Design and Analysis of a Community Size Solar Powered Reverse Osmosis System for Pakistan

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Introduction

- Pakistan economy mostly relies on agriculture and around **22.2%** of that contributes to its overall gross domestic product (GDP).
- In 1950s Pakistan has the water capacity of around 5000m3 per capita and it **has decreased now to 1000m3 per capita**.
- Overall worldwide, the countries that are facing difficulty in availability of freshwater are now relying on water desalination processes but at the cost of **electricity consumption**.
- This energy requirement is a big challenge as the world is already heading towards a **big global climate change**. Extracting this much amount of energy from the conventional thermal power plants would not only make the environment poor but would put the cost of production of water at a very higher rate.
- Thankfully, Pakistan lies on the **region of good solar irradiance** ranging from 5–7 kWh per $m2$ per day and sunshine hours of 1,500–3,000 per year which can be used for solar powered reverse osmosis systems.
- Hence **renewable technology based reverse osmosis (RO)** systems can be a good source of sustainable fresh water production method.

Reverse Osmosis Desalination System

- Reverse osmosis convert **unfiltered feed water to clean water** when feed water is pressurized and passed through a membrane.
- A membrane is an equipment that **has small pores** that allow water molecules to pass through but stop contaminants.

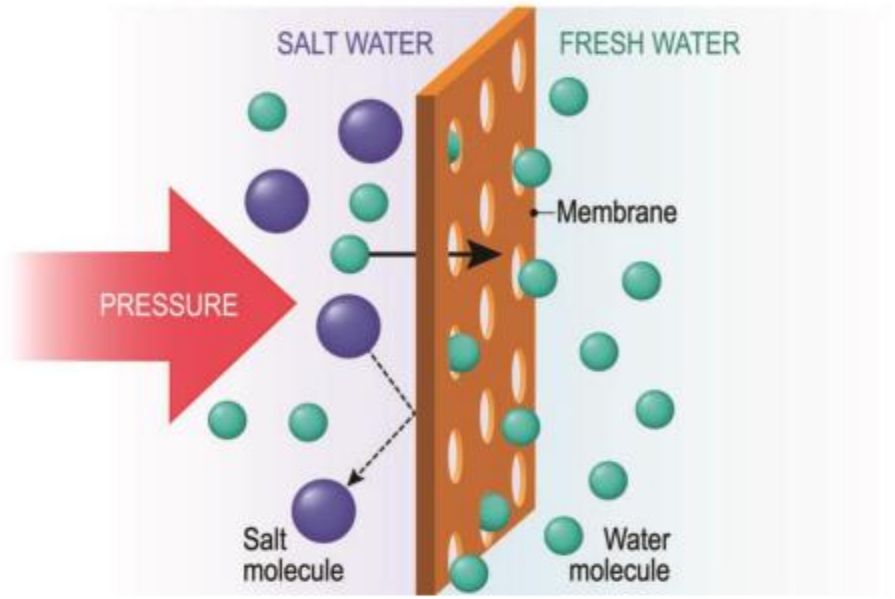

Fig 1: Reverse Osmosis Membrane Diagram

Reverse Osmosis Desalination System

- Water is passed through inlet filters followed by passing through the membrane.
- The **storage tank** provide a buffer for the consumption and production of clean water.
- The brine water can be used for dishwashing and other cleaning purpose so that it is not wasted and utilized for i**ncreasing efficiency of the system**.

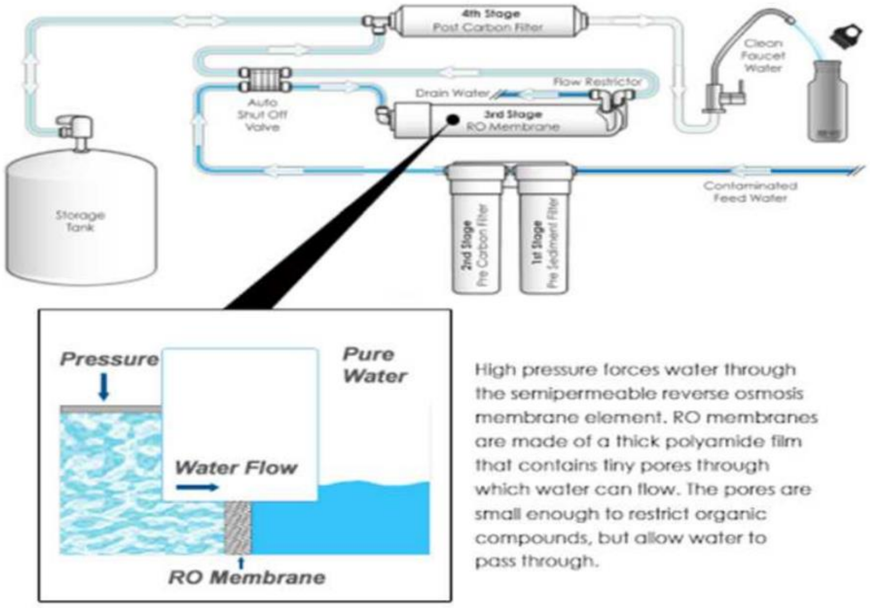

Fig 2: Reverse Osmosis System Flow Diagram

Pakistan Data Analysis

Solar Potential

- The location of Pakistan on map lies within latitude 23.45º to 36.75ºN and longitude 61º to 75.5ºE.
- The Renewable Energy Policy 2006 of Alternative Energy Development Board (AEDB) Ministry of Energy and Power division Pakistan, explains that Pakistan is highly rich in terms of solar energy.
- The annual average solar radiation of Pakistan is about 5.5 kWh/m2. The Areas of Sindh and Baluchistan are even richer in terms of solar radiation excluding the coastal areas of these provinces.

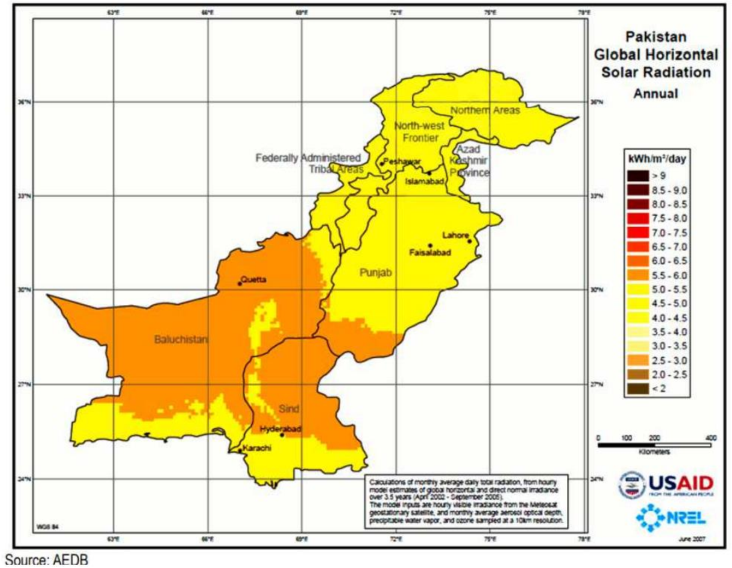

Fig 3: Pakistan Global Horizontal Solar Radiation Map

Pakistan Data Analysis

Drinking Water Quality

Table 1: Comparison of Pakistan standard with WHO for Biological Parameters [20]

Parameter	Standard Value for Pakistan	WHO Standards
All water intended for drinking measuring E coli or thermo tolerant coliform bacterial	Must not be detectable in any 100 ml Sample	Must not be detectable in any 100 ml Sample
Treated water entering the distribution system (E. coli or thermo tolerant coliform and total coliform bacteria)	Must not be detectable in any 100 ml Sample	Must not be detectable in any 100 ml Sample
Treated water in the distribution system (E. coli or thermo tolerant coliform and total coliform bacteria)	Must not be detectable in any 100 mL sample In case of large supplies, where sufficient samples are examined, it must not be present in 95% of the samples taken throughout any 12-month period	Must not be detectable in any 100 mL sample In case of large supplies, where sufficient samples are examined, it must not be present in 95% of the samples taken throughout any 12-month period

Table 2: Comparison of Pakistan standard with WHO for Physical Parameters [20]

Parameter	Standard Value for Pakistan	WHO Standards
Color	≤15 TCU	≤15 TCU
Taste	None	None
Odor	None	None
Turbidity	<5 NTU	<5 NTU
TDS	<1000	<1000
pH	6.5-8.5	6.5-8.5

Table 3: Comparison of Pakistan standard with WHO for Chemical Parameters [20]

Parameter	Standard Value for Pakistan	WHO Standards
Aluminum (Al) mg/L	≤0.2	0.2
Antimony (Sb)	≤0.005 (P)	0.02
Arsenic (As)	≤0.05 (P)	0.01
Chloride (Cl)	<250	250
Chromium (Cr)	≤0.05	0.05
Copper (Cu)	2	2
Cyanide (CN)	≤0.05	0.07
Lead (Pb)	≤0.05	0.01
Manganese (Mn)	≤0.5	0.5
Mercury (Hg)	≤0.001	0.001
Fluoride (F)	≤1.5	1.5
Nitrate (NO3)	≤50	50
Nitrite (NO2)	≤3 (P)	3

Literature Review

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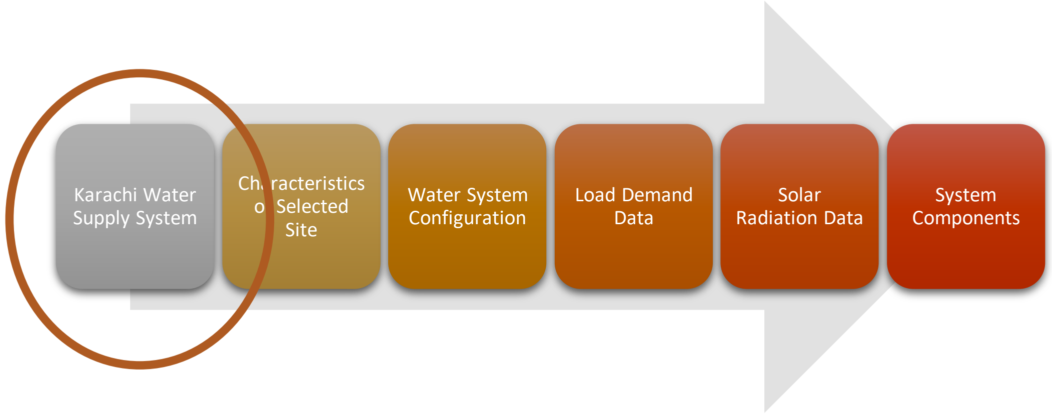
Author	Conclusion
Muhammad Wajid Saleem, Asad Abbas, Muhammad Asim, Ghulam Moeen Uddin, Tariq Nawaz Chaudhary and Asad Ullah	The paper used PVsyst software for solar calculation and deduced that 19, 15 and 40 PV panels will be used by Lahore, Hasil Pur, and Faisalabad respectively
Abdul Ghafoora, Anjum Munir , Tauseef Ahmed , Muhammad Nauman , Waseem Amjad and Azlan Zahid	It was concluded that around 18% more daily PV energy was utilized using the tracking system and also 10% more PV energy was used when the panels were cooled
M.A. Abdelkareem, M. El Haj Assad, E.T. Sayed, B. Soudan, R	It was concluded that solar tracking and cooling of PV cells eventually makes the process overall efficient.
C. Liu, K. Rainwater, L.F. Song,	It was concluded that most portion of energy loss is in the membrane section of the system.
E. Dimitriou, P. Boutikos, E.Sh. Mohamed, S. Koziel, G. Papadakis	It was concluded that water flux drop when pressurized water is passed through it.
A. Ghermandi, R. Messalem,	It was concluded in their work that photovoltaic based reverse osmosis is a good technology which has a potential to reach to 2-3 US$ per m3
R. Eke, A. Senturk, M. Dakkak, A. Babelli,	It wasconcluded that solar trackers can increase around 30% of energy in Turkey
H. Bentaher, H. Kaich, N. Ayadi, M. Ben Hmouda, A. Maalej, U. Lemmer,	It was suggested to utilize the maximum potential of solar tracking system during the day time for increasing system efficiency

Site Selection & System Design

- Karachi Water Supply System
- Characteristics of Selected Site
- Water System Configuration
- Load Demand Data
- Solar Radiation Data
- System Components

Site Selection & System Design



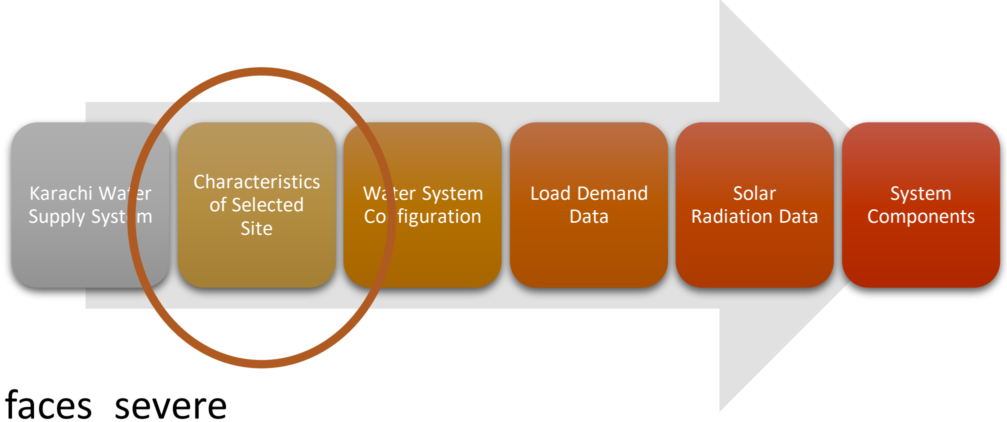
Karachi Water Supply System

Fig 4: Haleji Lake

Fig 5: Keenjhar Lake

Fig 6: Hub Dam

Site Selection & System Design



Characteristic of Selected Site

- Karachi is situated in the south of Pakistan and faces severe population migration, water crisis and pollution issues in the last few years.
- Qasim Town as the selected location for this study is a slum area in Karachi city, Sindh Province, Pakistan (24°49'37.2"N 67°15'08.1"E).
- This is a Slum community with families having **very low income** to support their living.
- This area is currently **relying on water tanker system** and unscheduled limited supply of contaminated water from the government water supply lines.
- The **cost of water tanker is very high** and it became highly unfeasible for such low income community to purchase expensive water for drinking purpose.
- This selected community has around 223 houses with a total population of **approximately 780 persons**.
- The ground water total dissolved solids (TDS) was found to be 1612 mg/L and hardness was found as 518.49 mg/L.

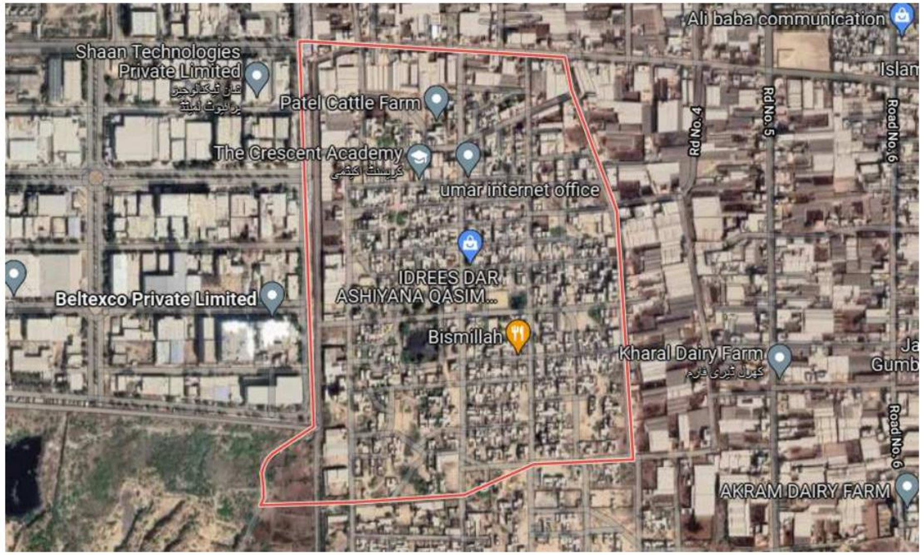
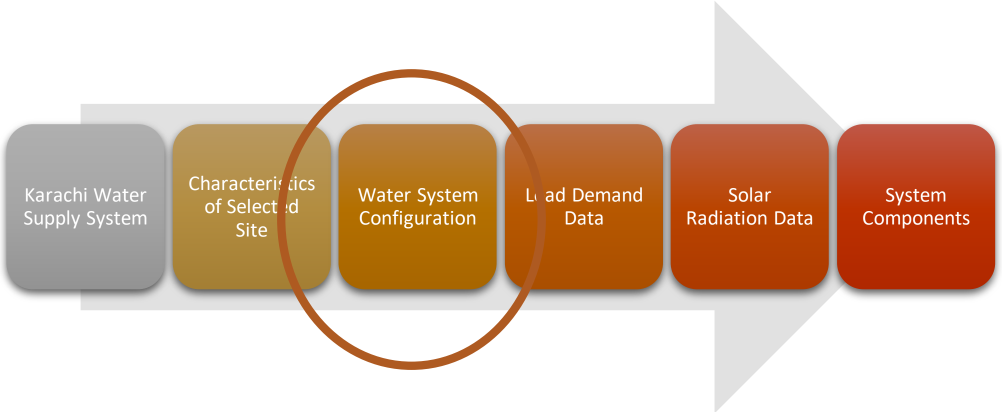


Fig 7: Google Map of Qasim Town

Site Selection & System Design



Water System Configuration

- A submersible pump is installed to extract the brackish ground water from a **depth of 300 feet's**.
- On average, drinking water consumption by a person in **one day is 3.7 liters.**
- In order to feed the complete community of 780 persons around **2964 liter of water is required per day**.
- A brackish water tank is used that has a **capacity of 4000 liters** so that sufficient quantity of brackish water is stored once pumped from the ground.
- A pressure pump is utilized to increase the tank's brackish water pressure and then passed through the reverse osmosis (RO) system before it leaves to the drinking water storage tank and finally is available for community utilization from the common header.

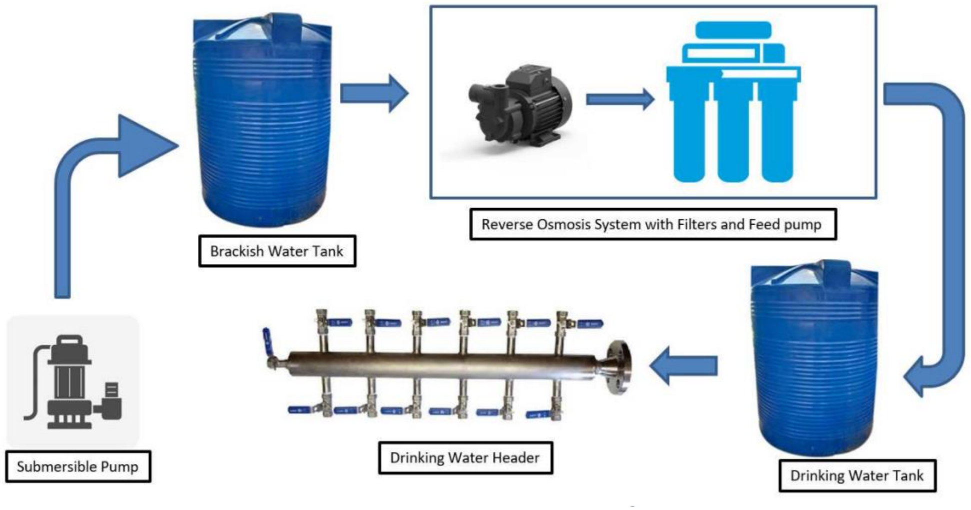


Fig 8: Water System Configuration

Site Selection & System Design

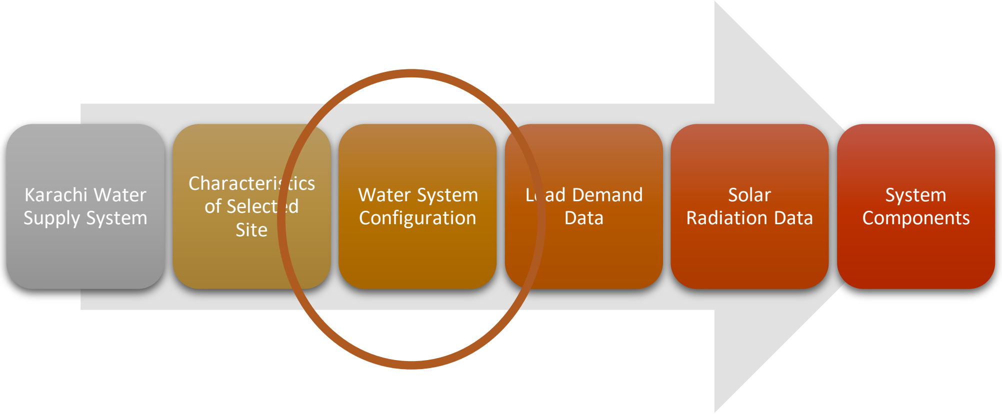
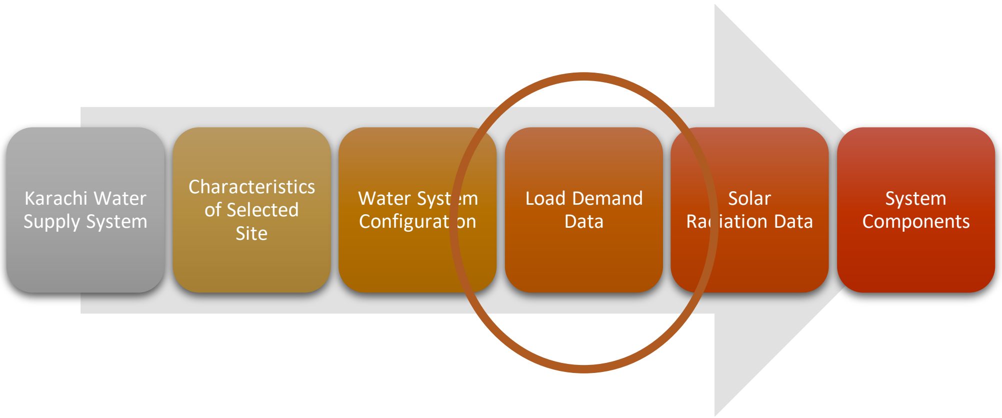


Fig 9: US Defender RO System

Parameter	Description
Configuration	Single Pass
Feed Water Source	City or Well Water
Standard Recovery Rate	48%
Recovery Rate with Concentrate Recycle	Up to 75%
Permeate Flow	2.78 GPM
Minimum Feed Flow	5.78 GPM
Membrane per Vessel	01
Membrane Quantity	02
Membrane Size	4” x 40”
Pump Type	Multi-Stage
Motor	1.10 KW
Pump RPM	3450 @ 60 Hz

Site Selection & System Design



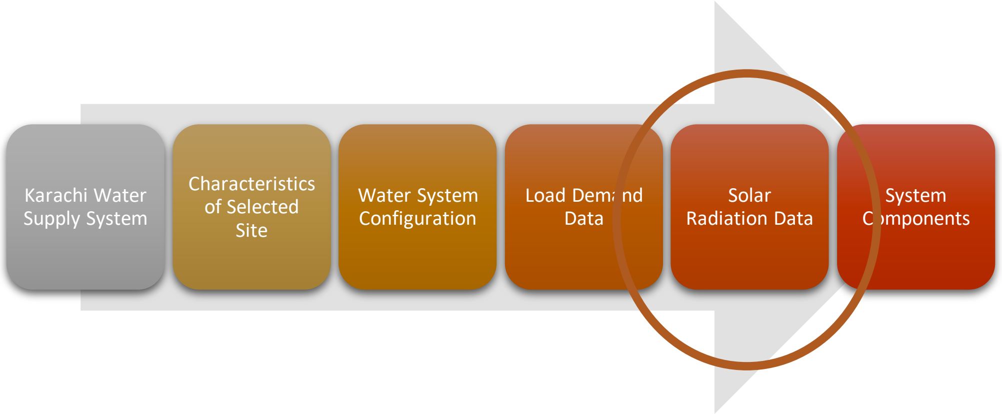
Electrical Load Requirement

- The major components of load in the system are submersible pump motor, complete RO system load and miscellaneous load.
- The complete system **will run for 06 hours in a day** to produce sufficient drinking water for the complete community.
- Based on the total dynamic head of 320 feet's, liquid flow rate of **2.175 gallons per minute** and pump efficiency of 50%, a 1.5 horsepower single phase induction motor is selected to be coupled with the submersible pump.
- The complete RO system for producing 2.175 gallons per minute has a power requirement of 0.5 kilowatt.
- Some miscellaneous energy that will be required which includes area lightning, control equipment etc. would require a maximum of 0.3 kilowatt.
- Hence the total energy required will be **approximately 2.0 kilowatt** for running the system smoothly at a production rate of more than **2.175 gallons per minute**.

Table 4: Electrical Load Summary

Component	Load (KW)
Submersible pump motor	1.2
Reverse Osmosis System including feed pump	0.5
Miscellaneous	0.3
Total Load	2.0

Site Selection & System Design



Solar Radiation Data

- The selected location has significant solar irradiance because of its favorable location.

- Based on the database, which is downloaded from NASA's prediction of worldwide energy resources, the monthly radiation and clearness index.

- The average annual solar irradiance **in this region is 5.45 kWh/m2/day,** while the maximum and minimum irradiance occurs in May and December, respectively.

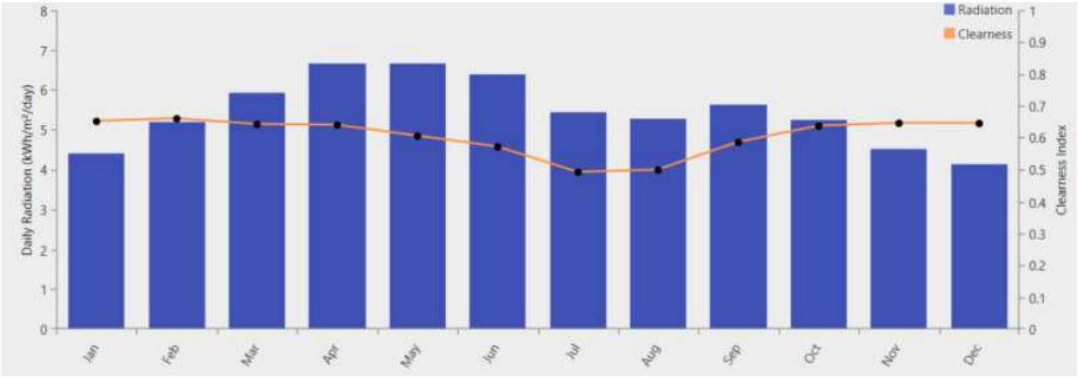
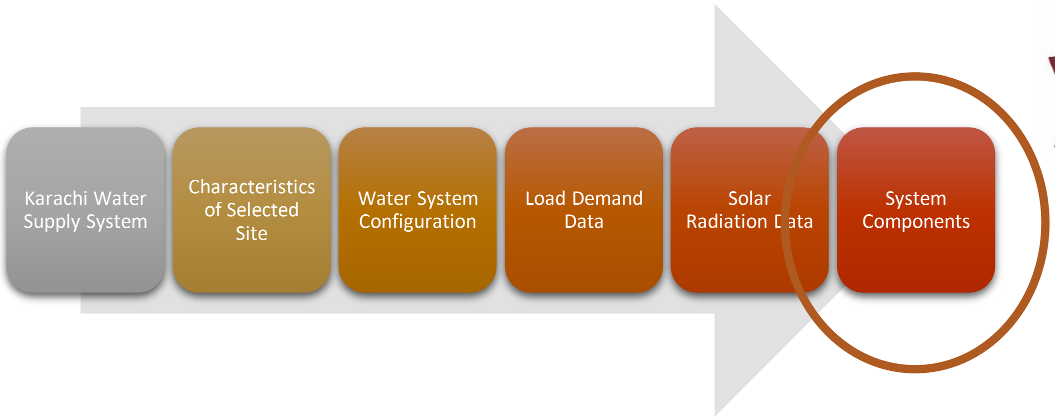


Fig 10: Solar Radiation and Clearness Index

Site Selection & System Design



System Components

Max Power 340W Solar Panel (Quantity: 15 Panels)

Trojan SCS-200 116Ah Lead Acid Battery (Quantity: 20 Batteries)

Max Power Suntronic 6KW Inverter (Quantity: 01 Inverter)

System Design in HOMER PRO Software

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- Hybrid optimization of multiple energy resources (HOMER) software from the National Renewable Energy Laboratory (NREL) is an enhanced software for simulation of micro grids.
- This software allows to use various components including conventional generator, extensive renewable and storage resources.
- The optimization feature of this software enables a designer to evaluate a stand-alone hybrid PV system with cost effective solutions, incorporating the highest percentage of renewable energy for grid stability and considering environmental concerns i.e. to reduce carbon dioxide emissions.
- The system design includes a PV array, lead acid battery and inverter feeding the load. The system has a daily energy requirement of 12 kilowatt hour with peak load of 3.63 kilowatt. The PV has 4.8 kilowatt of maximum power and uses a 6.0 kilowatt of inverter.
- Result of Homer Pro with optimization suggest 20 12-volt batteries with 4 batteries in each string to keep the DC bus voltage at 48 volts.

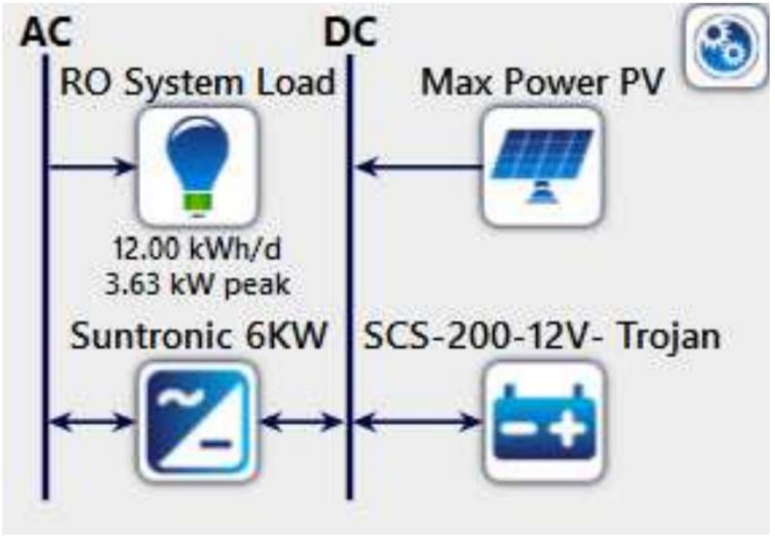


Fig 11: System Configuration HOMER

Results

Electrical Analysis

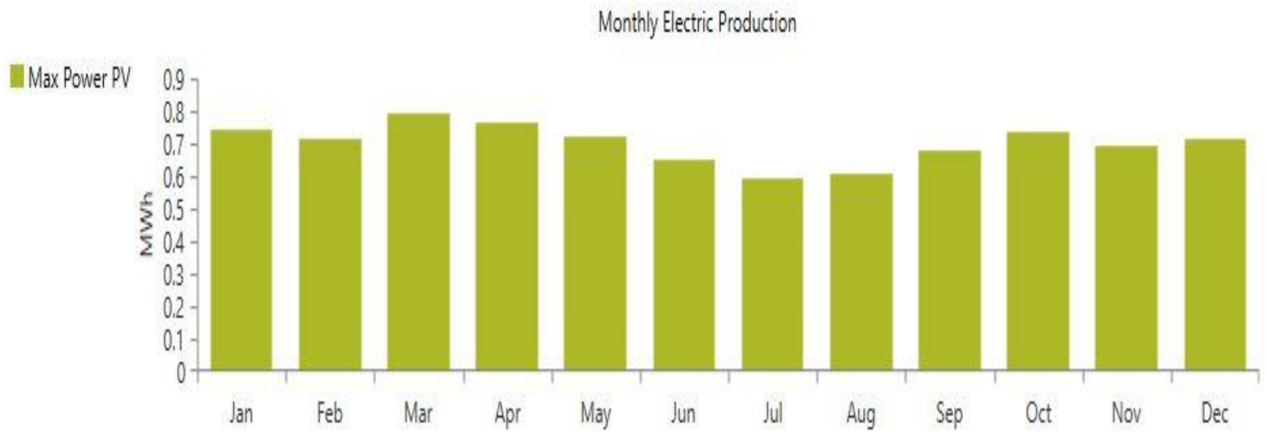


Figure 12: Monthly Electric Power Generation

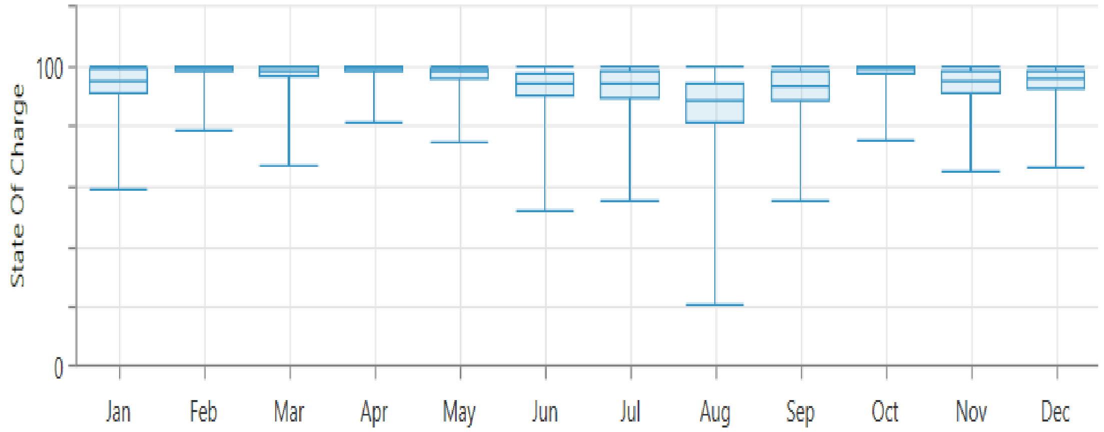


Figure 13: Monthly SOC Battery

Results

Electrical Analysis

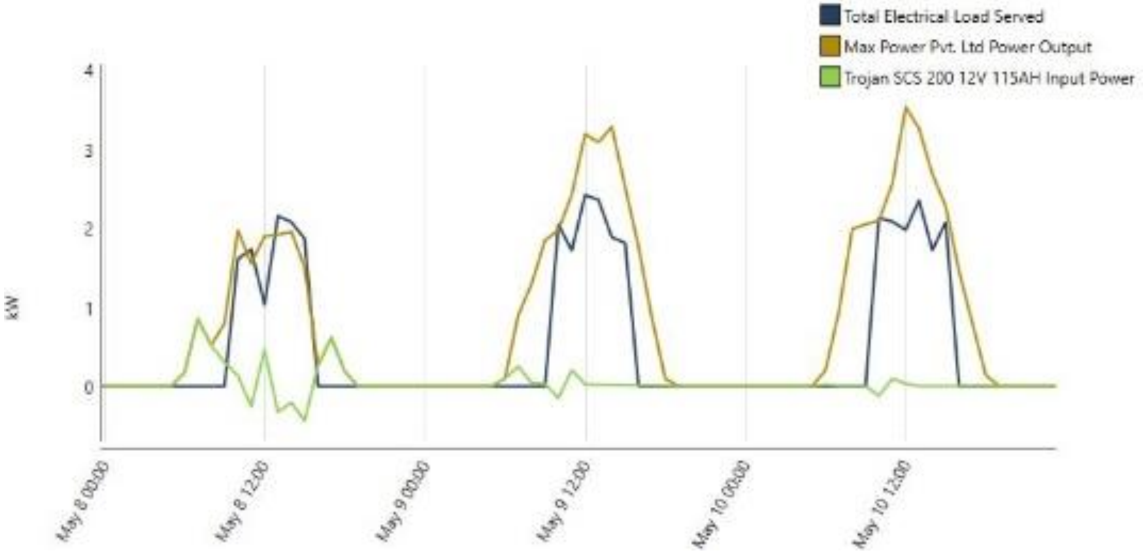


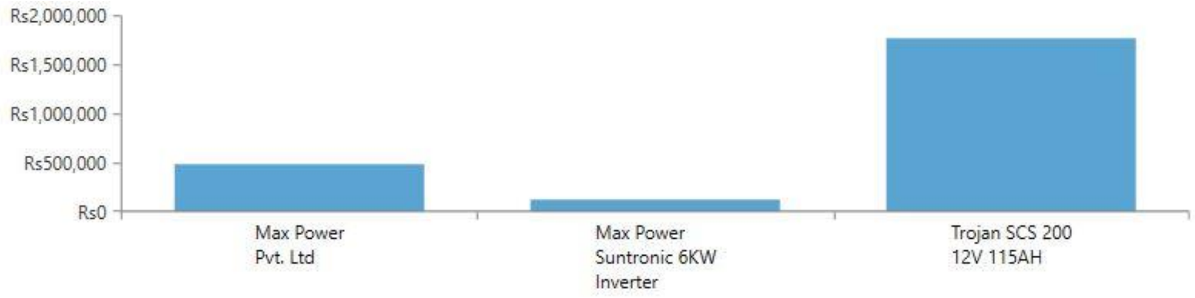
Figure 14: comparison of total electrical load served, PV Panel Power output and battery input power

Table 5: Summary of Electrical Parameters

Parameter	**Value**
PV Maximum Power	4.80 KW
Number of Batteries Required	20; 5 set of 4 strings
Inverter	4.30 KW
Renewable Energy Fraction	100%
PV Maximum Production	8418 KWH/Year
Battery Autonomy	44.6 hours
Battery Annual throughput	480 KWH/Year
Battery Nominal Capacity	27.9 KWH
Battery Usable Nominal Capacity	22.3 KWH
Inverter Mean Output	0.500 KW

Results

Economic Analysis



Component	Capital (Rs)	Replacement (Rs)	O&M (Rs)	Fuel (Rs)	Salvage (Rs)	Total (Rs)
Max Power Pvt. Ltd	Rs278,401.04	Rs245,949.95	Rs0.00	Rs0.00	-Rs33,346.58	Rs491,004.42
Max Power Suntronic 6KW Inverter	Rs73,149.34	Rs64,622.88	Rs0.00	Rs0.00	-Rs8,761.75	Rs129,010.47
Trojan SCS 200 12V 115AH	Rs530,000.00	Rs0.00	Rs1,292,751.65	Rs0.00	-Rs64,058.78	Rs1,758,692.88
System	Rs881,550.38	Rs310,572.83	Rs1,292,751.65	Rs0.00	-Rs106,167.10	Rs2,378,707.77

Figure 15: Cost Summary

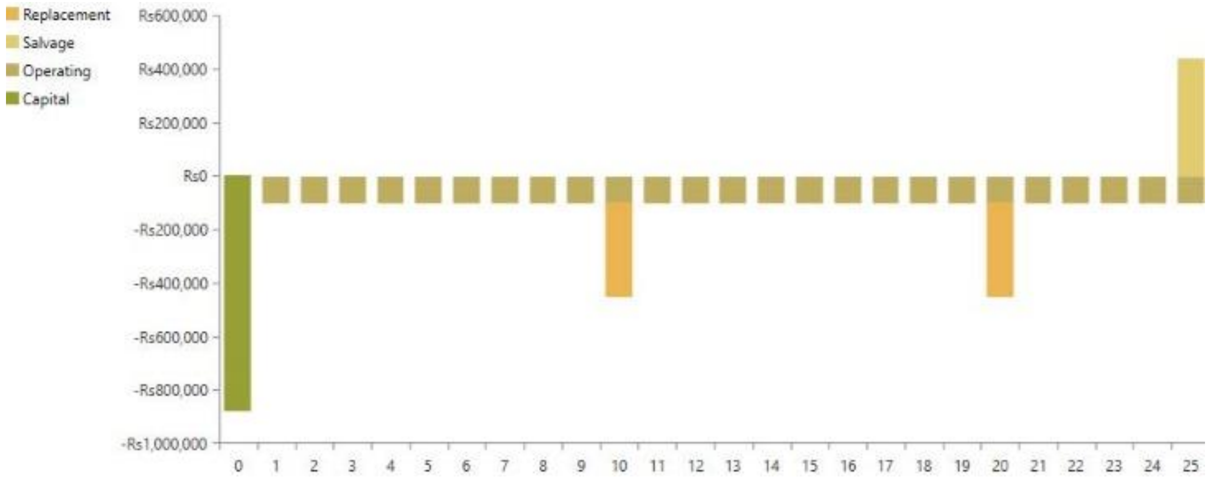


Figure 16: Cash Flow

Results

Economic Analysis

Table 6: Summary of Economic Parameter

Parameter	Value (PKR)
Net Present Cost	2.38 Million
Cost of Energy	42.04
Operating Cost	115,812/year
Initial Capital	881,550
PV Panel Capital Cost	278,401

Dynamic Modelling Using Bond Graph

- **Multidisciplinary techniques** are becoming increasingly crucial in the modelling process.
- Bond graph approach establishes a **common vocabulary** for understanding relationships and similarities among various modelling methodologies.
- It provides **a uniform domain independent graphical representation** of multidisciplinary models.
- Bond graph provides a clear graphical representation from which other representations can be derived, e.g. linearized state equations, system transfer functions, or differential equations.
- Bonds connect the component ports, demonstrating how power is transferred between them. A half-arrow on one end of the bond indicates the direction of power transfer. In a bond graph, there are two variables: effort (e) and flow (f).
- The system, which is composed of many energy domains such as mechanical, electrical, and hydraulic, is turned into a single model in order to simplify the system's analysis.

Energy Domain	Effort (e)	Flow (f)	Generalized Momentum	Generalized Displacement
Translational Mechanics	Force	Velocity	Momentum	Displacement
Rotational Mechanics	Torque	Angular Velocity	Angular Momentum	Angle
Electro-magnetic	Voltage	Current	Flux Linkage	Charge
	Magneto-motive Force	Magnetic Flux Rate	------	Magnetic Flux
Hydraulic	Total Pressure	Volume Flow	Pressure Momentum	Volume
Thermodynamic	Temperature	Entropy Flow	------	Entropy
Chemical	Chemical Potential	Molar Flow	------	Molar Mass

Figure 17: Bond Graph Language

System Description

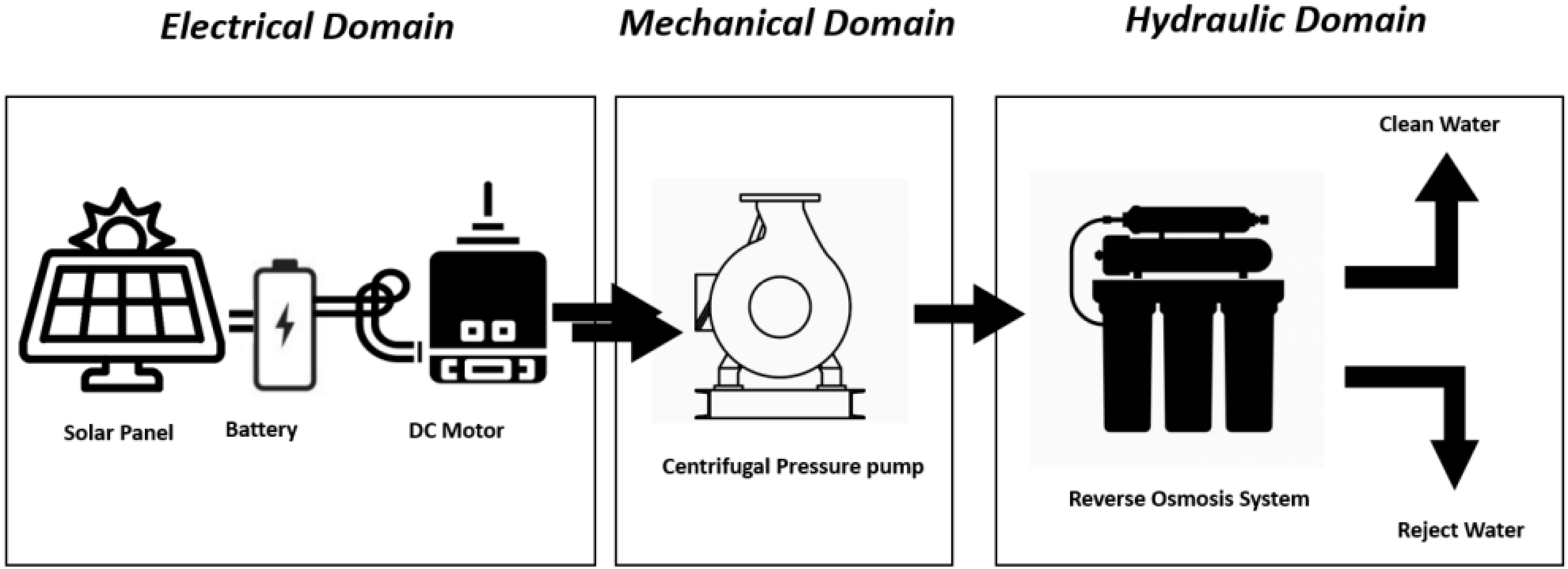


Figure 18: Block Diagram of Complete System

System Dynamic Modelling using Bond Graph

Generalized Model of System

- The distinct systems are connected with the power variable defined as effort and flow.

- Electrical domain output of motor torque and motor speed is used as the input to the mechanical domain. The mechanical domain outputs the Pump Pressure and pump flow rate that is used as the input to the hydraulic domain and eventually producing clean and reject water.

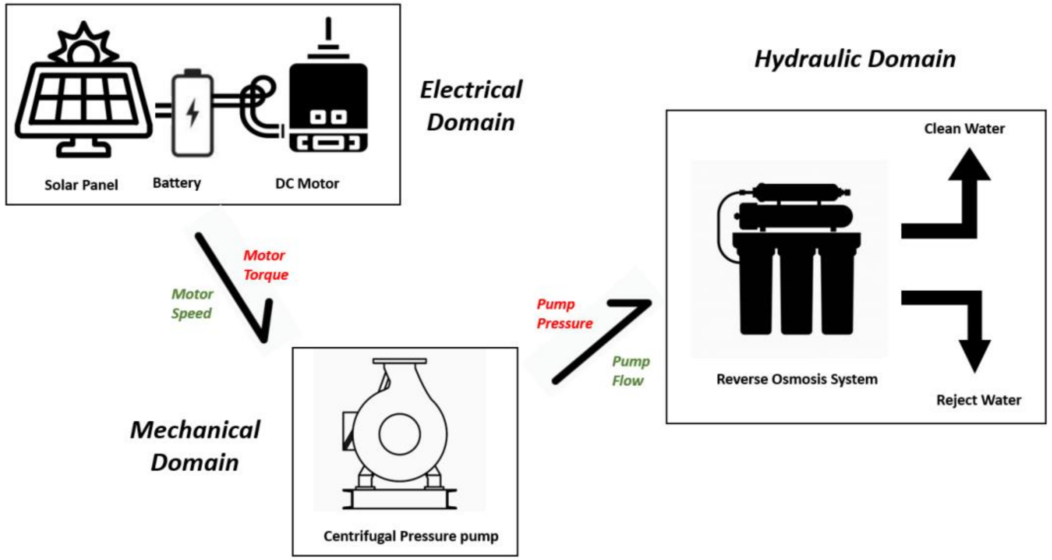


Figure 19: Generalized Bond Graph Model of System

Detailed System Bond Graph Modelling

Electrical System Modelling

- In order to reduce the complexity of the system, the solar panel and battery are modelled as a voltage source.
- The DC motor model is created in which motor resistance and inductance are modelled as R-element and I-element respectively.
- The conversion from electrical domain to mechanical domain is executed with the help of gyrator that relates effort to flow with the motor constant.

Element	Description	Value	Unit
Se	Voltage Source	24.0	V
R	Winding Resistance	5.0	Ohm
I	Winding Inductance	0.03	H
GY	Motor constant	0.02848	Nm/A

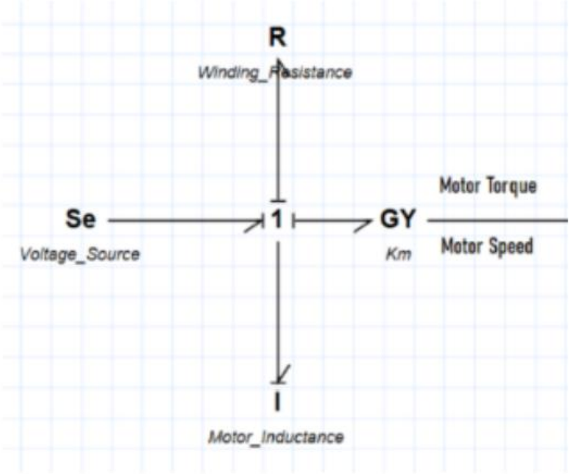


Figure 20: Bond Graph Model of Electrical System

Detailed System Bond Graph Modelling

Pressure Pump Modelling

- An electric motor rotates an impeller in a centrifugal pump that adds energy to the water after it is directed into the core of the rotating impeller.
- The modelling of a single stage pump is done in the bond graph by the help of the gyrator element whereas R-element represent losses due to impeller/diffuser wear and fluid disk friction, I-(inertia) element models the rotating fluid of the pump and another R-element represents the pipe loss when water is transmitted from pump discharge to the reverse osmosis system inlet.

Element	Description	Value	Unit
GY	Centrifugal Pump Equations Modelled	Pressure & Flow rate	Bar & GPM
R	Impeller Loss	0.05	Bar
R	Pipe Loss	0.0005	Bar
I	Rotating Fluid Inertia	0.125	kgm^2

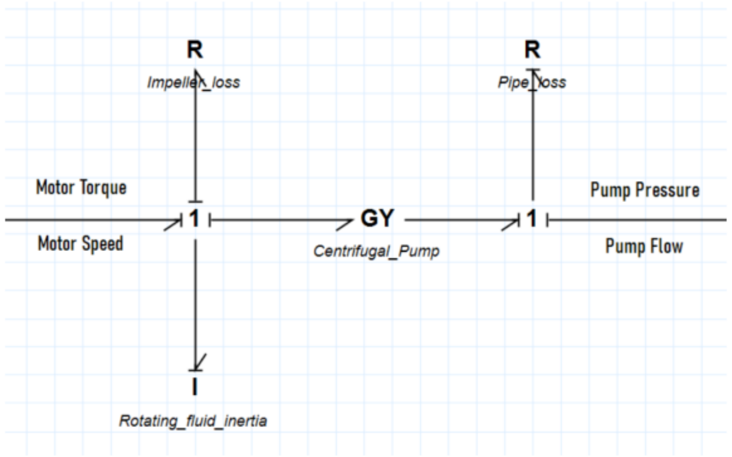


Figure 21: Bond Graph Model of Centrifugal Pump

Detailed System Bond Graph Modelling

Reverse Osmosis Membrane Modelling

- By applying the external pressure which is from the centrifugal pump clean water and dirty water are separated.
- The feed water pressure from the pump must be large enough to overcome the osmotic pressure and the membrane resistance, as well.
- A quantity of the feed water permeates through the membrane reducing strongly the water salt concentration to get the fresh water (purified water), and the remaining feed water becomes very concentrated brine (waste/dirty) water.
- The feed water flow is used by both the clean water and rejected water.
- To reduce this complex modelling the system is converted to complete hydraulic system.

Element	Description	Value	Unit
C	Membrane Water Storage	2.0e-07	m^3/bar
R	Clean water resistance	1.0	bar
R	Reject water resistance	0.0005	bar
R	Reject water valve	Eq. (7)	bar
Se	Clean water	5.0	bar
Se	Reject water	2.0	bar

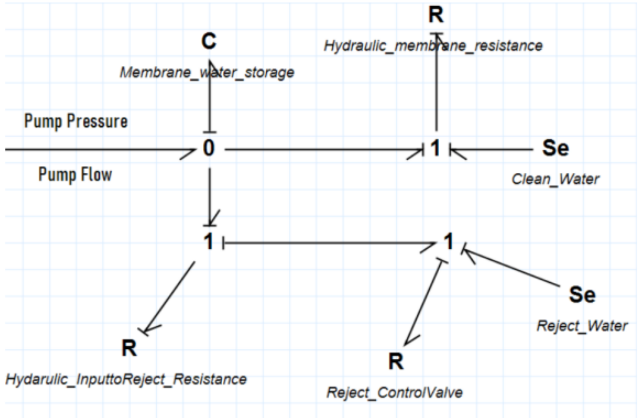


Figure 22: Bond Graph Model of Reverse Osmosis System

Detailed System Bond Graph Modelling

Reverse Osmosis Membrane Modelling

- The system is modelled using a C-element that represent the water storage under pressure inside the membrane. The membrane is considered as a tank which has radius 0.025 meters with water density of 1000 kg/m^3.
- Two R-elements are used to model the hydraulic membrane resistance on the clean water side and on dirty water side which depends highly on the membrane temperature and conductivity.
- To control the pressure of reject water, a non-linear valve is modelled using the R-element.
- The clean water pressure, hydraulic load losses and osmotic pressure are all modelled using the Se-element with its summation. In order to keep the dirty water at required pressure Se-element is also used to model that.

Table 3 – Reverse Osmosis System Parameters

Element	Description	Value	Unit
C	Membrane Water Storage	2.0e-07	m^3/bar
R	Clean water resistance	1.0	bar
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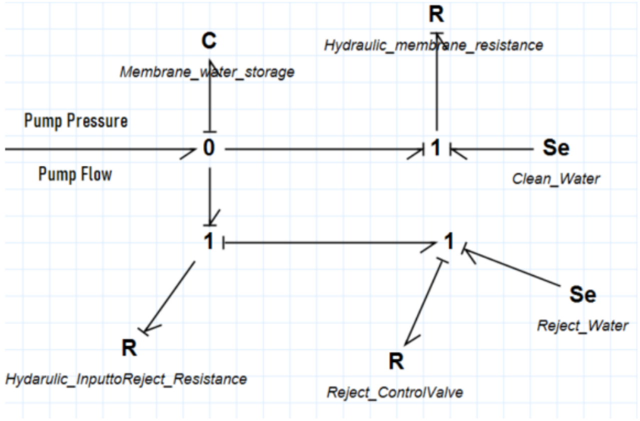


Figure 22: Bond Graph Model of Reverse Osmosis System

Detailed System Dynamic Modelling using Bond Graph

Complete System Modelling

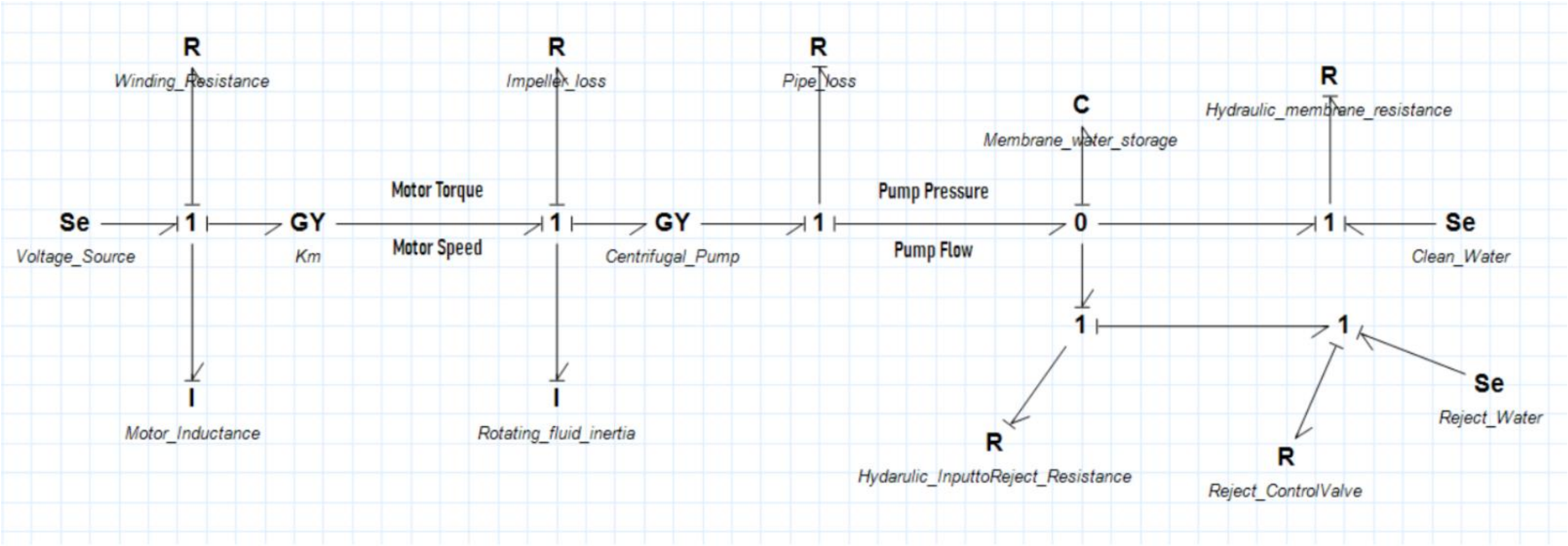
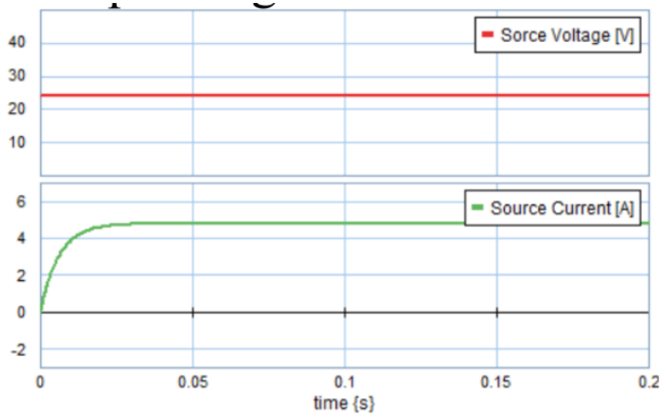
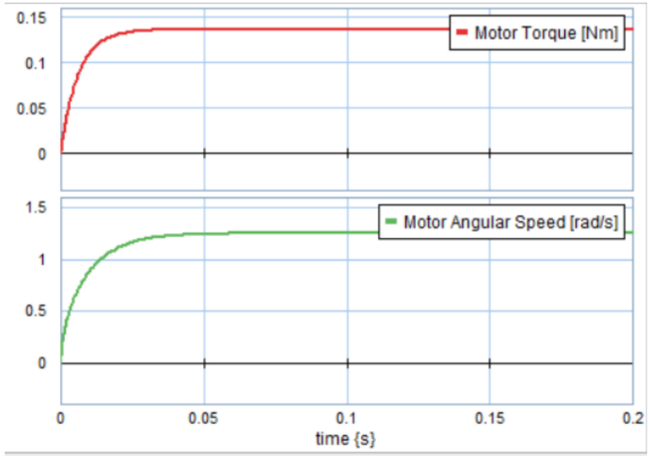


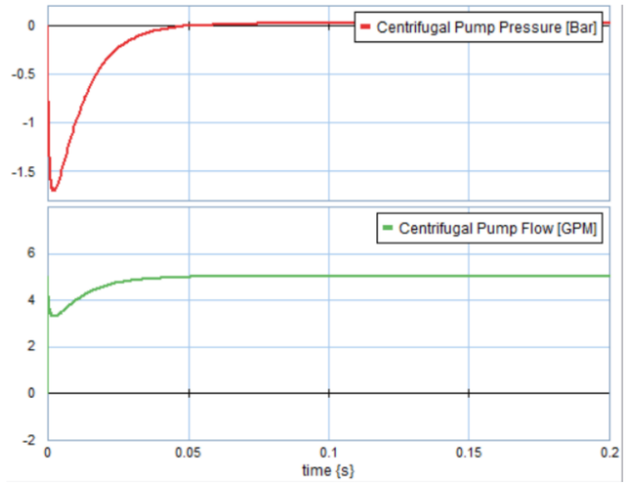
Figure 23: Complete System Bond Graph Model

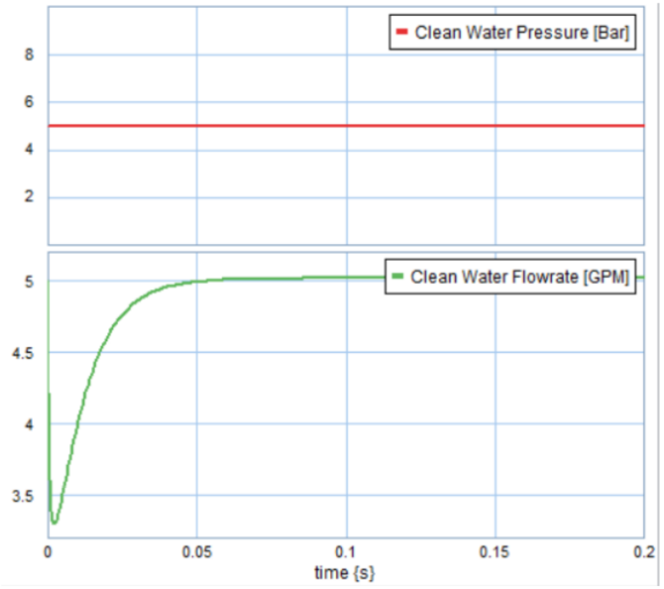
Analysis and Results

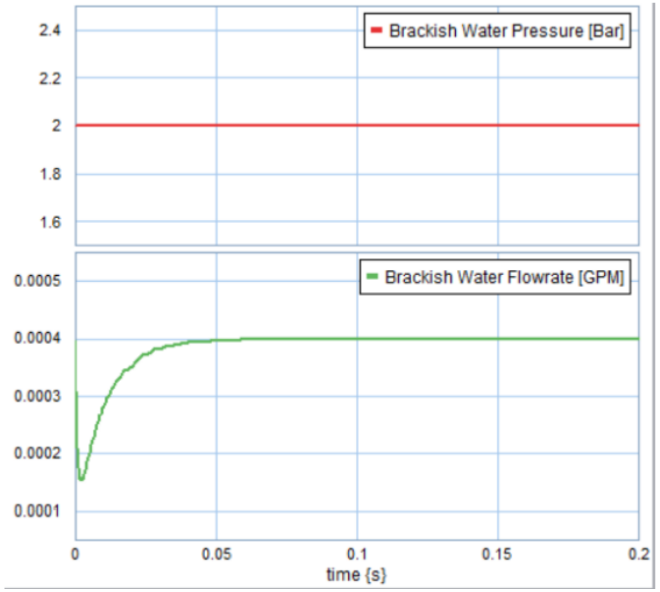
Normal System Dynamic Response





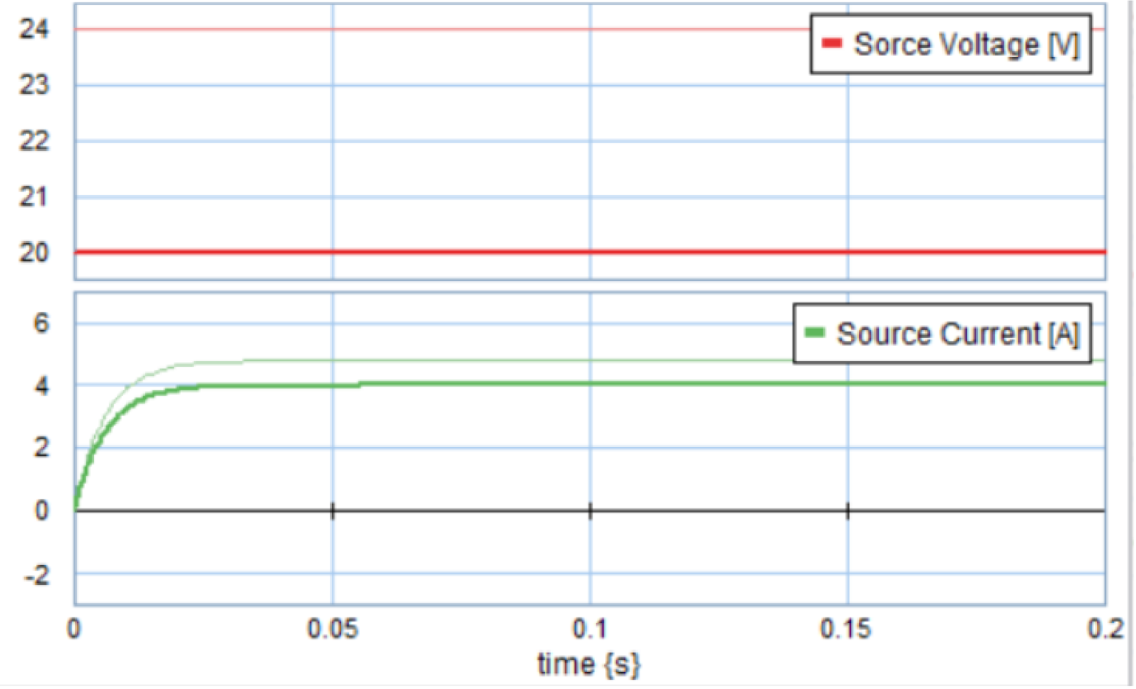


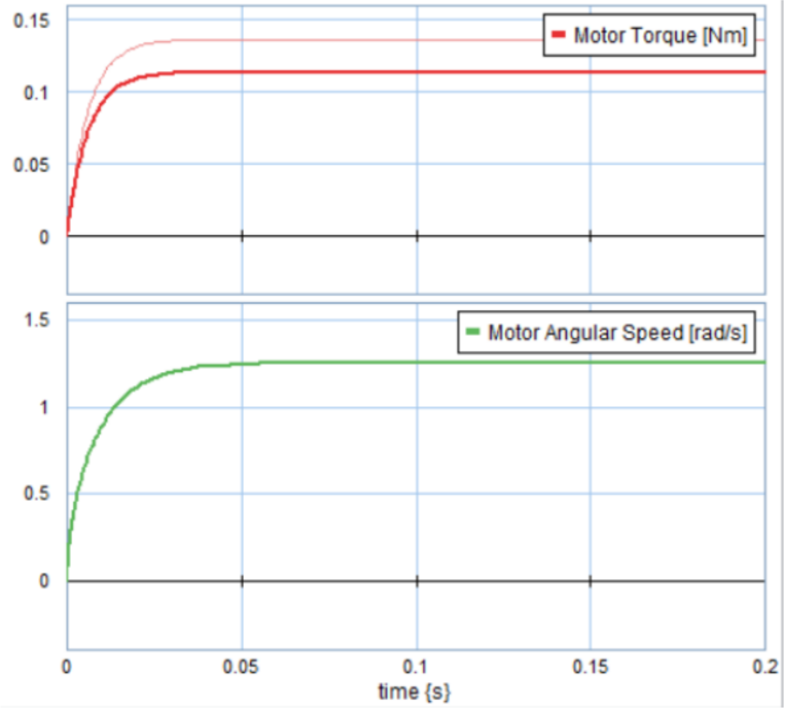




Analysis and Results

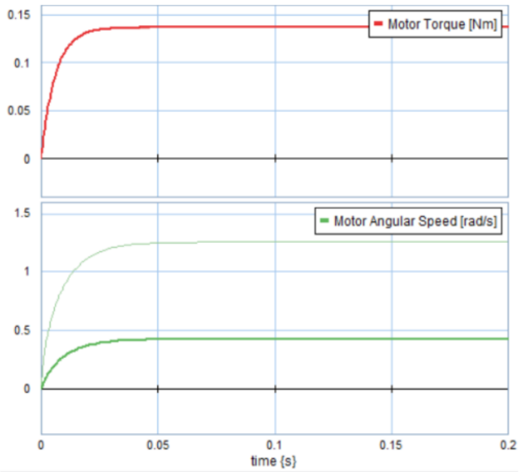
Comparison of Voltage Reduction Due to Solar Power

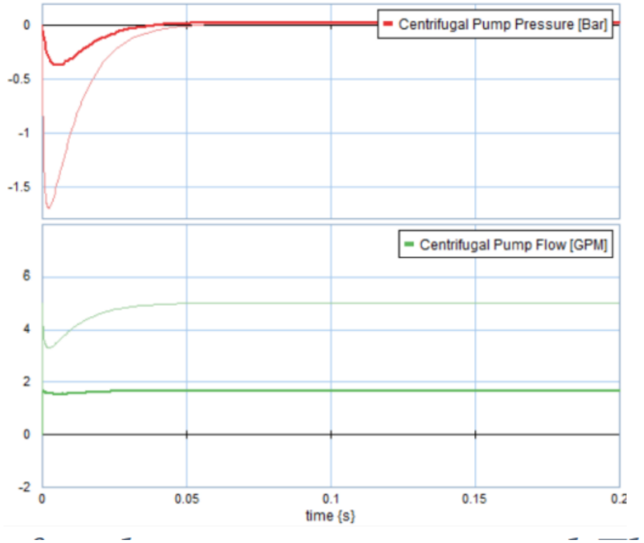


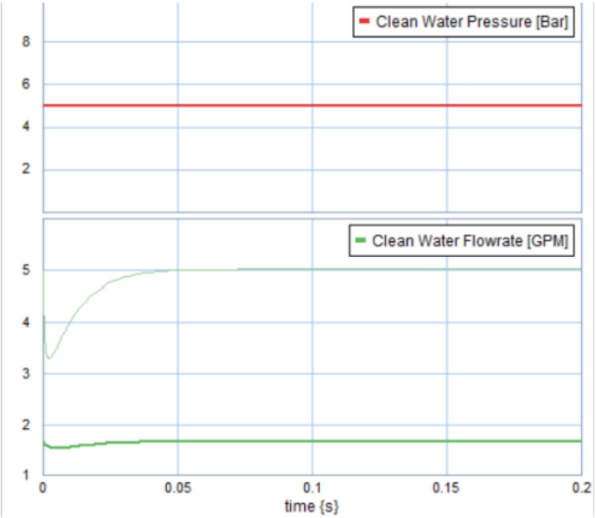


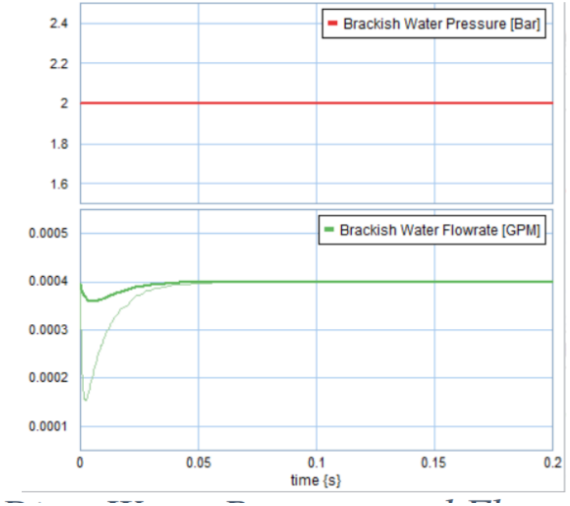
Analysis and Results

Comparison of Increased Clean Water Side hydraulic resistance









SCADA System Design

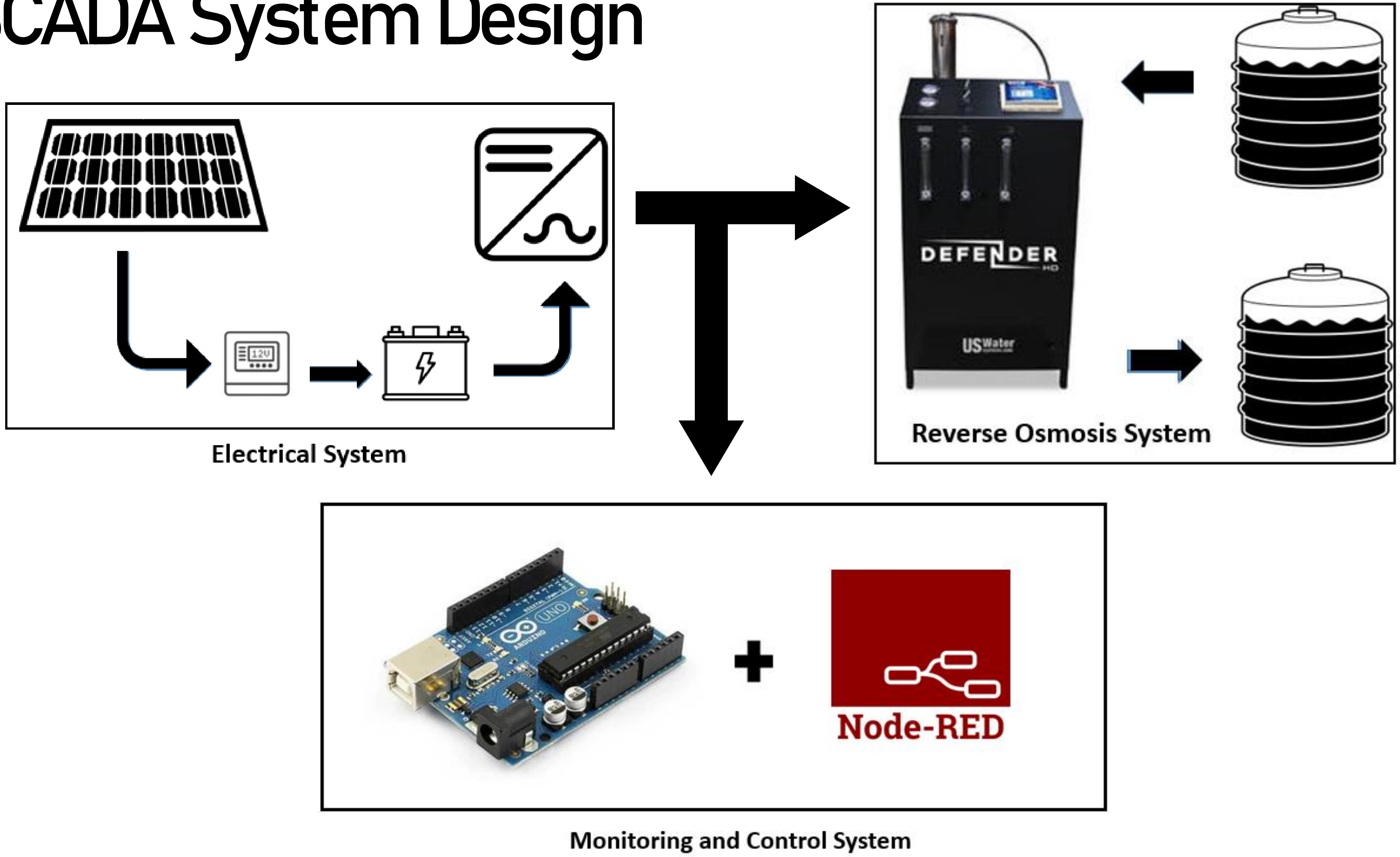


Fig 24: Overall System Block Diagram

System Description – Monitoring and Control System

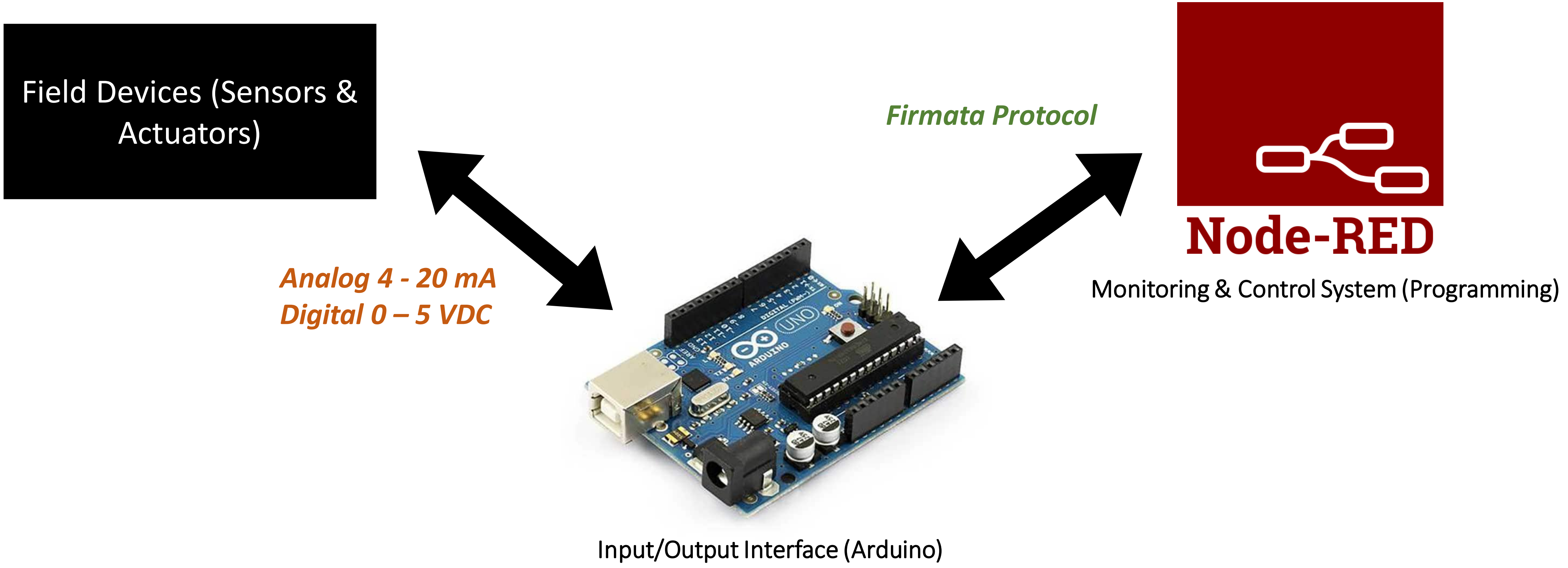


Fig 25: Monitoring and Control System Design

Instrumentation System Design

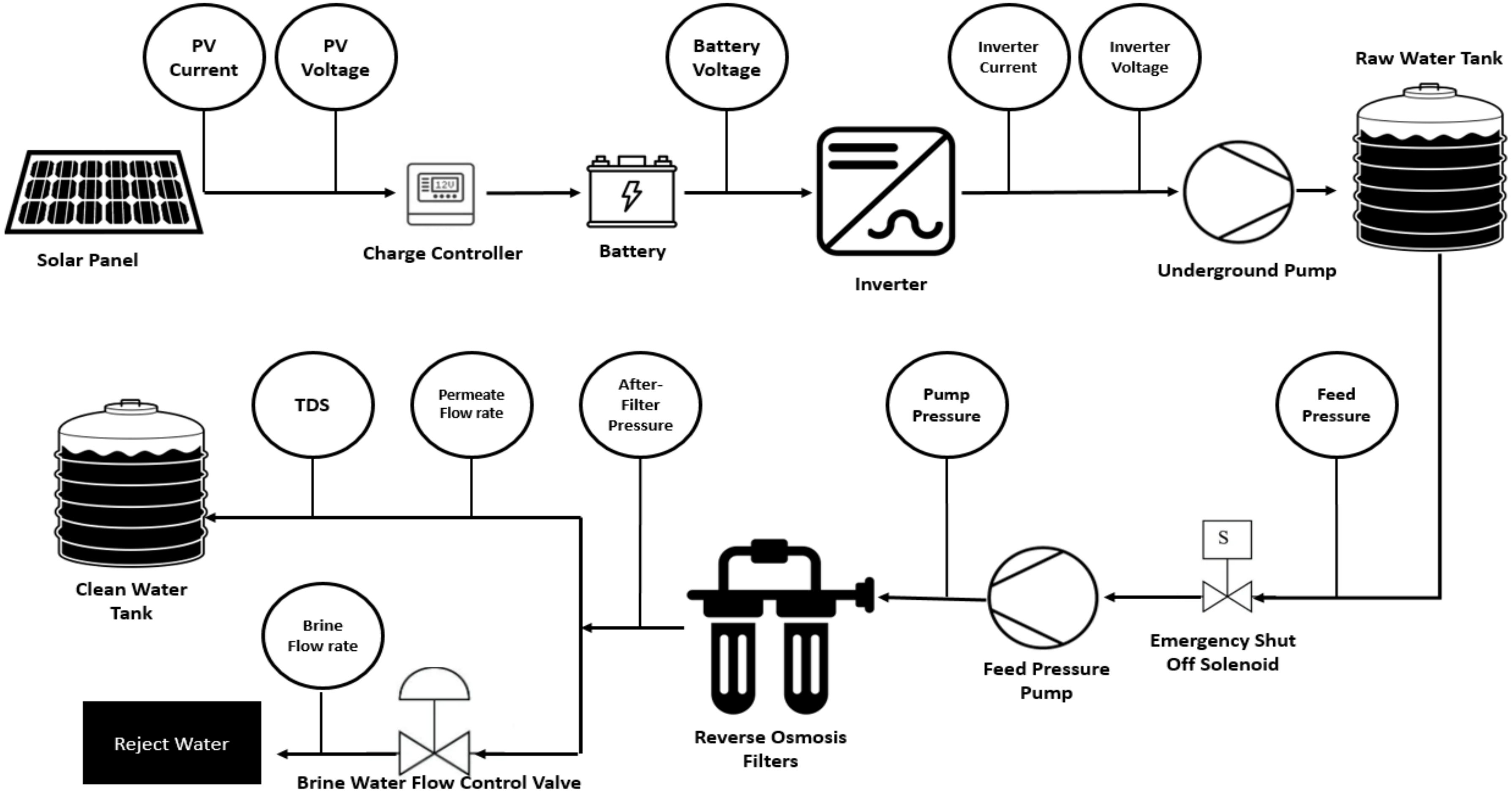


Fig 26: Process Flow and Instrumentation System Design

Monitoring and Control System Design

Energy Loop

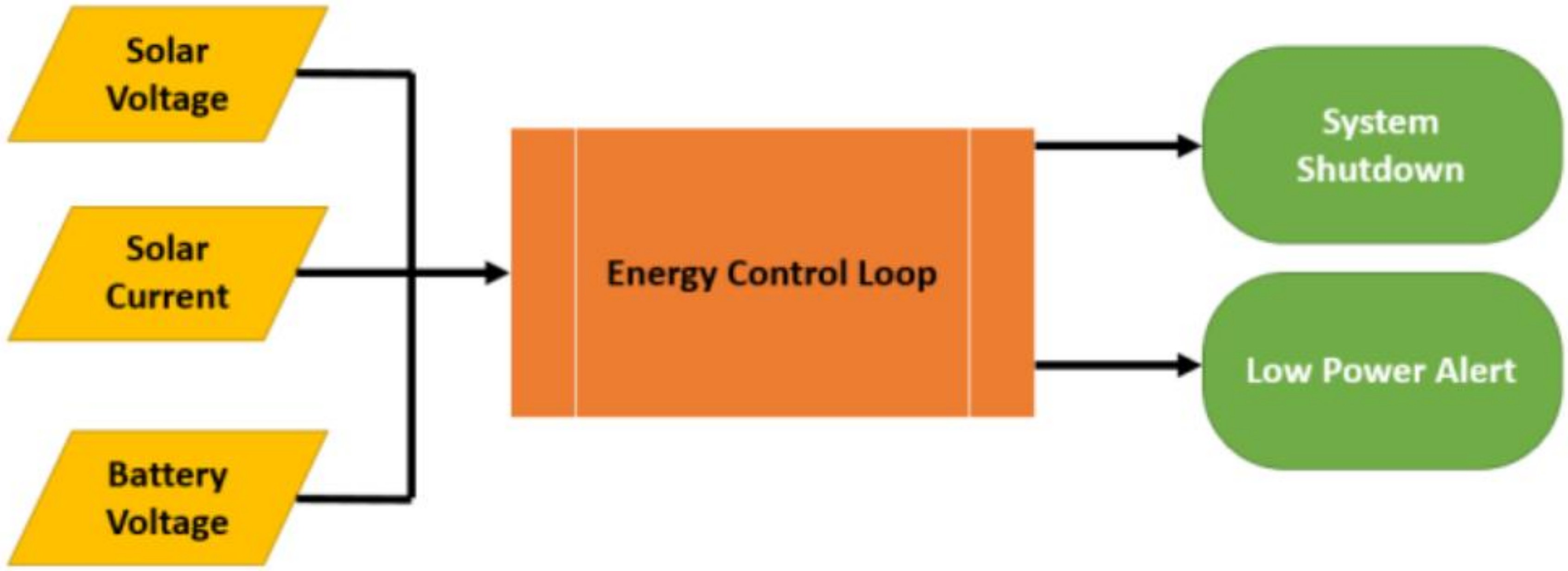


Fig 27: Energy Loop

Monitoring and Control System Design

Pressure Loop

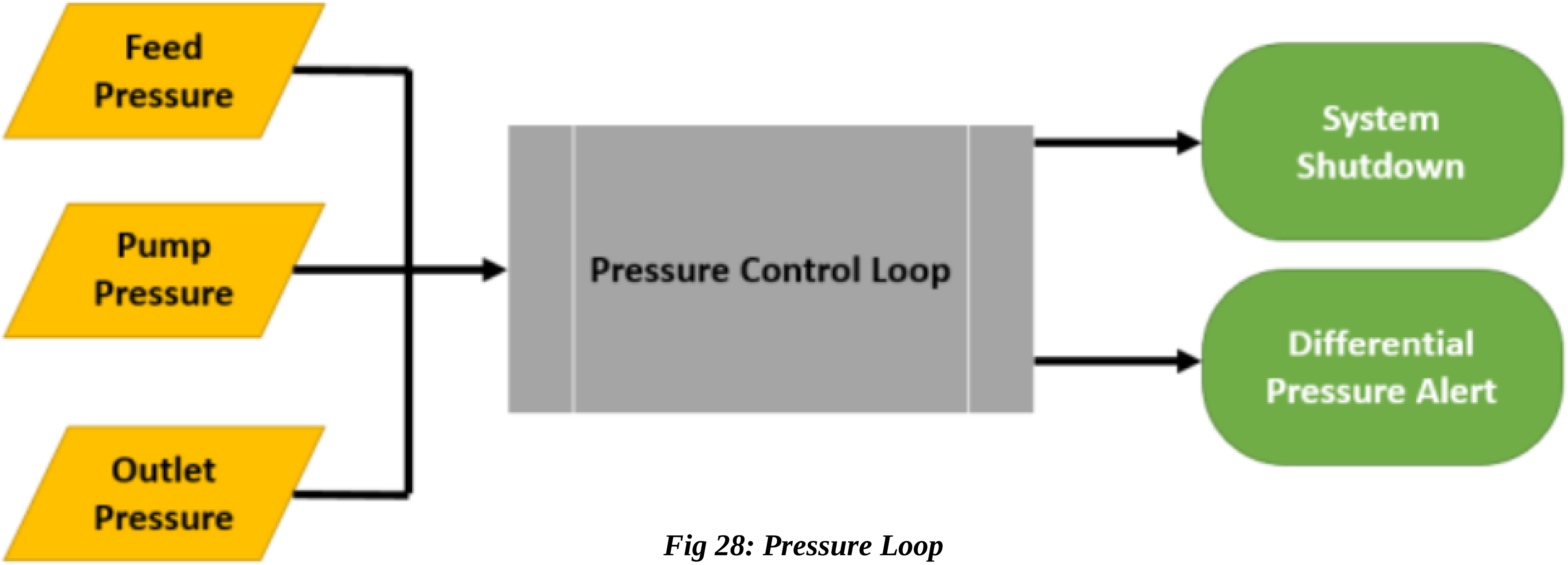


Fig 28: Pressure Loop

Monitoring and Control System Design

Product Loop

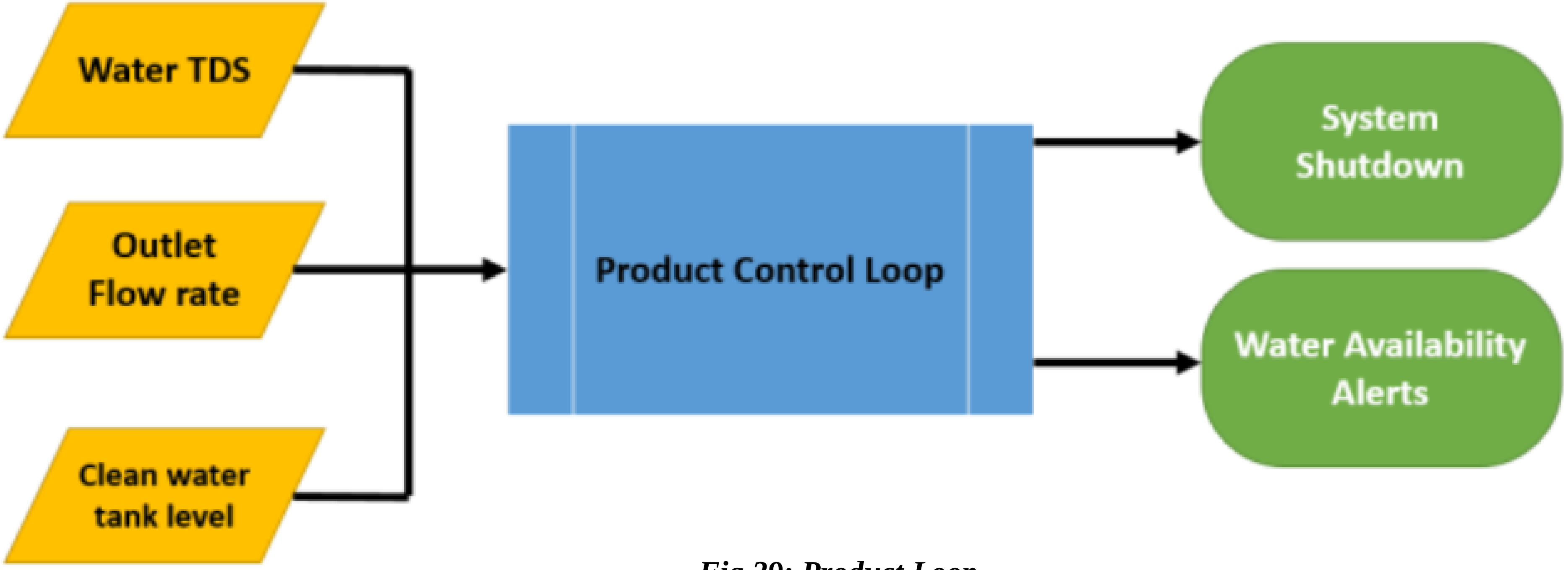


Fig 29: Product Loop

SCADA System Description

- Electrical System and Reverse Osmosis system incorporated to send I/O signals to remote terminal unit (RTU)
- RTU sends the data to main terminal unit (MTU) where Node-Red, Grafana and InfluxDb are running.
- Node-Red for HMI and system programming
- InfluxDB for local database.
- Grafana for data analytics and dashboard.

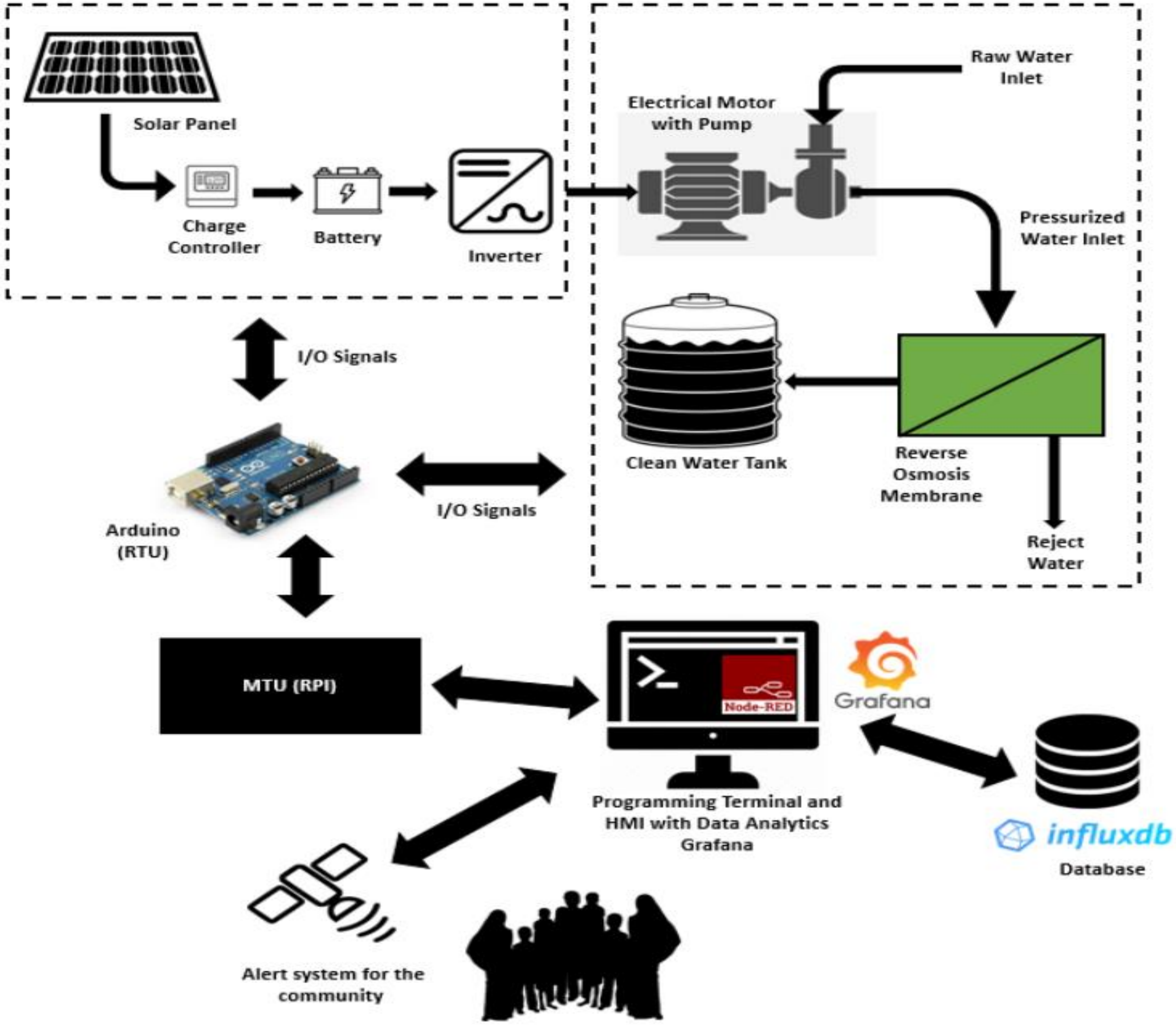
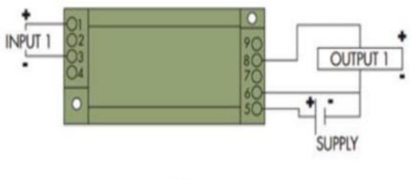


Fig 30: Overall System Block Diagram

Field Instrument Devices



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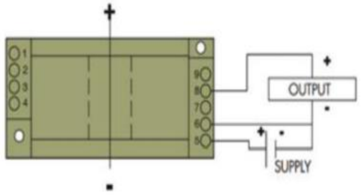

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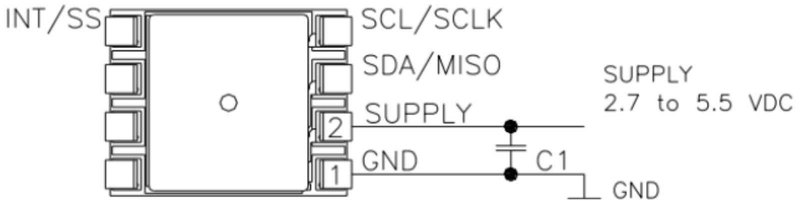
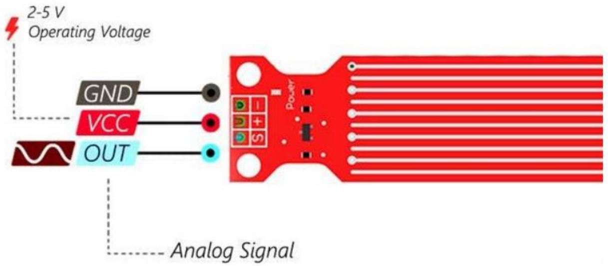
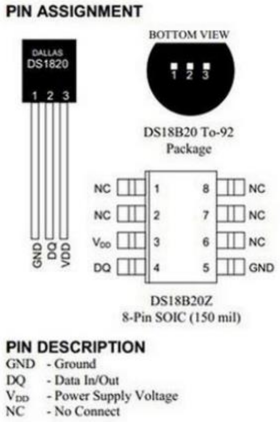
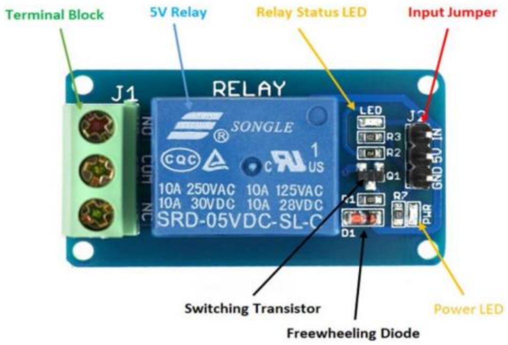
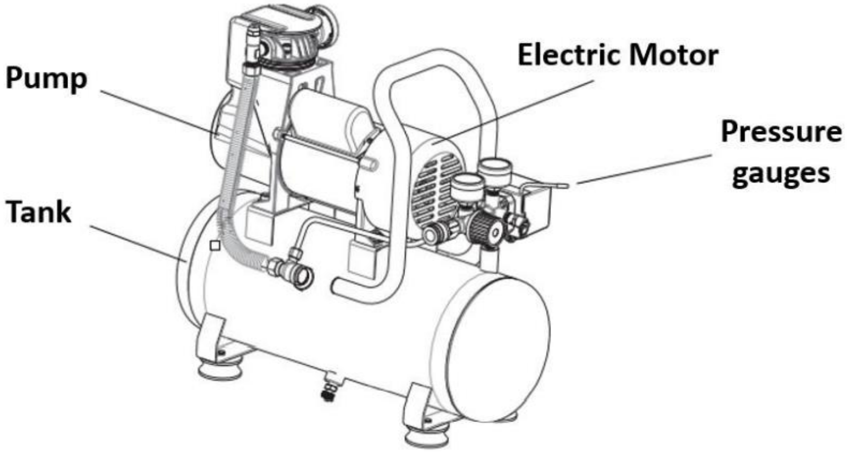


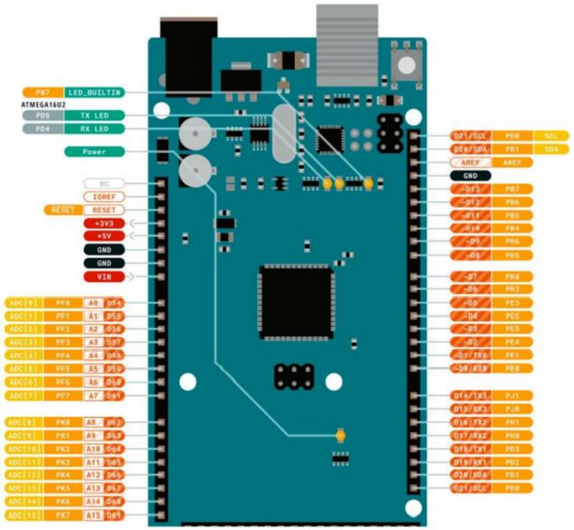


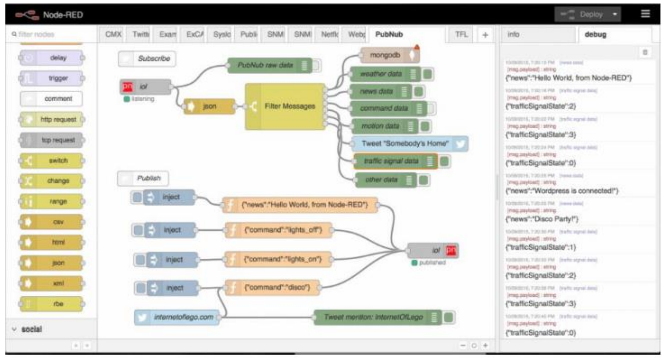


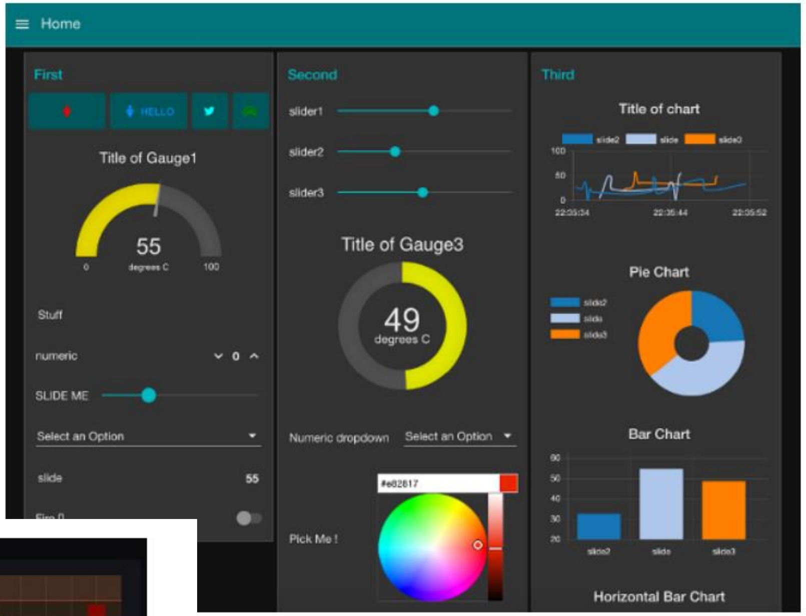




Remote Terminal Unit (RTU) & Main Terminal Unit (MTU)







Algorithms

Algorithm 1: Field Sensor Data Acquisition, Storage and Display

Initialization;

1. Start Service Node-Red
2. Check Service Node-Red
3. If Running
    a. Open localhost:1880
    b. While Read and store data from pins A0, A1, A2, A3, A4, A5 and A6 using /dev/ttyACM0
        i. Send A0, A1, A3 and A6 to chart display
        ii. Send A2, A4 and A5 to gauge display
        iii. Send A0 to Solar Current tag database
        iv. Send A1 to Solar Voltage tag database
        v. Send A2 to Inlet Pressure tag database
        vi. Send A3 to Inlet Temperature tag database
        vii. Send A4 to Pump Pressure tag database
        viii. Send A5 to Outlet Pressure tag database
        ix. Send A6 to Tank level tag database
    c. End
4. Else Check System
5. End

Algorithm 2: System Operation

Initialization;

1. Start Service Node-Red
2. Check Service Node-Red
3. If Running
    a. Open localhost:1880/ui
    b. Click System On button
    c. Click Pump On button
4. Else
    a. Click Pump Off button
5. Else If
    a. Click System Off button
    b. Pump Off button Automatically activated by interlocking
6. End Check System
7. End

Algorithms

Algorithm 3: Alert System for Community

Initialization;

1. Start Service Node-Red
2. Check Service Node-Red
3. If Running
    a. Open localhost:1880/ui
    b. Set Clean Water Level Lower Set Point Variable
    c. Set Clean Water Level Upper Set Point Variable
    d. While Read Dashboard button status and Pin A6
        i. If A6 value is less than the Clean Water Level Lower Set Point
            1. Send Message to community: "Warning, The clean water level availability is very low"
        ii. End
        iii. If A6 value is greater than the Clean Water Level Upper Set Point
            1. Send Message to community: "Notification, The clean water level availability is very High"
        iv. End
        v. If System ON button is active
            1. Send Message to the community "System Status: The System has been turned ON!"
        vi. Else If System OFF button is active
            1. Send Message to the community "System Status: The System has been turned OFF!"
        vii. Else If Pump ON button is active
            1. Send Message to the community "System Status: The Main Pump is running!"
        viii. Else if Pump OFF button is active
            1. Send Message to the community "System Status: The Main Pump turned OFF!"
        ix. Else if Send Maintenance Alert Button is active
            1. Send Message to the community "Alert, The System will remain non-operational today because of maintenance activity. The system will be back online tomorrow. Apologies for the inconvenience caused!"
        x. Else if Send System Normalization Alert Button is active
            1. Send Message to the community "Alert, The system has been restored and fully functional after the maintenance shutdown"
        xi. End
    e. End
4. End Check System
5. End

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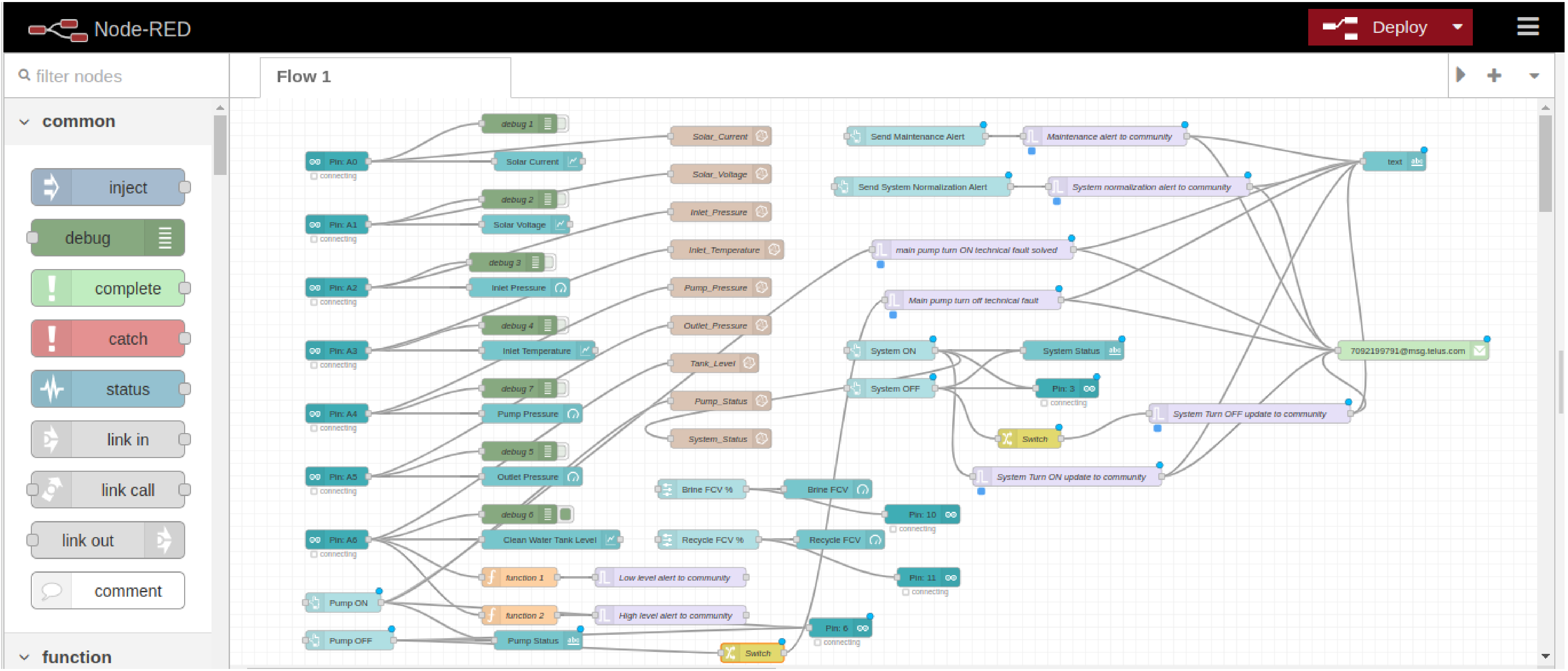
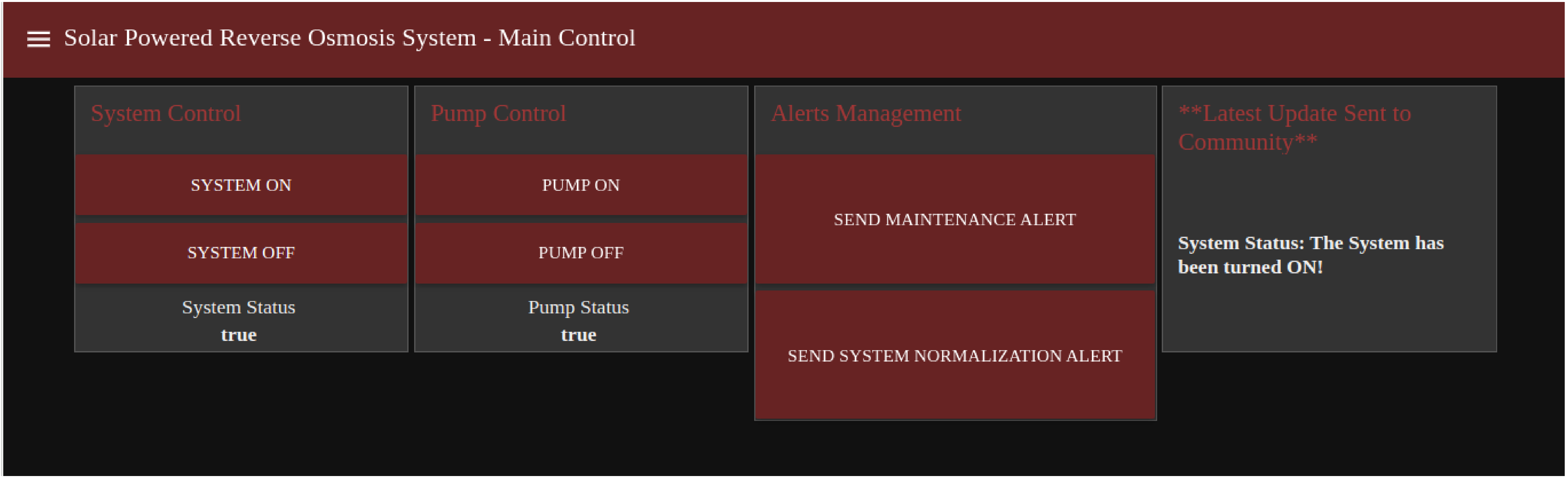
Implementation

NODE-RED PROGRAMMING



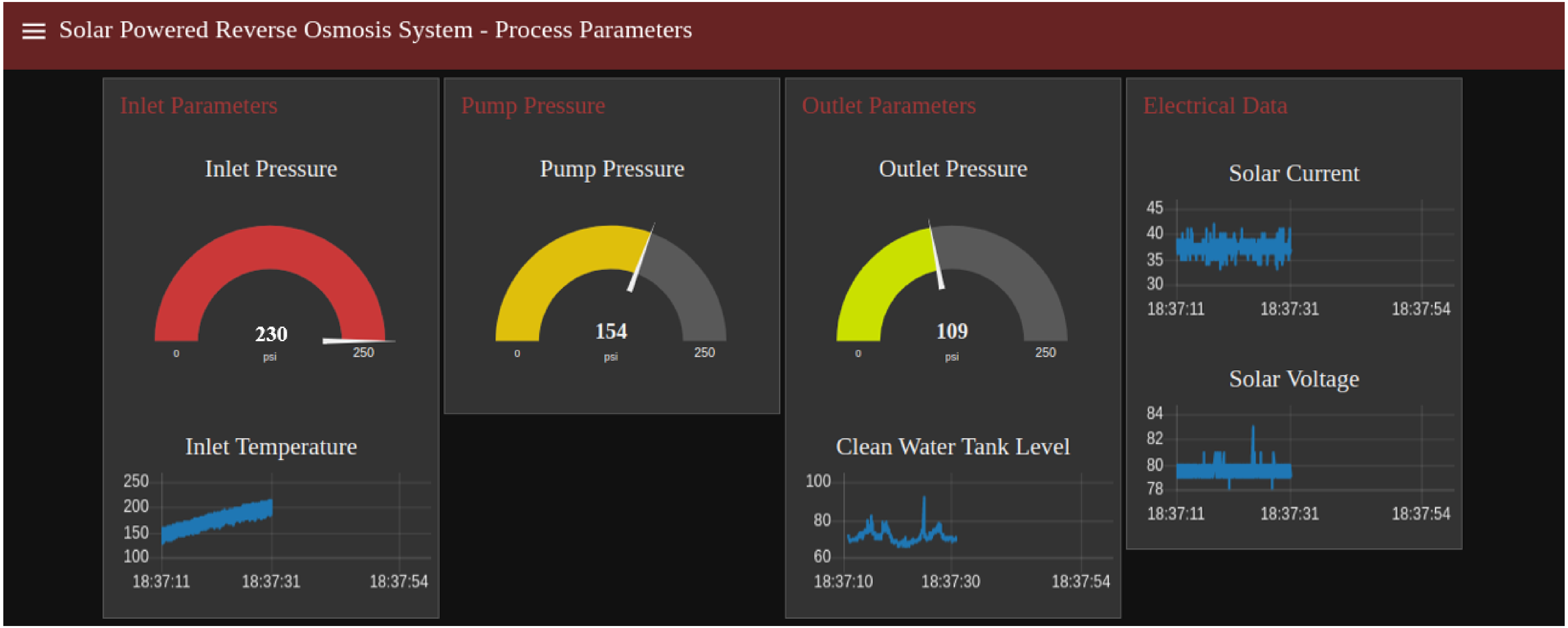
Implementation

HUMAN MACHINE INTERFACE SCREEN



Implementation

ON-LINE DASHBOARD FOR DATA MONITORING



Implementation

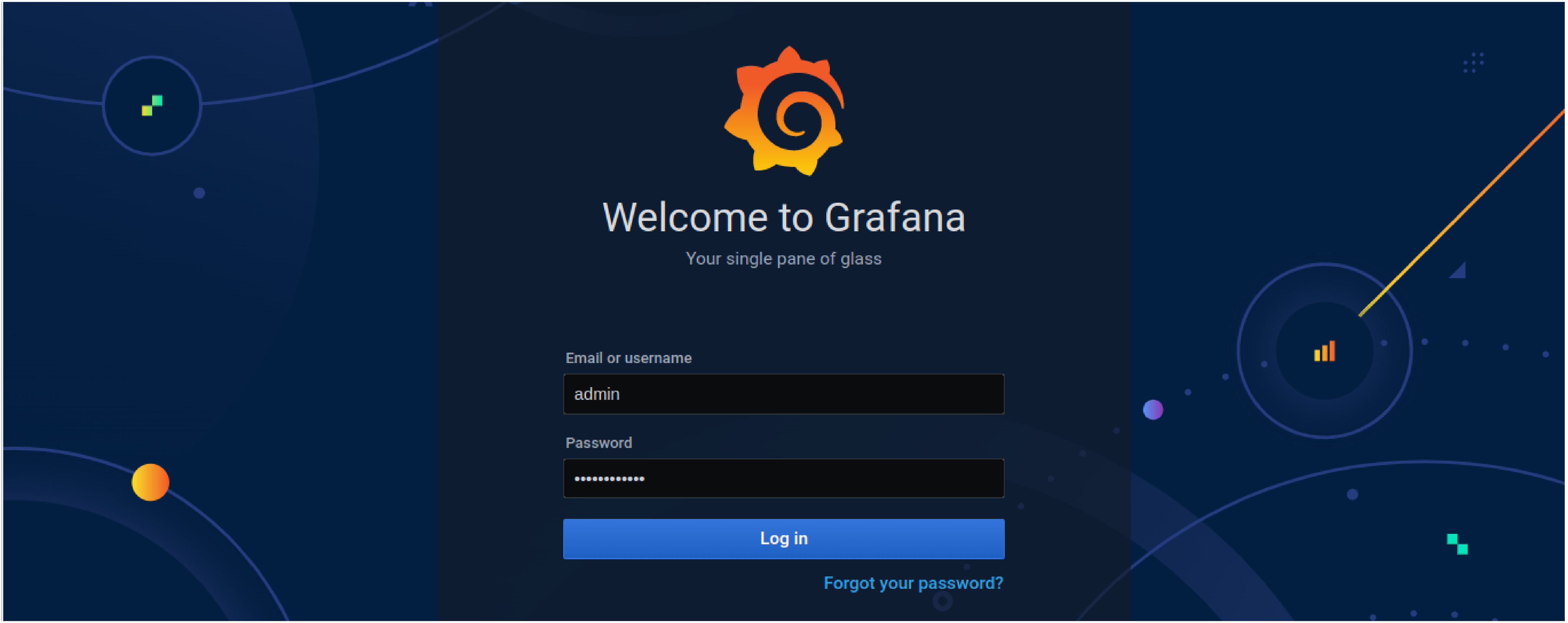
INFLUXDB DATABASE FOR LOCAL SERVER

```
sheikhusmanuddin@raspberry:~ $ influx
Connected to http://localhost:8086 version 1.5.3
InfluxDB shell version: 1.5.3
> SHOW DATABASES
name: databases
name
----
_internal
TUTORIAL2
SOLAR_CURRENT
SOLAR_VOLTAGE
INLET_PRESSURE
INLET_TEMPERATURE
PUMP_PRESSURE
OUTLET_PRESSURE
TANK_LEVEL
REVERSE_OSMOSIS_DATABASE
> USE REVERSE_OSMOSIS_DATABASE
Using database REVERSE_OSMOSIS_DATABASE
> SHOW MEASUREMENTS
name: measurements
name
----
INLET_PRESSURE
INLET_TEMPERATURE
OUTLET_PRESSURE
PUMP_PRESSURE
PUMP_STATUS
SOLAR_CURRENT
SOLAR_VOLTAGE
SYSTEM_STATUS
TANK_LEVEL
>
```

```
> SELECT*FROM OUTLET_PRESSURE 10
ERR: error parsing query: found 10, expected ; at line 1, char 29
> SELECT*FROM OUTLET_PRESSURE LIMIT 10
name: OUTLET_PRESSURE
time                value
----                -----
1665074754970220051 0
1665074757487287431 108
1665074757510673715 106
1665074757545755363 105
1665074757776176506 106
1665074757780819804 105
1665074757795003298 104
1665074757803238538 105
1665074757881305242 104
1665074757916199604 105
>
```

Implementation

SECURED LOCAL DATA ANALYTICS GRAFANA

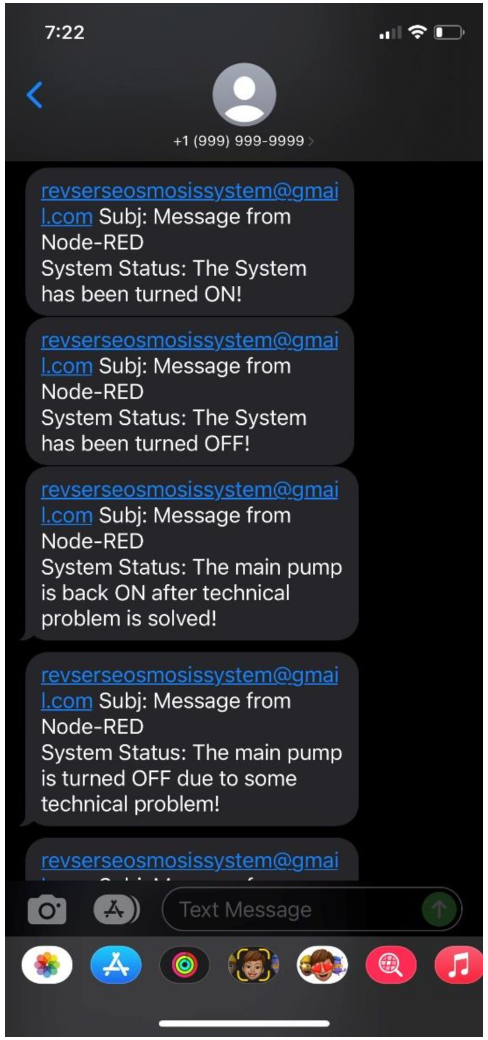


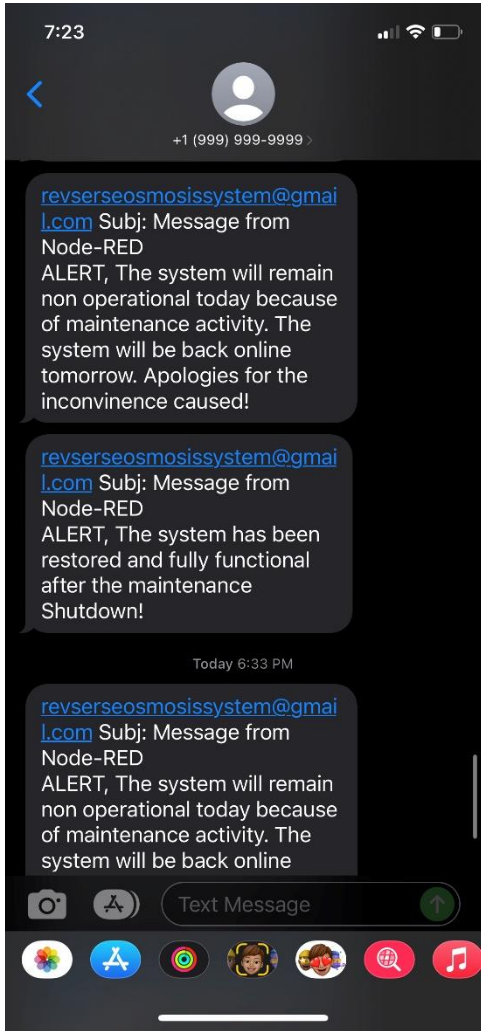
Implementation

GRAFANA BASED DATA ANALYTICS AND VISUALIZATION DASHBOARD

Implementation

SMS BASED ALERT SYSTEM





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Implementation

Implementation

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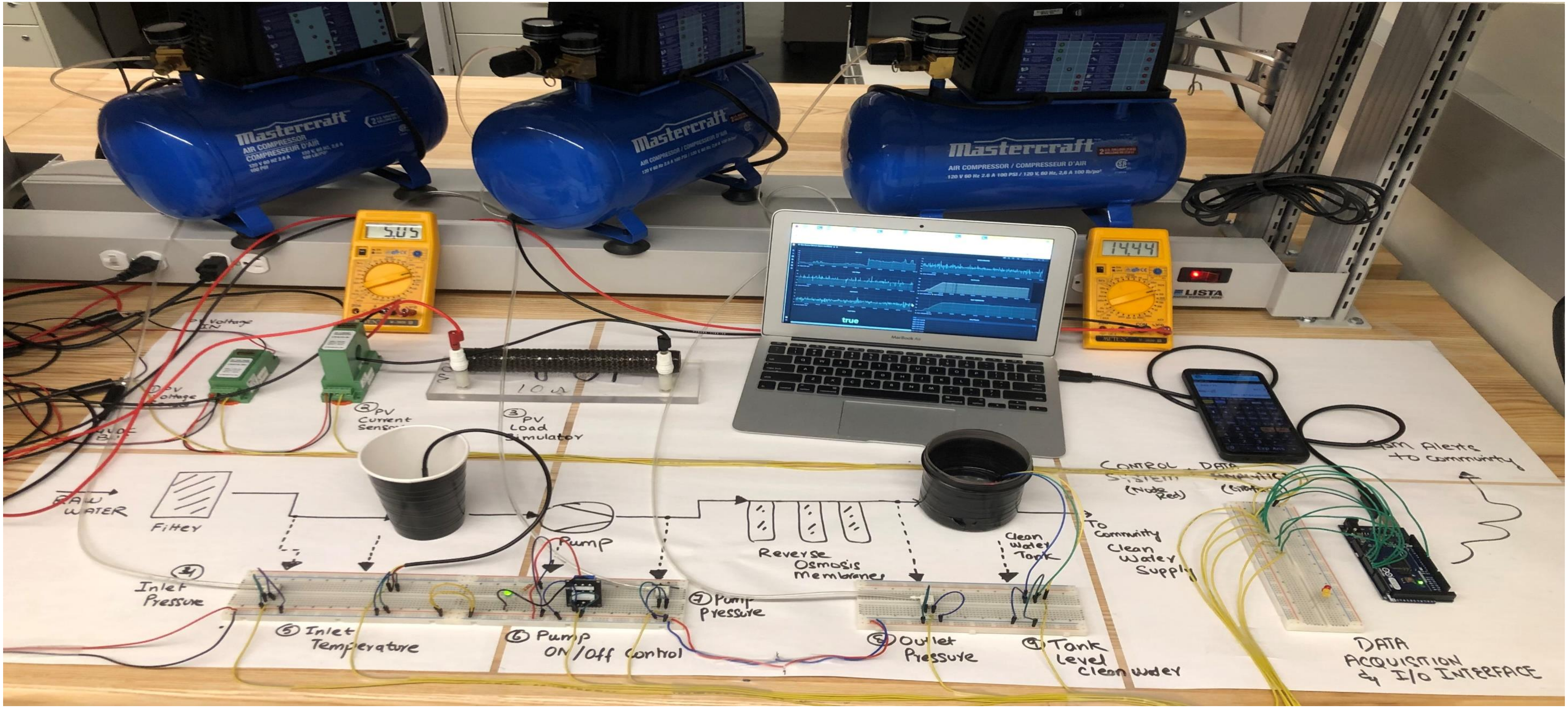


Research Contribution

- The main contributions of this thesis are listed below:
  - An **extensive literature review** was carried out and extensive research papers were studied and compared.
  - System **design, PV sizing and economic analysis** for a solar powered reverse osmosis desalination system based on a community in Karachi Pakistan.
  - **Dynamic modelling** of the system **using bond graph modelling** as the system incorporates multi-disciplinary domains of electrical, mechanical and hydraulic systems.
  - Design **of field instrumentation devices** for reverse osmosis system monitoring and control loops.
  - Development of **hardware prototype for an open-source**, low-cost, internet of things based **SCADA system** with local database **and Grafana based data analytics provision**.
  - Development of an **alert system for the community** to be aware about status and updates from the system.

Thesis Conclusion

- The availability of clean drinking water is one of **the biggest challenge of the world**. Worldwide the population is increasing exponentially that result in **increasing demand for clean drinking water**. Almost all processes in the world require power for execution from **conventional power generation methods**.

- This research focuses on a community located in the **biggest city of Pakistan, Karachi**, which has **limited access to clean water** and **heavily rely on tanker system**.

- To tackle the challenge of **this community water desalination system** was proposed in this thesis with **solar powered system so** that both of the world biggest challenges are addressed.

- The research work provides detailed literature review followed by **system sizing, dynamic modelling, instrumentation & control design and SCADA system design with alert system to** the community.

Future Work

- There are few things that can be further investigated in the design and analysis of a solar powered reverse osmosis system to ensure that the work can be easily translated into reality:

  - It would be **important to investigate the feasibility of reverse osmosis system based on different locations** where solar irradiance is not much **and community size is varying**. This could have implications on system sizing and overall design.

  - Secondly, the **dynamic modelling is a very vast field and there can be many inputs added to the system in order to see the most realistic and actual response**. These factors could include system leakages, pressure pump faults, electrical jerks, detailed membrane and pump modelling utilizing a team of chemical and mechanical engineers etc.

  - The design approach is versatile and can be used on different desalination system. The SCADA design is unique, low-cost, secure and provide reliable monitoring, control and alert system, which can be applied on different existing desalination plants.

List of Publications

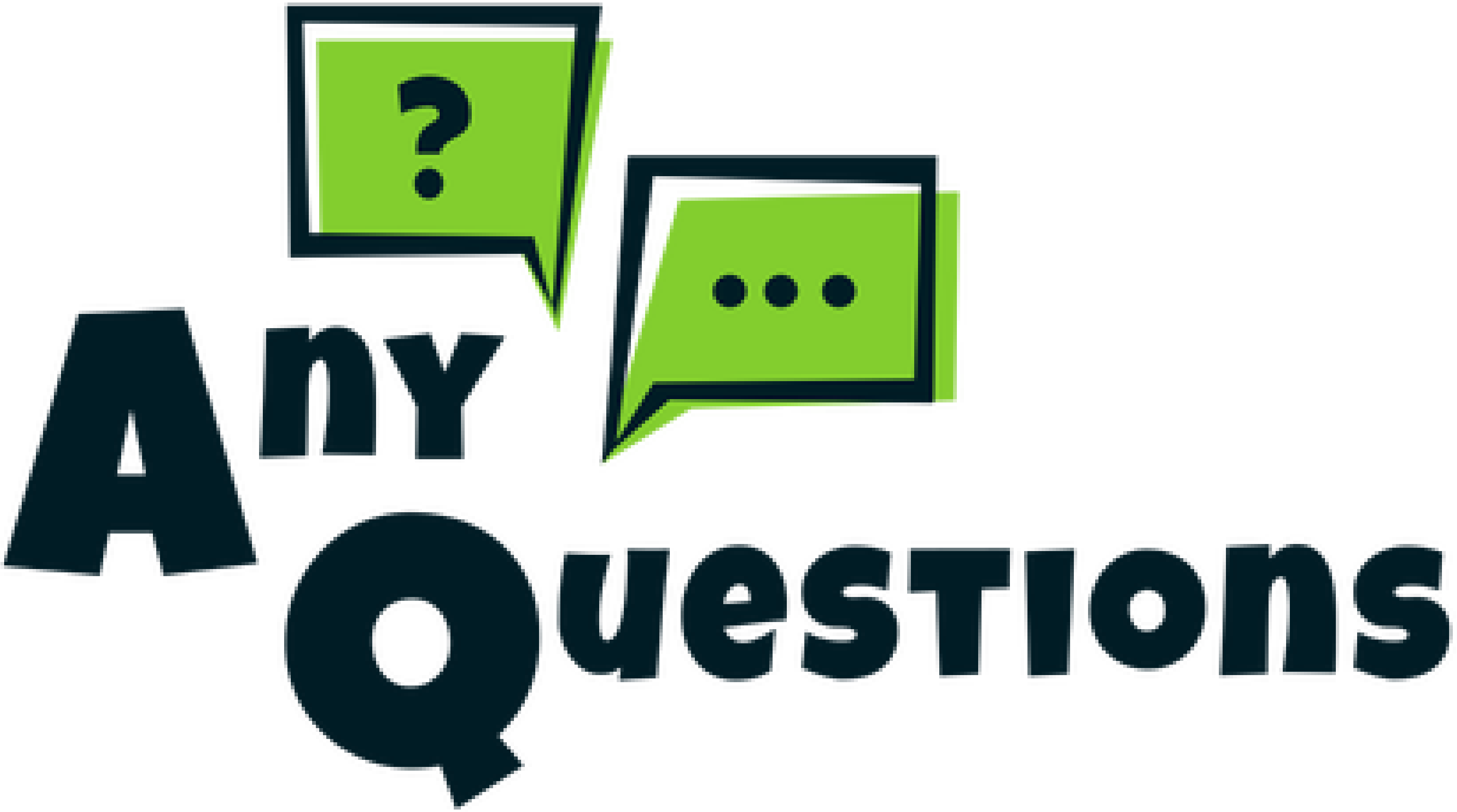
1. Sheikh Usman Uddin, M. T. Iqbal, “Design and Economic Analysis of a Solar Powered Drinking Water Reverse Osmosis Desalination System for a Community in Pakistan.” Presented at the 12th IEEE Annual Conference on Computing and Communication Workshop and Conference (CWCC 2022**), Las Vegas, United States of America.**

2. Sheikh Usman Uddin, Geoff Rideout, “Dynamic Modeling and Analysis of Solar Powered Reverse Osmosis Desalination System for Pakistan using the Bond Graph Model.” Presented at the IEMTRONICS 2022 (International IOT, Electronics and Mechatronics Conference), **Toronto, Canada.**

3. Sheikh Usman Uddin, M. T. Iqbal, “Instrumentation and Control Design for a Solar Powered Reverse Osmosis Desalination System for a Community in Pakistan.” Presented at The 31th Annual Newfoundland Electrical and Computer Engineering Conference (NECEC 2022), **St. John’s, Newfoundland.**

4. Sheikh Usman Uddin, Mirza Jabbar Baig, M.T.Iqbal, “Design and Implementation of an Open-Source, Internet-of-Things based SCADA System for a Community Solar Powered Reverse Osmosis System” submitted for publication in **MDPI Sensor Journal (2022).**

5. Sheikh Usman Uddin, Abdul Azeez, Onyinyechukwu Chidolue, M. T. Iqbal, “Design and Analysis of a Solar Powered Water Filtration System for a Community in Black Tickle-Domino.” Presented at the IEMTRONICS 2022 (International IOT, Electronics and Mechatronics Conference), **Toronto, Canada.**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Any
Questions