Time Series Model of Photovoltaic Generation for Distribution Planning Analysis

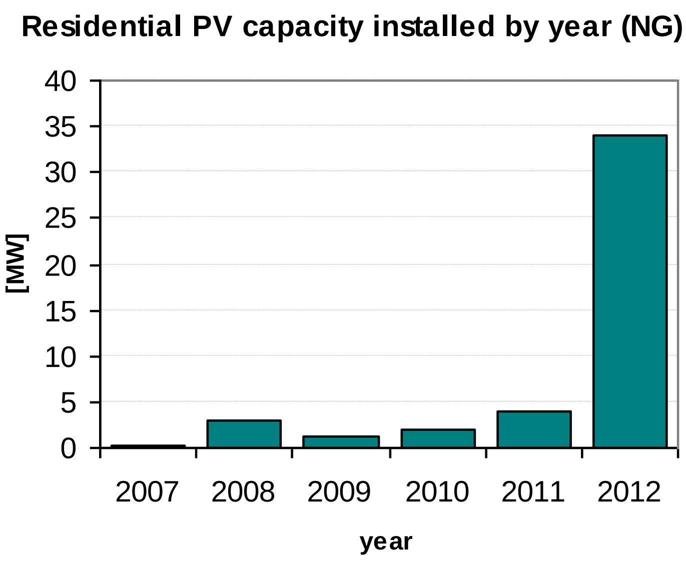
Jorge Valenzuela

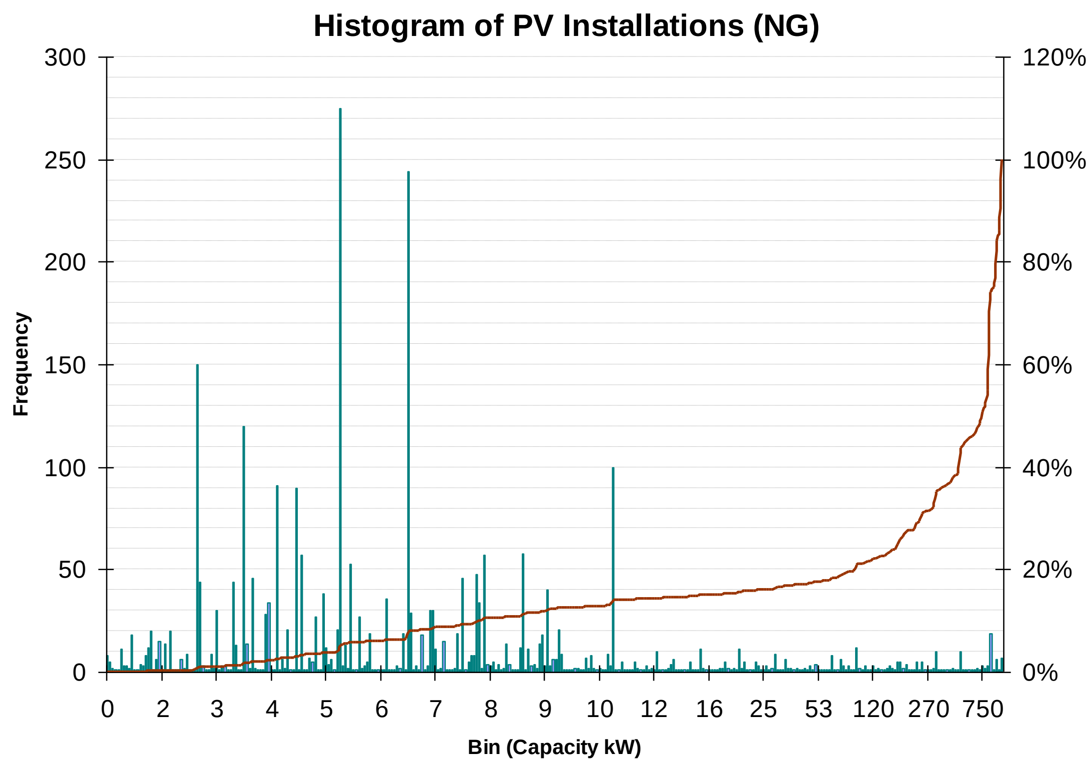
Overview

- Introduction: The solar “problem” and our limitations
- Modeling
    - What information do we have?
    - Solar Irradiation characteristics
    - Simple Model & Time Series
    - Error analysis
- Examples of use
    - Light load problems
    - Peak conditions
- Conclusions and Comments
- Outlook

Introduction - The solar "problem"

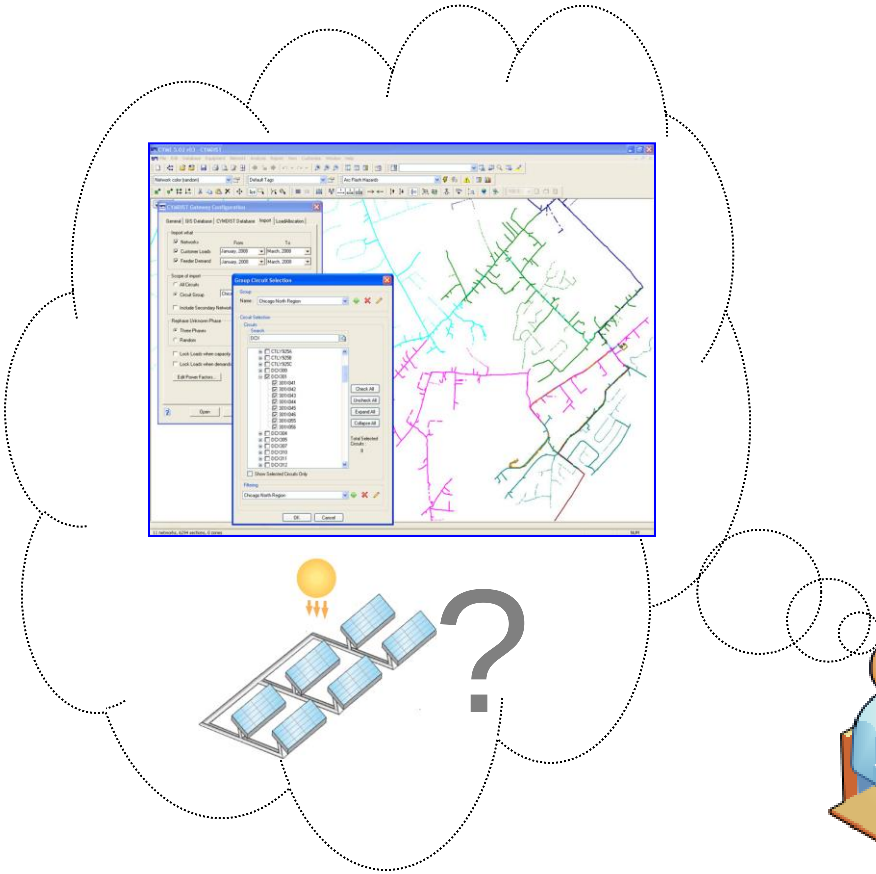
- Current deployment rate in Massachusetts:
  - From 2007 solar capacity increased from 7MW to 250 MW
  - Goal: 1,600 MW of PV installed in Massachusetts by 2020
  - In 2012, 34 MW of "residential" PV was added (NG territory)



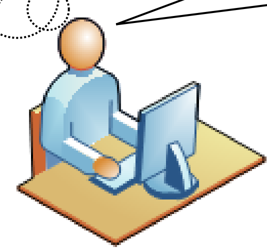


Introduction - Our limitations

- Visibility:
  - Real time generation
  - Geographical location



- What level of generation should I use during my long term studies?
- How will PV installations affect Peak and Light load conditions?
- What kind of voltage effects will the PV units have on my feeders?
- What kind of impact the future levels of PV penetration will have on my feeders?
- What effect would PV units have on DG limits during switching events?

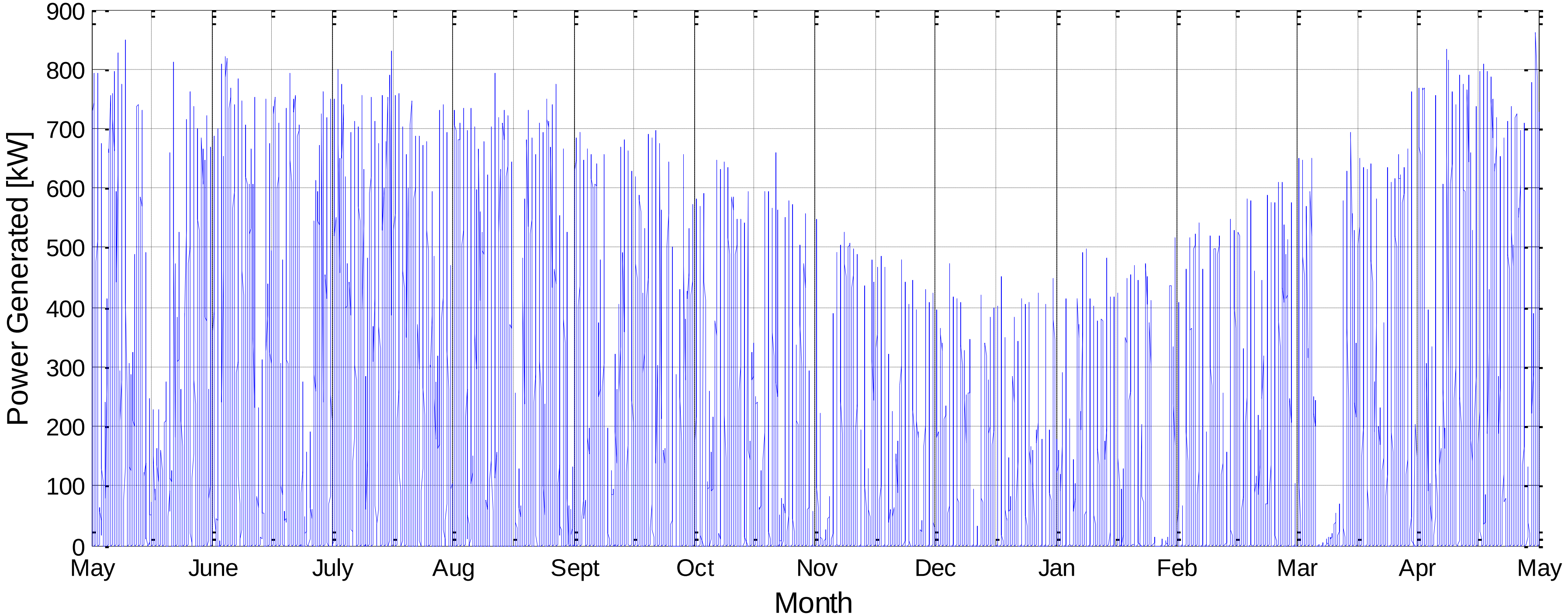


Decisions need to be made for the next 5, 10, 15 years!

Solar generation - What we have

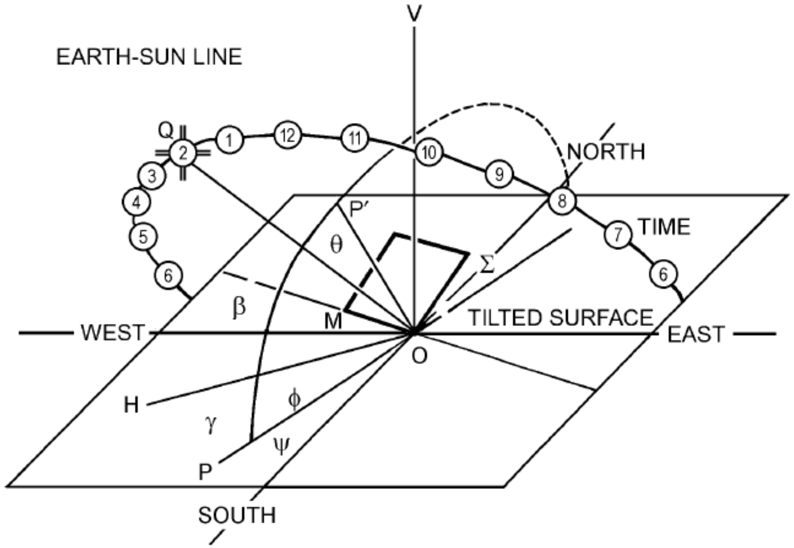
Sutton/Northbridge Solar Power Project

- 4,683 solar panels, 983 kW (DC)
- Real Time generation monitoring
- Irradiation and Temperature monitoring



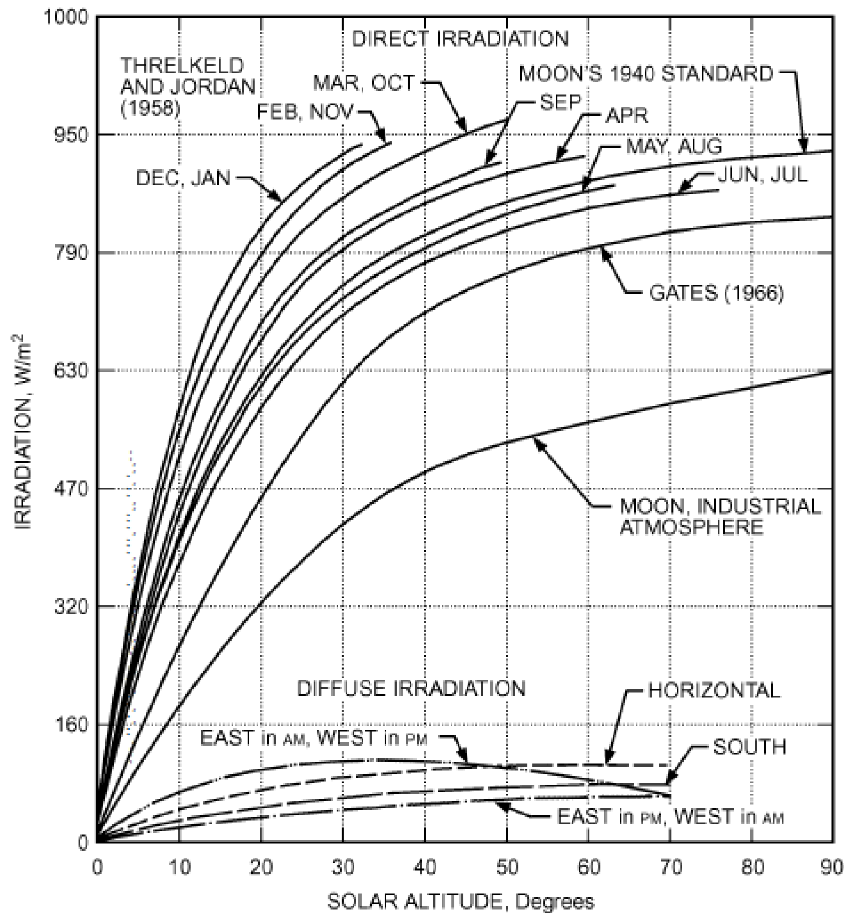
National Grid – Delivery Services, "Sutton/Northbridge Solar Power Project", (http://www.nationalgridus.com/masselectric/solar/sutton.asp, 2013, [Accessed June 2013])

Solar irradiation - Characteristics



$$I_T = I_D * \cos(\theta) + I_d + I_r$$

$$I_D = A * e^{-B/\sin(\beta)} \; ; \; I_d = C * I_D * F_{SS} \; ; \; I_r = I_{tH} * \rho_g * F_{sg}$$



I_D: Direct irradiation [W/m²]
I_d: Diffuse irradiation [W/m²]
I_r: Reflected irradiation [W/m²]
θ: Incident angle
A: Apparent solar irradiation coefficient
B: Atmospheric extinction coefficient
β: Solar altitude angle
C: Ratio of diffuse radiation on a horizontal surface to the direct solar radiation
F_{SS}: Angle factor between surface and sky
F_{sg}: Angle factor between surface and ground
I_{tH}: Total horizontal irradiation

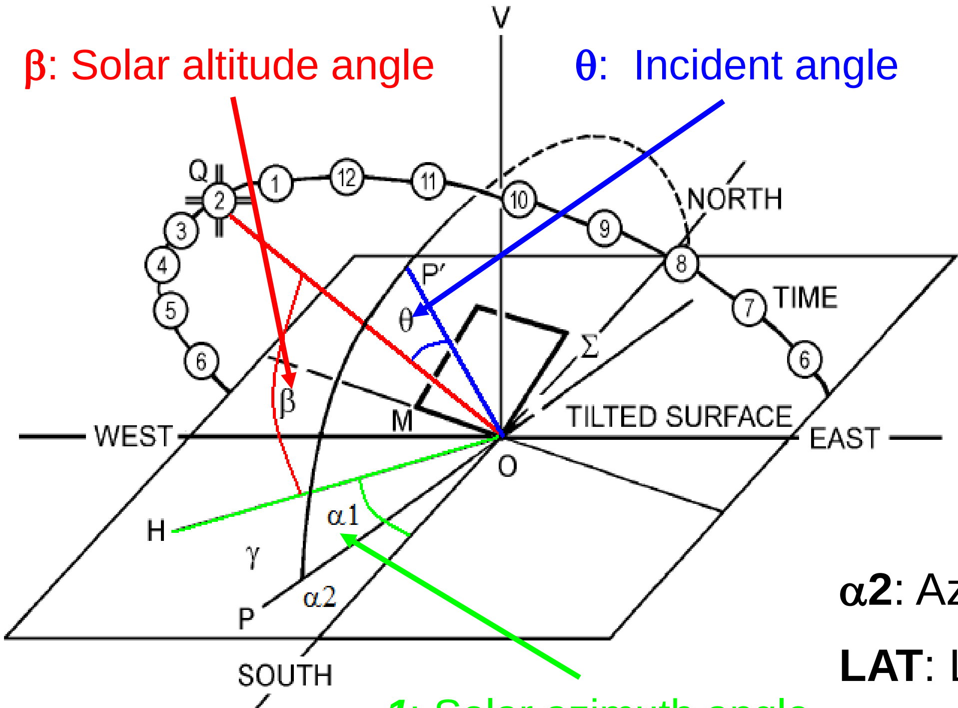
American Society of Heating, Refrigerating and Air-Conditioning Engineers, “2011 ASHRAE Handbook - Heating, Ventilating, and Air-Conditioning Applications (I-P Edition)”, (ISBN: 978-1-936504-06-0, Apr 2012)

Solar irradiation - Modeling

$$I_T = I_D * \cos(\theta) + I_d + I_r \;;\; I_D = A * e^{-B/\sin(\beta)} \;;\; I_d = C * I_D * F_{SS} \;;\; I_r = I_{tH} * \rho_g * F_{sg}$$

β: Solar altitude angle

θ: Incident angle



α1: Solar azimuth angle

$$\cos(\theta)=\sin(\beta)*\cos(T)+\cos(\beta)*\sin(T)*\cos(\alpha_1-\alpha_2)$$

$$\sin(\beta)=\cos(LAT)*\cos(\delta)*\cos(H)+\sin(LAT)*\sin(\delta)$$

$$\alpha_1=\cos^{-1}\left(\frac{(\sin(\beta)*\sin(LAT)-\sin(\delta))}{\cos(\beta)*\cos(LAT)}\right)*\mathrm{sgn}(H)$$

$$H=((\mathrm{Time(mins)}-720)/4)*15^{o}$$

$$\delta=23.45^{o}*\sin\left(360^{o}*\left(284+N\right)/365\right)$$

α2: Azimuth angle of solar panel (0 if facing South)

LAT: Latitude angle

T: Tilt of the solar panel (set to LAT)

H: Number of Sun hours

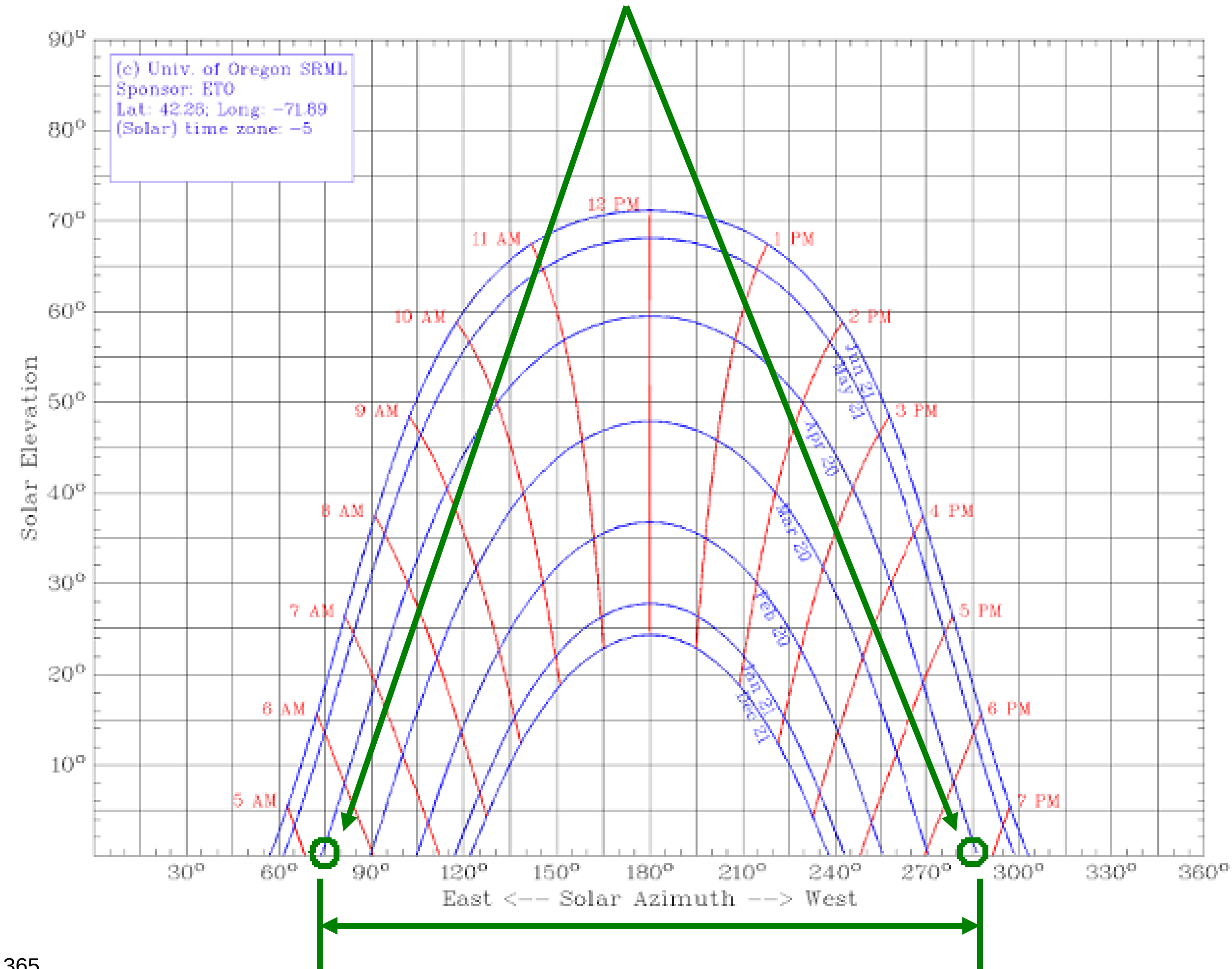
δ: Declination angle

N: Day Number (1=January 1st)

Solar irradiation - Modeling

nationalgrid

$$SS = 720\text{min} \pm \cos^{-1}(-\tan(L)*\tan(\delta))*4\text{min/deg}$$



$$SV(t)=\sum_{N=1}^{365} u\Big(t-\big(1440*N-720-\cos^{-1}(-\tan(L)*\tan(\delta))*4\big)\Big) + u\Big(t-\big(1440*N-720+\cos^{-1}(-\tan(L)*\tan(\delta))*4\big)\Big)$$

UO SRML: Sun path chart program [online] (Available from: http://solardat.uoregon.edu/SunChartProgram.html, 2007, [Accessed June 2013])

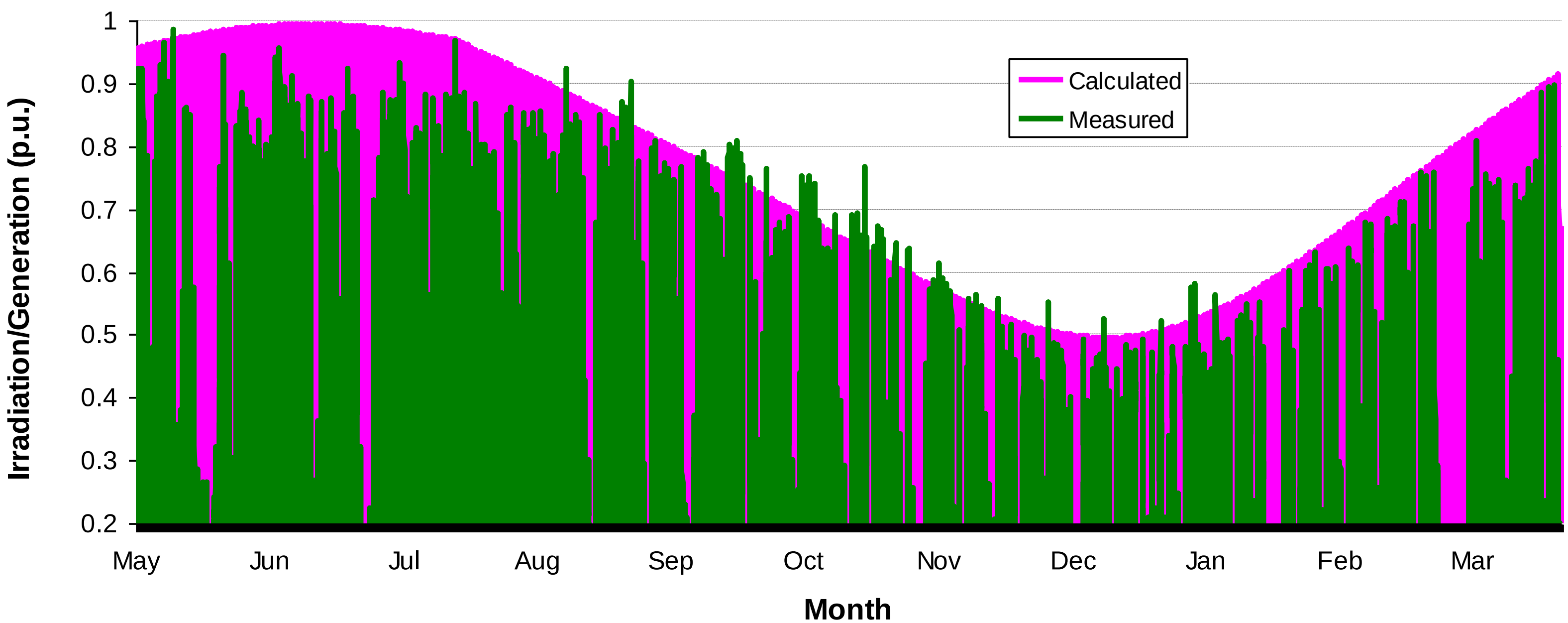
Solar irradiation - Model comparison

$$I_T = \left(A * e^{-B/\sin(\beta)} * \left(\cos(\theta) + C * F_{SS}\right) + I_{tH} * \rho_g * F_{sg}\right) *$$

$$\left[\sum_{N=1}^{365} u\left(t-\left(1440*N-720-\cos^{-1}(-\tan(L)*\tan(\delta))*4\right)\right) + u\left(t-\left(1440*N-720+\cos^{-1}(-\tan(L)*\tan(\delta))*4\right)\right)\right]$$

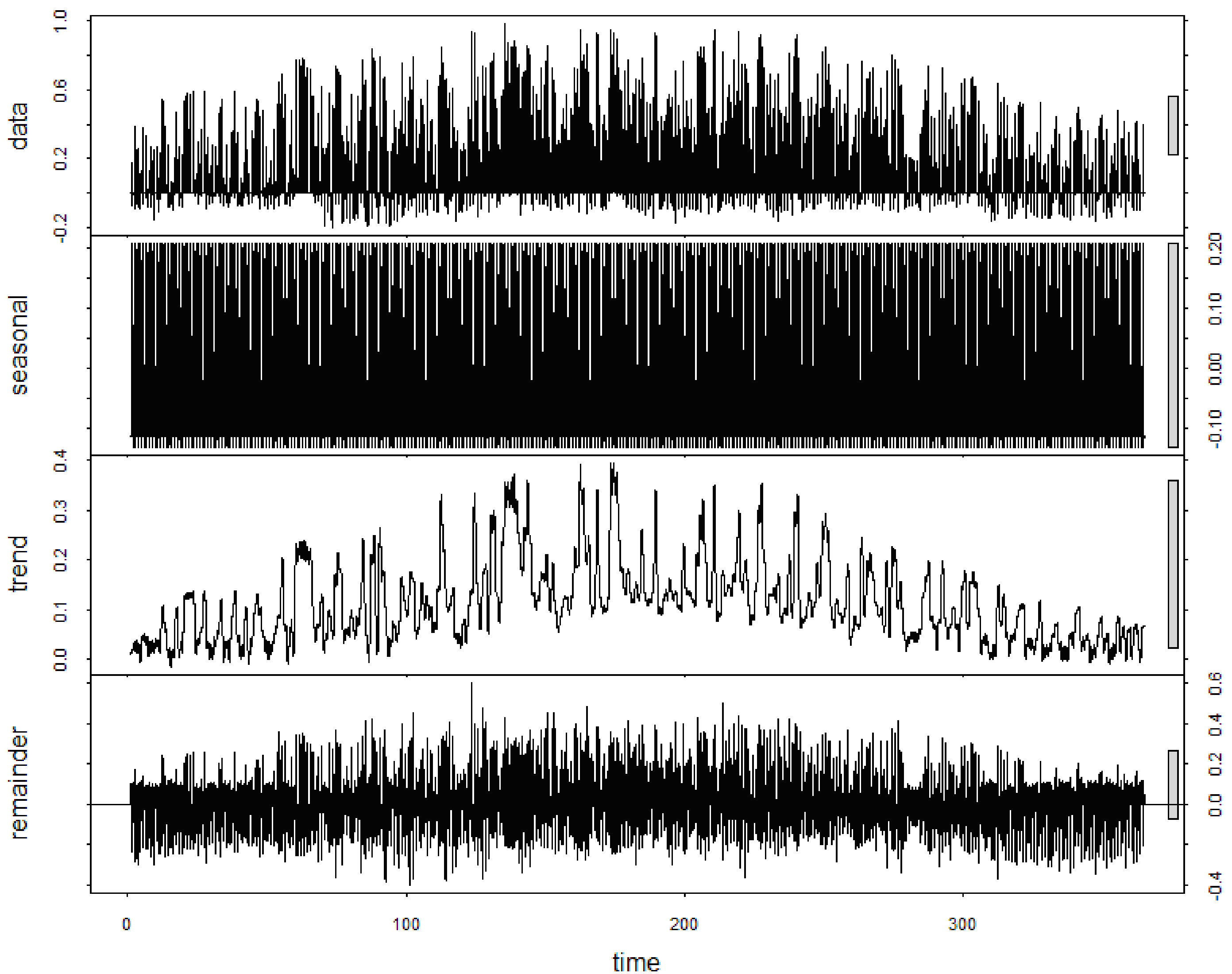
A: Apparent solar irradiation coefficient
B: Atmospheric extinction coefficient
C: Ratio of diffuse radiation on a horizontal a horizontal surface to the direct solar radiation

θ: Incident angle
β: Solar altitude angle
F_{SS}: Angle factor between surface and sky
F_{sg}: Angle factor between surface and ground
I_{tH}: Total horizontal irradiation



nationalgrid

Solar irradiation - Error decomposition

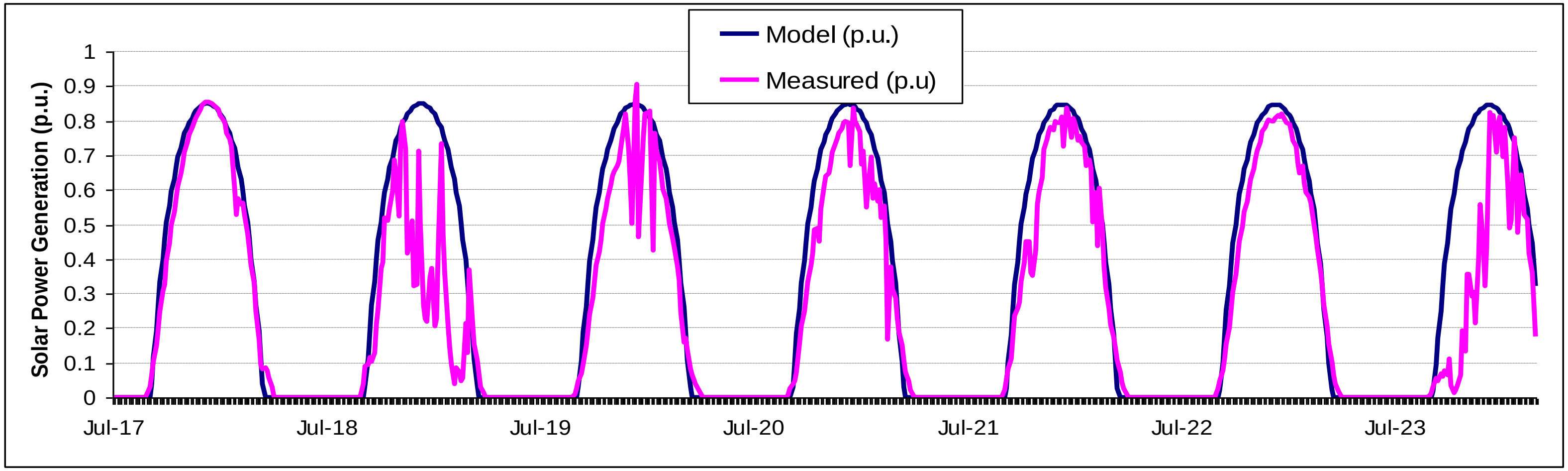


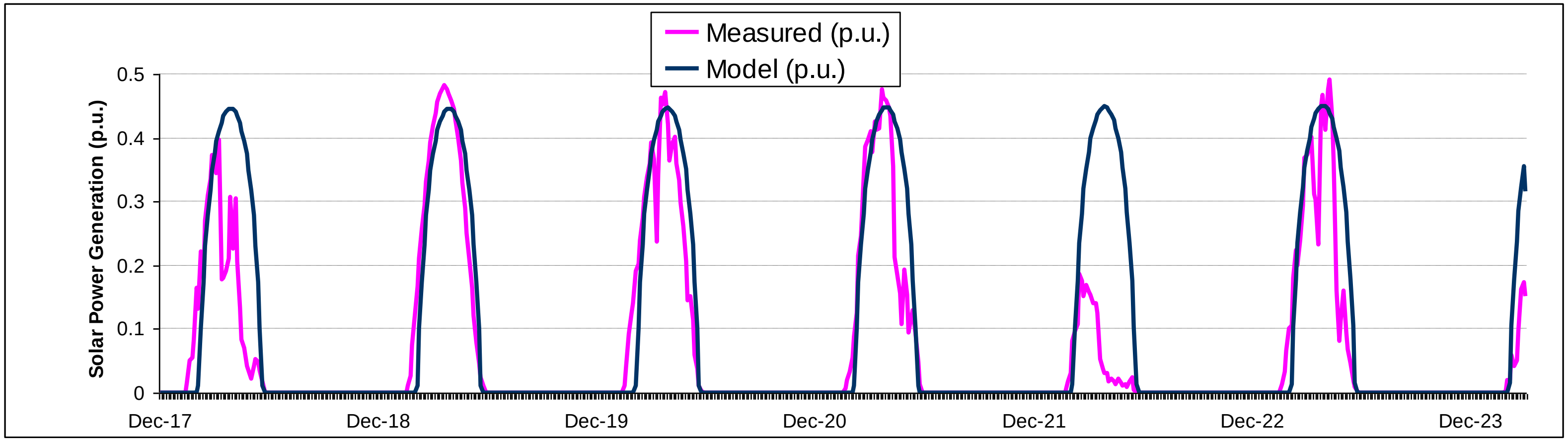
R. B. Cleveland, W. S. Cleveland, J.E. McRae, and I. Terpenning, “STL: A Seasonal-Trend Decomposition Procedure Based on Loess”, (Journal of Official Statistics, 6, 3–73, 1990)

Solar generation - Simplified model

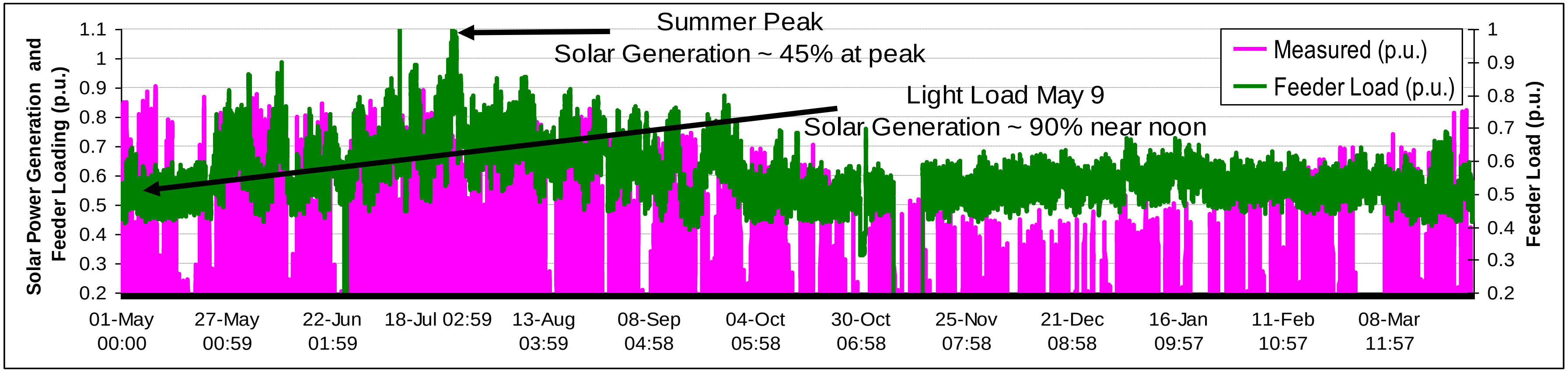
$$P_g = P_{Nom} * \left(0.9 * I_T - 0.23 * \sin(2 * \pi * (t + 14400)/1051200) * rand(t)\right) * SV(t)$$

$$SV(t) = \sum_{N=1}^{365} u\left(t - \left(1440 * N - 720 - \cos^{-1}(-\tan(L) * \tan(\delta)) * 4\right)\right) + u\left(t - \left(1440 * N - 720 + \cos^{-1}(-\tan(L) * \tan(\delta)) * 4\right)\right)$$

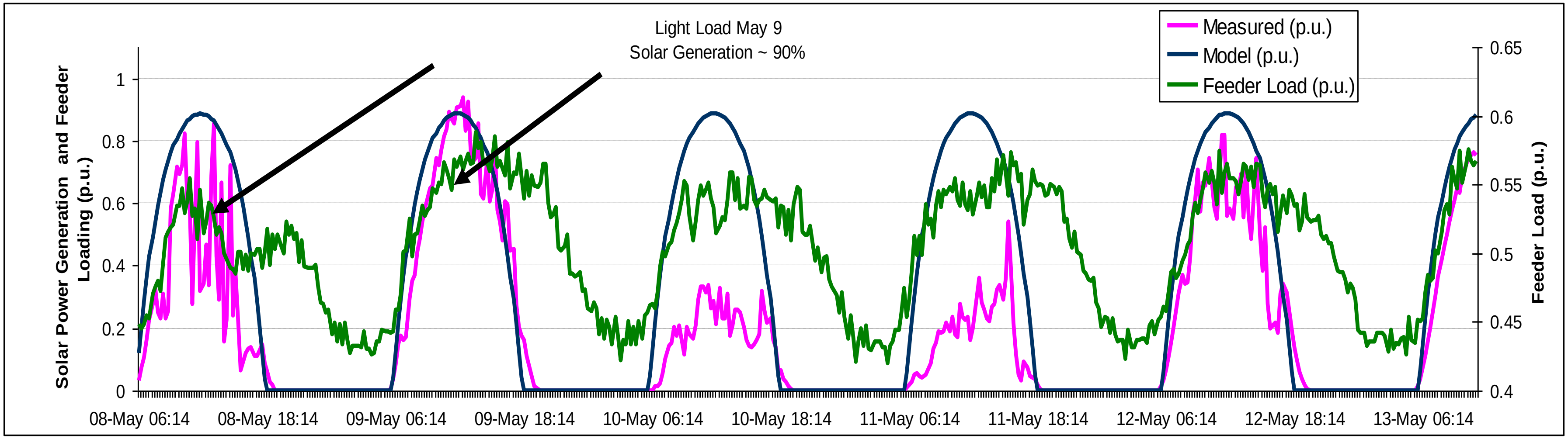




Examples of use

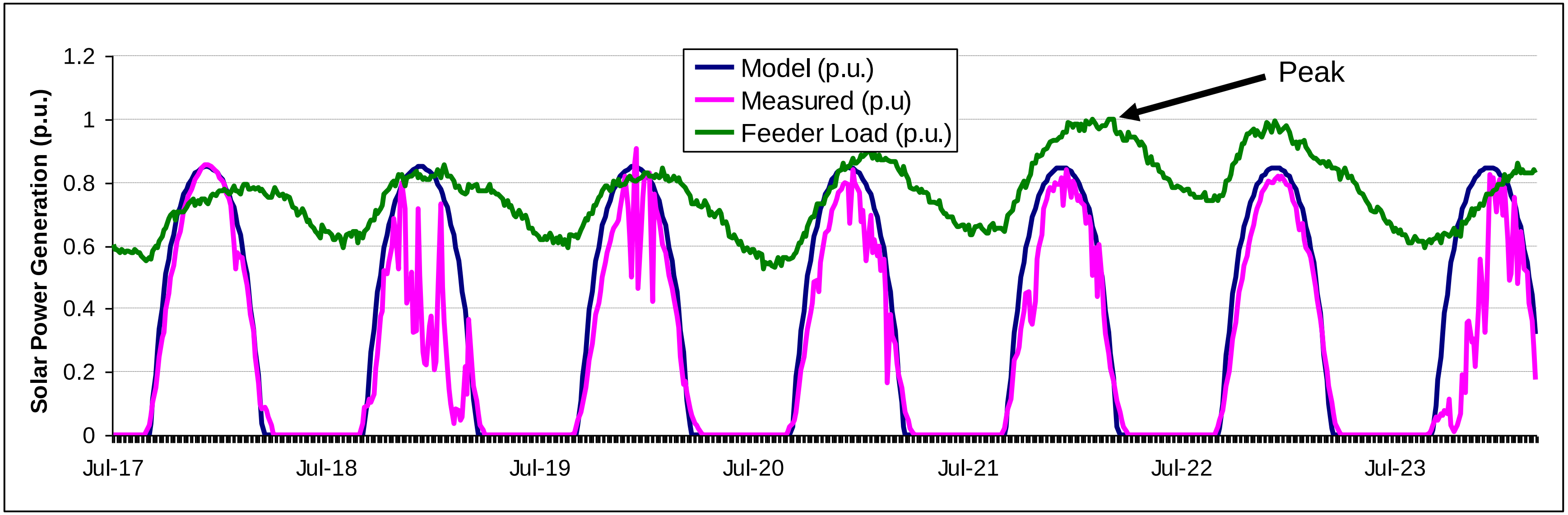


- In New England, the effects on feeders from solar generation during May can be bigger than during Summer time



Examples of use

- Also, during annual coincidental peak time, solar generation gets close to 45% of the nameplate



- For this particular area, capacity planning analysis (Peak) can be done considering PV generation of up to 45% (even a 65% can be used as a conservative number)
- Depending on the study, different loading levels can be chosen. A “clear sky” value would give the most “reasonable” value for the maximum expected solar generation

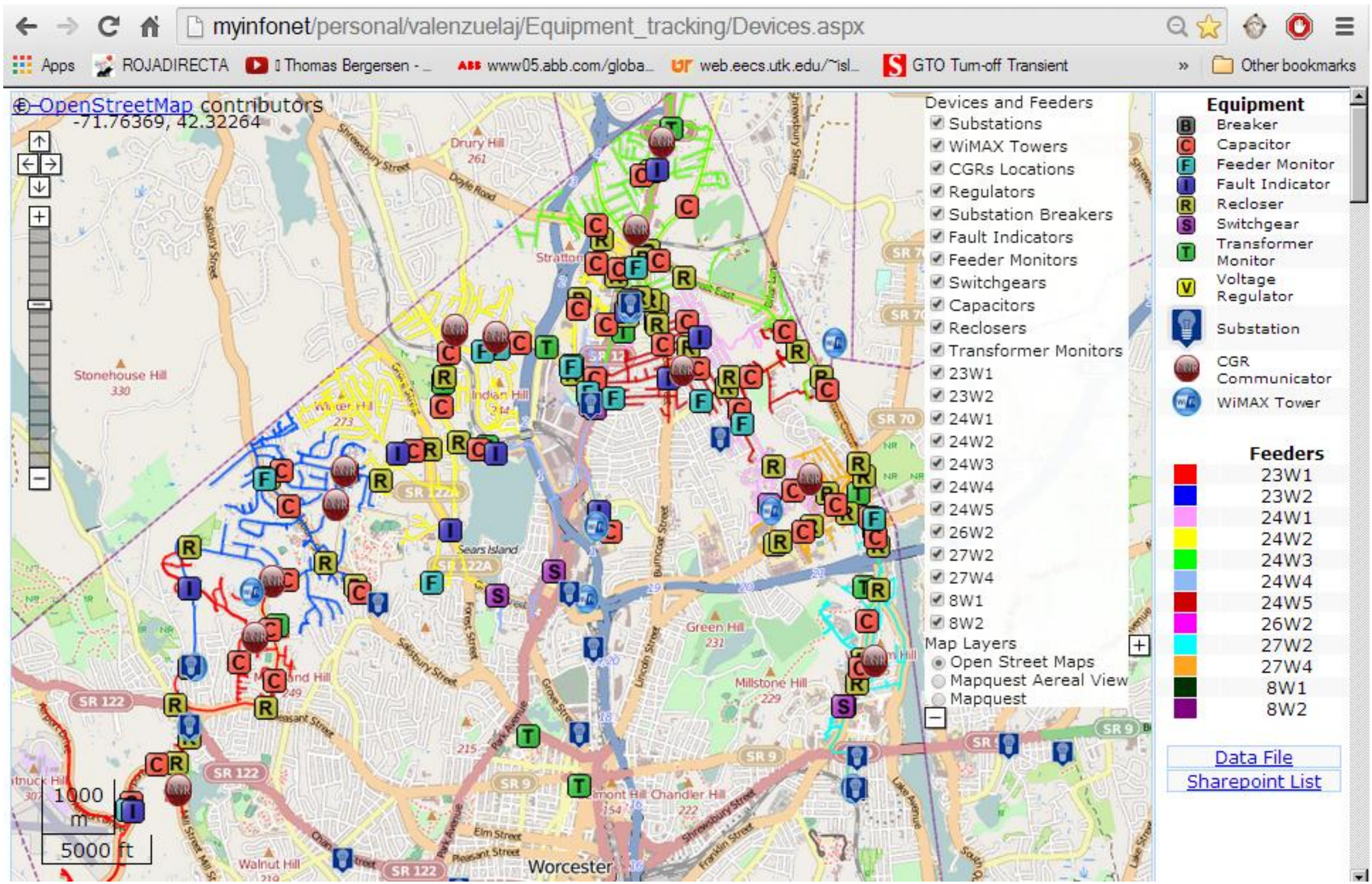
nationalgrid

Conclusions and Comments

- A procedure to create a solar generation model was presented. The model can bring more clarity to planners by estimating generation of solar units that are not “visible” on the system
- The model, based on solar irradiation, can be easily customized to the location of analysis
- Local data of solar generation, if available, can be used to calibrate the model. This requires error analysis
- Once implemented for a certain region, it can be saved as a lookup table for easy reference
- “Clear sky” values of generation can be used for planners to do their analysis during peak and light load conditions. The same can be applied to DG limits on feeders during temporary switching
- Analysis of the error between theoretical values and local measurements presents an opportunity for modeling (stochastic) of cloud coverage

nationalgrid

Outlook – More data!



Thank you!