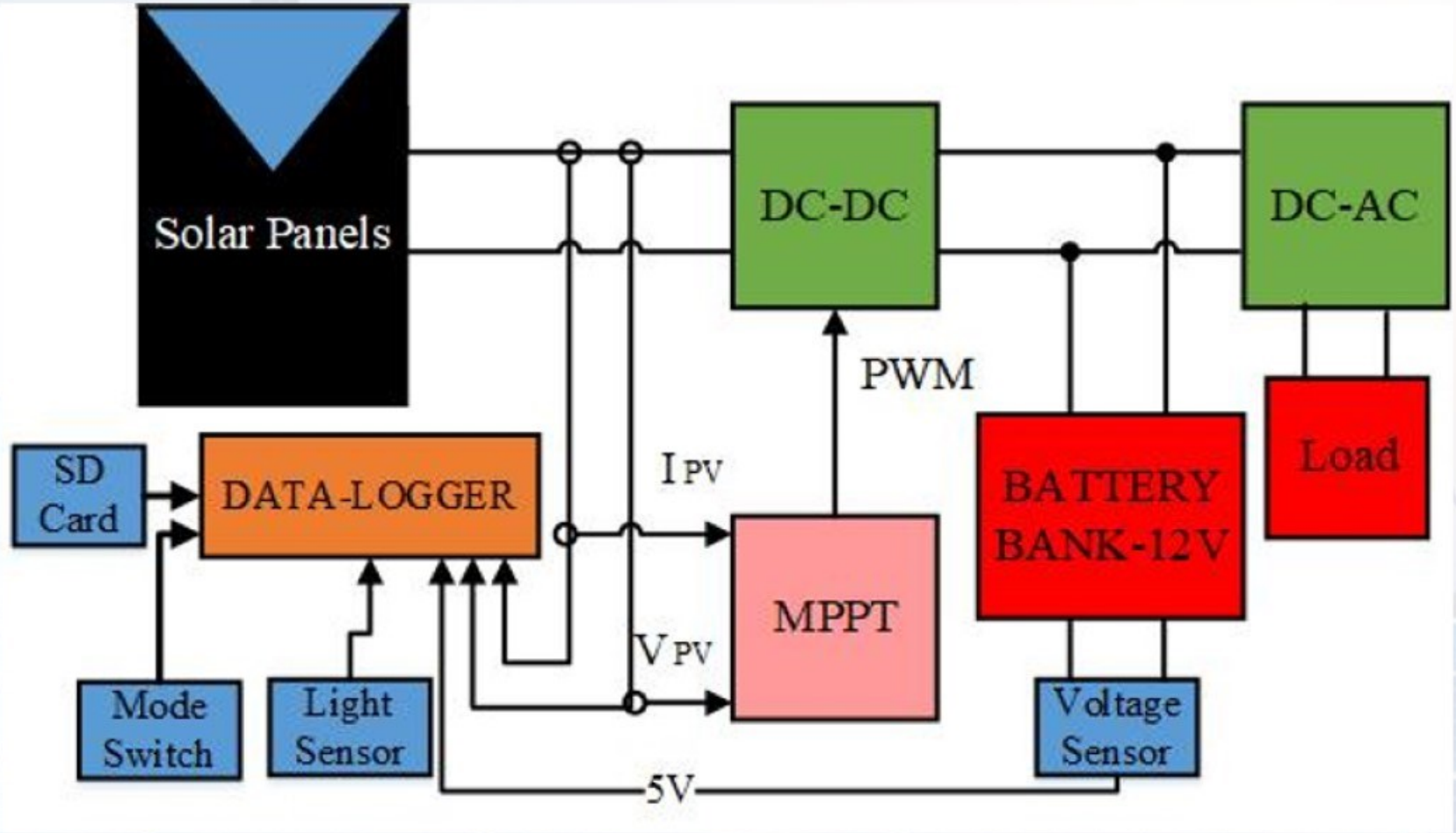
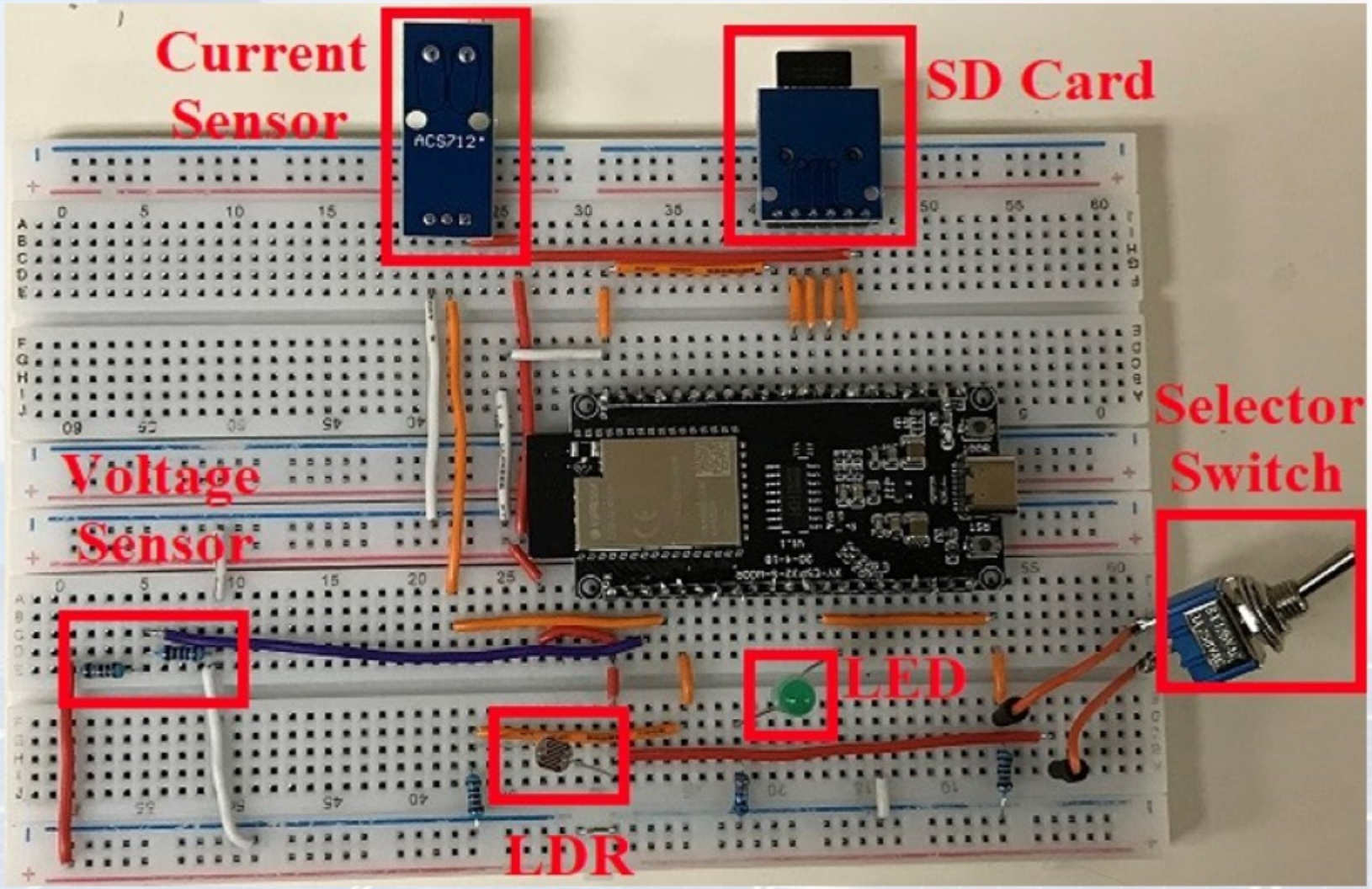
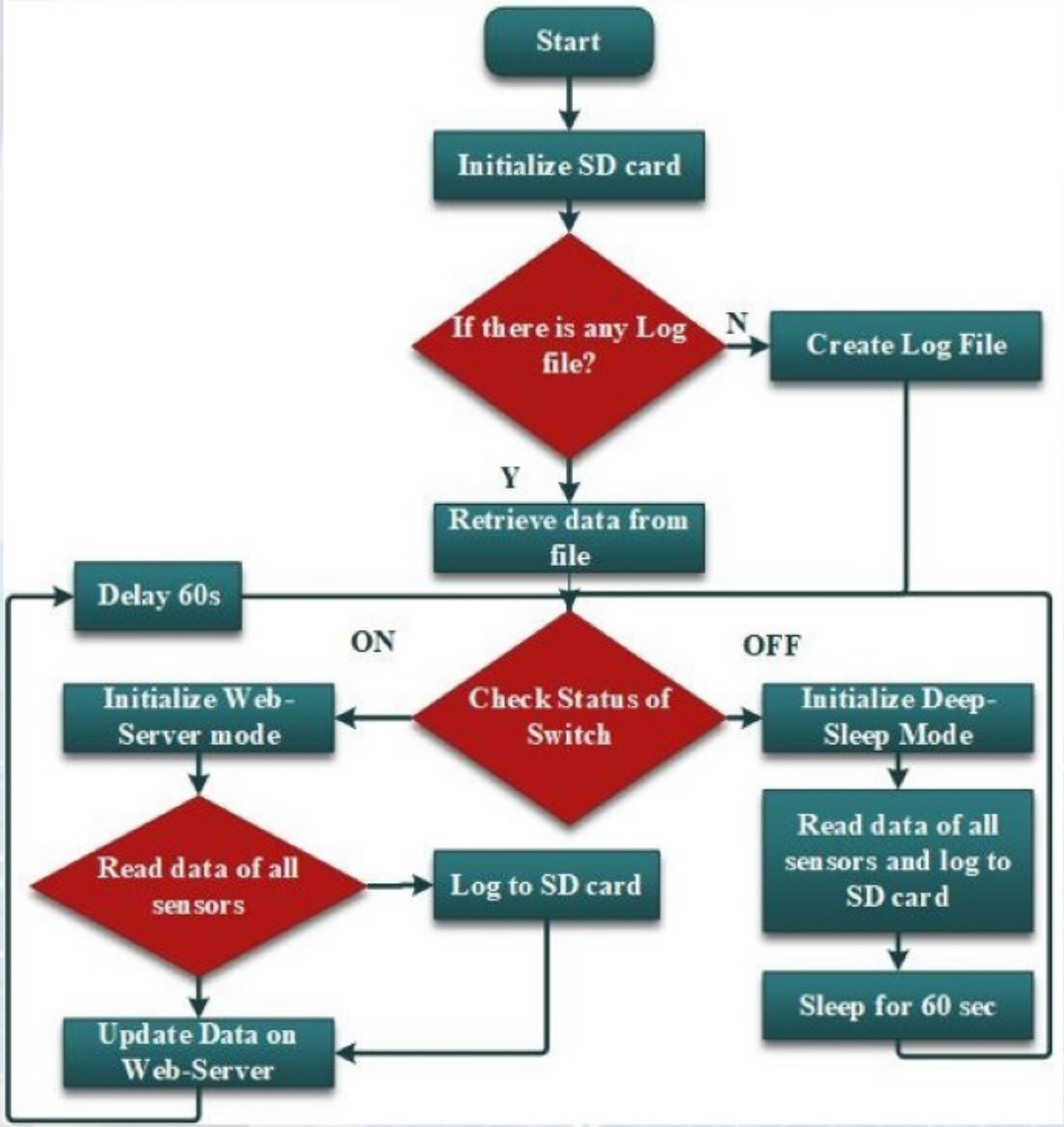
Control and Data-logging of System



Breadboard Model of the Data-logger



Programming Flow-chart



Web-Portal


172.20.10.2/DV
Tuition fees by univ...
Post-Graduation W...
Newfoundland and...
Course-1 with Sala...
Download Course...
CCECE 2020 – THE...
Data Logger v1.0
Voltage
14.11
Power
123.85
PV Current
8.8
Sunlight
100
Power/Sunlight
Voltage/Current
Records⇓
Records⇑
Refresh(ON)
Setup
Log Size
Log View
Log Erase

Self Power Consumption of Data-logger

- ❑ Monitoring = 430mW
- ❑ Deep-Sleep = 4.5mW
- ❑ Data-logging = 175mW

- ❑ Annual Energy @ 60 Sec logging cycle = 64 Wh

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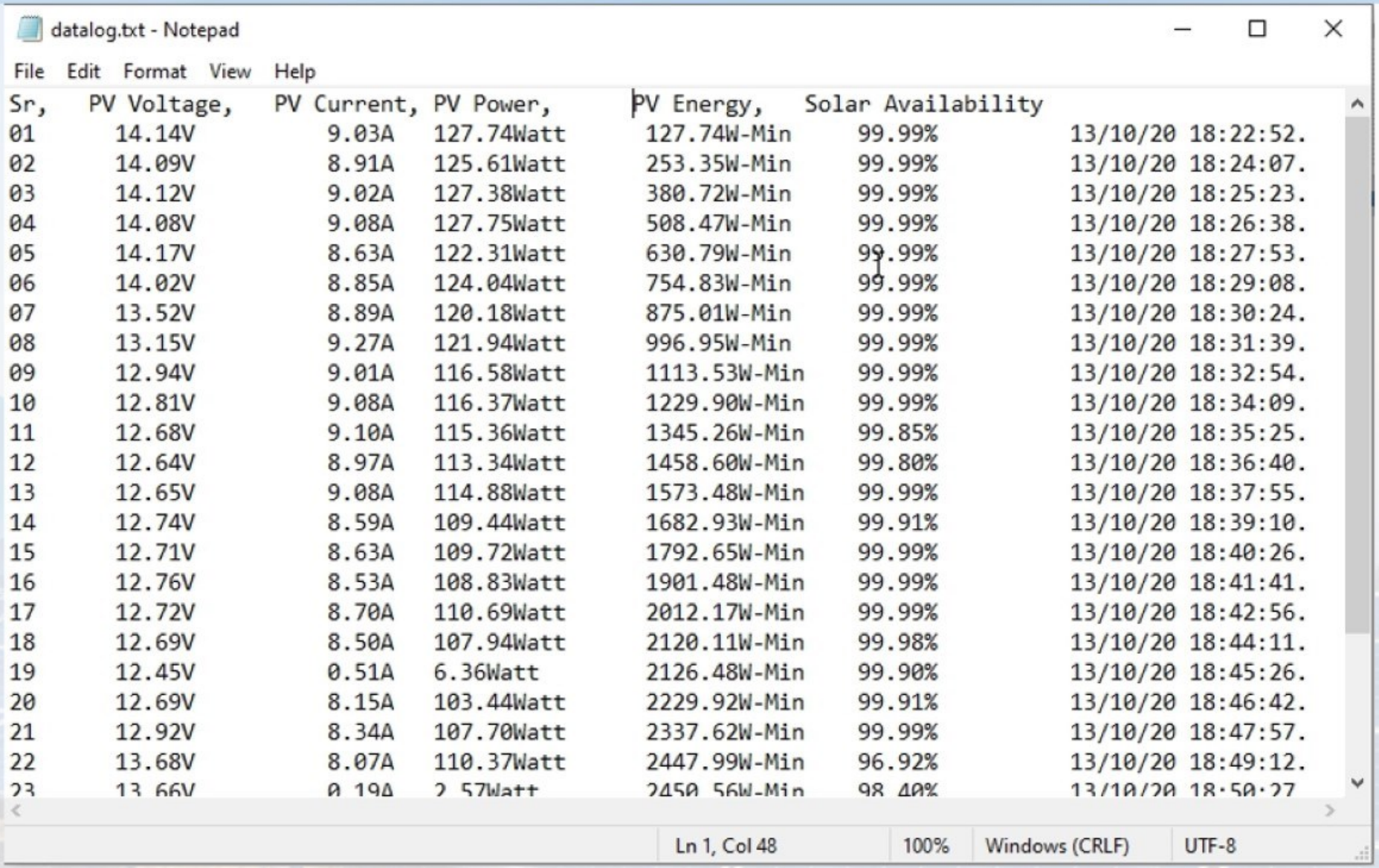
Logged data file



datalog.txt - Notepad

File Edit Format View Help

Sr,	PV Voltage,	PV Current,	PV Power,	PV Energy,	Solar Availability	
01	14.14V	9.03A	127.74Watt	127.74W-Min	99.99%	13/10/20 18:22:52.
02	14.09V	8.91A	125.61Watt	253.35W-Min	99.99%	13/10/20 18:24:07.
03	14.12V	9.02A	127.38Watt	380.72W-Min	99.99%	13/10/20 18:25:23.
04	14.08V	9.08A	127.75Watt	508.47W-Min	99.99%	13/10/20 18:26:38.
05	14.17V	8.63A	122.31Watt	630.79W-Min	99.99%	13/10/20 18:27:53.
06	14.02V	8.85A	124.04Watt	754.83W-Min	99.99%	13/10/20 18:29:08.
07	13.52V	8.89A	120.18Watt	875.01W-Min	99.99%	13/10/20 18:30:24.
08	13.15V	9.27A	121.94Watt	996.95W-Min	99.99%	13/10/20 18:31:39.
09	12.94V	9.01A	116.58Watt	1113.53W-Min	99.99%	13/10/20 18:32:54.
10	12.81V	9.08A	116.37Watt	1229.90W-Min	99.99%	13/10/20 18:34:09.
11	12.68V	9.10A	115.36Watt	1345.26W-Min	99.85%	13/10/20 18:35:25.
12	12.64V	8.97A	113.34Watt	1458.60W-Min	99.80%	13/10/20 18:36:40.
13	12.65V	9.08A	114.88Watt	1573.48W-Min	99.99%	13/10/20 18:37:55.
14	12.74V	8.59A	109.44Watt	1682.93W-Min	99.91%	13/10/20 18:39:10.
15	12.71V	8.63A	109.72Watt	1792.65W-Min	99.99%	13/10/20 18:40:26.
16	12.76V	8.53A	108.83Watt	1901.48W-Min	99.99%	13/10/20 18:41:41.
17	12.72V	8.70A	110.69Watt	2012.17W-Min	99.99%	13/10/20 18:42:56.
18	12.69V	8.50A	107.94Watt	2120.11W-Min	99.98%	13/10/20 18:44:11.
19	12.45V	0.51A	6.36Watt	2126.48W-Min	99.90%	13/10/20 18:45:26.
20	12.69V	8.15A	103.44Watt	2229.92W-Min	99.91%	13/10/20 18:46:42.
21	12.92V	8.34A	107.70Watt	2337.62W-Min	99.99%	13/10/20 18:47:57.
22	13.68V	8.07A	110.37Watt	2447.99W-Min	96.92%	13/10/20 18:49:12.
23	13.66V	0.19A	2.57Watt	2450.56W-Min	98.40%	13/10/20 18:50:27

Ln 1, Col 48 100% Windows (CRLF) UTF-8

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Costing of Data-logger

Sr.	Components	Price C$
1	ESP32-S2-WOOR	6.60
2	Card reader	0.50
3	Memory card	5.50
4	Current sensor	1.50
5	Light sensor	0.10
6	Voltage sensor	0.10
7	Selector switch	0.60
8	LED light	0.10
9	Miscellaneous	15.00
	TOTAL	**30.00**

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Research Contribution

- Reliable electrification solution for rural communities of developing countries
- Easy Fault detection of PV system by data-logger
- Ultra-low power consumption of designed PV data-logger
- Open source data-logging solution for any domestic PV system
- Simple PV monitoring and data extraction platform
- Low Cost PV data-logger

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Future Work

- Better graphics of web-portal
- Data management settings
- Centralize database for multiple data-loggers
- Load management and control

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Publications

- A. U. Rehman and M. T. Iqbal, "Design and Control of an Off-Grid Solar System for a Rural House in Pakistan," 2020 IEEE 11th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), Vancouver, BC, Canada, 2020, pp. 0786-0790.
- A. U. Rehman, M. Tariq Iqbal, Design of an Ultra-Low Powered Data-Logger for Stand-Alone PV Energy Systems, European Journal of Electrical Engineering and Computer Science, Vol. 5, No. 5, 2020.
- A. U. Rehman, H. Elsaraf, A. Zare, M. T. Iqbal, "Design and analysis of a rooftop PV system for an apartment building in Newfoundland", Proceedings of Newfoundland Electrical and Computer Engineering Conference (NECEC 2020), St. John's, Newfoundland and Labrador, Nov. 2020.
- T. Akhtar, A. U. Rehman, M. Jamil, and S. O. Gilani, “Impact of an Energy Monitoring System on the Energy Efficiency of an Automobile Factory: A Case Study,” Energies, vol. 13, no. 10, p. 2577, May 2020.

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[2] N. V Nehovski, N. N. Tomchev, T. S. Djamiykov, and K. K. Asparuhova, "Datalogger for Small Solar Systems," in 2018 IX National Conference with International Participation (ELECTRONICA), 2018, pp. 1–3.

[3] V. Gupta, P. Raj, and A. Yadav, "Design and cost minimization of PV analyzer based on arduino UNO," in 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI), 2017, pp. 1337–1342.

[4] López-Vargas, M. Fuentes, M. V García, and F. J. Muñoz-Rodríguez, "Low Cost Datalogger Intended for Remote Monitoring of Solar Photovoltaic Standalone Systems Based on ArduinoTM," IEEE Sens. J., vol. 19, no. 11, pp. 4308–4320, 2019.

[5] N. A. Othman, M. R. Zainodin, N. Anuar, and N. S. Damanhuri, "Remote monitoring system development via Raspberry-Pi for small scale standalone PV plant," in 2017 7th IEEE International Conference on Control System, Computing and Engineering (ICCSCE), 2017, pp. 360–365.

[6] Choi, J. Jeong, J. Han, W. Park, and I. Lee, "Implementation of IoT based PV monitoring system with message queuing telemetry transfer protocol and smart utility network," in 2017 International Conference on Information and Communication Technology Convergence (ICTC), 2017, pp. 1077–1079

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