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Instrumentation for Evaluating PV System Performance Losses from Snow

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INSTRUMENTATION FOR EVALUATING PV SYSTEM PERFORMANCE LOSSES FROM SNOW

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ABSTRACT

When designing a photovoltaic (PV) system for northern climates, the prospective installation should be evaluated with respect to the potentially detrimental effects of snow preventing solar radiation from reaching the PV cells. The extent to which snow impacts performance is difficult to determine because snow events also increase the uncertainty of the solar radiation measurement, and the presence of snow needs to be distinguished from other events that can affect performance. This paper describes two instruments useful for evaluating PV system performance losses from the presence of snow: (1) a pyranometer with a heater to prevent buildup of ice and snow, and (2) a digital camera for remote retrieval of images to determine the presence of snow on the PV array.

1. INTRODUCTION

For northern locations in winter, snow reduces the amount of PV energy produced, with the severity of the reduction a function of the amount of snow received and how long it remains on the PV modules. Snow remains the longest on PV modules when sub-freezing temperatures prevail, small PV array tilt angles prevent snow from sliding, the PV array is closely integrated into the roof, and the roof or other structure in the vicinity facilitates snow drifting onto the PV modules. Presently, there is little information pertaining to predicting performance losses from snow, but it has been identified for some locations as a serious loss factor.[1]

To precisely determine snow losses would require identical systems operating side-by-side, with one system allowing snow to accumulate naturally and with the other having the snow immediately removed. Of course, this is impractical for most situations, and removing snow immediately is an insurmountable task. However, if an accurate irradiance measurement is made with a pyranometer, we can estimate what the PV performance should be without snow on the PV modules. Unfortunately, pyranometer measurements are also affected by snow. When covered with snow, the measurement will be low and not reflect the true solar resource. Additionally, sometimes the measurements are erroneously high if the sun melts the snow nonuniformly and the sun's rays are reflected (concentrated) onto the pyranometer sensor.

Our approach for instrumentation for evaluating PV system performance losses from snow is twofold: (1) a pyranometer with a heater to prevent buildup of ice and snow, and (2) a digital camera for remote retrieval of images to determine the presence of snow on the PV array. This paper describes these instruments and their use to determine losses related to snow for PV systems located at the National Renewable Energy Laboratory (NREL).

2. INSTRUMENTATION

As described in the previous section, a pyranometer with a heater and a digital camera with remote image retrieval capabilities are the additional instrumentation requirements for determining performance losses from snow.

2.1 Pyranometer with Heater

For the irradiance measurement, it is desirable to use a small pyranometer to minimize the surface area subject to snow accumulation and to minimize the heating requirements. Consequently, we used a Li-Cor pyranometer and mounted it on top of a vertical rod to further prevent snow accumulations from interfering with operations. The top of the rod was machined for securing the Li-Cor pyranometer with a tilt angle of 40° from horizontal, which is equal to the site latitude and matches the tilt angle of most of the PV systems located at NREL.

For the heating element, a 3-foot piece of 120-V AC electric water pipe heating cable was wrapped around the Li-Cor pyranometer and vertical rod, and the ends of the heating cable were secured with electrical tape. This is shown in Fig. 1. The temperature is regulated with a Johnson Controls A419 Series Electronic Temperature Controller, Model No. A419 AEC-1, with the temperature sensor located near the top of the vertical rod and under the heating cable.

Fig. 1: Heated pyranometer components. (a) Li-Cor pyranometer, (b) heating cable, and (c) temperature sensor for temperature controller. The ends of the heating cable are secured with electrical tape.

Fig. 2: Heated pyranometer demonstrating effectiveness in preventing snow and ice accumulation.

The controller is set to turn on the power to the heating cable if the temperature sensor is equal to or less than 35°F (1.7°C) and to turn off the power when the temperature sensor reaches 60°F (15.6°C). Raychem heat-shrinkable fabric tubing is used to cover the installed heating cable. The fully assembled unit is shown in Fig. 2.

2.2 Digital Camera with Remote Image Retrieval

For this work, a CC640 digital camera from Campbell Scientific, Inc., was placed on the roof of the building to record images of the PV arrays being studied. This setup is shown in Fig. 3. The camera may be connected to a Campbell Scientific datalogger that is programmed to take images at required intervals and then transfer them from the camera to the data logger. Any of the available Campbell Scientific communication protocols may be used to retrieve images from the datalogger.

The camera may also be operated in standalone mode without the need for a datalogger. The camera's clock is used to time image acquisitions, and the images are stored on a removable compact flash memory card (up to 10,000 images). We used this method because remote access capability was not required for this work. Other remote cameras are also available that allow images to be retrieved by phone modem, internet, or wirelessly.

Fig. 3: CC640 digital camera from Campbell Scientific, Inc., located on building roof.

3. USE AND EXPERIMENTAL RESULTS

For the five PV arrays shown in Fig. 4, the heated pyranometer and digital camera were used to determine PV system performance losses associated with a snowfall beginning about 7 a.m. on the morning of January 26, 2009.

The five PV arrays use crystalline PV modules and are grid-connected. PV array number 1 is building-integrated (BIPV) with a PV module tilt angle of 15° from horizontal. The other PV arrays are open-rack mounted with a PV module tilt angle of 40° from horizontal.

Fig. 4: PV arrays, identified by numbers, for evaluating performance losses from snow.

The snowfall ended at about 11:00 a.m. on the morning of January 26, with a total accumulation of about eight inches. Figure 5 shows the digital images for January 26–30 for 9:00 a.m., 12:00 p.m., and 3:00 p.m. PV arrays 3, 4, and 5 began shedding snow in the afternoon of January 26th, but wind during the night re-covered the PV modules with snow and drifting also occurred on the roof of the shed where PV array 1 was installed. By noon on the 27th, the snow had been shed from PV arrays 4 and 5; and by 3 p.m., the snow was also gone from PV array 2, and only a small amount remained on PV array 3. Beginning in the morning of the 28th, no snow remained on the rack-mounted PV arrays 2, 3, 4, and 5.

Snow remained the longest on PV array 1, with one module retaining snow until the morning of the 29th. Interestingly, the east side of PV array was free of snow about 1 day before the west side. To better understand the thermal characteristics of BIPV arrays, two different mounting methods had been used. The west side was mounted directly on the roof sheathing, but the east side was raised about an inch using battens to promote air flow. Apparently, the increased air flow promoted snow removal.

Figures 6, 7, and 8 show the meteorological and PV system performance data for January 26–30, 2009 using data recorded at 15-minute intervals. Figure 6 provides dry-bulb temperature and wind-speed measurements. Figure 7 shows solar radiation values measured with the Li-Cor pyranometer with heater and those measured with a Kipp and Zonen CM11 pyranometer. Snow on the CM11 pyranometer significantly reduced measurement values until the afternoon of the 27th, at which point the snow had melted from the CM11 and both pyranometers, began providing comparable measurements.

PV system performance is shown in Fig. 8 using the performance ratio (PR) metric.[2] The PR is a dimensionless quantity determined as the final PV system yield (kWh/kW or hours) divided by the reference yield (equivalent hours at the reference irradiance). The PV performance was consistent with the images showing snow on the PV modules. Even a small amount of snow remaining on the PV modules significantly lowered the PR. PV system 1did not regain its normal PR until January 30th.

Daily summary data are provided in Table 1. Compared to the Li-Cor pyranometer with heater, the Kipp & Zonen pyranometer at the same tilt (40°) underreported the solar radiation by 58% on the 26th and by 44% on the 27th. For the remaining days without snow on the Kipp & Zonen pyranometer, the two pyranometers provided daily totals within 4%.

PR calculations used solar radiation measurements recorded by the Li-Cor pyranometer for PV systems 2 through 5. Because the tilt angle for PV system 1is less than that for the other PV systems, it used solar radiation measurements from the Kipp and Zonen with a tilt from horizontal of 15° for its PR calculations. PR values were near zero for all PV systems on the 26th. In fact, slightly negative values occurred because the PV arrays put out sufficient voltage that some inverters came out of sleep mode and increased their standby losses.

On the 27th, PR values improved for systems 2 through 5 as the snow began to slide from the PV modules and had returned to normal values by the 28th. For PV system 1, the PR did not return to normal values until the 30th, when the last of its snow was gone. For this one snowfall, PV system 1 lost nearly four days of production. Considering that during this period the solar radiation was about 35% greater than the January average because of the relatively clear days following the snowfall, the “effective” loss in production was about 5 days.

Fig. 5: Digital images for January 26–30, 2009, for 9 a.m., 12 p.m., and 3 p.m.

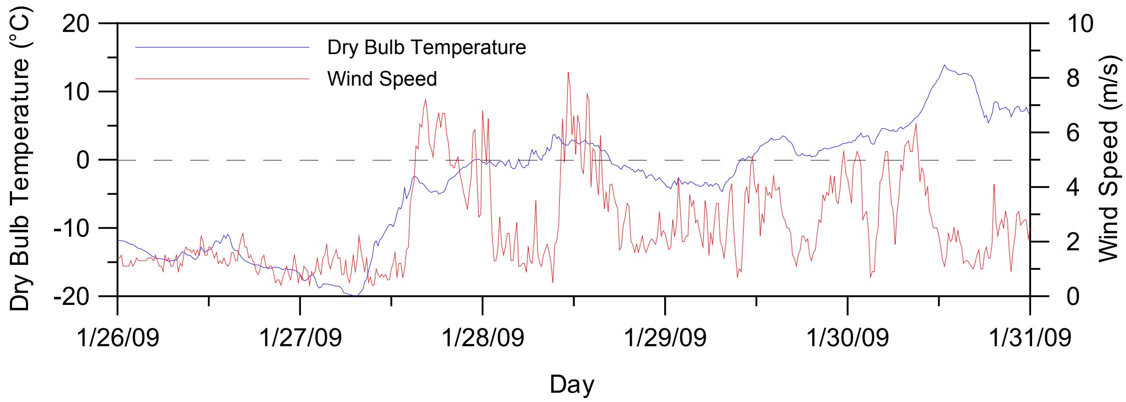

Fig. 6: Dry-bulb temperature and wind speed for January 26–30, 2009.

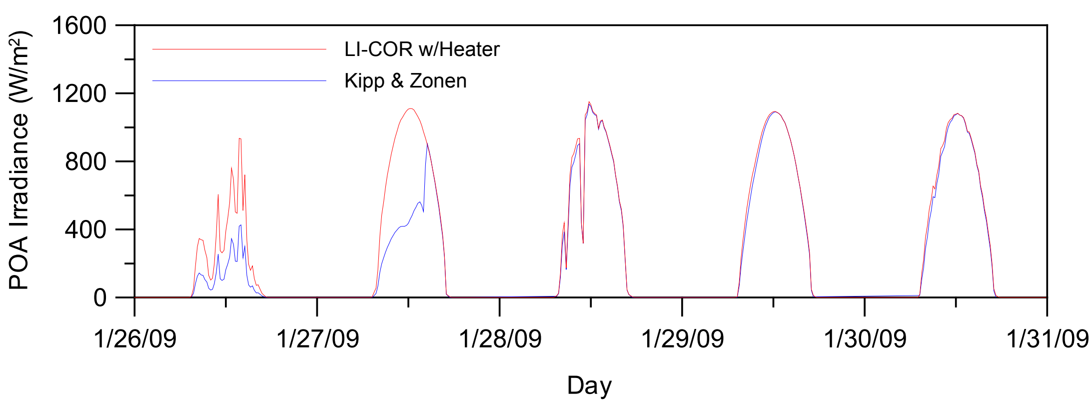

Fig. 7: Plane-of-array (40° tilt) solar radiation measured with Li-Cor pyranometer with heater and Kipp and Zonen CM11.

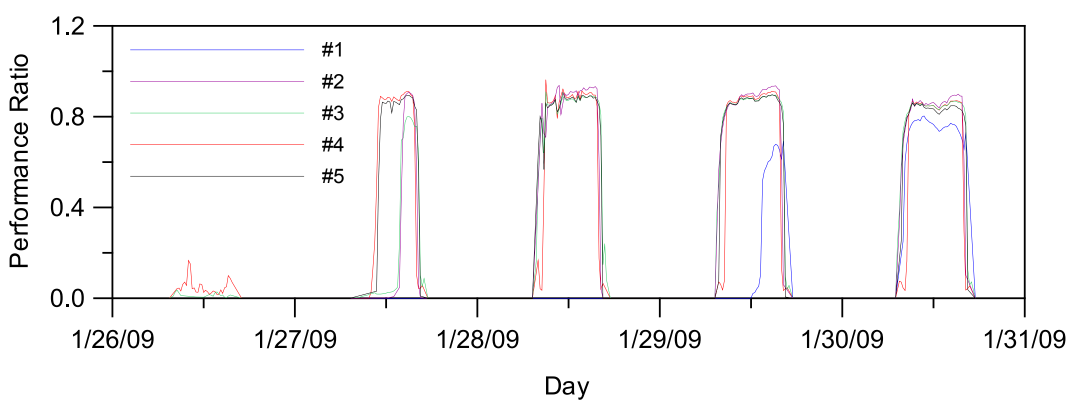

Fig. 8: Performance ratio (PR) values for January 26–30, 2009 determined using 15-minute data.

Table 1. Daily POA Solar Radiation and PV System Performance Ratios

Date	Solar Radiation (kWh/m^2)			PV System Performance Ratios				
	Li-Cor w/Heater (40° Tilt)	Kipp & Zonen (40° Tilt)	Kipp & Zonen (15° Tilt)	System 1	System 2	System 3	System 4	System 5
1/26/09	3.15	1.33	1.25	-0.116	-0.013	0.010	0.047	-0.016
1/27/09	7.38	4.17	4.15*	-0.034	0.188	0.216	0.621	0.576
1/28/09	6.73	6.56	4.86	-0.028	0.859	0.857	0.824	0.855
1/29/09	7.42	7.19	5.22	0.194	0.847	0.847	0.799	0.839
1/30/09	7.17	6.92	5.07	0.741	0.820	0.827	0.773	0.804

* Snow was cleaned from this pyranometer at noon on the 27th

4. SUMMARY

A pyranometer with a heater to prevent buildup of ice and snow and a digital camera for remote retrieval of images were shown to be useful instruments for evaluating PV system performance losses from the presence of snow. Application of the instruments and their use for analysis was demonstrated for a snowfall occurring on January 26, 2009 and subsequent losses in PV system performance were determined. Most of the PV systems lost 1 to 2 days of energy production. But the BIPV system, with a smaller tilt angle, lost 4 days of energy production.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

(1) Ueda, Y., Kurokawa, K., Itou, T., Kitamura, K., Miyamoto, Y., Yokota, M., Sugihara, H., Performance Ratio and Yield Analysis of Grid Connected Clustered PV Systems in Japan, *Proceedings of the IEEE 4th World Conference on Photovoltaic Energy Conversion*, May 2006, pp. 2296–2299.

(2) IEC, “Photovoltaic System Performance Monitoring-Guidelines for Measurement, Data Exchange, and Analysis, IEC Standard 61724,” Geneva, Switzerland, 1998.

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