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Remote Data Acquisition System for Photovoltaic Water Pumping System in Sukkar, Pakistan

Omair Ahmed and M. Tariq Iqbal

***Abstract* — Access to high-speed internet connectivity is limited in Sukkur, Pakistan, making alternative communication technologies essential for real-time monitoring and control of photovoltaic (PV) water pumping systems. This research paper presents the design, implementation, and evaluation of a GSM-based remote data acquisition and logging system for a PV water pumping system in Sukkur. Leveraging abundant sunlight in the region, the proposed system utilizes 2G GSM technology for communication between the PV system and the remote monitoring station. A network of sensors captures key parameters, and the acquired data is processed, stored, and transmitted using 2G GSM, enabling remote access and real-time monitoring from any location with GSM coverage. The implemented system incorporates an Arduino microcontroller for core operation and employs an SD card for data logging. Real-time data logging allows for detailed tracking and analysis of system performance, facilitating troubleshooting and optimization. Data stored on the SD card can be transferred to a computer for further analysis using data analysis software or custom applications, providing meaningful representation of trends and insights into system operation. The system also features an OLED display for real-time feedback on essential parameters, including solar irradiance, water level, and pump status. Furthermore, the integration of user prompts and GSM communication enables remote monitoring and control, empowering users to inquire about system status and remotely activate or deactivate the pump through SMS commands. The system offers a robust and adaptable solution for efficient management and maintenance of the solar-powered water pumping system in Sukkur, Pakistan.**

***Key words* — GSM; Pakistan; PV water pumping system; remote data acquisition system.**

I. Introduction

In recent years, the utilization of renewable energy technologies has revolutionized various sectors, including agriculture and water resource management [1]–[3]. To meet the increasing demand for irrigation in regions with limited access to reliable electricity grids, photovoltaic (PV) water pumping systems have emerged as a sustainable solution [4], [5]. By harnessing solar power, these systems offer an environmentally friendly and cost-effective alternative to traditional diesel or grid-connected pumps [6]–[8].

Efficient monitoring and control mechanisms are crucial for optimizing the performance and effectiveness of PV water pumping systems [9], [10].

Accurate and real-time data acquisition plays a vital role in enabling informed decision-making, effective maintenance, and performance evaluation [11]–[13]. However, traditional manual data collection methods are labor-intensive, time-consuming, and prone to human errors. Consequently, the integration of remote data acquisition and logging systems has become imperative for ensuring the reliable operation of PV water pumping systems.

There has been a growing interest in the use of wireless technologies for monitoring and control of water pumping systems in recent years. This is due to the many advantages that wireless technologies offer, such as their flexibility, low cost, and ease of installation. In [14], a GSM-based distribution transformer monitoring system was developed. The system used a GSM modem to collect data from sensors installed on the transformer, and then sent the data to a central database for analysis. In [15], a GSM-based monitoring and control system was developed for photovoltaic power generation systems. The system used a GSM modem to collect data from sensors installed on the photovoltaic panels, and then sent the data to a central server for analysis. In [16], a wireless monitoring management system for water supply pipe network based on GPRS was developed. The system used GPRS to collect data from sensors installed on the water supply pipe network, and then sent the data to a central server for analysis. In [17], the study describes the design and implementation of a real-time monitoring system for fresh water quality. The system uses a wireless sensor network to collect data from sensors installed in a freshwater resource, and then sends the data to a central server for analysis. Thomson *et al*. in [18] presented a novel application using simple microprocessor, accelerometer, and GSM components to record graduated time-step information flows of lever pumps. Shariff *et al*. in [19] have explored the hardware and software design for a photovoltaic remote monitoring system. The system uses a voltage sensor, current sensor, temperature sensor, and irradiation sensor to collect data from a photovoltaic system. The data is then transmitted to a central monitoring station using a GSM modem. Mo *et al*. [20] presented a system for automatically measuring and reporting water quality. The system uses a GSM network to send data from sensors to a central monitoring station. Barsoum and Peter have presented a system for monitoring and controlling the temperature and soil moisture in a greenhouse [21]. The system uses a GSM modem to transmit data from sensors in the greenhouse to a central monitoring station.

Some other studies explored the data logging system along with data acquisition systems. For instance, the study presents the design and development of a fast and low-cost data logger for PV water pumping systems [22]. The data logger uses a microcontroller to collect data from sensors installed on the PV system, and then stores the data in a memory card. Hunar

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O. Ahmed, Department of Electrical Engineering, Memorial University of Newfoundland, Canada
(corresponding e-mail: oahmed@mun.ca)
M. T. Iqbal, Department of Electrical Engineering, Memorial University of Newfoundland, Canada
(e-mail: tariq@mun.ca)

et al. [23] explored the use of a GSM wireless datalogger to monitor a small hydro power generation system. The datalogger collects data from sensors and transmits it to a central monitoring station using a GSM modem. Getu [24] proposed a system for remotely controlling water pumps in a garden plantation using Arduino and GSM technology. The system uses a microcontroller, a GSM modem, and sensors to collect data on the water level in the tank and the soil moisture level. Another study [25] explored a system for remotely monitoring the operation of a power transformer using GSM technology. The system uses a microcontroller, a GSM modem, and sensors to collect data on the load currents and temperature of the transformer. Similarly, in [26] suggested a system for remotely monitoring the water level in a tank using GSM technology. The system uses a microcontroller, a GSM modem, and a water level sensor. The data is stored and then transmitted to a mobile phone, where the user can view it and act if necessary.

Several other studies have explored the utilization of wireless technologies such as Wi-Fi and IoT for monitoring and controlling of water pumping systems. For instance, [27] describes how to design and assemble a low cost online monitoring and Wi-Fi data acquisition system using free software applied to microgeneration based on renewable energy sources. The system uses an embedded Wi-Fi modem coupled to a microcontroller board based on the free tool SanUSB. Another study [28] have explored a system for monitoring the performance of a photovoltaic water pumping system using the Internet of Things (IoT). The system uses a microcontroller, a GSM modem, and sensors to collect data on the performance of the system. The data is then transmitted to a cloud-based server, where it can be viewed by the system operator. Similarly, [29] describes a system for monitoring the performance of a water pumping system using a lithium-ion battery, free open-source software, and IoT technologies. [30] explores a system for monitoring using IoT technologies

In Sukkur, Pakistan, where access to 3G, 4G, and Wi-Fi networks is unavailable, alternative communication technologies are necessary for real-time monitoring and control of PV water pumping systems. This research paper focuses on the design, implementation, and evaluation of a GSM-based remote data acquisition and logging system for a photovoltaic water pumping system in Sukkur, Pakistan. The city experiences abundant sunlight throughout the year, making it an ideal location for harnessing solar energy. However, due to the lack of high-speed internet connectivity, traditional remote monitoring systems that rely on 3G, 4G, or Wi-Fi networks are not viable options. Therefore, in this study, the focus is on utilizing 2G GSM technology to establish communication between the PV water pumping system and the remote monitoring station. The proposed remote data acquisition and logging system will employ a network of sensors to capture essential parameters.

The acquired data will be processed, stored and then transmitted to the user using the 2G GSM, enabling remote access and real-time monitoring from any location with GSM coverage.

The paper is organized as follows: Section II illustrates the methodology of the proposed system. Section III explores the results; Section IV discusses the results and Section V concludes the paper.

II. Simulation of the Proposed Setup

This section presents the simulation of the proposed system. The simulation is done in Proteus VSM. The software does not have the libraries to simulate the Arduino Microcontroller. However, the library is available online and are imported in the simulation environment. Fig. 1 shows the simulation of the proposed system. The logic state point is used to imitate the light dependent resistor module that provides a digital input to the microcontroller. When the logic state is set to zero, it suggests that there is high solar irradiance while when it is set to one, it presents a lower solar irradiance. A simple DC motor is also used to imitate the water pump and is controlled by a relay. A library of GSM module with model GSM900 is imported into the environment to simulate the GSM connectivity. However, the library is not fully functional resulted in partial responses.

The setup was designed and tested for the logic when there is sufficient sun light / solar irradiance and level of water is low in the tank. The ultrasonic sensor measures the distance to the water level and sends the value to Arduino using I2C. The Arduino converts the value to cm and displays it on the LCD. As the water level increases, the distance gets lower and at full level, the ultrasonic measures 5cm. This is the threshold where the system assumes the water level is high. Below that level it is considered low. Fig. 1a shows the state of pump when the conditions are met, Fig. 1b and Fig. 1c illustrates the state of pump when either one of the conditions are not met resulting in pump not running. Fig. 1d illustrates the communication between Arduino and the GSM900 module, however, the library is not fully functional resulting in missed responses and partial communication. The setup was validated in the simulation setup and moved to the hardware experimental setup. The hardware experimental setup is discussed in next section.

III. Experimental Setup

This section explores the experimental setup that has been built to test the proposed system. Fig. 2 shows the experimental setup of the proposed system. The following subsections presents the components used it this setup.

A. *Water Tanks*

The setup includes two water tanks. One tank represents an underground water storage while the other tank represents an outer water tank utilized for water storage. The underground water tank has a dc motor installed to its bottom surface. The outer tank has an ultrasonic sensor to measure the water level. Fig. 3 illustrates the water tanks along with other essential components.

B. *Arduino Uno R3*

In this setup, an Arduino UNO R3 is used as the main controlling station as shown in Fig. 1. All the peripherals are connected to this microcontroller. The sensors send the data to Arduino microcontroller and the microcontroller processes them. The microcontrollers require 5V to work. Two solutions were available, (a) Run with a computer USB port, and (b) run with an independent dc source. Since, this

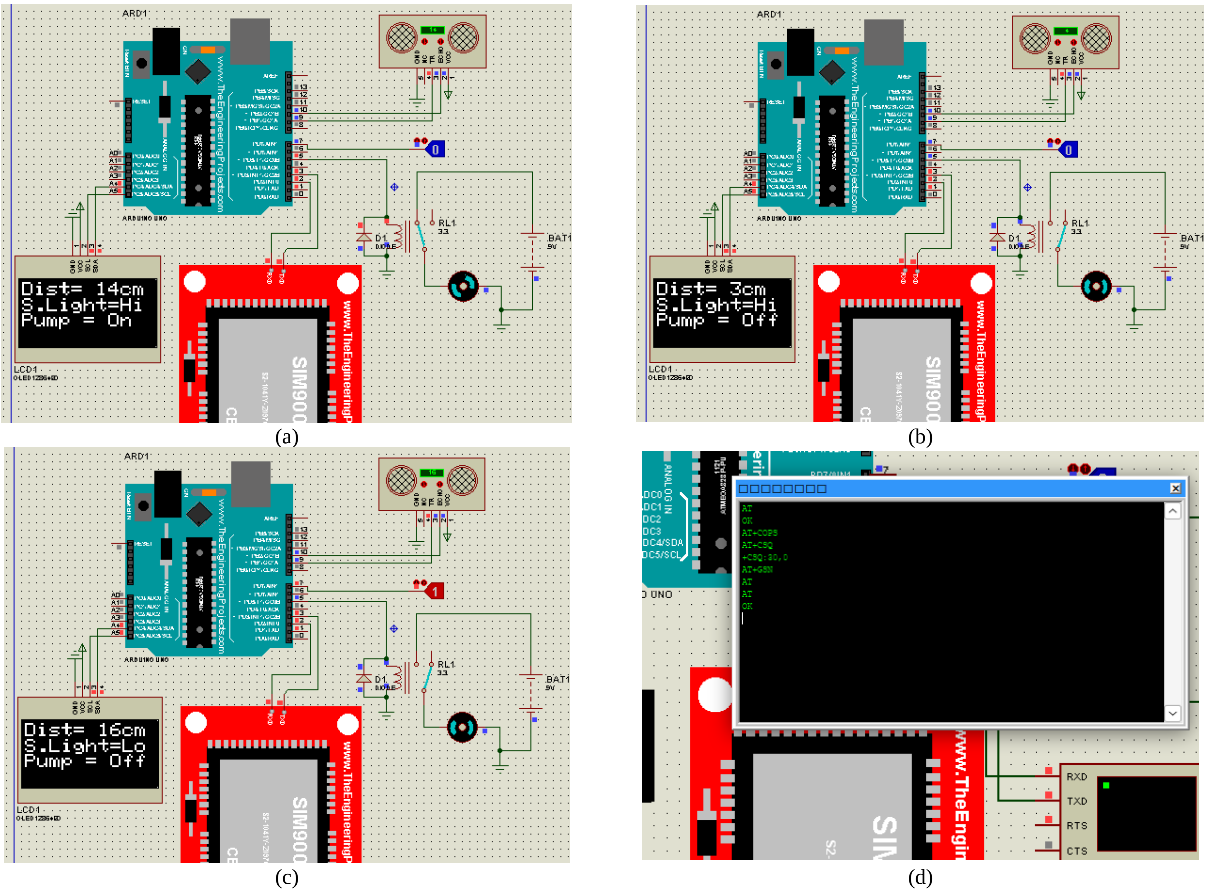

Fig. 1. Simulation Setup of the proposed system

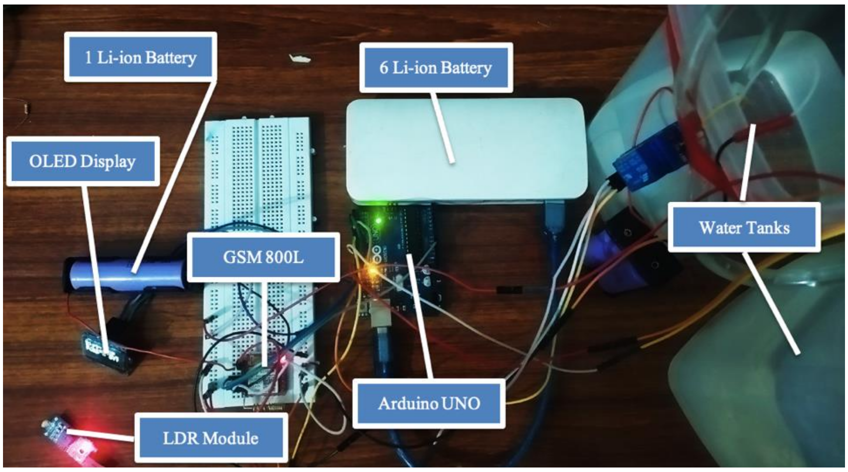

Fig. 2. Experimental Setup of the proposed system.

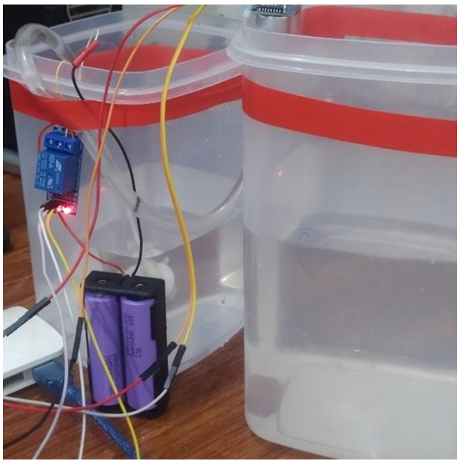
Fig. 3. Two water tanks. The left one represents an underground water storage, while right one represents the outer water storage tank. The underground water tank is installed with a DC water pump that is controlled by Arduino using SPDT relay; nd powered by a battery pack of two 18650 Li-ion battery cells. The outer tank is fitted with an ultrasonic sensor.

setup is to be installed remotely; the microcontroller relates to a battery pack with six Li-Ion 3.7V cells that are stepped-up using a built in DC-DC converter as illustrated as white box in Fig. 1. This ensures a stable 5V input to the Arduino microcontroller.

C. Organic Light-Emitting Diode (OLED) 128 x 64 Display

For local display, the setup includes an Organic Light-Emitting Diode (OLED) 128 × 64 Display. The OLED display is connected to Arduino using I2C protocol. The OLED can be configured to display any values or text.

D. Ultrasonic Distance Sensor

Ultrasonic sensor is utilized in this setup to measure the water level of the outer tank. The ultrasonic sensors transmit an ultrasonic sound that is received after hit by an obstacle, in this case water.

E. Photoresistor

Photoresistor or Light dependent resistor (LDR) is used to measure the available sunlight for photovoltaic panel. The LDR ensures that there is enough solar irradiance to turn on the pump on PV panel rather than battery. However, in absence of sunlight, the system can still be run on battery backup. Fig. 4 shows the LDR module used in this experimental setup.

F. GSM SIM800L

Since, the setup is to be installed at a remote location where there is not electricity or internet is available, a GSM module was required to communicate with the system. The location does not have Wi-Fi or 3G connection. However, there was 2G GSM with SMS service was available. Therefore, the setup includes an SIM800L Module that is connected to Arduino and provides communication between the user/observer and the system.

G. Water Pump

To imitate a PV water pump, a small DC water pump is utilized in this setup. The pump requires minimum of 5V to work and is installed in underground water tank. This pump is also connected with a relay that controls its operation.

H. 18650 Li-ion Battery Cells

In this setup, three sets of 18650 Li-ion battery packs are utilized. Each pack consists of one or several 18650 Li-ion cells. Each cell has capacity of 3000 mAh with 3.7 V output. One battery pack imitates a large battery backup system that is being charged by PV panels and can run the water pump. This battery pack has two Li-ion cells connected in series to provide more 5 V to the water pump.

Second battery pack is enclosed in a casing and hold 6 Li-ion cells and provides 5V output thorough a step-up DC-DC converter and powers the Arduino microcontroller. The third battery pack has only one cell and is utilized to power up the SIM800L module as this module requires voltage in between 3.4 V and 4.4 V.

I. Single Pole Double Throw (SPDT) Relay

A Single Pole Double Throw (SPDT) relay was utilized to control the operation of the DC water pump. This SPDT relay is connected to the larger battery pack and is controlled by a pin on Arduino microcontroller.

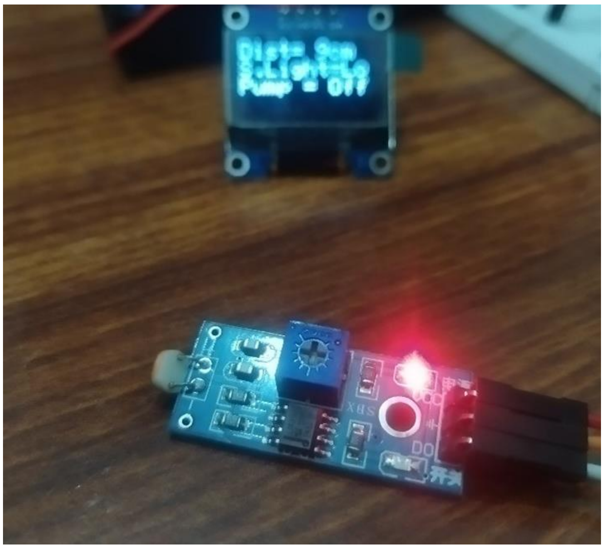

Fig. 4. LDR module used in this setup. The LDR module provides the output in digital format resulting in High or Low: High when there LDR does not detect sunlight and Low when there is enough sunlight.

J. Secure Digital (SD) Card

The setup also includes a Secure Digital (SD) card that is used to store the collected parameters from sensors. An 8 GB SD card is connected with Arduino using an SD card reader. This ensures enough storage for data logging.

IV. Methodology

The system depicted in Fig. 5 illustrates a comprehensive flow chart that outlines the essential steps required for the optimal functioning of the solar-powered water pumping system. The flow chart encompasses various scenarios that the system may encounter and highlights the corresponding actions the system must undertake in response.

To begin, the system initiates by checking the availability of sufficient solar irradiance to activate the photovoltaic (PV) pump. If the measured irradiance falls below the threshold value required to start the pump, the system enters a waiting period of one minute before rechecking the irradiance level. This iterative loop continues indefinitely until the irradiance surpasses the threshold, as it is crucial for the system to rely on adequate solar energy to operate effectively.

Upon confirming the presence of sufficient irradiance, the system proceeds to monitor the water level within the tank. If the water level is already high, indicating the tank is adequately filled, the pump remains deactivated.

However, if the water level is low, signaling the need for water replenishment, the system sends a signal to the relay, activating the pump motor. Concurrently, the OLED screen connected to the local system displays the current state of the pump, providing immediate feedback on its operation.

After a set time, the system reevaluates the water level to ensure it has not exceeded the predetermined limit. If the water level has reached or exceeded this limit, the system automatically shuts off the pump to prevent overflow or any potential damage. Conversely, if the water level remains below the limit, the system continues to operate the pump until the limit is reached, ensuring a controlled and efficient water flow.

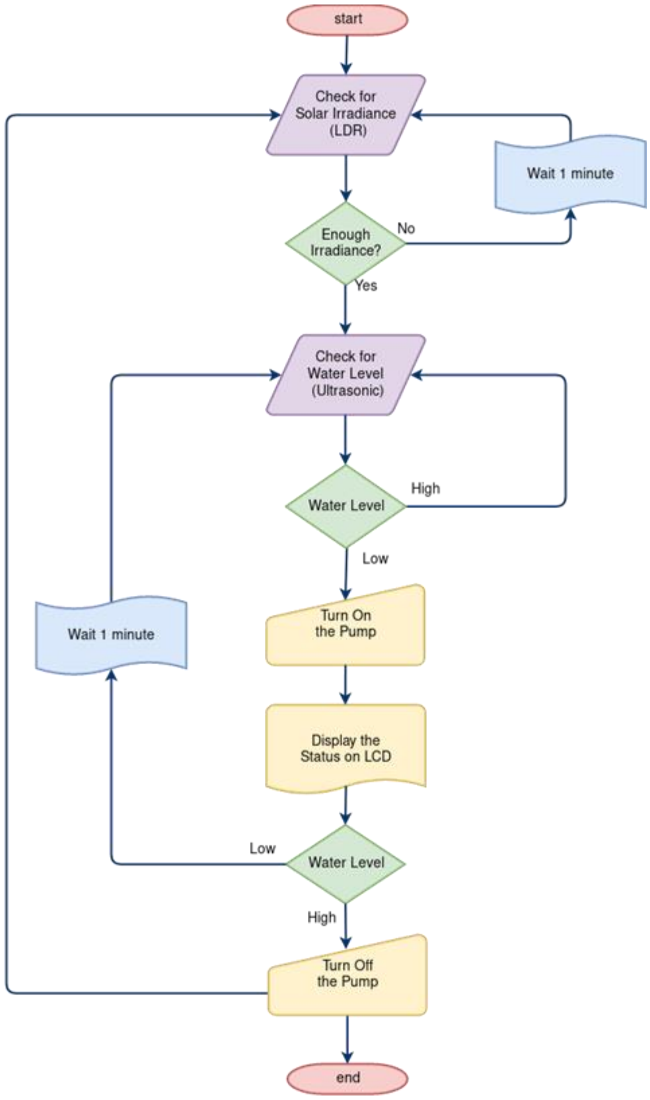

Fig. 5. Flowchart of the control strategy of PV water pumping system.

Once this loop is completed, the system again checks the water level. If the water level drops below the low level once more, indicating the need for further water supply, the pump resumes its operation. This iterative process ensures the continuous maintenance of a safe and adequate water level within the tank, promoting both system reliability and user convenience.

The flow chart presented in Fig. 5 serves as a comprehensive guide, outlining the necessary steps for the system to operate optimally. By relying on sufficient solar irradiance and activating the pump only when the water level falls below the low level, the system maximizes its efficiency and effectiveness.

Moreover, the incorporation of an automatic shut-off mechanism when the water level exceeds the predetermined limit serves as a crucial safety feature, preventing potential overflow or damage.

Table I shows the control logic used for the system. Three levels are defined for both water level and solar irradiance. These are (a) Low, (b) Mid, and (c) High. The pump turns on when there is at least Mid solar irradiance. The pump does not turn on when there is Low irradiance even though water level is required. This is because Low irradiance will not be enough to power up the pump.

TABLE I: CONTROL LOGIC FOR THE PROPOSED SYSTEM

		Water level		
		Low (0)	Mid (1)	High (2)
Solar Irradiance	Low (0)	Off	Off	Off
	Mid (1)	On	On	Off
	High (2)	On	On	Off

In addition to its autonomous operation and user prompts, the solar-powered water pumping system incorporates a battery backup feature. This allows the system to run on battery power if prompted by the user to forcefully turn on the pump, even in situations where the solar irradiance may be insufficient. This battery backup capability ensures continuous water pumping operation, providing a backup solution when the system relies on stored energy rather than solar power. However, it's important to note that the system imposes a time limit for forcefully turning on the pump. This time limit is set to prevent excessive battery usage and optimize energy efficiency. Once the set time for forceful pump activation is reached, the system will automatically revert to its default mode of operation, where the pump relies on solar power and the available irradiance level. This time limit acts as a safeguard, preventing unnecessary battery drainage and promoting sustainable energy use.

Fig. 6. The status of the experimental setup is shown on the OLED connected to the Arduino.

V. RESULTS AND DISCUSSIONS

Fig. 6 illustrates the status of the pump on the attached OLED. The results correspond the same output as simulated in the simulation setup. In Fig. 7, a user initiates a system status prompt by sending an SMS with the message "Status?" to the system as shown in Fig. 7 (a). Upon receiving the SMS, the system acknowledges the message and proceeds to read its contents.

The system then displays a brief acknowledgement on the second line of the display, indicating that the SMS has been received as illustrated in Fig. 7b. After a short delay, typically a few seconds, the system formulates a response and sends it back to the user as shown in Fig. 7c. This response contains the current system status, providing the user with the necessary information they requested.

The user prompts the system to turn on the pump by sending an SMS command with the message "Pump ON" as shown in Fig. 7d. Upon receiving the SMS, the system recognizes the command and acknowledges the message as illustrated in Fig. 7e. The system then processes the command

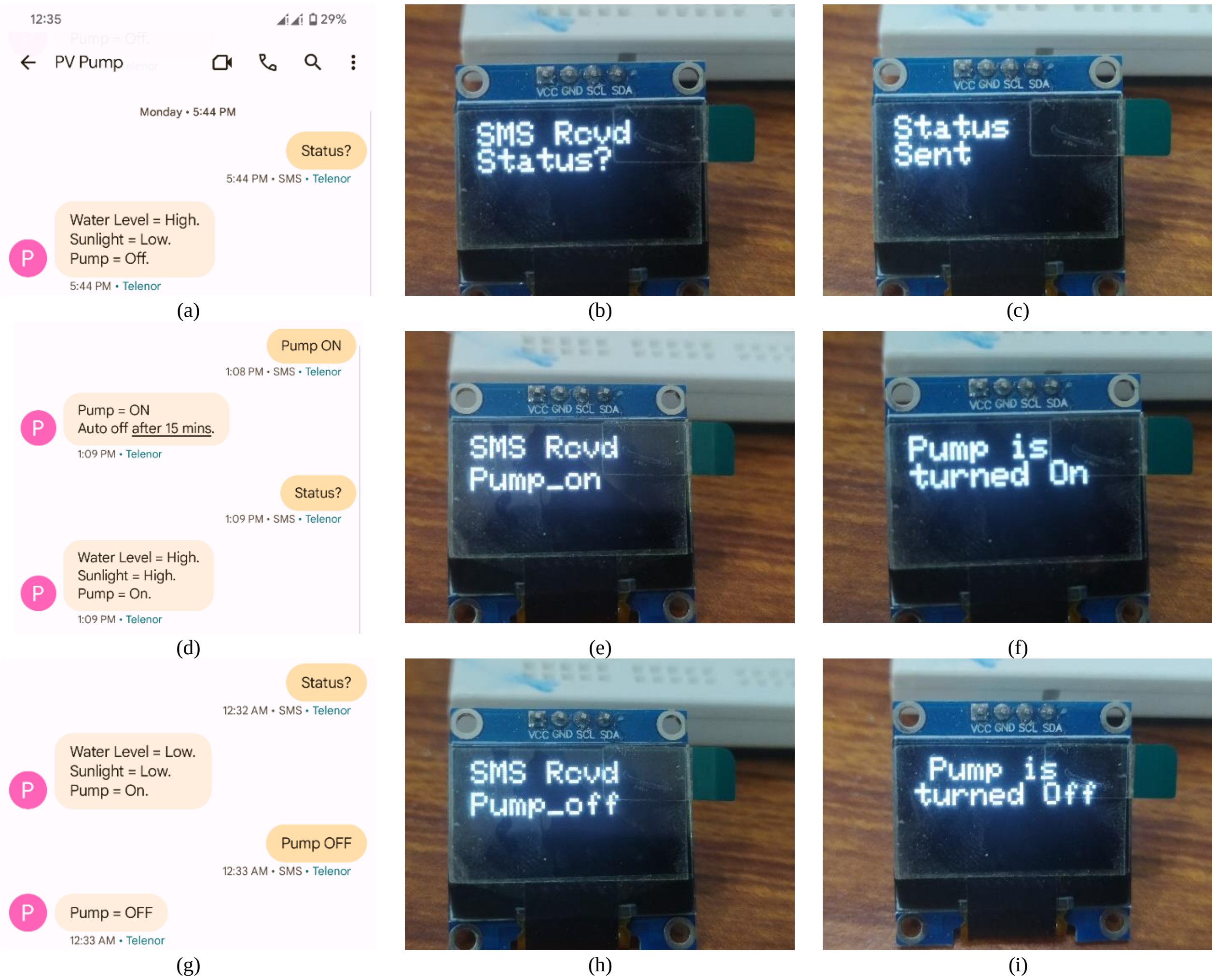

Fig. 7. User prompt about system status and manual control of the water pump.

and initiates the pump activation procedure. After a brief delay to ensure proper pump startup, the system sends a response back to the user, confirming the pump activation as shown in Fig. 7f. This response serves as an acknowledgment and provides reassurance to the user that their command has been successfully executed. The pump will continue operating until it receives a command to turn off or reaches a predetermined condition for automatic shut-off.

In a similar manner, the user can prompt the system to turn off the running pump by sending an SMS command with the message "Pump OFF" as illustrated in Fig. 7g. Upon receiving this specific command, the system recognizes the user's intent and acknowledges the received SMS as depicted in Fig. 7h. Once the system processes the command, it initiates the procedure to deactivate the pump. This involves safely shutting down the pump and halting the water pumping operation. After ensuring the pump has been successfully turned off, the system sends a response back to the user, confirming the pump deactivation as depicted in Fig. 7i. This response serves as an acknowledgment and provides reassurance to the user that their command has been executed, and the pump is no longer in operation.

Table II presents the data logged using the proposed system, stored on an SD card, and extracted using a computer. The data represents the water level in centimeters (cm), solar irradiance, and the status of the pump (ON or OFF) during different instances. It is important to note that the pump only turns on when the water level is high, and the solar irradiance is also high.

It can be observed that when the water level is at 21 cm, indicating a low water level, the pump remains off. This is because the corresponding solar irradiance is recorded as low, which does not meet the requirement for pump activation. However, when both the water level and solar irradiance are high, as shown in instances 2 to 6, the pump is turned on. This indicates that the system is functioning as intended, activating the pump to replenish the water when both conditions are met.

The data further demonstrates the consistent behavior of the system. Instances 7 to 11 illustrate that when the water level drops to 7 cm, the pump remains off if the solar irradiance is low. Conversely, when the solar irradiance is high, the pump is turned on, indicating a responsive system that operates based on the combination of water level and solar irradiance.

Instances 18 and 21 also highlight the system's adherence to this rule, as the pump remains off despite a low water level when the solar irradiance is low.

The data provides evidence of the proposed system's functionality, accurately reflecting its operation based on the recorded water level and solar irradiance. It demonstrates the system's ability to activate the pump only when both conditions are met, ensuring efficient water management in response to environmental factors.

TABLE II: LOGGED DATA USING THE PROPOSED SETUP

Sr. No	Water Level (cm)	Solar Irradiance	Pump Status
1	21	LOW	OFF
2	18	HIGH	ON
3	15	HIGH	ON
4	12	HIGH	ON
5	9	HIGH	ON
6	7	HIGH	ON
7	7	LOW	OFF
8	5	HIGH	ON
9	5	LOW	OFF
10	5	LOW	OFF
11	21	HIGH	ON
12	18	HIGH	ON
13	15	HIGH	ON
14	12	HIGH	ON
15	9	HIGH	ON
16	7	HIGH	ON
17	7	LOW	OFF
18	7	LOW	OFF
19	5	HIGH	ON
20	5	LOW	OFF
21	5	LOW	OFF
22	21	HIGH	ON
23	18	HIGH	ON
24	15	HIGH	ON
25	12	HIGH	ON

VI. CONCLUSION

The research paper presented a comprehensive remote data acquisition system for a photovoltaic water pumping system in Sukkur, Pakistan, where high-speed internet connectivity is limited. By utilizing 2G GSM technology, the system enabled real-time monitoring and control, overcoming the challenges posed by the lack of access to 3G, 4G, or Wi-Fi networks in the region. The integration of sensors, an Arduino microcontroller, an SD card for data logging, and an OLED display provided a robust platform for data collection, storage, analysis, and visualization. The data logging capabilities of the system allowed for the tracking and analysis of essential parameters, such as solar irradiance, water level, and pump status. Real-time feedback through the OLED display provided immediate visibility into system performance and potential issues. Moreover, the transfer of data from the SD card to a computer facilitated in-depth analysis using data analysis software or custom applications, enabling meaningful representation and insights into system operation. The incorporation of user prompts and GSM communication enhanced the system's usability and adaptability, allowing users to remotely inquire about system status and control the pump through SMS commands. This feature empowered users to actively manage the water pumping process based on their needs, providing convenience and flexibility.

CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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