Project Abstract

Industrial particulate emissions from sectors such as thermal power plants, cement manufacturing, steel production, chemical processing, and waste-to-energy facilities pose a significant threat to ambient air quality, particularly in densely populated industrial clusters. Fine particulate matter, especially $PM_{2.5}$ and PM_{10}, is directly associated with respiratory disorders, cardiovascular diseases, environmental degradation, and non-compliance with national emission standards. Electrostatic Precipitators (ESPs) are widely deployed across industries due to their ability to remove particulate matter with relatively low pressure drop and operating cost compared to fabric filters and wet scrubbers. However, conventional ESP systems powered by high-voltage DC or high-frequency AC supplies often fail to achieve optimal collection efficiency for ultrafine particles (<2.5 μm). Limitations such as inadequate particle charging, non-uniform corona field distribution, re-entrainment, back corona effects, high energy losses, and restricted dynamic control of pulse characteristics hinder their performance. Furthermore, many existing ESP installations in India rely on imported and outdated power supply systems that are energy-intensive and insufficiently optimized for Indian industrial flue gas conditions, including variations in temperature, humidity, particulate resistivity, and chemical composition.

This project proposes the design, development, and validation of a cost-effective, pulse-energized Electrostatic Precipitator powered by a single-phase PWM-based power converter integrated with an optimized pulse transformer and intelligent digital pulse control. Unlike conventional systems, the proposed solution will generate programmable high-voltage pulses with adjustable amplitude, duty cycle, frequency, rise/fall time, and waveform shape (square or composite), enabling precise control over corona initiation and particle charging. Rapid pulse rise times will enhance ionization efficiency and improve ion drift velocity, thereby increasing collection efficiency for fine particulates while minimizing spark generation and back corona effects. Key design parameters—including discharge gap configuration, electrode geometry, transformer insulation coordination, impedance matching, and flue gas characteristics—will be systematically optimized through modeling, simulation, and prototype validation. Adaptive control algorithms using microcontroller/DSP-based systems will dynamically regulate pulse parameters in response to load and process variations, ensuring stable corona discharge and energy-efficient operation.

Benchmarking against conventional DC ESPs, high-frequency AC systems, and global pulse-energized ESP technologies indicates that while pulse systems can achieve up to 99.5% efficiency for fine particles, existing commercial solutions are costly, complex (often three-phase based), and maintenance-intensive. The proposed single-phase pulse ESP aims to deliver $\geq 99\%$ efficiency for particles >2.5 μm and $\geq 90\%$ efficiency for $PM_{2.5}$, with energy consumption not exceeding 1.5 kWh per 1,000 m^3 of treated gas. High-voltage electrodes will be designed for reliable operation up to 70 kV with integrated spark suppression, arc detection, over-voltage protection, insulation monitoring, and emergency shutdown mechanisms to ensure safety and reliability. The modular design approach will enhance maintainability while reducing footprint and installation complexity.

By replacing conventional imported power supplies with an indigenous, optimized single-phase pulse converter architecture, the proposed system is expected to reduce overall system cost by 30–40% compared to commercially available pulse ESP solutions, without compromising performance. The project will also enable retrofitting of existing ESP installations, significantly improving fine particle collection efficiency, reducing energy

losses, and lowering industrial pollution levels. Beyond environmental benefits, the development of this technology presents strong potential for intellectual property (IP) generation, export opportunities, and large-scale commercialization across Indian and global markets. The outcome will contribute to cleaner industrial operations, regulatory compliance, and advancement of indigenous high-voltage power electronics solutions tailored to real-world industrial conditions.