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Solar Monitoring System Reliability: Challenges and Prospects for Modern Engineering

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Abstract

Solar energy becomes more accepted as a viable source of renewable energy in the society. However, quantitative information on a system's post install real performance becomes a major concern. There are many factors that can impact a system's real world performance such as a bad cabling (high resistance/impedance caused by loose connectors or improper wiring), defective inverters, inconsistencies on solar panel output, environmental factors like weather, accidental damage, as well as general manufacturing defects. The solar monitoring system composed of power meters, data loggers, string current sensors, inverter interface system, data logger, and weather stations is one of the most overlooked components of a Residential and Commercial sized site. The data logger-gateway is the central device for collecting data and transforming it into useful information and alerts. Reliability issues to your data-logger gateway system can and will impact your ability to identify issues with your system, troubleshoot them, and resolve them in a cost effective manner. This process and networking come with its challenges, especially where there is computer system networking. This study examines some of the challenges of solar monitoring system reliability with a view of develop an effective framework in modern engineering and sustainability.

Keywords: *Solar monitoring, System reliability, Engineering, Computer system networking*

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Background to the Study

Solar power is the key to a clean energy future. Every day, the sun gives off far more energy than we need to power everything on earth. (Solar power - unlimited source of energy, 2019), Solar power is the conversion of energy from sunlight into electricity, either directly using photovoltaics (PV), indirectly using concentrated solar power, or a combination. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect(wikipedia, 2019).

As Solar systems are getting incorporated into our society, Solar power plants need to be monitored for optimum power output. This helps retrieve efficient power output from power plants while monitoring for faulty solar panels, connections, dust accumulated on panels lowering output and other such issues affecting solar performance. (IOT Solar Power Monitoring System, 2019), the monitoring of real time data generated from the solar plants becomes necessary so as to enhance the overall performance of the solar power system and sustain its stability.

The traditional monitoring systems mainly include manual investigation and remote wired monitoring. And there exists some drawbacks such as time-consuming and wiring complexity, which is difficult when monitoring in the large-scale PV array. Therefore, monitoring remotely is essential for every solar power system and harnessing the power of IoT for monitoring solar power system by using digital technologies and more advanced computational facilities is promising. The IoT reduces the effort of human by introducing machine to machine interaction, which is applied to effectively facilitate the integration of the remote monitoring of solar system. The scope of the project is to design a system that remotely monitors the performance of solar panels via internet. It is restricted only to monitoring of power and temperature output and transmits the data over the internet.

The Research Problem

Solar power plants need to be monitored for optimum power output. And naturally, there are variations in power generation from solar power plant due to changes in temperature, solar irradiance, and others factors lowering the power output like faulty solar panels, connections, and dust accumulated on panels and other such issues affecting solar performance. The study proposes an IoT based solar power monitoring system that allows for automated solar power monitoring from anywhere over the internet. The system recognizes dust and failures of panels due to different problem.

Objective the Study

The aim of the project is to design an IoT based solar power monitoring system that allows for automated solar power monitoring and control.

Literature

Monitoring of Solar Energy using IOT

In a study conducted by Padma, Ilavarasi, Amith and Anusan (2017) to to monitor and control the voltage output of a solar panel kept at distant location and observing the output in the server using Internet of Things (IOT), they noted that each server page consists of a unique IP address that allows the user to access the output page. Further controlling of solar panel outputs are enabled using relay boards and circuits. With the aid of this system, monitoring and controlling process is made easy and efficient. The basic concept behind the proposed model is monitoring and controlling the voltage output of solar panel at distant location using Internet of things (IOT). Power generated by solar panel is monitored in real-time and updated in server. Server updating helps real time tracking and monitoring of solar power generated in solar farms by using advanced processor PIC16F 1947 which is a 16-bit microcontroller. Also, GSM serves as an important part as it is responsible for controlling the load on the field and sends information to the receiver through coded signals. An integrated wired/wireless solution allows rapid growth of technologies by improving performances and productivity. The entire ranch can be controlled by IOT system, and it can be implemented based on the requirement of application.

Advantages

1. Solar panel voltage is measured, controlled and monitored using voltage sensor.
2. Load connected to the solar are controlled automatically using GSM.
3. Real-time tracking using IP based server connection.

Disadvantages

1. Distance covered by the system is limited by the IP based server connection.
2. Other solar parameters are not included such solar temperature and current.
3. Inadequate solar parameters for visual analysis.

Solution

1. Internet is used instead of IP server connection. This has no distance limit if connection is established between the client and the server, information and data can be transmitted all around the world.
2. Visual and graphical representation of collected data is possible due to more parameters gotten from the solar panel in a real time.

Also Manish, Suyash, Arvind, and Rawandale (2018) conducted a similar study. The aim of their work is to remotely monitor a solar plant for performance evaluation using IoT. In their design they propose an automated IOT based solar power monitoring system that allows for automated solar power monitoring from anywhere over the internet. They use ATmega controller based system to monitor solar panel parameters. Their system constantly monitors the solar panel and transmits the power output to IOT system over the internet. IOT ThingSpeak is used to transmit solar power parameters over the internet to IOT ThingSpeak server. It now displays these parameters to the user using an effective GUI and also alerts user when the output falls below specific limits. This makes remotely monitoring of solar plants very easy and ensures best power output.

Internet of Things (IoT) platform integrates data from the different solar panels and applies analytics to share the most valuable information with applications built to address specific needs.

These powerful IoT platforms such as ThingSpeak, Microsoft Azure and Google cloud platform etc can pinpoint exactly what information is useful and what can safely be ignored. This information can be used to detect faults, make recommendations, and detect possible problems before they occur. The information picked up by connected sensors enables to make smart decisions based on real-time information, which helps save time and money.

Advantages

1. Real-Time base system.
2. Solar information and data are transmitted using wireless.
3. ThingSpeak is used as the platform for data analysis in both pattern and graphical representation of the data.
4. All solar panel are monitored using sensors.

Disadvantage

1. Distance covered by the system is limited by the connection mode used for data transmission.

Solution

1. This is resolved in my project work, Esp8266 is used for communication for exchange of data via internet network.

Jayaharsha and Kishore (2017) added that the main aim of their research is to facilitate common small scale installations of solar panels with cost effective and reliable monitoring system, with access from anywhere in the world. So that it drives all people to use this monitoring system so that their maintenance expenses are reduced significantly. And also recognizes dust and failures of panels due to different problem. And this causes timely maintenance and enhances power output from plant. Finally saves money for plant installers and saves lot of energy losses due to dust and temperatures and soiling of panels. In their design Arduino microcontroller was used to read the solar panels parameter through some few sensors, with the help of esp8266 the sensor value can be monitored on ThingSpeak.

With this paper they made an attempt to solve the problem of monitoring of solar power plants that users are facing today. For this purpose, they used the tools of newer technologies. They applied the concepts of IoT and tried to monitor solar panel parameters and other parameters related to solar power plant operation and maintenance with the help of IoT and ThingSpeak open source IoT platform. The low cost monitoring device has lot of scope because monitoring and maintenance plays key role in solar power plants. Appropriate monitoring improves efficiency of plant and operating conditions. It has some disadvantages like loss of privacy and cyber security and also this project requires Internet connectivity as well. This may not be available at all conditions and server may breakdown sometimes. Open source platforms may not be good for large scale plants monitoring. However, it is very useful for small installations and remote location plants. A provision of advance remotely manages the Solar PV plants of various operations like remote shutdown, remote management is to be incorporate with this system later. For machine learning algorithms implementation reliable data is obtained. Real time data is readily available to study the load patterns and power generation patterns. Power system scheduling becomes easy and load predictions will be most accurate. This will also facilitate preventive maintenance, fault detection, historical analysis of the plant in addition to real time monitoring.

Advantages

1. Data are track in a real-time base.
2. No limitation to distance, data can be gotten anywhere in the world because internet is used as the communication mode.
3. New open source IoT tools (ThingSpeak) is used for data analysis.

Disadvantage

1. Though this system seems ok the only disadvantage of this project is lack of monitoring display system at the solar based station, all data and information are monitored via internet.

Solution

1. LCD display is used in my proposed project, which makes it easier to monitor the solar panel information at the base station without going through the stress of retrieving data via internet.

Finally in a paper developed by Jie Wan, Munassar, Al-awlaqi, MingSong, Michael1, Xiang Gu1, JinWang, (2018), they present a framework of the Wearable ICloud-based health monitoring system (WISE), which adopts a number of interconnected wearable sensors to observe the health condition of the subject. A set of biomedical signals can be obtained, including the blood pressure, the heartbeat, and the body temperature. Due to the limited memory and computing capacity of the sensor nodes, as well as to avoid the adoption of a smart phone as a processing unit, the sensor data collected from those wearable sensors will be transmitted to the cloud server directly via internet.

Design Methods

System Overview

In the design of the prototype system, different parameters of the solar panel like voltage, current, power and the temperature are monitored. This system is designed using Arduino Nano Controller. The voltage is monitored using a voltage divider principle; current is measured using ACS712 current Sensor and temperature by temperature sensor LM35. The designed prototype will integrate voltage and current sensors to measure both voltage and current output of the solar panel. The system incorporates with it a temperature sensor to be able to monitor the amount of radiation from the sun and the equivalent solar panel output. The system computes power output from the solar panel by multiplying the voltage and current measured and displays the results on ThingSpeak server. This is achieved using C programming language.

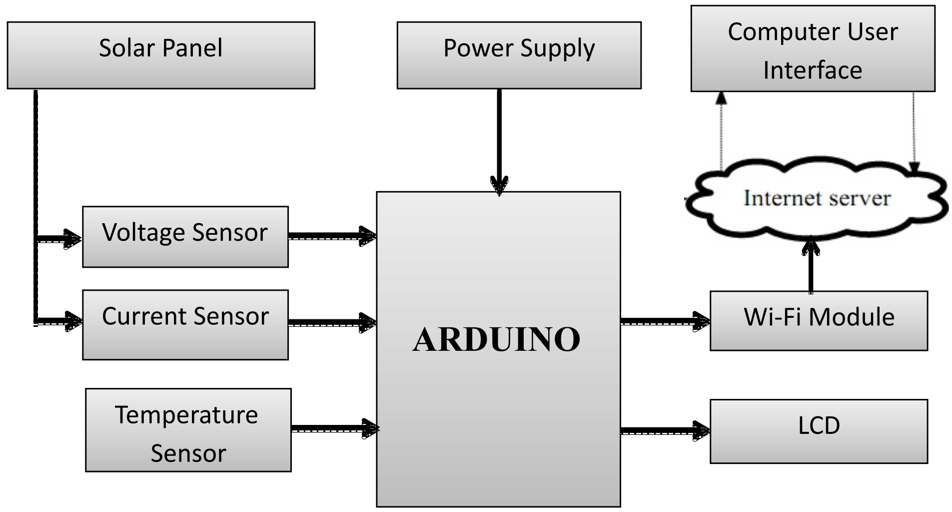

Figure 1: Block diagram representing the system architecture

System Components

In choosing the component for the prototype, several factors were considered when selecting hardware components. The first consideration was the selection of the component package to use for each part. Most of the electrical components in the design were selected in a surface mount package. This reduced the foot print required for each component and the overall space required on the veroboard. The power and voltage rating for each of the components was considered to make sure that none of the components would become overstressed during use. Finally, cost and availability were considered; several of the components are as follows:

Arduino Uno

Arduino is an open-source computer hardware and software company, project and user community that designs and manufactures kits for building digital devices and interactive objects that can sense and control the physical world. Arduino boards may be purchased preassembled, or as do-it-yourself kits, the Arduino project provides an integrated development environment (IDE) based on a programming language named Processing, which also supports the languages C and C++. The Arduino Nano is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. The main purpose of using Arduino Nano is because of its high functionality with simplicity and familiarity. Arduino Nano bridges the gap between solar panel and IoT (Internet of Things). It is powered with 5 volts dc supply for its operation.

Voltage Divider Circuit

A voltage divider (also known as a potential divider) is a passive linear circuit that produces an output voltage (Vout) that is a fraction of its input voltage (Vin). Voltage division is the result of distributing the input voltage among the components of the divider. A simple example of a voltage divider is two resistors connected in series, with the input voltage applied across the resistor pair and the output voltage emerging from the connection between them. By using appropriate resistors we can get Vout as fraction of Vin and connecting across the panel terminal we can sense the voltage of panel or power plant.

ACS712 Current Sensor

A current sensor is a device that detects electric current (AC or DC) in a wire, and generates a signal proportional to it. The generated signal could be analog voltage or current or even digital output. It can be then utilized to display the measured current in an ammeter or can be stored for further analysis in a data acquisition system or can be utilized for control purpose. Direct current input, unipolar, with a unipolar output, which duplicates the wave shape of the sensed current digital output, which switches when the sensed current exceeds a certain threshold ACS712 current sensor operates from 5V and outputs analog voltage proportional to current measured on the sensing terminals. You can simple use a microcontroller ADC to read the values. It provides up to 3000 VRMS galvanic isolation. The low-profile, small form factor packages are ideal for reducing PCB area over sense resistor op-amp or bulky current transformer configurations. The low resistance internal conductor allows for sensing up to 20 A continuous current providing typical output error of 1%.

LM35 Temperature Sensor

LM35 is a precision IC temperature sensor with its output proportional to the temperature (in oC). The sensor circuitry is sealed and therefore it is not subjected to oxidation and other processes. With LM35, temperature can be measured more accurately than with a Thermistor. It also possess low self-heating and does not cause more than 0.1oC temperature rise in still air. The operating temperature range is from -55°C to 150°C. The output voltage varies by 10mV in response to every oC rise/fall in ambient temperature, i.e., its scale factor is 0.01V/ oC. It is connected to the Arduino board.

ESP8266 WIFI MODULE

The ESP8266 is a low-cost Wi-Fi chip with full TCP/IP stack and MCU (Micro Controller Unit) capability produced by Shanghai-based Chinese manufacturer, Espressif Systems. The chip first came to the attention of western makers in August 2014 with the ESP-01 module, made by a third-party manufacturer, AI-Thinker. This small module allows microcontrollers to connect to a Wi-Fi network and make simple TCP/IP connections using Hayes-style commands. However, at the time there was almost no English-language documentation on the chip and the commands it accepted. The very low price and the fact that there were very few external components on the module which suggests that it could eventually be very inexpensive in volume, attracted many hackers to explore the module, chip, and the software on it, as well as to translate the Chinese documentation.

LCD (Liquid Crystal Display)

It is an electronic display module and find a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on. In our model it is also used to directly display parameters at plant control panel.

Implementation processes

This involves the following basic steps:

i. Hardware design.

ii. Software development for the voltage, current and temperature monitoring and power calculation: The system software is to be implemented in C Language.

iii. Create a ThingSpeak application, an open source IOT platform use as the repository centralized server.

The design consists of a sensor node and a central server. The sensor node in the network is connected to the voltage, current and temperature sensors and reads their outputs and passes them to the arduino. The arduino is programmed to calculate the power from the voltage and current readings and the data is wirelessly reported to the server for processing. The server displays the readings from the node through a user visual interface in real time. This system can help the stakeholders to know the amount of power delivered by the solar panel at every interval.

Hardware Design

This stage involves the design of the various hardware components require to produce the system.

The Design of the Power Supply Unit

This is the circuit that will supply power to the full system. The system requires 5 volts dc and this voltage level will be obtained from the 12V/7AH battery which will be charged via the solar panel. This will ensure continuous power supply to the system.

The circuit diagram is as shown below:

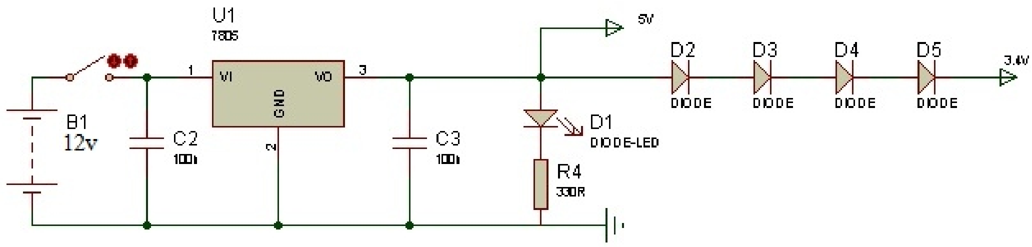

Figure 2: Circuit Diagram of the Power Supply Unit

U1 (7805): This is the voltage regulator.

Regulator specifications:

i. Maximum input voltage = 30V

ii. Maximum output voltage = 5.5V

iii. Operating temperature = 0%- 150%

For effective Voltage regulation, the minimum input voltage should be:

$$V_{min} = V_{out} + V_{ref} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

V_{min} = Minimum input voltage
V_{out} = required output voltage: 5V
V_{ref} = Datasheet Stipulated reference voltage; 3V
$V_{min} = 5 + 3$
$V_{min} = 8V$

The output voltage after the capacitor is 13.70 Volts. This is enough to supply the minimum input voltage (8 volts). Therefore, the voltage regulator could be comfortably used.

C_3 are transient capacitor. The rating is stipulated in the 7805 voltage regulator's datasheet as 0.1uF. Hence, C_3= 0.1uF. This capacitor helps for smoothening of the output from the voltage regulator. It is also to prevent spikes in the DC output voltage waveform in the event of transient disturbances. It is known as a buffer capacitor whose value is gotten from the datasheet of the regulator. Current limiting resistor calculation:

$$R_4 = \frac{V_{out} - V_D}{I_D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

V_{out} = Output voltage of regulator
V_D = Voltage drops across diode
I_D = Forward current of LED

Light emitting diode characteristics:
Forward current of LED = 10mA and voltage drop = 2V. Therefore

$$R_4 = \frac{5 - 2}{10 \times 10^{-3}}$$

$$R_4 = 300\Omega$$

This value of resistor is not in the market, so the appropriate value to use is:

$R_4 = 330\Omega$

Design of the Display Unit

The 16x2 liquid crystal display (LCD) is connected to the arduino through the 4 high bits (D7, D6, D5, D4). The LCD is power with 5volts and the brightness is controlled via variable 10K resistor.

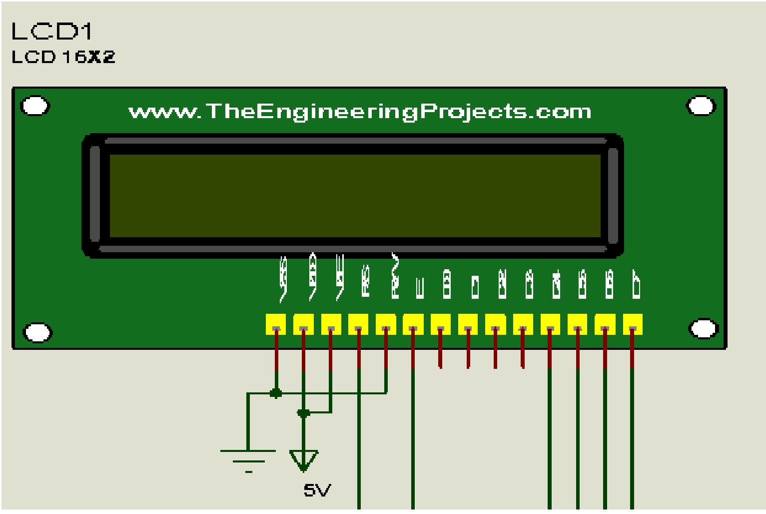

Figure 3: Circuit Diagram of the Display Unit

LM35 Temperature Sensor

Lm35 is a precision IC temperature sensor with its output proportional to the temperature (in ^{0}C). Output voltage varies by 10mV in response to every ^{0}C rise/fall in ambient temperature, i.e., its scale factor is 0.01V/ ^{0}C. Pin 2 (V_{out}) is connected to the Arduino board.

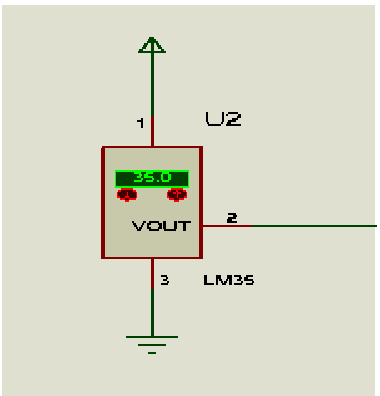

Figure 4: LM35 Temperature Sensor

ACS712 Current Sensor

In the design of this prototype an ACS712 current sensor is used because as stated the low-profile, small form factor packages are ideal for reducing PCB area over sense resistor op-amp or bulky current transformer configurations. The low resistance internal conductor allows for sensing up to 20 A continuous current. The output from this sensor is connected to the arduino ADC to read the values.

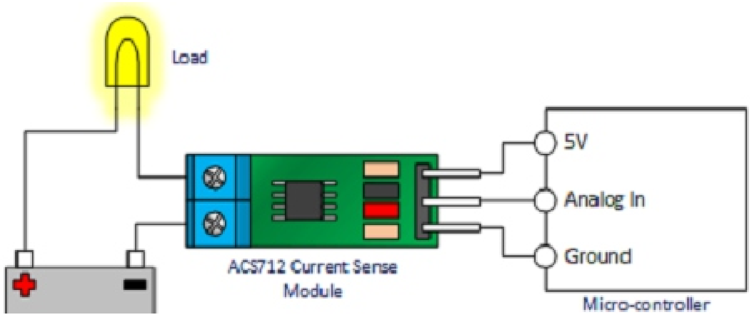

Figure 5: ACS712 Current Sensor

ESP8266 Wi-Fi Module

The second stage output of 3.4V from the power supply designed above is used to power the WiFi Module and was obtained from the four diodes connected in series and; each having 0.4V voltage drop, i.e. cumulative voltage drop of 1.6V.

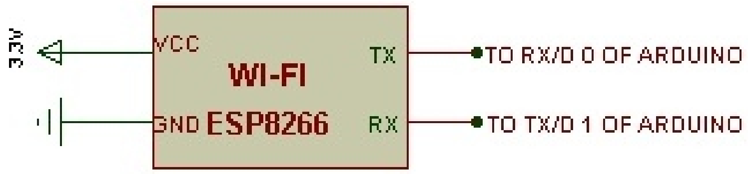

Figure 6: ESP8266

Voltage Divider

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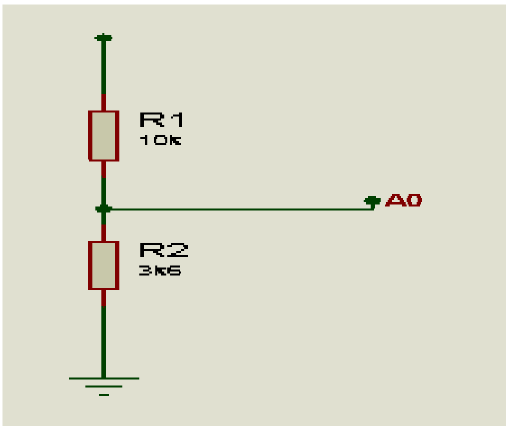

Figure 7: Voltage Divider

Arduino Nano

The Arduinonano a microcontroller board based on the ATmega328P. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, and a min USB connection.

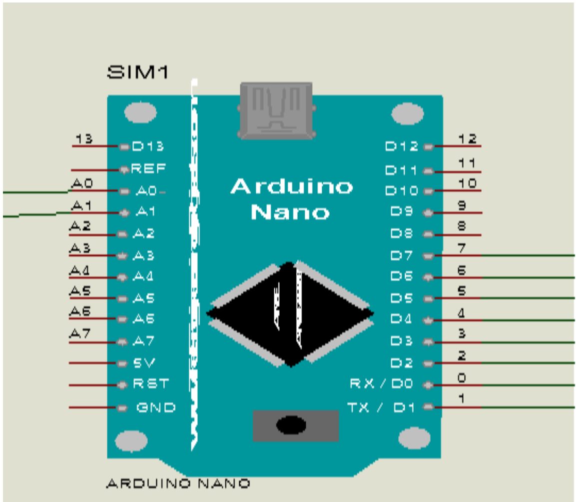

Figure 8: Arduino Nano

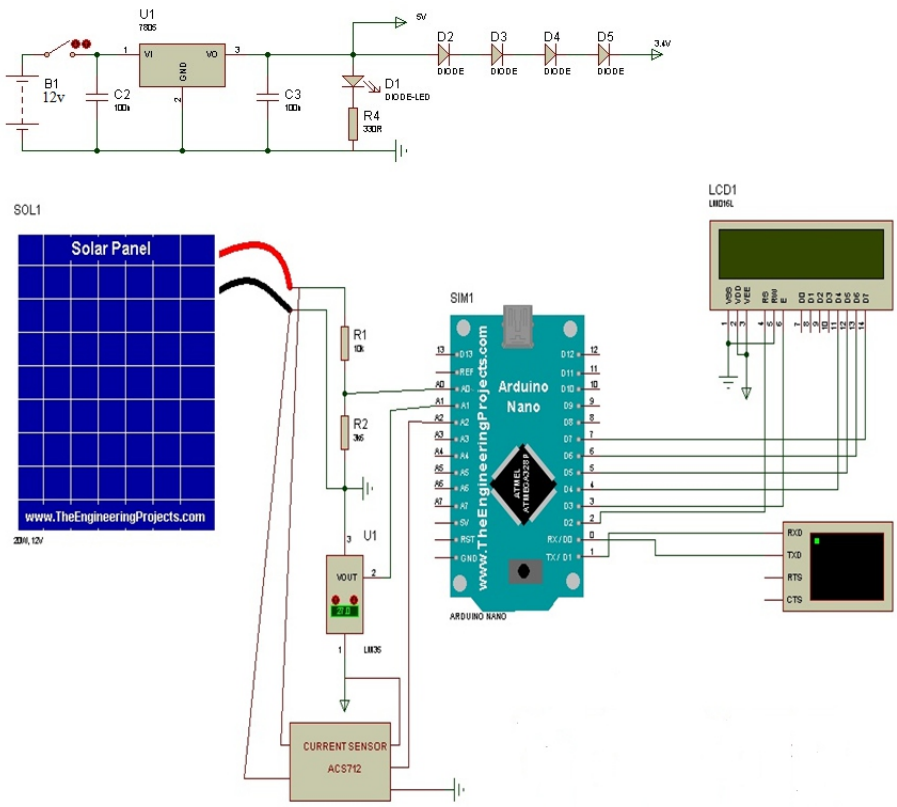

Figure 9: Full Circuit Diagram

Software Development

The figure below shows the flowchart of the programming. The program was written in C programming language using Arduino compiler. It comprises the input, processing and the output. The Start and stop of the program are represented by oval shapes whereas the input and output statements are presented in parallelograms. Processing statements are presented in rectangular shapes.

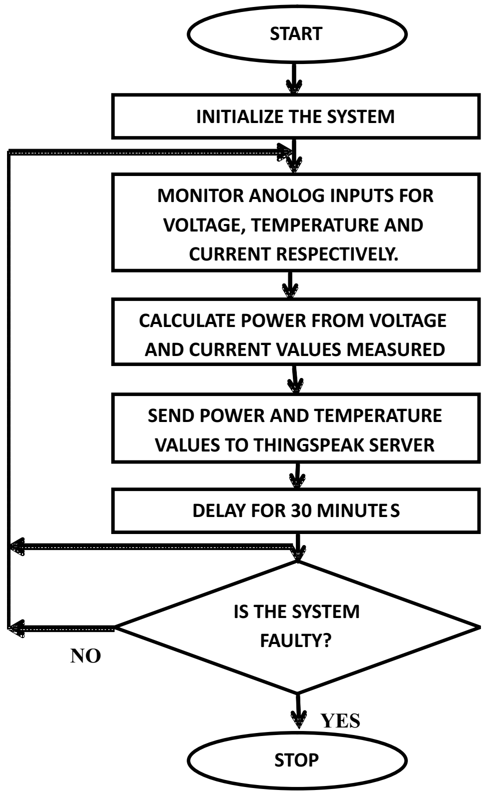

Figure 10: The Flowchart of the Program

Create ThingSpeak Application as the Repository Centralized Server

ThingSpeak is a platform providing various services exclusively targeted for building IoT applications. It offers the capabilities of real-time data collection, visualizing the collected data in the form of charts, ability to create plugins and apps for collaborating with web services, social network and other APIs.

At the heart of ThingSpeak is a ThingSpeak Channel. A channel is where you send your data to be stored. Each channel includes 8 fields for any type of data, 3 location fields, and 1 status field. Once you have a ThingSpeak Channel you can publish data to the channel, have ThingSpeak process the data, and then have your application retrieve the data. 8 fields for storing data of any type, these can be used to store the data from a sensor or from an embedded device. The three location fields can be used to store the latitude, longitude and the elevation and one status field which contain a short message to describe the data stored in the channel.

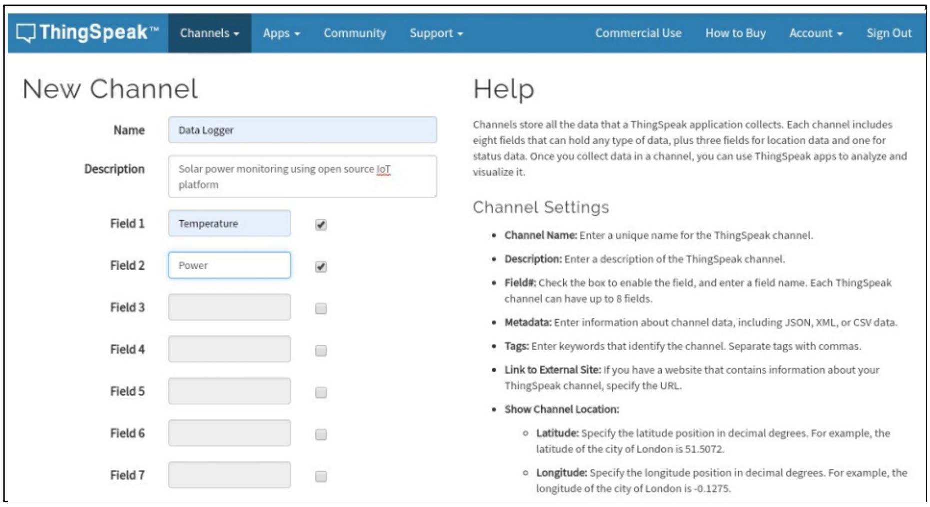

Figure 11: ThingSpeak – Create a Channel Public

System Operation

The circuit is an embedded solution to improve solar panel performance. The system comprises of three sensors, current sensor, voltage sensor and temperature sensor. The system is embedded in a solar inverter to monitor the solar panel performance and ensure regular maintenance of the solar inverter. The full circuit is powered by the inverter's battery and this ensures continuous supply of power to the system. The basic operation of the circuit involves the arduino continuously monitoring the three sensors connected to it and based on the output of the voltage and current sensors; the arduino calculates the power produce by the solar panel at a corresponding temperature value. These values are sent to the ThingSpeak server for the necessary stakeholders to decide if the solar inverter is functioning at optimally. When the power drops below the expected value at a corresponding temperature value, maintenance is carried out on the system.

Conclusion

The study focused on examining some of the challenges of solar monitoring system reliability with a view of develops an effective framework in modern engineering and sustainability. The review of literature and model assessment has made an attempt to address some of the problems of monitoring solar power inverter that users are facing today. The study applied the concepts of IoT and tried to monitor solar panel parameters and other parameters related to solar power operation such as temperature and maintenance with the help of IoT and ThingSpeak open source IoT platform. It suggests that that appropriate monitoring structure will improve efficiency of solar inverter and operating conditions. This applies as an emerging tool in modern day engineering.

Policy Recommendation

The provision of advance remotely managed Solar PV system of various operations like remote shutdown, remote management is to be incorporate with this system later. For machine learning algorithms implementation, reliable data is obtained. This real time data is readily available to study the load patterns and power generation patterns. Power system scheduling becomes easy and load predictions will be most accurate. This will also facilitate preventive maintenance, fault detection, historical analysis of the inverter in addition to real time monitoring.

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