Increasing Dust Removal Efficiency of Electrodynamic Screens Using Frequency Optimization via COMSOL Multiphysics®

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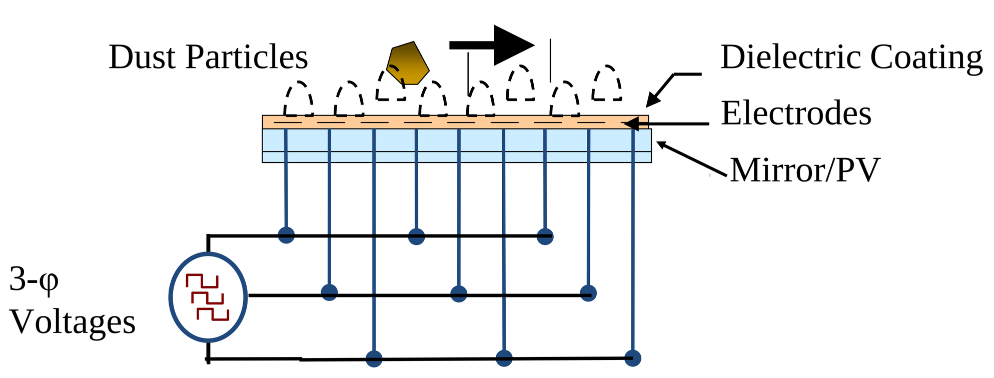
Introduction

Utility-scale solar power plants are often located in deserts where they receive large amounts of sunlight but also experience regular dust storms. These storms deposit dust on the power plants' photovoltaic (PV) and concentrating solar power (CSP) surfaces, decreasing efficiency by 5 to 40% annually. [1] Current dust cleaning methods are water-, labor-, and energy-intensive, and an alternative cleaning method being developed is the electrodynamic screen (EDS). [2] [3]

An EDS is a series of parallel electrodes embedded between two thin dielectric layers. A voltage wave is applied across these electrodes resulting in oscillating potentials and creating a wave pattern in the electric field above the EDS surface. This electric field charges dust particles and directs their motion off the EDS surface.



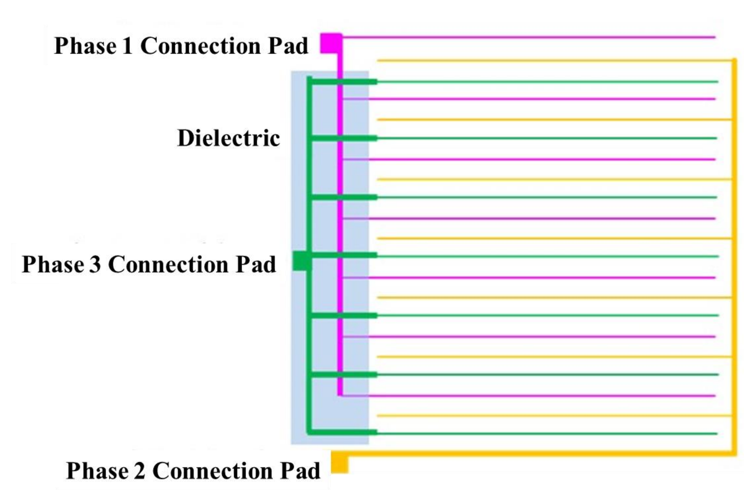


Figure 1. (Above) A diagram showing how an EDS operates
Figure 2. (Right) A diagram of the electrode geometry of an EDS

Computational Methods

A model of the EDS system's electrostatics and particle movement was created using the following COMSOL physics interfaces:

AC/DC: Electrostatics

Electrode Potentials

$V_1 = V_{max} \cdot cos(\omega t + 30°)$

$V_2 = V_{max} \cdot cos(\omega t + 150°)$

$V_3 = V_{max} \cdot cos(\omega t + 270°)$

Electric Field

$\nabla \cdot D = \rho_V$

$E = -\nabla V$

Fluid Flow: Particle Tracing for Fluid Flow

Electrical Force $F = eZ(-\nabla V)$

Gravity $F = m_p g \frac{(\rho_p - \rho)}{\rho_p}$

Electrical Force $F = \frac{1}{\tau_p} m(u - v)$

$\tau_p = \frac{\rho_p d_p^2}{18\mu}$

The geometry of the EDS system being modeled is shown below:

Particle Properties	Value	Units
mass, m_p	$0.33 * 10^6$	kg
density, ρ_p	2200	kg/m^3
diameter, d_p	60	m
charge, q	$30 * 10^{-12}$	C
charge number, Z	$1.8 * 10^8$	

Table 1. Properties of the modeled particles

System Properties	Value	Units
max voltage, V_{max}	1000	V
dielectric height, h_d	25	μm
electrode width, w_e	80	μm
electrode spacing, s_e	700	μm
electrode height, h_e	3	μm

Table 2. Properties of the EDS system

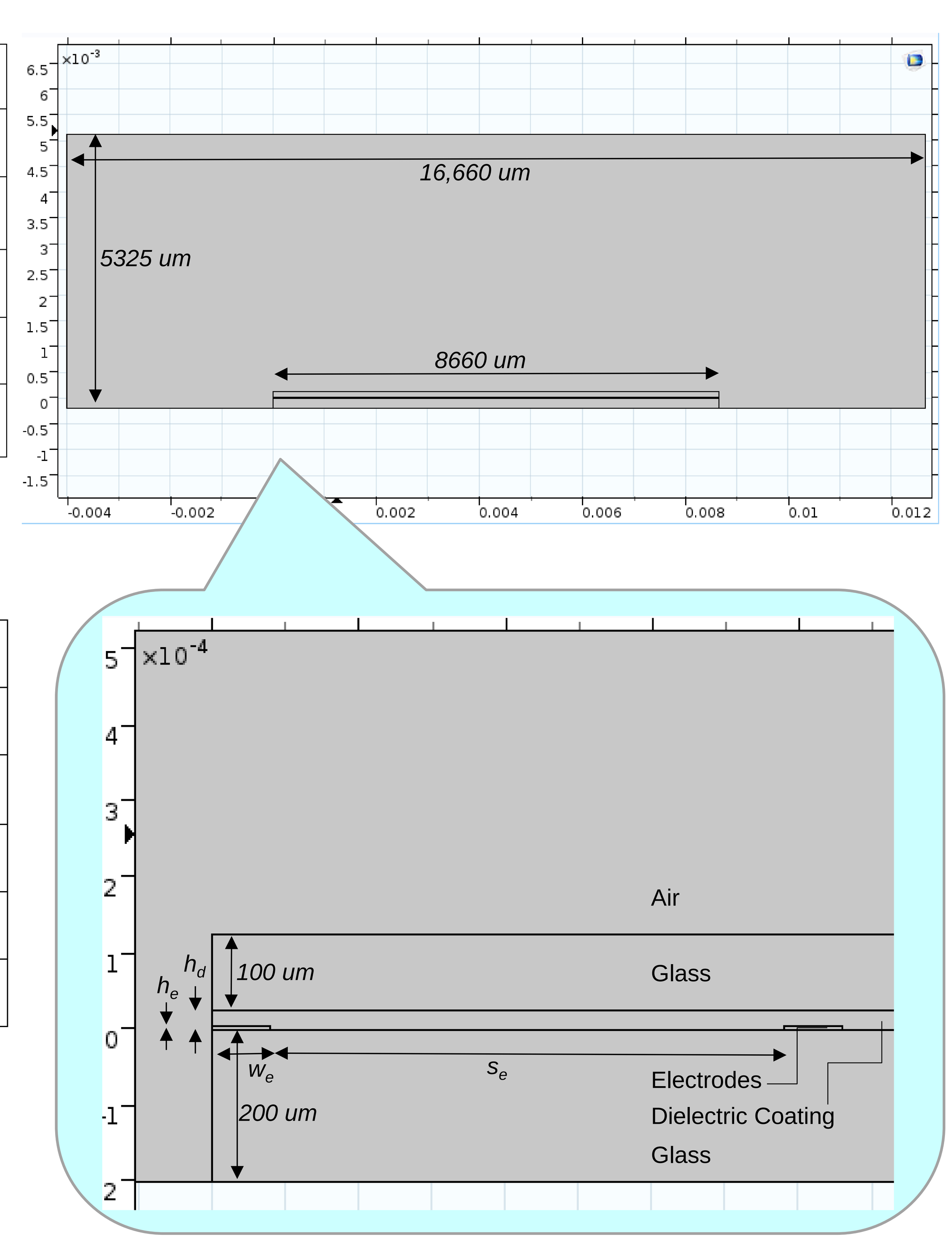


Figure 3. (Right) A diagram showing the cross-section of a 12-electrode EDS, with a magnification to show the system's layers.

Results

For each frequency $\omega = \{1, 5, 25, 50, 100, 150, 200, 250\ Hz\}$, a time-dependent electrostatics study was conducted, resulting in solutions for the system's electric potential. The results of these simulations were used by the time-dependent particle tracing studies, which resulted in the trajectories of 50 particles over time $t = [0s, 1s]$.

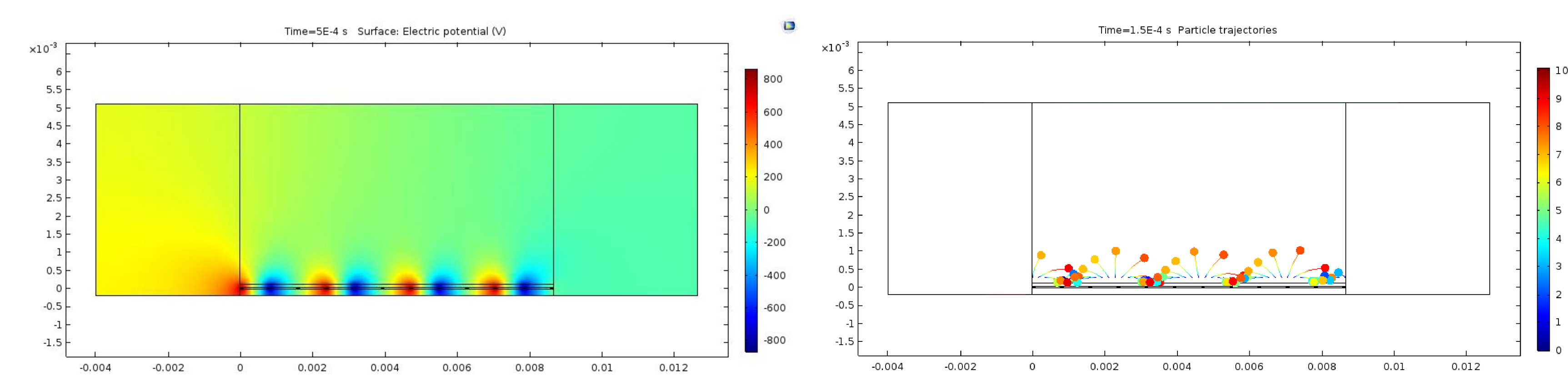


Figure 4, 5. The electric potential and particle trajectories of a 5Hz EDS system at time t=0.0005 s.

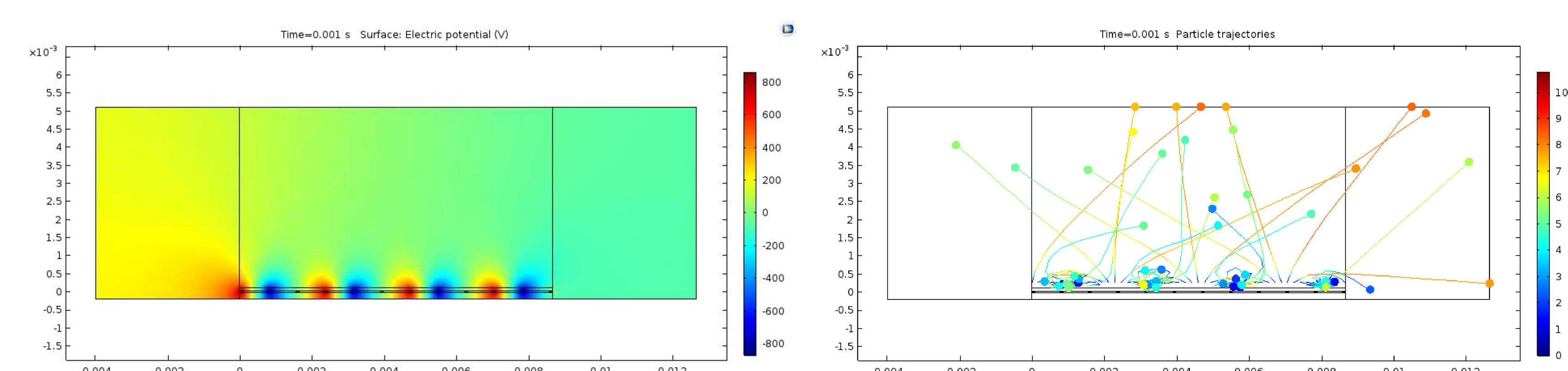


Figure 6, 7. The electric potential and particle trajectories of a 5Hz EDS system at time t=0.001 s.

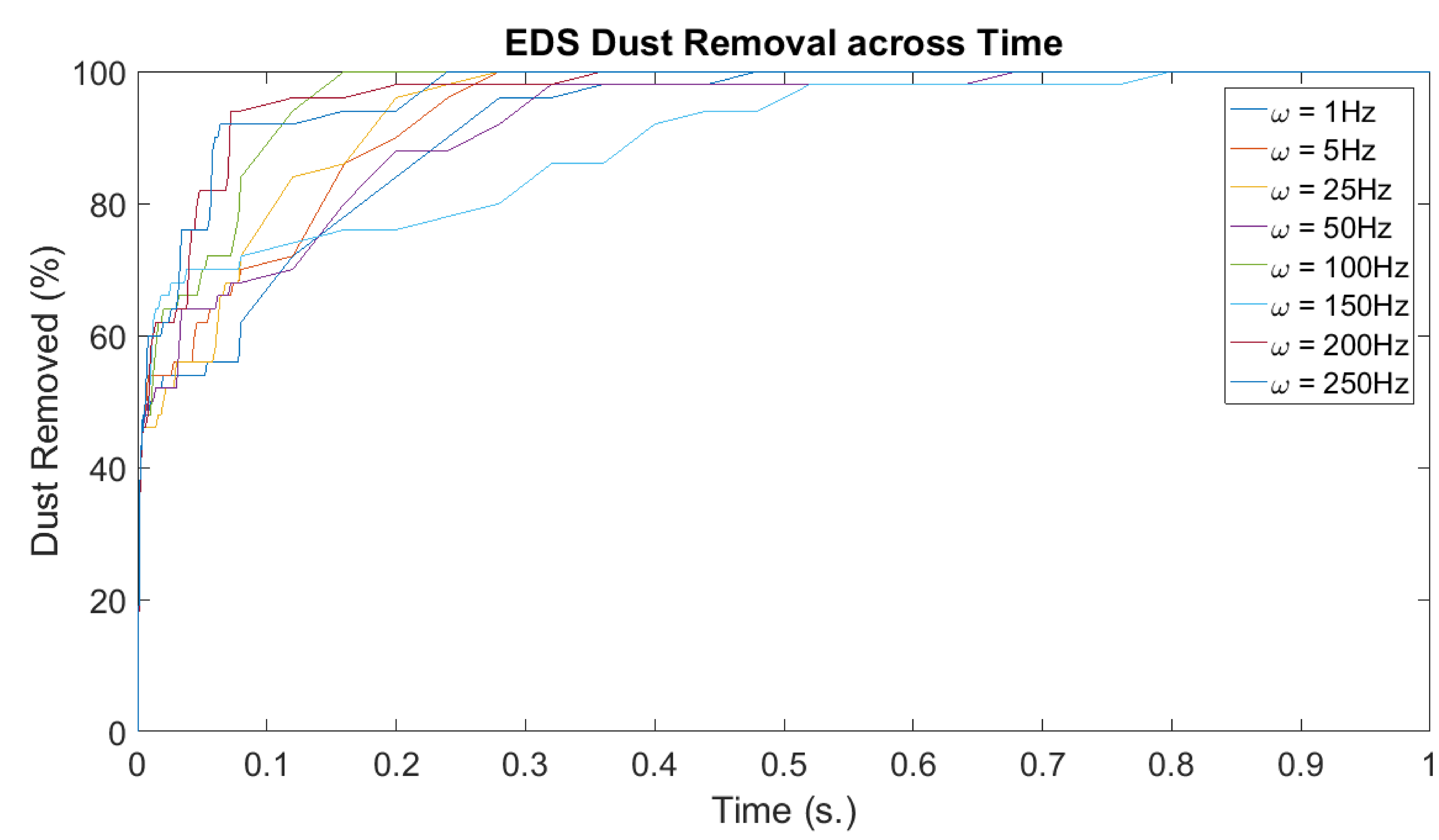


Figure 8. A graph of the percentage of the system's 50 particles which are removed during the first second of EDS activation. Each colored line represents a different EDS operation frequency.

Conclusions

The results demonstrate that operating an EDS at a higher relative frequency results in faster dust removal. But because all frequencies clear 100% of the dust within the first second of operation, the dust removal speed may not need to be the primary factor considered in choosing EDS operating frequency. Future work includes modeling the effects of more forces, modeling different sized and charged dust particles, and validating the results against experimental data.

References

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Acknowledgements

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