

Robust Power Supply Design and Parameter Monitoring of Electrostatic Precipitator

Ujjwal Thor^{1,*}, Gaurav Shinde¹, Rajat Samrit¹, Vrushali G. Raut¹

Abstract

This paper focuses on the development of a high-performance power supply system tailored for electrostatic precipitators (ESPs) to improve their efficiency in industrial applications. The proposed system converts alternating current (AC) to direct current (DC) using an AC to DC converter, followed by a boost converter to elevate the output voltage to the levels required for effective ESP operation. The boost converter ensures the output voltage remains stable, compensating for fluctuations and optimizing performance. Additionally, a robust monitoring system is integrated to continuously measure and analyze critical parameters such as temperature, vibrations, and ground resistance of ESP. This monitoring system enhances safety and reliability by enabling predictive maintenance and rapid fault detection. The overall design aims to achieve high power conversion efficiency, precise voltage control, and comprehensive monitoring, thus ensuring the effective and sustained performance of electrostatic precipitators in minimizing air pollution.

Keywords: Electrostatic precipitator, monitoring system, ESP32, real-time monitoring, direct current (DC)

INTRODUCTION

Electrostatic precipitators (ESPs) are widely used in industrial applications for controlling air pollution by efficiently capturing and removing particulate matter from exhaust gases. The effectiveness of an ESP is highly dependent on the reliability and performance of its power supply system. To achieve optimal performance, it is crucial to maintain a consistent and high voltage, as well as monitor various parameters that influence the ESP's efficiency and operational safety.

This project aims to develop a power supply system that enhances the performance of ESPs by converting alternating current (AC) to direct current (DC) using an AC to DC converter. The DC output is then further boosted to the required high voltage using a boost converter, ensuring stable and efficient operation even under variable conditions [1–5].

*Author for Correspondence

Ujjwal Thor
E-mail: ujjwalthor007@gmail.com

Student, Department of Electronics and Telecommunication Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India

Received Date: June 03, 2025
Accepted Date: September 04, 2025
Published Date: December 26, 2025

Citation: Ujjwal Thor, Gaurav Shinde, Rajat Samrit, Vrushali G. Raut. Robust Power Supply Design and Parameter Monitoring of Electrostatic Precipitator. International Journal of Power Electronics Controllers and Converters. 2025; 11(2): 62–68p.

To safeguard the system and facilitate predictive maintenance, a comprehensive monitoring system is integrated to measure key parameters such as temperature, vibrations, and ground resistance. By continuously tracking these factors, the monitoring system enables early detection of potential faults, enhances the safety and reliability of the ESP, and ensures long term operational stability [6–10].

This project combines efficient power conversion, voltage regulation, and real-time monitoring to support cleaner industrial processes and reduce environmental impact.

RELATED WORK

An electrostatic precipitator (ESP) is a highly efficient filtration device used to remove fine particles, such as dust and smoke from a flowing gas, using the force of an induced electrostatic charge. In this system, the flue gas is first passed through a pre-treatment chamber to distribute the particles evenly before entering the ESP unit. The core operation involves two primary components: discharge electrodes and collecting plates. A high-voltage power supply, typically delivering DC voltage in the range of 20–100 kV, is applied between these electrodes and plates. As the gas passes through the ESP, the discharge electrodes ionize the particles by generating a corona discharge. These ionized particles become negatively charged and are attracted to the positively charged collecting plates, where they accumulate and form a dust layer. Periodically, mechanical rapping mechanisms or vibrating devices dislodge this accumulated layer, allowing it to fall into hoppers for removal.

In the context of the project, the power supply unit is designed to provide stable and adjustable high-voltage DC output to ensure efficient particle charging and collection. Advanced monitoring of key parameters, such as input and output voltage, current, temperature, and spark rate, is integrated into the system. These parameters are continuously tracked using sensors and microcontroller-based circuitry, enabling real-time data acquisition and safety control. Monitoring these variables not only helps in optimizing ESP efficiency but also ensures safe operation by detecting abnormalities like voltage spikes, insulation failures, or excessive particulate loading. Overall, the developed power supply and monitoring system significantly enhance the operational reliability, environmental compliance, and maintenance capabilities of electrostatic precipitators.

SYSTEM ARCHITECTURE DESIGN

Power Supply for ESP

- Step Down Motor (230V to 5V) Reduces 230V AC from the mains to 5V AC for safer running and processing.
- AC to DC Conversion (Diodes 1N4007) Converts 5V AC to 5V DC using diode rectification.
- Boost Converter Converts the 5V DC to an advanced voltage using a boost motor circuit. The control of this circuit is regulated by PWM signals.
- PWM frequency and Duty Cycle creator This module adjusts the frequency and duty cycle of the PWM signal to control the IRF540N MOSFET, which governs the voltage boost process.
- Affair Voltage dimension the final affair voltage is measured with a digital multimeter to validate successful voltage conversion from Figure 1.

ESP32 Microcontroller Unit

This unit serves as the core regulator of the system. It performs several crucial functions:

- Collects data from colorful detectors (temperature, vibration, ground resistance).
- Manages data processing and visualization.
- Handles communication through its erected – in Wi-Fi module.

Sensors Connected to ESP32

- *Temperature Sensor*: Measures the temperature of the ESP or surrounding environment to ensure that the system operates within safe temperature limits.
- *Vibration Sensor*: Monitors vibrations in the ESP structure to detect potential mechanical issues or instabilities.
- *Ground Resistance Sensor*: Measures the resistance to ground, ensuring that the ESP is properly grounded for safe and efficient operation.

System Flow

- *The system consists of two main sections*: Power conversion and sensor monitoring.
- It starts with a Step-Down Transformer that converts 230V AC to 5V AC.

- This AC voltage is then rectified using 1N4007 diodes to obtain DC voltage.
- The DC voltage is fed into a Boost Converter, controlled by a PWM Frequency and Duty Cycle Generator, which regulates the gate of an IRF540N MOSFET.
- The boosted output voltage is measured using a Digital Multimeter to verify conversion accuracy.
- A regulated power supply powers the ESP32 Microcontroller, which collects data from the connected sensors: Ground Resistance, Temperature, and Vibration.
- The ESP32 processes this data and sends it to a web page using its built in Wi-Fi capabilities. This enables real-time monitoring from any internet-connected device, making the system highly suitable for smart monitoring in industrial, environmental, and infrastructure applications.

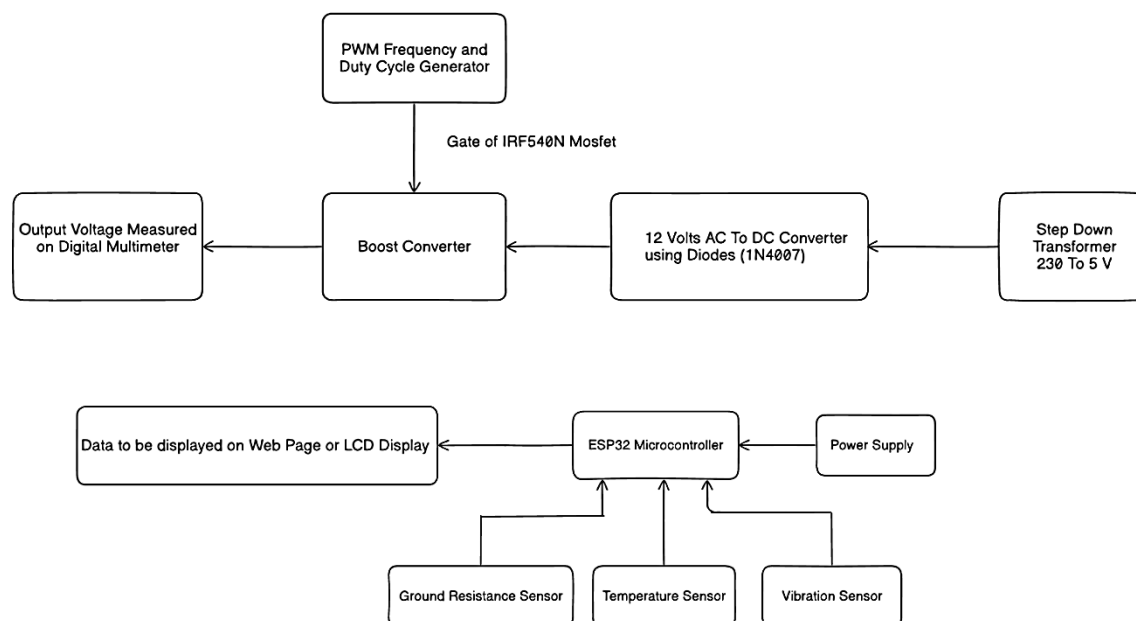


Figure 1. Block diagram of proposed system.

HARDWARE USED

Power Supply Components

The power supply system of the project is designed to convert high-voltage AC from the mains into a stable high-voltage DC suitable for the operation of an Electrostatic Precipitator (ESP). It begins with a step-down transformer that converts 230V AC into a safer 5V AC. This AC voltage is then converted into DC using a bridge rectifier circuit built with 1N4007 diodes, which can handle up to 1000V and 1A current. To remove ripples and stabilize the DC voltage, capacitors are used for filtering; these also serve an essential role in the subsequent boost conversion stage from Figure 2. A 220 μH inductor is used along with a boost converter to step up the 5V DC to the high voltage required for effective ESP operation. The boost converter is controlled using a PWM (Pulse Width Modulation) generator circuit, which adjusts the duty cycle to regulate the output voltage. The switching in the boost converter is achieved using an IRF540N MOSFET, which functions as a high-speed electronic switch. The boosted output voltage is verified using a digital multimeter to ensure accuracy and system efficiency. Collectively, these components ensure a reliable, efficient, and high-performance DC power supply tailored for industrial ESP systems.

MONITORING SYSTEM COMPONENTS

ESP32 Microcontroller

The ESP32 is a powerful, low-cost microcontroller from Figure 3 with integrated Wi-Fi and Bluetooth capabilities, widely used in IoT applications. It features dual-core processing, allowing for efficient multitasking, and supports various programming environments, including Arduino and Micro Python. With its rich set of peripherals, such as GPIO, ADC, and PWM, the ESP32 is ideal for projects

requiring connectivity and sensor integration. Its versatility and affordability make it a popular choice among hobbyists and professionals alike.



Figure 2. Power supply components.

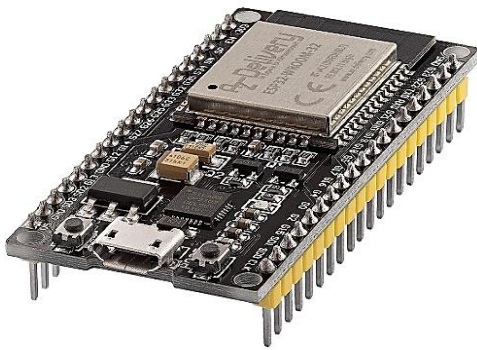


Figure 3. Esp32 microcontroller.

DS18B20 Temperature Sensor

The DS18B20 is a digital temperature sensor from Figure 4 that communicates over a 1-Wire interface. It provides 9 to 12-bit temperature readings, with a range of -55°C to $+125^{\circ}\text{C}$. The sensor is known for its accuracy and ease of use, making it popular in various applications, including weather stations and home automation systems. Its unique 1-Wire protocol allows multiple sensors to be connected to a single data line, simplifying wiring and reducing costs.

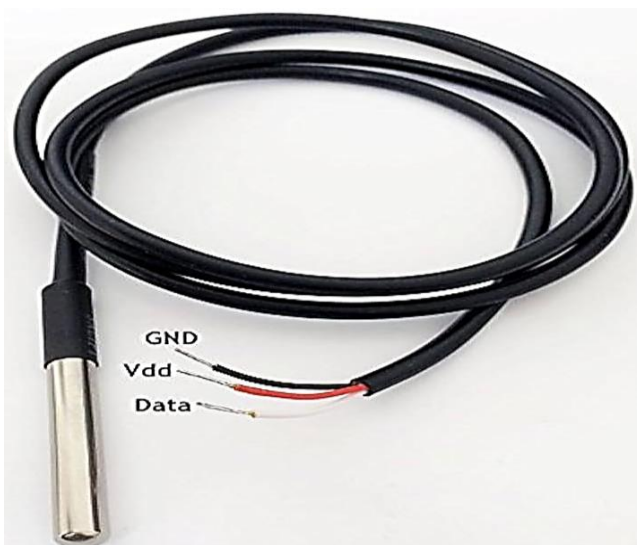


Figure 4. DS18B20 temperature sensor.

ADXL345 Accelerometer

ADXL345 is a small, thin, low-power from Figure 5, 3-axis accelerometer with high resolution (13-bit) measurement at up to $\pm 16g$. It communicates via I2C or SPI interface and features a built-in motion detection capability, making it suitable for various applications such as mobile devices, gaming, and health monitoring. The device also includes a tap detection feature, free-fall detection, and activity/inactivity monitoring, which can help in power management and enhancing user experience in portable devices.



Figure 5. ADXL345 accelerometer.

INA219 High Side Current Sensor

The INA219 High Side Current Sensor from Figure 6 is a precision device used for measuring current, voltage, and power in various applications. It operates on the principle of high-side sensing, allowing it to measure current flowing through a load while maintaining isolation from ground. The sensor communicates via I2C, making it easy to integrate with microcontrollers.

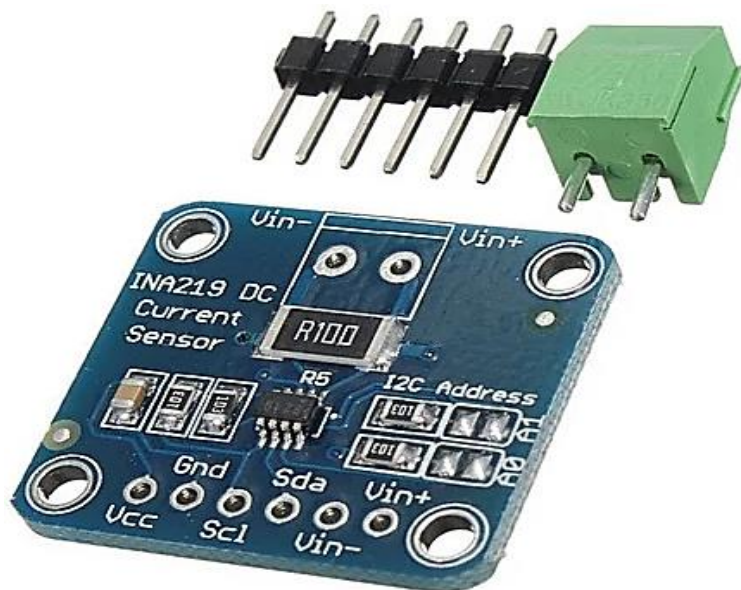


Figure 6. INA219 high side current sensor.

Its high accuracy and low offset voltage make it ideal for battery management systems and energy monitoring. In resistance measurement, the INA219 can help determine the resistance by calculating voltage drop across a known resistor, providing valuable data for efficiency analysis in electronic circuits.

RESULTS AND DISCUSSION

The developed power supply system successfully converted a 5V input into a stable high-voltage DC output using a boost converter from Figure 7 (a), achieving up to 100V. Components, like the IRF540N MOSFET and 220 μH inductor, ensured efficient operation. The ESP32 microcontroller effectively interfaced with sensors – DS18B20 for temperature, INA219 for ground resistance, and ADXL345 for vibration – and transmitted real-time data via Wi-Fi. All system functionalities were verified through simulation and hardware testing.

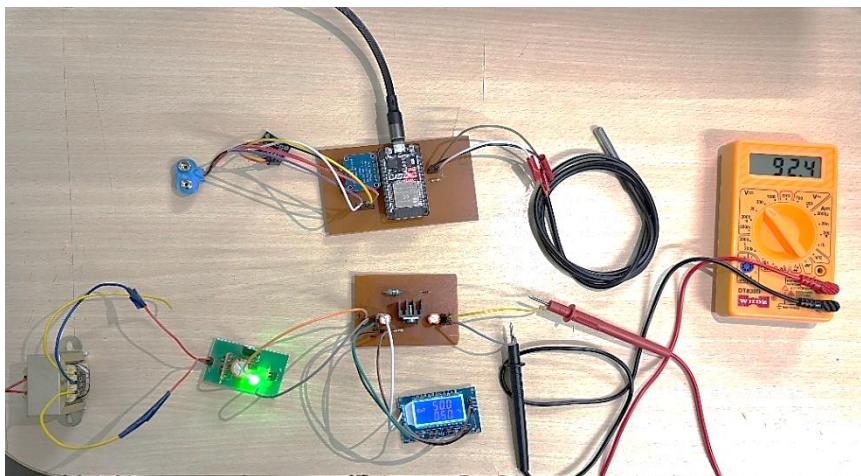


Figure 7 (a). Hardware result of power supply.

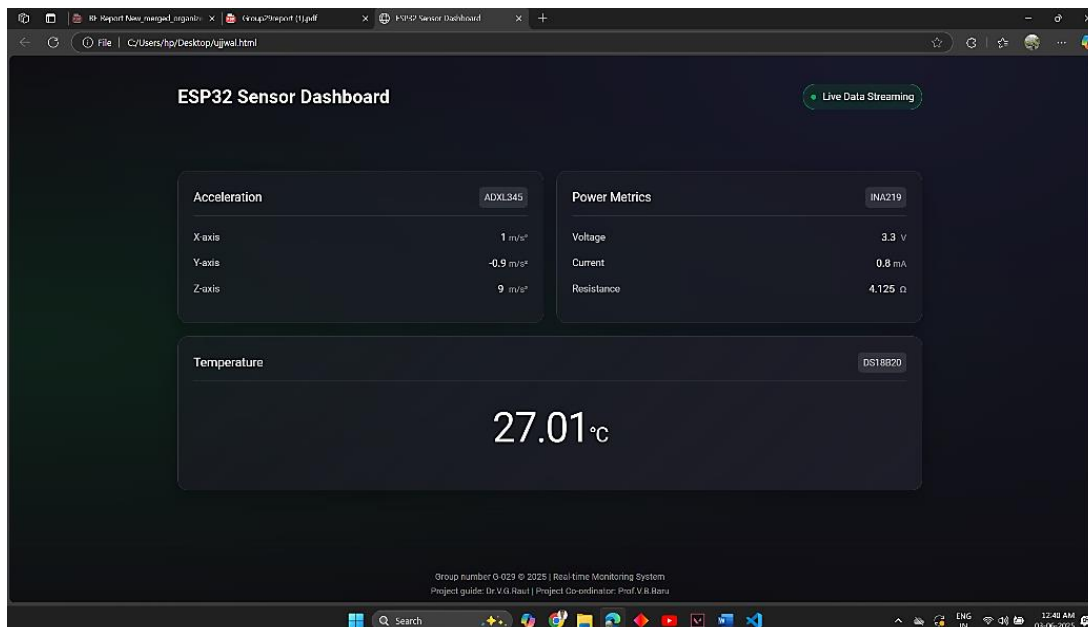


Figure 7 (b). Software result of monitoring system.

The system demonstrated reliable high-voltage generation from Figure 7 (b) and effective real-time monitoring, addressing key limitations in traditional ESP setups. The high-duty-cycle boost converter worked well up to 100V, though higher outputs. The integrated sensor system significantly improved

fault detection and maintenance efficiency. Overall, the project enhanced the safety, performance, and monitoring capabilities of ESP systems.

CONCLUSIONS

In conclusion, the development of a high-efficiency power supply system for electrostatic precipitators addresses critical challenges in industrial air pollution control. By employing an AC to DC converter coupled with a boost converter, the system ensures a stable and consistent high voltage, enhancing the particle collection efficiency of ESPs.

The integration of a real-time monitoring system for parameters, such as temperature, vibrations, and ground resistance, significantly improves reliability and safety, enabling proactive maintenance and reducing operational costs.

This innovative approach not only enhances the performance and longevity of electrostatic precipitators but also supports environmental compliance by minimizing harmful emissions. Overall, the proposed system contributes to cleaner and safer industrial operations, promoting sustainable and eco-friendly practices.

Acknowledgments

This project titled “To Develop a Power Supply for Electrostatic Precipitator (ESP) and Monitor Its Parameters” has been realized due to the guidance and support of many individuals, without whom I would not have succeeded in implementing my ideas. I would like to take this opportunity to express my heartfelt gratitude to them.

I would like to thank Prof. V. G. Raut Mam for the invaluable support and guidance that she has imparted throughout the duration of this project. I am truly grateful to her for her constant encouragement, timely feedback, and motivation that greatly contributed to the successful completion of this work.

I extend my special thanks to the Head of the Department of Electronics and Telecommunication, Dr. M. B. Mali, for his continuous support and for providing the necessary resources and infrastructure. I would also like to thank all the faculty members and staff of the department for their cooperation and assistance at various stages of the project.

Their collective support and encouragement made this work possible. Thank you all.

REFERENCES

1. Sharma A, Patel PK. Design and optimization of electrostatic precipitators for industrial applications. In: IEEE Industry Applications Society Annual Meeting; 2019.
2. Goyal VK, Shukla A. Isolated DC–DC boost converter for wide input voltage range and wide load range applications.
3. Omkar N, Rahul S, Vijaykrishna R. Smart environmental monitoring using ESP32 microcontroller. IOSR J Electron Commun Eng (IOSR-JECE). 2020.
4. Yetter RA, Stein SW. Review of electrostatic precipitator technology. IEEE Trans Ind Appl. 2018.
5. Subhani N, May Z, Alam MK, Khan I. An improved non-isolated quadratic DC–DC boost converter with ultra-high gain ability. IEEE Trans Ind Electron. 2021.
6. Rashid MH. Power electronics: Circuits, devices and applications. 4th ed. Pearson Education; 2013.
7. Kumar P, Jain A. Design and simulation of high voltage DC–DC boost converter. Int J Eng Res Technol (IJERT). 2021.
8. Subramaniam K. Real-time monitoring system for industrial equipment using IoT. Int J Comput Appl. 2020;177(25).
9. Kuphaldt TR. Lessons in electric circuits – Volume 3: Semiconductors. Open Book Project; 2007.
10. Vahid F, Givargis T. Embedded system design: A unified hardware/software introduction. Wiley; 2002.