Instrumentation and Control Design for a Solar Powered Reverse Osmosis Desalination System for a Community in Pakistan

Sheikh Usman Uddin
Electrical and Computer Engineering
Memorial University of Newfoundland and Labrador
St.John's, Canada
suddin@mun.ca

M. Tariq Iqbal
Electrical and Computer Engineering
Memorial University of Newfoundland and Labrador
St.John's, Canada
tariq@mun.ca

***Abstract*— Accessibility of fresh water is the biggest challenge of today's world. In order to meet the increasing demand of clean water without impacting the environment renewable energy needs to be integrated with reverse osmosis (RO) system to provide a clean drinking water system. This paper provides system design which includes selection of renewable energy system, reverse osmosis system and control system that can be integrated together to form a complete clean drinking water system. This paper further provides an elaborative instrumentation system design system that will fulfill the needs of water for a community in Pakistan. Furthermore, control system strategy is discussed to ensure that all process parameters are measured that will enable the system to work at its required capacity. Lastly, the hardware prototype setup designed in the lab is discussed to measure process parameters and ensure the system is fulfilling the operational and control requirements.**

***Keywords*— Solar Energy, Reverse Osmosis, Instrumentation, Control System.**

I. Introduction

Pakistan economy mostly relies on agriculture and around 22.2% of that contributes to its overall gross domestic product (GDP) [1]. In 1950s Pakistan has the water capacity of around 5000 m^3 per capita and it has decreased significantly now [2]. There is huge water crisis worldwide and countries are looking for different ways in order to extract water. Desalination of water is one of the solution available today for production of clean water but this process requires huge amount of energy which in turn is achieved by burning fossil fuels. Considering the excessively increasing requirement of water and saving the atmosphere at the same time renewable energy technology based reverse osmosis desalination system provides a good source of clean fresh water. Thankfully, Pakistan lies on the region of good solar irradiance ranging from 5–7 kWh per m^2 per day and sunshine hours of 1,500–3,000 per year [3] which can be used for solar powered reverse osmosis systems. The desalination process now is used worldwide and its utilization trend has shown an increase in the recent years [4]. The Solar powered reverse osmosis converts the brackish water to fresh water as the water passes through membranes and remove approximately 98% salt from it [5]. This paper focuses on providing a solution to a community located in Pakistan that has no access to clean water by selecting the separate systems available in the market on the basis of the community requirement. These systems can be broken down as electrical, mechanical and control system. Furthermore, the instrumentation design, control system strategy and hardware prototype is discussed.

II. Literature Review

In this section, several papers related to the photovoltaic-based reverse osmosis system are reviewed. Focus was given to papers in which instrumentation and control system work were applied. MIT research work showed how small solar powered system produced clean water for a village community in Mexico [6] and was enough for whole community. Another study was conducted in which analysis was done to understand the behavior of system according to the temperature of the solar panels. The study concluded that 10% more energy from the photovoltaic panels was generated when the system was cooled [7]. Another paper was reviewed in which elaborative instrumentation on just reverse osmosis system was discussed and concluded that performance of such system is highly depended on temperature and pH of the water [8]. Edward [9] study provides a new approach for reverse osmosis system instrumentation and control design by applying artificial intelligence based software technology in order to make the system robust and more efficient. Francisco [10] analyzed how the variation of renewable energy source can affect the output on desalination water production. His work includes the parameter of flow and pressure. Thomas [11] worked on reverse osmosis system without batteries. He further designed the instrumentation and data acquisition on LabView and analyzed the results of the system. Glueckstern [12] utilizes the microprocessor based programmable logic controller with active sensors to analyze the performance of on-line reverse osmosis system plant. It records all historical data for data analytics to further optimize plant performance in future. All these research approaches provided a great insight on how to design the system, select its instrumentation and finalize a robust control strategy.

III. System Description

The overall system will comprise of an electrical system which is based on the renewable energy technology powering up the main water desalination system which is based on reverse osmosis technology. The system will have important instrumentation and will provide that information to a centralized control system. The figure 1 below shows the complete block diagram of the system.

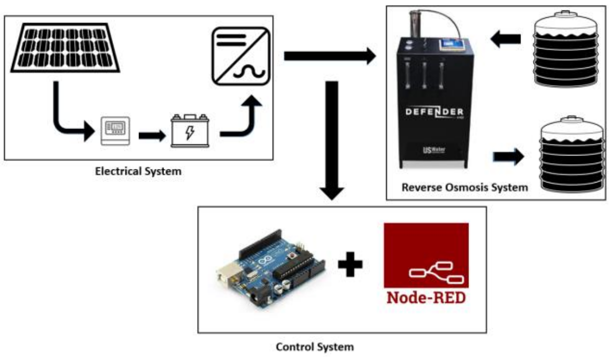

Figure 1 –Block Diagram of Complete System

A. Electrical System

The electrical system will use the solar energy. The energy is converted and stored in the battery and used for running the motors of the system. The load of the system is 2.0 kW as the per the system design [13]. The table 1 below summarizes the important electrical parameters of the system design [13].

Table 1: Summary of Electrical Parameters [13]

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

B. Reverse Osmosis Desalination System

Reverse osmosis system converts unfiltered feed water to clean water when feed water is pressurized and passed through a membrane. The water flows through the membrane and more contaminants are accumulated to the more concentrated side of the membrane whereas clean drinking water is accumulated to less concentrated side of the membrane [14]. According to the water requirement of community which is 2964 liters of water per day [13] system available in market were reviewed and selected. The selected system is US water Defender system. The company offers various models but the model selected is DFWHRO-4000 in order to meet the requirements of the community. The figure 2 shows the physical hardware of the system [15]. The table 3 shows the important design parameters of the system [15].

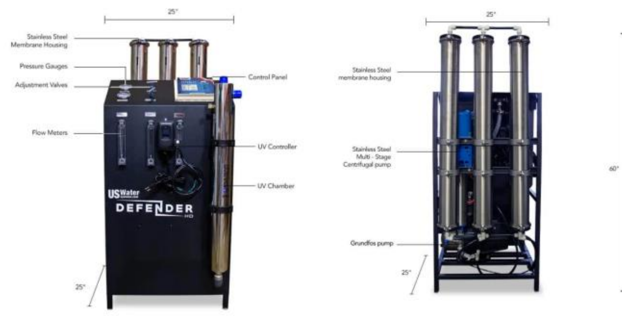

Figure 2 – Physical Hardware of the Reverse Osmosis System [15]

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

Table 3 – Important Design Parameter of the Reverse Osmosis System [15]

C. Control System and Monitoring

Arduino embedded with Node Red is used as the overall control system for this water purification system. It is an open source platform to embed different sensors, develop control strategies and execute several operations. Arduino is only used for data acquisition from field sensors whereas the node red then takes care of all programming and control decisions. The biggest advantage of Arduino microcontroller is that it’s simple to use even for beginners and it has the capability to execute detailed control logics. The Arduino board available in the market and the Arduino IDE which is the programming software for performing the coding is used. On the other hand, Node red is an open source programming tool where you can develop codes and link the physical hardware by online coding. It contains a browser based programming platform where you can install several libraries to connect and communicate with the physical world [16]. The biggest advantage of using node red is that it uses easy to wire programming language where you can visualize the node flows and how the code sequence will execute. The figure 3 shows the programming environment of node red.

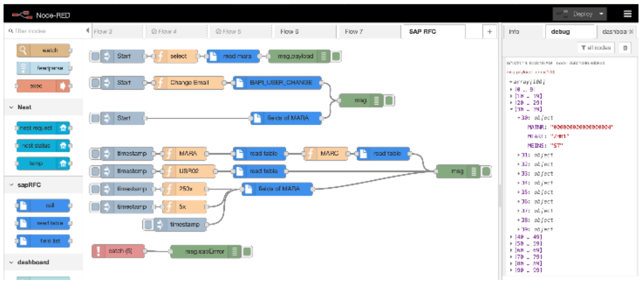

Figure 3 – Browser based Programming Environment of Node Red

Lastly, in order to integrate the field devices with the online browser based control system of Node red, Firmata protocol is used for communication between Arduino (Input/Output Interface) and Node red (Control System). Firmata is a protocol for communicating with microcontrollers from a software based on computer. The protocol is loaded on the firmware of the microcontroller so that the microcontroller act as the support for that package [17]. The most commonly implemented versions of firmata is for Arduino and Spark.io. The figure 4 below shows the block diagram for the integration of field devices (Sensors) with Input/Output interface (Arduino) that can be communicated using firmata protocol with the control system (Node Red).

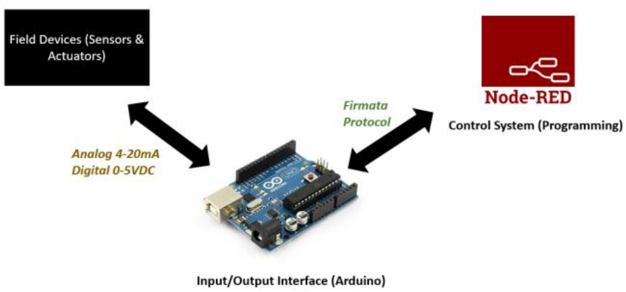

Figure 4 – Block Diagram of Control and Monitoring System Implementation

IV. INSTRUMENTATION SYSTEM DESIGN

A. Electrical System Instrumentation Design

The important parameter of the complete electrical system needs to be tracked in order to analyze the performance of the system. The instrumentation selected for the electrical system includes solar panel current and voltage measurement. Using the two parameters system can decide the available power at any point in the day.

B. Reverse Osmosis System Instrumentation Design

In order to ensure that the system is running smoothly several parameters need to be measured and tracked. The important parameter of the complete reverse osmosis system needs to be tracked includes feed water pressure, inlet temperature, pump status, pump pressure, outlet pressure after membranes and clean water tank level. Feed water pressure is measured to ensure that the system have the required inlet pressure available for smooth operation. The inlet temperature is measured to calculate the efficiency of the system because the conversion efficiency is dependent on the water temperature. The pump status is monitored for operational sequence and alerts. The pump pressure is measured to ensure pump is running at its full capacity and maximum efficiency is achieved. The outlet pressure and clean water tank level is measured to provide updates to the nearby community.

C. Complete Instrumentation and Control System Design

The overall process and instrument diagram will provide the snapshot of the complete instrumentation system. The figure 5 shows the complete system process and instrument diagram with all sensing points and control actuators.

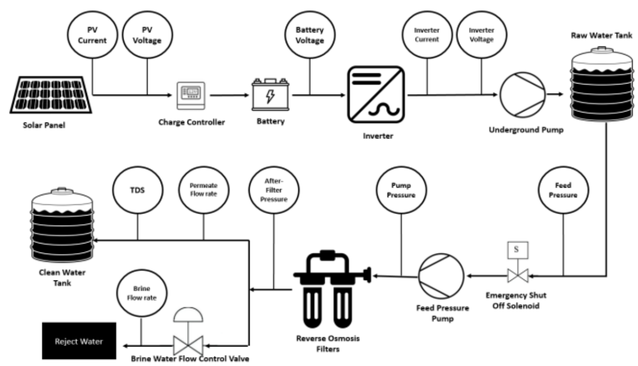

Figure 5 – Complete System Process and Instrument flow Diagram

V. CONTROL AND MONITORING SYSTEM DESIGN

In order to ensure that the overall system works according to the operational requirement control system strategy needs to be implemented. The complete control strategy is elaborated further and three major control loops are explained.

A. Energy Control Loop:

The energy control loop works by taking solar voltage, solar current and battery voltage as the inputs. The system alerts the user about the available power to run the system and generates alerts for low solar power and low battery power. It can shut downs the system when the battery voltage drops down the set point level. The figure 6 shows the block diagram for energy control loop operation.

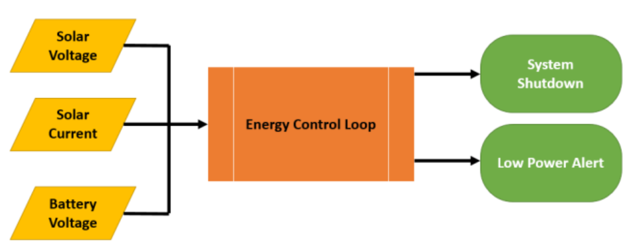

Figure 6 – Energy Control Loop

B. Pressure Control Loop:

The pressure control loop takes the feed pressure, pump pressure and outlet pressure as the inputs and alerts the user according to desired values. The system is shut down if the feed pressure is lower than the set point. The differential pressure between the pump pressure and outlet pressure is also calculated to alert the user about the condition of membrane and for its replacement. The figure 7 shows the block diagram for pressure control loop operation.

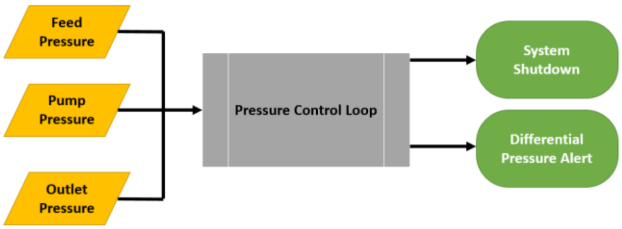

Figure 7 – Pressure Control Loop

C. Product Control Loop:

The product control loop takes the input of the outlet water total dissolved solids (TDS), outlet flow rate and clean water tank level. The system is shut down if the TDS is higher than the set point. Alerts are provided about the availability of water level in the tank and forecast is made on the future availability of water based on the outlet flow rate. The figure 8 shows the block diagram for energy control loop operation.

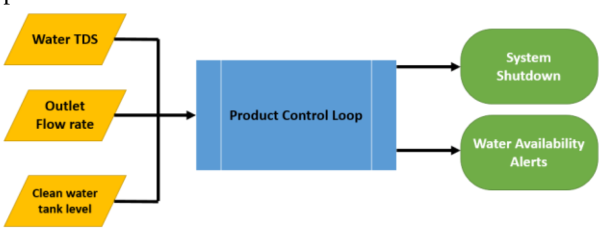

Figure 8 – Product Control Loop

D. Overall Control System Strategy:

The overall control system strategy will provide the snapshot of the complete control system which comprises of three control loops elaborated earlier as energy, pressure and product control loops. The figure 9 shows the complete control system strategy.

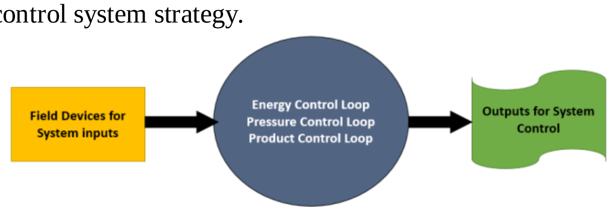

Figure 9 – Complete Control Strategy

VI. Hardware Implementation

In order to test the designed instrumentation and control system for the integrated solar powered based reverse osmosis system an experimental lab setup was created as shown in figure 10. The experimental lab setup has all major sensors required to control the system with Arduino microcontroller as the input and output interface. The elaborated control system was developed in the node red browser based control system and was integrated with field devices by firmata protocol. The system was found to operate as per the operational requirements.

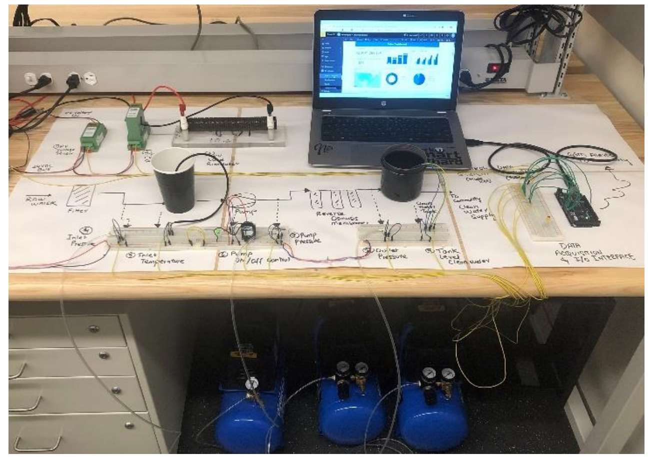

Figure 10 – Experimental Laboratory Setup

VII. Conclusion

The paper provides a unique system integration design by utilizing the Solar Energy for water availability (Reverse Osmosis Desalination System) using software based control system approach (Node Red) for a community in Pakistan. It further elaborates the important instrumentation required to ensure the system operation and monitoring of critical process parameters. Furthermore a detailed system design is elaborated using three control loops defined as energy, pressure and product. Lastly an experimental laboratory setup was created to verify the operation and monitoring of the system to ensure its stability.

References

[1] A. Khan and N. Awan, "Inter-Provincial Water Conflicts in Pakistan: A Critical Analysis," J. South Asian Middle East. Stud., vol. 43, no. 2, pp. 42–53, 2020, doi: 10.33428/jsoutasiamiddeas.43.2.0042

[2] B. Ahmad, "Water Management: A Solution to Water Scarcity in Pakistan," J. Indep. Stud. Res.- Manag. Soc. Sci. Econ., vol. 9, pp. 111–125, Dec. 2011, doi: 10.31384/jisrmsse/2011.09.2.9.

[3] M.S. Khalil, N.A. Khan, I.A. Mirza, Renewable Energy in Pakistan: Status and Trends, University of Engineering and Technology, Taxila-Pakistan Alternate Energy Development Board, Islamabad, Pakistan, 2003.

[4] C. Fritzmann, J. Löwenberg, T. Wintgens, T. Melin, State-of-the art of reverse osmosis desalination, Desalination, 216 (2007) 1–76.

[5] M. Wilf, Fundamentals of RO-NF Technology, Proceedings of International Conference on Desalination, Limassol, Cyprus, 2004.

[6] In the World: Small Mexican village produces clean water with solar powered system; Jennifer Chu;MIT News; https://news.mit.edu/2013/clean-water-solar-powered-system-0911 (Assessed 17th Jan 2022)

[7] M.A. Abdelkareem, M. El Haj Assad, E.T. Sayed, B. Soudan, Recent progress in the use of renewable energy sources to power water desalination plants, Desalination, 435 (2018) 97–113

[8] Muhammad Faisal Idrees; Performance Analysis and Treatment technologies of Reverse Osmosis Plant; Case Studies in Chemical and Environmental Engineering; https://doi.org/10.1016/j.cscee.2020.100007
[9] Edward Fredkin, Roger Banks; Computerized Instrumentation and Control for Reverse Osmosis Systems; Desalination; https://doi.org/10.1016/0011-9164(89)85010-6
[10] Francisco J. García Latorre, Sebastián O. Pérez Báez, Antonio Gómez Gotor; Energy performance of a reverse osmosis desalination plant operating with variable pressure and flow, Desalination, Volume 366, 2015,Pages 146-153,ISSN 0011-9164, https://doi.org/10.1016/j.desal.2015.02.039.
[11] Thomson, A. Murray, Reverse-osmosis desalination of seawater powered by photovoltaics without batteries; ISNI: 0000000135320571; https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.416745
[12] P. Glueckstern, M. Wilf, J. Etgar, J. Ricklis; Use of microprocessors for control, data aquisition and on line performance evaluation in a reverse osmosis plant, Desalination, Volume 55, 1985, Pages 469-480, ISSN 0011-9164, https://doi.org/10.1016/0011-9164(85)80091-6.
[13] S. U. Uddin and T. Iqbal, "Design and Economic Analysis of Solar Powered Drinking Water Reverse Osmosis Desalination System for a Community in Pakistan," 2022 IEEE 12th Annual Computing and Communication Workshop and Conference (CCWC), 2022, pp. 1059-1064, doi: 10.1109/CCWC54503.2022.9720759.
[14] What is Reverse Osmosis System and how does it work?, Fresh Water Systems, https://www.freshwatersystems.com/blogs/blog/what-is-reverse-osmosis (Accessed 10th Oct 2022)
[15] Defender Whole House RO System, US Water Systems, https://www.uswatersystems.com/defender-whole-house-ro-system.html (Accessed 10th Oct 2022)
[16] NodeRed, https://nodered.org/ ; (Accessed 11th Oct 2022)
[17] Firmata Protocol; Github; https://github.com/firmata/protocol ; (Accessed 11th Oct 2022)