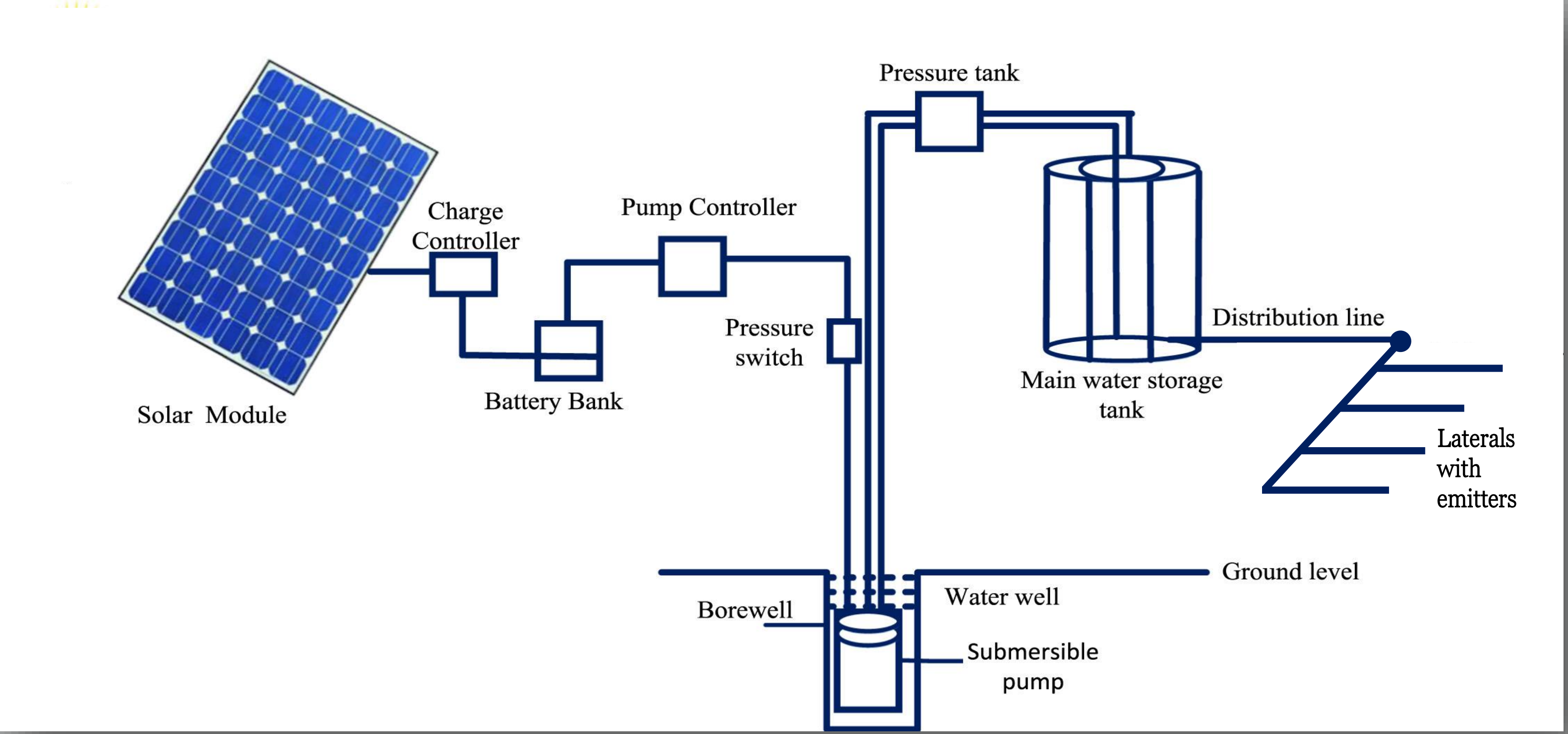

Design and Analysis of Solar Water Pumping for Drip Irrigation in Iran

Mohammad Zamanlou, M.Eng.
Supervisor: Professor Tariq Iqbal

M.Eng. Seminar Presentation

Fall 2020

Department of Electrical & Computer Engineering
Memorial University
St. John's, NL, Canada

Presentation Overview

- Introduction
- Load Analysis & System Sizing
- Dynamic Modelling & Control System (MATLAB/Simulink)
- IoT-based SCADA & Data Logging System
- Conclusion & Contributions & Publications
- Questions

Introduction

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Topic & Site Selection

- **Reasoning >> Environmental Crises in Iran**

1. Global Warming (**Fossil fuels** are the main source of energy generation)
2. Water Crisis (Mis-use of Water in Irrigation)

Introduction

Site Selection

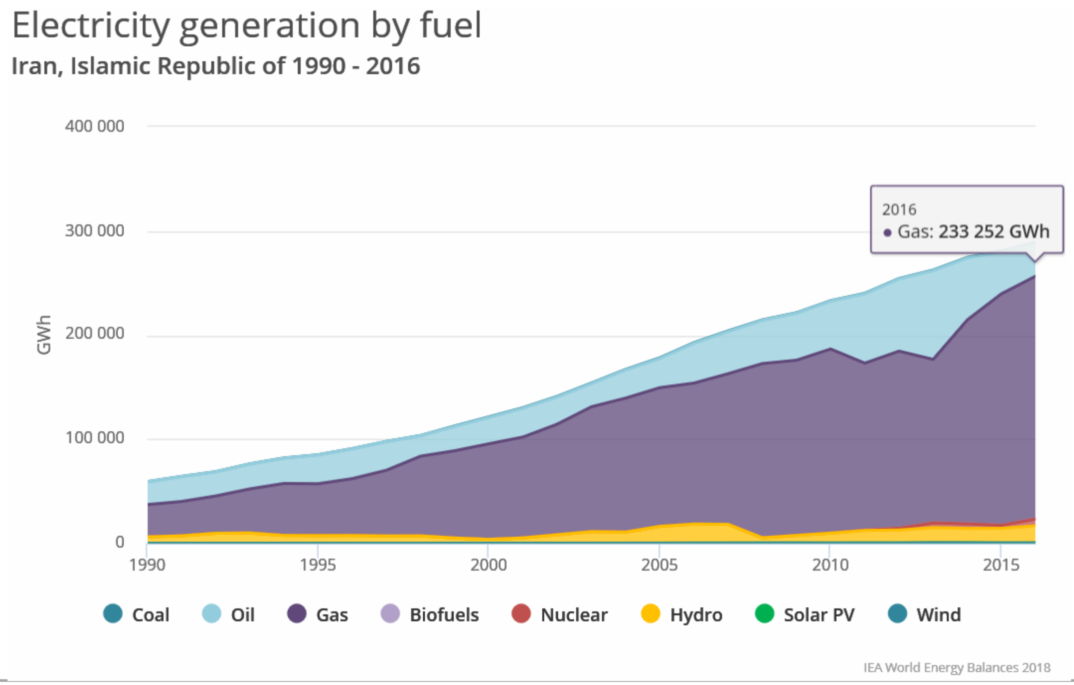
Global Warming

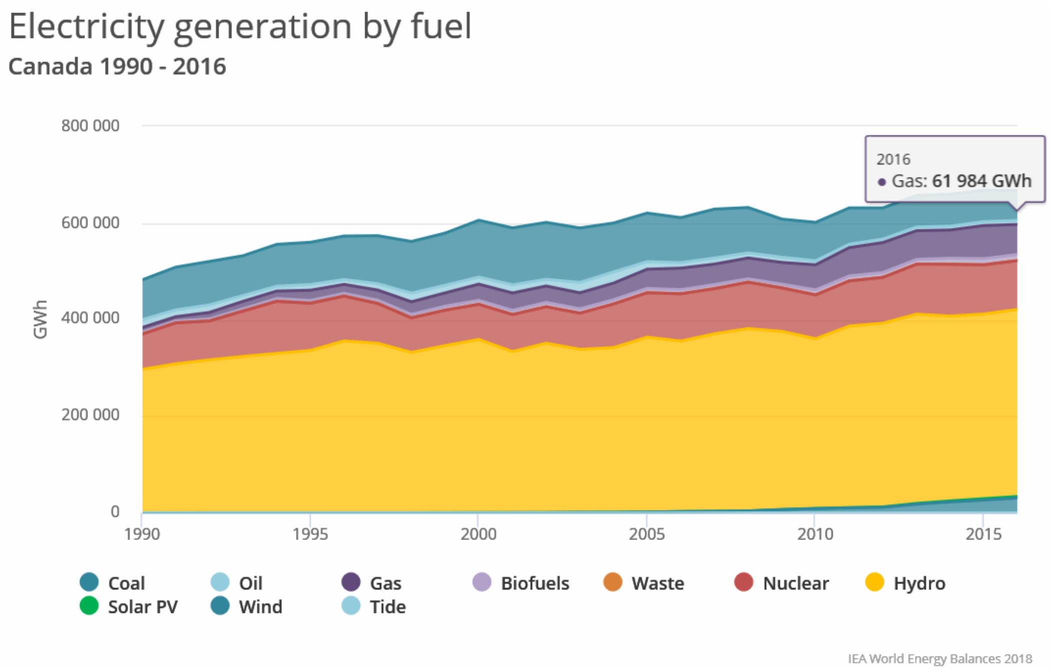
Iran

(Mainly from Fossil fuels)

Vs

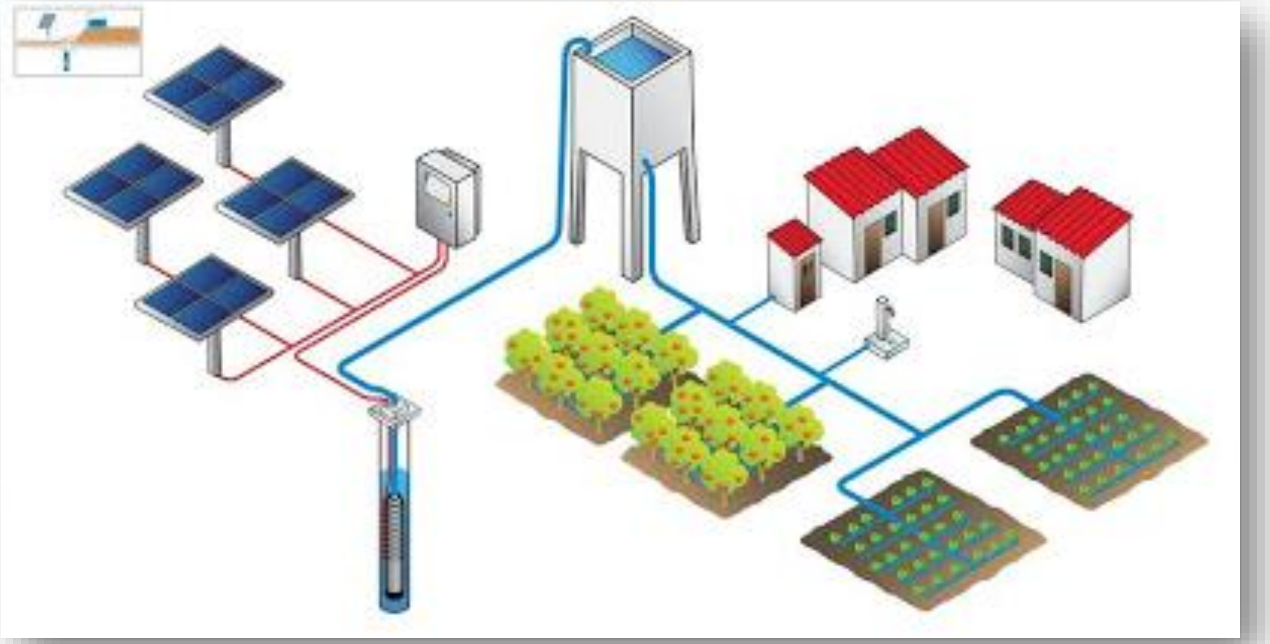
Canada





Introduction

Solar Water Pumping



Solar PV system offers:

- Causes no pollution
- Long life-cycle
- Unattended operation
- Low maintenance cost
- Easy installation

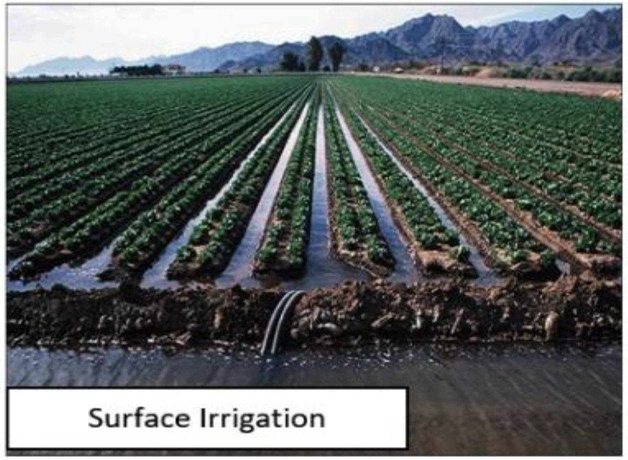
Designed for a 14.7 Hectare Grape Garden - Urmia, West Azerbaijan, Iran

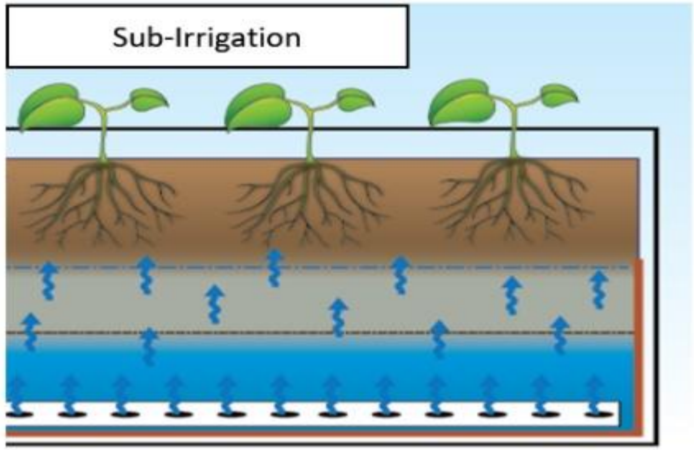
Introduction

Irrigation Methods

Solution for **Water Crisis** in Iran

Irrigation Method	Water Efficiency
Surface Irrigation	50–65%
Level Basin	60–80%
Sub irrigation	50–75%
Overhead irrigation	60–80%
Sprinkler irrigation	60–85%
Drip irrigation	80–90%





Load Analysis & System Sizing

System Load Sizing

Food and Agriculture Organization of the United Nations

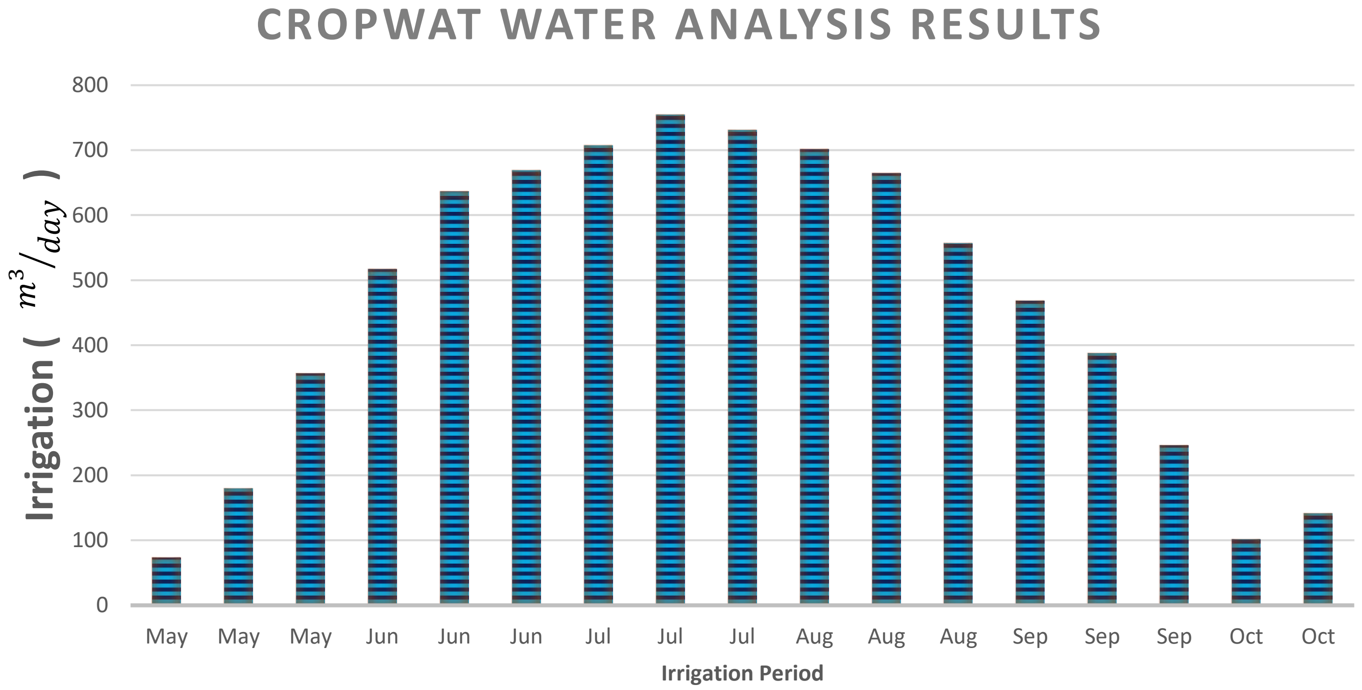
1. Flow rate:

Tools:

- CropWat v8.1
- ClimWat for CropWat

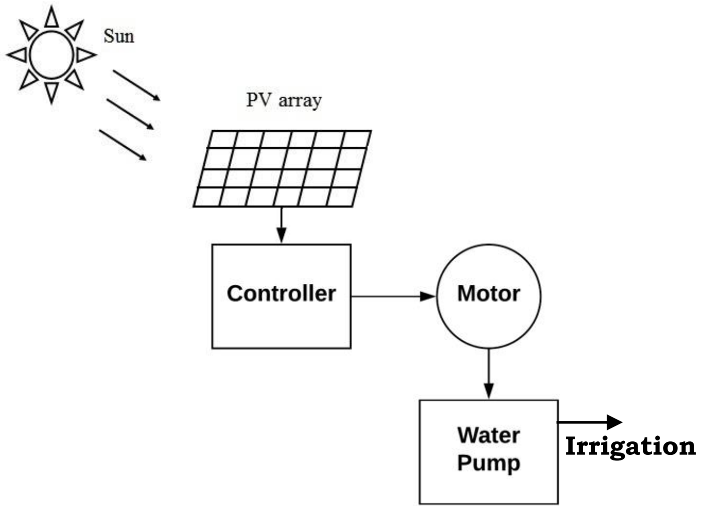
2. Total Dynamic Head:

Ground water Level + Elevation

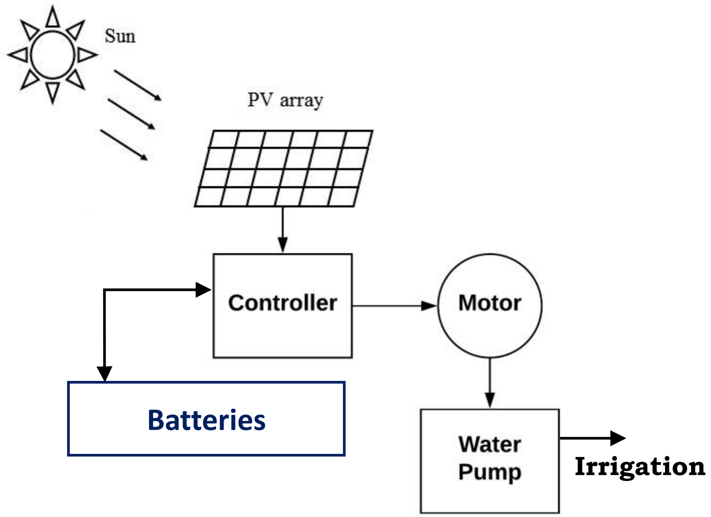


System Diagram

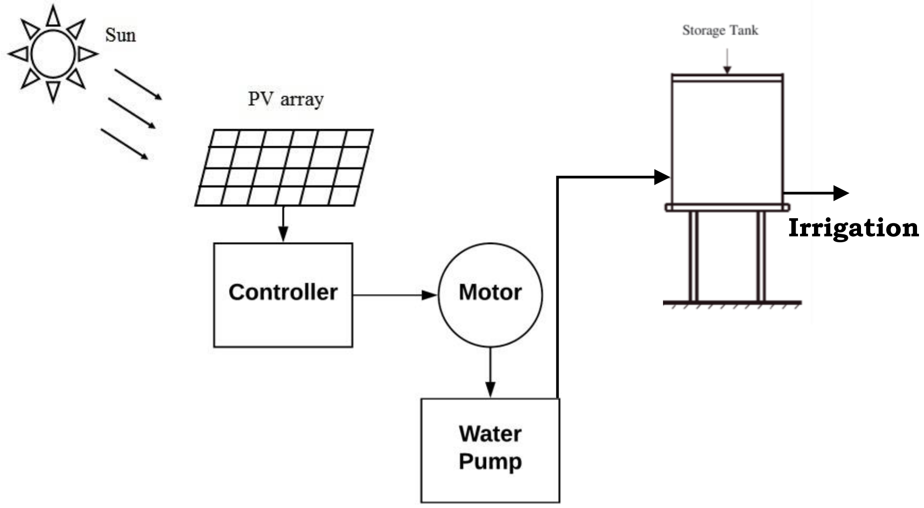
Without Storage System



With Battery Storage System



With Water Tank Storage



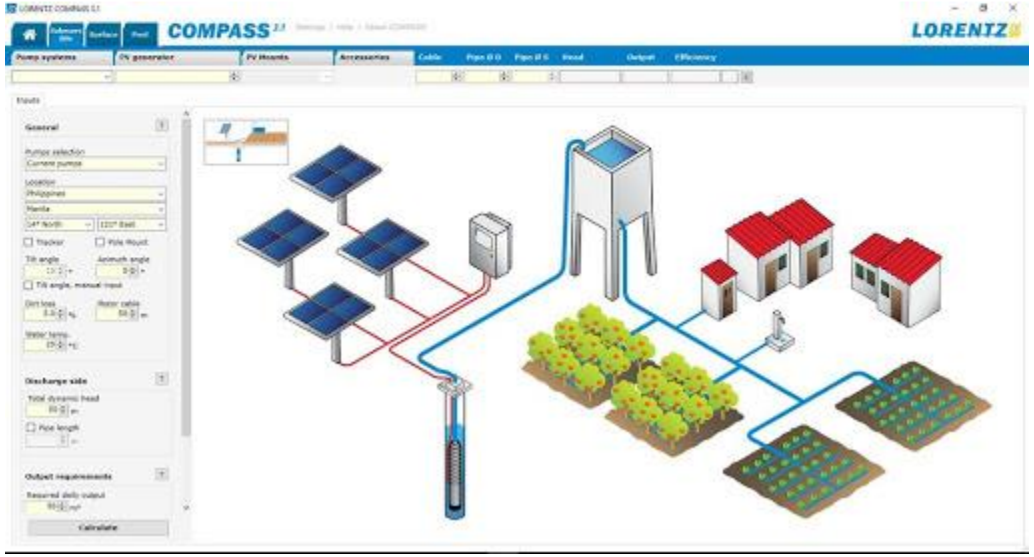
System Sizing without Storage System

Using Lorentz Compass3

Design Factors:

1. Flow rate (July): **755** $m^3/_{day}$

2. Total Dynamic Head: **45**m



LORENTZ

PSk2-25 C-SJ95-4

Solar Submersible Pump System for 8" wells

System Overview

Head	max. 60 m
Flow rate	max. 112 m³/h

Technical Data

Controller PSk2-25

- High efficiency solar pump controller
- Hybrid power (solar / grid / generator) support with LORENTZ SmartSolution
- Inputs for water meter, pressure sensors, digital switches
- Simple configuration with LORENTZ PumpScanner Android™App
- Onboard data logging and system monitoring
- Inbuilt applications for constant pressure, constant flow and daily amount
- Integrated Sun Sensor
- Active temperature management
- Integrated MPPT (Maximum Power Point Tracking)

Power	max. 25 kW
Input voltage	max. 850 V
Optimum Vmp**	> 575 V
Motor current	max. 40 A
Efficiency	max. 98 %
Ambient temp.	-30...50 °C
Enclosure class	IP54

Motor AC DRIVE SUB 6" 18.5kW

- Highly efficient 3-phase AC motor
- Frequency: 25...52 Hz
- Premium materials, stainless steel: AISI 304
- No electronics in the motor

Efficiency	max. 84 %
Motor speed	1,400...2,965 rpm
Power factor	0.87
Insulation class	F
Enclosure class	IP68
Submersion	max. 150 m

Pump End PE C-SJ95-4

- Non-return valve
- Premium materials, stainless steel: AISI 304
- Centrifugal pump

Efficiency	max. 74 %

Pump Unit PUk2-25 C-SJ95-4 (Motor, Pump End)

Borehole diameter	min. 8,0 in
Water temperature	max. 30 °C****

Standards

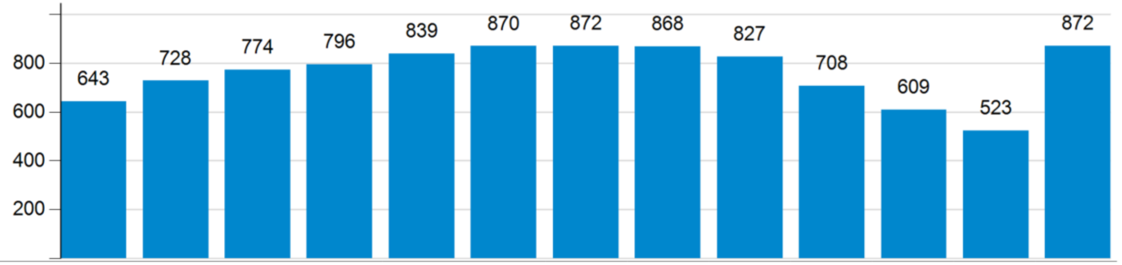
CE 2006/42/EC, 2004/108/EC, 2006/95/EC

IEC/EN 61702:1995, IEC/EN 62253 Ed.1

System Design without Storage System

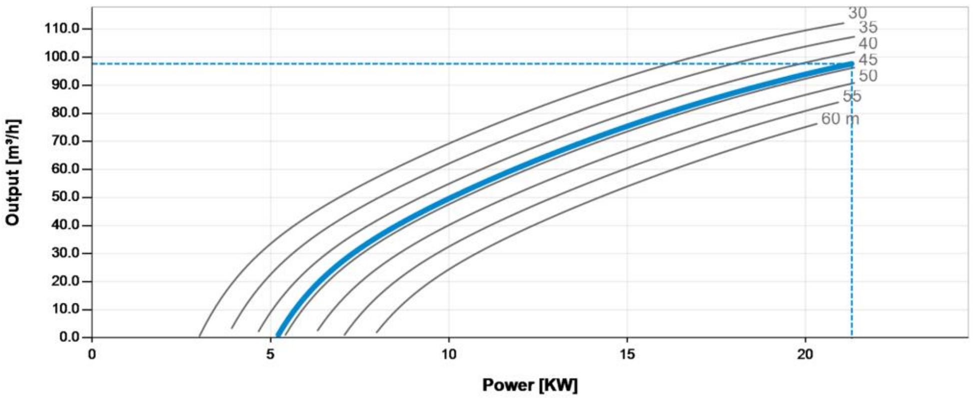
Lorentz Compass3 **Results**:

Daily values	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.

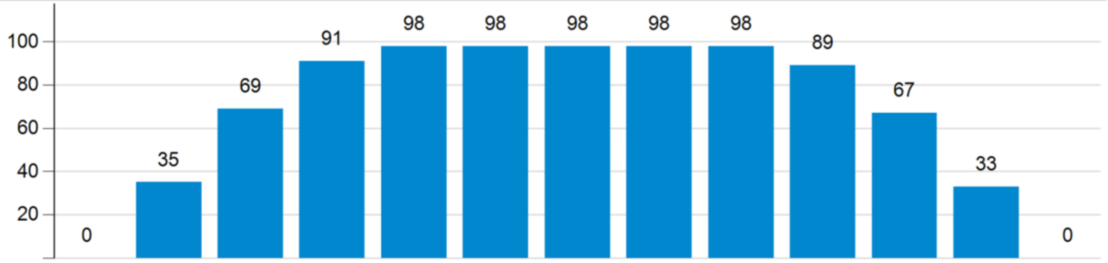


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.
Energy [kWh]	143	172	195	192	198	212	210	212	207	166	137	119	210
Irradiation [kWh/m²]	4.0	4.8	5.6	5.7	6.1	6.6	6.6	6.7	6.4	4.9	3.9	3.3	6.6
Rainfall [mm]	1.1	0.93	1.6	1.9	1.3	0.23	0.13	0.033	0.10	0.63	1.1	0.97	0.83
Ambient temp. [°C]	-4	-2	2	9	15	20	23	22	18	12	4	-1	10

Pump Chart



Hourly values	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00



	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
Energy [kWh]	2.3	8.1	14	19	23	26	26	25	23	19	14	7.8	2.2
Irradiation [kWh/m²]	0.066	0.24	0.43	0.61	0.75	0.84	0.87	0.84	0.75	0.61	0.43	0.24	0.066
Ambient temp. [°C]	18	18	19	21	23	25	27	28	28	28	28	27	27

System Design without Storage System

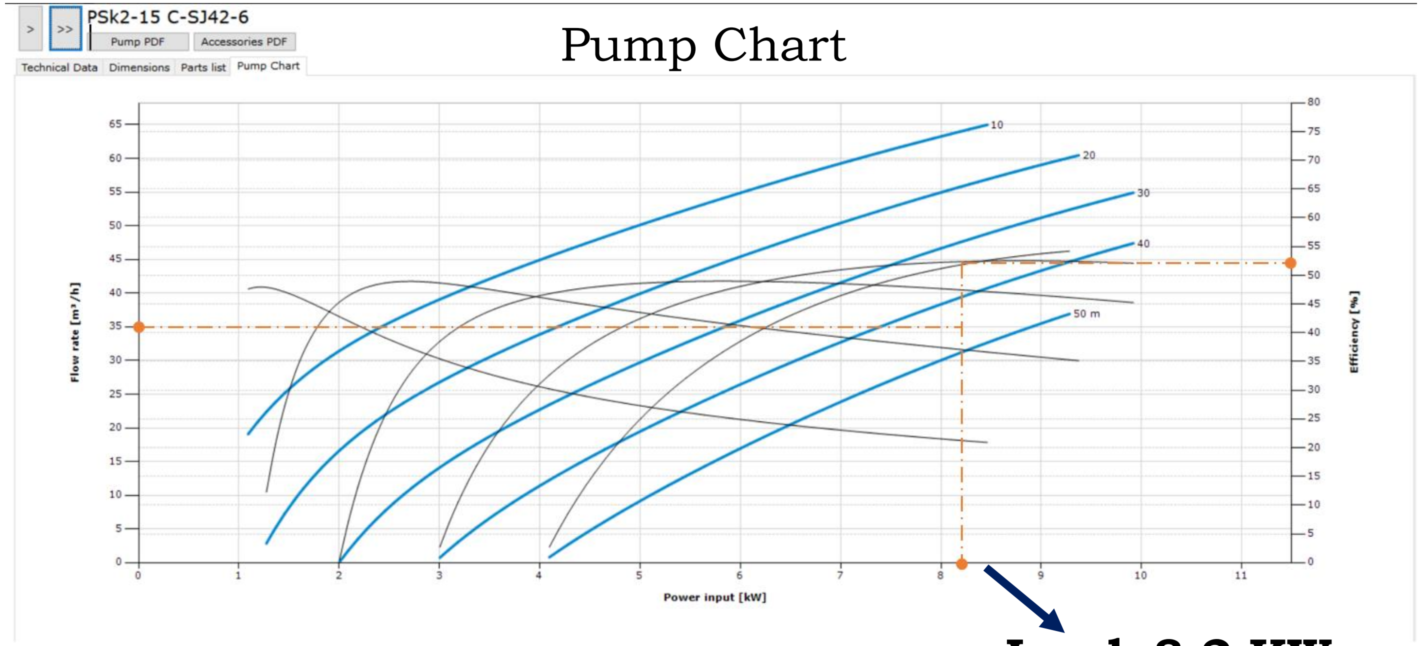
System Costs:

Component	Model	Capital Cost (CAD)
Pump System	PS25K2 C-SJ95-4	19,934.99
Pump Controller	PS25k Controller-18.5kVA	10,826.51
PV Panels	Suntech Power315 (44.4kw)	24,937.25
Total		55,698.75

System Sizing with Storage System

1. Flow rate (Constant): **35** m^3/h
2. Total Dynamic Head: **45**m

Pump Chart



Load=8.2 KW

LORENTZ

PSk2-15 C-SJ42-6

Solar Submersible Pump System for 6" wells

System Overview

Head	max. 50 m
Flow rate	max. 65 m³/h

Technical Data

Controller PSk2-15

- High efficiency solar pump controller
- Hybrid power (solar / grid / generator) support with LORENTZ SmartSolution
- Inputs for water meter, pressure sensors, digital switches
- Simple configuration with LORENTZ PumpScanner Android™App
- Onboard data logging and system monitoring
- Inbuilt applications for constant pressure, constant flow and daily amount
- Integrated Sun Sensor
- Active temperature management
- Integrated MPPT (Maximum Power Point Tracking)

Power	max. 15 kW
Input voltage	max. 850 V
Optimum Vmp**	> 575 V
Motor current	max. 24 A
Efficiency	max. 98 %
Ambient temp.	-30...50 °C
Enclosure class	IP54

Motor AC DRIVE SUB 6" 11kW

- Highly efficient 3-phase AC motor
- Frequency: 25...50 Hz
- Premium materials, stainless steel: AISI 304
- No electronics in the motor

Efficiency	max. 80 %
Motor speed	1,400...2,850 rpm
Power factor	0.87
Insulation class	F
Enclosure class	IP68
Submersion	max. 150 m

Pump End PE C-SJ42-6

- Non-return valve
- Premium materials, stainless steel: AISI 304
- Centrifugal pump

Efficiency	max. 69 %

Pump Unit PUk2-15 C-SJ42-6 (Motor, Pump End)

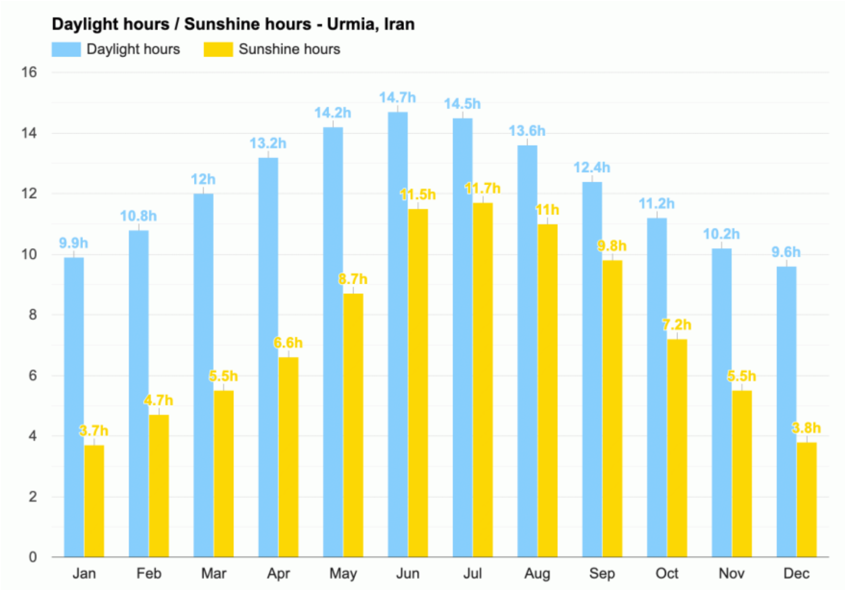
Borehole diameter	min. 6,0 in
Water temperature	max. 30 °C****

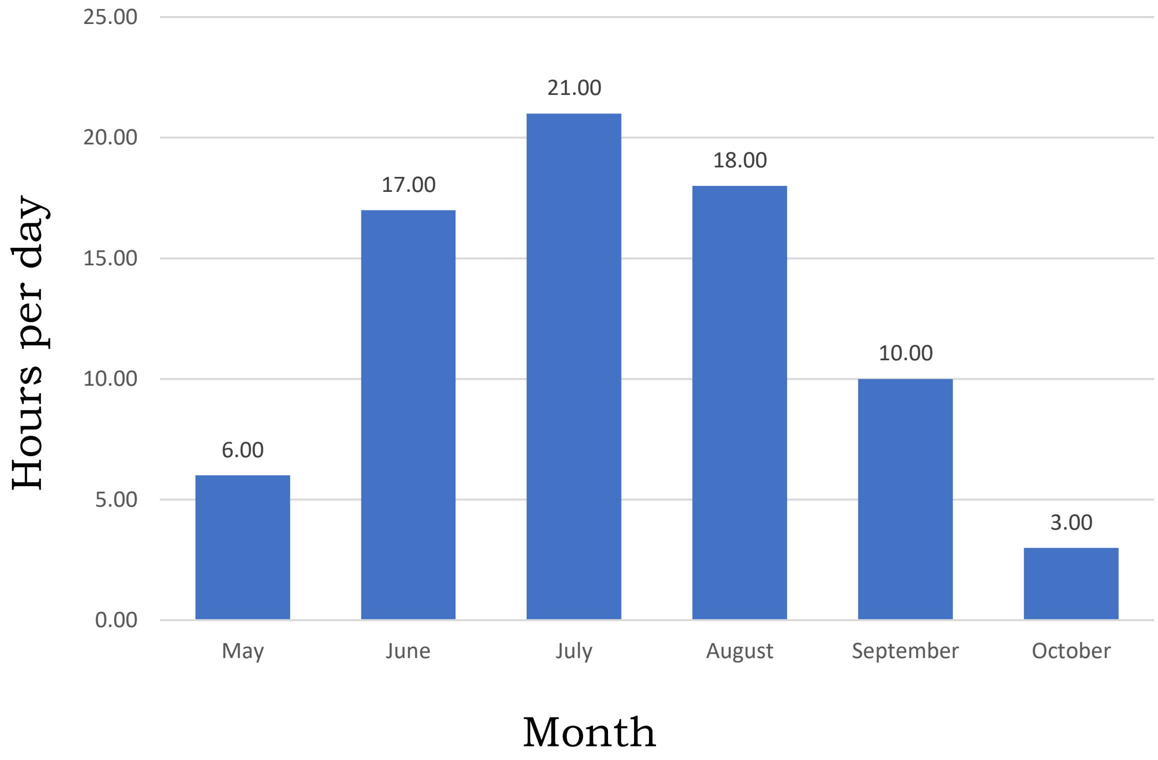
System Sizing with Storage System

Load Profile:

Note:
Flow rate is constant: **35** m^3/h

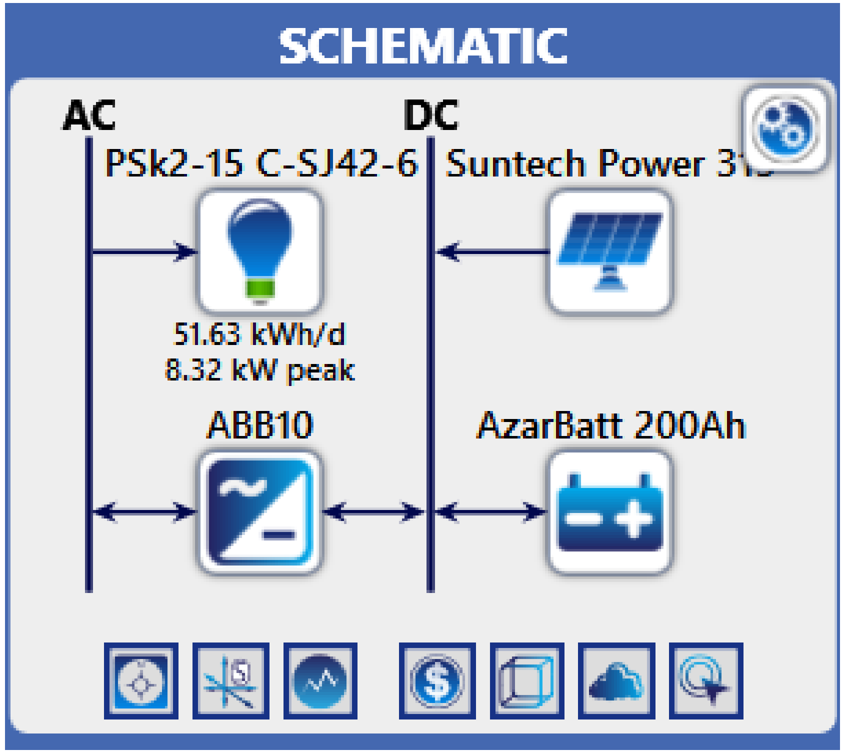
Load=8.2 KW





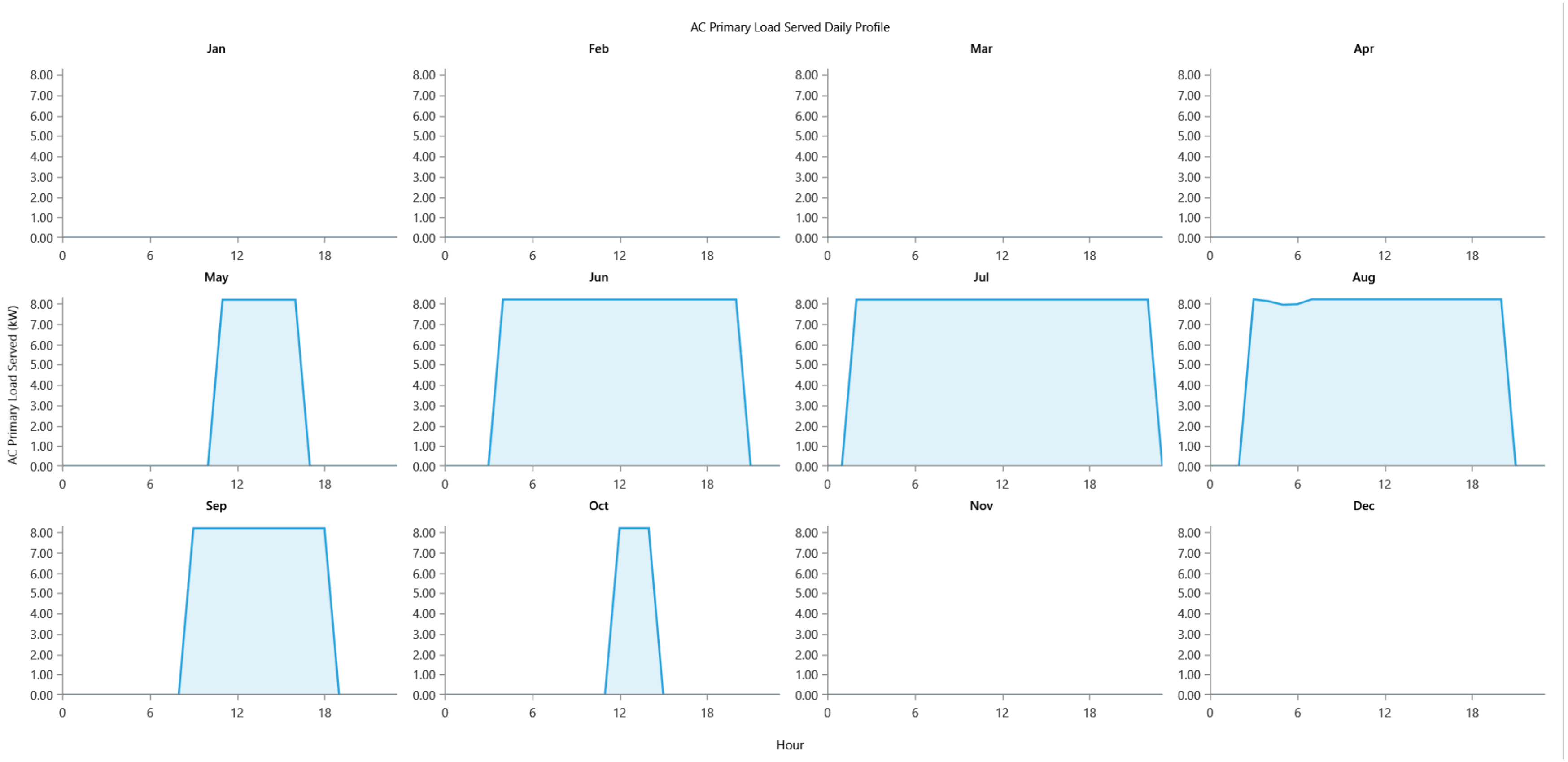
System Design with Battery Storage System

Optimization with HOMER Pro Micro Grid Analysis Tool:



System Design with Battery Storage System

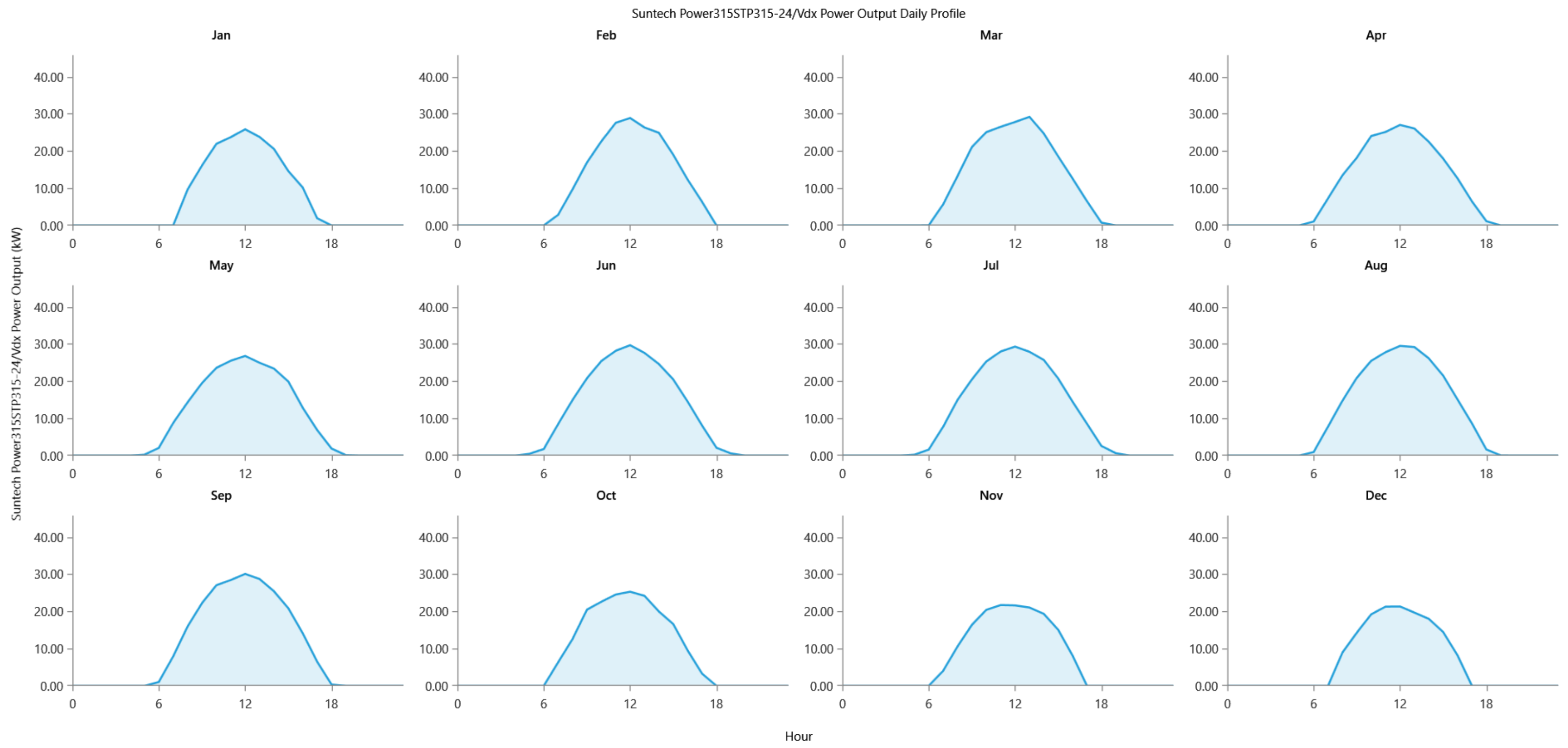
Results of the HOMER Optimization:



Daily profile: Primary Load Served (KW)

System Design with Battery Storage System

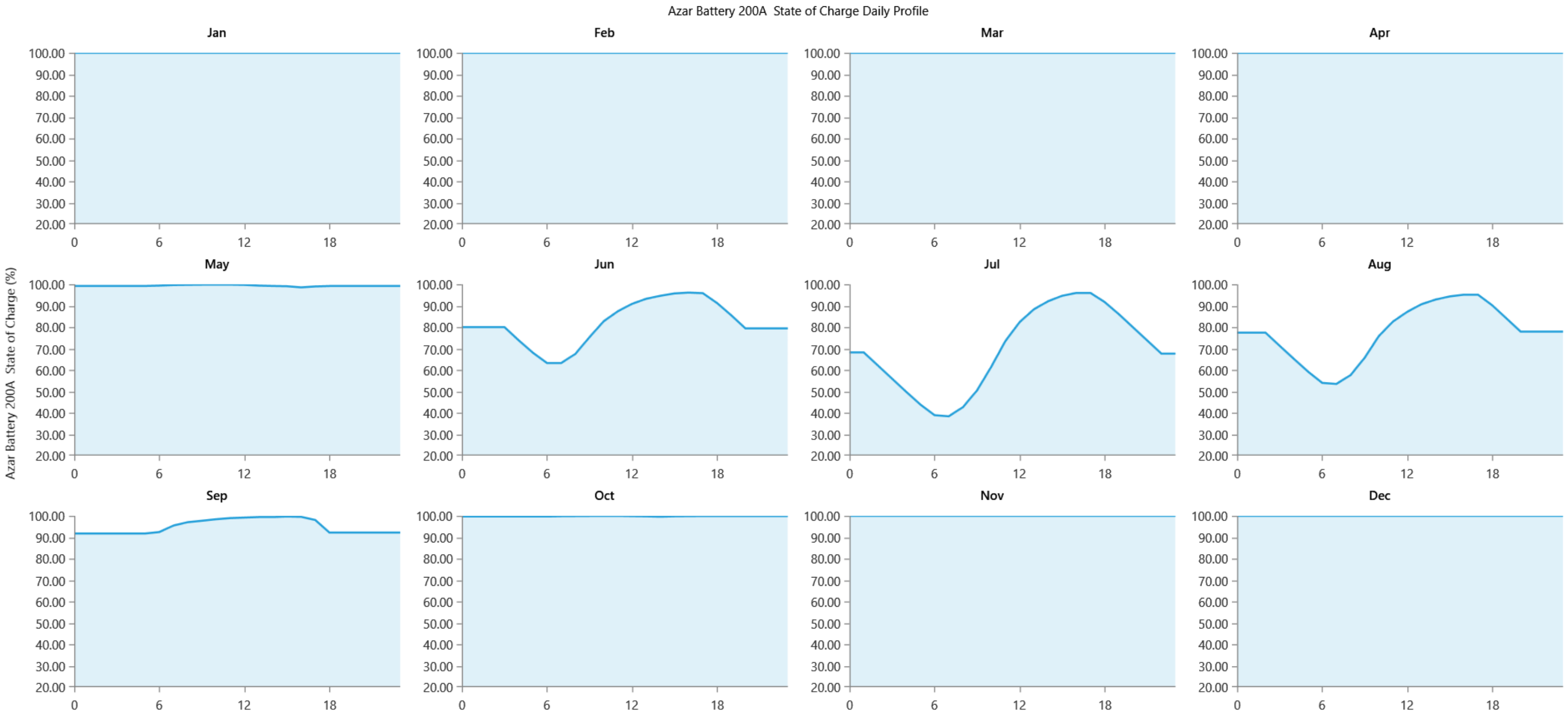
Results of the HOMER Optimization:



Daily profile: PV panels Power Output (KW)

System Design with Battery Storage System

Results of the HOMER Optimization:



Daily profile: BSS state of charge (%)

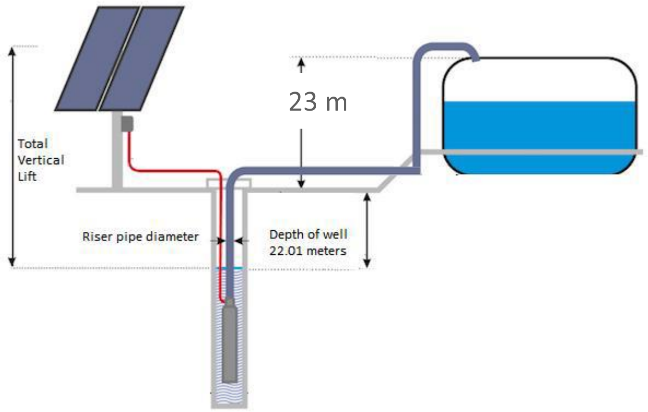
System Design with Battery Storage System

System Costs:

Component	Model	Capital Cost (CAD)
Pump System	PS15k2 - C-SJ42-6	15,284.68
Inverter	ABB PVI 10.0 I OUTD-x-US-480	5,096.00
PV Panels	Suntech Power 315w (44.4kw)	24,937.25
Battery Storage	Azar Battery 200Ah (x60)	4,860.00
Total		50,177.93

System Design with Water Tank Storage

1. Irrigation Flow rate (Constant): **35** m^3/h
2. Total Dynamic Head: **45**m



Water Reservoir for **Gravity fed Irrigation**:

- Must be able to contain at least 1-day worth of water ⟹ Water Tank Capacity: about 800 m^3
- Must be elevated to add constant **pressure** in distribution line

1 meter of head = 1.42197 PSI
Required pressure for Emitters= 15-30 PSI } ⟹ Tank Elevation: 20 m

System Design with Water Tank Storage

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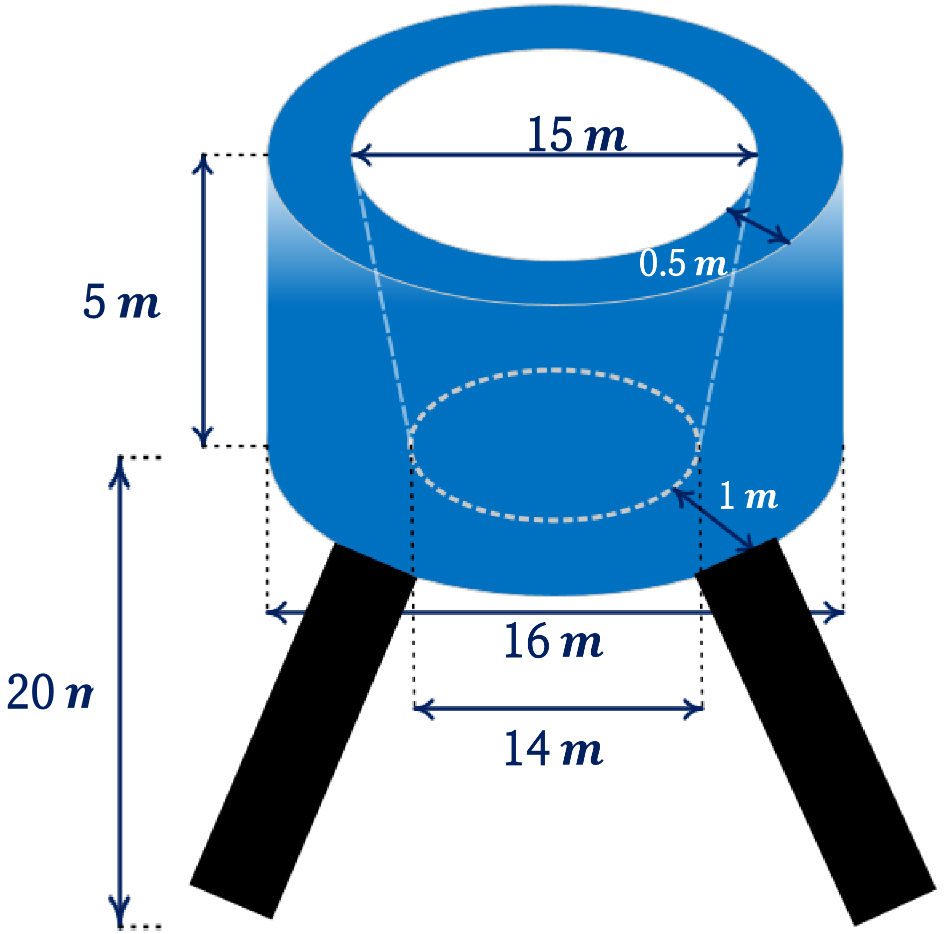
Cistern Design:

✓ **Water Capacity** of the Designed Tank = $826.63\ m^3$



System Design with Water Tank Storage

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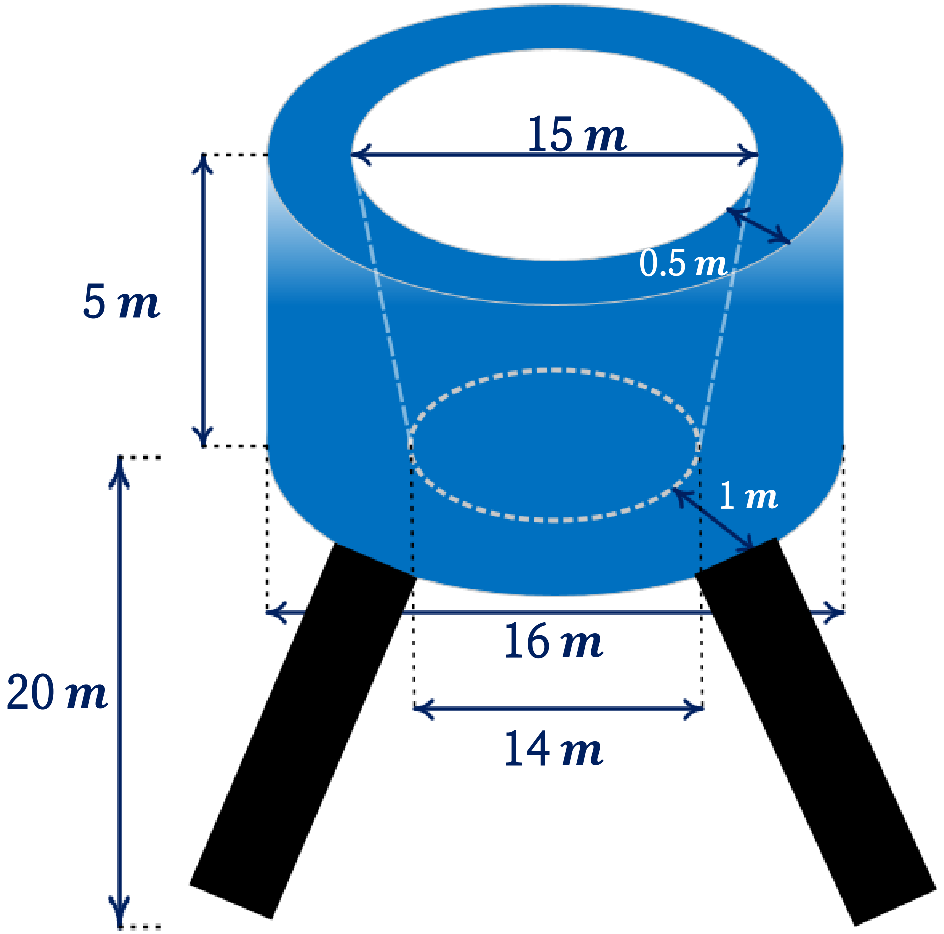
Cistern Design:

- ✓ **Concrete used in** the Designed Tank = 178.68 m^3
- ✓ Concrete Unit Price: 24 CAD/m^3
- ✓ Concrete **Total** Price only for cistern construction

  24 x 178.68 = 4,288.32 CAD



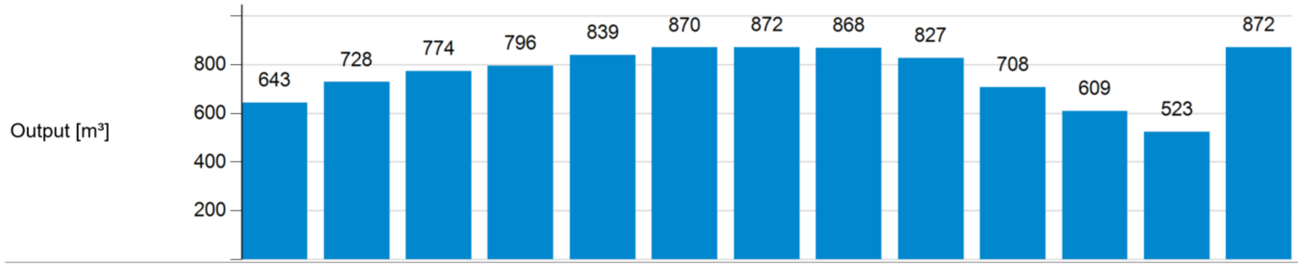
System Design with Water Tank Storage

Water Pump Output:

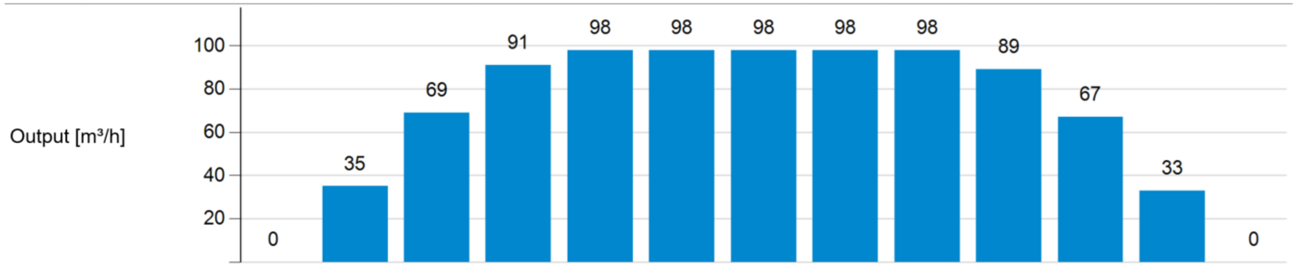
Same as without storage system

✓ However

Irrigation Flow rate can remain Constant: **35** $^{m^3}/_{h}$



Daily values	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.
Energy [kWh]	143	172	195	192	198	212	210	212	207	166	137	119	210
Irradiation [kWh/m²]	4.0	4.8	5.6	5.7	6.1	6.6	6.6	6.7	6.4	4.9	3.9	3.3	6.6
Rainfall [mm]	1.1	0.93	1.6	1.9	1.3	0.23	0.13	0.033	0.10	0.63	1.1	0.97	0.83
Ambient temp. [°C]	-4	-2	2	9	15	20	23	22	18	12	4	-1	10



Hourly values	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
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Irradiation [kWh/m²]	0.066	0.24	0.43	0.61	0.75	0.84	0.87	0.84	0.75	0.61	0.43	0.24	0.066
Ambient temp. [°C]	18	18	19	21	23	25	27	28	28	28	28	27	27

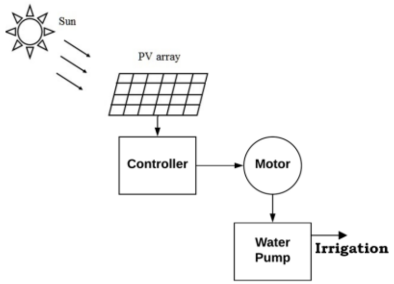
System Design with Water Tank Storage

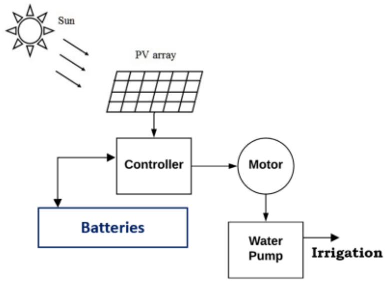
System Costs:

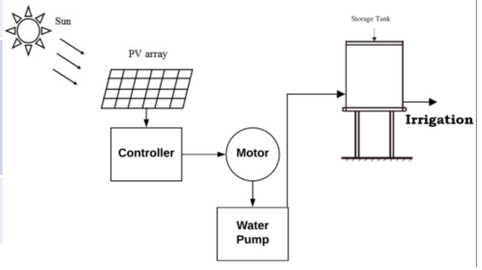
Component	Model	Capital Cost (CAD)
Pump System	PS25K2 C-SJ95-4	19,934.99
Pump Controller	PS25k Controller-18.5kVA	10,826.51
PV Panels	Suntech Power 315w (44.4kw)	24,937.25
Cistern	Concrete C-35 ($178.68\ m^3$)	4,288.32
Total		59,987.07

Comparison

Component*	Without Storage (A) ($CAD)	With Battery Bank (B) ($CAD)	With Water Tank (C) ($CAD)
Pump system	19,934.99	15,284.68	19,934.99
Pump Controller	10,826.51	5,096.00	10,826.51
PV Panels	24,937.25	24,937.25	24,937.25
Battery Storage	N\A	4,860.00	N\A
Cistern (Concrete)	N\A	N\A	4,288.32
Total	**55,698.75**	**50,177.93**	**59,987.07**

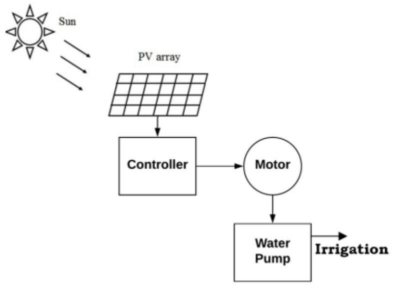


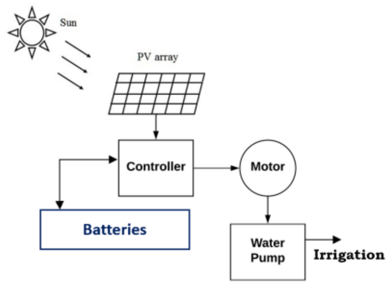


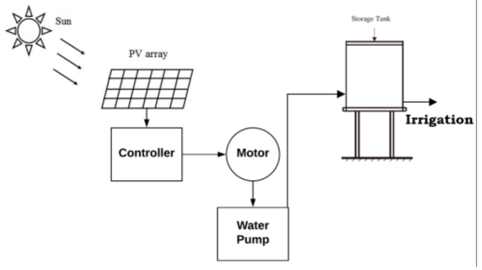


Conclusion

Cost	Without Storage System	With Battery Storage System	With Water Tank Storage
Pumping System	Medium	Low	High
Piping System	High	Low	Low
	Flowrate: up to 98 m^3/h	**Flowrate: 35 m^3/h**	**Flowrate: 35 m^3/h**
Suggested System	**Solar Pumping with Battery Storage System**		







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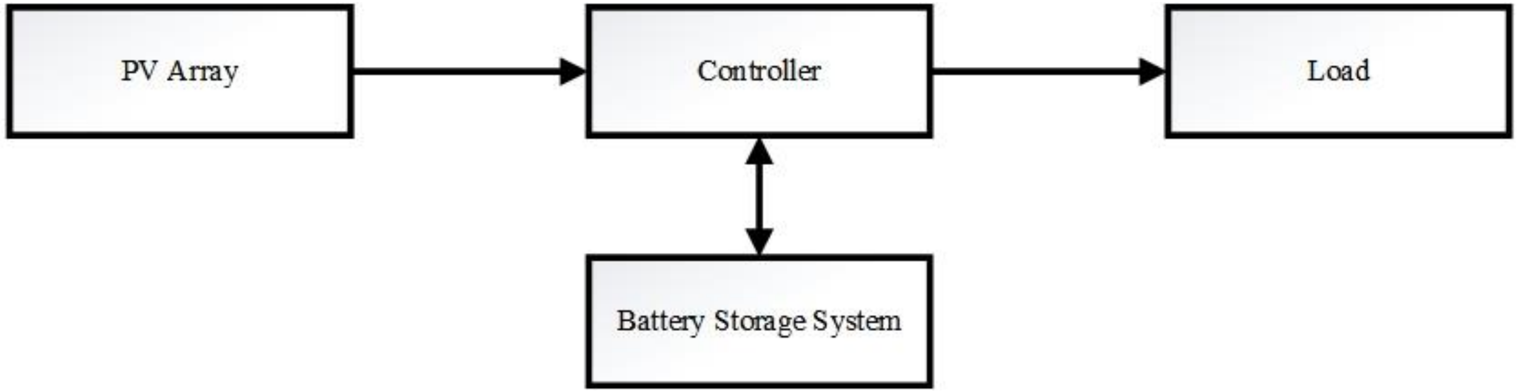
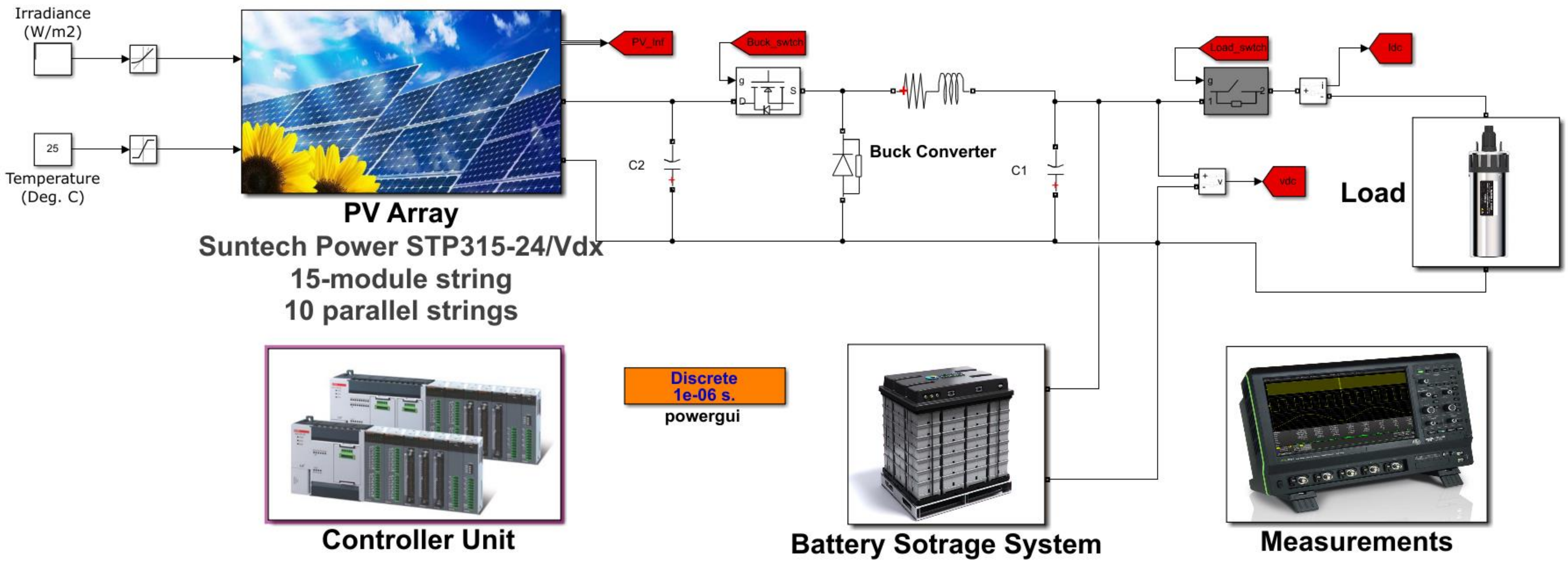
Dynamic Modelling & Control System

MATLAB/Simulink

Dynamic Modelling & Control System

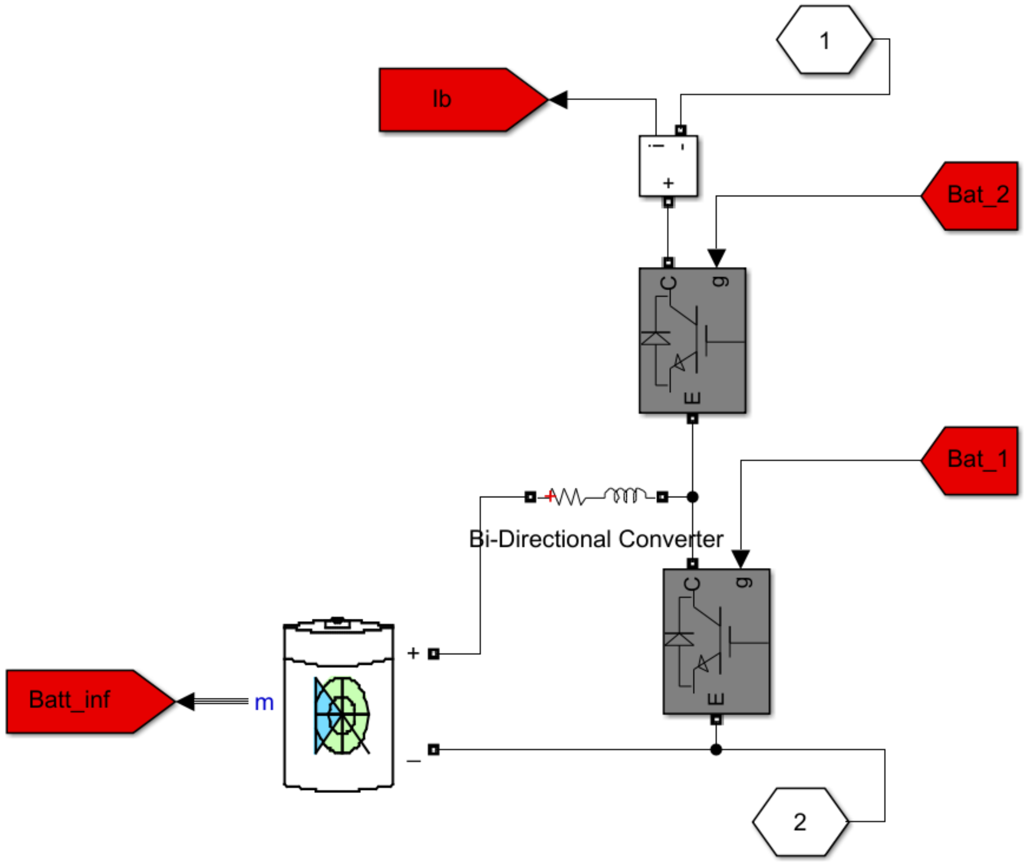


Dynamic Modelling & Control System



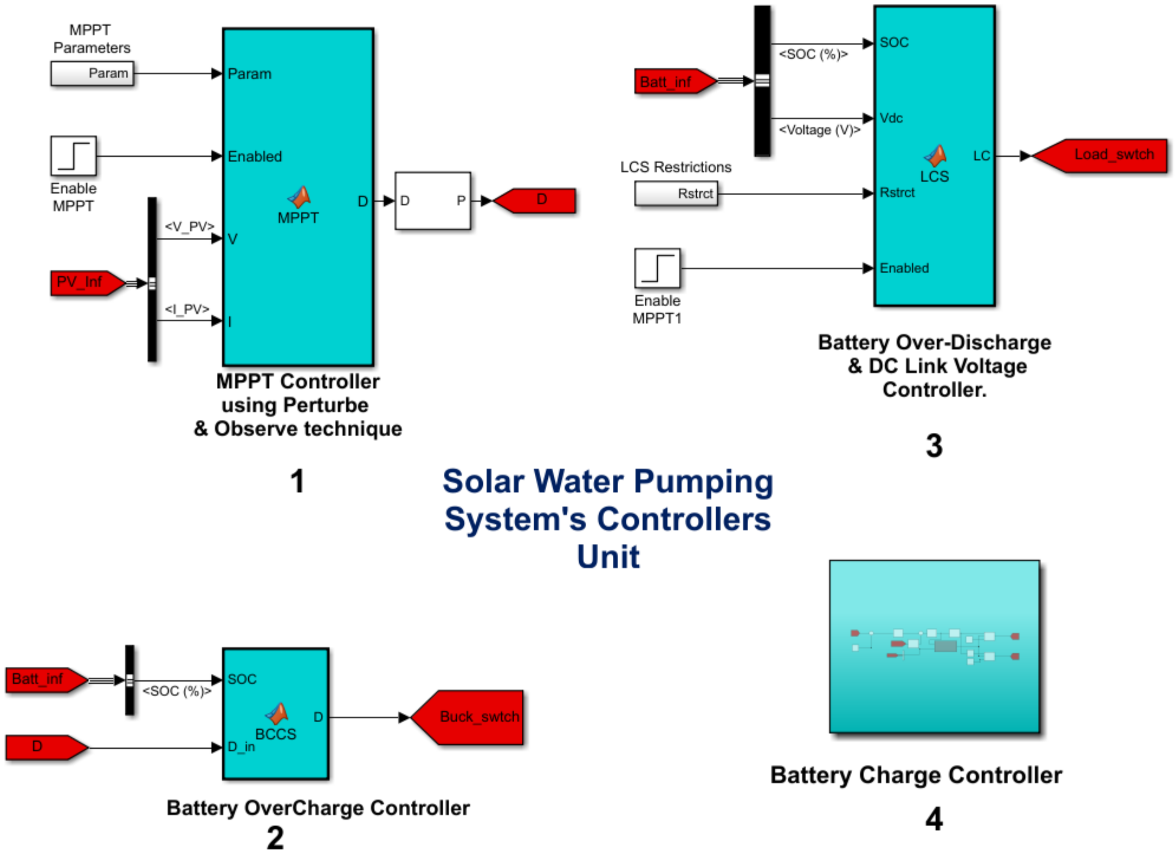
Dynamic Modelling & Control System

Battery Storage System



Dynamic Modelling & Control System

Controller Unit



Dynamic Modelling & Control System

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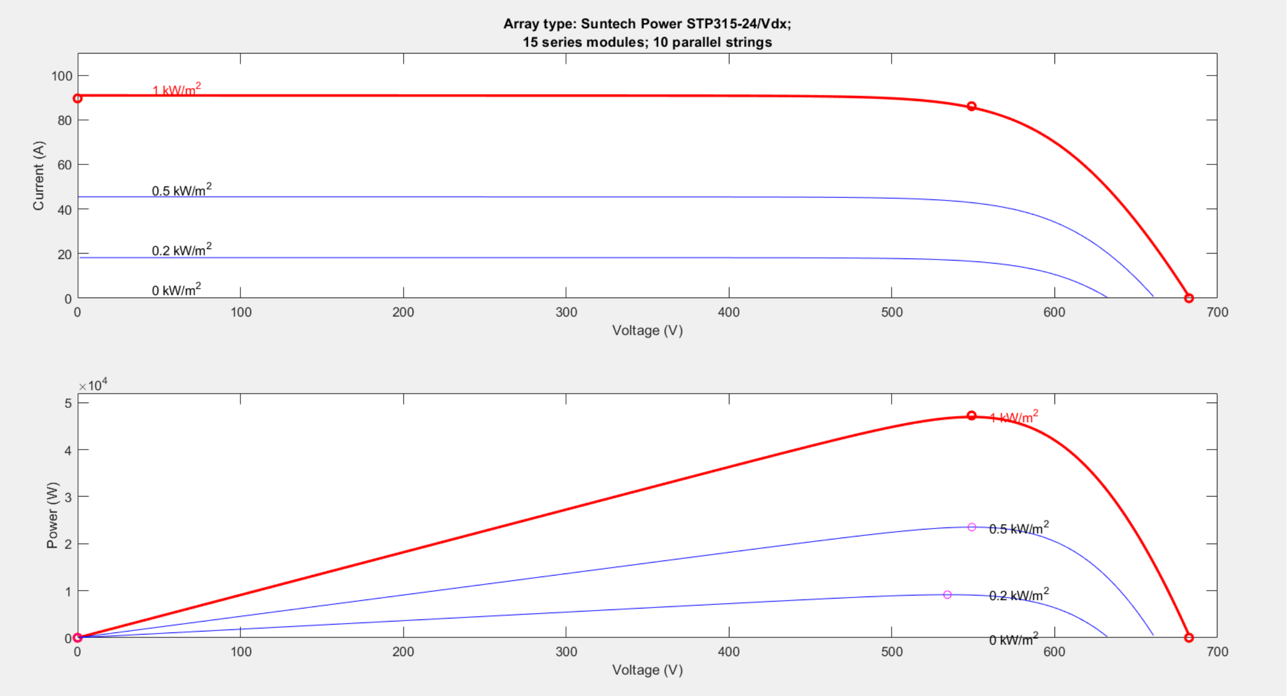
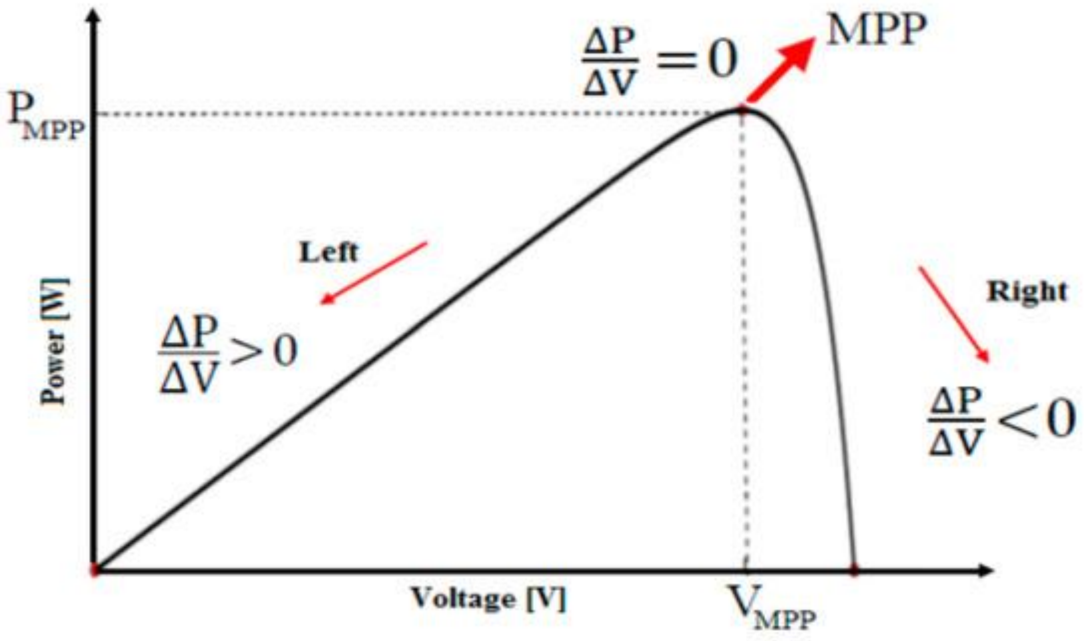
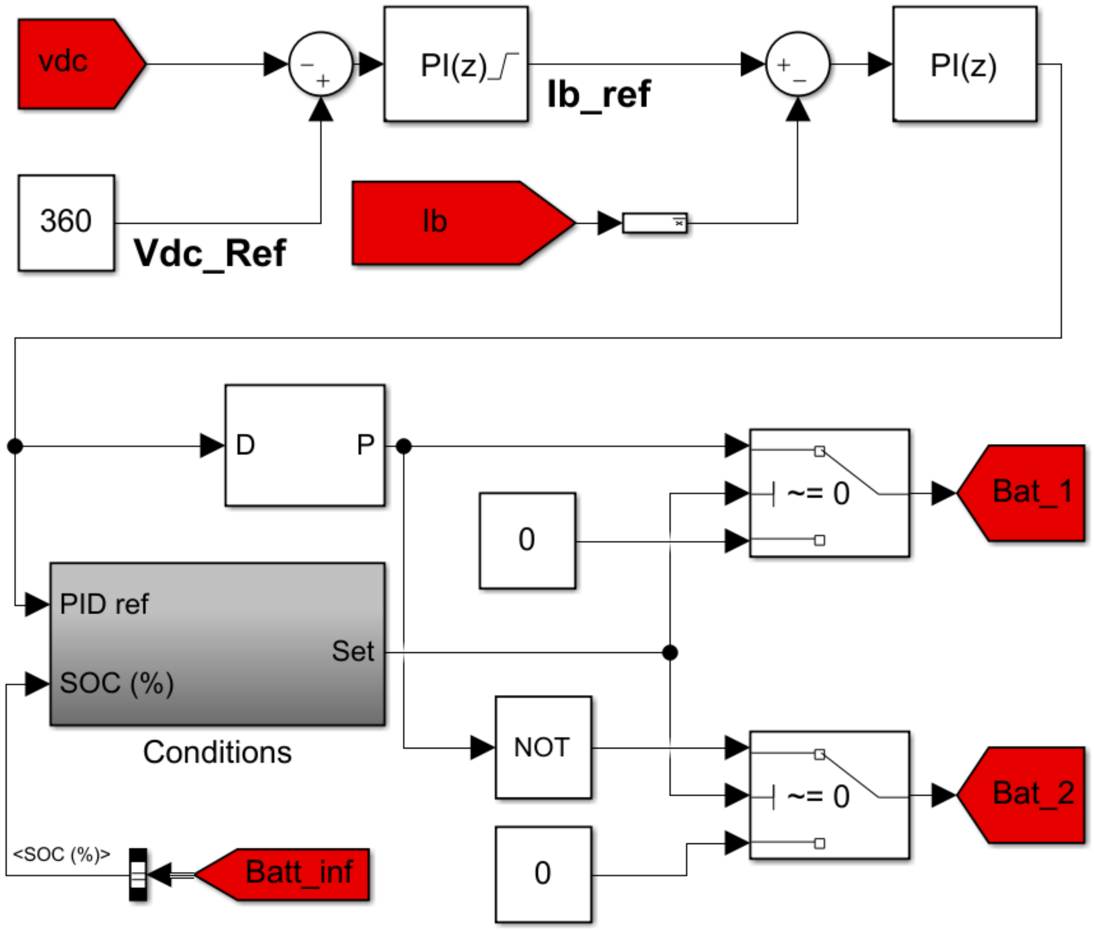
MPPT using P&O Method





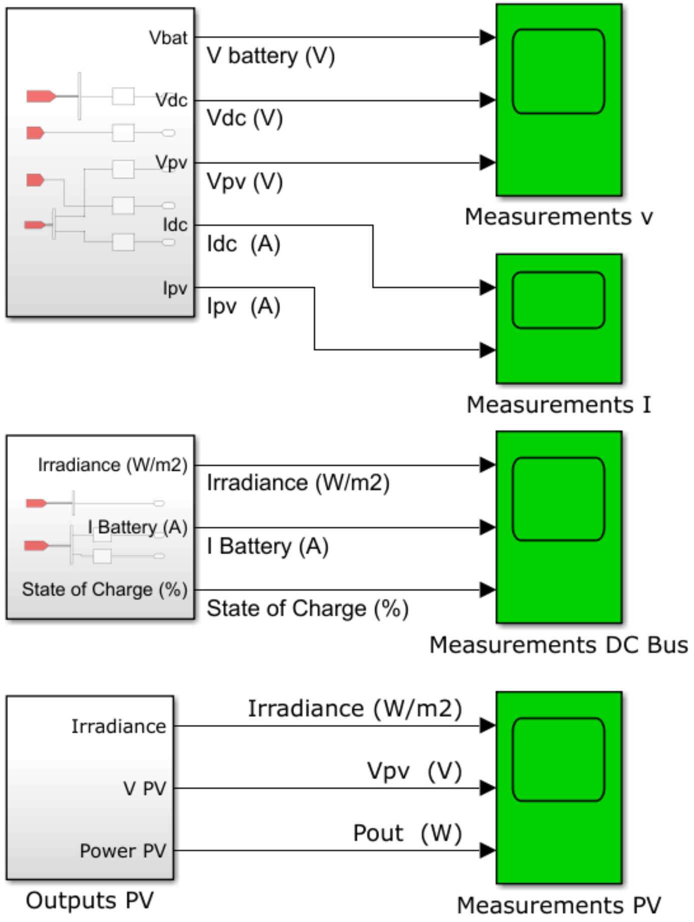
Dynamic Modelling & Control System

Battery Charge Controller



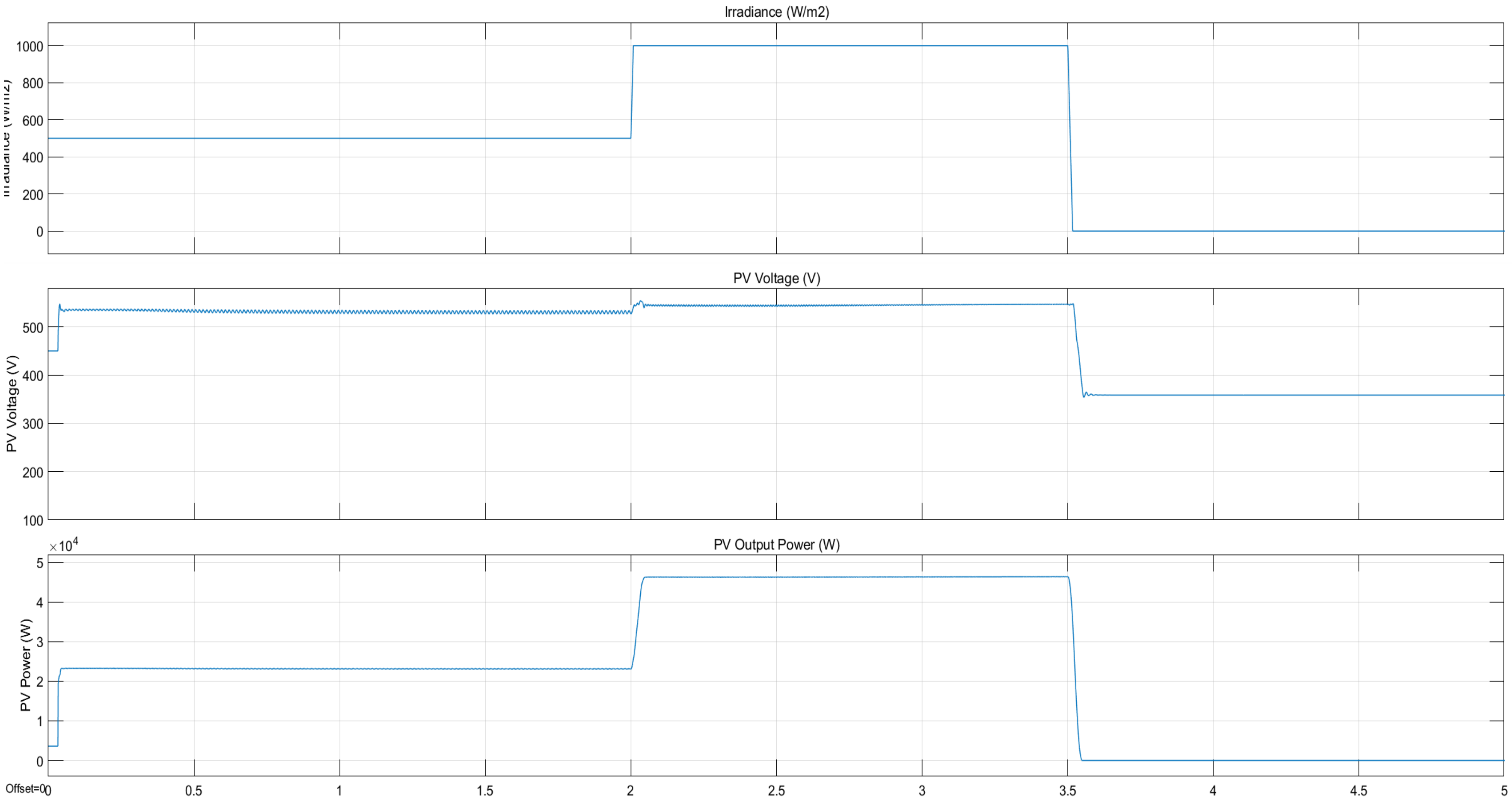
Dynamic Modelling & Control System

Measurement Unit



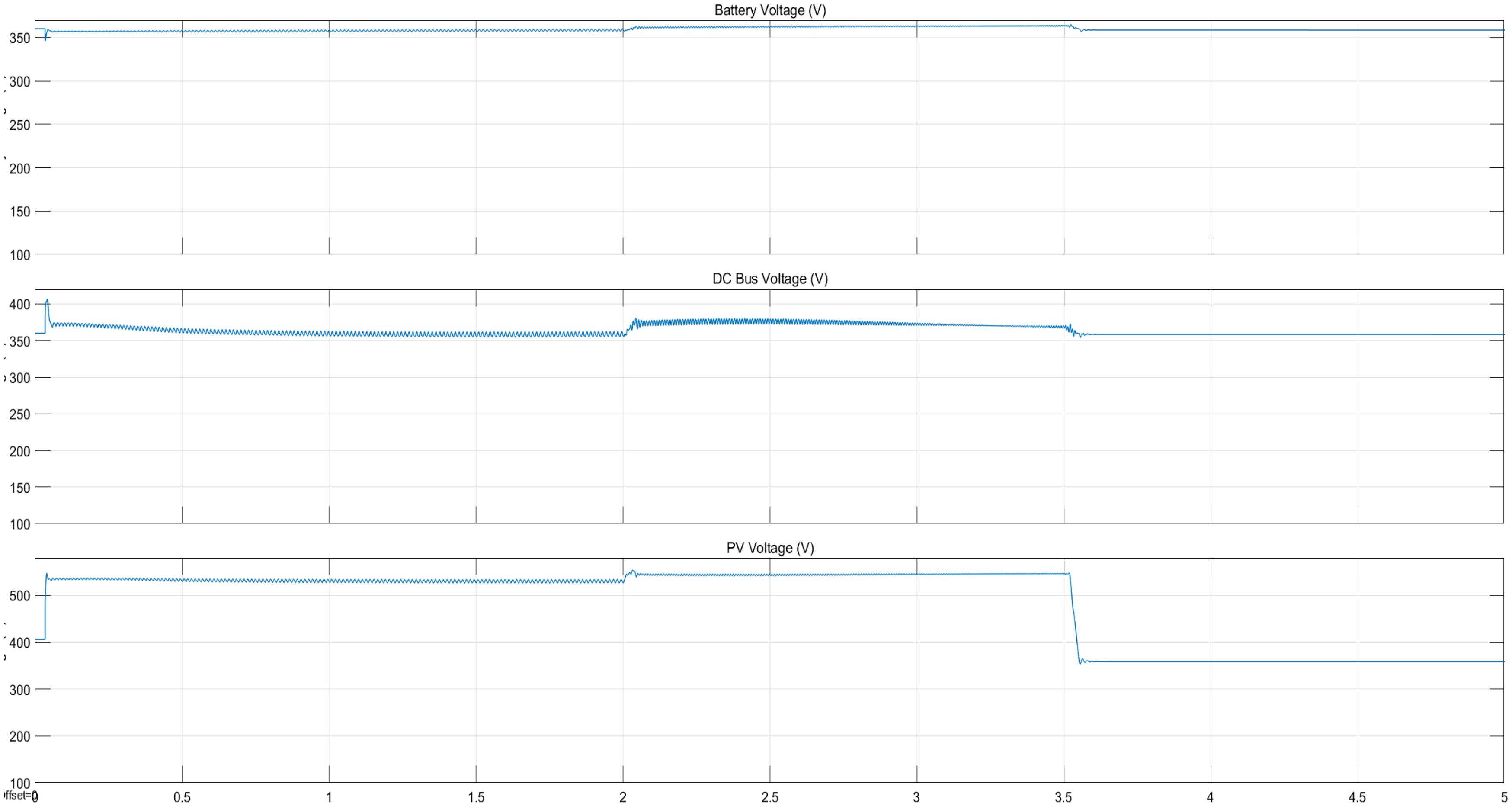
Dynamic Modelling & Control System

Results (1)



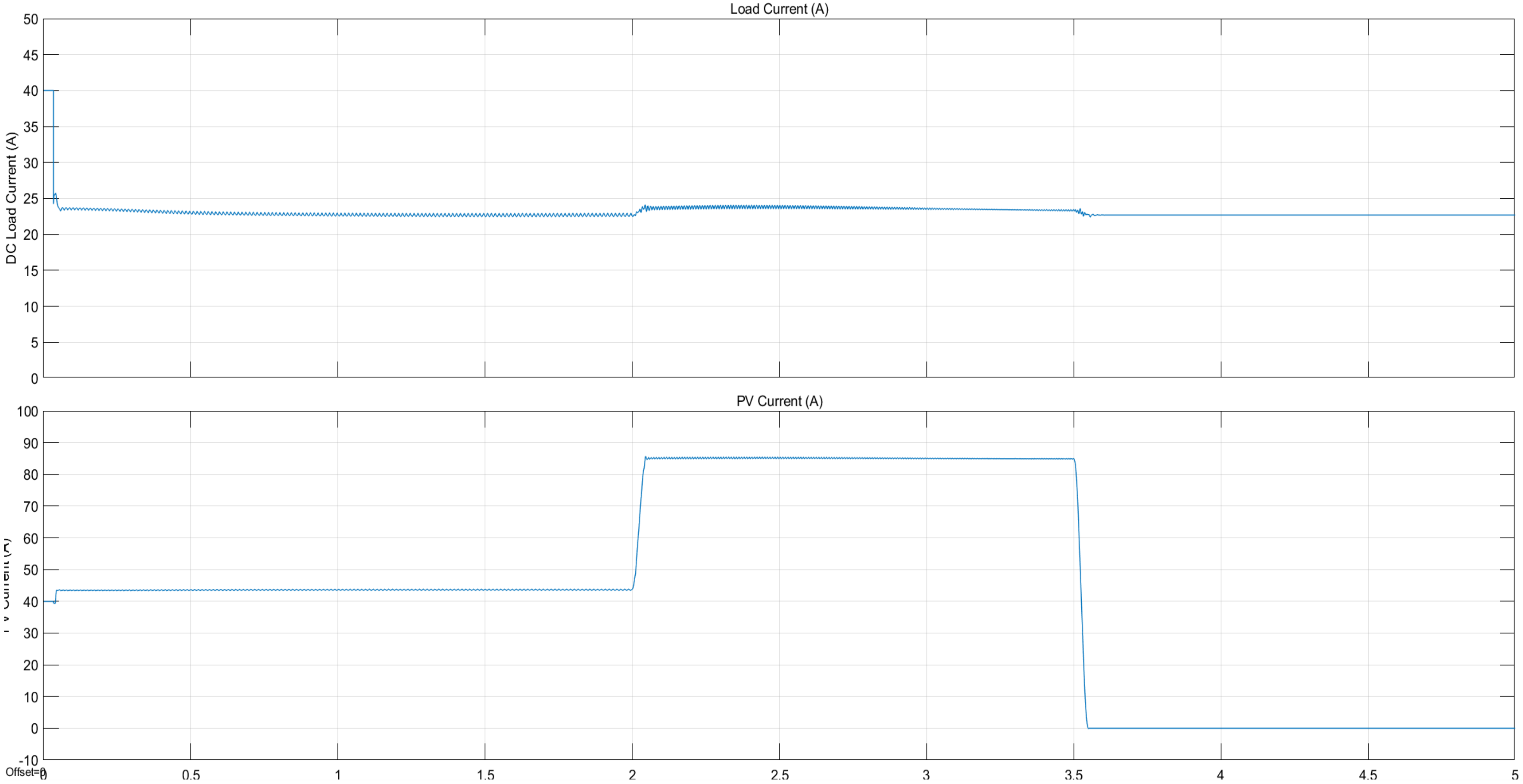
Dynamic Modelling & Control System

Results (2)



Dynamic Modelling & Control System

Results (3)

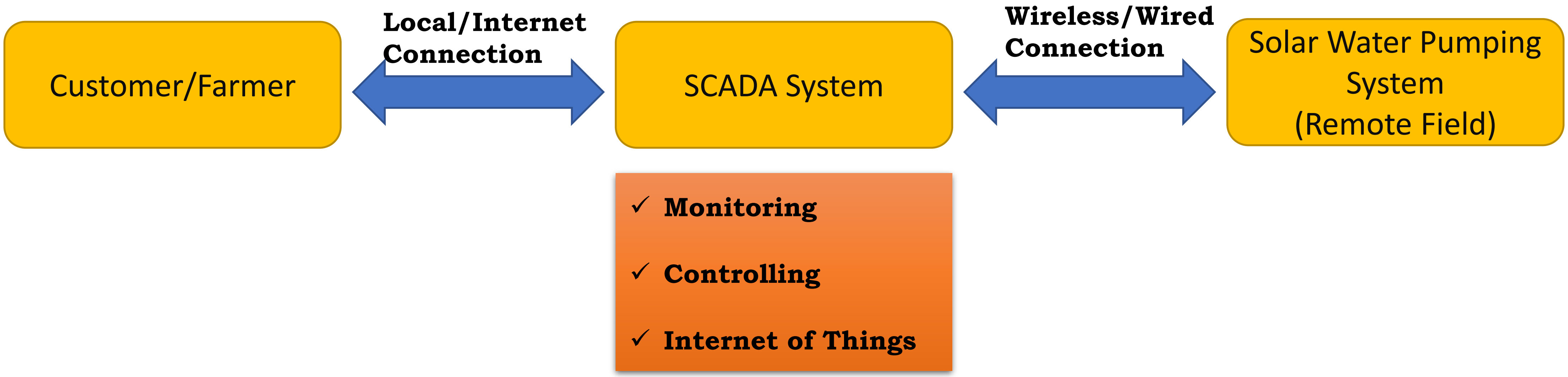


IoT-Based SCADA & Data Logging System

Introduction

SCADA

- ✓ **Supervisory Control and Data Acquisition**



Literature

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Project 1

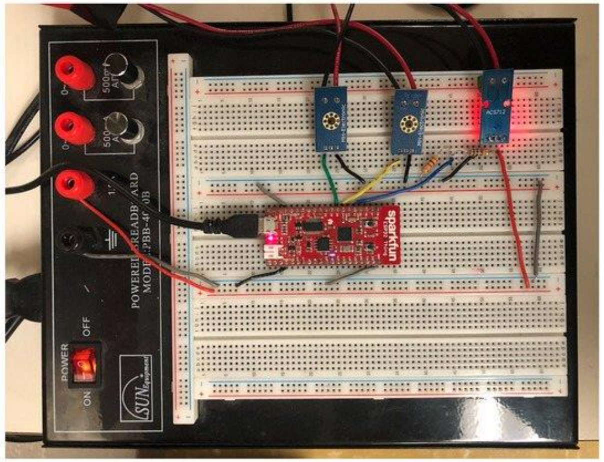
Low-Cost, Open Source IoT-Based SCADA System Design Using Thinger.IO and ESP32 Thing

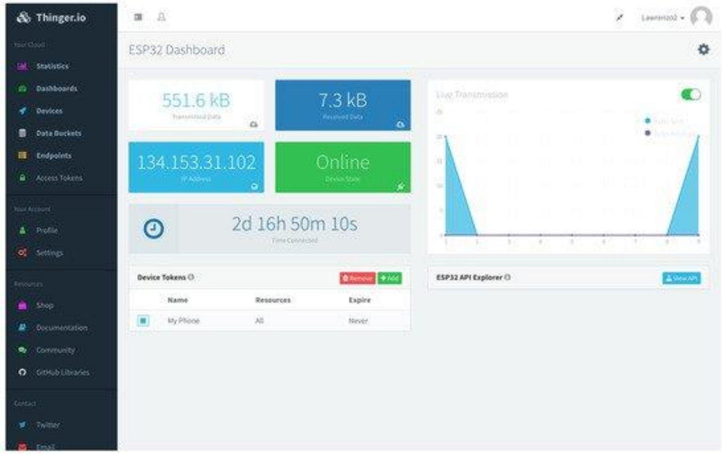
2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE)

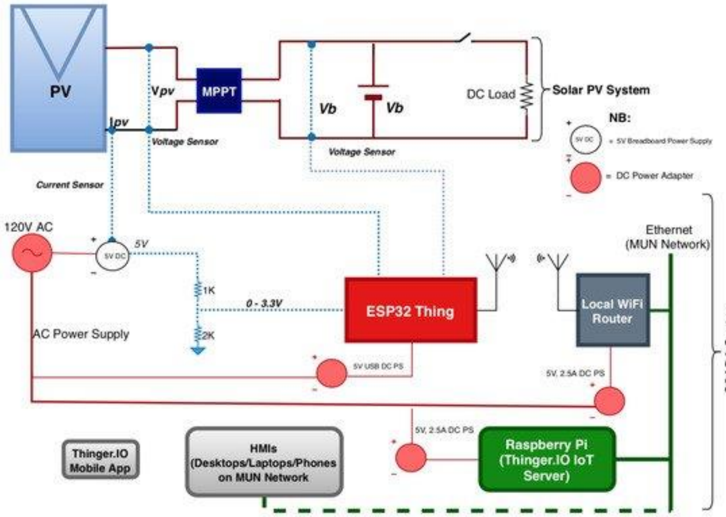
Set up to remotely monitor a 260 W, 12 V Solar PV System.

Data Stored Online on Thinger.IO Cloud (WiFi Only)

A few HMIs were Designed







Literature

Project 2

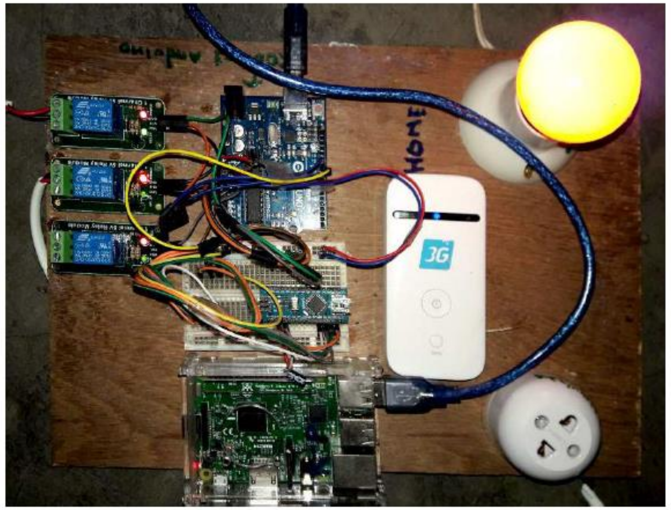
Advanced Home Automation System Using Raspberry-pi and Arduino

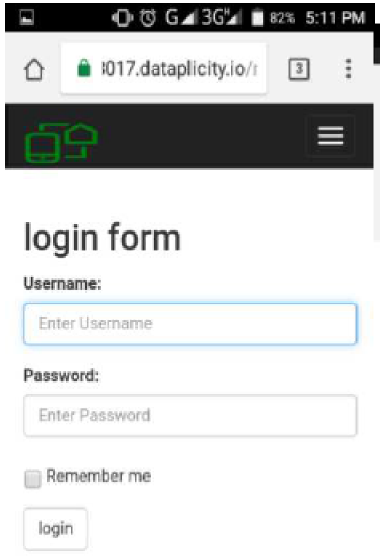
International Journal of Computer Science and Engineering (IJCSE)
ISSN(P): 2278-9960; ISSN(E): 2278-9979
Vol. 8, Issue 2, Feb - Mar 2019; 1-10

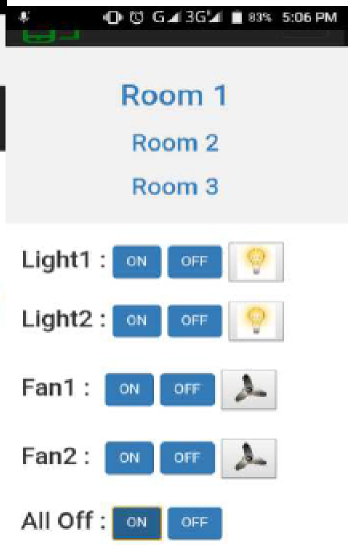
Data Stored Locally on Raspberry Pi Server

NGINX for HTTP basic-authentication

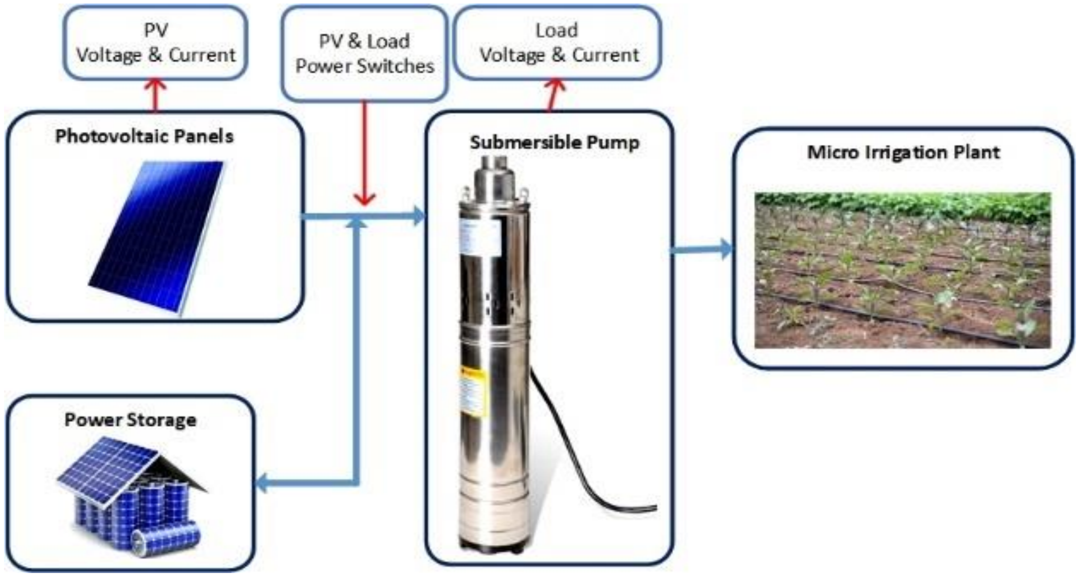
Dataplicity for Exposing to the Internet (3rd Party App) (WiFi Only)



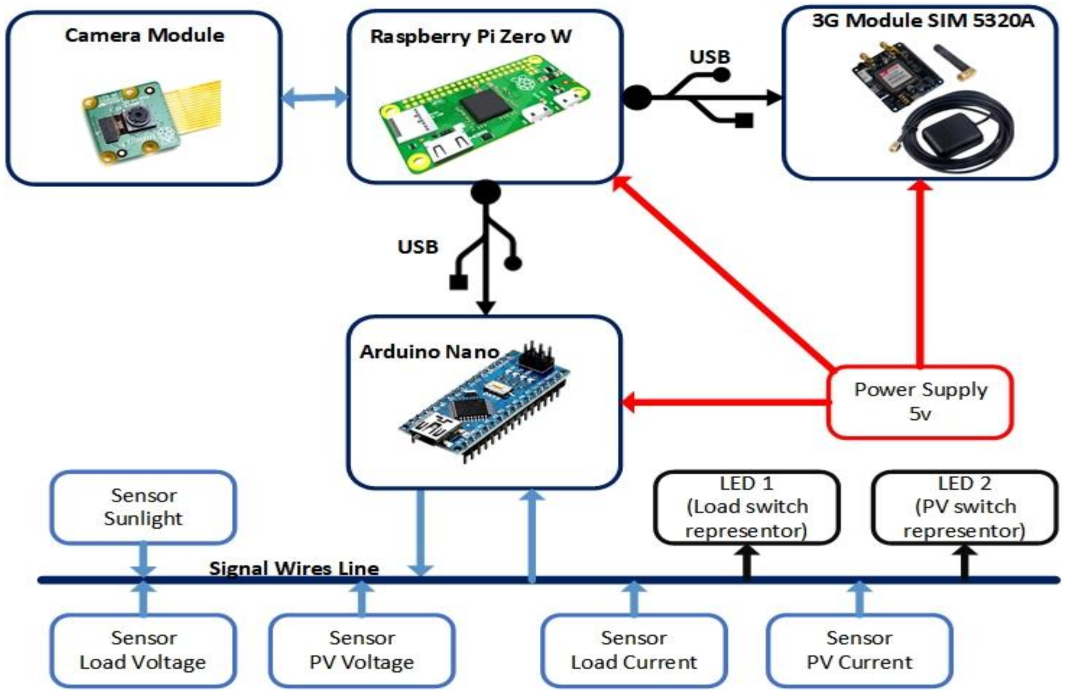




System Diagram



A. Solar Pumping Schematic Diagram



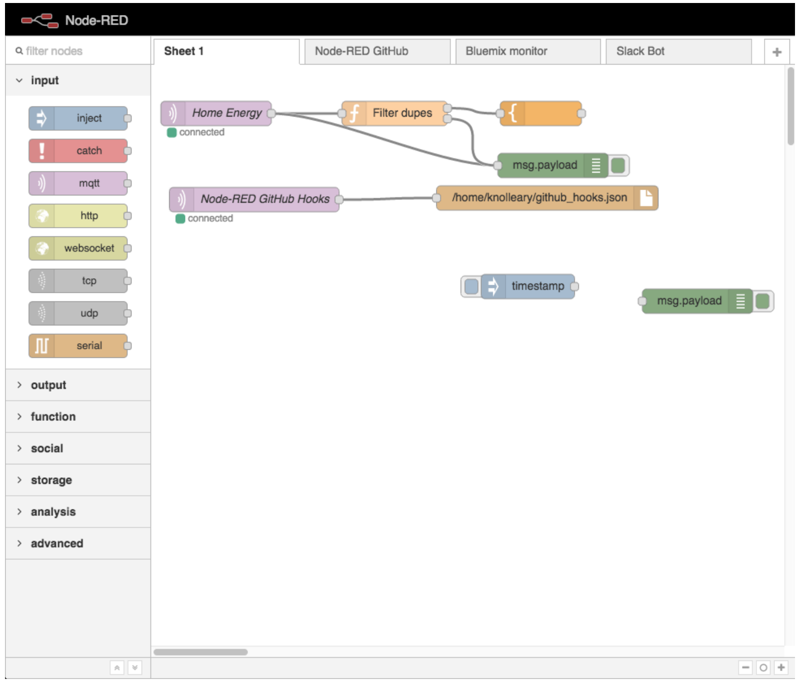
B. Designed SCADA System Schematic Diagram

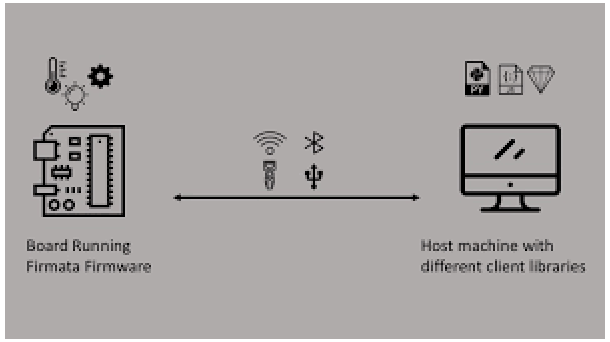
Technology used in the Project

Node-RED

User Interface Dashboard

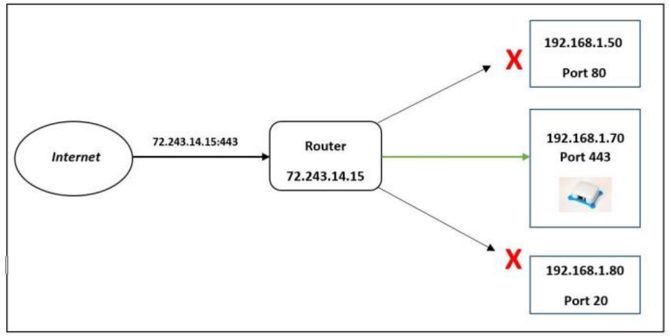
Firmata

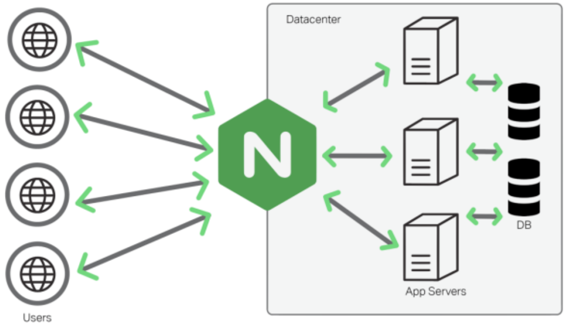




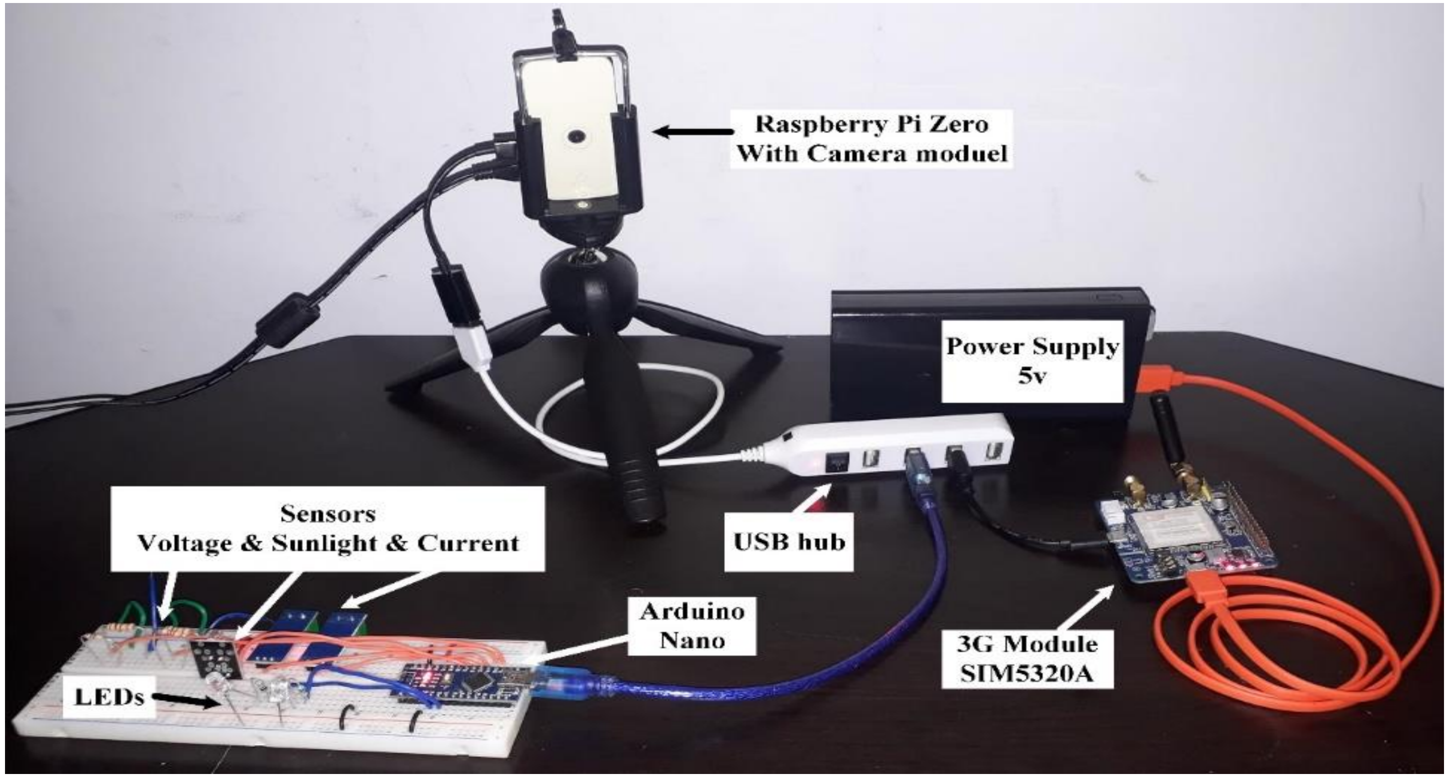
Port Forwarding

NGINX **Basic HTTP Encryption**

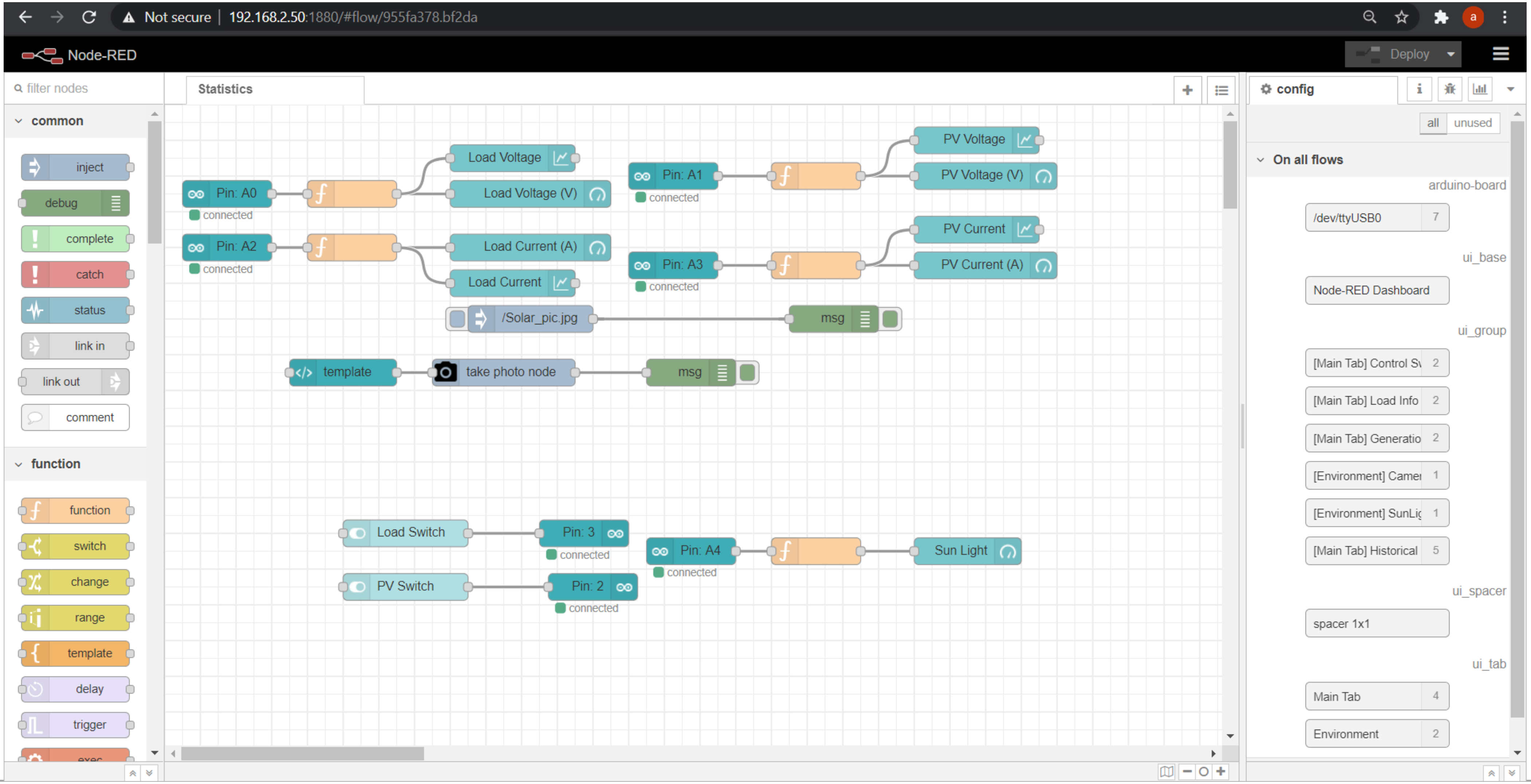




Experimental Set-up

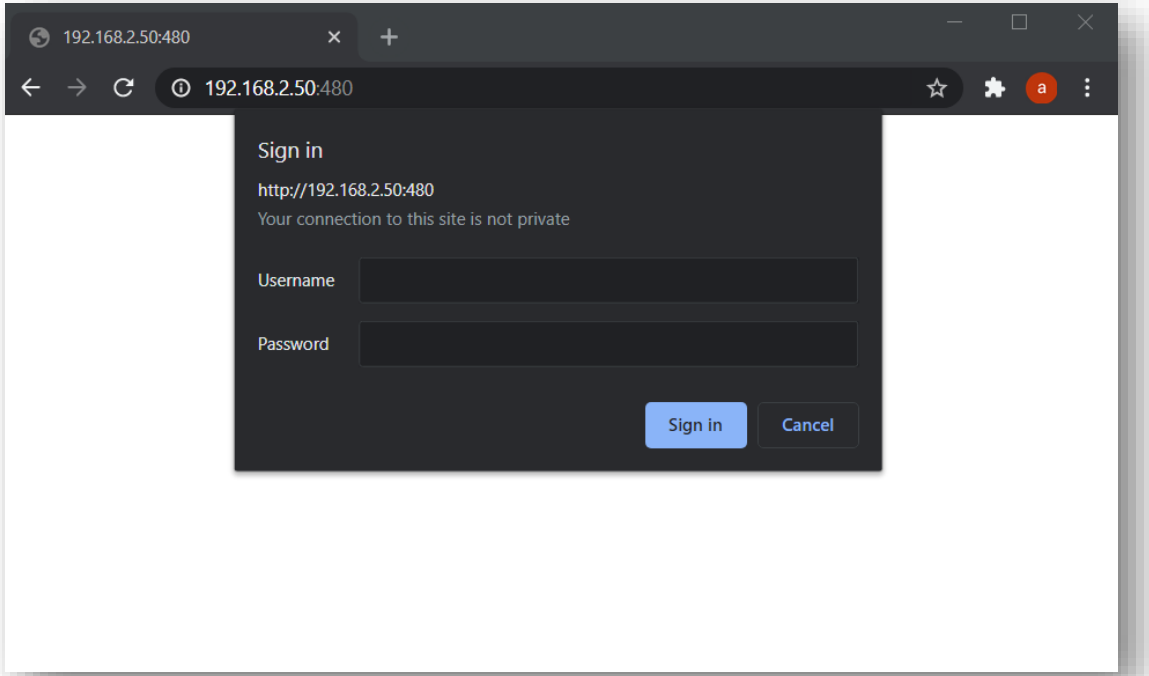


Node-RED Program

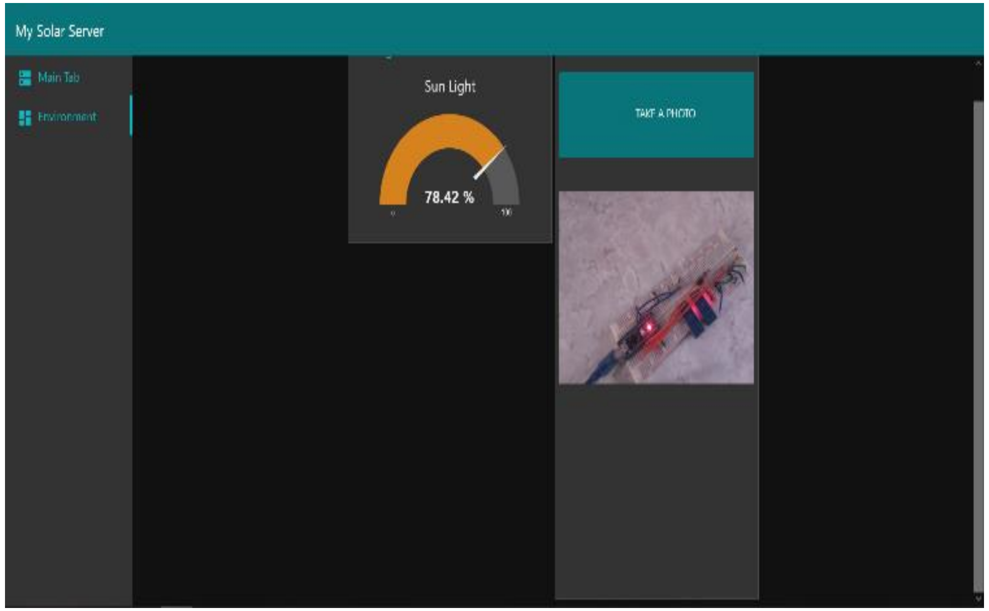


Internet Connections List

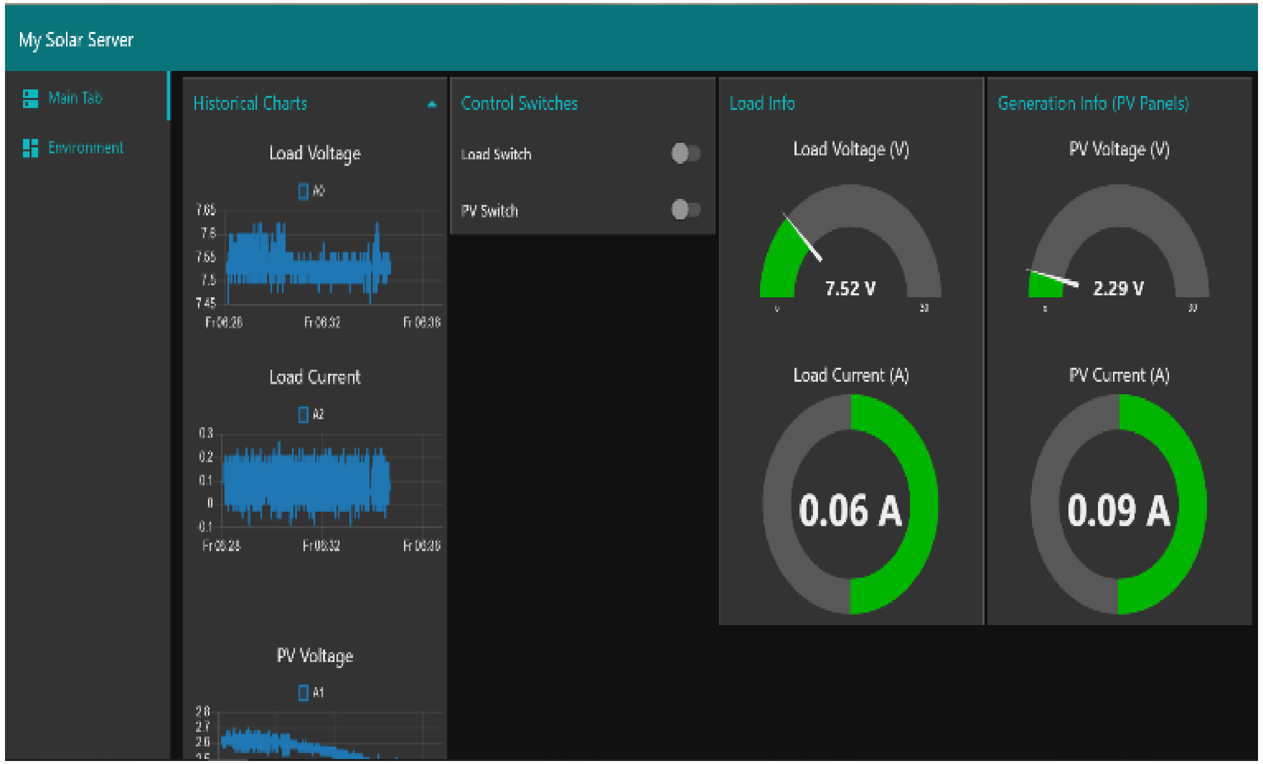
```
pi@mysolarserver:~ $ ifconfig -a
lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
        inet 127.0.0.1  netmask 255.0.0.0
        inet6 ::1  prefixlen 128  scopeid 0x10<host>
        loop  txqueuelen 1000  (Local Loopback)
        RX packets 7  bytes 362 (362.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 7  bytes 362 (362.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

ppp0: flags=4305<UP,POINTOPOINT,RUNNING,NOARP,MULTICAST>  mtu 1500
        inet 25.127.244.104  netmask 255.255.255.255  destination 10.64.64.64
        ppp  txqueuelen 3  (Point-to-Point Protocol)
        RX packets 8  bytes 158 (158.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 9  bytes 221 (221.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

wlan0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        inet 192.168.2.50  netmask 255.255.255.0  broadcast 192.168.2.255
        inet6 fe80::97f2:39ac:23b5:9c10  prefixlen 64  scopeid 0x20<link>
        ether b8:27:eb:42:fb:fb  txqueuelen 1000  (Ethernet)
        RX packets 4866  bytes 328121 (320.4 KiB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 4508  bytes 626122 (611.4 KiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

wwan0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        inet 169.254.232.145  netmask 255.255.0.0  broadcast 169.254.255.255
        inet6 fe80::e9bf:3966:5b83:b966  prefixlen 64  scopeid 0x20<link>
        ether 3a:63:47:37:f2:28  txqueuelen 1000  (Ethernet)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 60  bytes 11098 (10.8 KiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

pi@mysolarserver:~ $ route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         192.168.2.1     0.0.0.0         UG    302    0        0 wlan0
10.64.64.64     0.0.0.0         255.255.255.255 UH    0      0        0 ppp0
169.254.0.0     0.0.0.0         255.255.0.0     U     203    0        0 wwan0
192.168.2.0     0.0.0.0         255.255.255.0   U     302    0        0 wlan0
pi@mysolarserver:~ $ Connection reset by 192.168.2.50 port 22
PS C:\Users\Mr. Engineer>
```



SCADA IoT Dashboard



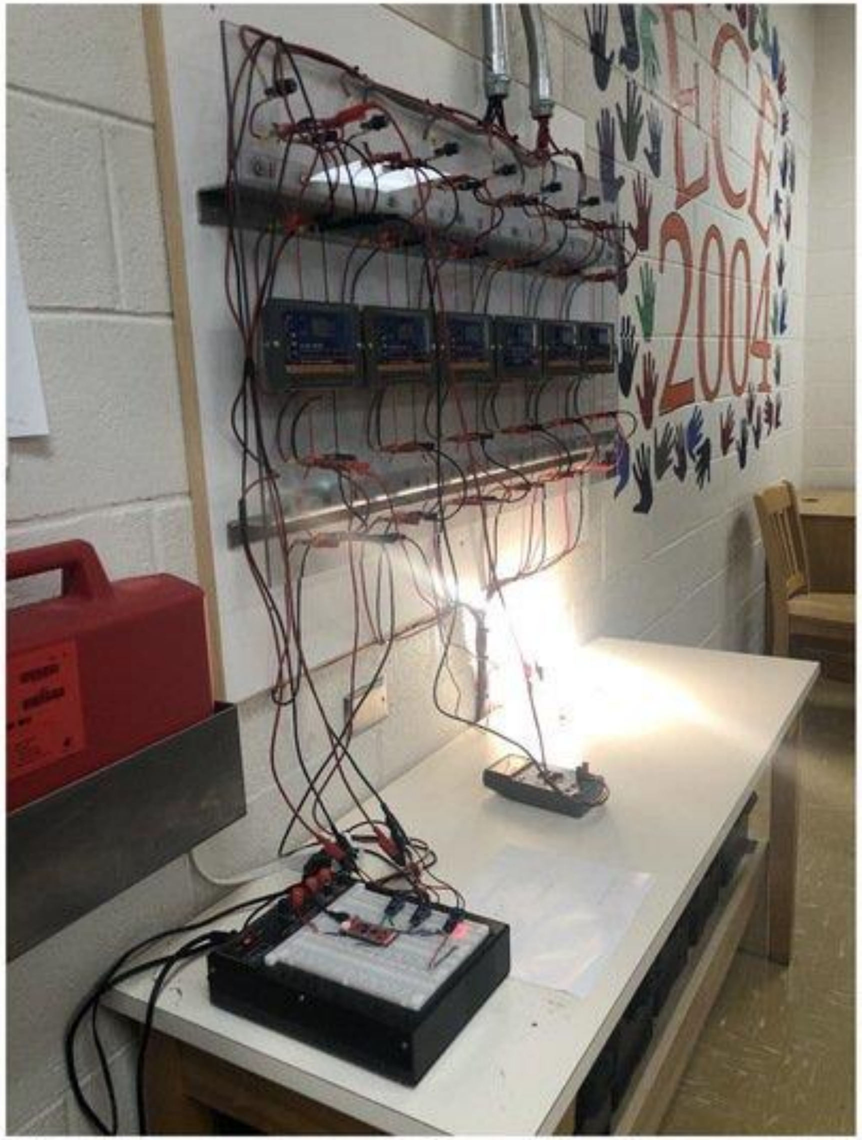
Environment Tab



Main Tab

Engineering Energy Systems Laboratory

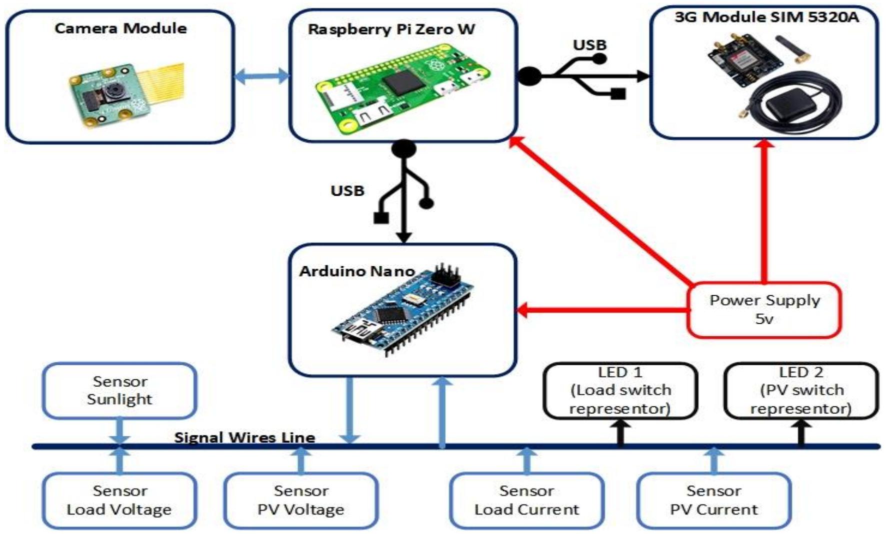
Unavailable due to COVID-19



Cost Analysis

System Costs:

Component	Cost (CAD)
Raspberry Pi Zero	37.60
Arduino Nano	4.80
Camera Module	13.99
3G Module SIM5320 A (optional)	105.99
Internet Plan (Iran) 48GB/year	6.5
Total	56.39 – 162.38



Open-Source SCADA System

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Cost Comparison

Microsoft Azure

In addition to components cost (Same components), Minimum 12.80 $CAD/month for each IoT Hub unit to implement the SCADA

Microsoft Azure — Contact Sales | Search | My account | Portal | Sign in

Overview | Solutions | Products | Documentation | Pricing | Training | Marketplace | Partners | Support | Blog | More | Free account

Region: Canada East

Currency: Canadian Dollar ($)

Pricing

– IoT Hub — Connect your IoT devices and build your IoT solution to turn data into business intelligence.

Basic tier

EDITION TYPE	PRICE PER IOT HUB UNIT (PER MONTH)	TOTAL NUMBER OF MESSAGES/DAY PER IOT HUB UNIT	MESSAGE METER SIZE
B1	$12.80	400,000	4 KB
B2	$64	6,000,000	4 KB
B3	N/A	300,000,000	4 KB

Conclusion

- ✓ Importance of advancing & publicizing renewable energy technologies in agriculture
- ✓ SCADA IoT based systems
- ✓ Proposed system successfully implemented
- ✓ Cost-effective & Low power consumption
- ✓ Data is stored locally and is secure
- ✓ Available for remote places through WiFi or Cellular networks

Contributions

- ✓ Water requirement analysis
- ✓ System sizing & analysis without storage
- ✓ System sizing & analysis with a storage
- ✓ Dynamic modelling & control system in MATLAB/Simulink
- ✓ IoT-based SCADA and data logging system

Future Work

- The study and comparison of solar water pumping system for different locations in Iran need to be studied.
- It is suggested to study the impact of using solar water pumping in reducing the carbon emissons over a set period.
- It is suggested to study using solar water pumping in a vast number in a specific area. For example, in a city like Urmia, West Azerbayjan, the difference it can make to convert all types of irrigation systems into solar water pumping.
- The study and comparison of using solar water pumping for other types of fruits/crops needs to be done which will advance the solar water pumping technology. The common fruits/crops in Urmia West Azerbayjan are apples, cherries, apricot, grapes, wheat, cucurbits
- The study and comparison of solar water pumping for different types of irrigation systems can be studied such as flood irrigation, sprinkler irrigation, and micro-irrigation.

Future Work

- The study and comparison of solar water pumping with different types of pumping systems need to be studied such as surface and centrifugal submersible pumps.
- The study and comparison of regular pumping systems and solar water pumping need to be studied.
- The study and comparison of using different types of PV panels need to be done.
- The study and comparison of different types of battery storage systems need to be done.
- It is suggested to develop a simplified mathematical model of the system in Simulink. Therefore, the system can be simulated for a year or several years to observe its various components' responses. The designed dynamic model in this thesis takes a lot of time to only simulate the system for a short period because of the type of the Simulink blocks used in it.
- A dynamic model for solar water pumping systems with water tank storage can be developed. Therefore, two types of system structures can be compared with each other.

My Publications (7)

[1] M. Zamanlou, M. T. Iqbal, “Design and Analysis of Solar Water Pumping with Storage for Irrigation in Iran,” **2020** IEEE 17th International Conference on Smart Communities: Improving Quality of Life Using ICT, IoT and AI (HONET), Virtual Conference, Charlotte, NC, USA

[2] C. A. Osaretin, M. Zamanlou, M. T. Iqbal, S. Butt, “Open Source IoT-Based SCADA System for Remote Oil Facilities Using Node-RED and Arduino Microcontrollers” **2020** IEEE Information Technology, Electronics and Mobile Communication Conference (IEMCON), Virtual Conference, Vancouver, BC, Canada

[3] M. Zamanlou and M. T. Iqbal, “Development of an Economical SCADA System for Solar Water Pumping in Iran,” 2020 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), Vancouver, BC, Canada, **2020**, pp. 1-4, doi: 10.1109/IEMTRONICS51293.2020.9216408.

[4] A. M. Sharan, M. Zamanlou, “Energy Efficiency Enhancement of Electrical Vehicles,” International Journal of Engineering and Applied Sciences (IJEAS), ISSN: 2394-3661, Volume-7, Issue-5, **May 2020**

[5] M. Zamanlou, M. T. Iqbal, “Design and analysis of a solar water pumping system for drip irrigation of a fruit garden in Iran,” The 28th Annual Newfoundland Electrical and Computer Engineering Conference (IEEE NECEC), **2019**, St. John’s, NL, Canada

[6] A. M. Sharan, M. Zamanlou, “Accurate And Efficient Power Generation Of Photovoltaic Systems Using Wireless Technology,” International Journal of Engineering and Applied Sciences (IJEAS), Volume-6, Issue-4, pp 2394-3661 **April 2019**

[7] M. Sharan, M. Zamanlou, Md. H. Rahman, Md. A. Al-Mehdi, “Centralized Power Generation of Solar Parks using Wireless Controlling,” 2019 International Journal of Current Engineering and Technology, Vol.9, No.3 (**May/June 2019**), pp 405-411

Invited Talks (2)

[1] IEEE NL Young Professionals Chapter Invited Technical Talk, “Design & Analysis of a Solar Water Pumping System for Micro Irrigation of a Fruit Garden,”
Memorial University, St. John’s, NL, Canada, **December 2019**

[2] NSERC Energy Storage Technology Network Winter School, “Battery Storage System vs Water Tank Storage for Solar Water Pumping in Iran”,
Simon Fraser University, Surrey, BC, Canada, **February 2020**

On The News (2)

[1] ***The Telegram***, “Memorial University professor, students develop wireless solar park capabilities,”
St. John’s, NL, Canada, **June 2019**

[2] ***The Telegram***, “Memorial University research aims to improve electric vehicles”,
St. John’s, NL, Canada, **July 2020**

Acknowledgment

My sincere thanks to my supervisor, Dr. Tariq Iqbal

Thanks to my mother, my father, and my uncle

Thanks to Avrin Goom Azaran company for funding

Thanks to Memorial University

Thanks to all the friends

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[3] E. T. Maddalena, C. G. D. S. Moraes, G. Braganca, L. G. Junior, R. B. Godoy, and J. O. P. Pinto, "A Batery-Less Photovoltaic Water-Pumping System with Low Decoupling Capacitance," in *IEEE Transactions on Industry Applications*, 2019, doi: 10.1109/TIA.2019.2900412.

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Questions