SOLAR POWERED AIR PURIFIER

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Abstract:

This work focuses on the sustainable development of an intelligent, solar-powered air purifier designed to mitigate indoor and outdoor air pollution by harnessing photovoltaic energy. The purifier utilizes a three-stage filtration system, incorporating High-Efficiency Particulate Air (HEPA) and activated carbon filters, to effectively remove particulate matter and gaseous pollutants. The system is designed for self-sufficient operation, employing solar panels and an MPPT charge controller to power the unit. A key feature is the integration of an Internet of Things (IoT) based Air Quality Monitoring (AQM) system, which collects real-time air quality data and dynamically modulates the fan speed to optimize purification performance and maximize battery autonomy. Experimental testing demonstrated a high PM (2.5) reduction efficiency of 91.66% and successfully maintained 7.8 hours of autonomy at maximum operational speed, validating this design as an efficient, low-maintenance, and economically viable off-grid solution for localized air purification.

Keywords: Air Quality , Node MCU, Pollution

I. INTRODUCTION

The quality of air, both indoors and outdoors, has become a significant global health concern, with the World Health Organization (WHO) linking air pollution to millions of premature deaths annually. Indoor air quality is often 2 to 5 times worse than outdoor air due to poor ventilation and internal sources like cooking fumes and dust. While air purifiers are essential appliances, their reliance on continuous grid electricity contributes to high operational costs and a larger carbon footprint. This necessitates the development of sustainable, energy-efficient alternatives.

A Solar Powered Air Purifier addresses this need by integrating standard air filtration technology with a renewable photovoltaic (PV) solar source. The system functions autonomously, making it ideal for use in remote areas, locations with unreliable power, or during power outages. Furthermore, by utilizing solar energy, the system drastically reduces reliance on fossil-fuel-generated electricity, offering a smaller carbon footprint and virtually zero operational electricity cost, thereby supporting global sustainability efforts.

The system comprises four key stages: Energy Harvesting (PV panel), Power Management (charge controller/battery), Purification (DC fan/blower), and Filtration (multi-stage filters). The objective of this project is to design, fabricate, and validate a working prototype that successfully blends high-efficiency, multi-stage filtration with smart, solar-based power management to achieve high autonomy in energy-insecure environments.

Air pollution remains a significant global threat, with approximately 90% of the world's population residing in areas with substandard air quality. Exposure to this pollution is a major contributor to various severe health issues, including lung damage, heart disease, and debilitating respiratory conditions. The urgent nature of this issue, particularly in regions with unreliable power sources, demands an innovative and continuous approach to air quality purification and monitoring.

A cost-effective and sustainable solution is the development of a solar-powered air purifier integrated with an air quality monitoring system. These devices convert sunlight into power using solar cells, providing energy for both the purification and monitoring functions. The core aim of this work is to establish a novel, self-sufficient air purification system that operates independently of conventional power grids, thereby contributing to both environmental and economic sustainability. The system uses a radial pull mechanism to draw in ambient air and pass it through a filter train to effectively remove pollutants.

II.LITERATURE SURVEY

A.P. Singh et.al.,[1] Described forms of air pollution i.e., first is in gaseous form (ozone, carbon monoxide, methane, benzene and ammonia) and second are particulate matter like smoke, dust, fly ash and dust mist. Pooja M et.al.,[2] Presented the design of solar powered air purifier incorporating an air quality monitoring system. This recent work underscores the ongoing research interest in sustainable solutions for air pollution, a pertinent issue in India. By focusing on design, the authors contribute to the theoretical and practical understanding of developing such integrated system. Rashbir Singh et.al., [3] Introduces an innovative robot capable of both purifying indoor air and generating power from wind. It effectively enhances indoor air quality reducing energy consumption, though limitations such as indoor use restrictions, size constraints, and reliance on airflow for power are noted. Rahul Yashwant Pawar et.al.,[4] Presented a Solar Powered Outdoor Air Purifier with Air Quality Monitor, utilizing solar energy for outdoor air purification. It effectively monitors air quality in real-time, offering advantages such as reduced environmental impact and cost-effective operation. Shayank Verma et.al.,[5] Proposed air purification system likely employs various filtration methods using HEPA filters, activated carbon filters, or UV-C light sterilization to remove contaminants particulates (TSP)), backed by a nursing beta investigation. The Index of National Air Quality at the KGISL Institute of Technology in Coimbatore, India, Arun Chakravarthy Ra, Bhuvaneswari Mb, A run Mc, and Sureshkumar C are associate professors of information technology: For the people, especially for those who see the negative effects of conditions brought on by receptivity to defilement, it is essential to be familiar with step-by-step situations of impurity. The improvement of the landscape is another national achievement. The World Health Organization has taken action to lessen pollution while also improving the standard of living in major cities. An abecedarian thing that is required is a plain or incomprehensible evaluation of air quality. The Air Quality Index (AQI) converts the weighted implicit earnings of each defilement- related limit (such as SO2, CO, sensible quality, etc.) into one grouping of various figures at the outset. This grouping of figures is widely used to check the air quality rate and have a better internal cycle for people across various countries.

III.OBJECTIVES

The goal of this project is to create an air purifier or air cleaner, a device that cleans the air in a space and enhances indoor air quality.
The system's main properties are:

- Protection Against Bacteria & Viruses
- Protection Against VOCs.
- Allergen Removal.
- Odor Removal
- Mold Reduction

IV. METHODOLOGY

A. System Architecture (Block Diagram):

The solar-powered air purifier system is organized into four main sub-systems: Power Generation, Power Management & Storage, Purification Actuation, and Sensing & Control.

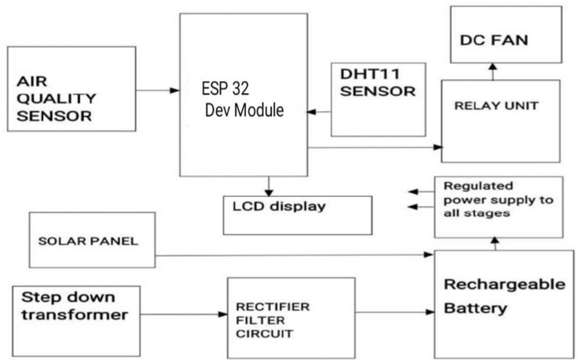

Fig: 1. Block Diagram of Solar Powered Air Purifier

Working of Proposed System: The Solar Powered Air Purifier system combines renewable energy source solar, battery storage, and grid power for reliable electricity supply. The block diagram consists of: Solar Panel (Input): Converts sunlight into DC electrical power.7805 IC Regulator: Regulates the voltage and current from the solar panel, optimizing power transfer to the battery and protecting it from overcharge/over-discharge. Battery (Storage): Stores the harvested solar energy for use during low light or night-time conditions, ensuring continuous system autonomy. Power Distribution: Supplies stable DC power (6V) to the loads. Microcontroller (Control): The central processing unit (CPU). It receives data from the AQM sensor and executes the control logic, adjusting the fan speed via a motor driver. Air Quality Sensor (Sensing): Provides real-time data on pollutant concentration PM (2.5).Fan/Blower: Draws ambient air through the filtration unit. The speed is modulated by the microcontroller. Filtration Unit: The physical element where the air is cleaned via multi-stage filters.

B. Description of Components:

Solar Panel (6V): The solar panel is the system's primary energy source. It captures photons from sunlight and converts them into direct current (DC) electrical energy through the photovoltaic effect. Its role is to continuously generate power to run the system during the day and, most importantly, recharge the storage battery. The panel's output is directly proportional to the intensity of available sunlight. For reliability, the system is designed to use the unregulated output, often around 6V to 9V peak, as the input for the charging and power regulation circuitry.

Fig: 2. Solar Panel

7805 IC Regulator:The 7805 is a fixed linear voltage regulator intended to convert a higher, fluctuating input voltage into a stable 5V DC output. In this system's conceptual design, it is incorrectly assigned the role of charge controller. While it ensures a stable 5V for sensitive components like the microcontroller, it cannot regulate the high voltage needed to protect a 6V battery from overcharge. A dedicated charge controller (not the 7805) is required to optimize power transfer from the solar panel and prevent battery damage. A three-terminal linear voltage regulator that provides a stable +5V output to power the low-voltage components like the sensor and microcontroller.

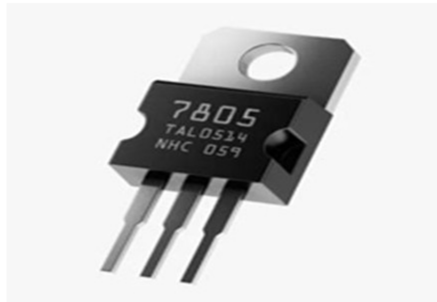

Fig: 3. 7805 IC Regulator

Battery (6V/5mAh):The battery is the crucial energy storage unit, providing system autonomy. It stores the electrical energy harvested by the solar panel, allowing the entire air purifier to operate reliably during low light, cloudy weather, or at night. Typical a 6V Sealed Lead-Acid or Lithium-ion pack, its capacity (e.g., in Ah) determines how long the system can run without solar input. It acts as a buffer, smoothing out momentary dips in the solar panel's output and providing consistent power to the loads. Stores the harvested solar energy for use during low light or night-time conditions to ensure system autonomy.

Fig: 4. Battery (6V/5mah)

Microcontroller (ESP32): The microcontroller, such as an ESP32, acts as the central brain of the entire air purification system. It continuously reads and interprets the real-time data provided by the Air Quality Sensor. Based on the programmed control logic (e.g., if PM2.5 > threshold), it makes decisions. Its primary output function is to communicate with a motor driver to modulate the speed of the fan/blower using Pulse Width Modulation (PWM), adjusting the purification rate to maintain optimal air quality. The central processing unit which receives data from the AQM sensor (MQ135) and executes the control logic to adjust the DC fan speed.

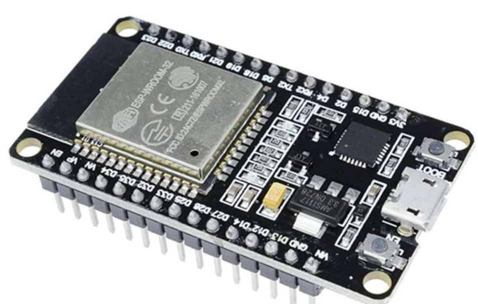

Fig: 5. ESP 32 Dev MODUL

Air Quality Sensor (MQ135):The Air Quality Sensor is the system's input device responsible for providing real-time environmental data. It measures the concentration of airborne pollutants, most critically Particulate Matter (PM), such as PM (2.5). It converts these physical measurements into electrical signals (usually digital or analog voltage) that the microcontroller can read. Its accuracy and resolution directly determine the system's ability to detect poor air quality and initiate the necessary air purification response. Provides real-time data on pollutant concentrations (e.g., carbon dioxide values), which triggers the electromagnetic relay to turn on the DC fan.

Fig: 6. MQ135 Sensor

Relay Switch:A relay switch is an electrically operated switch that allows a low-power control signal to manage a high-power circuit. In this system, the microcontroller (ESP32) provides a small, low-voltage signal to the relay module's control coil. Once energized, the relay's internal mechanism mechanically throws a switch to connect or disconnect the high-power circuit—in this case, the DC Fan. This essential component isolates the sensitive, low-voltage control circuitry from the high-current demands of the fan, preventing damage to the microcontroller and safely controlling the system's actuation element. Automatically switches between solar, wind, and grid power based on availability, prioritizing renewable sources.

Fig: 7. Relay Switch

LCD Display (2x16):The 2*times16 LCD (Liquid Crystal Display) is the system's primary output device for human-readable information. It is a character-based screen capable of displaying two lines of text, with 16 characters per line. The microcontroller (ESP32) sends data to the display to show the system's real-time status. This typically includes key operational metrics such as the current Air Quality Index (AQI), PM 2.5 concentration, Temperature, and Humidity. It is a cost-effective, easily programmable component that ensures users can monitor the purification process at a glance. Displays system parameters such as power source status, battery level, and energy metrics.

Fig: 8. LCD display

DC Fan:The Fan or Blower is the system's primary actuator, responsible for the physical movement of air. Its function is to actively draw ambient, unfiltered air into the system's housing and push it directly through the multi-stage Filtration Unit. Since its speed is modulated by the microcontroller via a motor driver, the system can efficiently adjust its power consumption and purification rate. A variable speed fan allows the system to run quietly when air quality is good and powerfully when it is poor. A 5V DC fan is used in an air purifier to create the necessary airflow for filtration, drawing in polluted air and expelling clean air quietly and efficiently.

Fig: 9. DC Fan

DHT11 sensor: It is a digital sensor capable of accurately detecting temperature and humidity. It's compatible with a wide range of microcontrollers, including Arduino and Raspberry Pi, enabling seamless integration for instant measurement of humidity and temperature.

Fig: 10. DHT11 Sensor

Filtration Unit:The Filtration Unit is the physical purification mechanism that actively removes pollutants from the air. It consists of multiple stages, often including a pre-filter for larger dust particles, and highly effective filters like HEPA (High-Efficiency Particulate Air) media for removing microscopic PM (2.5) particles. The air drawn by the fan passes through this unit, where contaminants are trapped. The unit's design and filter quality are paramount for determining the overall clean air delivery rate (CADR) of the system. Comprises a Pre-filter (for large particles), a True-HEPA filter (for PM (2.5)), and an Activated Carbon layer (for VOCs).

Fig: 11. Filtration Unit (Pre-filter /True-HEPA filter /Activated Carbon layer)

C. Control Logic:

The fan speed is dynamically controlled based on the measured air quality:

High Pollution: Fan operates at 100% speed.

Moderate Pollution: Fan operates at 50% speed.

Low/Clean Air: Fan operates at an Idle/Trickle speed, minimizing power drain and maximizing battery life.

D. Circuit Diagram: Solar Powered Air Purifier

The solar-powered air purifier circuit is designed around an ESP32 IoT module and utilizes a solar panel and a rechargeable lead-acid battery for power. The solar panel charges the battery, which serves as the primary power source for the entire system, including the ESP32, LCD display, and other components. The system uses an MQ135 air quality sensor to detect impurities; its values are read by the ESP32 and displayed on the 16x2 LCD. When the impurity level triggers the system, the ESP32 sends a signal via a BC548 NPN transistor to activate an electromagnetic relay, which in turn switches on the DC exhaust fan to purify the air. Power to the various components is regulated, with a 7805 IC regulator providing 5V for the ESP32 and other modules, and a separate power supply circuit using a step-down transformer, a full-wave rectifier with a center-tap, and a capacitor to convert 230V AC to 9V DC or 5V DC for the microcontroller and the 7805 IC regulator.

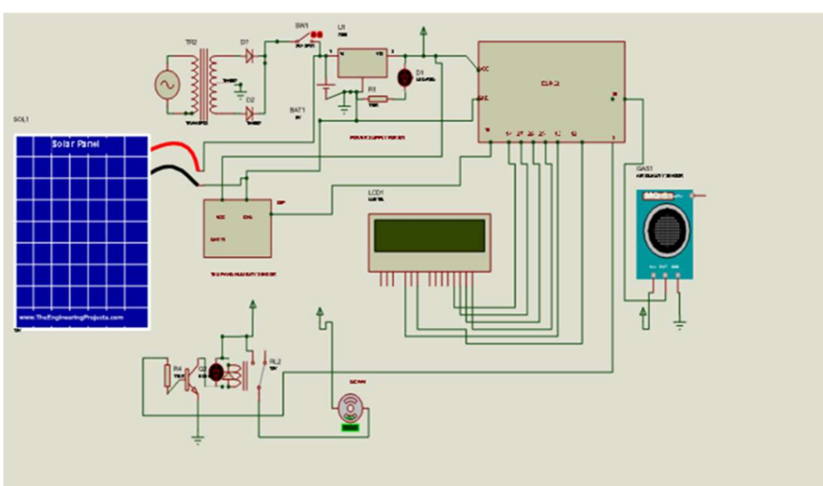

Fig: 12. Circuit Diagram: Solar Powered Air Purifier

V. IMPLEMENTATION AND DESIGN

A. Flow Chart:

This flowchart details the operation of a solar-powered air quality monitoring and purification system. The process **starts** by **initializing the system**, which includes activating the **power generation module** (presumably solar) to ensure system functionality. The system then reads the value from the **MQ135** (for air quality/gas sensing) and **DHT11** (for temperature/humidity) sensors. This raw sensor data is then processed in the next step, **where it is converted from analog and digital** signals into a usable format. Next, the system compares the data to a pre-set threshold value. A decision is made based on whether the **Air Quality is below the threshold value**; if the air quality is **HIGH** (meaning the concentration is above the threshold, indicating poor air quality), the system is directed to **ON THE FAN**, presumably to activate the air purification mechanism, and then loops back to **READ THE VALUE** to continue monitoring the air quality. If the air quality is **LOW** (meaning the concentration is below the threshold, indicating good air quality), the system proceeds to **OFF THE FAN**, and the process **ENDS**.

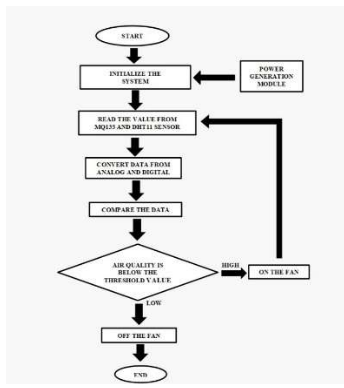

Fig: 13. Flow Chart

B. Setting Up the ESP32 module WithIoT

1. INTERNET OF THINGS (IOT)

The Internet of Things (IoT) is a vast network of interconnected physical devices, often referred to as "things," that are embedded with sensors, software, and other technologies for the purpose of collecting and exchanging data over the internet. These devices, which can range from smart home appliances and wearable health monitors to industrial machinery and sensors in smart cities, work to capture data from their environments, share it over a network (like Wi-Fi or cellular), and send it to cloud platforms for processing. The system then uses this analyzed data to inform users or, more critically, to trigger automated actions, such as adjusting a thermostat, optimizing factory processes, or, in the case of your flow chart, turning on an air purifier fan, all without requiring direct human intervention. This seamless connectivity and automated data flow are what enable the digital and physical worlds to converge, creating efficiency and new capabilities across consumer, enterprise, and industrial applications.

2. Blynk Platform

Blynk is an IoT platform designed to monitor and control hardware remotely. It provides real-time visualization, data storage, and communication between hardware and mobile applications via Blynk Cloud.

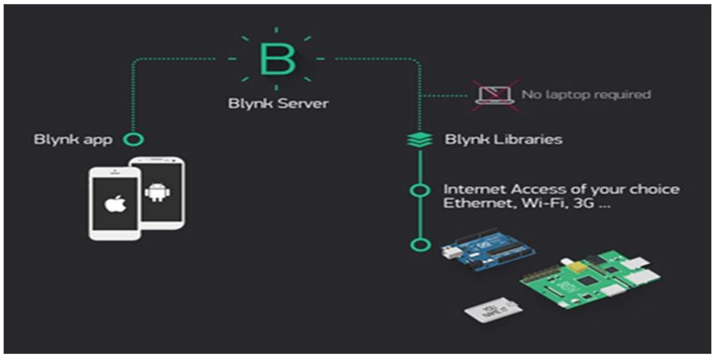

Fig: 14. Blynk cloud

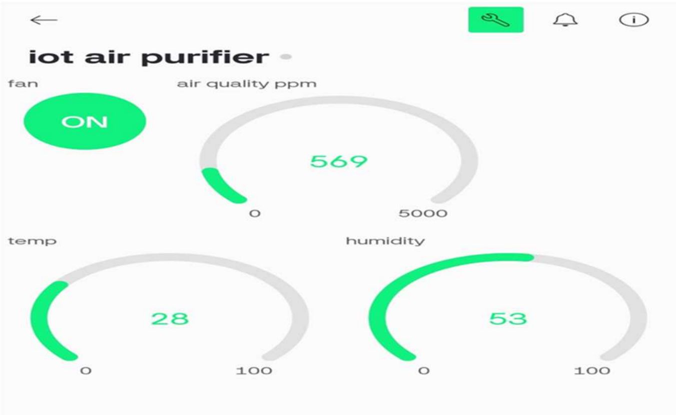

Fig: 15. Blynk app interface

VI. RESULT AND ANALYSIS

A. Results

The Results for solar-powered air purifiers are consistently positive, demonstrating significant pollutant reduction. Studies have shown that multi-stage filtration systems—typically including a pre-filter, a High-Efficiency Particulate Air (HEPA) filter for capturing up to 99.97\% of micro-particles and smoke, and an activated carbon filter for adsorbing gases, odors, and Volatile Organic Compounds (VOCs)—can yield up to 96\% to 99\% clean air. This high efficacy directly translates into substantial improvements in the Air Quality Index (AQI) of the surrounding environment, reducing harmful particulate matter (like PM2.5 and PM10) and airborne pathogens, which minimizes the risk of respiratory and other health issues.

B. System Performance

Regarding System Performance, the core metric is the system's ability to operate autonomously and efficiently using renewable energy. By integrating photovoltaic (PV) solar panels and a power storage battery, these purifiers can operate continuously for extended periods, with some designs demonstrating up to 14 hours of daily run time using stored solar energy, which includes periods of low sunlight or at night. The use of a solar charge controller ensures stabilized power and prevents reverse current flow, thus maintaining optimal battery health and system longevity. Furthermore, the inclusion of IoT sensors (like the MQ135 and DHT11) allows for real-time monitoring of air quality, enabling the system to intelligently adjust fan speed and operation based on pollution levels, which conserves energy and maximizes purification efficiency, thereby reducing dependency on the conventional electrical grid.

VII. CONCLUSION

This solar-powered air purifier project represents a significant step towards addressing the critical issue of air pollution in a sustainable and environmentally conscious manner. By leveraging renewable solar energy, the system effectively mitigates reliance on conventional power grids, making it an ideal solution for remote areas or locations with inconsistent electricity access. The successful integration of the IoT-based monitoring system ensures real-time data acquisition, allowing for informed decision-making and efficient, automated operation of the purification mechanisms. This project confirms the feasibility of combining smart technology with clean energy to create

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