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Solar Energy Based Smart Irrigation System using IoT

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Abstract

This paper proposes a solar-based smart irrigation system that utilizes Internet of Things (IoT) technology to automate irrigation in agriculture. Traditional irrigation systems can lead to over-watering or under-watering of crops, which can result in reduced crop yield and wastage of water resources. Additionally, they often require significant energy costs to operate and can waste significant amounts of water through evaporation, runoff, and inefficient distribution. These systems also offer limited monitoring and control capabilities, requiring farmers to physically inspect their fields to ensure that the irrigation system is functioning correctly. However, a solar energy smart irrigation system using IoT can overcome these issues by continuously monitoring soil moisture levels, optimizing water usage, and offering remote monitoring and control capabilities. This makes it an ideal solution for farmers looking to maximize their crop production while minimizing their environmental impact. The system includes soil moisture sensors, an Arduino, a solar panel, a water pump, a wireless communication module (Node MCU) and a grid as an alternative source of an energy when there is no sufficient energy from the solar energy. The sensors collect soil moisture, Potassium, sodium and phosphorus data and transmit it to the cloud, which then activates the water pump if the moisture level is below a predetermined threshold. The solar panel provides the necessary power for the system, making it energy-efficient and environmentally friendly. The system also allows for remote monitoring and control of irrigation through a mobile application or a web-based interface. The proposed system offers a cost-effective, sustainable, and efficient solution to irrigation in agriculture, with the potential to increase crop yields while conserving water resources using IoT technologies to automate and optimize irrigation practices in agriculture. The system utilizes soil moisture sensors, Potassium, sodium and phosphorus sensors, and

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amount of water needed for crops. The system is designed to be energy-efficient, cost-effective, and easy to use. It can be remotely controlled and monitored via a mobile application, allowing farmers to have real-time access to their irrigation systems. This system has the potential to improve crop yields, conserve water resources, and reduce labor costs associated with manual irrigation practices.

Keywords: Sunlight, Solar, Arduino, Battery, Grid, Solid State Relay (SSR), etc

1. INTRODUCTION

A. Description of the Proposed

The agriculture industry is vital for feeding the world's growing population, but it is also one of the largest consumers of water resources [1]. Inefficient irrigation practices can lead to water waste and reduce crop yields [2]. To address this issue, the development of smart irrigation systems has gained popularity in recent years [1][3]. These systems utilize modern technologies such as the Internet of Things (IoT) and renewable energy sources like solar power to improve the efficiency and effectiveness of irrigation practices [4][6]. The agriculture industry is one of the largest consumers of water resources. Inefficient irrigation practices can lead to water waste and reduce crop yields [5]. To address this issue, the development of smart irrigation systems has gained popularity in recent years [3]. These systems utilize modern technologies such as the Internet of Things (IoT) and renewable energy sources like solar power to improve the efficiency and effectiveness of irrigation practices [5].

This research focuses on a solar-based smart irrigation system that uses IoT technologies to automate and optimize irrigation practices [1]. The system is designed to be cost-effective, energy-efficient, and easy to use for farmers [3]. It consists of soil moisture sensors, temperature and humidity sensors, and weather forecasting data, which are used to determine the optimal time and amount of water needed for crops [3].

The system can be remotely controlled and monitored via a mobile application, allowing farmers to have real-time access to their irrigation systems [2]. With the help of IoT technologies, the system can adjust irrigation schedules based on changing weather patterns and soil conditions, reducing water waste and increasing crop yields. Additionally, the use of solar power ensures that the system is environmentally friendly and can operate in remote areas without access to grid electricity [2]

The solar-based smart irrigation system using IoT technologies has the potential to revolutionize the agriculture industry by improving water efficiency and reducing labor costs associated with manual irrigation practices [4][3].

B. Objective of the Proposed

The objective of a solar-based smart irrigation system using IoT is to provide a sustainable and efficient solution for irrigation in agriculture [4]. The system aims to achieve the following objectives:

1. Optimizes Water Usage: The system aims to optimize water usage by providing farmers with real-time information about soil moisture levels and weather conditions [5]. This information is used to determine the optimal amount of water required for crops, reducing water wastage and conserving water resources [5][6].

2. Improves Crop Yield: By providing crops with the optimal amount of water, the system aims to improve crop yields and quality [6]. This helps to increase the profitability of the farming operation and promote sustainable agricultural practices [6].

3. Uses Renewable Energy Sources: The system uses solar power as a renewable energy source, reducing dependence on non-renewable sources of energy and promoting sustainable energy practices [7][8].

4. Provide Real-time Monitoring and Control: The system provides farmers with real-time monitoring and control over their irrigation systems [6][7]. This enables farmers to make informed decisions about water usage, adjust irrigation schedules based on changing weather patterns, and optimize crop yields [5][6].

5. The objective of a solar-based smart irrigation system using IoT is to provide a sustainable and efficient solution for irrigation in agriculture, helping to improve crop yields, conserve water resources, and promote sustainable agricultural practices [6].

2. SYSTEM DESCRIPTION

A. Proposed System

A solar energy smart irrigation system using IoT can offer numerous benefits to farmers [4][5]. By continuously monitoring soil moisture levels, adjusting water flow rates, and optimizing water usage, it can help increase crop yield and reduce water wastage [5]. Additionally, by using renewable solar energy to power the system, it can significantly lower energy costs and reduce the environmental impact of farming operations [5][6]. Remote monitoring and control capabilities also provide farmers with real-time data on their crops and irrigation system, allowing them to make more informed decisions and adjust their operations as needed [4][5]. Overall, a solar energy smart irrigation system using IoT can help farmers improve their efficiency, reduce costs, and increase their overall crop yield [6].

B. Proposed Block Diagram

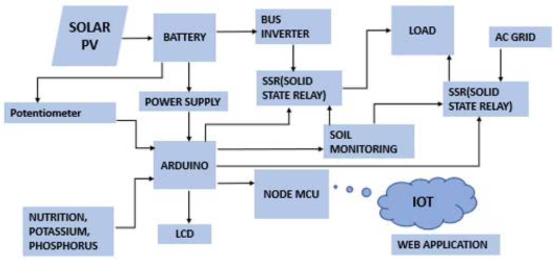

Figure 1. Block diagram of proposed system

Table 1. Component Specifications

PARAMETERS	RATINGS
Solar Panel	12V
Operating Battery	12V
Boost Inverter	12V – 230V
Solid State relay (SSR)	12V
Soil moisture sensor, Potassium sensor, Sodium sensor, Phosphorus sensor	3.3V to 5V
Wi-Fi module (such as ESP8266 or ESP32)	5V
Arduino Uno board	7 to 12 V
Own website https://soil-monitoring-kiot23.netlify.app/	Software

C. solar PV panel

Solar power is the process of directly converting sunlight, a renewable energy source, into electricity using photovoltaics (PV), indirectly converting sunlight into electricity using concentrated solar power, or combining both of these methods. Photovoltaic cells turn light into an electric current via the photovoltaic effect [8].

The solar panel in a solar energy smart irrigation system using IoT is responsible for collecting and converting the sun's energy into electricity [7][8]. The solar panel uses photovoltaic (PV) cells to convert sunlight into direct current (DC) electricity, which is then sent to the battery bank for storage [8]. The energy stored in the battery bank is then used to power the irrigation system, including the pump, microcontroller, and sensors [9]. The use of renewable solar energy to power the system is a significant advantage over traditional irrigation systems, which often rely on fossil fuels or grid electricity [8][9]. This not only reduces energy costs but also reduces the environmental impact of farming operations. Additionally, the solar panel can be sized and configured to meet the specific energy needs of the irrigation system, ensuring that it operates reliably and efficiently [8].

3. MAXIMUM POWER POINT TRACKING (MPPT)

A. Introduction

A Maximum Power Point Tracker (MPPT) is an electronic device that is used to optimize the power output of a photovoltaic (PV) system. It works by tracking the maximum power point (MPP) of the PV system [8], which is the point at which the system produces the maximum amount of power [8].

The MPP of a PV system depends on various factors, such as the solar irradiation level, temperature, and shading [9]. An MPPT uses a DC-to-DC converter to match the impedance of the PV system to the load, and it continuously adjusts the output voltage and current to maintain the MPP of the system [8][9].

The main benefit of using an MPPT is that it can increase the efficiency of a PV system up to 30% or more, compared to a system without an MPPT [8]. Because an MPPT ensures that the system operates at the MPP, which maximizes the power output of the system [9].

MPPTs are commonly used in various applications, such as solar-powered water pumps, solar-powered lighting systems, and grid-tied PV systems [9]. They are available in various sizes and configurations to suit different types of PV systems and loads [10].

B. Working of MPPT

Maximum Power Point Tracking (MPPT) is an electronic system used in solar energy smart irrigation systems to maximize the efficiency of the solar panel [9]. The MPPT controller continuously monitors the output of the solar panel and adjusts the load to ensure that the panel is always operating at its maximum power point, which is the point at which the panel produces the maximum power for a given set of conditions [9].

In a solar energy smart irrigation system using IoT, the MPPT controller works by adjusting the load on the solar panel to ensure that it is operating at its maximum power point [9][10]. This is achieved by continuously monitoring the output voltage and current of the solar panel and adjusting the load impedance to maximize power output [9]. The MPPT controller also accounts for changes in temperature, shading, and other environmental factors that can affect the performance of the solar panel. By maximizing the efficiency of the solar panel, the MPPT controller helps to ensure that the irrigation system operates reliably and efficiently, even in challenging environmental condition [9].

MPPT (Maximum Power Point Tracking) is an important component of a solar energy smart irrigation system using IoT. It is used to maximize the efficiency of the solar panel by ensuring that it operates at its maximum power point (MPP). The MPP is the point at which the solar panel output voltage and current are optimized for maximum power output [10][11].

The MPPT controller continually adjusts the voltage and current of the solar panel to ensure that it operates at its MPP, regardless of weather conditions or other external factors that may affect the panel's output. This results in higher energy efficiency and increased power output from the solar panel [9].

C. Implementation.

The following are the steps involved in implementing the MPPT controller

i. Select an MPPT controller: There are many MPPT controllers available in the market. Select an MPPT controller that is compatible with the solar panel and battery bank that is used in the irrigation system [9][10].

ii. Connect the MPPT controller: Connect the MPPT controller to the solar panel and battery bank [10]. The MPPT controller will regulate the voltage and current of the solar panel to ensure that it operates at its maximum power point and that the battery bank is charged efficiently [10].

iii. Configure the MPPT controller: Configure the MPPT controller according to the specifications of the solar panel and battery bank used in the irrigation system. This may include setting the charging voltage and current limits, adjusting the temperature compensation settings, and selecting the appropriate battery type [10][11].

iv. Test the system: Test the system to ensure that the MPPT controller is functioning correctly. This may involve monitoring the voltage and current of the solar panel and battery bank and verifying that the battery bank is being charged efficiently [11].

v. Monitor and optimize the system: Continuously monitor the system to ensure that it is operating efficiently [9]. Make adjustments to the MPPT controller settings as needed to optimize the system's performance and ensure that it is producing enough energy to power the irrigation system and charge the battery bank [9][10].

By implementing an MPPT controller in a solar energy smart irrigation system using IoT, farmers can ensure that their irrigation system operates efficiently and that they maximize the use of renewable solar energy, which can significantly reduce energy costs and the environmental impact of farming operations [10][1].

4. DC TO DC CONVERTER

A DC-to-DC converter is an important component in a solar energy smart irrigation system using IoT [10]. It is used to convert the DC voltage output of the solar panel to the required DC voltage level for the irrigation system's components, such as the pump, Arduino, and sensors [10].

In a solar energy smart irrigation system using IoT, the DC-to-DC converter is typically used to step down the voltage output of the solar panel to a lower voltage level that is suitable for the irrigation system's components [11]. This helps to optimize the system's efficiency by ensuring that the components receive the appropriate voltage level for their operation [10][11].

5. BATTERY OPERATION

A. Introduction

A battery is an essential component in a solar energy smart irrigation system using IoT. It provides energy storage for the system, enabling it to operate even when there is insufficient sunlight to power the system directly from the solar panel [9].

In a solar energy smart irrigation system using IoT, the battery is typically charged by the solar panel during the day when there is ample sunlight [10][11]. The battery stores the energy generated by the solar panel, which can then be used to power the irrigation system during periods of low sunlight or at night [12][13].

The battery is typically connected to a charge controller, which regulates the charging current and voltage to ensure that the battery is charged safely and efficiently [11]. The charge controller also helps to prevent overcharging or undercharging of the battery, which can damage the battery and reduce its lifespan [11][12].

The battery is connected to the irrigation system's components, such as the pump, microcontroller, and sensors, providing a reliable source of power even when there is insufficient sunlight to power the system directly from the solar panel [12].

Here, we can utilize a 12-volt storage battery to store energy from the solar panels and an alternative source from the grid, as well as a transformer to lower the voltage. In this case, the solar panel can only produce 12V when the sun is at its strongest. which is sufficient to start charging the battery [15].

6. INVERTER

A. Introduction

An inverter is an electronic device that converts direct current (DC) to alternating current (AC) [6]. It is used in a variety of applications, including power backup systems, solar power systems, and motor drives [7][8]. Inverters are typically used to convert DC power from a battery or solar panel into AC power that can be used to power appliances, lights, and other devices [8][9].

Inverters work by using a process called pulse width modulation (PWM) to switch the DC input on and off at a high frequency, creating an AC waveform [7][8]. The output waveform can be modified to simulate various types of AC waveforms, such as sine waves, square waves, and triangular waves [7].

Inverters can vary in size and capacity, ranging from small, portable models that can power a laptop or cell phone, to larger models that can power an entire home or building. They can also vary in efficiency [7][8], with some models able to convert up to 98% of the DC input power into AC output power [8][14].

B. Boost Inverter

This 12V DC to 220V AC inverter circuit was created using a few components that are readily available. In locations where it is impossible to obtain an AC supply from the mains, inverters are frequently required [13]. The DC electricity is transformed into AC power using an inverter circuit. When using a low voltage DC supply or battery to generate high voltage, inverter circuits are quite beneficial. You can also utilize a DC-DC Converter circuit, although it has some voltage restrictions. [4][5]. Utilizing IC CD4047, the 12V DC to 220V AC inverter circuit was created. An oscillating switching pulse device is the IC CD4047. A switch is provided by the n-channel power MOSFET IRFZ44n [4]. Inversely, a Step-up transformer is utilized to convert low AC voltage using the 12-0-12V secondary transformer. Boost inverter is a type of inverter that is used to convert a low DC voltage of 12 volts to a higher AC voltage of 230 volts [12][1]. This type of inverter is commonly used in applications where a low voltage DC power source, such as a battery or a solar panel, needs to be converted to a higher voltage AC power source, such as for powering appliances or devices that require 230V AC power [6][3].

The term "boost" refers to the fact that this type of inverter uses a DC-DC boost converter circuit to step up the low DC voltage to a higher DC voltage [5], which is then converted to AC voltage by the inverter circuit. The boost converter uses high-frequency switching to increase the voltage, and then the inverter circuit produces a stable AC output [3][12].

A 12V to 230V boost inverter is commonly used in off-grid and mobile power systems, such as in RVs, boats, and other vehicles. It can also be used in emergency backup power systems, where a low voltage DC battery is used to power essential appliances during power outages [11][12].

When selecting a 12V to 230V boost inverter, it is important to consider the wattage and efficiency of the inverter, as well as any additional features such as surge protection or built-in cooling fans [11][10]. It is also important to ensure that the inverter is compatible with the devices or appliances that will be powered by the AC output [13][7].

7. SOLID STATE RELAY (SSR)

Switching between solar energy and grid energy using an SSR controlled by an Arduino is a common approach in solar power systems [9][10]. The Arduino can be used to monitor the power output from the solar panels and the energy demand from the load, and then trigger the SSR to switch between the two sources of power [11].

the basic steps involved in using an Arduino to control the switching of an SSR in a solar power system are as follows:

i. Connect the Arduino to the solar inverter and the SSR: The Arduino should be connected to the solar inverter using an analog input pin to measure the power output from the panels, and a digital output pin to trigger the SSR [9][10]. The SSR should be connected to the solar inverter and the grid power source [11][12].

ii. Monitor the solar power output: The Arduino should continuously monitor the power output from the solar panels using the analog input pin [12][11]. This can be done by measuring the voltage or current output from the panels and converting it to a power measurement using Ohm's law [13][14].

iii. Monitor the energy demand from the load: The Arduino should also monitor the energy demand from the load using sensors or other monitoring devices [7]. This can be done by measuring the voltage or current draw from the load and calculating the power demand [10].

iv. switching between solar and grid power: The Arduino should compare the solar power output to the energy demand from the load, and determine when it is necessary to switch between solar and grid power [9][8]. This can be done using a simple algorithm that compares the two values and triggers the SSR when necessary [9].

Trigger the SSR to switch power sources: When the Arduino determines that it is necessary to switch between solar and grid power [9], it can trigger the SSR using the digital output pin [8]. This will disconnect the solar inverter from the load and connect the grid power source to the load [7].

By using an Arduino to control the switching of an SSR in a solar power system [8][7], it is possible to create an efficient and reliable source of energy for the home or building, while maximizing the use of solar energy and reducing reliance on grid power [10][13].

8. ARDUINO

A. Introduction

To collect information from soil monitoring sensors that measure levels of potassium, sodium, and phosphorus, you can use an Arduino board (ESP8266) along with the appropriate sensors and a data logging shield or module [11].

i. Choose the appropriate sensors: There are several types of sensors that can be used to measure soil nutrients, such as potassium, sodium, and phosphorus [12]. You can choose the sensors that meet your specific needs and requirements [13]. Some examples of sensors that can be used are the Gravity Analog Soil Moisture Sensor, the Gravity Analog Capacitive Soil Moisture Sensor, and the Gravity Analog pH Sensor [12][13].

ii. Connect the sensors to the Arduino board (ESP8266): You will have to connect the sensors to the appropriate pins on the Arduino board (ESP8266) [11]. You can refer to the datasheet or instructions of the sensors to know which pins to use [11].

iii. Code the Arduino board (ESP8266): You will have to write a code that allows the Arduino board to read the data from the sensors and store it in a format that can be analyzed later [13]. You can use the Arduino Integrated Development Environment (IDE) to write the code [12].

iv. Set up data logging: You can use a data logging shield or module to store the data collected by the Arduino board [11]. The data can be stored on an SD card or sent wirelessly to a computer or server for analysis [1].

Analyze the data: You can analyze the data collected by the Arduino board [13].

B. General Process of connecting Arduino to IoT

Here is the step-by-step process to build the system that sends data from an Arduino to ThingSpeak and controls a motor with a Cayenne app:

- Connect the Wi-Fi module to the Arduino board and configure it to connect to your Wi-Fi network [14].

- Connect the Wi-Fi module to the Arduino board following its respective wiring diagram [13].

- Configure the Wi-Fi module to connect to your Wi-Fi network. You will need to provide the Wi-Fi network name (SSID) and password in the Arduino code [14].

- Create a new project on ThingSpeak and create channels for the data you want to send [14].

- Sign in to ThingSpeak or create a new account if you don't have one [13].

- Create a new channel for the data you want to send. For example, you could create a channel for soil moisture, temperature, humidity, or any other data that you want to monitor [13].

- Define the fields that you will use to store the data. Each field can store a different type of data, such as a number or a string. Give each field a name that describes the data it represents [12].

- Note down the channel ID and API key that you will use later to send data from the Arduino to ThingSpeak [13].

- Install the Cayenne app on your smartphone and create an account [12]. Install the Cayenne app on your smartphone from the app store. Create an account or sign in if you already have one. Create a new project on Cayenne and add a button widget to control the motor [13][12][14]. Create a new project on Cayenne by clicking on "Add new" and selecting "Arduino" [14].

- Choose your Arduino board from the list of supported devices. Add a button widget to the dashboard by clicking on "Add new" and selecting "Button" [13][14].Configure the button widget to control the motor by selecting the pin that is connected to the relay module [12].
- Write the Arduino code to send data to ThingSpeak using the Wi-Fi module and control the motor using the Cayenne app [13][12].
- Open the Arduino IDE and create a new sketch.
- Include the required libraries for the Wi-Fi module, ThingSpeak, and Cayenne. Connect the Wi-Fi module to your Wi-Fi network by providing the network name (SSID) and password. Connect to ThingSpeak by providing the channel ID and API key that you noted down earlier [10].
- Read the sensor data that you want to send to ThingSpeak and send it using the ThingSpeak library [12].
- Control the motor using the Cayenne app by reading the button widget state and setting the pin connected to the relay module accordingly [12].
- Upload the sketch to the Arduino board and make sure it is working properly [11].
- Your Arduino system should now be sending data to ThingSpeak and controlling the motor with the Cayenne app [12].

9. OUTPUT AND RESULT

The proposed model is implemented using HTML version 5 and CSS version 3 and the output results of a solar energy smart irrigation system are observed. The outcomes can vary depending on the specific design and implementation of the system [1][12]. However, some possible outputs and results are:

i. Efficient use of water: A solar energy smart irrigation system can optimize water usage by delivering the right amount of water to plants based on their specific needs. This can result in up to 50% water savings compared to traditional irrigation systems [6][7][9].

ii. Cost savings: By using solar energy to power the irrigation system, the cost of electricity can be eliminated, resulting in significant cost savings over time [9][4].

iii. Increased crop yield: By providing the right amount of water to plants, a solar energy smart irrigation system can increase crop yield by up to 20% [2][4].

iv. Remote monitoring and control: With remote monitoring and control capabilities, farmers can access real-time data on the status of their crops and irrigation system. This can help them make informed decisions and respond quickly to any issues [8]. The fig.2 depicts the hardware connections of the system and the figures 3 – 9 are the dashboard outcomes observed.

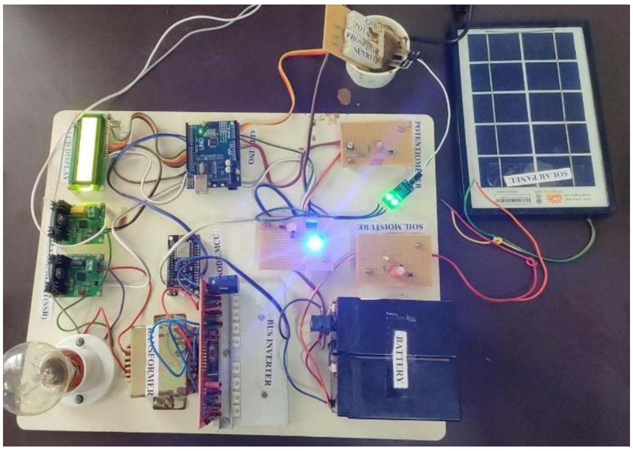

Figure 2. Hardware Prototype

The Results below are the output observed from the dashboard developed using HTML version 5 and CSS version 3

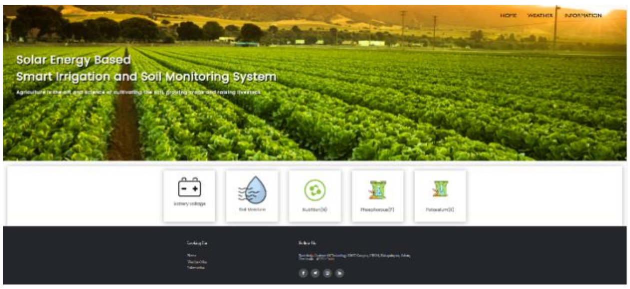

Figure 3. Dashboard

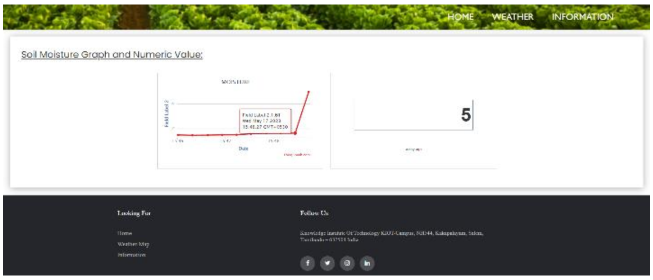

Figure 4. Battery Monitoring

Figure 5. Soil Moisture Monitoring

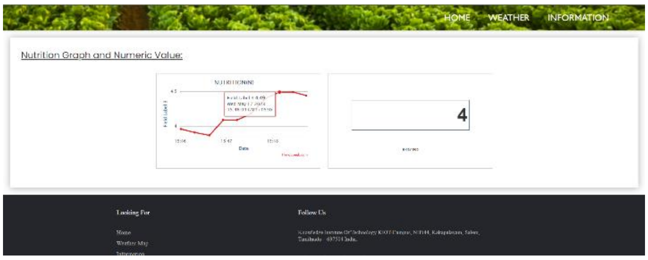

Figure 6. Soil Nutrition Level Monitoring

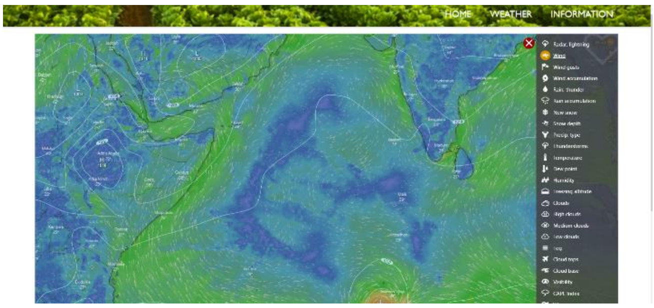

Figure 7. Weather Map

10. CONCLUSION

In conclusion, a solar energy smart irrigation system is an efficient and cost-effective way of irrigating crops. By using renewable solar energy to power the irrigation system, farmers can save money on electricity costs while reducing their carbon footprint. The system is designed to optimize water usage by delivering the right amount of water to plants based on their specific needs, resulting in significant water savings. Additionally, the system can increase crop yield by up to 20% by providing the ideal growing conditions for crops. With remote monitoring and control capabilities, farmers can access real-time data on the status of their crops and irrigation system, helping them make informed decisions and respond quickly to any issues. Overall, a solar energy smart irrigation system is an environmentally friendly, cost-effective, and efficient solution for farmers to irrigate their crops and maximize their yield.

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