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Snow Loading on a Tilted PV Module in Northern Michigan

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Abstract

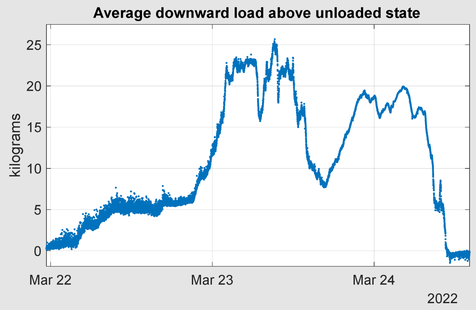
As PV systems are proliferating at northern latitudes, there is additional need to understand the effects of snow accumulation on PV modules. Sandia National Laboratories has installed an experimental platform in Calumet, MI to measure both static and dynamic snow loading on a photovoltaic (PV) module throughout the course of a winter characterized by periods of persistent snow, in which the module remains under continuous load, as well as repeated snowfalls of varying load. This poster describes the magnitude of snow load, the rate of load change, and the spatial distribution of load on a PV module over the 2021-2022 winter.

Background

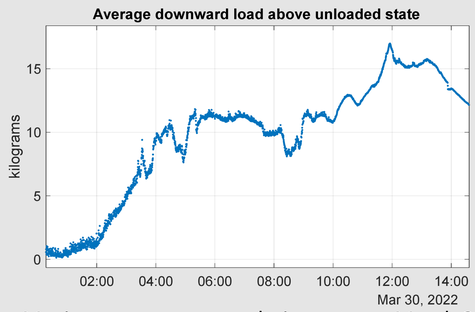
As snow accumulates on PV modules, the forces on the module increase until the snow is removed. Many times, the snow removal is accomplished when the snow slides from the bottom of a tilted PV module. This sliding effect will dominate the “dynamic” changes in snow load across a PV system [1]. Extreme stresses due to high snow load may cause cell cracking or racking failure. Thus, the mechanical stress on PV modules due to snow loading, and the dynamic nature of snow shedding from PV modules is a research area that requires study in order to inform the design of PV modules for cold climates.

Sandia has developed a platform to measure the loading on each corner of a PV module and deployed this platform at Michigan Technological University in Calumet, Michigan prior to the 2021-2022 winter season [2]. The platform holds a 1.675 m^2 PV module at a 35 degree tilt to the horizontal while measuring the downward (rather than in-plane) load at each corner of the PV module, recording the average, minimum, and maximum loads at a 1-second interval. The platform and module present a load to the sensors, but these loads have been removed in our analyses to present only the load due to snow. An on-site weather station records irradiance and precipitation. Any frozen precipitation is melted by a heated rain gauge and Snow Water Equivalent (SWE) is measured. Keweenaw county recorded 8.25 meters of snowfall over the 2021-2022 winter [3], providing ample opportunity to study snow loads on PV modules

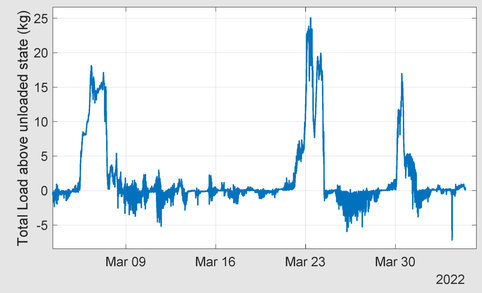
The snow load measurement station installed in 2021.

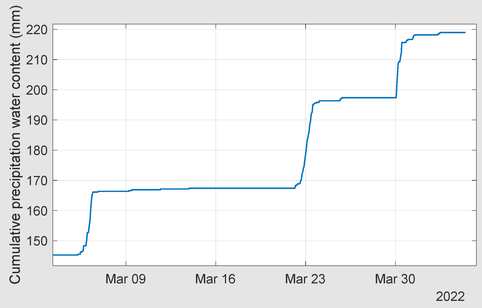


Maximum snow accumulation on March 23 resulted in a little more than 25 kg of load on the PV module (15.3 kg/m^2 or 150 Pa).

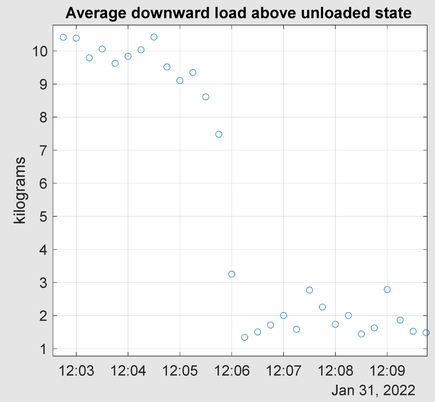


Maximum snow accumulation rate on March 30 increased the total load on the PV module by 16 kg in 12 hours.

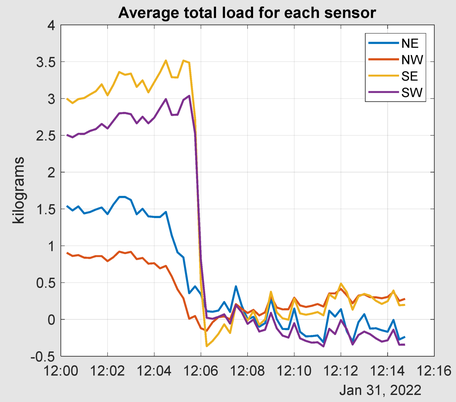




When snowfall accumulates on the PV module, as in these 3 snow events, the loading of the PV module is approximately 0.4-0.5 kg per mm SWE (water content) per m^2 of PV area.



Fast snow shedding on January 31. The entire shedding period experienced load changes of -8.5 kg/minute. Maximum load reduction was -4.25 kg in 15 seconds.



Load shedding is not evenly distributed across the PV module. Most of the load is lost from the southern edge of the PV.

Nearby PV modules at 12:00 and 12:15 also show rapid snow shedding.

Results & Discussion

Throughout the winter of 2021-2022, the maximum load measured due to snow on the PV module was approximately 25 kg as a result of a snow on March 22-23 that provided about 40 cm (16 inches) of snow, with 30 mm SWE. However, the maximum rate of load accumulation occurred on March 30, where 11.5 cm (4.5 inches) of wet, heavy snow, equivalent to 21 mm of rain, accumulated on the PV at a rate of approximately 16 kg in 12 hours.

As demonstrated over the snow falls on March 22-23 and March 30, the density of snow varies such that the SWE is not consistent for a given depth of snow. When the snow is accumulating on the PV, we found a relatively consistent correlation between the measured SWE and the load on the PV module. As shown over three events in March 2022, the PV module load is approximately 0.4 to 0.5 kilograms of load per mm of SWE per square meter of PV area. For weather stations that measure equivalent water content, these figures provide a consistent estimate of the snow load that can accumulate on PV. This is, of course, specific to the module tilted at 35 degrees relative to the horizontal and needs further study at other tilt angles.

Lastly, we looked at the maximum rate of snow shedding from a PV module. In our data set, the fastest snow shedding occurred on January 31 just after noon. In a 1-minute period the PV module shed almost 8.5 kg of snow, with the maximum measured rate of 4.25 kg of snow in 15 seconds. However, as might be expected, the load of the snow was not evenly distributed and most of the load reduction occurred from the southern (lower) edge of the PV module.

Conclusion

Over the course of the 2021-2022 winter in Calumet, MI, Sandia measured loading due to snow on a tilted PV module. Snow load on the module reached a maximum of 15.3 kg/m^2 and could accumulate at a rate of approximately 1.3 kg/h. Snow shedding off of the module caused rapid load changes in excess of -4.25 kg in 15 seconds The shedding caused uneven loading across the module, with most of the load shedding from the southern (lower) side of the module.

The depth of snowfall did not consistently correlate with the loads on the PV module due to the varying density of the snow. However, if the Snow Water Equivalent (SWE) is measured, a consistent load can be estimated at 0.4 to 0.5 kg per mm SWE per m^2 of PV for snow accumulating on a PV module tilted at 30 degrees. Further study into these effects for modules of differing size and tilt will continue at the site in future winter seasons.

[1] J. Bogenrieder et. al., 2018. “Technology-dependent analysis of the snow melting and sliding behavior on photovoltaic modules,” Journal of Renewable and Sustainable Energy 10, 021005.
[2] L. Burnham, et. al. Dedicated cold-climate field laboratory for photovoltaic system and component studies: the Michigan Regional Test Center as a case study, 49th Photovoltaic Specialists Conference, 2022, Philadelphia, PA.
[3] https://keweenawcountyonline.org/snowfall2.php

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