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# Differences in Snow Shedding in Photovoltaic Systems with Framed and Frameless Modules

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***Abstract* — Energy losses due to snow coverage can be high in climates with large annual snowfall. These losses may be reduced with region-specific system design guidelines. One possible factor in snow retention on PV systems could be frame presence and/or shape. Sandia is studying the effect of module frame presence on photovoltaic module snow shedding for a pair of otherwise-identical PV systems in Vermont. The results of this study provide a summary of the findings after the 2018-2019 winter period. The results clearly show that the presence of a frame inhibits PV performance in mild winter conditions.**

## I. Introduction

As solar photovoltaic (PV) systems become less expensive [1], they are being installed more frequently in climates that, until recently, had been considered ill-suited for PV energy, including northern climates with high annual snowfall. Snowfall in these climates can be a significant source of energy loss [2] and consequent reduction in levelized cost of energy. Prior studies have found that annual energy losses due to snow can exceed 30% [3], but they are typically less than 10% [4-8]. Accounting for even relatively small snow-related losses in PV system performance is important for large scale systems [9].

Efforts to develop models to predict snow loss, such as that developed by Marion et al., predict the amount of snow that slides off PV modules under given environmental conditions such as [7]. Sandia National Laboratories has partnered with the U.S. Army Corp of Engineers Cold Regions Research and Engineering Laboratory, Michigan Technological University, and the University of Alaska, Fairbanks to study the effect of snow on PV systems and research designs and products that reduce energy loss in snowy conditions. One system design consideration for snow loss mitigation is the presence or shape of a PV module's frame [10-12] as well as height of the modules above ground. Our research adds another dimension to snow-loss models and may.

To provide more quantitative data on the impact of the presence of a frame on PV performance in snowy regions, we collected data from a pair of adjacent 6kW PV systems populated with modules having identical electrical and physical properties, differing only in the presence or absence of an aluminum module frame. The PV systems were located in Vermont, with a south-facing fixed-tilt rack, tilted 35 degrees from horizontal. Each system was monitored for performance including measurements of module temperatures, string electrical measurements, and a camera photographing several modules of each system. The analysis of this data clearly shows the effect of a frame on the snow shedding ability of a PV module and the subsequent energy loss occurring due to reduced snow shedding.

Fig. 1. Photograph of the two PV systems at the VT field site. Left modules are framed, right modules are frameless.

## II. Data and Analysis

The electrical performance of each system is measured by Sandia's custom measurement hardware employing high accuracy shunts and voltage dividers for measurement of string current and system voltage. Measurements are made every 5 seconds and averaged into 1-minute recorded data. Photographs, such as that shown in Fig. 1, are taken every 15 minutes. The open source Fiji/ImageJ image analysis software (https://fiji.sc/) is used to automatically process batches of photographs to determine the amount of the PV system that is covered by snow, in percent. Only the modules nearest to the center of the image are counted, such that each module has approximately the same area in the photo. The performance data and image data are time stamped and synchronized to allow for analysis and cross-comparison.

Fig. 2 presents the data from December 25, 2018 after a heavy snowfall on the 24$^{th}$. The day is mostly sunny and the snow began to slide off the frameless modules between 9:45 and 10:00 with almost complete shedding by 12:00. The framed modules, however, shed later and over a longer period, and did

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not complete shedding until 13:00. This resulted in power loss that day of approximately 3.2 kWh of energy, or about 13% of energy, relative to the frameless modules. Fig. 4 shows a similar trend on December 8 which resulted in the framed modules producing 9% less energy than the frameless modules.

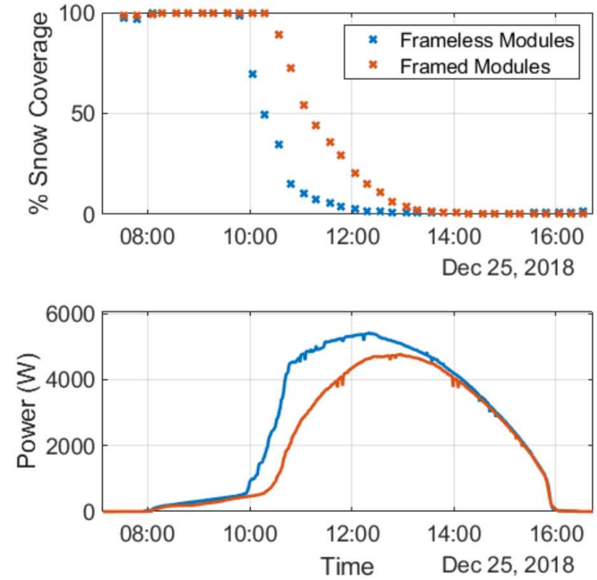


Fig. 2. Snow shedding of framed and frameless modules along with power measurements for each system on December 25.

Fig. 3. Framed and frameless PV modules shedding snow at different rates, shown at 10:45 on December 25.

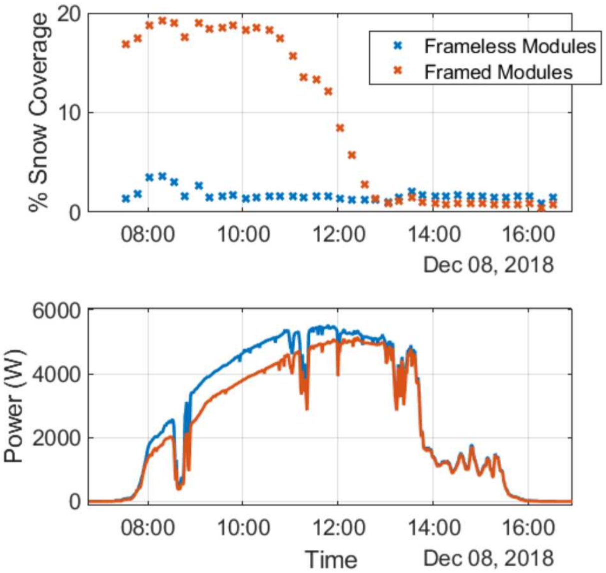


Fig. 4. Snow shedding of framed and frameless modules along with power measurements for each system on December 8

## III. DISCUSSION

These data indicate that frameless modules typically shed snow more quickly than framed modules, and the energy gains of frameless modules relative to framed modules could exceed 10% on snowy days. These findings present an opportunity to increase energy yield in snowy climates through design optimizations in cold climates. We note, however, that in these instances, the primary mode of snow removal was snow sliding down the module face. This mode is predominant when the module temperature is above 0° C.

However, when the module/snow interface temperature is below 0° C, snow sliding is inhibited, and sliding may not be the primary snow removal mechanism [7]. Fig 5 and Fig. 6 show that the framed and frameless modules are shedding snow at approximately the same rate when the module temperatures remained just below 0° C and ambient temperatures were approximately -10° C.

Fig. 5. Framed and frameless PV modules shedding snow at similar rates, shown at 14:15 on January 12, 2019.

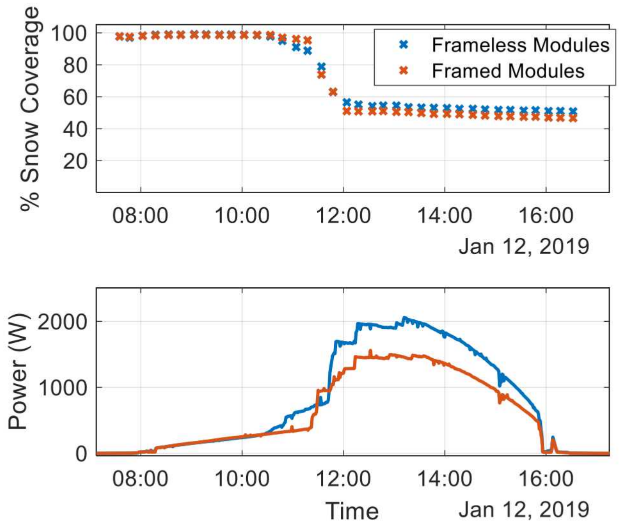


Fig. 6. Framed and frameless PV modules shedding snow at similar rates, shown at 14:15 on January 12, 2019.

The snow shedding model by Marion et al. has been improved by researchers at SunPower to include the effect of snow build-up on the ground after shedding from a PV system [13], as can happen in an area with frequent and large snowfalls. Our pictures indicate that there is a greater volume of snow build up beneath frameless modules as shown in Fig. 7. Note that snow buildup is much higher under the frameless modules. This indicates that under some conditions, the slower snow shedding of the framed modules allows the snow to either melt or sublime rather than shed cleanly down the module face. Thus, the calculation of snow volume beneath PV systems may be related to the speed at which they shed snow rather than a simple assumption that all snow which has shed is deposited on the ground. This can become an important consideration for optimal PV system design in snowy environments as failing to leave enough clearance for the buildup of snow that has slid off the modules can cause ground interference and much higher losses than otherwise expected [3]. For example, see Fig. 8 and 9, where cumulative snowfall and shedding has produced snow buildup sufficient to prevent further sliding on the frameless modules. This condition caused energy losses of approximately 18% and persisted for 5 days before temperatures warmed enough to sufficiently melt the buildup and allow for complete shedding.

Fig. 7. Snow buildup underneath modules after the December 25, 2018 shedding event. Frameless modules are on the right. Note increased buildup due to faster snow shedding on frameless modules.

Fig. 8. Increased snow accumulation under the frameless modules on January 30 preventing further sliding.

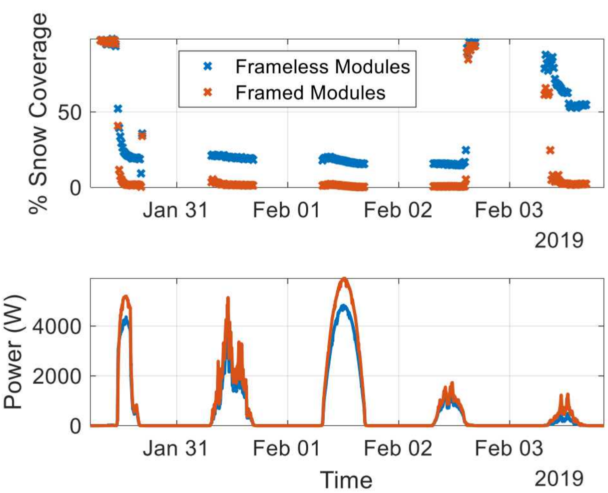


Fig. 9. Snow accumulation prevented snow sliding on frameless modules for 5 days.

The results presented here indicate for snowy regions that frequently have temperatures hovering around 0° C during the winter, frameless modules will have higher energy production than those with frames. This would indicate that life cycle analysis (LCA) models should be updated to show this benefit; although they already show a significant improvement in environmental performance for frameless modules [14].

## IV. CONCLUSION AND FUTURE WORK

When snow sliding is the primary mechanism for PV systems shedding snow, the presence of a PV module frame impedes snow sliding and thereby reduces energy production. The Sandia-led research team's goal is to characterize energy losses in snowy climates and make strides to reduce this energy loss.

One clear method of reducing energy losses could be to install PV modules without frames, or with frames designed to aid snow shedding. However, system designs that facilitate snow shedding may also require additional ground clearance to allow for more snow accumulation at the foot of the PV modules.

The data and analysis presented here may also provide an additional factor to advance pre-existing snow shedding models.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] R. Fu, D. J. Feldman, and R. M. Margolis, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018," National Renewable Energy Lab. (NREL), Golden, CO (United States), NREL/TP-6A20-72399, Nov. 2018.

[2] R. E. Pawluk, Y. Chen, and Y. She, "Photovoltaic electricity generation loss due to snow – A literature review on influence factors, estimation, and mitigation," *Renewable and Sustainable Energy Reviews*, vol. 107, pp. 171–182, Jun. 2019.

[3] N. Heidari, J. Gwamuri, T. Townsend, and J. M. Pearce, "Impact of Snow and Ground Interference on Photovoltaic Electric System Performance," *IEEE Journal of Photovoltaics*, vol. 5, no. 6, pp. 1680–1685, Nov. 2015.

[4] T. Sugiura, T. Yamada, H. Nakamura, M. Umeya, K. Sakuta, and K. Kurokawa, "Measurements, analyses and evaluation of residential PV systems by Japanese monitoring program," *Solar Energy Materials and Solar Cells,* vol. 75, no. 3, pp. 767–779, Feb. 2003.

[5] L. Powers, J. Newmiller, T. Townsend, "Measuring and modeling the effect of snow on photovoltaic system performance," in *Proc. 35th IEEE Photovoltaic Specialists Conf.*, Jun. 2010, pp. 973-978

[6] T. Townsend and L. Powers, "Photovoltaics and snow: An update from two winters of measurements in the SIERRA," in 2011 *37th IEEE Photovoltaic Specialists Conference,* 2011, pp. 003231–003236.

[7] B. Marion, R. Schaefer, H. Caine, G. Sanchez, "Measured and modeled photovoltaic system energy losses from snow for Colorado and Wisconsin locations," in *Solar Energy*, vol. 97, pp. 112-121, 2013.

[8] R. W. Andrews, A. Pollard, and J. M. Pearce, "The effects of snowfall on solar photovoltaic performance," *Solar Energy*, vol. 92, pp. 84–97, Jun. 2013.

[9] R. W. Andrews and J. M. Pearce, "Prediction of energy effects on photovoltaic systems due to snowfall events," in 2012 *38th IEEE Photovoltaic Specialists Conference*, 2012, pp. 003386–003391.

[10] M. M. D. Ross, "Snow and ice accumulation on photovoltaic arrays: An assessment of the TN conseil passive melting technology, report# EDRL 95-68 (TR), energy diversification research laboratory, CANMET." Natural Resources Canada, Varennes (1995).

[11] C. Libby, S. Kurtz, and S. Coley, "Field testing of flat-plate and concentrator photovoltaic systems at the Solar Technology Acceleration Center," in *2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC),* 2015, pp. 1–6.

[12] A. Weiss and H. Weiss, "Photovoltaic cell electrical heating system for removing snow on panel including verification," in *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA),* 2016, pp. 995–1000.

[13] D. Gun, G. Kimball, M. Anderson, "Dynamic Snow Loss Model and Validation," in *Proc. PVPMC 2018, May 2018.*

[14] J. Peng, L. Lu, and H. Yang, "Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems," *Renewable and Sustainable Energy Reviews*, vol. 19, pp. 255–274, Mar. 2013.