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Design and Fabrication of Solar Powered Pollution Control System: A Performance and Economic Analysis

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Abstract- Air pollution is a critical global challenge, particularly in urban and industrial corridors. This study presents the design, fabrication, and performance evaluation of an autonomous solar powered air pollution control system. The prototype integrated a 100 W photovoltaic (PV) panel, a 12V 20Ah battery, and a multistage filtration unit consisting of a pre-filter, HEPA filter, and activated carbon filter. The experimental results indicate a maximum solar power generation of 38.8 W and a battery backup time of 8.5 h. The system achieved a significant reduction in pollutants, with average efficiencies of 70.4% for PM_{2.5} and 68% for PM₁₀. Economic analysis shows a 40–60% reduction in the total project cost compared to commercial alternatives, demonstrating the feasibility of the system for small-scale industrial and roadside applications.

Keywords: Solar Energy, Air Purification, HEPA Filter, Pollution Control, Renewable Energy, PM_{2.5}.

I.INTRODUCTION

Air pollution has become one of the most pressing environmental and public health concerns worldwide, particularly in rapidly urbanizing and industrialized regions. The continuous rise in vehicular emissions, industrial activities, and construction processes has led to a significant increase in airborne pollutants such as particulate matter (PM_{2.5} and PM₁₀), carbon monoxide (CO), and sulfur dioxide (SO₂). Prolonged exposure to these pollutants poses serious health risks, including respiratory and cardiovascular diseases, thereby necessitating the development of effective air quality management solutions.

Conventional air purification systems are predominantly designed for indoor use and rely heavily on grid-based electricity. While these systems are effective in controlled environments, their applicability in outdoor or remote locations is limited due to high energy consumption, installation constraints, and operational costs. Moreover, the increasing demand for sustainable and energy-efficient technologies has highlighted the need to transition toward cleaner and renewable energy-driven solutions.

In this context, solar energy emerges as a promising alternative due to its abundance, renewability, and environmental compatibility. The integration of photovoltaic (PV) systems with air purification technologies enables the development of autonomous systems capable of operating independently of conventional power sources. Such systems are particularly advantageous for deployment in roadside environments, industrial zones, and off-grid locations where air pollution levels are typically high.

Recent advancements in filtration technologies, including High-Efficiency Particulate Air (HEPA) filters and activated carbon filters, have significantly improved the capability of air purifiers to capture fine particulate matter and gaseous pollutants. When combined with efficient airflow management systems,



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these filters can substantially enhance pollutant removal efficiency. However, the challenge lies in designing a system that balances filtration performance, energy consumption, and cost effectiveness.

The present study focuses on the design, fabrication, and performance evaluation of a solar powered air pollution control system. The proposed system integrates a photovoltaic energy source with a multi-stage filtration unit to provide a sustainable and portable solution for outdoor air purification. In addition to evaluating the system's pollutant removal efficiency, the study also examines its energy performance and economic feasibility, thereby offering a comprehensive assessment of its practical applicability.

II. LITERATURE REVIEW

Recent research has focused on integrating renewable energy sources with advanced filtration technologies. Pojta et al. (2021) developed a low cost solar purifier that achieved a 96% clean-air production rate over 14 h of daily operation [1]. Ganesh et al. (2022) emphasized the importance of multi-stage filtration, combining HEPA and activated carbon with UV lights for outdoor PM₁₀ and PM_{2.5} treatment [3]. Furthermore, hybrid systems using both solar and wind energy have shown substantial reductions in CO and HC emissions near traffic sources [5]. These studies underscore the transition towards autonomous purification systems that utilize real-time air quality monitoring [6, 7].

III. PROBLEM STATEMENT

Rapid urbanization and industrial growth have led to a substantial increase in air pollution levels, particularly in roadside and industrial environments. High concentrations of particulate matter (PM_{2.5} and PM₁₀) and harmful gases such as carbon monoxide (CO) and sulfur dioxide (SO₂) pose serious risks to human health and the environment. Conventional air purification systems are primarily designed for indoor use and depend on continuous grid electricity, making them unsuitable for outdoor or remote applications. Additionally, commercially available systems are often expensive, energy-intensive, and lack portability, limiting their widespread deployment in pollution-prone areas. Therefore, there is a critical need to develop an efficient, cost-effective, and portable air pollution control system that can operate independently of grid power while maintaining adequate pollutant removal efficiency for outdoor conditions.

IV. OBJECTIVES

The main objectives of the present study are:

1. To design and develop a solar-powered air pollution control system suitable for outdoor and off-grid applications.
2. To fabricate a prototype incorporating a photovoltaic energy system and a multi stage air filtration unit.
3. To evaluate the performance of the system in terms of pollutant removal efficiency for PM_{2.5}, PM₁₀, and gaseous pollutants.
4. To analyze the energy performance of the system, including solar power generation, battery backup, and overall efficiency.
5. To conduct an economic analysis to assess cost-effectiveness and payback period in comparison with conventional air purification systems.
6. To propose potential improvements and future enhancements for large-scale and continuous operation.



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V. METHODOLOGY

The project was executed in the following structured phases:

1. Problem Identification: Analyzing the surge in urban air pollution and selecting solar energy as a viable power source.
2. Design Phase: Utilization of CAD software for 2D drawings and calculation of airflow rates.
3. Material Procurement: Sourcing components such as PV panels, DC blowers, and HEPA filters based on cost efficiency.
4. Fabrication: Structural welding, component mounting and electrical wiring.
5. Testing and Analysis: Measurement of solar output, battery cycles, and filtration efficiency.

VI. DESIGN AND FABRICATION

System Components

The system consists of a Mild Steel (MS) angle frame supporting the following:

- Solar Panel: 100 W PV module for energy harvesting.
- Energy Storage: 12V 20Ah Lead-Acid battery.
- Blower: 12V DC motor blower for air suction.
- Filtration Unit: Pre-filter (large particles), HEPA filter (fine PM), and Activated Carbon filter (gases/odors).

Fabrication Process

The frame was cut using a power hacksaw and joined by arc welding. The solar panel was mounted at an optimal tilt angle to achieve maximum irradiance. The DC blower and filter chamber were installed within a custom duct arrangement, followed by electrical connections to the charge controller and battery.

VII. EXPERIMENTAL RESULTS AND DISCUSSION

Solar and Battery Performance

The system was tested under varying sunlight conditions. Peak power generation was observed at 1:00 PM, reaching 38.8 W under an irradiance of 890 W/m².

Table 1: Solar Performance Data

Time	Solar Irradiance (W/m ²)	Panel Voltage (V)	Current (A)	Output Power (W)
9:00 AM	520	14.8	1.0	14.8
11:00 AM	760	17.6	1.7	29.9
1:00 PM	890	18.5	2.1	38.8
3:00 PM	710	16.9	1.5	25.3



5:00 PM	480	13.6	0.9	12.2
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The battery reached a full charge (13.5V) within 6 h of peak sunlight, providing a total backup time of 8.5 h for the blower.

Air Quality Improvement

The tests were conducted at a high-traffic roadside location. The system demonstrated robust removal of particulate matter and gas pollutants.

Table 2: Air Quality Measurement (Before vs. After)

Parameter	Before ($\mu\text{g}/\text{m}^3$ or ppm)	After ($\mu\text{g}/\text{m}^3$ or ppm)	% Reduction
PM2.5	162	48	70.4%
PM10	225	72	68.0%
CO	9.1	2.9	68.1%
SO ₂	0.041	0.015	63.0%

Efficiency Calculations

• Air Flow Rate:

With a duct diameter of 0.15 m and air velocity of 3.2 m/s, the flow rate (Q) was calculated as 203.7 m³/hr.

• Pollution Removal Efficiency:

Calculated using the formula:

$\eta = (C_{\text{before}} - C_{\text{after}}) / C_{\text{before}} \times 100$ The average efficiency obtained was 67%. • System Energy

Efficiency:

The ratio of useful blower power to solar power was found to be 46.3%.

Economic and Operational Analysis

The total project cost was approximately Rs 9,500, which is significantly lower than that of commercial systems (Rs 35,000+). With zero daily operating costs, the estimated payback period is 2–2.5 years compared with grid-powered units.

VIII. CONCLUSION AND FUTURE SCOPE

The developed solar-powered pollution control system successfully achieved a balance between filtration efficiency and energy sustainability. It provides a 70% reduction in PM2.5 levels, without any dependency on grid electricity.

Future Scope includes:

- Integration of IoT for real-time remote air quality monitoring.
- Implementation of an automatic self cleaning mechanism for the filters.
- Scaling the design for larger industrial exhaust systems is required.



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- Addition of hybrid wind-solar charging for 24/7 operations.

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