**Symbols**

ηnom = nominal (best) efficiency of panel

γ = temperature coefficient for efficiency of panel

lXX = loss from “xx”

ηref = reference efficiency

Tref = reference temperature

PAC = AC output

A = panel area (m2)

I = irradiance (W/m2)

G = global effective irradiance on top of module(W/m2)

Gb = effective beam irradiance (W/m2)

Gd = sky diffuse irradiance (W/m2)

Gr = effective ground-reflected diffuse irradiance (W/m2)

Tm = module temperature (°C)

Ta = ambient temperature (°C)

ν = windspeed (m/s)

m = experimental constant

Fsnow = loss from snowcover

Csnow = fraction of snowcover

Mside = number of cells on panel

**Constants**

ηref = 0.9673 [1]

Tref = 25 °C [1]

m = -80 W/m2/°C

Istc = 1000 W/m2 [2]

ηinv,nom = 0.96 [2]

**Assumed values**

A = 10,000 m2 for utility and = 2 m2 for rooftop

**Cell temp (Sandia Cell Temp Model)**

G = Gb + Gd + Gr [2]

Tm = G\*ea+b\*ν + Ta [2]

Tc = Tm + G/1000\*ΔT [2]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Structure | Mounting | a value | b value | ΔT |
| Glass/Cell/Polymer sheet | Open rack | -3.56 | -0.075 | 3 |
| Glass/Cell/Glass | Open rack | -3.47 | -0.0594 | 3 |
| Polymer/Thin Film/Steel | Open rack | -3.58 | -0.113 | 3 |
| Glass/Cell/Polymer Sheet | Insulated rack | -2.81 | -0.0455 | 0 |
| Glass/Cell/Glass | Close roof mount | -2.98 | -0.0471 | 1 |

**Snow**

If Dsnow > Dsnow @ i-1 and Dsnow > 1cm and Dsnow > 1cm/hr, then Csnow = 1, [2]

Elseif, Dsnow < 1cm, then Csnow = 0, [2]

Else, Csnow = Csnow @ i-1 [2]

If Ta > , then Aslide = 0.10 \* (1.97 \* sin βs) where Csnow = Csnow\*Aslide [2]

Fsnow = 1 - [2]

**Efficiency**

Poly- or mono- crystal (standard): ηnom = 15% and γ = -0.47%/°C [1]

CdTe or CIGS (thin film): ηnom = 10% and γ = -0.2%/°C [1]

η = ηnom \* (1 + γ \* (Tcell – Tref)) [1]

**Inefficiencies**

lsoil = 2%; lshading = 3%; lmismatch = 2%; lwiring = 2%; lconnections = 0.5%; llight-induced degredation = 1.5% (= 0% for CdTe); lnameplate rating = 1% (0% for CdTe); lavailability = 3% [1]

ltotal = [1]

**Inverter**

Pdc,0 = A\*ISTC\*ηnom \* ltotal [2]

Pdc = I \* ltotal \* A \* η [2]

ζ = Pdc/ Pdc,0 = I \* η / (ISTC\*ηnom) [2]

ηinv = ηinv,nom/ηref \* ( – 0.0162 \* ζ - 0.0059/ζ + 0.9858) [1]

**Power output**

PAC = Pdc \* ηinv [1] when not exceeding maximum rating power output

Otherwise: PAC = PAC0 = PDC0 \* ηinv, nom

**Panel tilt angle [3]**

If latitude is between 25-50 degrees (all USA):

Optimal tilt = latitude \* 0.76 + 3.1

**Finding irradiance on module [4]**

S\_module = S\_horizontal \* sin(alpha + beta) / sin (alpha)

Beta = optimal tilt

Alpha = 90 – omega + delta

Omega = latitude

Delta = 23.45 \* sin(360/365 \* (284 + d))

**Bibliography**

1. Dobos, A. P. *PVWatts Version 5 Manual*. www.nrel.gov/publications. (2014).
2. Gilman, P. *et al.* *SAM Photovoltaic Model Technical Reference Update*. www.nrel.gov/publications. (2016).
3. <https://www.solarpaneltilt.com/>
4. https://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-a-tilted-surface