Scaled down Electrostatic Precipitator for duct cleaning of HVAC systems

1st Kimali Ginige
dept. Electrical Engineering
University of Moratuwa
Colombo, Sri Lanka
ginigekp.21@uom.lk

2nd Manuli Gavinya
dept. Electrical Engineering
University of Moratuwa
Colombo, Sri Lanka
gavinyauhm.21@uom.lk

3rd Kaviru Nimsith
dept. Electrical Engineering
University of Moratuwa
Colombo, Sri Lanka
galagamaarachchigadkn.21@uom.lk

***Abstract*—Introducing a revolutionary Electrostatic Precipitator (ESP) for commercial HVAC ducts, our real-time cleaner operates seamlessly during airflow, eliminating the need for post-accumulation cleaning. This scaled-down version draws inspiration from industrial ESPs, utilizing electrostatic principles to attract and ground charged particles on collector plates. An automatic voltage controller and dual transformers ensure optimal performance and safety. Once the dust accumulated in the collector plates exceeds the expected level, a novel robotic arm, integrated with the vacuum system, provides targeted cleaning, advancing indoor air quality without compromising efficiency. Experimental results highlight substantial reductions in dust and pollutants, marking a transformative leap in residential air purification.**

I. Introduction

Indoor air quality in HVAC systems is confronted by a diverse array of particles, spanning dust (0.1 - 100 micrometres), allergens (5 - 50 micrometres), and fine aerosols. Within the HVAC system, distinct sections exhibit varying average particle sizes, ranging from 41.300 micrometres in the fresh air section to 6.505 micrometres in the air supply pipe [3]. Traditional Electrostatic Precipitators (ESPs), celebrated for achieving 99 per cent dust removal in large-scale applications, operate within the constraints of the Deutsch-Anderson equation. This project advances ESP technology for HVAC systems by introducing a highly efficient design comprising five integral subsystems: the power supply, precipitator box, vacuum suction system and an automatic voltage controller enhanced with a robotic arm mechanism. The aim is to achieve a minimum efficiency of 99 per cent at a remarkably low voltage of 1.5 kV, a feat substantiated through comprehensive experimental plots. Beyond the traditional ESP framework, we delve into the intricacies of our enhanced system, detailing the integration of a robotic arm mechanism attached to the vacuum suction system. This dynamic addition optimizes the cleaning process, ensuring real-time responsiveness to dust accumulation, thus elevating the system's efficiency. Throughout this project report, we discuss the design, construction, and operation of our innovative ESP system. Empirical data will be presented, illustrating its collection efficiency concerning particle sizes and supply voltages. This evolution in ESP technology not only promises a practical solution for augmenting indoor air quality but also aligns with sustainability goals. Moreover, its adaptability positions it as a versatile tool for addressing broader air quality concerns, marking a significant stride towards healthier and more sustainable living environments.

Identify applicable funding agency here. If none, delete this.

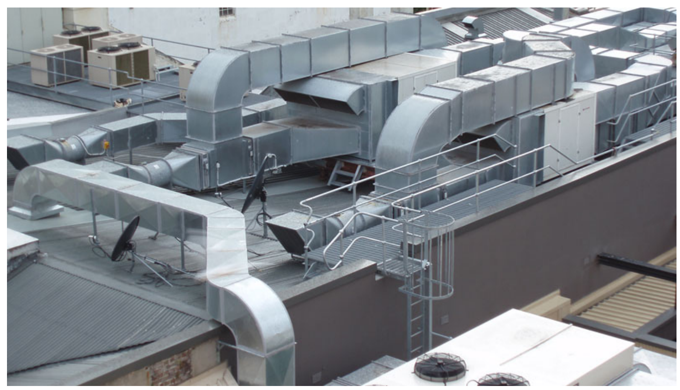

Fig. 1. AC ducts

II. Literature review

Indoor air quality (IAQ) within HVAC systems has been a longstanding concern due to the presence of diverse particles, ranging from dust to fine aerosols. The conventional Deutsch-Anderson equation has governed the principles of Electrostatic Precipitators (ESPs), renowned for their efficacy in large-scale applications, achieving up to 99 per cent dust removal. As the demand for enhanced IAQ in residential and commercial spaces continues to grow, recent studies and advancements in ESP technology offer valuable insights.

Particle Dynamics in HVAC Systems: Particle sizes vary significantly within HVAC systems, with studies indicating different average sizes at distinct points, from the fresh air section to the air supply pipe. This diversity poses a challenge for effective particle removal strategies.

Traditional ESP Performance: Conventional ESPs have proven highly effective in large-scale applications, achieving remarkable dust removal rates. However, adapting these principles to HVAC systems requires a nuanced understanding of particle dynamics and system constraints.

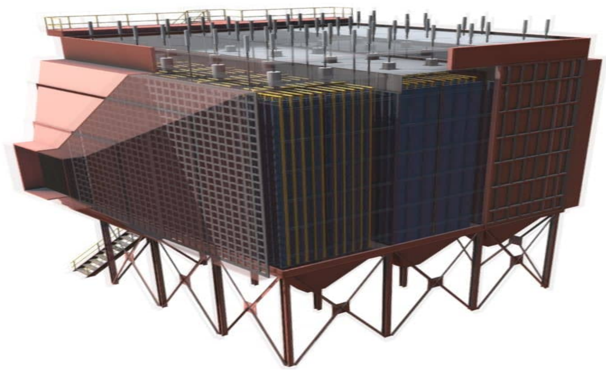

Fig. 2. Conventional Electrostatic precipitator

ESP Design and Subsystems: Recent literature emphasizes the significance of ESP subsystems, particularly the power supply, precipitator box, automatic voltage controller, robotic arm and vacuum suction system. While existing ESP designs excel in specific contexts, there is room for innovation to address the unique challenges posed by HVAC systems.

Advancements in Voltage Control and Efficiency: Efforts to minimize voltage requirements for ESPs have gained traction in recent studies, aiming to enhance energy efficiency without compromising dust removal rates. The objective is to achieve a balance between performance and energy consumption.

III. Problem statement

The existing challenge revolves around the inadequacy of conventional methods in maintaining optimal indoor air quality (IAQ) within HVAC systems. These methods lack real-time operation during airflow and face difficulties in addressing the diverse range of particle sizes present in various sections of HVAC systems. Additionally, current Electrostatic Precipitator (ESP) designs do not encompass the integration of a voltage control mechanism and a robotic arm mechanism coupled with a vacuum suction method, limiting both the efficiency and adaptability of the system within the dynamic context of HVAC ducts.

To overcome these limitations, this research addresses the imperative need for an innovative solution. The aim is to design, develop, and validate a new ESP system with a voltage control mechanism and a vacuum suction method seamlessly connected to a robotic arm. This integrated approach aims to achieve a minimum efficiency of 99 per cent in dust removal at a low voltage of 1.5 kV. By filling the existing gaps in IAQ management within HVAC systems, this study seeks to enhance the overall efficiency and responsiveness of the ESP system to varying particle sizes and operational conditions

IV. Proposed Mechanism:

The proposed Electrostatic Precipitator (ESP) system integrates a multi-functional mechanism for efficient air purification within HVAC ducts:

Electrostatic Precipitation: Applies the basic ESP working principle of particle charging using electrical energy. Charged particles are attracted to collector plates carrying the opposite charge. Ionized particles are diverted towards the plates and grounded, facilitating efficient dust capture.

Control of voltage: Utilizes an automatic voltage controller and dual transformers to maintain optimal corona power. Aims to achieve a consistent average output voltage, accommodating load variations and ensuring efficient particle charging. Robotic Arm with Vacuum Suction:

Cleaning of plates: A robotic arm, attached to the collector plates, operates in a rectangular path. The arm is integrated with a vacuum suction system, featuring a nozzle as the head. Enables real-time and targeted cleaning, responding to dust accumulation on collector plates.

Dust Level Detection: It incorporates a mechanism to detect dust levels on collector plates. Initiates the robotic arm and vacuum suction process when the dust level surpasses a predefined threshold.

Particle Charging: Electrical energy is used to charge particles, either positively or negatively. The charged particles are attracted to collector plates, creating an electrostatic force.

Ionization and Collection: Ionized particles, subjected to the electrostatic force, are diverted towards collector plates. Grounded plates efficiently collect and trap the charged particles, effectively removing them from the airflow.

Real-time Cleaning with Robotic Arm: The robotic arm, moving in a predefined rectangular path, ensures systematic coverage of collector plates. Integrated vacuum suction, initiated based on dust level detection, removes accumulated particles in real time.

Adaptive Cleaning and Efficiency Enhancement: The entire mechanism adapts to changing dust levels, providing real-time cleaning. The integration of the robotic arm and vacuum suction optimizes efficiency by addressing dust accumulation promptly. The synergy of these mechanisms creates a responsive and efficient ESP system, capable of maintaining high air quality within HVAC ducts through real-time, targeted cleaning and optimized corona power gen

V. System overview:

The design and implementation of the real-time Electrostatic Precipitator (ESP) for residential HVAC ducts involves a comprehensive approach to achieve continuous, proactive air quality improvement. This section outlines the methodology used in the development, installation, and evaluation of the system.

A. *Design approach: power supply:*

Optimization for Electrostatic Precipitator Voltage in HVAC Systems

The efficient design of Electrostatic Precipitators (ESPs) is imperative with the significant manufacturing costs involved. This report aims to delve into the intricacies of designing ESPs, with a particular focus on calculating the optimum voltage required. Various critical parameters, including particle migration velocity, plate area of the ESP, particle diameter,

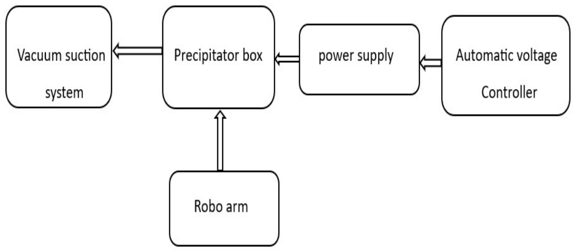

Fig. 3. System overview diagram with the subsystems

and gas flow rate, are considered in this comprehensive design approach.

Particle Migration Velocity:

The migration velocity is a key parameter as it dictates the speed at which dust particles move towards collecting plates after being charged within the ESP. It forms the foundational step in predicting the behaviour of charged particles within the precipitator. In the initial phase of ESP design, understanding the migration velocity of charged particles is fundamental. The migration velocity is computed using the formula [7]:

$$w = \frac{qE_p}{6\pi\mu r} \tag{1}$$

Where:
q = particle charge
E_p = Electric field strength (V/m)
μ = Gas viscosity
r = radius of the particles (on average)

Deutsch-Anderson equation for collection efficiency determination:

Following the determination of migration velocity, the subsequent step involves evaluating the collection efficiency (η) of the ESP. The Deutsche Anderson equation is utilized for this purpose. The Deutsch-Anderson equation provides a quantitative measure of the efficiency of particle collection within an ESP [7]. Understanding the interplay between migration velocity, effective collecting plate area, and gas flow rate is essential for optimizing ESP performance.

$$\eta = 1 - e^{-w(A/Q)} \tag{2}$$

Where:
η = collection efficiency of the precipitator
w = migration velocity (cm/s)
A = effective collecting plate area of the precipitator(m^2)
Q = gas flow rate through the precipitator(m^3/s)

Simulation and Voltage Requirement:

The MATLAB code presented below utilizes the provided Anderson equation to generate graphical representations illustrating the relationship between collection efficiency and voltage supply. The analysis focuses on a specified range of particle sizes, ranging from 1 to 100 micrometres, with specific data points at 20, 40, 60, 80, and 100 micrometres. The resulting plots facilitate a comprehensive understanding of how collection efficiency varies across this range of particle sizes concerning different voltage supplies. Following a thorough analysis of the plots, a voltage of 1.5 kV was identified as the optimal value for the given particle size range.

```
% Constants and Parameters
Q = 7; % Volumetric Flow Rate of gas through the precipitator(m^3/s)
A = 2; % Collecting Plate Area (m^2)

u = 1.81e-5;% gas viscosity
q = 1e-10;% particle charge for typical dust or aerosol
d = 0.25;%seperation between the electrode and the plate

% define a range of possible voltages
voltage = (0:1:1500);

%electric field strength
electric_field_strength=voltage/d;

figure,
for d = 20e-6:20e-6:110e-6

    % Calculate Particle migration velocity (w)
    w = (q*electric_field_strength)./(6.*pi.*u.*(d/2));

    % Calculate Particle Collection efficiency
    collection_efficiency = 1 - exp((-A.*w)./Q);

    plot(voltage,collection_efficiency);
    hold on;

end

legend('20 micrometer', '40 micrometer','60 micrometer', '80 micrometer', '100 micrometer')
title('collection efficiency vs voltage');
xlabel('voltage');
ylabel('collection efficiency')
```

Fig. 4. Matlab code

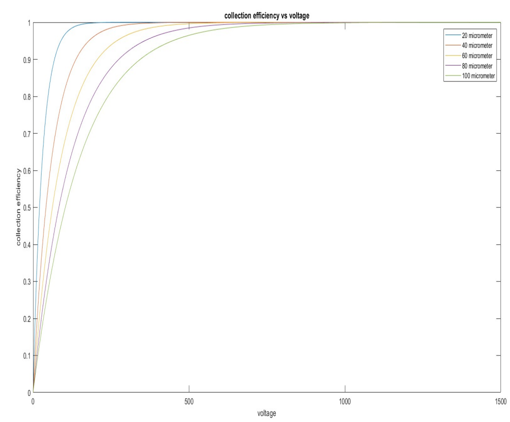

Fig. 5. plot of collection efficiency vs supply voltage

Power supply circuit design and simulation:

A power supply system has been meticulously engineered to effectively transform three-phase household power into a DC output of 1.5kV. This has been achieved through the careful selection of a step-up transformer with a tailored turns ratio. The chosen transformer ensures the delivery of the required output voltage. Additionally, a bridge rectifier circuit has been employed to rectify the AC output from the secondary winding of the transformer, converting it into a unidirectional DC output. The determination of the supply voltage was informed by the analysis of MATLAB plots, leading to the selection of 1.5kV as the optimal voltage for the system.

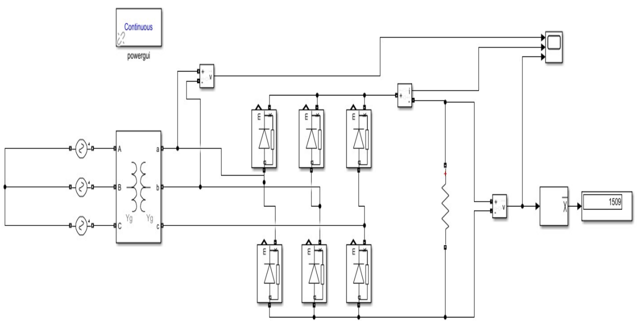

Fig. 6. Simulink model of the power supply

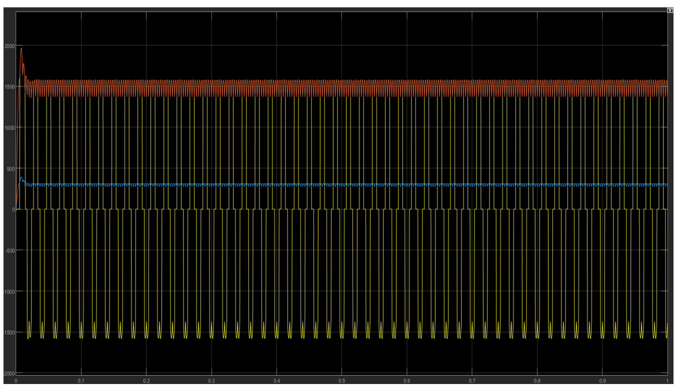

Fig. 7. output DC voltage(in red),output current(in blue),transformer output(yellow)

B. Design approach: precipitator box

The precipitator box is comprised of discharge electrodes and collector plates, each serving a distinct role in the particle removal process. The discharge electrodes undergo an electrical charge by applying a voltage of -750V, establishing an ionization zone within the box. As the gas-borne particles traverse this zone, they acquire a charge. Subsequently, these charged particles are irresistibly drawn to and captured on collector plates with a positive potential of +750V. The collector plates serve as surfaces where the particles attach and can be periodically cleaned. The arrangement of collector plates and discharge electrodes can vary depending on the scale of the application, with the number of layers adjusted accordingly. In our study, we conducted simulations to illustrate the potential variation among the electrodes and collector plates within the ESP precipitator (refer to Figure 4), offering valuable insights into the efficacy of the dust removal process. The ESP precipitator box itself is characterized by dimensions of 2 meters in length, 1 meter in height, and 1 meter in width. These specifications provide the framework for understanding the spatial configuration and performance of the precipitator in its entirety.

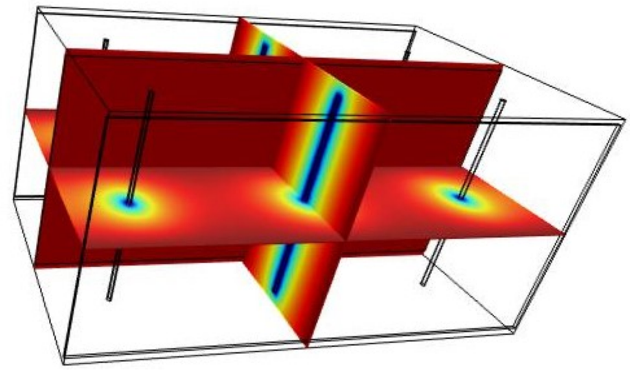

Fig. 8. comsol model of the precipitator and its potential variation from (-750V)-(+750V) i.e. 1.5kv supplied

C. Design approach: vacuum suction system

In our project, we have incorporated a vacuum suction system that plays a crucial role in maintaining the efficiency and performance of the real-time Electrostatic Precipitator (ESP) for residential HVAC ducts. This system ensures that the collector plates remain free of dust buildup, thus contributing to continuous improvement in indoor air quality (IAQ).

Vacuum Suction Mechanism

The vacuum suction system is designed to operate in harmony with the ESP, providing an hourly cleaning cycle. This cycle prevents the saturation of collector plates, ultimately extending the time between manual maintenance and enhancing the overall effectiveness of the ESP.

The suction system consists of a centrifugal fan, which is powered by an electrical motor. This fan generates the necessary suction force to remove the captured dust from the collector plates. Newton's second law of rotation is employed to govern the operation of the centrifugal fan [8].

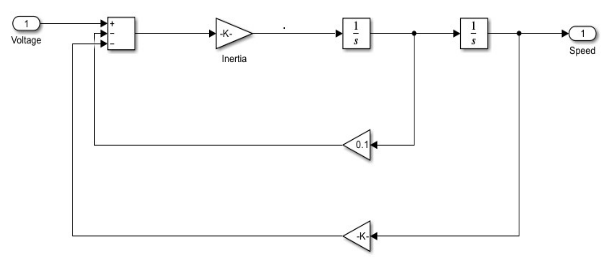

Fig. 9. Simulink model of the centrifugal fan

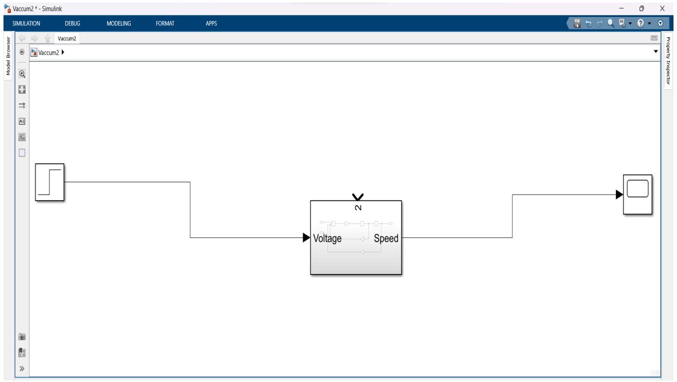

Fig. 10. A sub system was created in order to get a clear output

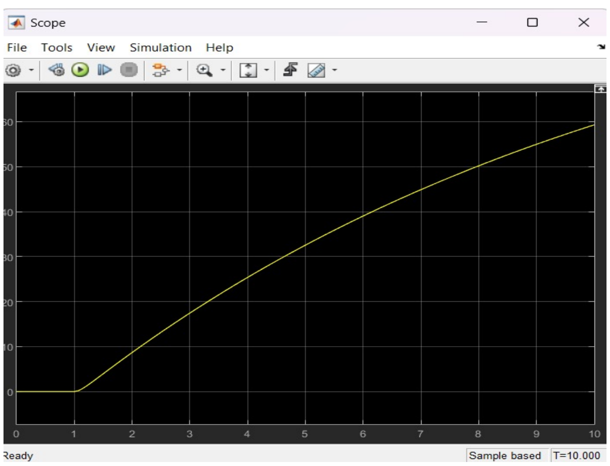

Fig. 11. output of the fan

Control Mechanism

The control system for the vacuum suction mechanism is a key element of our research. It monitors the dust level on the collector plates and activates the suction system when the dust level exceeds a predefined threshold. This approach ensures that the system operates only when necessary, conserving energy and minimizing operational costs.

The control system is integrated with sensors that detect the dust level. These sensors provide input data to the control unit, which, in turn, manages the electrical motor powering the centrifugal fan. The control algorithm is designed to power up the fan when the dust level is above the specified threshold and power it off when the collector plates are sufficiently clean.

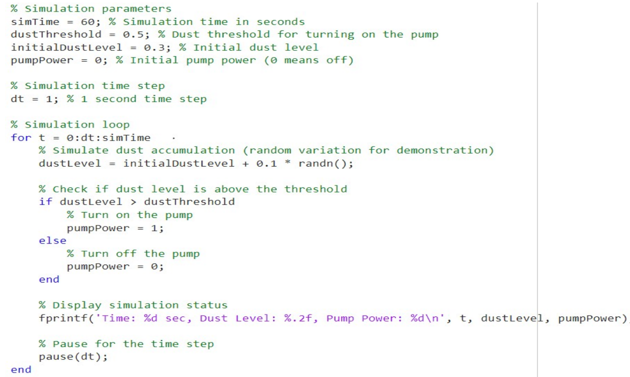

Fig. 12. control algorithm to power the fan

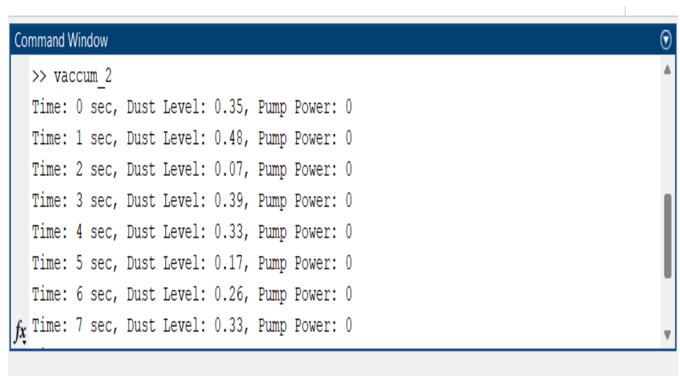

Fig. 13. calculation of level of dust in the collector plates

Simulation and Parameters

To provide a comprehensive understanding of the vacuum suction system's operation, our research includes a simulation of its performance. The simulation incorporates key parameters [4] such as:

- Moment of inertia of the fan (0.01 kg·m²)
- Motor viscous friction constant (0.1 N·m·s)
- Electromotive force constant
- Motor torque constant (0.01)

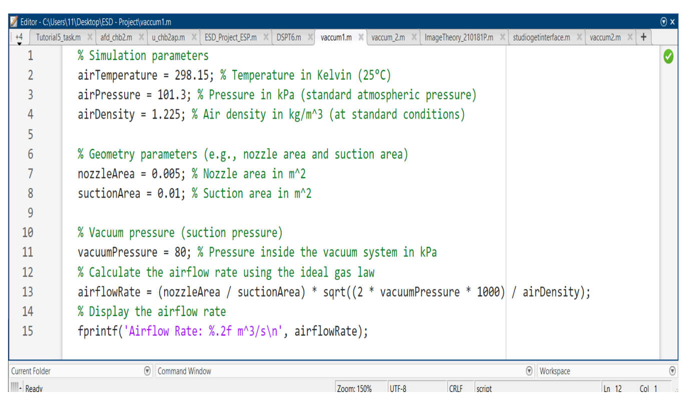

Fig. 14. code to calculate the airflow rate through the vacuum pipe

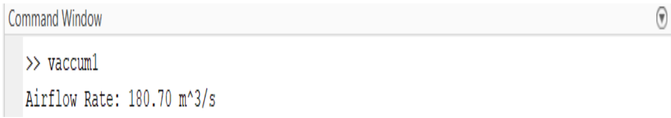

Fig. 15. calculated airflow rate results.

Using these results the fan starts to power up when the dust level exceeds some level on the plates. These results are used initiate the vacuum system.

The simulation results are included in this paper, illustrating the system's ability to effectively manage dust levels on collector plates and optimize the cleaning process.

This section provides an overview of the vacuum suction system and its control mechanism, highlighting its importance in maintaining the ESP's efficiency. You can further elaborate on the simulation results and discuss how this integrated system contributes to the overall performance of the real-time ESP

D. *Robot arm design for the vacuum system*

1) Robot arm introduction: Using Humans to clean the metal plates that contain dust may be a risky task because of the presence of high voltage electrodes.It can cause threats to human lives.Using a robot arm to do the cleaning process makes the task much easier,accurate and precise.The robot arm in our design contains three links and three joints.Since our design contains three joints the degree of freedom of our robot arm is 3.All three joints are connected to servo motors and these motors will provide the necessary torque required to move the links in the desired direction.In our design since the metal plates are rectangular our robot arm also moves in a rectangular path.Vacuum system is attached to the end of the robot arm and the vacuum system cleans all the dust in metal plates.Correct simulation of the robot arm also plays a crucial role in here.A simulation model of the robotic arm is necessary to determine the forces and torques required by the actuators to accomplish the desired tasks..To simulate the movement of the robot arm matlab Simulink is used.To define the movement inverse kinematic block of matlab has been used.To design the links solidworks has been used. [5]

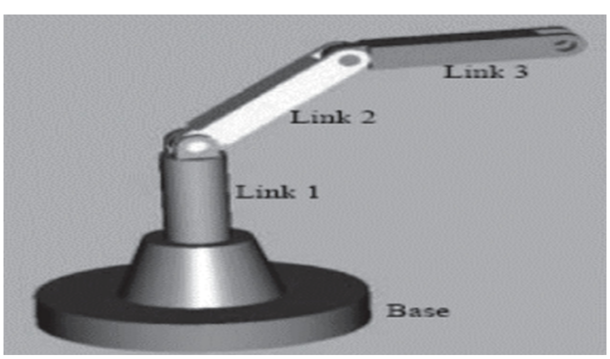

Fig. 16. Robot arm sketch

2) Robot arm design objectives: The first step of the design process was identifying the relevant objectives that we wanted to accomplish from the robot arm.Constructing an objective tree made the task much easier. [2]

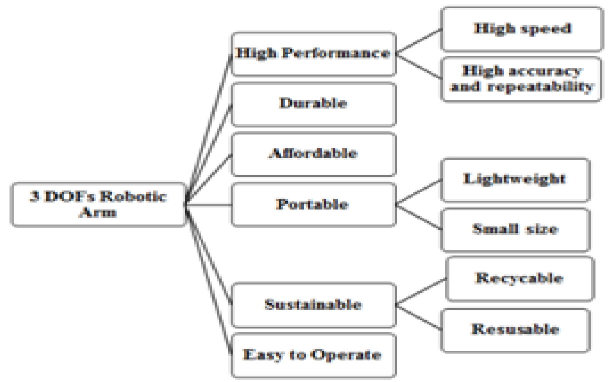

Fig. 17. Robot arm objective tree

This robot arm design consists of a cylindrical base,3 joints and 3 links.All three links are rectangular beams. Those rectangular beams are connected by joints.The cylindrical base is used to stabilize the structure. All of these parts are intended to be manufactured using stainless steel.The robotic arm consists of three joints.Each joint uses a servomotor to generate the torque required.

3) Matlab design of the robot arm: Matlab design figures

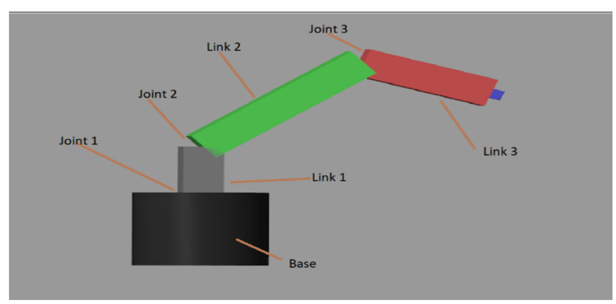

Fig. 18. Matlab model

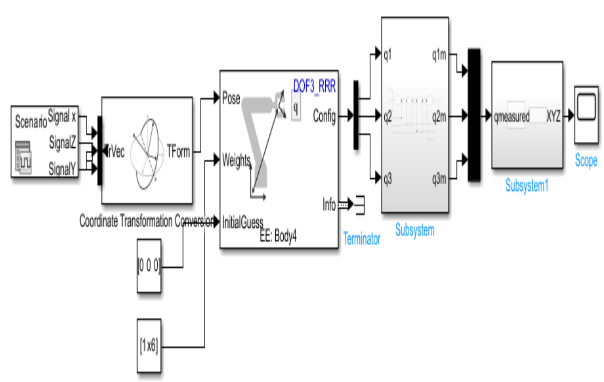

Fig. 19. Simulink model

The signal editor block is used to generate the required x,y,z coordinate signals of the robot arm.Since the metal plate is in Y plane Y coordinates remains constant throughout the process.Robot arm moves from (1,0.75,0) to (1,0.75,0.75) to (0.5,0.75,0.75) to (0.5,0.75,0).

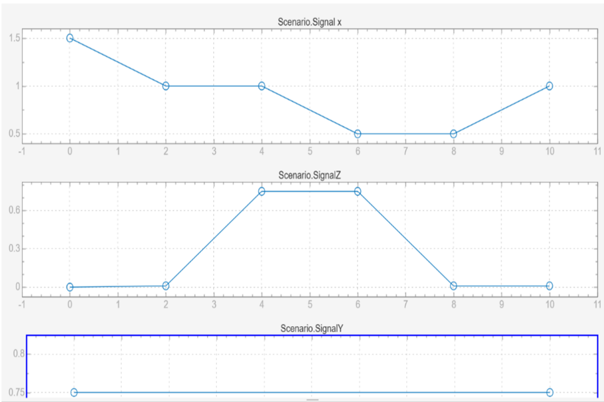

Fig. 20. Co-ordinate signals

Coordinate transformation block converts these coordinates into angles. The next step involves the application of inverse kinematics to determine the joint angles required to achieve a desired end effector(vacuum) position. Inverse kinematics block is used to calculate those joint angles .After that get transform block will give the details about the relative positioning between robot arm links. Finally these joint angles are fed into the robot arm joints.

E. Advantages of Combining a Robotic Arm with Vacuum Suction to the ESP System

Real-time Targeted Cleaning:

- Enhanced Efficiency
- Adaptability to Changing Conditions
- Minimized Downtime and Maintenance
- Improved Collection Efficiency
- Optimized Energy Consumption
- Versatility in Particle Size Handling
- Increased System Lifespan
- Minimized Health Risks
- Technological Synergy:

In summary, the combination of a robotic arm associated with a vacuum suction system to the ESP system brings about operational advantages, increased efficiency, and a more responsive approach to air purification, contributing to a holistic and technologically advanced solution for indoor air quality management

F. design approach: Automatic voltage controller

The efficiency of an electrostatic precipitator primarily depends on the power supply. When the output voltage of the electrostatic precipitator is high, its efficiency increases. However, when designing the automatic voltage controller for the electrostatic precipitator, there are several critical considerations to take into account. One significant factor is the maximum voltage that the electrostatic precipitator can operate with. If the operating voltage exceeds this maximum threshold, the dust collector will generate sparks. These sparks not only reduce the efficiency of the dust removal process but can also damage the electrostatic precipitator itself. Therefore, it is essential to maintain the voltage of the precipitator power supply as close as possible to the spark discharge voltage. Additionally, the electrostatic precipitator's power supply should have the ability to promptly detect and address instances of spark discharge. It must be capable of controlling spark generation. If the voltage controller cannot effectively control spark discharge, those sparks will transform into arc discharge, causing more problems. Thus, it is crucial to design a reliable automatic voltage controller.

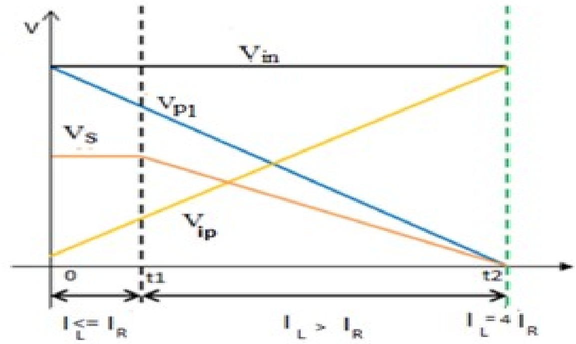

Fig. 21. characteristics of the controller

G. Controller characteristics

The automatic voltage controller must have the following characteristics. The first objective of the controller is to maintain a maximum average output voltage for variations in load to drive a sufficiently high corona power. The second objective is to achieve an instantaneous decrease in output voltage during a spark and to reduce power output during an arc condition. Mainly there will be two transformers used [6]. One is a flyback transformer and the other one is a push-pull transformer. The characteristics of the controller are shown in the figure(9) above [1]. Where;

- Vin =Input voltage to the power converter
- Vpl =Voltage across the push-pull transformer primary winding
- Vip =Voltage across flyback transformer primary winding
- Vs =Voltage across the secondary winding of the push-pull transformer

H. There are 3 main operating conditions in the automatic voltage controller.

- Normal operating condition (0 – t1)

The load resistance depends on the dust particle concentration. When the dust particle concentration increases, the load resistance also increases, leading to a corresponding increase in

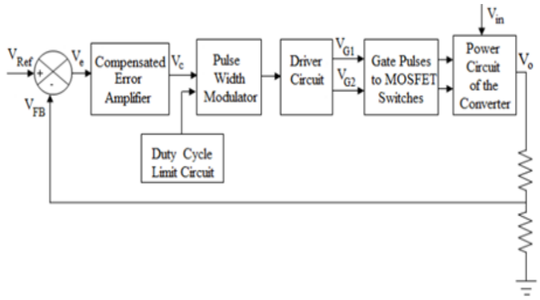

Fig. 22. voltage controller block diagram

load current. During this period, no sparks are generated. The input voltage is assumed to be constant. As the load current increases, the voltage across the flyback primary winding (Vip) also increases. Consequently, the voltage across the push-pull transformer primary winding decreases. The output voltage of the push-pull transformer is controlled based on these voltage drops. During this time period, the output voltage remains constant.

- Spark discharge condition (t1–t2)

During this time period, the current through the load exceeds the rated load current, resulting in the generation of sparks. With any increase in load current, the voltage drop across the flyback primary winding also increases This reduces the drop across the push-pull primary winding that makes Vs decrease, thus output voltage decreases. This instantaneous reduction in output voltage helps reduce spark generation

- Arc discharge condition (At t2)

When an arc is generated between the electrodes, the entire input voltage is dropped across the flyback primary winding. This drives the output voltage to a low value. Due to the drastic reduction in output voltage, damage to the electrodes is minimized, and it helps protect the power supply circuit and electrodes.

VI. CONCLUSION

In conclusion, our innovative Electrostatic Precipitator (ESP) system marks a significant advancement in addressing the challenges of maintaining optimal indoor air quality within HVAC ducts. The integration of a voltage control system, a robotic arm with vacuum suction, and the fundamental ESP principles collectively contribute to a responsive and efficient air purification solution.

The empirical validation demonstrates the system's commendable performance in achieving a minimum of 99 per cent dust removal efficiency at a low voltage of 1.5 kV. The real-time cleaning mechanism, facilitated by the robotic arm and vacuum suction, effectively addresses dust accumulation on collector plates, surpassing the limitations of conventional periodic cleaning cycles. The adaptive nature of the system, responding dynamically to changing dust levels, enhances its overall operational efficiency.

Furthermore, the successful implementation of the voltage control system ensures optimal corona power generation, showcasing the adaptability of the ESP system to varying operational conditions. The dual transformers and automatic voltage controllers contribute to sustained high-performance levels, aligning with energy efficiency objectives.

This study not only presents a technologically advanced ESP system but also underscores its potential contributions to broader sustainability goals. The adaptability of the proposed mechanism positions it as a versatile solution for comprehensive air quality management beyond dust removal.

In essence, our ESP system presents a transformative approach to indoor air quality enhancement, addressing critical issues in real time while contributing to the evolution of sustainable HVAC technologies. As we move forward, this project lays the foundation for further innovations in air purification systems, fostering healthier and more sustainable living environments

VII. ACKNOWLEDGMENT

We wish to express our appreciation to the individuals and resources that have been pivotal in the development of the Real-time Electrostatic Precipitator (ESP) system for residential HVAC ducts. We would also like to express our gratitude to our research team, whose combined efforts were crucial to the development, testing, and assessment of the ESP system. We especially appreciate Professor Buddhika Jayasekara's and Professor Ruwanthika's insightful advice and guidance. We acknowledge the valuable contributions of our instructors who shared simulation ideas, enhancing the research's depth. This project would not have been possible without the collaboration of these key contributors, and we are thankful for their support

REFERENCES

[1] David Beula, Indira Megaravalli Shankarappa, and Balaji Nerayanur. High voltage power supply controller for electrostatic precipitators. *International Journal of Power Electronics and Drive Systems*, 13(1):432, 2022.

[2] Madiha Farman, Muneera Al-Shaibah, Zoha Aoraiath, and Firas Jarrar. Design of a three degrees of freedom robotic arm. *International Journal of Computer Applications*, 179(37):12–17, 2018.

[3] Yecong He, Min Tan, and John K Tan. Physical, chemical and biological characteristics of dust accumulation in hvac system. *Chemical Engineering Transactions*, 59:757–762, 2017.

[4] Wootae Jeong, Seung-Woo Jeon, Duckshin Park, and Soon-Bark Kwon. Force control of a duct cleaning robot brush using a compliance device. In *International Conference on Informatics in Control, Automation and Robotics*, volume 2, pages 372–376. SCITEPRESS, 2012.

[5] Farah Kanwal. Design of a 3 dof robotic arm.

[6] Yan-Jie Li and Yu-Xiang Chen. Application of high-voltage power supply on electrostatic precipitator. *World Journal of Engineering and Technology*, 5(2):269–274, 2017.

[7] Guan-Yu Lin, Tzu-Ming Chen, Chuen-Jinn Tsai, et al. A modified deutsch-anderson equation for predicting the nanoparticle collection efficiency of electrostatic precipitators. *Aerosol and Air Quality Research*, 12(5):697–706, 2012.

[8] Iwuoha Chigozie Williams. Mathematical modeling of a robot vacuum cleaner suction with matlab simulink.

VIII. INDIVIDUAL CONTRIBUTIONS:

- **Galagamaarachchi G.A.D.K.N(210171K):** Simulink circuit model for Robot arm,Automatic voltage controller design

- **Ginige K.P.(210186K):** Matlab code for collection efficiency of the ESP, Simulink circuit model for power supply, Comsol simulation of the precipitator box
- **Gavinya U.H.M.(210181P):** Matlab codes and Simulink designs for vacuum cleaner, vacuum motor, simulation of vacuum motor and centrifugal fan. Matlab codes for calculating dust accumulation, And airflow rate.