TECHNICAL MEMORANDUM

Impact of Soiling and Pollution on PV Generation Performance

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The City of San José Solar America Showcase requested technical and operational questions on the installation of a PV array along the flight path to/from the San José International Airport. The question related to the deposition of "oily residue" onto the proposed PV array. This letter will attempt to address these concerns by quantifying, based on a literature search, the average annual loss due to soiling, the impact of cleaning, and a recommended cleaning schedule.

A search was made of the Department of Energy, its research laboratories and experiment stations, electrical and solar organizations and industrial web sites to identify any issues with soiling losses of PV arrays. The search returned five studies on this topic including one study that discussed average annual energy losses in "Urban/Highway/Airport" installations in California. [1, 2, 3, 4, 5]

Performance Loss Due to Pollution

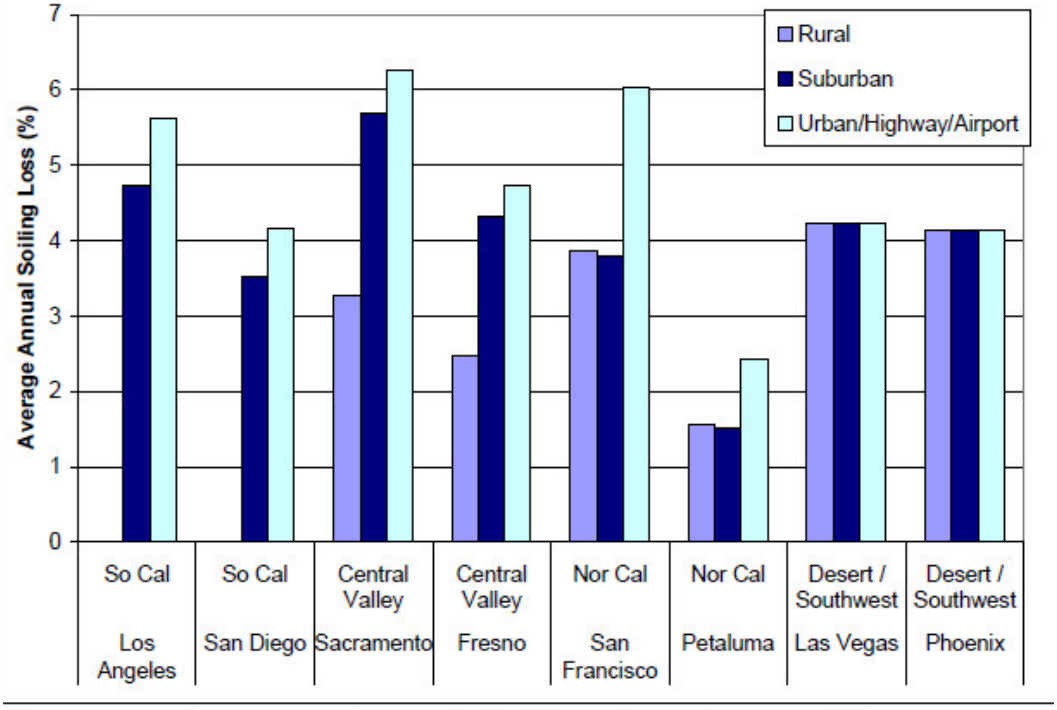
The Southwest Technology Development Institute (SWTDI) [1] tested and evaluated several PV systems throughout the country, including a 300 kW system at Georgetown University in Washington, DC. This system is located along the flight path for Reagan National Airport. After being in operation for 3 years, SWTDI selected modules in the array that were subjected to cleaning. After being "scoured" with a nonabrasive pad and solution of soap and ammonia, the power output was increased by 23% compared to measurements taken prior to the cleaning. Although the sources of contaminants were not identified, this study indicates the effectiveness of cleaning PV modules located along a flight path. Additionally, the output of the cleaned modules was compared to the output of spare modules that had never been installed. The cleaned modules had lower output by 9.5% than the spare modules that had never been installed.

In 2006, Mitchell [5] undertook a review of the energy loss of photovoltaic systems from the accumulation of dirt and particulate matter for 46 large, grid-connected PV systems in California and the Desert Southwest. Mitchell found that photovoltaic system efficiency for systems located in Urban/Highway/Airport settings in Northern California declines by approximately 0.16 percent per day between significant rainfall

events. This daily loss finding equates to an annual energy loss between 2.5 – 6.0 percent depending on system location. An additional finding was that there is not a well-defined amount of rain required to clean a system. In fact, some light rains caused efficiency to go down significantly while others improved efficiency dramatically.

Kimber [4] conducted a controlled study of soiling losses on three identical systems at a commercial office park in Los Angeles and showed that annual system losses due to soiling are approximately 5 percent. One system was cleaned twice over the dry period, one system once, and the third was not cleaned. Kimber emphasizes that economics of system cleaning will differ and that for purposes of this study in Southern California, cleaning economics required an energy value of approximately $0.25/kWh to justify the cleaning cycle.

EXHIBIT 1
Average Daily Soiling Loss By Region and Environment



Source: Proceedings of the 4th World Conference on Photovoltaic Energy Conversion [5]

Häberlin [2] studied the impact of semi-permanent energy loss due to unusual pollution sources. In this case, the PV array was located less than 50 m from a rail line. Strips of pollution that was not washed away by seasonal rains were analyzed and found to have high levels of iron dust from the railway lines. The strips also trapped pollen and fostered growth of pioneer plants. After four years of gradual decline in output reaching 8-10 percent, the modules were cleaned and most of the power loss due to pollution was reversed.

Hammond [3] conducted a study in which it was discovered that bird droppings are much more serious than soiling due to dirt and dust. Losses were higher, approaching 8 percent, and were not fully recovered even by heavy rain.

Urban Pollution Composition

With regard to being in the flight path of the San José International Airport, there was no evidence discovered in this brief literature search to indicate that the particulate matter deposited near airports is different than that found in every urban environment. Airborne particulate matter and sooty material are a product of many sources such as power plants, automobile exhaust, railroad, airport and marine activities.

The Environmental Monitoring Division of the Department of Natural Resource Protection of Broward County, Florida, conducted a month long study [6] of dry deposition in and around the Ft. Lauderdale- Hollywood International Airport and also in the Melaluca Isles neighborhood since residents there had complained of oily material being deposited on their homes and vehicles. Their concerns were that these sooty deposits were being generated by airplane traffic and fuel. The study concluded that there was no evidence obtained to indicate that the neighborhoods adjacent to the airport are being negatively impacted with regard to particulate matter. The amount of soot correlated to the amount of automobile traffic in the area.

Given this information, it follows that studies of the impact of pollution in urban environments on PV installations are relevant whether or not the proposed location is near an airport.

Although no literature was identified, CH2M HILL learned that cleaning studies were conducted on a PV system in Queens, NY that was located in the flight path of JFK Airport, however the primary concern for soiling was caused by seagull droppings and not jet exhaust. [7] According to the lead investigator, Jet A fuel has been a noted concern but no long-term data exists regarding its effect on PV modules. There are likely other sources of pollutants that in conjunction with potential jet exhaust would warrant regular cleaning. A recommended cleaning technique is to use soap and water with a medium to high pressure wand or brush, however care/common sense should be applied to not damage the module and/or frame and to prevent water from entering the module so that delaminating does not occur.

Conclusions

Being in an urban environment in an arid climate, PV systems can suffer dramatic losses between rain events due to the accumulation of soiling. Unusual soiling such as iron dust, plant matter, and bird droppings can create semi-permanent losses that are not fully recovered from even severe rain events. Depending on the severity of the pollution deposition and the cost/difficulty of cleaning, one or two cleanings during the dry season should accomplish both short term and long term goals of reclaiming losses due to soiling from various sources. In any event, the system output and the precipitation should be monitored closely to determine cleaning requirements. Based on the literature

review and conversations with National Laboratory personnel, CH2M HILL makes the following conclusions and recommendation:

- Most studies that investigated the effect of cleaning soiled modules, have made conclusions that are specific to the climate and environmental factors of the site (rainfall; sources, quantity and amount of pollutants, PV module tilt, etc.).
- The benefit, frequency and method of cleaning soiled modules depend on conditions at the site and should be monitored to determine an appropriate plan. A cost benefit analysis should be performed to determine a final cleaning plan.
- The City of San José should engage in a cleaning schedule for the PV modules (with recommendations for the cleaning agent and method from the PV module manufacturer to not impact the warrant).
- As part of the cleaning plan, the City or power purchase agreement provider should also take performance measurements (curve tracer readings before and after the cleaning) to determine the difference in performance. The schedule should be based on the measureable difference in performance (less frequent cleanings if not significant).
- The City of San José should ensure that an infrastructure is in place to accommodate the pressure spray cleaning requirements (i.e. safety railing, tie points for lanyards, etc.). The City can also investigate the use of recycled or gray water for PV module cleaning.
- Aircraft exhaust will likely not be the only contributor to PV module soiling. Other sources may include vehicle exhaust from nearby highways and rail system.
- The City should publish its findings so that it can be referenced for future projects.

References

[1] Southwest Technology Development Institute "Southwest Region Experiment Station 1988 Report", U.S. Department of Energy, New Mexico, 1988

[2] H. Häberlin, J.D. Graf, "Gradual Reduction of PV Generator Yield due to Pollution," Proceedings of the 2nd World Congress oh Photovoltaic Energy Conversion, Vienna, Austria, 1998

[3] R. Hammond, D. Srinivasan, A. Harris, K. Whitfield, J. Wohlgemuth, "Effects of Soiling on PV Module and Radiometer Performance," Proceedings of the 26th IEEE PVSC, Anaheim, California, USA, September 29 – October 3, 1997

[4] A. Kimber, "The Effect of Soiling on Photovoltaic Systems (sic) Located in Arid Climates," Berkeley, California, USA, 2006.

[5] A. Kimber, L. Mitchell, S. Nogradi, H. Wenger, Proceedings of the 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA; May 7-12, 2006

[6] B. Strouse, "Atmospheric Dry Deposition Study," Department of Natural Resources Technical Report Series TR: 93-1, Broward County, Florida, 1993.

[7] Telephone conversation with Byron Stafford, National Renewable Energy Laboratory, June 2009