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# A Solar Energy Harvesting System for WSN Nodein Industrial Sectors

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*Abstract*—**Energy can be harvested from a variety of sources, including the sun, wind, mechanical vibrations, temperature changes, etc. Continuously providing energy and storing it for future use, energy harvesting subsystem enables WSN nodes to last potentially forever. In this paper, a long-term and reliable power source for the wireless sensor network node in industrial sectors is proposed using a solar energy harvesting technology. The system consists of a solar panel, an MPPT algorithm controller, a rechargeable battery, and a wireless sensor node. It prefers to use the solar energy whenever the sunshine is adequate and harvested by using a rechargeable battery. The rechargeable battery is used as the power supply for WSN node. It is helpful for conditions such as overcast, rain, and night. The system adapts a maximum power point tracking (MPPT) circuit to take full gain of solar energy. And also it ensures the battery an incredibly long life. Also the wireless sensor network node is based on the gas leakage detection in the industrial sectors. The sensor node will detect the gas leakage and various parameters like temperature and humidity. Then all these data are transmitted wirelessly through Bluetooth module and forwarding these data using the Wi-Fi module NodeMCU to the Blynk mobile application. This system is particularly appropriate for outdoor-based wireless sensor nodes in the Internet of Things (IoT).**

*Index Terms*—**Solar energy harvesting; WSN; MPPT; Rechargeable battery; Gas leakage.**

## I. INTRODUCTION

Energy harvesting is the process of harvesting energy from the environment or from a surrounding system and converting it to available power supply for the electronic circuits [1]. Energy harvesting works by capturing small amounts of ambient energy that would otherwise be dissipated or wasted as heat, vibration, light, and other forms of waste. It acts as a backup power source for electronic devices. It also includes a way for powering an embedded system using renewable energy sources such as wind, solar, thermal, and electromagnetic waves. Among these solar energy harvesting is one of the most common energy harvesting techniques utilized around the globe. Solar energy harvesting that provides an alternative power source for an energy-constrained wireless sensor network (WSN) node [2].

The wireless sensor network is one of the most significant technologies in the 21st century [3]. The Wireless Sensor Networks are the basic building blocks of today's modern internet of Things (IoT) infrastructure in smart buildings, smart parking, and smart cities [4]. A WSN includes a group of mini embedded devices are called sensor nodes (as shown in Fig. 1) and that communicates with a common gateway using radio signals. A microcontroller, transceiver, external memory, power source, and one or more sensors are common components of sensor nodes. Usually, the processing power and storage capacity of a sensor node are bound to minimize its costs, energy utilization and size. Sensor nodes are either powered by batteries, energy harvesting or joining them to the power grid. Energy harvesting is an attractive solution to extend battery lifetime in a wireless sensor node (WSN) [5]. Most low-power small devices are powered by batteries. Energy harvesting can improve the lifetime of batteries and make self-sustainable low-powered devices, thus avoiding the necessity of replacing batteries. The energy-storage techniques for energy-harvesting systems in sustainable wireless sensor nodes can be classified into two technologies, i.e., supercapacitors and rechargeable batteries [6]. Rechargeable batteries are best for applications that require a higher level of energy. While supercapacitors are best for applications that require fast charging/discharging, charging/discharging at higher currents, and durability over multiple cycles, they are not ideal for all applications.

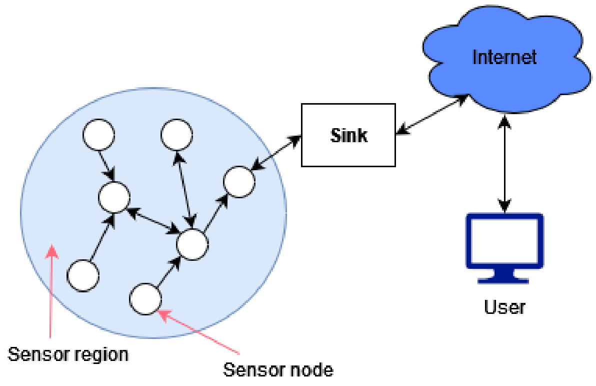


Fig. 1. Illustration of a wireless sensor network

WSNs are used in variety of commercial and industrial applications. Four sources of input energy (solar, vibrations, RF, thermal gradients) and its combinations can possibly be used for harvesting of electrical energy in the most of industrial applications [7]. For example, a typical WSN system can be used to detect the gas leakages in the industrial sectors. The majority of LPG explosions are triggered by gas leakage that goes unnoticed in the pre-detection stage. This action necessitates the use of a technology that can detect early leakage.

This paper aimed at a solar energy harvesting system for WSN nodes in industrial sectors that prefers to use solar power to charge the lead acid battery and is based on maximum power point tracking (MPPT). Then the battery is used as the power supply for WSN node. The WSN node will detect the gas leakage and various parameters like temperature and humidity. The remaining sections are organized as follows. The related works are covered in Section 2. Section 3 presents the design and methodology for the proposed work. Section 4 presents the result and analysis of the proposed system. Finally, Section 5 concludes the paper.

## II. RELATED WORKS

Yin Li and Ronghua Shi [8] studied an intelligent solar energy-harvesting system for wireless sensor networks [8]. The lithium battery's charge management is handled by hardware rather than software. When the sunshine is adequate, it prefers to use solar energy, with the lithium battery acting as a backup power source in situations like overcast, rain, and night. To fully utilise the solar energy, the system employs a maximum power point tracking (MPPT) circuit.

J. A. Khan, H. K. Qureshi and A. Iqbal are proposed a survey of energy management in wireless sensor networks [9]. For the remotely deployed energy stringent sensor nodes in WSN, energy management is critical. R. L. Rosa, C. Dehollain, A. Burg, M. Costanza and P. Livreri are proposed an energy-autonomous wireless sensor with simultaneous energy harvesting and ambient Light Sensing [10]. A wireless sensor platform with a single photovoltaic transducer that can harvest energy while also monitoring the ambient light.

Fabio Ongaro, Stefano Saggini, and Paolo Mattavelli are proposed a Li-on batterysupercapacitor hybrid storage system for a long lifetime, photovoltaic-based wireless sensor network [11]. For a photovoltaic (PV) based wireless sensor network, the system uses a power management architecture that leverages both supercapacitor cells and a lithium battery as energy storage. R. Babu Bollipo, Suresh M., Praveen K. B. are proposed a review of hybrid, optimal, intelligent and classical PV MPPT techniques [12].

S. Thakran, J. Singh, R. Garg and P. Malhajan are implemented P&O algorithm for MPPT in SPV system [13]. The MPPT algorithm is written in Arduino IDE and implemented in Arduino UNO R3 [13]. Linxi Dong, ZhiyuanQiao, Haonan Wang, Weihuang Yang,Wensheng Zhao, Kuiwen Xu ,Gaofeng Wang, Libo Zhao and Haixia Yan are proposed a gas leak detection based on a wireless monitoring system [14].

## III. DESIGN & METHODOLOGY

In this section, the design and methodology of the proposed system is explained. Energy harvesting and management may be the most practical solution to the problem of making WSNs self-sufficient. Supercapacitors and rechargeable batteries are two types of energy-storage technologies used in energy-harvesting systems in sustainable wireless sensor nodes. Because supercapacitors have a lower power density and a higher leakage overhead than rechargeable batteries, they are less efficient. Since supercapacitors have a larger leakage overhead and a substantially lesser power density than rechargeable batteries.

The proposed system is an intelligent solar energy harvesting system based on maximum power point tracking (MPPT) for wireless sensor nodes and the energy-harvesting system using a lead acid battery as the storage. Here, the wireless sensor system designed and developed effectively to detect gas leakages and monitoring the temperature and humidity parameters in the industrial sector.

### A. Solar panel selection

The power requirement for solar panel can be calculated by using the equation below,

$$P = V\,I \quad (1)$$

Substituting value of the battery voltage and charging current.
P = 12V × 1A = 12W
This is the minimum required wattage of solar panel to charge 12V Lead acid battery. Table 1 shows the specifications of solar panel.

TABLE I
SOLAR PANEL SPECIFICATIONS

| Parameters | Values |
|---|---|
| Maximum Voltage, $V_{mp}$ | 17.1V |
| Maximum Current, $I_{mp}$ | 0.7A |
| Open Circuit Voltage, $V_{oc}$ | 21V |
| Short Circuit Current, $I_{sc}$ | 0.8A |
| Maximum Power, $P_{max}$ | 12W |

### B. Design of buck converter

The buck converter is high efficiency step-down DC/DC switching converter.
Let the initial values are,
Input voltage, $V_{in}$ = 18V
Output voltage, $V_o$ = 12V
Diode voltage drop = 0.7V
Transistor voltage drop = 0.7V
Frequency = 50KHz
Output current, $I_o$ = 1A
Minimum output current, $I_{min}$ = 0.1A
Inductor current ripple, $\Delta I_L$ = 0.1%
Output voltage ripple = 0.1%

The output voltage is related directly to the duty cycle (D) of the pulses. If we neglect the voltage drop across the transistor and diode then,

$$V_o = DV_{in} \quad (2)$$

$$D = 68\% \quad (3)$$

Inductance based on the specified minimum load current is given by,

$$L = \frac{V_o * (V_{in} - V_o)}{\Delta I_L * f_s * V_{in}} \quad (4)$$

$$L = \frac{12 * (18 - 12)}{0.1\% * 50 * 18} = 72156.62\mu H \quad (5)$$

Capacitance is given by,

$$C = 1134.5\mu F \quad (6)$$

### *C. MPPT circuit algorithm*

About 30-40% of the incident solar insolation is converted into electrical energy by a typical solar panel. Maximum power point tracking technique is used to improve the efficiency of the solar panel [15]. The maximum power transfer theorem states that a circuit's power output is greatest when its source impedance, or Thevenin impedance, meets impedance of the load. So, tracking the maximum power point becomes a problem of impedance matching. The Perturb and Observe (P&O) algorithm and the incremental conductance algorithm are the two MPPT algorithms that are most commonly used. The simplest and most popular approach for MPPT is the P&O

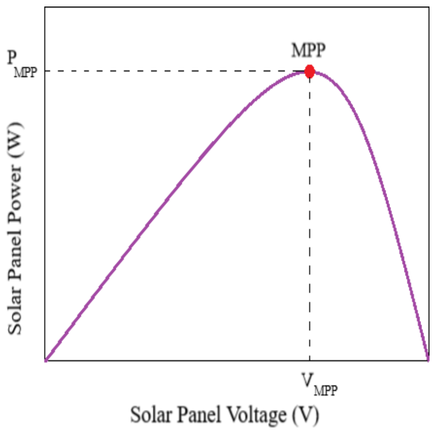


Fig. 2. P-V characteristics

algorithm method. In this method, the PV module voltage is sensed by a single sensor, the voltage sensor which reduces implementation costs and makes it simpler. The algorithm's time complexity is quite low when computing the maximum power, but after it gets very close to MPP, it continues to perturb in both directions. As a result, a small disturbance is added in the direction of increase. Power is determined based on the subsequent value at the subsequent instant. The direction changes and it moves away from the MPP in the following iteration, producing numerous local maxima at the same location. As a result, the maximum power point is moved from where it was initially.

The MPPT's job is to make sure the PV module is operating at its MPP and take out the maximum available power. When using an efficient MPPT algorithm, a solar system can efficiently generate its maximum power under favorable irradiation conditions. From the P-V curve of a solar panel shown in Fig. 2. It is clear that the slope is zero at the maximum point. For an increment in solar panel voltage, if the output power $\Delta P$ is greater than zero, then moving to maximum power point MPP; if $\Delta P$ lesser than 0 then moving away of the MPP. The flow chart of the P&O algorithm is illustrated

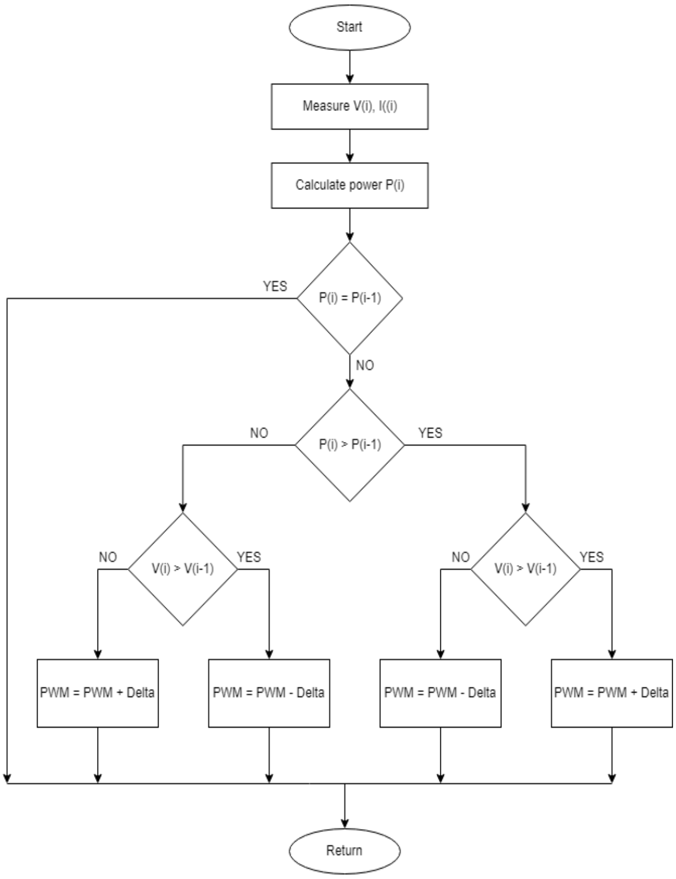


Fig. 3. Flow chart of the P&O algorithm

in Fig. 3. Initially the algorithm that reads the current and voltage readings from a solar panel and it utilizes these values to determine the power at that instant. The microcontroller will first detect the voltage and current, calculate the current power P(i) at the output, and then contrast it with the power P(i-1) that was previously detected. To extract the maximum power out of the solar panel, if P(i) is greater than P(i-1) the PWM duty cycle is increased. If P(i) is less than P(i-1), the duty cycle is reduced to make sure that the system returns to the previous maximum power. This MPPT algorithm is easy to use, affordable, and accurate.

### *D. Methodology*

The system is mainly comprised of a solar powered WSN which includes transmitter node and a receiver node as shown

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in Fig. 4. The wireless sensor system designed and developed effectively to detect gas leakages and monitoring the temperature and humidity parameters in the industrial sector. Also the entire system consists of solar panel, Lead acid battery, Microcontroller, gas sensor, Temperature and humidity sensor, wireless Bluetooth module, NodeMCU, Current sensor and LCD. Here Solar energy harvesting is the first part of the system. Since Solar power is the input source of power supply for WSN node and the energy is harvested in the lead acid battery through a buck converter. Through the DC-DC converter, the MPPT algorithm harvests the maximum power from the solar panel and then it charges the battery.

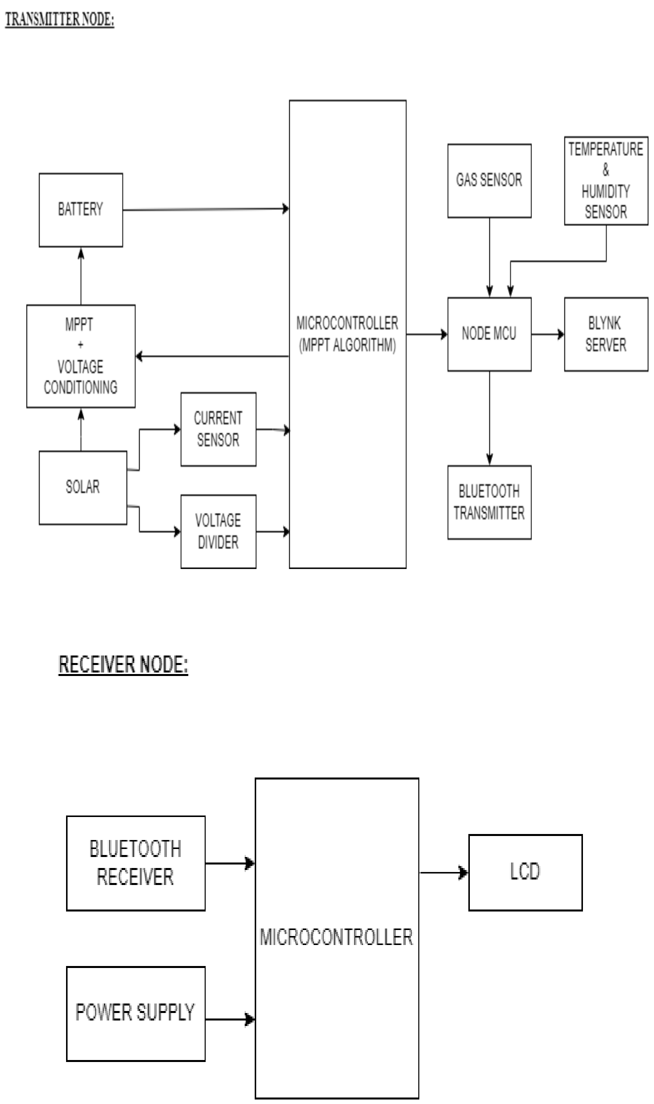


Fig. 4. Block diagram of the system

The voltage divider circuit is used to measure the solar panel and battery voltages. The analog inputs of the microcontroller board can be used to measure DC voltage between 0 and 5V, and this range can be extended by creating a voltage divider with two resistors. To measure the voltages of the battery and solar panel, a voltage divider lowers the voltage being measured to a range compatible with the microcontroller analog inputs. The current sensor reads the current value and converts it to a useful voltage value for current measurement. The design is used 12W solar panel to charge 12V lead acid battery. Lead acid batteries have a big capacity and are widely available across the world.

The WSN system is developed to detect the gas leakage using gas sensor and monitor the temperature and humidity in the industrial sectors. The gas sensor can be used to detect propane, H2, LPG, CH4, CO, alcohol, or smoke. All the sensor output is given to a NodeMCU, which is a microcontroller development board with Wi-Fi capability. Whenever the gas leakage is detected by the gas sensor from the transmitter node, all the data (gas sensor output, temperature and humidity) are transmitted wirelessly to the WSN receiver node via a Bluetooth module. And also can forwarding the information from the NodeMCU to the Blynk mobile application. In the receiver node section, Bluetooth receiver receives the data and display it on the LCD.

*E. Buck converter with driver circuit*

A synchronous buck converter circuit serves as the foundation of the Maximum Power Point Tracker (MPPT) circuit. It reduces the higher solar panel voltage to the battery's charging voltage. The microcontroller tries to maximize the watts input from the solar panel by controlling the duty cycle to keep the solar panel operating at its Maximum Power Point. The buck converter with driver circuit as shown in Fig. 5. A DC-

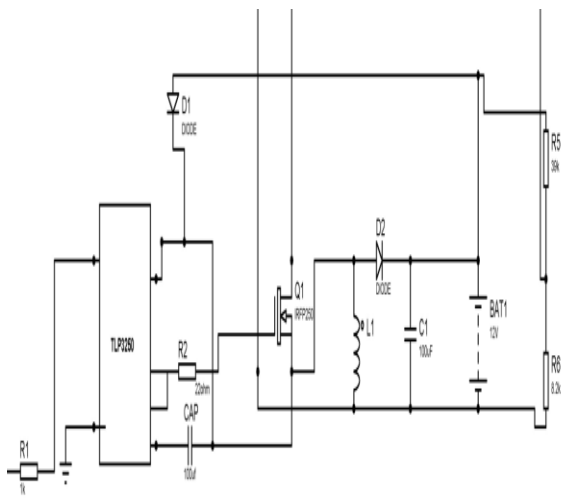


Fig. 5. Buck converter with driver circuit

DC converter known as a buck converter always produces an output voltage that is either lower than or equal to the input voltage. When the MOSFET Q1 is ON, current flows through the inductor (L1) and the output capacitor (C1), the diode is reverse biased. So no current flows through it. During the ON state electrical energy is stored in the output capacitor and magnetic energy is stored in the inductor. When the MOSFET is off, stored Energy in the inductor is collapsed and current complete its path through the diode (forward-biased).

Here the diode used to have a considerable amount of voltage drop which reduced the efficiency of the Converter. To improve the efficiency a Power electronics switch (TLP3250) is used to connect and disconnect the solar panel with the battery. A constant voltage can be maintained by rapidly switching the MOSFET at high frequency with different pulse sizes. The MPPT algorithm controlled microcontroller is interfaced to the TLP3250 photorelay.

*F. Flow of sensor node*

The wireless sensor system designed and developed effectively to detect gas leakages and monitoring the temperature and humidity parameters in the industrial sector. The flow of sensor node is shown in Fig. 6. MQ-2 can detect LPG,

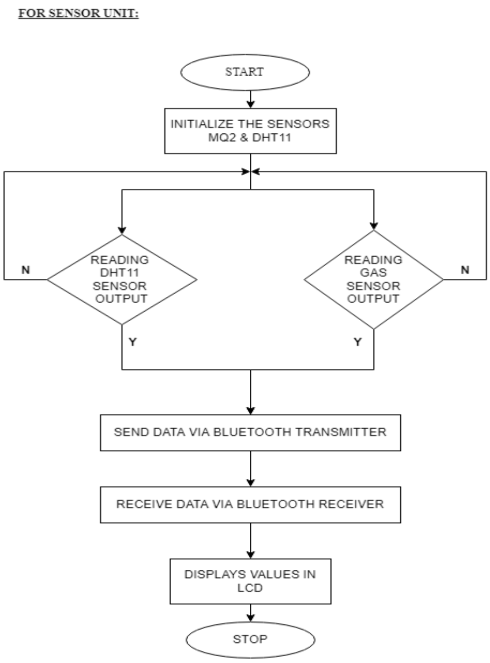


Fig. 6. Flow chart for sensor node

Smoke, Alcohol, Propane, Hydrogen, Methane and Carbon Monoxide concentrations and DHT11 measures the temperature & humidity values. For the sensor unit, initialize all the sensor MQ-2 and DHT11. Check the values of gas sensor and temperature and humidity sensor parallelly. If sensor value is high, send the data to receiver node through Bluetooth transmitter. Similarly, if the temperature and humidity sensor is high, Whenever the gas leakage is detected by the gas sensor, send the data to the receiver node wirelessly through Bluetooth transmitter. Otherwise, repeated the previous process. Then Bluetooth receiver receives all the data and displays it in the LCD.

## IV. Result and Analysis

In this section, the output and the different analysis carried out for the proposed system were discussed.

*A. Experimental results*

The solar panel voltages vary with respect to the intensity of the sunlight. When solar panels are providing their maximum power, it produces the largest solar panel voltage. Which is typically around day time. The open circuit voltages of a 12W solar panel are depicted in a line graph (Fig. 7) from 10:00am to 4:00pm on a particular day. Initially, it was 14.4V V. From

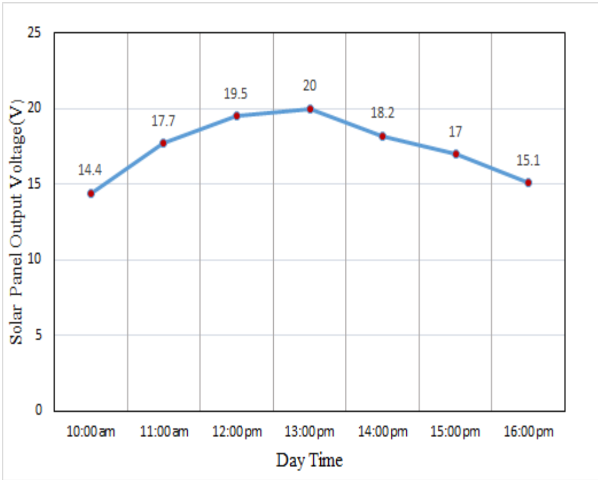


Fig. 7. Open circuit voltage of solar panel at different times

that time to 1:00 pm, the voltage increased and reaches a peak value of 20V. But from the time 1:00pm to 4:00pm, the voltage values are decreased. Here the smallest voltage is observed at 10am. These changes are due to the variation in solar irradiance.

The line graph (Fig. 8.) illustrates the solar panel voltage against lead acid battery voltage. Charging a 12V 7Ah battery with a 1A charger will take atleast 7 hours. Once the current has been stable at a low level for a few hours, the battery is fully charged. A 12V lead acid battery consists of 6 cells and provide 6*2.1 = 12.6V capacity. Here the battery output provide 12.3V since the battery is fully charged. Blynk is

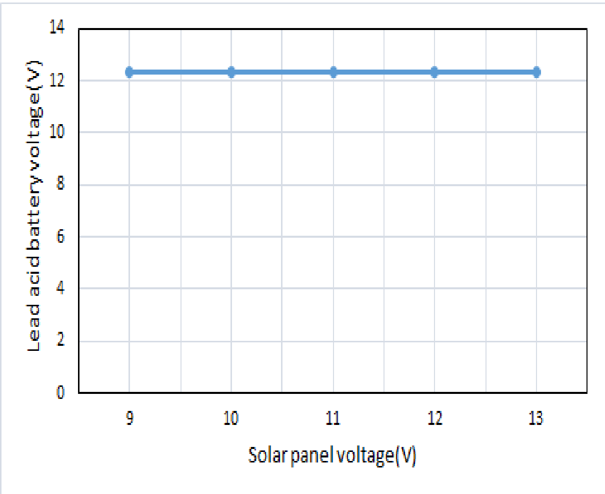


Fig. 8. plot of battery voltage against solar panel voltage

the IoT platform for connecting any hardware to the cloud, designing app to control them. Blynk library connected to

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ESP8266 NodeMCU and microcontroller to the Blynk cloud shows the various parameters. Fluctuations in the sunlight during sunny day, night etc., the solar and battery voltages are vary with respect to time. The plot of solar voltage, battery


Fig. 9. Plot of solar voltage, battery voltage and current using Blynk app.

voltage and current parameters of the system is shown in the Fig. 9.The maximum power point voltage V or maximum power point current I at which a solar panel should operate to obtain the maximum power output. As switch-mode dc-dc converter is used as an intermediate power processor, it changes the values of current and voltage levels such that maximum power can be extracted from a solar panel. The plot of voltage, current and power with MPPT is shown in Fig. 10.


Fig. 10. Plot of voltage, current and power using Blynk app

*B. Outputs of WSN system*


Fig. 11. Initial information display on the LCD.

The proposed system is a wireless sensor network system designed and developed effectively to detect gas leakages and monitoring the temperature & humidity parameters in the industrial sector. All the WSN transmitter node data transmitted through Bluetooth module are received in the receiver node, which displays all the data in the LCD as well as in Blynk app. At the initial stage, LCD displays the data as "INDUSTRIAL SECTOR" as shown in Fig. 11.


Fig. 12. Temperature and humidity readings

Fig. 12 shows the temperature and humidity readings in the industrial sector. The temperature values are measured in degree celsius.


Fig. 13. Gas leakage indication on LCD

Fig. 13 shows the indication of gas leakage. The gas sensor is suitable for detecting H2, LPG, CH4, CO, Alcohol, Smoke or Propane. Whenever the gas leakage is detected by the sensor on the transmitter node and displays the data on the LCD in the receiver node.


Fig. 14. Various Blynk app readings.

Fig. 14 shows the solar voltage, battery voltage and the temperature reading on the Blynk App.

Prototype of the solar energy harvesting system for WSN node in industrial sector as shown in the Fig. 15. The designed system consists of a solar panel that connected with buck converter and P&O algorithm for extracting maximum power. This dc-dc buck converter acting as a charge controller for

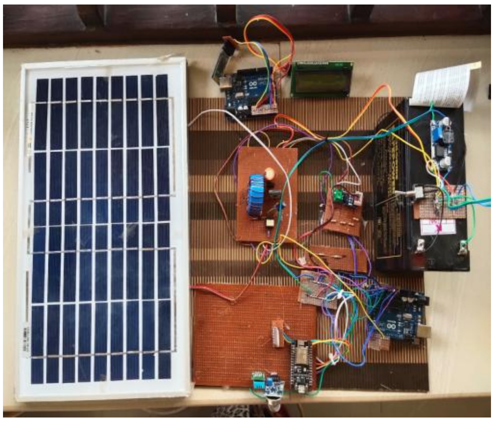

Fig. 15. Prototype of the proposed the system.

charging a 12V battery. The battery will power the WSN node. Thus the rechargeable batteries produce less waste because they can be recharged with a simple battery charger and reused hundreds of times. And also all the WSN nodes can be accessed through centralized monitoring system. It doesn't need wires or cords because it operates wirelessly.

## V. CONCLUSION

Solar energy harvesting is used to provide an alternate power source for a wireless sensor network node that is power constrained. Solar energy harvesting wireless sensor networks are used in industrial facilities, smart cities, farms, forests, greenhouses, and remote places to monitor and regulate applications such as light, temperature, humidity, pressure, and acceleration. WSN is one of the ways that can be used to detect gas leaks in a large area. The proposed system is the design and implementation of solar energy harvesting system for wireless sensor network nodes in industrial sectors. Solar energy harvesting part is designed by using MPPT circuit algorithm. The rechargeable battery is used as the power supply for WSN node which is charged by using a solar panel. The prototype of WSN system can be made to function effectively to detect or monitor the gas leakage and various parameters like temperature & humidity in industrial sectors. The system performs stably and safely with high reliability and simple composition.

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