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PVWATTS Version 2 – Enhanced Spatial Resolution for Calculating Grid-Connected PV Performance

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B. Marion, M. Anderberg, R. George,
P. Gray-Hann, and D. Heimiller

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National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

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B. Marion, M. Anderberg, R. George, P. Gray-Hann, and D. Heimiller
National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, CO 80401

ABSTRACT

This paper describes the latest version of PVWATTS and how its spatial resolution was improved by a factor of 25 by using a high-resolution (e.g., 40-km by 40-km cells) spatially uniform grid of meteorological input data. Like its predecessor, version 2 is Internet accessible. The user selects a grid cell containing the desired location from an electronic map, thereby initiating a selection by PVWATTS v.2 of the nearest TMY2 station that is climatically similar, followed by an hourly performance simulation for the TMY2 station. Performance is translated back to the selected grid cell based on differences in solar radiation and temperature using previously determined data grid sets of monthly solar radiation and maximum daily temperature.

1. Introduction

The original PVWATTS [1] is an Internet-accessible simulation tool for providing quick estimates of the electrical energy produced by a grid-connected crystalline silicon photovoltaic (PV) system for any of 239 locations. These locations correspond to the 239-station Typical Meteorological Year (TMY2) database [2] for the United States and its territories. Users select a location from a station map and set PV system parameters, or select default values, and PVWATTS performs an hour-by-hour simulation that provides monthly and annual alternating current (AC) energy production in kilowatts and energy value in dollars. System parameters that may be specified include size (AC rating for Standard Reporting Conditions), local electric costs, PV array type (fixed or tracking), PV array tilt angle, and PV array azimuth angle. The performance model used by PVWATTS is based on Sandia National Laboratories' PVFORM [3], but with fewer allowed specified inputs.

Before the release of version 2, if the desired location was between TMY2 stations, the PVWATTS user needed to choose between two or more stations based on which station they judged to be climatically similar, or in some cases, the nearest. In these instances, PVWATTS v.2 provides better performance estimates by the use of 40-km resolution data grid values of monthly solar radiation and maximum daily temperature to translate performance from a nearby TMY2 station to the desired grid cell. This paper explains the method of translation and describes the gridded data sets.

2. Gridded Data Sets

Performance is translated using 40-km resolution gridded data sets of monthly global horizontal, direct normal, and diffuse horizontal solar radiation; monthly average daily maximum dry bulb temperatures; and monthly average surface albedo. The 40-km grid resolution is based on the resolution of the cloud cover information used to model [4] the monthly solar radiation values. The cloud cover information is from the Real-Time Nephanalysis (RTNEPH) database originated by the Air Force Global Weather Center at Offutt Air Force Base, Nebraska. For compatibility, the same grid resolution was used when establishing data sets of surface albedo, daily maximum dry bulb temperature, and residential electric rates. Surface albedo data is from the Canadian Center for Remote Sensing; daily maximum dry bulb temperatures from the National Climatic Data Center; and 1999 residential electric rates from data compiled for utility service territories by RDI/FT Energy.

3. PV Performance Translation

The performance translation accounts for differences in solar radiation and dry bulb temperature between the TMY2 station and the desired data grid cell. Other factors, such as the influence of wind speed on PV module temperature and changes in inverter efficiency with power were not included in the corrections because they were assumed small when compared to the other corrections. The translation is based on the equation in PVWATTS that calculates DC power. The zero subscripts denote Standard Reporting Conditions.

$$Pmp = \frac{E}{1000} \cdot Pmp_0 \cdot \left[1 + \gamma \cdot \left(T - T_0\right)\right] \qquad (1)$$

Where:

Pmp = maximum power, W
E = plane-of-array (POA) irradiance, W/m^2
γ = Pmp correction factor for temperature = -0.005°C^{-1}
T = PV module temperature, °C

The translation accounts for changes in E and T between the reference TMY2 station and the data grid cell. The monthly POA irradiance for the data grid cell, E_{dg}, is determined by equation 2 as the sum of the direct beam, diffuse sky, and ground-reflected radiation components, which are scaled based on ratios of monthly direct, diffuse, and global radiation. Values for data grid cells are denoted by the subscript *dg* and for reference TMY2 stations by the subscript *TMY.*

$$E_{dg} = \frac{DN_{dg}}{DN_{TMY}} \cdot E_{TMY_{dn}} + \frac{DF_{dg}}{DF_{TMY}} \cdot E_{TMY_{sky}} + \frac{GH_{dg}}{GH_{TMY}} \cdot \frac{ALB_{dg}}{ALB_{TMY}} \cdot E_{TMY_{refl}} \qquad (2)$$

Where:

DN = Monthly direct normal radiation
DF = Monthly diffuse horizontal radiation
GH = Monthly global horizontal radiation
ALB = Monthly albedo
$E_{TMY_{dn}}$ = Monthly direct beam component of POA
$E_{TMY_{sky}}$ = Monthly diffuse sky component of POA
$E_{TMY_{refl}}$ = Monthly ground reflected component of POA

The monthly AC energy production, AC_{dg}, for the data grid cell is then determined as:

$$AC_{dg} = \frac{E_{dg}}{E_{TMY}} \cdot \left[1 + \gamma \cdot \left(T_{dg} - T_{TMY}\right)\right] \cdot AC_{TMY} \qquad (3)$$

Where:

$E_{TMY} = E_{TMY_{dn}} + E_{TMY_{sky}} + E_{TMY_{refl}}$
T_{dg} = Monthly average daily maximum dry bulb temperature for data grid cell
T_{TMY} = Monthly average daily maximum dry bulb temperature for reference TMY2 site
AC_{TMY} = Monthly AC energy production calculated for reference TMY2 site

To test the method, TMY2 data for one location were used to estimate the performance at another TMY2 location. First, TMY2 data were used to model monthly AC energy. These energy values are termed *modeled*. Next, the modeled values were translated to an adjacent TMY2 station location using equations 2 and 3. These energy values are termed *translated*. To evaluate the translation accuracy, the translated energy was compared to the station's own modeled energy. For a south-facing PV array at 40° tilt, the 95% confidence interval for the translation method is ±4.1% for monthly values and ±2.4% for yearly values.

Compared to simply using modeled energy from the nearest TMY2 station, the translation method decreased the confidence interval by a factor of four. For east- and west-facing PV arrays, the confidence intervals are increased somewhat because the translation does not directly account for differences in the ratio of morning to afternoon cloudiness between two locations. Assigning a reference TMY2 station to a grid cell that has similar diurnal cloudiness patterns minimizes this effect. Compared to long-term performance over many years, the PVWATTS calculations have an overall accuracy to within 10% to 12%.

4. Example Results

To run PVWATTS v.2, users point their browser to http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version2 and follow the on-line instructions. From an electronic map, the user selects the grid cell containing the desired location. Next, the user specifies system parameters, or accepts the default values, and clicks the calculate button to initiate the performance simulation. Figure 1 is an example of the HTML form that displays the results on the user's computer showing monthly and annual AC energy production (kWh) and energy value ($).

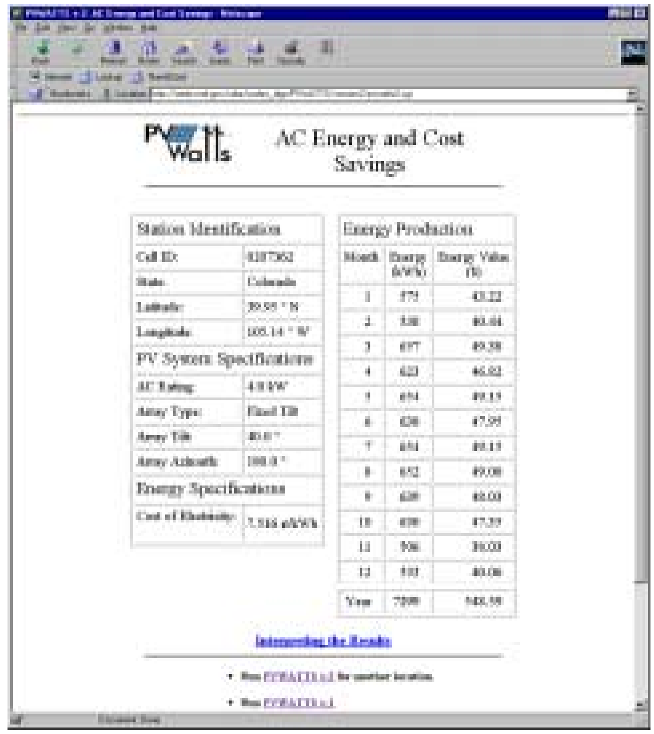

Fig 1. An example of PVWATTS v.2 output data displayed on a user's computer.

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