Prevention of dust accumulation in solar systems with emphasis on the electrodynamic protection technology

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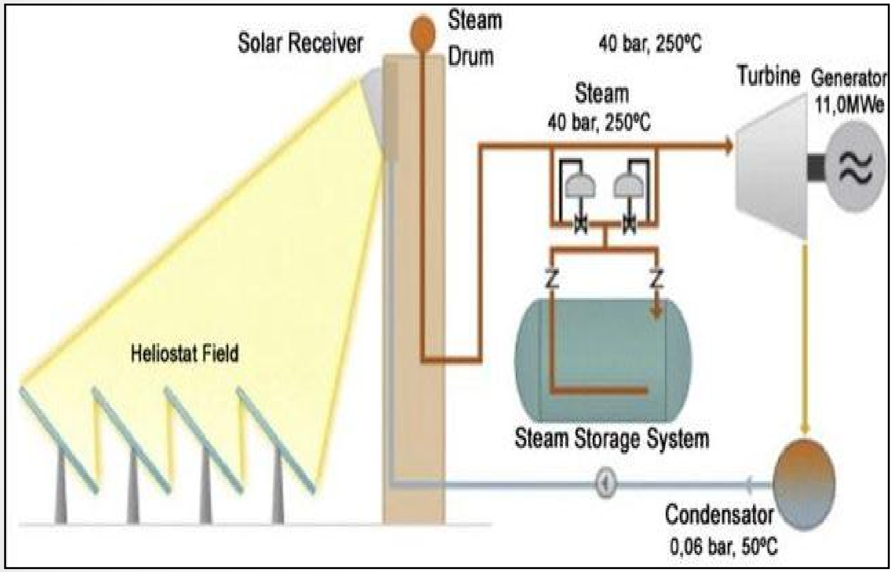
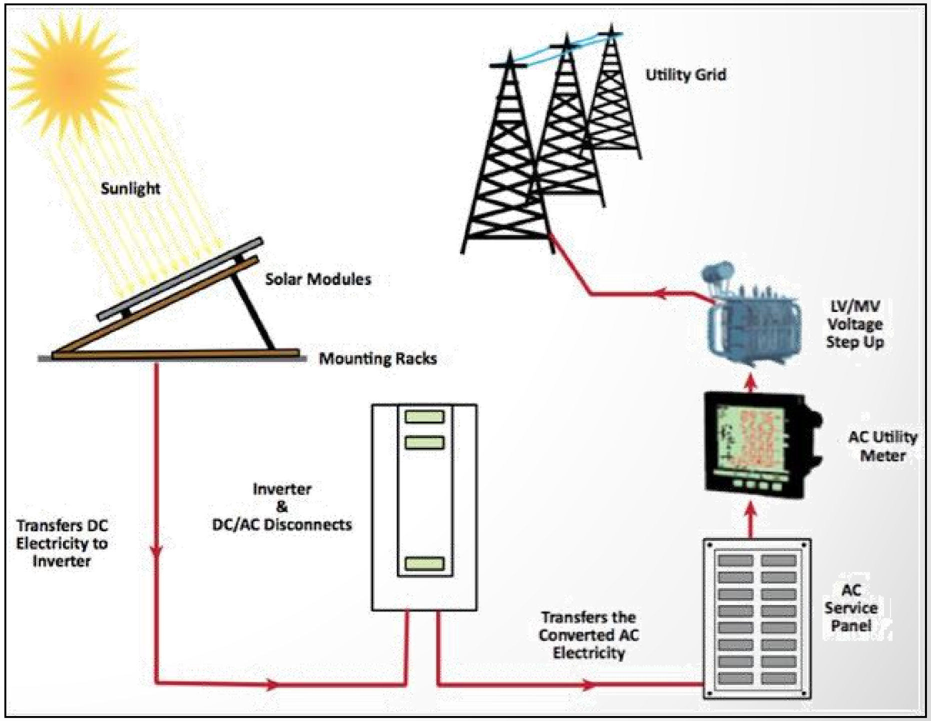
Solar technology

CSP System

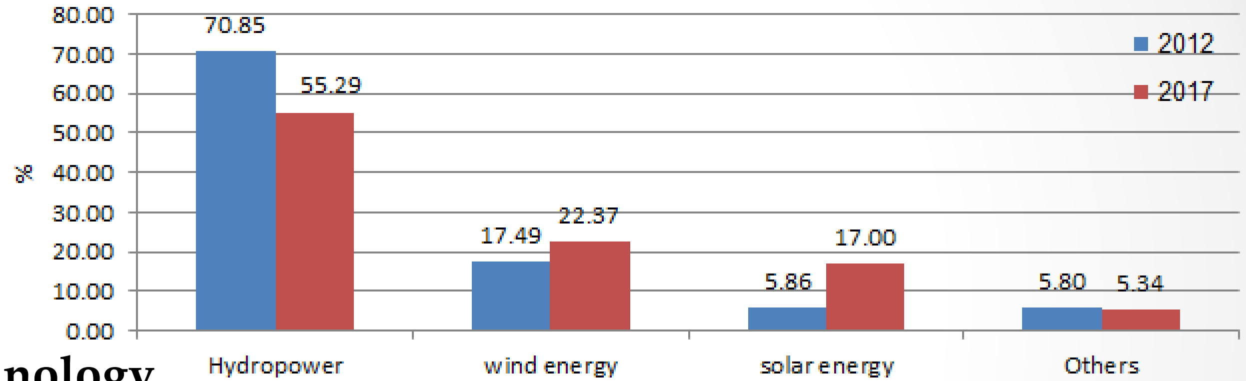


PV System

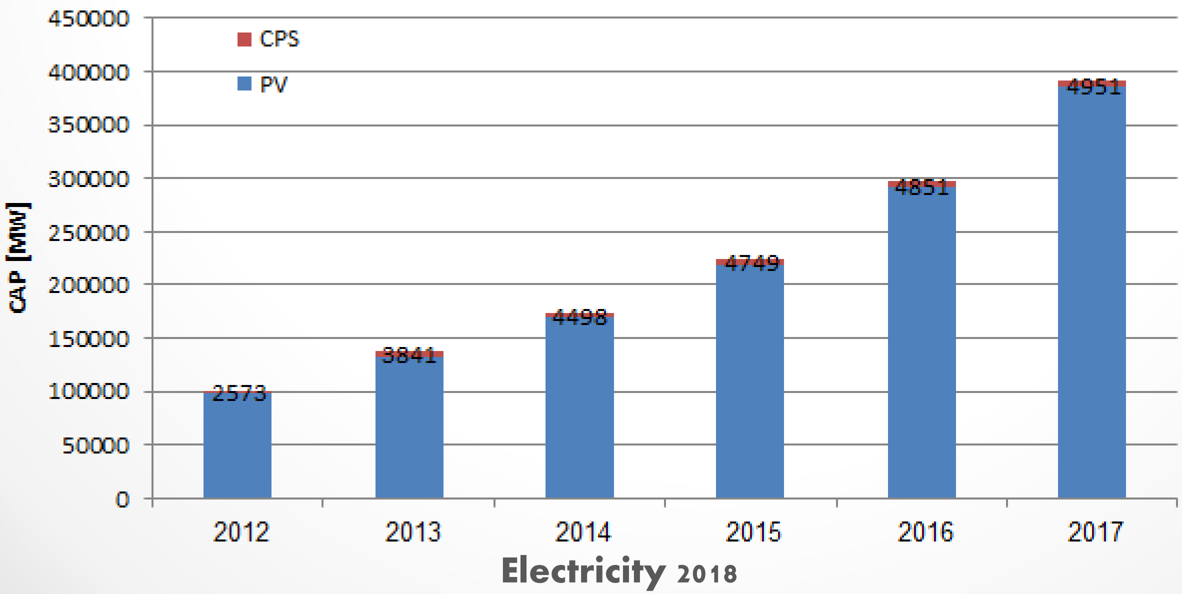


Status of Solar Energy

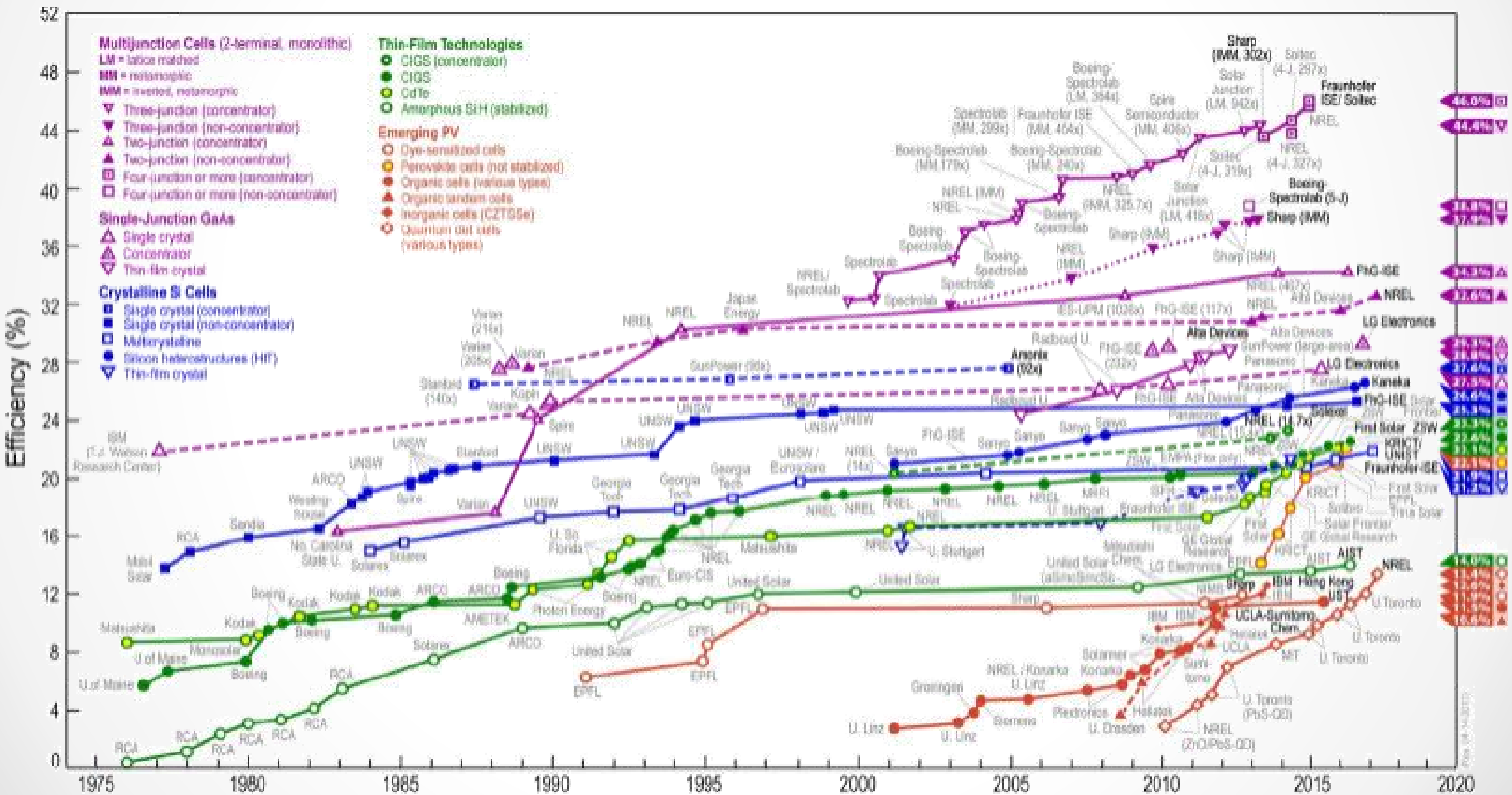
Tendency of the renewable energy



Tendency of solar technology



Best Research-Cell Efficiencies



NREL- National Renewable Energy Laboratory

From theory to the reality

Dust definition

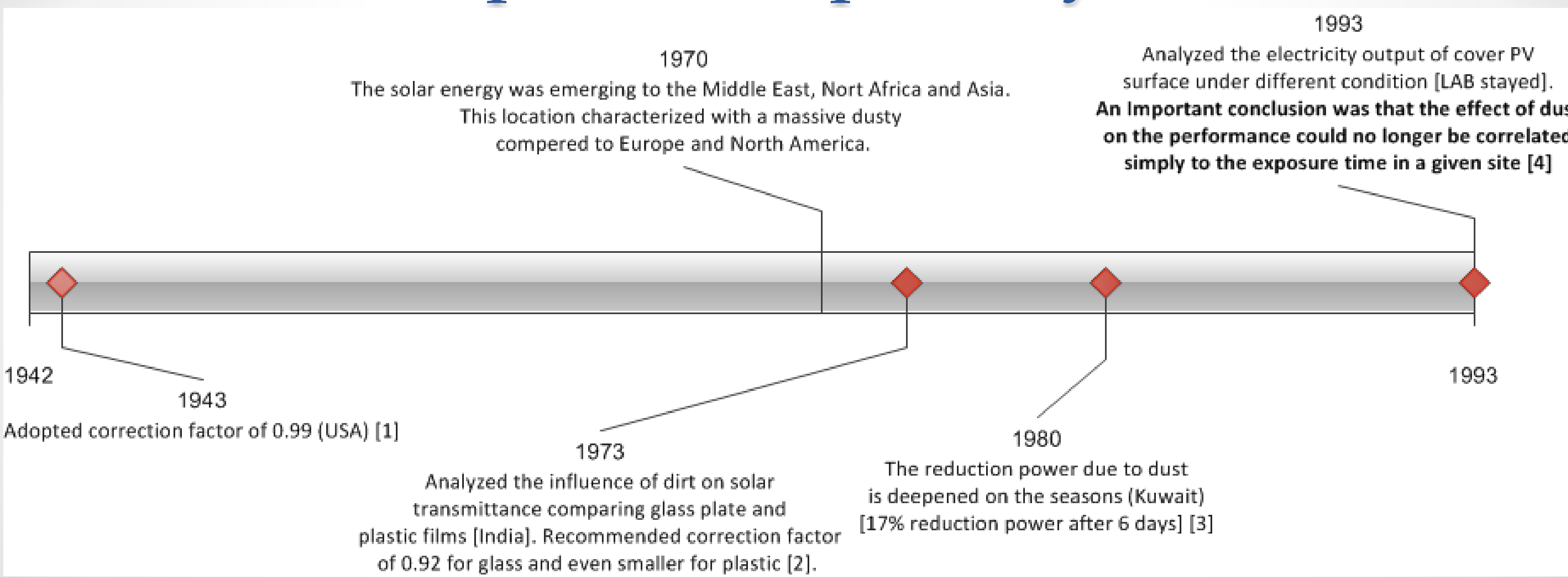
Dust is a generally term applying to minute solid particle with diameters less than 500 µm. It occurs in the atmosphere from various source such as:

- Dust lifted up by wind
- Pedestrian and vehicular movement
- Volcanic eruptions
- Pollution.

The consequence of dust problem

- Reduce the solar interaction with the active surface.
- Cause for "Hot-Spot" phenomenon.

The evolution of dust problem quantify

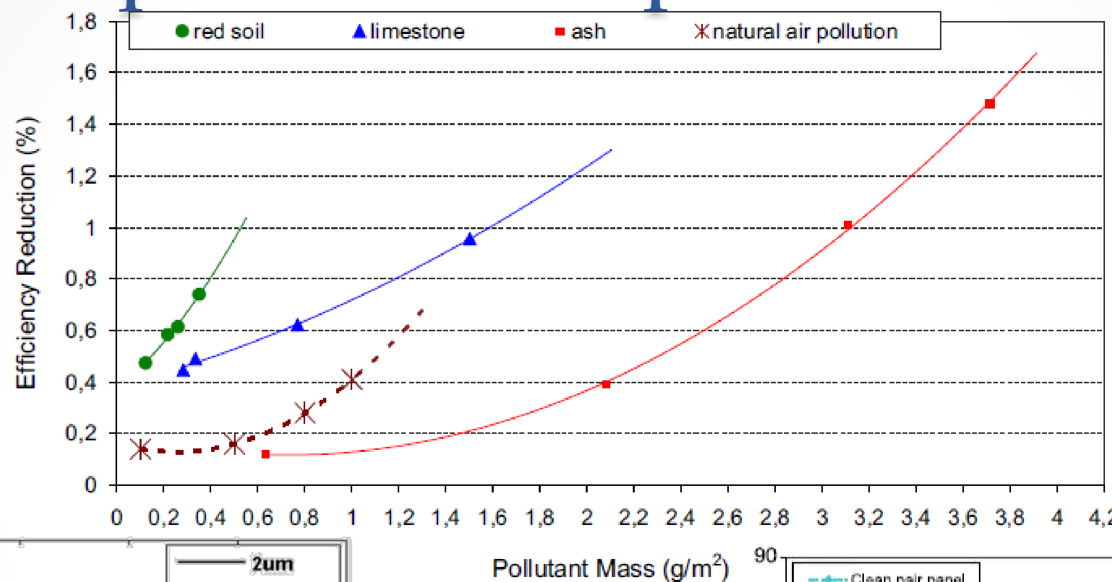


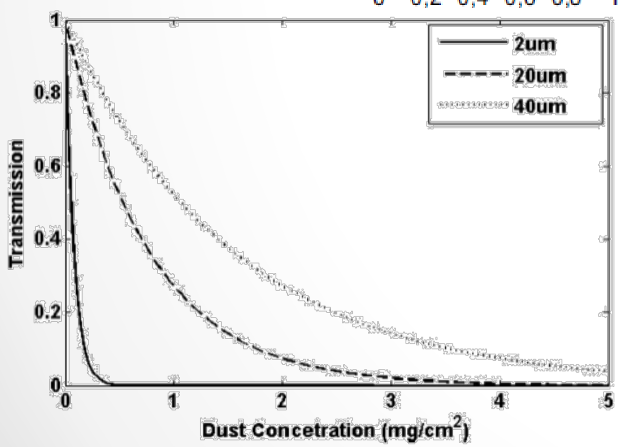
Hottel HC, The performance of flat plate solar heat collector, 1942
Grag HP, Effect of dirt on transparent covers in flat plate solar energy collectors, 1974
Wakim F, Introduction of PV power generation to Kuwait, 1980
El-Shobokshy MS, Degradation of photovoltaic cell performance due to dust deposition on its surface, 1993

Factors influencing the rate of dust accumulation

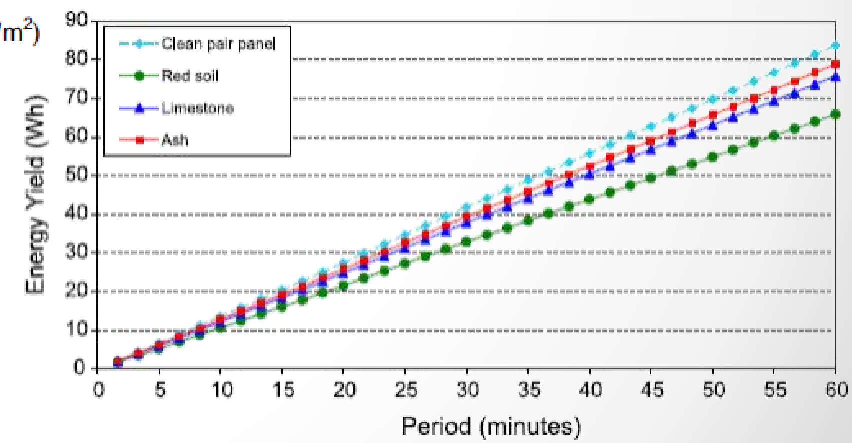
- Environmental condition
  - Wind velocity (direction and speed)
  - Temperature
  - Humidity
- Installation condition
  - System till-angle
  - System orientation
  - Site characteristics
  - Geographical region
  - Glazing Characteristics
- Dust properties
  - Chemical composition
  - Electrostatic property
  - Size distribution
  - Shape
  - Density

Impact of dust phenomenon





Transmission loss of solar radiation as a function of surface mass density of dust



Energy yield of the clean PV-panels compared with the polluted ones [1 g/m²]

J. K. Kaldellis, Simulating the dust effect on the energy performance of photovoltaic generators based on experimental measurements, Energy 36 (2011), 5154-5161

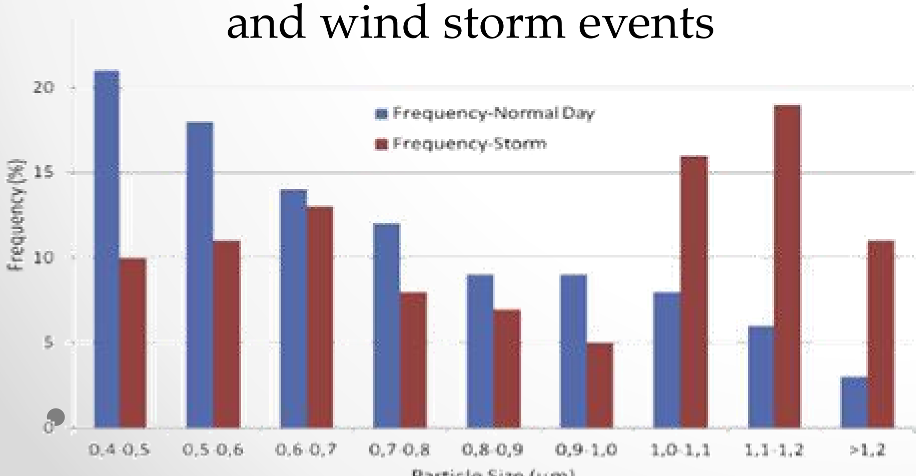
Impact of dust phenomenon

Dust analysis from PV or other surface in the MENA countries (Elminir)

Species	Countries (relative concentrations %)							
	Libya	Egypt			Saudi Arabia	Oman	Bahrain	Iraq
		Elminir (Helwan)	(Helwan)	(Toshka)				
B	ND	ND	ND	ND	ND	ND	ND	ND
C	0.8	–	1.1	0.2	0.8	0.5	0.1	1.6
O	(46.6)	–	(43.2)	(47.6)	(46.8)	(46.4)	(47.4)	(44.3)
Na	4.9	0.3–3.2	2.7	< 0.03	3.4	4.3	5.2	1.0
Mg	1.9	0–0.02	1.1	2.2	2.0	1.2	1.1	1.7
Al	0.2	0.07–2.9	3.2	0.1	0.2	0.2	0.1	0.4
Si	26.7	6.6–(27.5)	25.2	28.6	28.7	29.7	28.4	26.4
P	ND	ND	ND	ND	ND	ND	ND	ND
S	0.4	0.9–1.9	1.1	–	1.3	–	–	0.5
Cl	3.3	0.02–2.1	1.8	0.07	2.1	3.9	4.3	0.6
K	1.9	0.01–2.3	2.2	1.4	1.5	2.1	2.0	1.6
Ca	1.7	6.7–11.2	12.7	2.4	2.0	2.6	2.5	2.6
Ti	–	0.08–1.0	1.0	–	–	–	–	< 0.1(?)
Cr	–	ND	0.4	–	–	–	–	< 0.1(?)
Mn	–	ND	ND	0.04	–	–	–	0.06
Fe	–	1.1–2.1	3.1	–	–	–	–	0.5
Zn	–	1.2–3.8	2.7	–	–	–	–	0.3

T. Sarver, A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches, Renewable and Sustainable Energy Reviews 22 (2013) 698–733

Frequency of dust particles during normal days and wind storm events



M. Saidan, Experimental study on the effect of dust deposition on solar photovoltaic panels in desert environment, Renewable Energy 92 (2016), pp 499-505

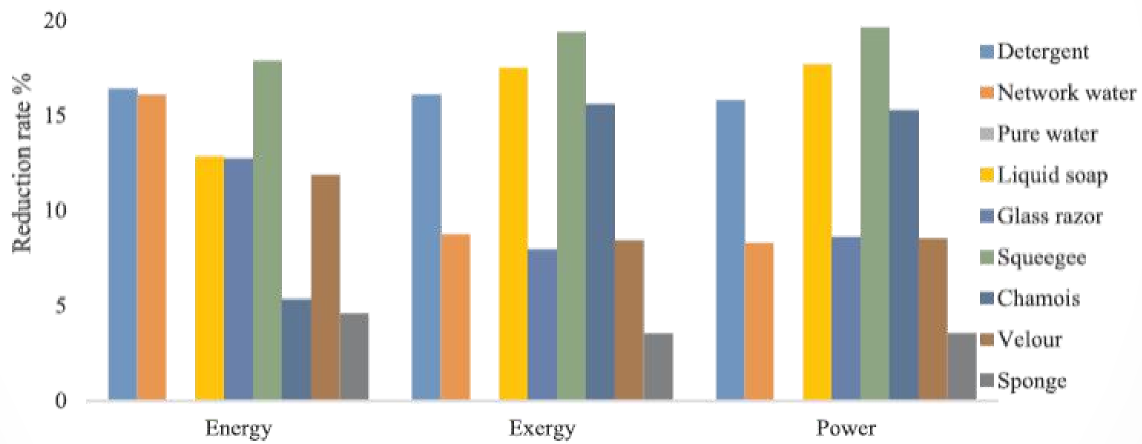
Prevention methods to the dust phenomenon

- Natural dust removal
  - Wind power
  - Gravitation
  - Rainwater
- Self cleaning-film
  - Hydrophilicity film (TiO2)
    - Photocatalytic activity
    - Hydrophilicity activity
  - Hydrophobic film
- Mechanical dust removal
  - Brushing
  - Blowing
  - Spraying\ Jet
  - Ultrasonic driving
  - Vibrating
- Electrostatic dust removal
  - Electrodynamic screen (EDS)

Choosing appropriate cleaning method can reduce a future costs

The common cleaning method

The most common mitigation technique is physically washing the surfaces of the solar devices with water or detergent solutions.



M. Gurturk, Effects of different parameters on energy – Exergy and power conversion efficiency of PV modules , Renewable and Sustainable Energy Reviews 92 (2018) 426–439

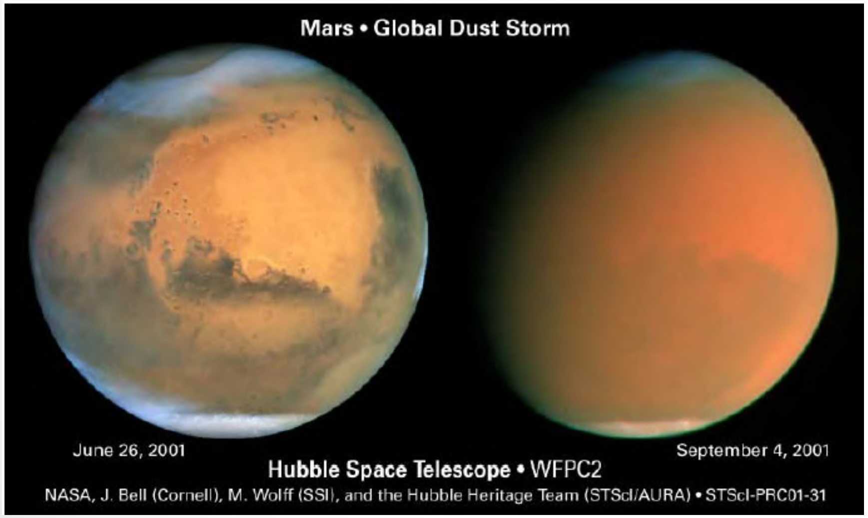
This technique is labor and resource (water) intensive, which, in turn, can lead to high operation and maintenance costs. thus making wet cleaning an unideal mitigation approach

Comparison between different cleaning method

Cleaning method	Advantages	Disadvantages
Natural	☑ There is no cleaning cost ☑ High wind can remove larger dust from the collector surface ☑ Heavy rainfall can restore the efficiency of solar panel	☒ Light rainfall in dusty environment can increase the dusty deposition. ☒ Rainfall events in arid and semi-arid zones are infrequent ☒ High wind can caused scratching on the collectors
Mechanical	☑ Cleaning can be performed whenever required ☑ High PV module efficiency can be maintained routinely	☒ Significant cost for labor and water resources ☒ Requires trained personnel ☒ Increasing the operation and maintenance costs
Self-cleaning	☑ Its improves cleaning efficiency of natural cleaning ☑ It lasts for couple of years	☒ Their lifetime is limited and is greatly site-specific ☒ Re-application of coating might reduce the optical performance
EDS	☑ It does not need water resources or labor for operation ☑ There is no mechanical movement involved in cleaning procedure ☑ The power consumption is very low	☒ The technology is in developmental stages

Developing motivation

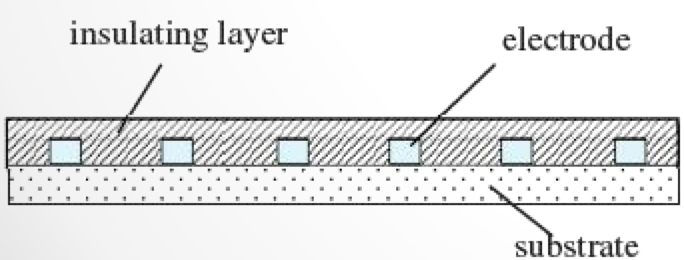
- Vikings Mars landers-1976.
- Sojourner Mars Rover- 4/07/1997.
- Spirit and Opportunity Mars Rover- 2004.



C. I. Calle, The electrostatic environments of Mars and the Moon, Journal of Physics: Conference Series 301 (2011) 012006

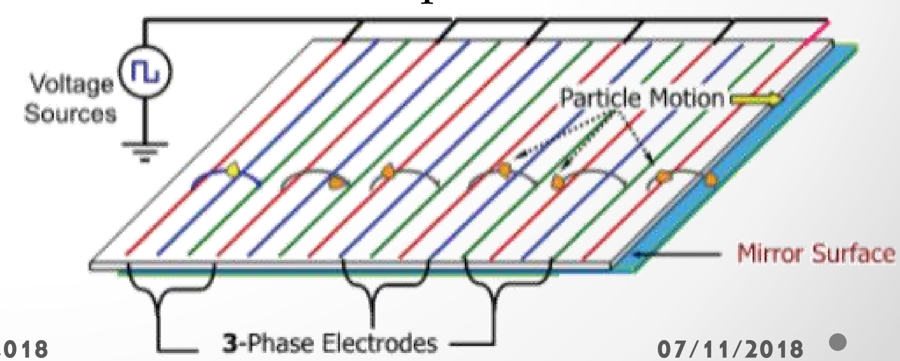
Operation principle

- The concept was developed by F.B. Tatom and collaborators at NASA in 1967 and further the concept was widely by Masuda at the University of Tokyo in the 1970s.
- This technique has been shown traveling wave of electric field could convey charged aerosol particles in traverse direction.



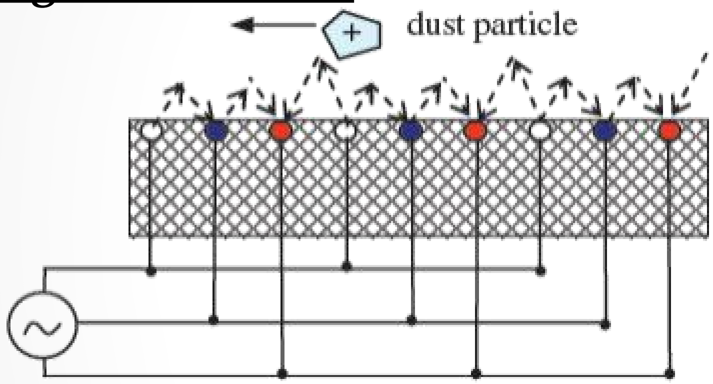
Cross-sectional view

Top view

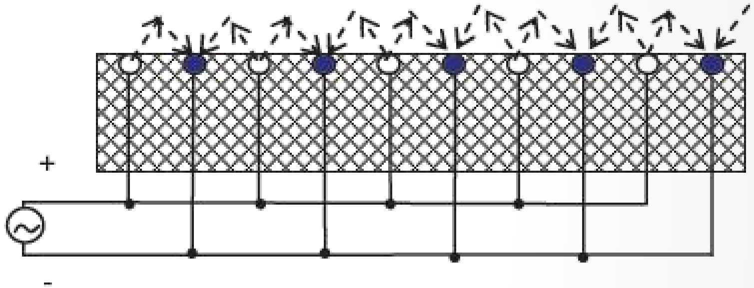


Operation principle

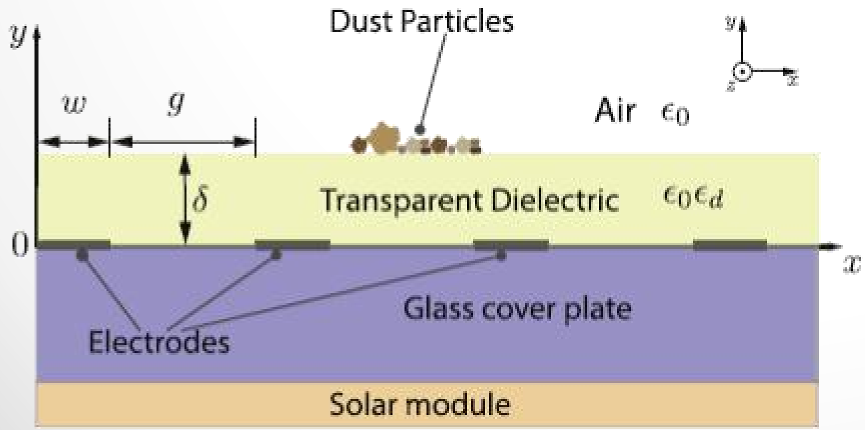
Traveling electric field:



Standing electric field:



Basic parameters:



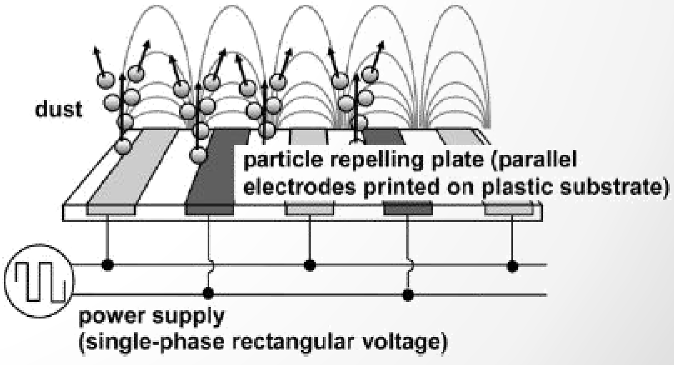
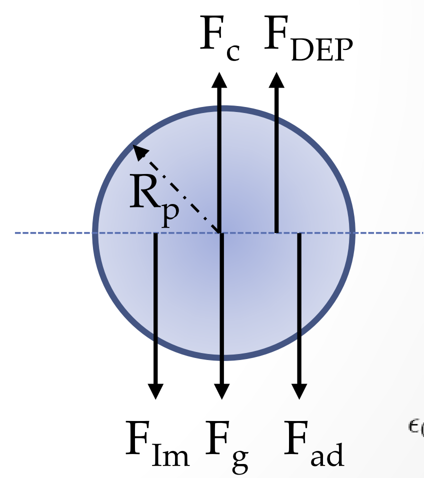


Fig. 1. Principle of electrostatic removal of lunar dust.

The forces exerted on the particle

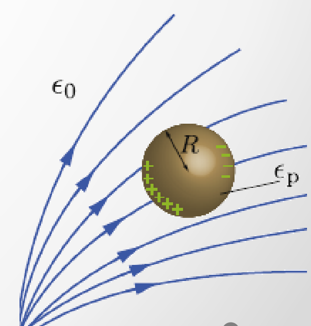
$$F_x = qE_x + 4\pi\varepsilon_0 R_p{}^3 \cdot \frac{\varepsilon_p - \varepsilon_0}{\varepsilon_p + 2\varepsilon_0}\left(E_x \frac{\partial E_x}{\partial x} + E_y \frac{\partial E_y}{\partial x}\right) - 6\pi\eta R_p V_x$$

$$F_y = qE_y + \underbrace{4\pi\varepsilon_0 R_p{}^3 \cdot \frac{\varepsilon_p - \varepsilon_0}{\varepsilon_p + 2\varepsilon_0}\left(E_x \frac{\partial E_x}{\partial x} + E_y \frac{\partial E_y}{\partial x}\right)}_{F_{DEP}} - 6\pi\eta R_p V_y - mg - F_{Im} - F_{ad}$$

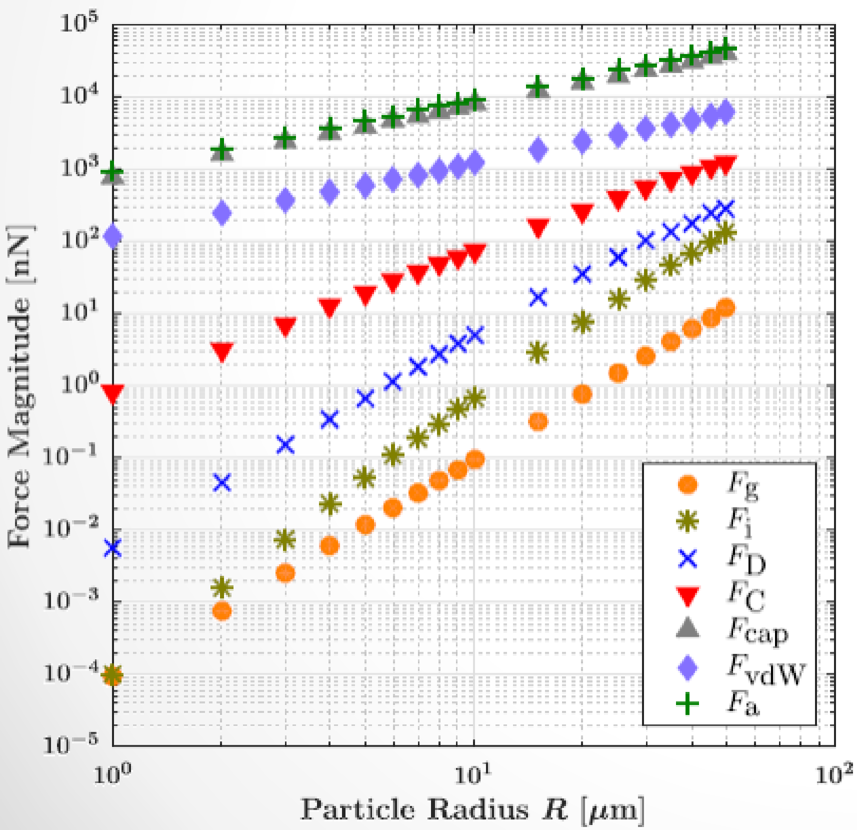


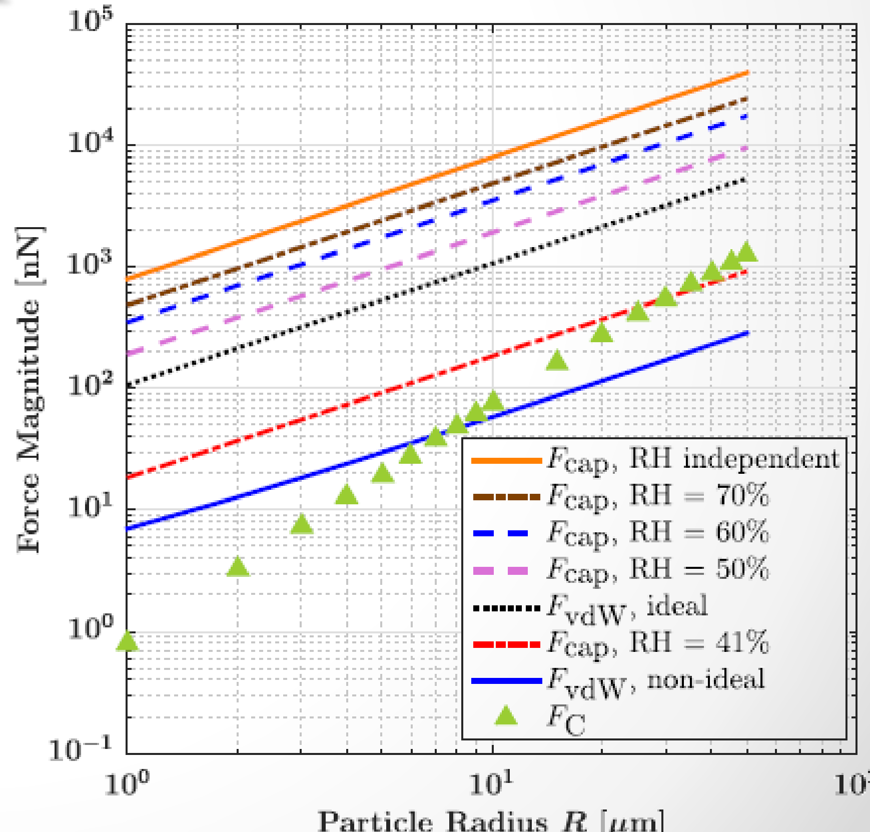
Where:

- qE_l- Coulomb force
- F_{DEP}- Dielectrophoretic force
- $6\pi\eta R_p{}^3 V_l$- Drag force
- mg- Gravitational force
- F_{Im}- Image force
- Fad- Adhesion force (Capillary force and Van-der Walls force)

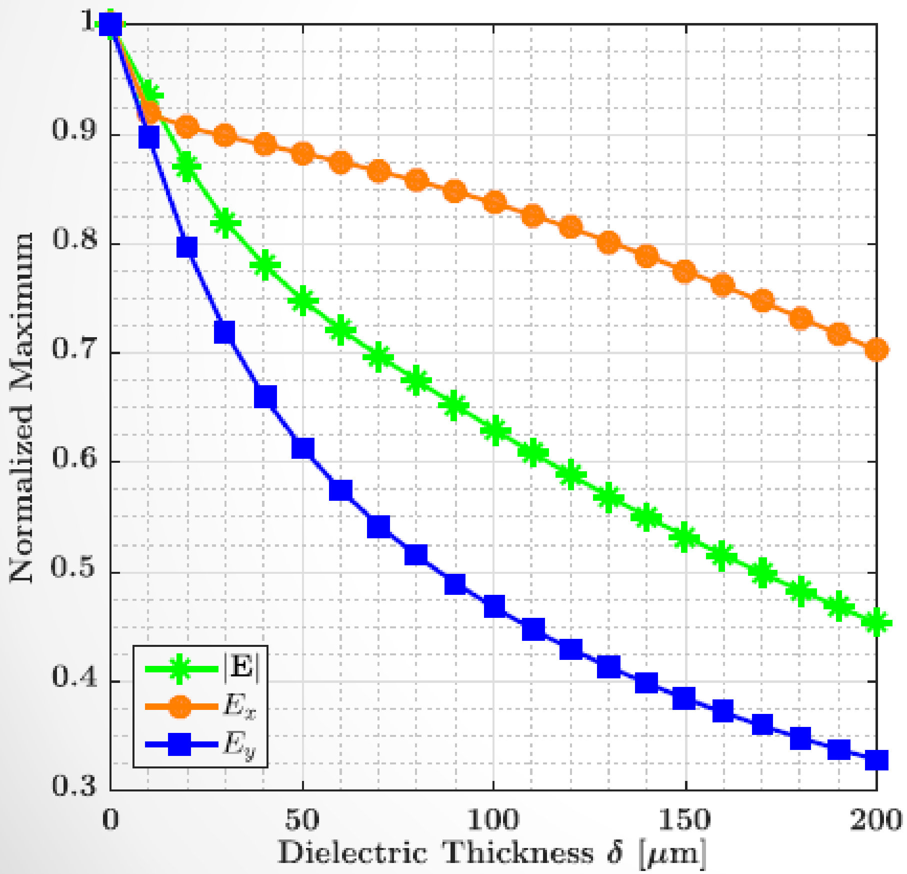


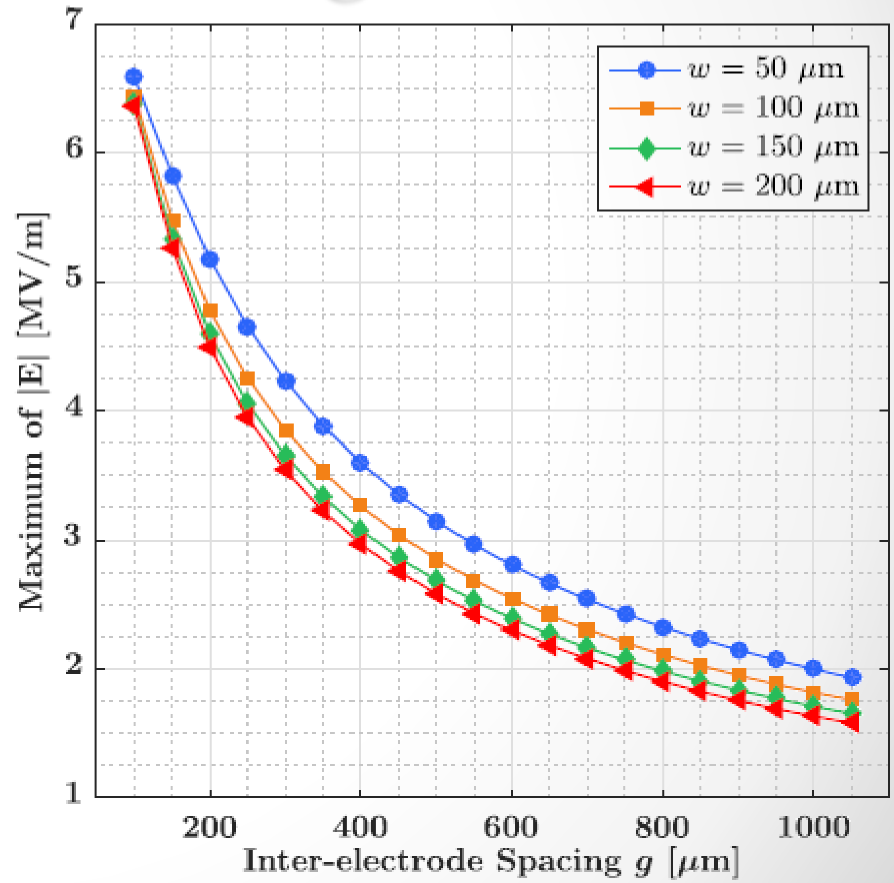
Comparison of the attracting and repelling forces exerted on the particle as functions of particle radius





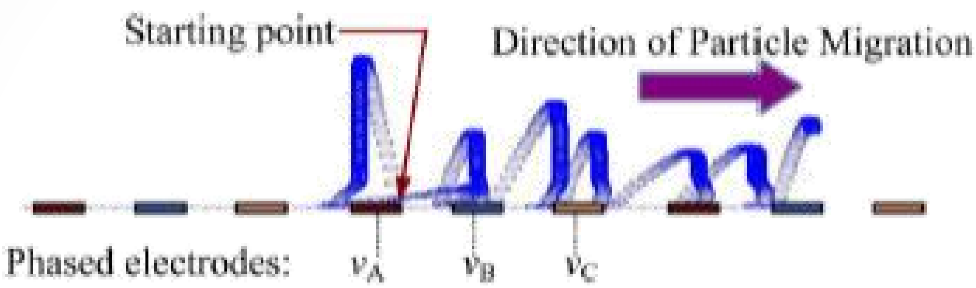
Parameters impact on the electrical field strength





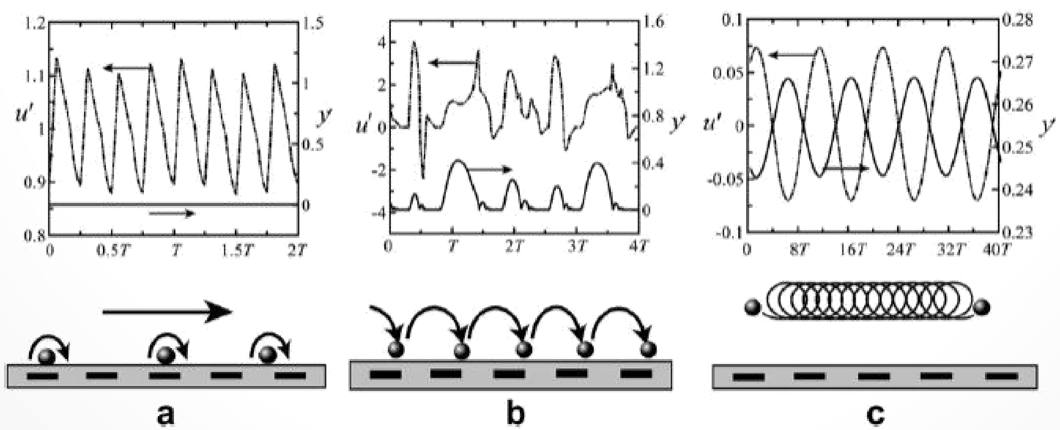
Sayyah A, Electrostatic force distribution on an electrodynamic screen, Journal of Electrostatics 81 (2016) 24-36.

Predicting particle trajectory



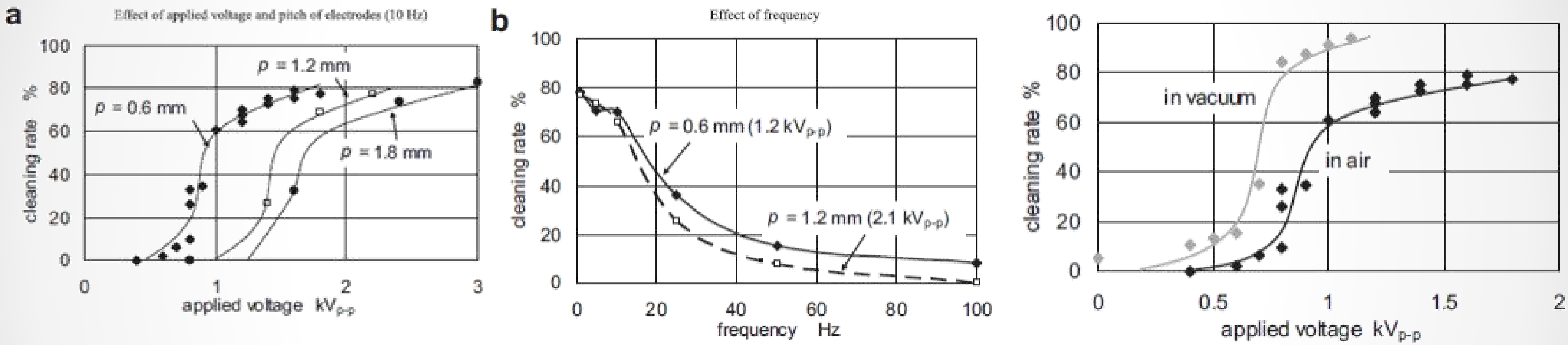
Horenstein M N, Modeling of Trajectories in an Electrodynamic Screen for Obtaining Maximum Particle Removal Efficiency, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 49, NO. 2, APRIL 2013

G.Q. Liu, J.S. Marshall / Journal of Electrostatics 68 (2010) 179–189 181



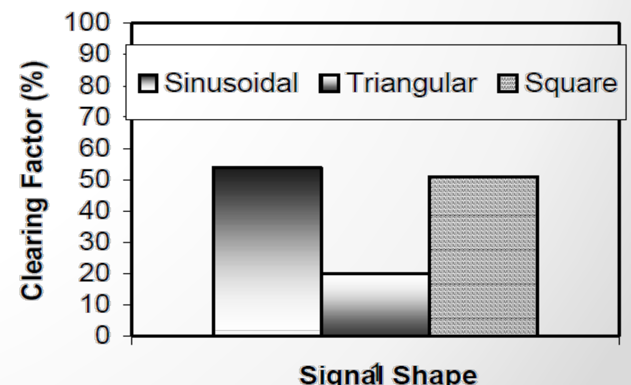
EDS Performance

Dry air (dew point -20^{o}C)
Vacumm (5 Pa)
P=6mm and f=10Hz



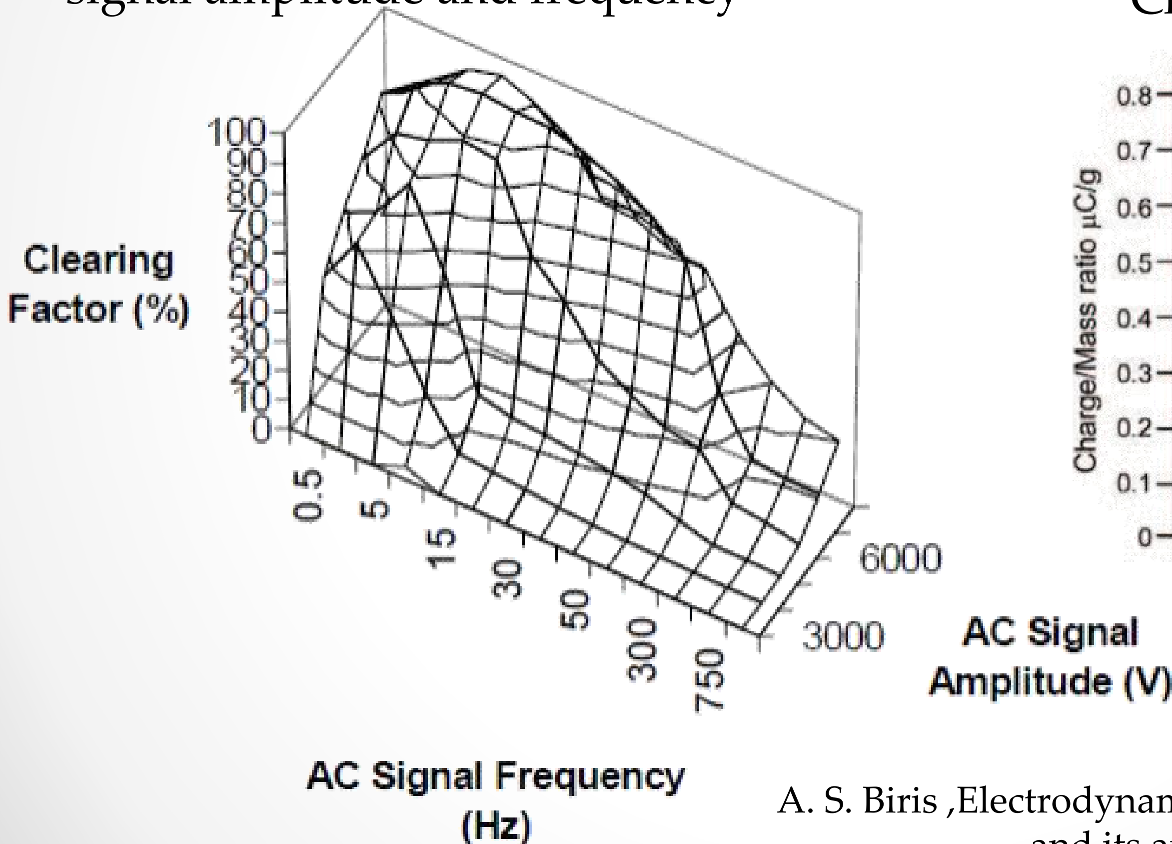
H. Kawamoto, Mitigation of lunar dust adhered to mechanical parts of equipment used for lunar exploration, Journal of Electrostatics 69 (2011),pp 365-369

Clearing factor as a function of the signal shape (6 kV and 50 Hz)

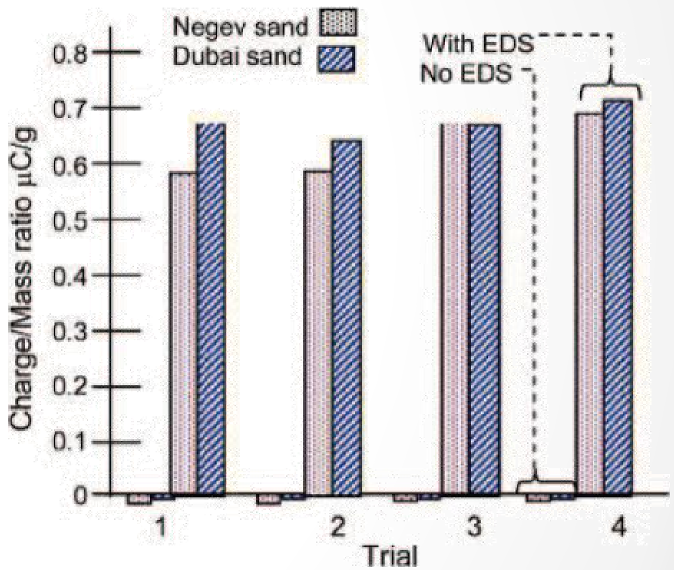


EDS Performance

Variation of the clearing factor with the signal amplitude and frequency

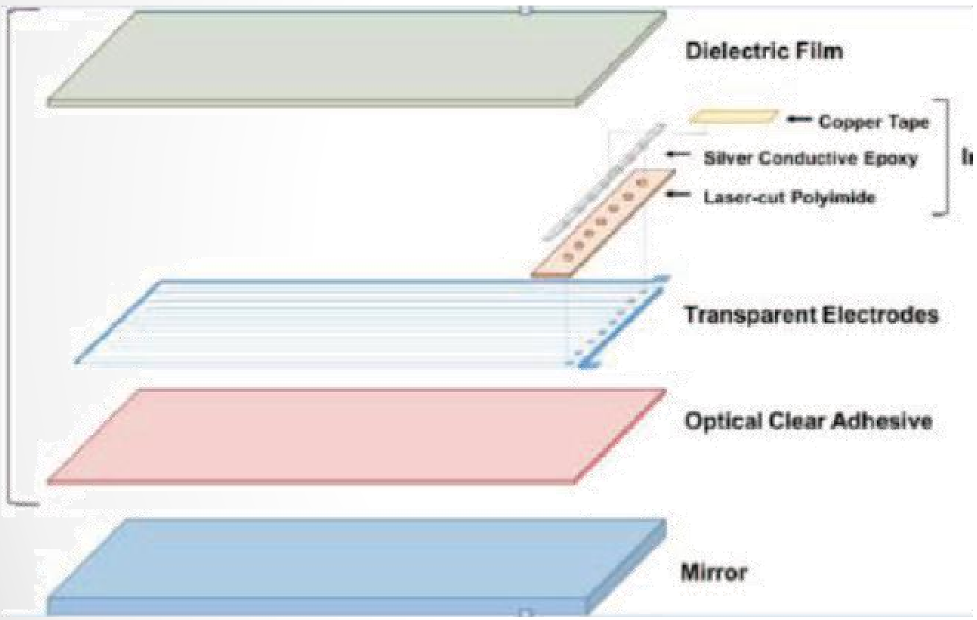


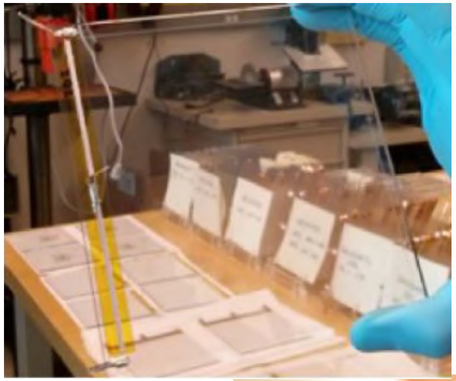
Charge to mass ratio

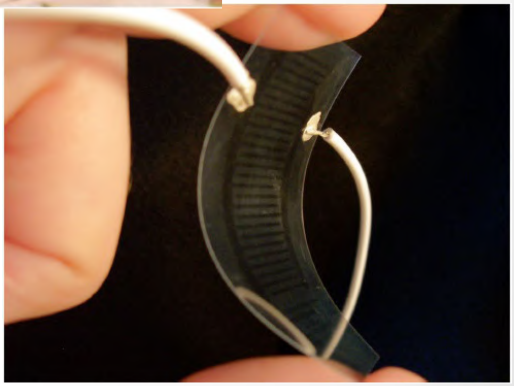


A. S. Biris ,Electrodynamic removal of contaminant particles and its applications, IAS 2004

Literature examples







M. N. Horenstein, "Modeling of trajectories in an electrodynamic screen for obtaining maximum particle removal efficiency," IEEE Transactions on Industry Applications, vol. 49, no. 2, pp. 707–713, 2013

M. K. Mazumder, Mitigation of Dust Impacts on Solar Collectors by Water-Free Cleaning with Transparent Electrodynamic Films: Progress and Challenges, IEEE Journal of Photovoltaic 2017

Brief summary

- ✓ Review on solar technology status.
- ✓ Dust effects.
- ✓ Prevention methods to dealing with dust phenomena.
- ✓ Physical principle beyond the EDS technologies, and identified the main forces that involves.
- ✓ EDS performance and the influence of the different parameters.

Thanks for your attentions