# Townsend's 2011 Monthly Snow Loss Model

## Purpose

This model is used to estimate the percentage of potential monthly photovoltaic (PV) energy sacrificed due to snow.

PV financing decisions are based on long-term energy estimates, and popular PV modeling software such as PVsyst include monthly inputs for soiling losses – snow in the winter, dust in the summer. This modeling tool uses common long-term weather characteristics such as monthly snowfall, temperature, and humidity, coupled with site-specific geometry characteristics such as tilt angle, slanted array length, and drop distance, to calculate a typical loss percentage for the winter months.

## Equations

The main equation is:

Loss, % = $C_1 \times Se' \times \cos^2(\text{tilt}) \times GIT \times RH\% \times M \times (1/T_{AIR}^2) \times (1/POA^{0.67})$

The supplemental equations include:

$Se'$ = 6-wk average of Se = 0.67 x Se,current month + 0.33 x Se,prior month

Se = (Monthly Snow, inches) x 0.5 x (1 + 1/n)

n = number of days per month with at least 1” of snow. “n” has a minimum of 1.0, even in months with no snow. This number does not need to be an integer. In any single month, it will be, but it is intended to capture a long-term average, so the number can be any real number ≥ 1.0. For example, n = 2.7 is valid, but n = 0.8 is not valid.

GIT = Ground Interference Term = $1 - C_2 \times (1/e^{\gamma})$

$\gamma$ = ratio, snow received/discharged = $[R \times \cos(\text{tilt}) \times Se']/[(0.5/\tan(P)) \times (H^2 - Se'^2)]$

$(H^2 - Se'^2)$ must be ≥ 0; P = angle of repose = 40°; R = row slanted length, inches;

H = drop height from lowest module edge to ground (or roof) below, inches

$C_1$ = 57,000 (fitted coefficient using mix of English and SI units as assigned above)

$C_2$ = 0.51

RH% = Relative humidity, entered as a percentage

M = Multiple parallel string multiplier, default = 1.0, or use 0.75 for two or more parallel dc source circuits in the plane of array upslope direction

$T_{AIR}$ = Air temperature, K (273.15 + Celsius temperature)

POA = Plane of array insolation, kWh/m$^2$ (for bifacial, include front and rear)

## Method

A combination of desktop theory and field testing was used to create equations relating the above-mentioned weather and site geometry terms to actual measurements. Snow is retained or cleared from an array via a changing combination of sliding, melting, evaporation, and mechanical force, subject to both surface adhesion and snow quality. While these varying forces are very difficult to predict analytically, empirical testing, if not simple, is nevertheless straightforward.

Field measurements were done by building a test bed near snowy Lake Tahoe, California, using a pair of modules at each of three tilt angles. For each tilt, one module was allowed to accumulate or shed snow naturally. The other was kept clear to provide an unsoiled best-case reference. The modules were kept clear via a thermostatically-controlled and insulated back side heat tape to quickly melt snow and prevent icing. The heating was supplemented with simple manual brushing as soon as practicable after each snow event. A snow depth pole was mounted alongside the testbed. The scene was monitored by a camera that stored hourly photos. One module pair was installed horizontally. The second pair was inclined at 24 degrees (per NREL practice, at latitude-15 degrees), and the third pair was set to the local latitude: 39 degrees. Measurements of short-circuit current from each of the six modules were stored every hour over two winters spanning 2009-2011. Simultaneous measurements of variables such as front and rear surface solar irradiance, air and module temperature, and humidity were stored locally and uploaded along with the photo record via a cell modem. The ratio of the snowy versus clean module production was summarized for each month. This was correlated against the amount of snowfall and a small set of related weather variables. This led to the equations described above, as first published at the 2011 IEEE PV Specialists Conference in Seattle, WA. The model has been made available in worksheet form since 2011, was added to Sandia's PVLIB open-source library in 2023, and as of 2026, has been made very user-accessible via a webpage created by courtesy of Kajal Sheth (see https://pv-snow-soiling-losses.streamlit.app/ ).

## Details

### Timing and variables

It is understandably tempting to establish a daily or even an hourly sequence of lost energy from snow. However, this study's results showed the random and somewhat chaotic unpredictability of the nature of snow deposition, dissipation, and quality make for a very imprecise ability to prepare shorter-interval forecasts. It is difficult to account for all of the factors that influence snow adherence properties, light transmission, and changing composition and density over time. In creating a suitable model, it feels obvious that the amount of snow and the tilt angle of the panel should be key factors affecting the percentage of energy loss, and this study confirms that. Beyond those two main influences, secondary influences such as the amount of insolation, air temperature, snow moisture content, and wind will generally also affect whether a given amount of snow will remain and block output or be partially or completely cleared from the surface, but not as predictably as snow quantity or tilt. Because of these many intersecting influences, this study found it would be unsatisfying and impractical to create a model capable of accurately predicting hour-by-hour, or even daily lost energy. However, the averaging power of longer-term trends enabled enough of these short-term effects to be overcome, such that suitable monthly losses could be estimated. Monthly loss estimates are very valuable in the context of long-term energy forecasting and financial decision-making.

## Ground interference

Another secondary influence concerns the effect of ground interference, or piled-up snow below the array. If the area below the bottom edge of the PV area is clear, the loss will be minimized; pile-up, on the other hand, can prolong zero-output conditions for weeks. The original Lake Tahoe testbed had a ground clearance of about 18 inches (0.5 m), so pile-up was frequent and prolonged in a climate which receives an average of 200 inches (5 m) per year of snow. A nearby commercial array at the same elevation and at a very similar 35° tilt, with a ground clearance of 6 feet and a regular practice of plowing the area in front of the array was available to supplement the main testbed results. This second array provided valuable data to bracket the best-case condition of no pile-up. This fortuitous installation enabled Townsend to develop a correlated pile-up condition equation as part of the overall model. The observed difference between the two similarly-tilted arrays' snow losses was about 2:1, leading to a fitted $C_2$ coefficient in the modulating pile-up equation of 0.51.

The following table lists recommended drop heights, H, for installations in which the height is not obvious, such as on residential rooftops. In this table, an offset is typically 3 to 6 inches; a building story is 120 to 144 inches (10-12 feet).

Table 1. Recommended drop heights, H

| Surface | Examples | Slope ≤10° | 10°<Slope<30° | Slope ≥30° |
|---|---|---|---|---|
| Smooth | Metal | At offset | At story | At story |
| Smooth | Spanish tile | At offset | At story | At story |
| Obstructed | Gutters, guards | At offset | At offset | At story |
| Rough | Shingle, conc. Tile | At offset | At offset | At story |
| Rough | Shake | At offset | At offset | At story |

## Tracking arrays

Townsend suggests using a row slanted length, R, of one-half of the array's typical W-E module length if the tracker is of the common "1P" (often referred to as portrait) orientation, or twice that if the tracker is of the "2P" type. The tilt angle should be set to the sum of the tracker's one-way rotation limit (typically, this is from 45 to 60 degrees), plus whatever N-S axis slope the tracker may have (typically, this is zero, though some older commercial trackers with a 20° tilt exist). For practical purposes, no tracker, whether 1-axis or 2-axis, should be defined to have much more than a 60° slope; losses at tilt angles steeper than this will quickly approach zero under almost any conditions.

## Bifacial

For bifacial arrays, which were not much of a commercial presence at the time the model was published, the author recommends two steps to assure good results. First, the POA insolation should include both the front and back side insolation. This will increase the natural heating effect and reduce predicted losses in accordance with what has been observed in fielded bifacial arrays. Second, the predicted monthly loss should be reduced before entering it into PVsyst;s monthly soiling table. The reduction should correspond to the amount of back side energy contribution under a preliminary modeling run with no soiling. For example, if the snow model indicates a 20% loss for January, and a no-soiling bifacial simulation shows a 90%/10% front and back side split for January output, the final run, with soiling, should be set to 90% of the 20% predicted loss, or 18%. While modeling snow loss for bifacial does require an extra preliminary simulation to determine a front and back energy proportion, it is the best way to use the snow model for this type of array.

## Multiple parallel source circuits

The original Lake Tahoe testing was done with one module in a portrait orientation, such that even a small amount of residual snow near the bottom of a module could result in a zero or near-zero output for the entire module. That situation is often the case. However, in arrays with landscape modules, especially arrays with multiple rows of modules in the upslope direction, it is reasonable to expect some production to come from the upper portions of the array before the entire array is cleared of snow. This does require that the dc architecture of the uphill rows is/are in parallel to the snow-covered rows below them. The optional 0.75 empirical correction, while coarse, will yield a more accurate result than the all-or-nothing geometry used in the original testing. One interesting model situation arises with the popularity of microinverter-type arrays, where each module is electrically in both dc and ac parallel, and would seem to qualify for using the 0.75 multiplier. However, many arrays, even with microinverters, are still physically mounted in a portrait orientation, meaning each module is its own vulnerable dc source circuit. In such cases, the normal 1.0 multiplier is more appropriate, since the entire module's output is going to be limited to the capabilities of its poorest cell, and the cells at the bottom are often covered with slumped snow after the upper cells have cleared themselves. It is a safe bet to use the 0.75 multiplier for most landscape-mounted configurations; using the 0.75 multiplier for portrait mounts is apt to understate the severity of snow loss, even for microinverter-equipped arrays.

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