Mechatronics and Automation Technology
J. Xu (Ed.)

doi:10.3233/ATDE241306

Solar-Powered and IOT-Aided Irrigation System for Small Farm-Scale Operation

Candidus U. EYA[a,1], MADU Malachy C[b], AGOMUO Hyginus[c], Nwokocha NATHAN[d], Joseph Okwu OGWUCHE[e], EZEA Obinna Fidelis[f]
[a] *Laboratory of Industrial Electronics, University of Nigeria Nsukka, Nigeria*
[b] *Electrical Engineering, University of Nigeria, Nsukka, Nigeria*
[c] *ROV Submersibles Engineer for many ROV and Subsea industries Nigeria, Nigeria*
[d] *Federal College of Education (Technical) Omoku, Rivers State Nigeria, Nigeria*
[e] *Electrical/Electrronics Engineering, Benue State Polytechnic, Ugbokolo, Benue State*
[f] *Electrical/Electronic Engineering, Federal Polytechnic, Ohodo, Igbo-etiti L.G.A, Enugu State, Nigeria*

Abstract. This article presents a Solar-powered and IOT-aided irrigation system for small farm-scale operation. The solar panel ensures a reliable and cost-efficient power source especially in remotest villages where there is no evidence of grid utility power supply. The system employs soil moisture sensors and a Wi-Fi module connected to a microcontroller for the supervision and control of the water pumping process, creating a connected irrigation solution enabled by the Internet of Things (IoT). This system instantly sends sensor data to the Blynk mobile application, enabling farmers to access and monitor the irrigation system through the app. Furthermore, the incorporation of IoT technology allows for the monitoring of flowrate, battery voltage, reservoir water volume, and soil sample water level. Inverted staircase and carrier-based modulation is used to generate firing pulses for Power MOSFETS switches. This system achieves improved water usage efficiency, streamlining farming operations and ultimately reducing electricity consumption and operational costs by harnessing solar energy. This research is applicable to both small-scale farms and, in the long run, larger agricultural lands.

Keywords. Blynk, boost converter, IoT, irrigation, microcontroller, pump, solar panel.

1. Introduction

Irrigation plays a crucial role in boosting agricultural productivity, benefiting economies worldwide. According to [1], it involves controlled water application to cultivated land, sourced from various places like groundwater, surface water, treated wastewater, and more. Irrigation serves purposes beyond agriculture, such as livestock cooling, sewage disposal, dust reduction, and mining. Different irrigation methods include surface irrigation, which spreads water across fields, drip irrigation that delivers water directly to plant roots efficiently, and sprinkler irrigation, using high-pressure sprinklers or overhead guns to distribute water over plants. Transitioning to renewable energy sources is essential for agricultural sustainability due to the high costs and environmental impact

[1] Candidus U EYA, Laboratory of Industrial Electronics, Power Devices and New Energy System, University of Nigeria, Nsukka; Email: candidus.eya@unn.edu.ng.

of fossil fuel-based systems. Nigeria, with its abundant solar energy potential, is well-positioned for this shift. naturally replenish themselves and are utilized for electricity generation and heating and cooling applications [2],[3].

The Internet of Things (IoT) is a communication technology framework where objects like smartphones, sensors, and appliances can connect with each other and the Internet. It has various applications, from automating household tasks to improving energy distribution, revolutionizing farming, environmental monitoring, healthcare, and industrial processes. In agriculture, IoT enables the creation of smart irrigation systems, automating water pumping to enhance farming practices, reduce labor, and lower costs [4].

The work introduces a smart irrigation system that combines solar energy and Internet of Things (IoT) technology with inverted -signals' modulation scheme. The inverted signals' modulation scheme combines inverted staircase signal to produce triggering signals. These signals have the ability to reduce low order high order harmonics simultaneously. The proposed system uses solar power to operate an electric water pump and employs a microcontroller with a soil moisture sensor to measure soil moisture accurately, delivering water as needed. This setup promotes efficient water conservation and simplifies irrigation tasks. The water pump works throughout the day and night with a battery backup. With IoT, sensor data can be transmitted to the internet and accessed via the Blynk mobile application on smartphones and laptops, and the data can be stored in the cloud for future use.

2. Literature Review

The researchers introduced a solar-powered portable water pump for smart irrigation, reducing electricity usage and operational costs [5]. They utilized a NodeMCU microcontroller with Wi-Fi, complex codes and various sensors to create an IoT-enabled system for monitoring soil conditions. An algorithm continuously updated data to the Blynk IoT cloud, accessible via smartphones. The design was inspired by wheeled luggage and included a water filter and nozzles for spraying. It improved water efficiency, aided farming practices, and allowed real-time pump control. The system used two 50W PV panels to power a battery for up to three hours of nighttime irrigation. Limitations included the cost of constructing the wheeled luggage and the cost of purchasing another solar panel where a boost converter can be used to raise the voltage of a single solar panel [5]. The authors developed a GSM-based Irrigation System utilizing a simple GSM device for communication. Users could send and receive instructions via SMS messages within a 10-meter range of the system. The system conveyed power supply status through Bluetooth or SMS and sent alerts via SMS if the water supply was unavailable despite electricity. Sensors measured soil moisture and temperature, transmitting data to users for analysis. Users could control irrigation via SMS commands. The setup involved an Arduino board and a GSM modem. Limitations included the absence of a renewable energy source, limited autonomy in scheduling water distribution, and a short communication range of under 10 meters [6]. Authors in [7] presented a smart irrigation system for paddy fields using solar energy and IoT. The goal was to replace labor-intensive methods and improve water efficiency, preventing over or under-irrigation. The system had two main components: the control unit and the receiving unit. The control unit included an Arduino UNO board with sensors like soil moisture, humidity, and temperature. Two microcontrollers processed data; one controlled the solenoid valve for irrigation, while the other transmitted data to the receiving unit. The receiving unit used an Arduino board and nRF24l01 to send data to the Thing-Speak cloud server. However, the system had limitations such as its reliance on Thing-Speak, which lacks compatibility with iOS and Android devices. Using the Blynk mobile application and monocrystalline solar panels could address these limitations. Monocrystalline panels are more efficient and suitable for non-tropical regions. Also, some researchers developed a specialized Smart Irrigation System for greenhouse farmers, allowing remote monitoring of temperature and soil moisture via an Android mobile device. The system used temperature and moisture sensors to collect data and sent notifications when specific conditions were met. It had two modes: manual and automatic, allowing users to activate it based on their preferences. However, it only worked on Android devices and did not incorporate renewable energy sources like photovoltaic systems, which could provide continuous electrical power [8]. This means that it cannot be sustain in rural settlement.

This research aims to create a smart irrigation system using renewable energy (solar panels, robust DC-DC converter, and PWM charge controller) suitable for both small and large-scale operations. It minimizes operational costs by raising the solar panel voltage with a PWM-controlled boost converter via Arduino signals. The system measures water volume in the reservoir using an ultrasonic sensor and controls pump flow rates with a PWM-controlled MOSFET. It also incorporates IoT capabilities through an ESPO1 module with Wi-Fi, allowing real-time monitoring of sensor data (flowrate, water level, reservoir volume, and battery level) via the Blynk mobile application. Data is stored in the cloud for easy access. Unlike systems limited to Android or desktop apps, this setup is versatile and compatible with various devices as well as reducing the effects of chattering effects with the aid of inverted signals' modulation scheme.

The proposed system uses computer simulation modelling and laboratory implementation. The block diagram is shown in figure 1. It is made up of solar panel, charge controller, WIFI module, Blynk app, arduino, driving pump, smart phone/Laptop outlet, sensors and battery.

3. Methodology

The proposed system uses computer simulation modelling and laboratory implementation. The block diagram is shown in figure 1. It is made up of solar panel, charge controller, WIFI module, Blynk app, arduino, driving pump, smart phone/Laptop outlet, sensors and battery.

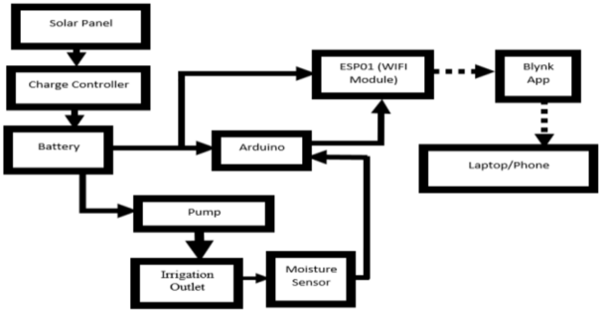

Figure 1. Block diagram of the proposed system

The system Hardware is divided into four units; power, control, module and indicator, pump control unit

3.1. Power Unit

A 30-watt monocrystalline solar, PWM charge control. A 12V 7Ah led acid battery, 0.5Hp pumps. The battery's voltage sensor-MCU using a 10k and 1k resistor voltage divider network, Blynk app, WIFI and Arduino are some of the materials used. The 12V from the battery is fed into a power switch which turns ON or OFF the system after getting the appropriate firing signal. The 12V power rail is connected to a 220uF filtering capacitor to enable a smooth dc source, this serves as the input to the 7805 regulators. The regulator is a linear regulator which regulates the 12V DC to a 5V DC power rail by use of internally built-in switching components and Zener diodes. The regulator output is also connected to a filtering capacitor and then to the power pins of the 5V-rated components. To indicate when power is present in the circuit, an LED is connected to the switch, turning ON once the system is powered

3.2. Control Unit

The control unit comprises an ATMEGA328p microcontroller and an ESP01 break out dev board. An external crystal oscillator was used to generate a 16MHz clock signal which is fed into the MCU. Two 22pF capacitors are coupled to the oscillator's clock in and clock out terminals to enable stable clock pulses to the MCU. A 10k pull-up resistor connected to the reset pin of the MCU and the 5V power rail was used to prevent the MCU from resetting as a result of static electricity in the surrounding. The control unit acts as the command center for the system, taking sensor readings as raw data, voltage values from the various voltage dividers, processing these data and making decisions from them while actively transmitting such data to the ESP01. The ATMEGA328p and ESP01 communicate using serial protocol, allowing a fast and efficient data link. The ATMEGA328p generates PWM signals used to control the pumping action of the Pumps and also the charging sequence and cut off of the solar charger. Data collected from the Ultrasonic sensor is processed and used to determine the flow rate of the actuator (pump). By reading the distance between the sensor and the surface of water at a predetermined interval, streams of data sets are collected all indicating the water height difference at different times. The reservoir is a fixed volume container and the height of the sensor is fixed, the only changing variable is the distance between the surface of the water and the sensor. With this in mind, code blocks are written and stored in the MCU to process incoming data sets and convert them to volume flow rate samples.

3.3. Module and Indicator Unit

This consists of the ultrasonic sensor, soil moisture sensor and amplifier. The ultrasonic sensor has four break-out pins: Trigger pin, Echo pin, Ground pin and power pin. Trigger pin send out pulses of sound into the environment at 40 kHz and at 10µs intervals. Echo pin picks up reflected pulses from the trigger pin whenever it bounces off an object, the echo pin sends out a voltage reading which would be processed into a distance value.

Ground pin: This pin is connected to the ground potential of the circuit.The voltage pin connected to the 5V rail of the circuit and serves as the power pin.

The Trigger and Echo pin of the sensor are both connected to digital pins of the MCU, the MCU generates the pulses that sent out signals converted to sound pulses by the transducer on the ultrasonic sensor and reads the incoming pulses from the ultrasonic sensor. This is a continuous process that enables the volume of water in the reservoir and flow rate from the pump to be calibrated, as shown in figure 2.

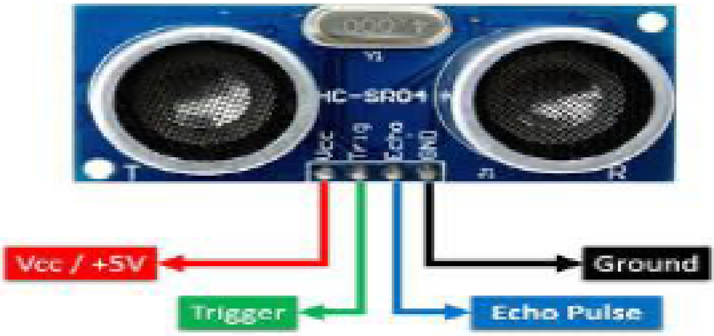

Figure 2. Ultrasonic Sensor

3.4. Selection of Soil Moisture Sensors

In this design, wires are used as the sensors for detecting water content levels in the soil. A wire is connected directly to the 5V power rail and fed into the sample soil; three wires are then fed into the soil but at different heights. These wires aren't energized but left floating. As water rises or falls in the soil, these wires conduct voltages based on the vertical position of water, once water touches the 5V energized wire and comes in contact with any of the sensor wires, they conduct, thus water completes the circuit. Water is not a good conductor making the voltages on the sensor wires to be low, thus an amplifier is required. The amplifier used in this design is an LM324 quad amplifier package set in a closed-loop amplifier configuration. The setup was designed to have an amplification factor of 1002. Three amplifiers are used corresponding to the three sensors used, a 1k and 100k resistor network was used to set the gain of the amplifier. The lm324 was powered by 5V, as the maximum measurable voltage of the MCU is 5V. The sensor wires are connected to the non-inverting input pins of the amplifiers. The wires are labeled H (high), L (low), and M (medium) based on the height they are placed in the soil sample.

3.5. CONTROL UNIT

3.5.1. Inverted Signals' Modulation Scheme

Inverted signals' modulation scheme is scheme that compares inverted staircase signal in(1) and triangular wave in (2) to produce special PWM for switching power MosFets expressed in (3)[9].

$$V_s = -\left[V_m \cos\left(\frac{J\omega t}{4N} - \frac{\pi}{2}\right)\right] \quad (1)$$

$$V_t = -\begin{bmatrix} 0 & {}^{1}/_{2f_{sw}} & {}^{1}/_{f_{sw}} \\ 0 & A_t & 0 \end{bmatrix} \quad (2)$$

V_m, J, ω , f_{sw}, and N signifies the maximum voltage, odd numbers, angular velocity, and total number of steps per

Cycle

$$V_a = \begin{cases} 1, & for\ V_s > V_t \\ 0, & for\ V_s < V_t \end{cases} \tag{3}$$

3.5.2. PUMP CONTROL UNIT

The pump used in the design is rated at 12V 500mA, DC power. It can be driven once it is powered by the source by the action turning OFF or ON by a simple switch. To enable control of flow rate, the pumps are coupled to IRFZ44N MOSFETs. The MOSFETs are turned ON and OFF with PWM signals from the MCU'S PWM-enabled pins derived from the modulation scheme used as in (3). Varying Duty cycles are fed to the code snippet that generates this signal, the duty cycles are determined by the desired flow rate. This control method enables higher precision and reduced overall power consumed by the pumps. The gates of the MOSFET's gates are pulled down to the ground to prevent their biasing by static electricity and a 1k resistor is connected from the MOSFET gate to the MCU pin to prevent excess sourcing of current by the MOSFET. The pumps are inductive loads therefore flyback diodes were connected across their terminals to prevent back EMF voltage spikes from flowing into the circuit whenever the pump switches. The proposed circuit diagram is shown in figure 3, while the MATLAB/Simulink model is shown in figure 4.

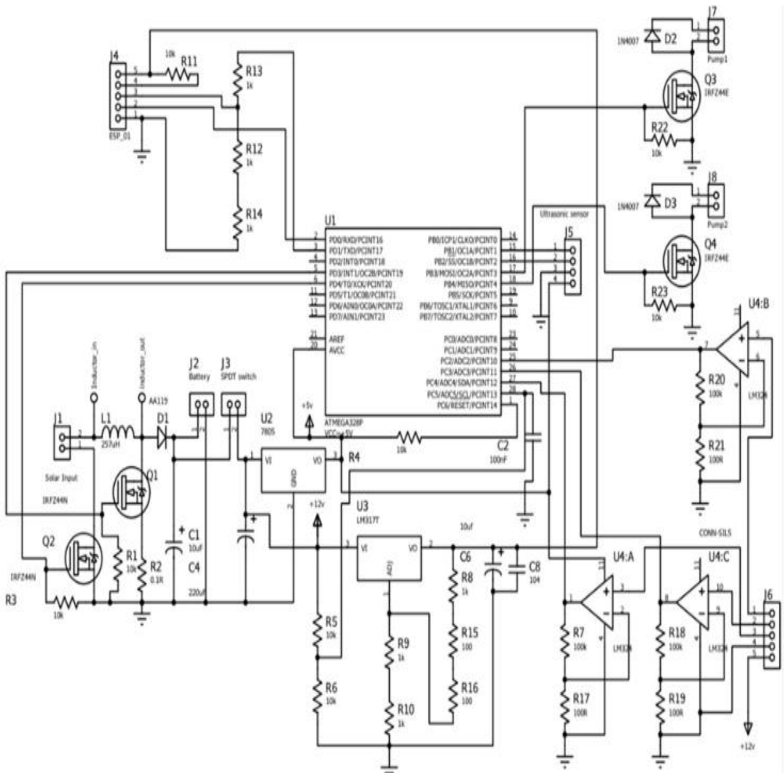

Figure 3. Circuit topology of the proposed system in Proteus Software

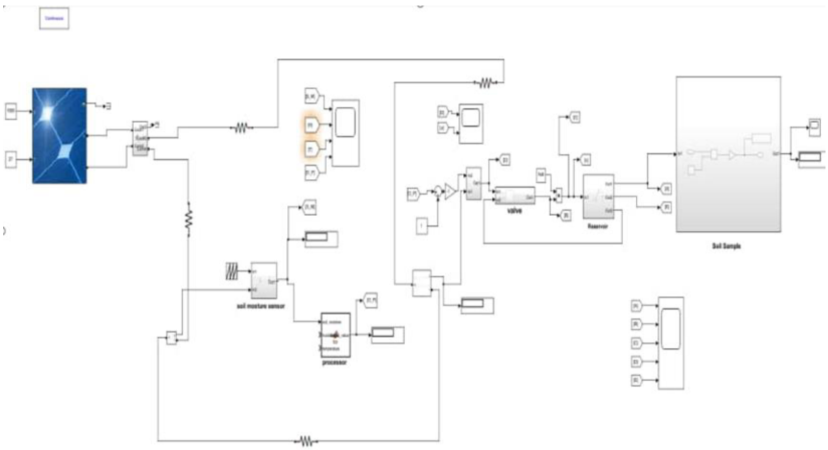

Figure 4. MATLAB/Simulink Model of proposed system

Figure 5 displays the flowchart operation of moisture detention in relative to pumping action of the inductive based pump. When the irrigation system is activated, the soil moisture sensor communicates with the Arduino, providing information about the soil's moisture level. If the soil moisture is high, the Arduino receives this data from the sensor and refrains from watering the soil. Conversely, if the soil moisture is low, the Arduino initiates the water-pumping process. This data is then transmitted over Wi-Fi to the Esp-01 and stored in the Blynk application, which can be accessed through a mobile phone or laptop.

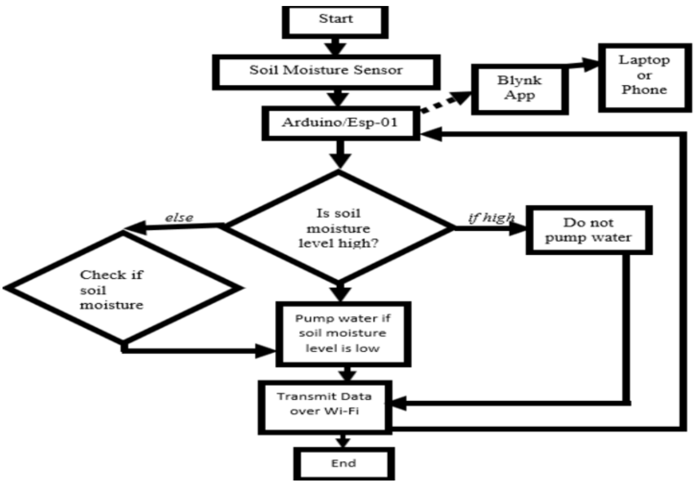

Figure 5. Flowchart of moisture sensing profile

4. Discussion of Results

The figure 6(a) displayed the soil sensor signal moisture profile while the figure 6(b) portrayed the corresponding pumping switching profile obtained from MATLAB/Simulink software. It is observed that at time interval of $0 \leq t \leq 0.012$sec, the voltage levels ranging from 0V to 40V is noticed. Then, the pumping switch was closed to allow the system to irrigate the farm area. At 41V to 100V and time interval of 0.0121 ≤ t ≤0.022sec, the pumping switch remained opened, this ensured reservation and regulation of the water from its supply. The same sequence is repeated through the operation.

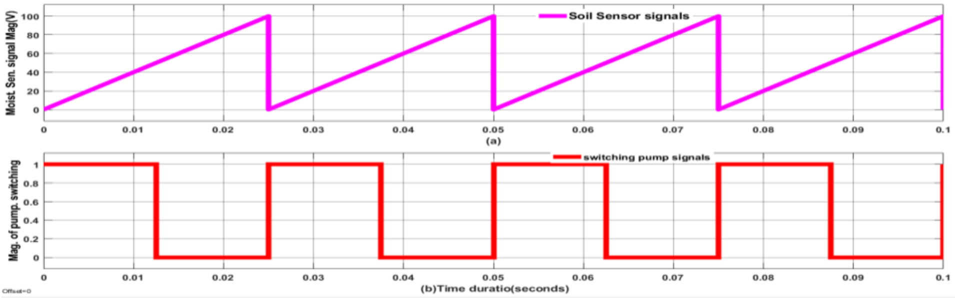

Figure 6. (a) sensor signal moisture. (b). Pump switch profile

When the soil's moisture is low, the microcontroller activates the pumping mechanism of the system and soil moisture rises gradually until desired level of soil moisture is achieved. If the reservoir's water level is low, it is shown by a uniform trajectory until the reservoir is refilled and pumping continues as shown in figure 7.

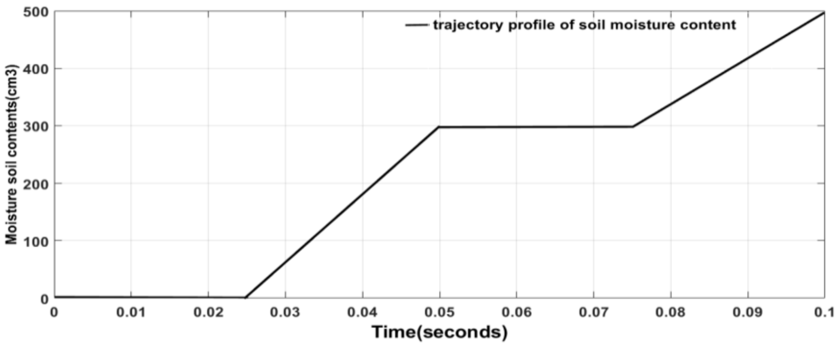

Figure 7. This represents the moisture content in the soil sample.

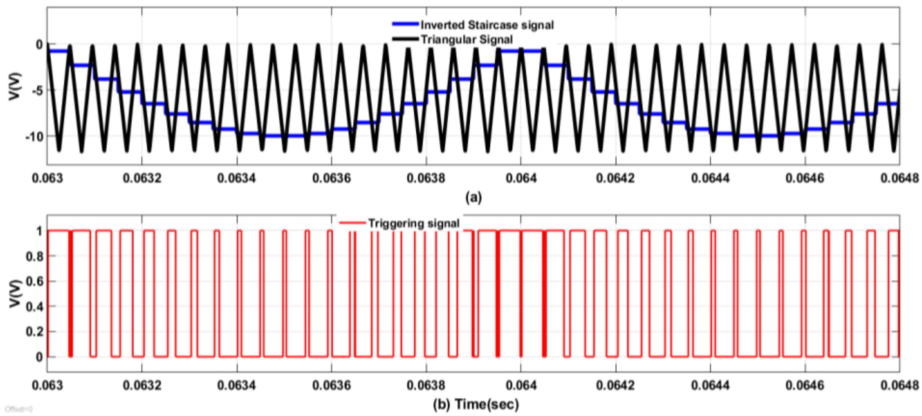

Figure 8. (a) Comparison of negative triangular wave and negative staircase signal (b) Switching pulse

Figure 8(a) represented comparison of (1) and (2) while figure 8 (b) displayed the signal of (3). It is observed that the negative staircase signal has an amplitude of 10.0V while the negative triangular wave has 12.0V. Figure 8(b) has varied sizes of the switching pulses for removing the ripples in the proposed system.

Figure 9 shows the proposed Laboratory experimental system. Laboratory implemented work shows the adaptable box containing the power DC-DC converter coupled-control units, solar panel of 150W, soil sample model and water reservoir.

Figure 10 showed graphical representations of the flow rate, battery voltage, reservoir water volume, and soil sample water level in wirelessly interfaced Blynk software in Mobile phone. Between time interval of 4:21 to 4.22pm.

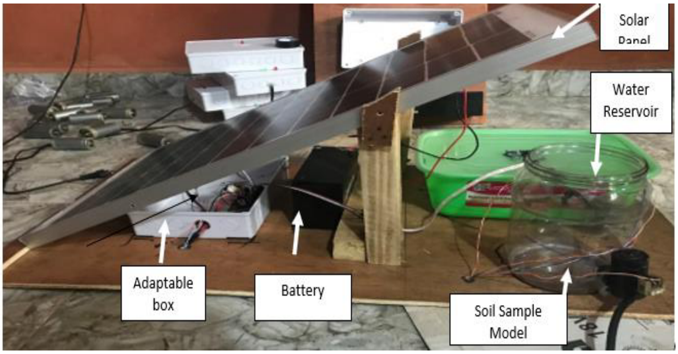

Figure 9. Prototype of Implemented of the test System

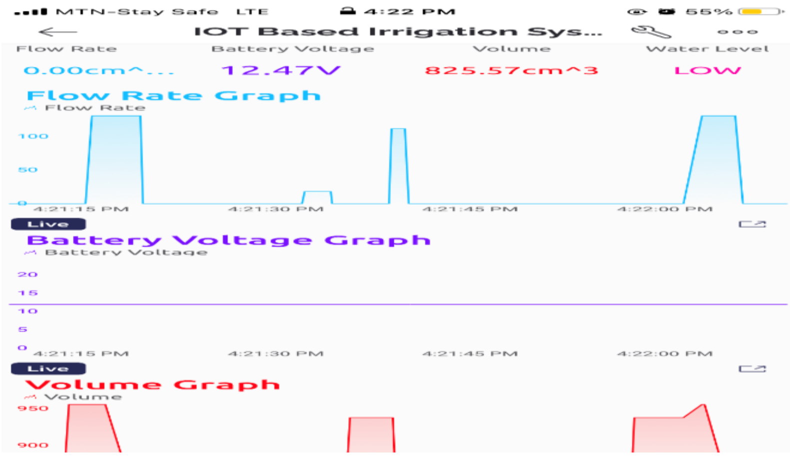

Figure 10. The Blynk mobile application (IOT) display

5. Conclusion

The research has successfully met its objectives, which involved integrating solar energy with a DC-DC step-up converter, creating an irrigation system with a DC water pump, soil moisture sensor, and ultrasonic sensor. It also developed an IoT-enabled smart irrigation system using the Blynk Mobile Application for monitoring various parameters and implemented cloud storage for data. It aimed to efficiently manage water resources, enhance agricultural output, promote renewable energy adoption, and contribute to technological progress. To improve the project, additional sensors like soil pH sensors can be incorporated to enhance the irrigation system.

References

[1] Wikipedia. Irrigation[Online]. Available: https://en.wikipedia.org/wiki/Irrigation
[2] Wikipedia. Renewable Energy" [Online]. Available: https://en.wikipedia.org/wiki/Renewable_energy
[3] Wikipedia. Solar Energy[Online]. Available: https://en.wikipedia.org/wiki/Solar_energy
[4] R. M. Ramli, W. A. Jabbers. Design and implementation of solar-powered with IoT-Enabled portable irrigation system[J]. Internet of Things and Cyber-Physical Systems, vol. 2, pp. 212-225, Dec. 2022. [Online]. Available doi: https://doi.org/10.1016/j.iotcps.2022.12.002
[5] R. M. Ramli, W. A. Jabbar. Design and implementation of PV with IoT-Enabled irrigation system[J]. Internet of Things and Cyber-Physical Systems, 2022, vol. 2, pp. 212-225.
[6] P. Lahande, Dr. B. Mathpathi. IoT Based Smart Irrigation System[J]. International Journal of Trend in Scientific Research and Development, 2018, vol. 2, issue 5, pp. 359-362.
[7] S. Nagaraja, et al. IoT Based Irrigation System Powered by Solar Energy[J]. SASTech Journal, 2020, vol. 19, pp. 13-17.
[8] L. A. Vishal, et al. Smart Irrigation System[J]. International Journal of Scientific Research in Science and Technology (IJSRST), 2016, vol. 2, issue 5, pp. 343-345.
[9] C.U Eya et al. Assessment of THD in DC-AC Boost Power Converter Using Zero-Free Staircase and Rectified[J]. AC Signals Based-Triangular Wave Modulation Schemes, (ICT4DA), 2022.