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THE EFFECT OF SANDSTORMS ON PV ARRAYS AND COMPONENTS

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ABSTRACT

Photovoltaic (PV) systems deployed in desert areas are exposed to wind-blown particles during most of their lifet Here, I describe the characteristics of wind-blown particles and with their effect on exposed surfaces. I provide insights for use in array design to minimize the effects of exposure and keep system costs as low as possible.

Finally, I present some data describing the exposure of polymer-encapsulated arrays to both field and laboratory wind-blown sand environments, and I present evidence that an encapsulated or "soft" array has a higher abrasion resistance and, therefore, a much higher probability of surviving a severe sand environment.

1. INTRODUCTION

The survivability of PV arrays in sandstorms frequently surfaces in discussions. Design data based on actual field experience with sandstorms are not readily available. However, much useful information can be gleaned from studies of wind-blown sand by several researchers. Designers seem to be unaware of the available material relating to this topic.

Serious experiments were first carried out in the 1930s and 1940s (1,2). In the 1960s, the U.S. Army also performed comprehensive studies of the erosive effects of wind-blown particles on man-made objects in desert areas (3). Other useful reports and papers are also readily available (4-6). In an attempt to provide some basic information for designers, I have summarized the effects of wind-blown particles on PV arrays derived from these classic sources, as well as first-hand experience accumulated during the course of several projects.

The deserts of the United States lie between 31° and 44° north latitude and are largely found in the states of California, Arizona, New Mexico, Texas, Colorado, Nevada, Oregon, and Washington. Not too surprisingly, desert areas coincide with those where the greatest insolation is available. The annual average daily global radiation on a horizontal surface ranges from 5 to 5.6 kWh/m^2 in these areas (7).

A PV system designer can readily compensate for the variations in temperature and moisture found in our deserts. The effect of wind loads on both fixed and tracking structures is also well understood. However, of equal or greater concern to a designer is the effect of wind-borne particles on a PV system.

2. CHARACTERISTICS OF WIND-BLOWN PARTICLES

The soils found in areas where PV systems are likely to be deployed are typically stony, hard-packed, sedimentary deposits. However, the surface deposits usually consist of loose sand, dust, and gravel that have usually been disturbed to an even greater extent during construction. These surface particles are easily picked up and carried by the wind, even during relatively calm periods.

While wind blows most of the time in the desert, severe sandstorms usually occur only about twice per year (on average). Storms of moderate intensity occur about four times per year. Most storms occur in late winter or spring and last for one to three days. Soils disturbed by man enhance the incidence of storms by making the desert surface more susceptible to wind forces (3).

Critical wind velocities at which particles start to move can be as low as 24-32 km/h (15-20 mph) and depend upon grain size and surface coherency. Fine particles or dust are often carried in very light winds. In dune areas, fine sand starts to move at about 16-24 km/h (10-15 mph). In other sandy areas, pickup starts at about 32 km/h (20 mph). On desert flats, materials start moving at 32-40 km/h (20-25 mph). Where the surface is heavily crusted, as on alluvial fans, movement begins at 48-56 km/h (30-35 mph) (Clements, 1963). If the desert surface is dusty, clouds of dust may rise to heights approaching 1000 m (3000 ft), completely blocking the sun (Pewe, 1981). There is not much that can be done to protect against dust storms, except to seal all electronic enclosures. Wind and rain will eventually remove most of the soil from the module surfaces.

However, sandstorms are a different matter; the designer can do much to minimize their effects. Once movement has begun, particles progress in a rolling, jumping, bouncing motion called saltation. A profile of a typical saltating curtain is shown in Fig. 1 (2). Sandstorms rarely exceed more than 1.5 m (6 ft) in height, and it is not uncommon to see the tops of structures and even heads of people sticking out of the saltating cloud (3).

Critical pick-up velocities vary widely for different sites, as shown in Fig. 2. The histograms show the increase in grain sizes with increasing wind velocities for soils from three different California sites. Figure 3 provides additional data for various soils and shows that particles may be picked up at very low wind velocities. The data in both Figs. 1 and 2 are based on laboratory tests using artificial wind sources (3).

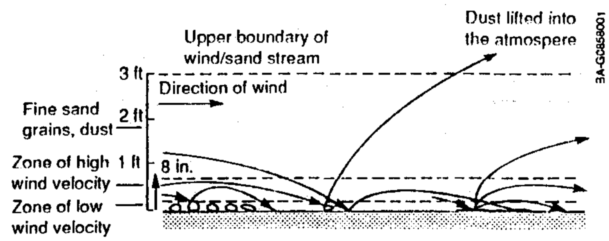

Fig. 1. Movement of sand grains in a saltating curtain (2)

The great bulk of material is carried within a 1 m (3 ft) of the ground. Figure 4 shows the cumulative weight of sand collected at different elevations during two sandstorms of different duration. The higher curve of May 1955 represents 86 days of collection. Most of the accumulation occurred during a 44 day period of strong winds.

In contrast, the plot of March 1953 represents a period of 30 days during lighter winds. These two periods represent extremes that define a typical "sandstorm" environment. The median height, below which 50% of the sand travels, is in the range 9-19 cm (3.5-7.5 in.); 90% of the sand travels below 46-89 cm (18-35 in.).

Individual grains may reach great heights. Grains of sand up to 2 mm (0.08 in.) in diameter have been found wedged into cracks in wooden powerline poles at heights up to 6 m (20 ft). Other observations, not confirmed, infer that grains as large as 0.125 mm (0.005 in.) may reach as high as 20 m (65 ft) (4).

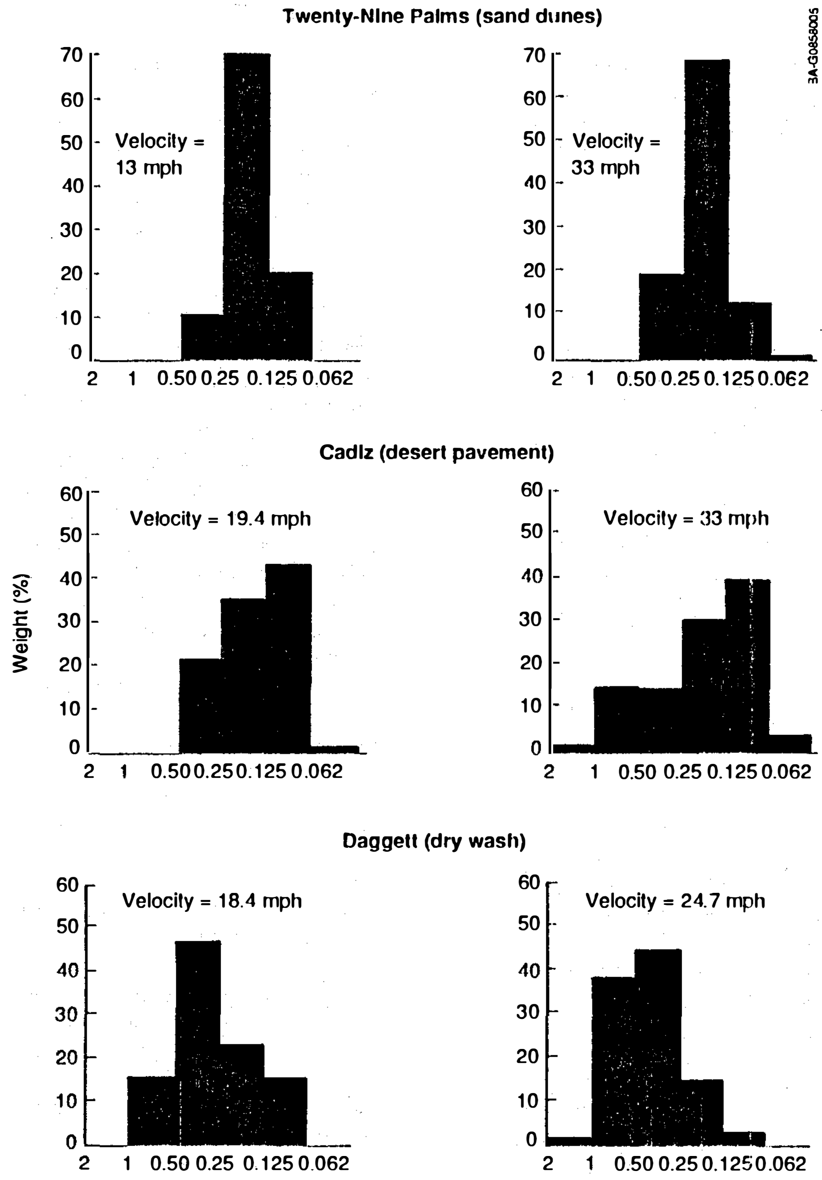

Fig. 2. Variation in sediment distribution with differing artificially produced wind velocities (3)

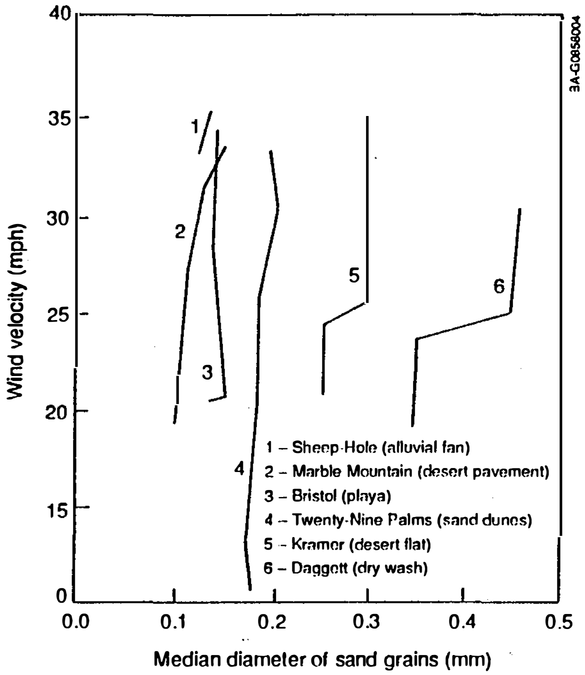

Fig. 3. Variation of median diameter of material transported with varying artificially induced wind velocity (3)

Massive amounts of material are carried in the saltating curtain. Clements et al. (3) record that at wind velocities of 29 km/h (18 mph), about 7 kg/h/m width (490 lb/h/ft width) of sediment were carried within 0.97 m (38 in.) of the ground. Nearly double that amount, 14.1 kg/h/m (990 lb/h/ft), was recorded in a 40-km/h (25-mph) wind.

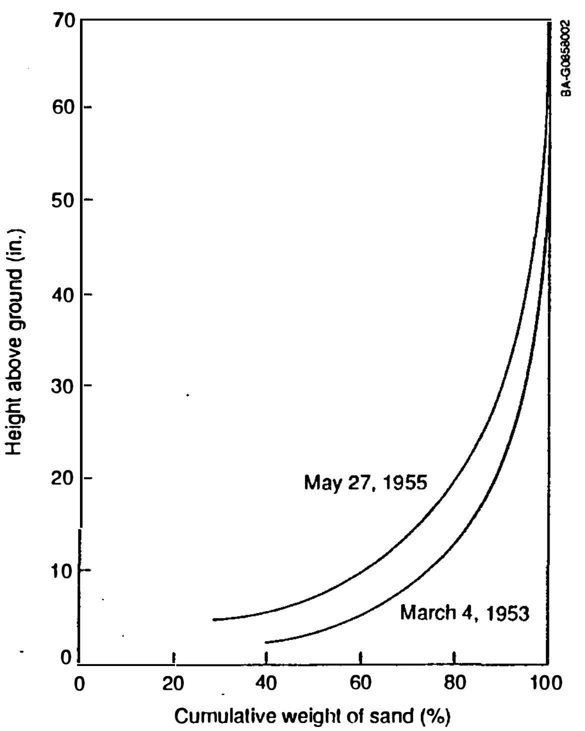

Fig. 4. Mass distribution of wind-blown sands in two typical storms (4)

3. EFFECTS OF WIND-BLOWN SAND AND DUST ON PV ARRAYS

The effects of sandstorms include blocking the sun, encroaching on installations by drifting sands, increasing wind loads, and electrostatic and erosive effects. Our discussion will concentrate on erosion by wind-blown particles and their effect on array design.

Most erosive damage occurs within the saltating curtain. Studies show that the zone of maximum cutting or wear occurs well above the average height below which 50% of the saltating material travels. The zone of maximum cutting represents the level at which grain size, number, and velocity combine to give the highest energy spectrum. This zone ranges 15-38 cm (6-15 in.) in height.

Figure 5 shows the average wear profiles measured on two 1-m (4-ft) high, 0.3-cm (0.125-in.) diameter lucite rods after eight and ten years of exposure in the California desert. Although maximum wear occurred at about 23 cm (9 in.) above the ground, abrasive cutting occurred from ground level up to the full height of the rods. The cutting effect at 107 cm (42 in.) is about equal to that at ground level.

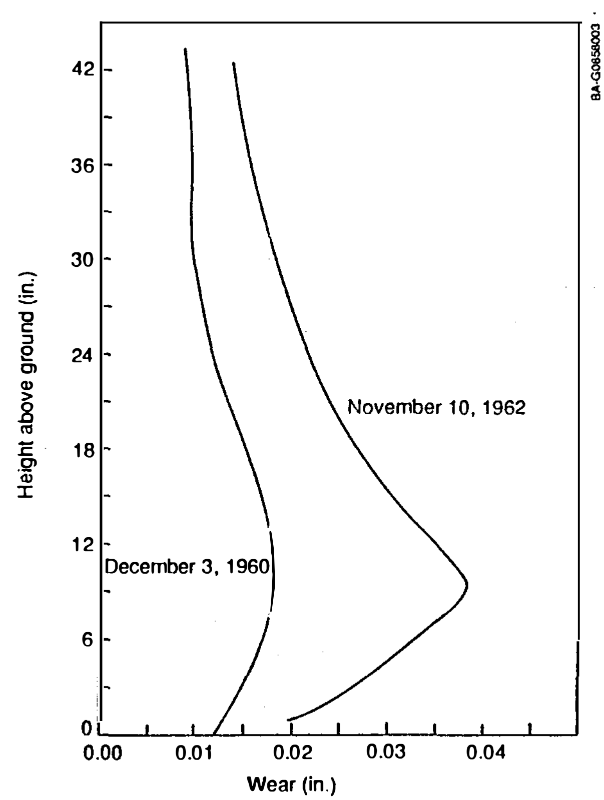

Fig. 5. Effect of wind-blown sand on sample Lucite rods (4)

Bricks exposed at ground level during the same test also experienced wear. The bricks ranged in hardness from 2.5 to 3.0 (Moh's scale). After 48 days, no wear was apparent. Pitting was first observed after 228 days, and one brick showed pits 0.5 cm (0.2 in.) deep after one year. After about 3½ years, the exposed upwind face of one brick had been cut back by more than 1.27 cm (0.5 in.); after six years, more than 3.8 cm (1.5 in.) had eroded away (4).

4. DESIGNING FOR MAXIMUM SURVIVABILITY

One of the most obvious ways to increase survivability is to raise the bottom edge of a PV array above the saltating curtain. If the array is fixed, this imposes certain constraints on the design. The center of pressure is raised and, because wind loading invariably increases with height, the designer is faced with increased structural cost. Beyond a certain point, the cost becomes prohibitive and a designer has to settle with a lower profile (i.e., array surface per linear meter of array).

Single- or double-axis trackers offer more effective ways of dealing with sandstorms. Raising their height to avoid wind-blown particles also increases the wind-induced moments on the modules, requiring stiffer structures and more massive foundations. However, tracking collectors offer the possibility of rotating to a horizontal position, lifting the modules out of the saltating curtain, as well as reducing wind loading. In especially windy areas, this feature alone may dictate the selection of tracking collectors.

Rotating the arrays to a horizontal position during windy periods does not necessarily mean a large loss of energy from the system. In desert areas, there seems to be a direct correlation between high winds and reduced insolation, the exact amount depending upon the specific site. Resource assessment and meterological observations at a given site can provide the designer with enough information to optimize plant performance. Also important to a designer are the ground surface characteristics. These determine the critical pick-up velocities at which materials start to saltate.

Other methods have been successfully used to minimize damage from wind-blown particles. It has long been noticed that "hard" objects suffer more from abrasion than "soft" ones. The records of auto insurance companies also verify that more damage is sustained by objects that try to move against a storm. Experiments were carried out in the 1960s to see whether a soft protective surface on a PV array would survive better than the traditional glass surfaces. Samples of glass- and silicon-covered solar cells were exposed under laboratory conditions to sand environments more severe than all but the most violent of sandstorms. For example, one test consisted of blowing 20-mesh Mohave Desert sand at 4.1×10^4 N/m^2 (6 psig) against glass and silicone (RTV) surfaces. The glass surface eroded about 0.089 cm (0.035 in.) after 8 h exposure. At 8.3×10^4 N/m^2 (12 psig), the sand penetrated 0.23 cm (0.09 in.) of window glass in 60 min.[1] The elastomeric specimen showed only a light opaque film that could be scraped off.

Epoxies were also considered but were rejected because of known degradation when exposed to the ultraviolet region in bright sunlight.

Some optical quality was lost because of sand particles sticking to the elastomer. However, we concluded that the elastomeric coating was preferable to the glass for long-term desert exposure. A coating of Mineralite 4x wet-ground mica applied to the elastomer surface reduces the accumulation of sand particles with a minor but acceptable loss in transmittance. The mica flakes apparently align themselves in a single, oriented layer, with the flat faces forming a molecular bond with the soft plastic. The surface of the flake is hard and supports only a minimal amount of material. The abrasion resistance of the mica appears to be high.

A prototype unit was exposed to the desert environment for a total of 53 days. The bottom of the test unit was approximately 76 cm (30 in.) above the ground; the top was about 91 cm (36 in.) high. During the test period, several severe sandstorms occurred where wind velocities exceeded 68 km/h (42 mph). On ten days, wind velocities exceeded 16 km/h (10 mph). No noticeable erosion or degradation of the polymer surface was measured on the field test model during the test. Subsequent observations on other units over longer periods of time showed similar results.

During the 1980's, the Jet Propulsion Laboratory investigated several encapsulants, including polymers, as low-soiling surfaces. Some success was achieved. However, the abrasion resistances of the materials to sandstorms is not well known (8).

5. SUMMARY

The PV system designer has several options available to increase the survivability of deployed systems. The height of the collectors can be raised to where the overall size and density of particles are lower; however, wind loads may increase to unacceptable levels. The collector envelope may need to be reduced to minimize cost.

Elastomeric coatings appear to have a higher abrasion resistance than that of glass. While their disadvantage is that the surface softness encourages particles under a certain size to adhere, which can result in severe transmittance losses, optical losses appear to be controllable by dusting the surface with mica flakes.

6. ACKNOWLEDGEMENTS

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[1]For calibration purposes, sand blown at 3.5×10^4 N/m^2 (5 psig) produces continuous pain on the back of the hand; 6.2×10^4 N/m^2 (9 psig) produces continuous pain on the palm!

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