B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Solar Model and Assumptions in Balancing Reserve Capacity Forecast Model

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Model Inputs

- Timestamped direct and diffuse irradiance sensor data from University of Oregon
- Latitudes/longitudes of sensors
- DC nameplate (Currently modeling at 1.25)
- AC nameplate (Currently modeling at 1)
- Overall efficiency (0.83)
- Cell temperature coefficient (0.035)
- Temperature coefficient (0.004)

Step 1: Calculate day-of-year- and time-of-day-based parameters

- Equation of Time (ET) – correction factor used in Solar Time equation
  - $ET = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)$
    - $B = \frac{360(n-81)}{364^o}$
      - n=nth day of year
  - Equation 2.27 in Ref. 1

- Local Solar Time (ST) – Adjustment to local standard time (lst) based on longitude shift
  - $ST = lst + ET + 4(lon_{std} - lon_{local})$
    - Where lon_{std} is the standard time meridian (120^o), lon_{local} is the longitude of the plant, and the 4 is in units of minutes/degree
  - Equation 2.26 in Ref. 1

- h_s – degrees from solar noon
  - $h_s = \frac{ST - 12*60}{4}$
  - Equation 2.25 in Ref. 1

Step 1: Calculate day-of-year- and time-of-day-based parameters cntd.

- δ_s – declination angle (Earth tilt angle)
  - $\delta_s = \sin^{-1}\left(23.45^o \cdot \sin\left(\frac{360\cdot(284+n)}{365^o}\right)\right)$
    - n=nth day of year
  - Equation 2.23 in Ref. 1

- α – Solar altitude angle
  - $\alpha = \sin^{-1}(\sin(lon_{local})\sin(\delta_s) + \cos(lon_{local})\cos(\delta_s)\cos(h_s))$
  - Equation 2.28 in Ref. 1

- a_s – Solar azimuth angle
  - $a_s = \sin^{-1}\left(\frac{\cos(\delta_s)\sin(h_s)}{\cos(\alpha)}\right)$
  - Equation 2.29 in Ref. 1

Step 1: Calculate day-of-year- and time-of-day-based parameters cntd.

- β=ρ – tracking angle
  - $\beta = \rho = \tan^{-1}\left(\frac{\sin(a_s)}{\tan(\alpha)}\right)$
    - Assumes a north-south-oriented tracking axis
  - Equation 4.13 in Ref. 2

- θ_i – angle of incidence
  - $\theta_i = \cos^{-1}\left(\sqrt{1 - \left((\cos(\alpha))^2 \cdot (\cos(a_s))^2\right)}\right)$
    - Assumes a north-south-oriented tracking axis
  - Equation 4.14 in Ref. 2

Step 2: Calculate daily info for each day in dataset

- Extend day-based values from step 1 to a 1-minute resolution vector based on the days of our dataset

Step 3: Calculate total irradiance

- I_{dn} – Direct normal component of irradiance
  - $I_{dn} = \cos(\theta_i) \cdot (Direct\ Normal\ Sensor\ Data)$
  - Equation 2.47 in Ref. 1

- I_{df} – Diffuse component of irradiance
  - $I_{df} = \left(\cos\left(\frac{\beta}{2}\right)\right)^2 \cdot (Diffuse\ Sensor\ Data)$
  - Equation 2.49 in Ref. 1

- Ground-reflected solar is not measured by the sensors and is thus ignored

- I_t – Total irradiance
  - $I_t = I_{dn} + I_{df}$

Step 4: Convert from Irradiance to Power

- Cell temperature
  - $cell\ temp = temp + I_t \cdot cell\ temp\ coef$
  - Equation 1 in Ref. 4

- Temperature coefficient
  - $temp\ coef = 1 - temp\ coef_{static}(cell\ temp - 28)$
  - Equation 8 in Ref. 3

- Predicted power, raw
  - $PP = NP_{DC} \cdot Efficiency \cdot \frac{I_t}{1000} \cdot temp\ coef$
  - Equation 8 in Ref. 3

- Predicted power, adjusted for DC to AC oversizing ratio
  - $PP(PP > NP_{AC}) = NP_{AC}$

References

1) Goswami, Dr. Y et al. (2000). *Principles of Solar Engineering*. New York: Taylor and Francis Group
   - We have a physical copy of this but it can also be found in pdf form on the internet.

2) Stine, W and Geyer, M (2001). *Power From the Sun*. Retrieved from http://www.powerfromthesun.net

3) Dobos, A (2013). *PVWatts Technical Manual*. NREL
   - https://www.nrel.gov/docs/fy14osti/60272.pdf
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     - Link to updated version

4) Alonso Garcia, M.C. and Balenzategui, J.L. (2004). *Estimation of photovoltaic module yearly temperature and performance based on Nominal Operation Cell Temperature Calculations.*