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# An experimental investigation of snow removal from photovoltaic solar panels by electrical heating

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ABSTRACT

A key challenge to the wide-scale implementation of photovoltaic solar panels (PV) in cold and remote areas is dealing with the effects of snow and ice buildup on the panel surfaces. In this study, a thermal method for snow removal from PV solar panels was experimentally tested. Nine PV panels were mounted at tilt angles of 30, 45 and 55° (three panels at each angle). One of the panels at each angle was insulated on the back with a heater embedded between the panel surface and a back layer of insulation. The other two panels remained unheated as reference cases. Outdoor tests were conducted under natural conditions including different snowfall conditions. Solar radiation, ambient temperature, relative humidity and wind speed were also measured during each test. Results showed that the frame at the bottom edge of the panels prevented the snow-cover from sliding off the panels. In addition, it was observed that the entire panel surface requires heat to remove snow, as the panel thermal conduction was not sufficient to conduct heat to unheated areas. To investigate these issues, the lower edge of the frame for one of the reference panels at tilt angle of 45° was removed, and the panel was heated using reversing electrical current flow through it. For most of the experiments with this panel, the snow-cover slid off the panel in less than 30 min.

## 1. Introduction

Increased concern related to climate change is driving the development and implementation of alternative energy sources as a means to reduce emissions related to the use of carbon-based fossil fuels. The use of photovoltaics (PV) to generate electricity from solar energy is being promoted as a promising technology for supplying significant "green" energy to the electrical grid. The continuous decline of the cost of solar systems has driven research into photovoltaic-thermal (PV/T) systems all around the world. This includes regions with cold climates that can lead to snow and ice accumulation on collector surfaces (Breyer et al., 2009; Burrett et al., 2009; Swanson, 2009).

A key challenge to the wide-scale implementation of solar photovoltaics in cold climates like Canada is dealing with the effects of snow and ice buildup on the panel surfaces. PV panel output depends on ensuring that solar panel surfaces are not shaded by obstructions such as snow and ice. The problem is severe as even partial snow-cover on PV modules may significantly reduce the output of a complete string of PV panels. As well, there currently is no practical mechanism to remove snow-cover from PV surfaces and long shut-down periods occur while plant operators wait for mild weather. Mechanical removal of snow from PV arrays has also been rejected by plant operators due to the fragile nature of the glass panels used to support PV cells.

Consequently, a thermal snow removal method to melt snow or induce the snow sliding off from PV panels would be beneficial in regions with significant snow fall.

### 1.1. The effect of snow accumulation on PV output

Several experimental and numerical studies have been performed to study the effect of snow on annual and monthly PV systems performance. Experiments on PV systems undertaken by Nakagawa et al. (2003) revealed that in a solar array which is connected in series, if only some cells are covered by snow, the module output will drop. Previous studies have indicated that annual snow losses on a PV system can be as high as 17% for a low profile system in Truckee California (south-facing panel tilt angle of 24°) and as low as 0.3–2.7% for a highly exposed roof mount system located in the New Munich Trade Fair Centre in Germany (south-facing panel tilt angle of 28°) depending on the orientation, tilt angle of the PV modules and meteorological factors (Becker et al., 2008; Brench, 1979; Marion et al., 2013; Ross, 1995; Townsend and Powers, 2011; Yoshioka et al., 2003).

Townsend and Powers (2011) mounted three pairs of photovoltaic modules at fixed south-facing tilt angles of 0°, 24° and 39° over a winter

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**Nomenclature**

*Latin symbols*

| | |
|---|---|
| $A$ | panel area ($m^2$) |
| $Al$ | albedo of snow |
| $C_p$ | specific heat of snow (kj/kg K) |
| $E$ | Output energy of the panels or heaters |
| $G_T$ | solar radiation ($W/m^2$) |
| $h$ | convective heat transfer coefficient ($W/m^2$ K) |
| $h_{fg}$ | latent heat of fusion for snow (334 kj/kg) |
| $h_s$ | Snow-cover thickness (m) |
| $I$ | panel current (A) |
| $K$ | conductive heat transfer coefficient (W/mk) |
| $L$ | Length of the panel (m) |
| $m$ | mass of the snow-cover per unit area ($kg/m^2$) |
| $q$ | heat flux (W) |
| $Res$ | the resolution of the DAQ (K) |
| $RSI$ | insulation thermal resistance ($m^2$ °C/W) |
| $P$ | pressure drop (Pa) |
| $P_m$ | maximum power (W) |
| $T$ | temperature (K) |
| $t$ | melting time (s) |
| $U$ | wind velocity (m/s) |
| $u$ | uncertainty (K) |
| $v$ | fluid flux through the snow-cover (m/s) |
| $V$ | PV panel voltage (V) |
| $x$ | vertical distance from the top of a panel (m) |

*Greek symbols*

| | |
|---|---|
| $\alpha$ | absorption coefficient |
| $\varepsilon$ | emissivity |
| $k$ | Snow permeability ($m^2$) |
| $\rho$ | Snow density ($kg/m^3$) |
| $\mu$ | Fluid viscosity (Pa s) |

*Sub- and superscripts*

| | |
|---|---|
| a | DAQ accuracy |
| amb | ambient |
| cal | calibration |
| CS | Clear sky |
| clear | Panel is clear |
| heater | Energy from the heater |
| m | maximum |
| mp | maximum power |
| n | estimated uncertainty for the 60 Hz noise signal |
| net | Net output energy of the panel |
| oc | open circuit |
| sc | short circuit |
| sunset | Sunset time |

period. The recorded monthly losses caused by the presence of snow ranged up to 80%, 90% and 100% of expected yields for tilt angles of 39°, 24° and 0° respectively. In addition, on an annual basis, losses were found to be 20% on average for all panels. Recently, Marion et al. (2013) measured and modeled photovoltaic system energy losses from snow for certain locations in Colorado and Wisconsin. Their experimental study included the use of two residential systems with stand-off roof mounts and two small commercial systems. Monthly energy losses as high as 90% and annual losses from 1% to 12% were reported. In general, it can be concluded that the power loss from snow can range from 1% to 20% on an annual basis while it can be more than 90% during winter when there typically is high demand of electricity for building heating purposes.

Some researchers have studied factors affecting snow shedding. Andrews et al. (2013a, 2013b) investigated the effect of panel tilt angle on the shedding of snow on PV modules. As expected, two major snow shedding mechanisms were observed: sheet sliding and snow melting. For module tilt angles of 15–40°, there was a snow accumulation gradient, with the snow more likely to remain at the base of the module. Conversely, for module angles of 10° and below, there was an even snow distribution over the whole face of the module, and the snow was more likely to melt on the panel surface rather than sliding from the face. It was noted by the authors that modules at tilt angles of 50° and 60° had a bias for snow accumulation towards the top of the modules likely due to local prevailing winds; The annual losses due to snowfall were measured up to 3.5% due to the small amount of snowfall on that specific year.

Heidari et al. (2015) studied the effect of ground interference on snow shedding from PV panels. They measured 5% to 12% energy loss for the elevated unobstructed modules. The obstructed modules experienced 29% to 34% energy loss revealing the importance of ground interference. They suggested that a snow-clearing mechanisms may be advantageous in snowy climates.

### 1.2. Snow removal methods for PV panels

Various snow removal methods for PV systems have been proposed in the past. One of the first attempts to clean snow from solar cells was made by Ross (1995). He developed a new passive melting system, based on the reflection of light onto the rear surface of the modules. A box was designed and mounted on the rear of the module including a dark side and a light transmitting enclosure which produced a greenhouse effect increasing the temperature of the cells. Although this method accelerated the melting process, it still required long periods to melt snow (in some cases one or two days) rather than melting the snow-cover on PV panels after the snow fall.

The other proposed method for snow removal from PV panels was using hydrodynamic surface coatings on the panels. Andrews and Pearce (2013) studied four hydrodynamic surface coatings to determine the snow clearing effectiveness of these surfaces compared to conventional plain glass. The following surface treatments were utilized: hydrophobic, hydrophilic, prismatic glass, and one unaltered module. The surface coatings tested did not have an appreciable positive effect on snow removal, and in some cases tended to impede the shedding of snow.

Recently, Weiss and Weiss (2016) proposed an active method for melting snow on PV panels by reversing current through the panel. They tried to initiate the avalanche for snow removal provided that the clamping effect on snow at the edge of the panel frame is overcome by additional heating. They proposed an electrical circuit detail for bypassing the diode; however they did not perform any experiments during an actual snow event. They just put a layer of snow onto panels manually instead of leaving panel outside during real snowfall events. In addition, the effects of meteorological factors such as solar radiation, ambient temperature, wind speed, etc. were not considered.

Van Straten (2017) introduced a patent for snow removal from PV panels. He proposed to install a box on the back of a panel with a small electrical heater inside. By using the natural convection effect, warm air was circulated inside the box to heat the panel. Although no results were provided supporting this patent, it seems that relying only on natural convection for heating a panel requires a long time to clean a PV panel. Without providing any experimental or numerical data, some researchers have proposed other methods for deicing PV panels mounted on the roofs. The proposals included architectural solutions,