Optimizing Array to Inverter Matching

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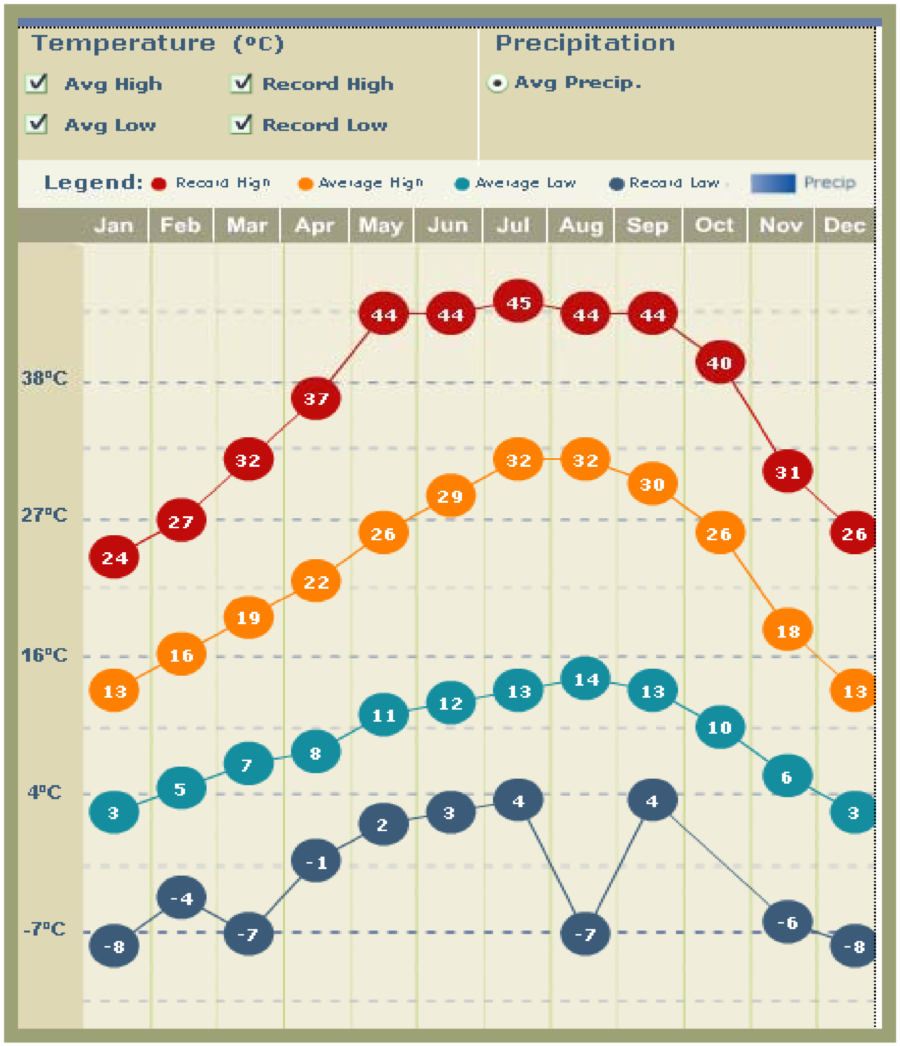
Presentation Outline

- The basics
  - What are we trying to accomplish ?
  - Where will the system be installed ?
  - What we need to know about modules
  - What we need to know about inverters?
- The equations
- Putting it all together graphically
  - 5 KW System
  - 250 kW System
- Conclusions:

What are We Trying to Accomplish ?

- Get the most power possible out of the system for the lowest cost
- Installed module cost is > $4.50/Watt
- Installed inverter cost is < $0.70/Watt
  - A 1% change in inverter utilization equates to 0.02% in installed array cost
- The goal is to maximize array performance NOT maximize inverter loading
  - Chronic over driving of the inverter leads to power limiting, reduced PV energy capture, and lower ROI
  - Occasional overdriving of the inverter has little effect on ROI

Where Will the System be Installed ?



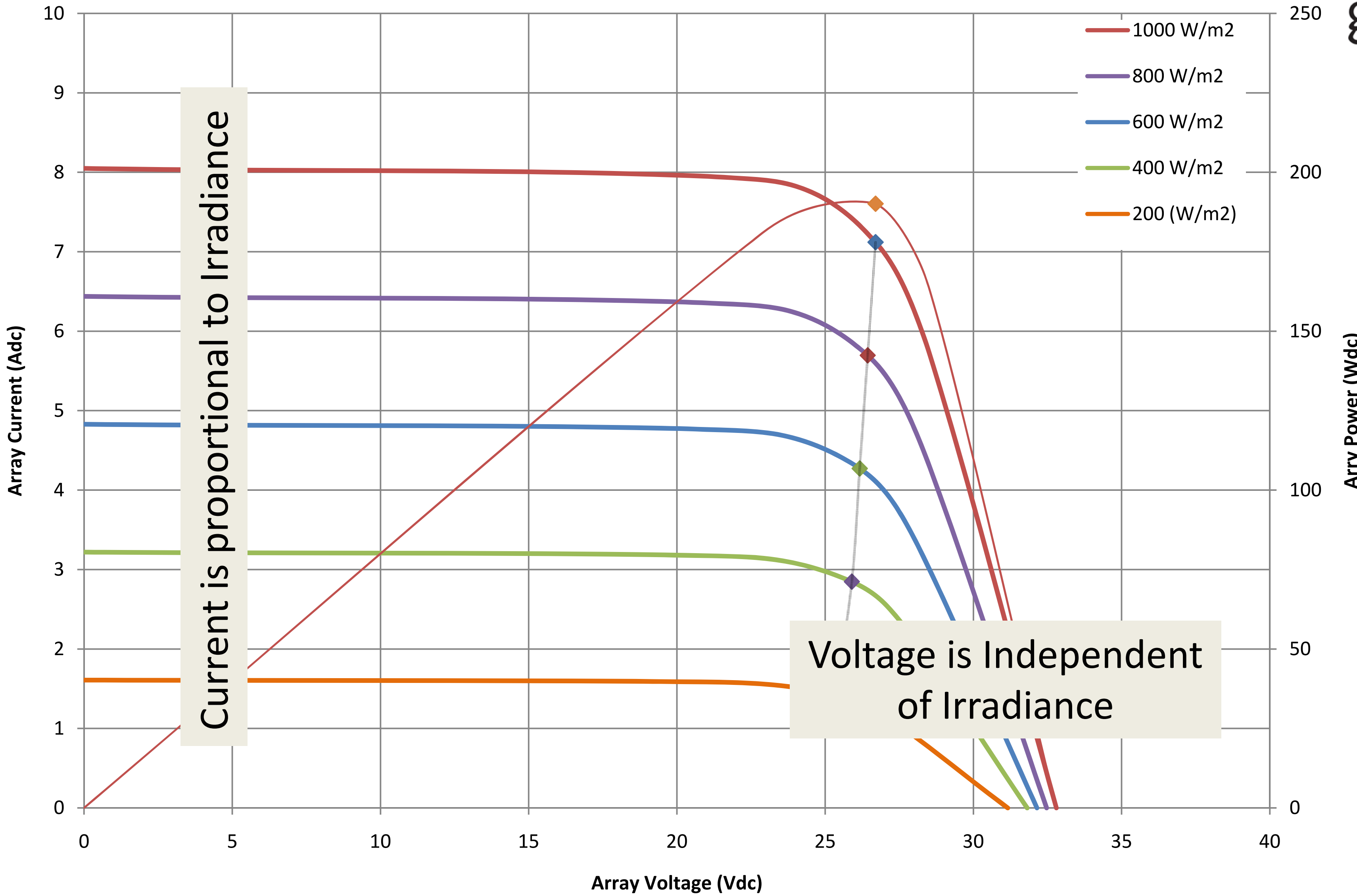
Historic temperature data provided by weather.com

- Example: Fairfield, CA
  - 38° 14' 57" N,
  - 122° 2' 20" W
- Ambient temperatures
  - Record Low: -8 °C
  - Average High: 32 °C
  - Record High: 45 °C
  - Use a design ambient temperature range of -8 to 45 °C (conservative)
- Assume roof mounting with cell ΔT of 30 °C

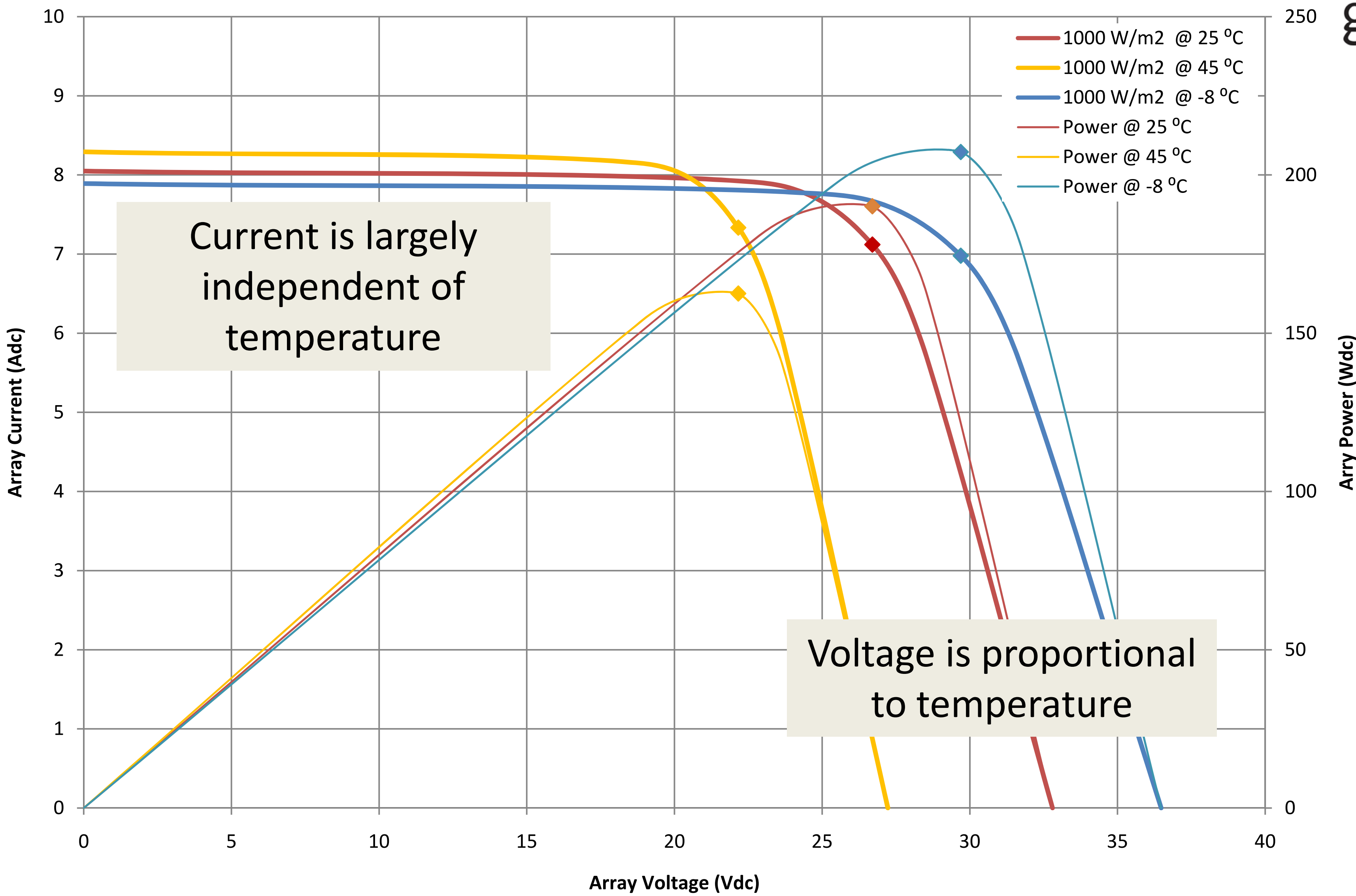
What We Need to Know About Modules

- Basic parameters
  - Pmp: 194.9 Wdc (STC Watts)
  - Pptc: 168.8 Wdc, (CEC Watts)
  - Voc: 32.8 Vdc
  - Vmp: 26.7 Vdc
  - Isc: 8.05 Vdc
  - Imp: 7.12 Vdc
- Temperature coefficients
  - Pmp_t: -0.49 % / ^{o}C
  - Voc_t: -0.34 % / ^{o}C
  - Vmp_t: -0.47 % / ^{o}C
  - Isc_t: 0.06 % / ^{o}C
  - Imp_t: 0.02 % / ^{o}C

Module IV Curve (STC)

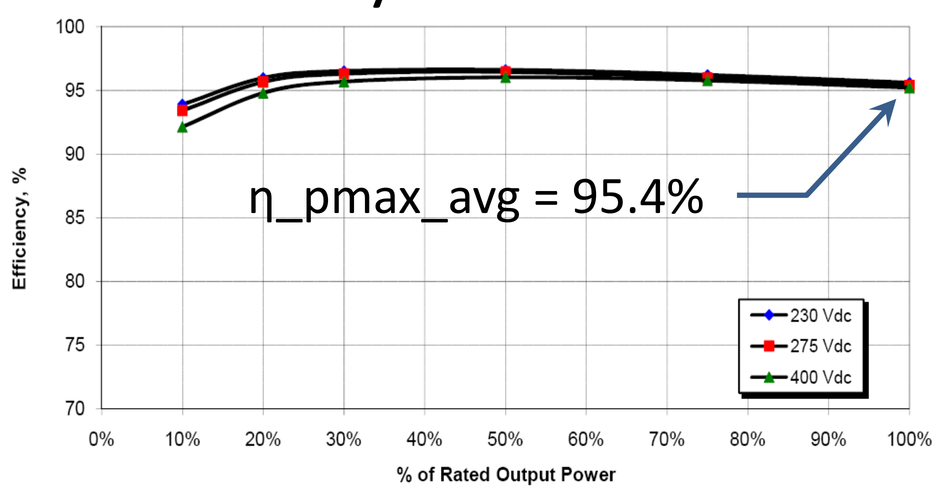


Module IV Curves (Tamb)

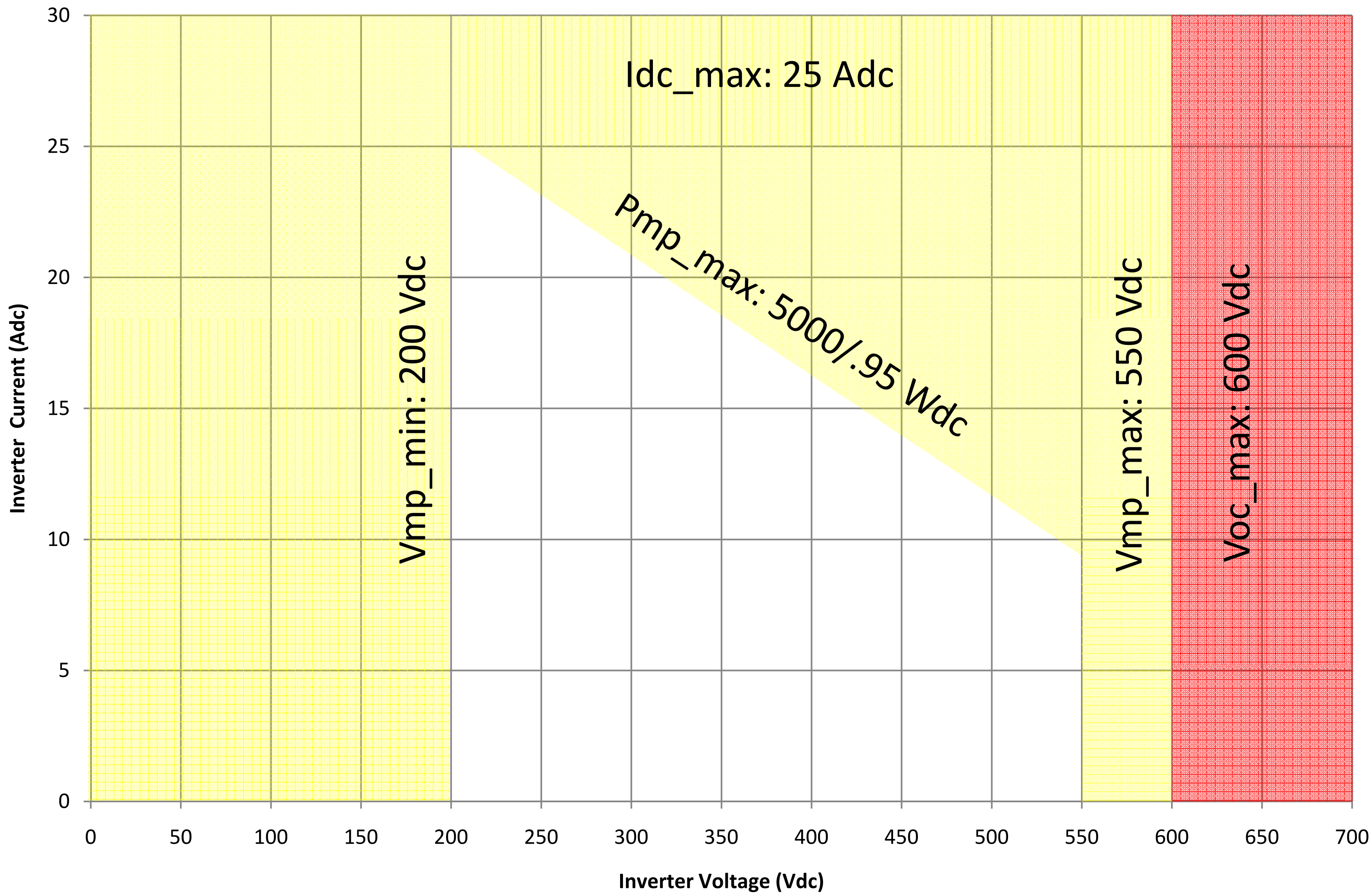


What We Need to Know About Inverters

- Basic parameters
  - Pmax: 5000 Wac
  - Voc_max: 600 Vdc
  - Vmp_min: 550 Vdc
  - Vmp_min: 250 Vdc
  - Idc_max: 25 Amps
  - η_cec 96%
- Efficiency curves



5 kW Inverter Operating Window



Module Equations (Voc)

- Voc_max (-8 ^oC)
  - Voc_max = Voc * (1+((Tamb – Tstc +ΔT) * Voc_t)
  - Voc_max = 32.8 Vdc + (32.8 Vdc *(-8^{o}C -25^{o}C +0^{o}C) * -0.34 %/ ^{o}C))
  - Voc_max = 32.8 Vdc + 3.68 Vdc = 36.48 Vdc
- Maximum number of modules in series
  - 600 Vdc / 36.48 Modules = 16.45 ➔16 modules
  - Cross Check to NEC Table 690.7

Tamb_min (°C)	Factor	Tamb_min (°C)	Factor	Tamb_min (°C)	Factor
24 to 20	1.02	-1 to -5	1.12	-26 to -30	1.21
19 to 15	1.04	-6 to -10	1.14	-31 to -35	1.23
14 to 10	1.06	-11 to -15	1.16	-36 to -40	1.25
9 to 5	1.08	-16 to -20	1.18		
4 to 0	1.1	-21 to -25	1.2		

  - 32.8*1.14 *16 = 598.27 ➔Code compliant

Module Equations (Vmp)

- Vmp_min (32 ^oC = Average high)
  - Vmp_min = Vmp * (1+((Tamb – Tstc +ΔT) * Vmp_t))
  - Vmp_min = 26.7 Vdc + (26.7*((32^{o}C -25^{o}C +30^{o}C) * -0.47 %/ ^{o}C))
  - Vmp_min = 26.7 Vdc – 4.64 Vdc = 22.06 Vdc
- Minimum number of modules in series @ 32 ^{o}C
  - 200 Vdc/22.06 = 9.07 ➔ 10 modules
- Vpp_min (45 ^{o}C = Record High)
  - Vmp_min = 26.7 Vdc + (26.7*((45^{o}C -25^{o}C +30^{o}C) * -0.47 %/ ^{o}C))
  - Vmp_min = 26.7 Vdc – 6.27 Vdc = 20.43 Vdc
- Minimum number of modules in series @ 45 ^{o}C
  - 200 Vdc/20.43 = 9.79 ➔ 10 modules

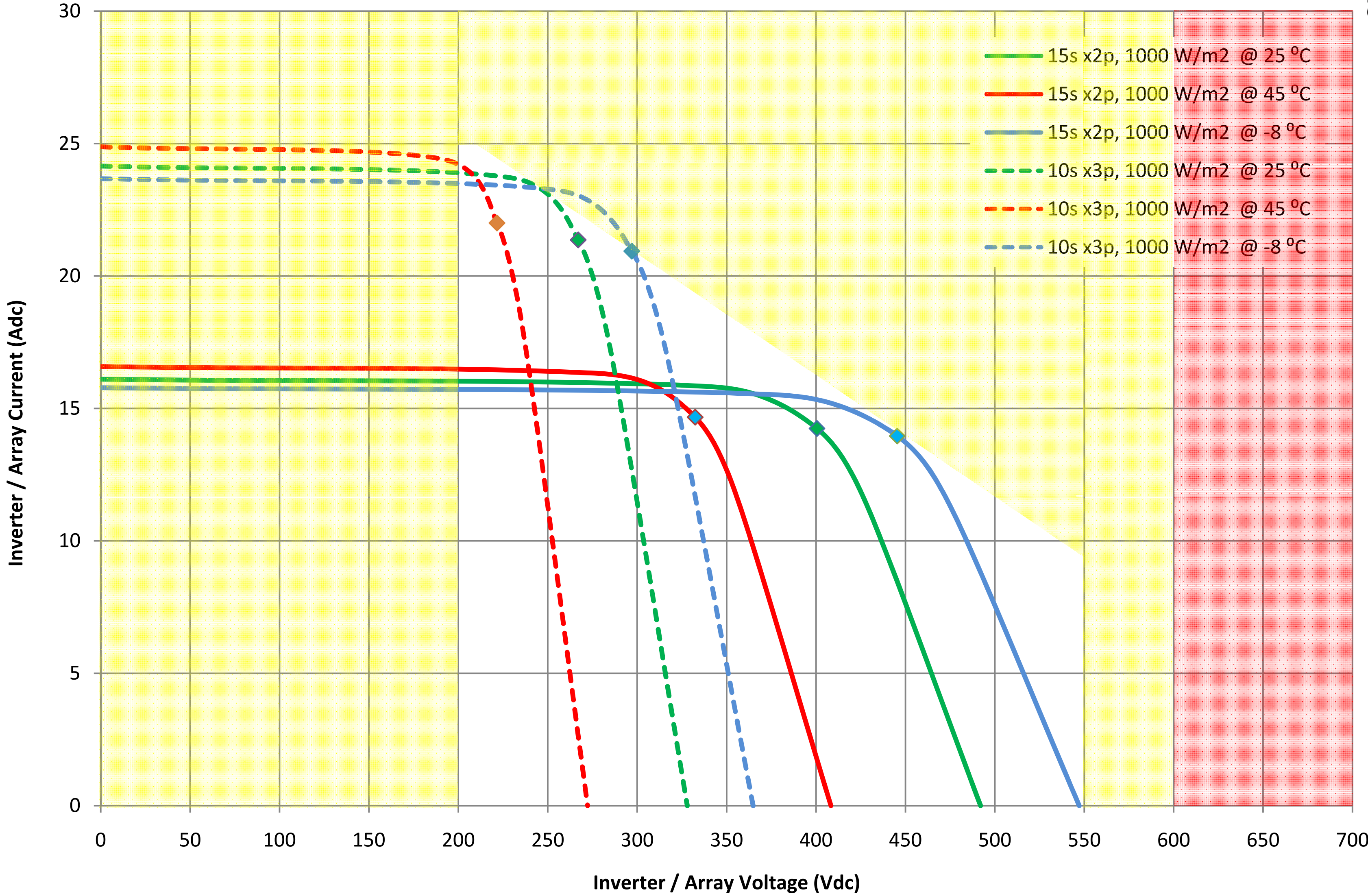
Module Equations (Isc)

- Detailed analysis normally not needed
  - Power and voltage limits usually dictate design
  - Isc_t (0.06 % / ^{o}C) and Imp_t (0.02 % / ^{o}C) are very small in magnitude and so temperature effects can be ignored.
- Imp_max (45^{o}C)
  - Imp_max = Imp * (1+((Tamb – Tstc +ΔT) * Imp_t))
  - Imp_max = 7.12 Adc+ (7.12 Adc*((45^{o}C -25^{o}C +30^{o}C) * 0.02 % / ^{o}C))
  - Imp_max = 7.12 Adc+ 0.07 Adc = 7.19 Adc
- Maximum number of modules (strings) in parallel
  - 25Adc/7.19 = 3.48 → 3 parallel strings of modules

Module Equations (Pmp)

- Pmp_max (25 ^{o}C – with delta T added)
  - Pmp_max = Pmp + Pmp*((Tamb – Tstc +ΔT) * Pmp_t)
  - Pmp_max = 194.9 Wdc + (194.9 *((25^{o}C -25^{o}C +30^{o}C) * -0.48 %/ ^{o}C))
  - Pmp_max = 194.9 Wdc – 28.1 = 166.8 Wdc
  - Pptc (CEC Watts) = 168.8 Wdc (shows close agreement to above)
- Estimate maximum number of modules needed
  - Pmp max <= Pac_max_inv / ηinv /Pmp_max (or Pptc)
  - Pmp_max <= 5000/0.954 /166.84 <= 31.41 (Pmp_max method)
  - Pmp_max <= 5000/0.96/168.8 <= 30.85 (CEC/Pptc_method)
- Maximum array configurations
  - 15 series * 2 parallel → 30 Modules
  - 10 series * 3 parallel → 30 Modules

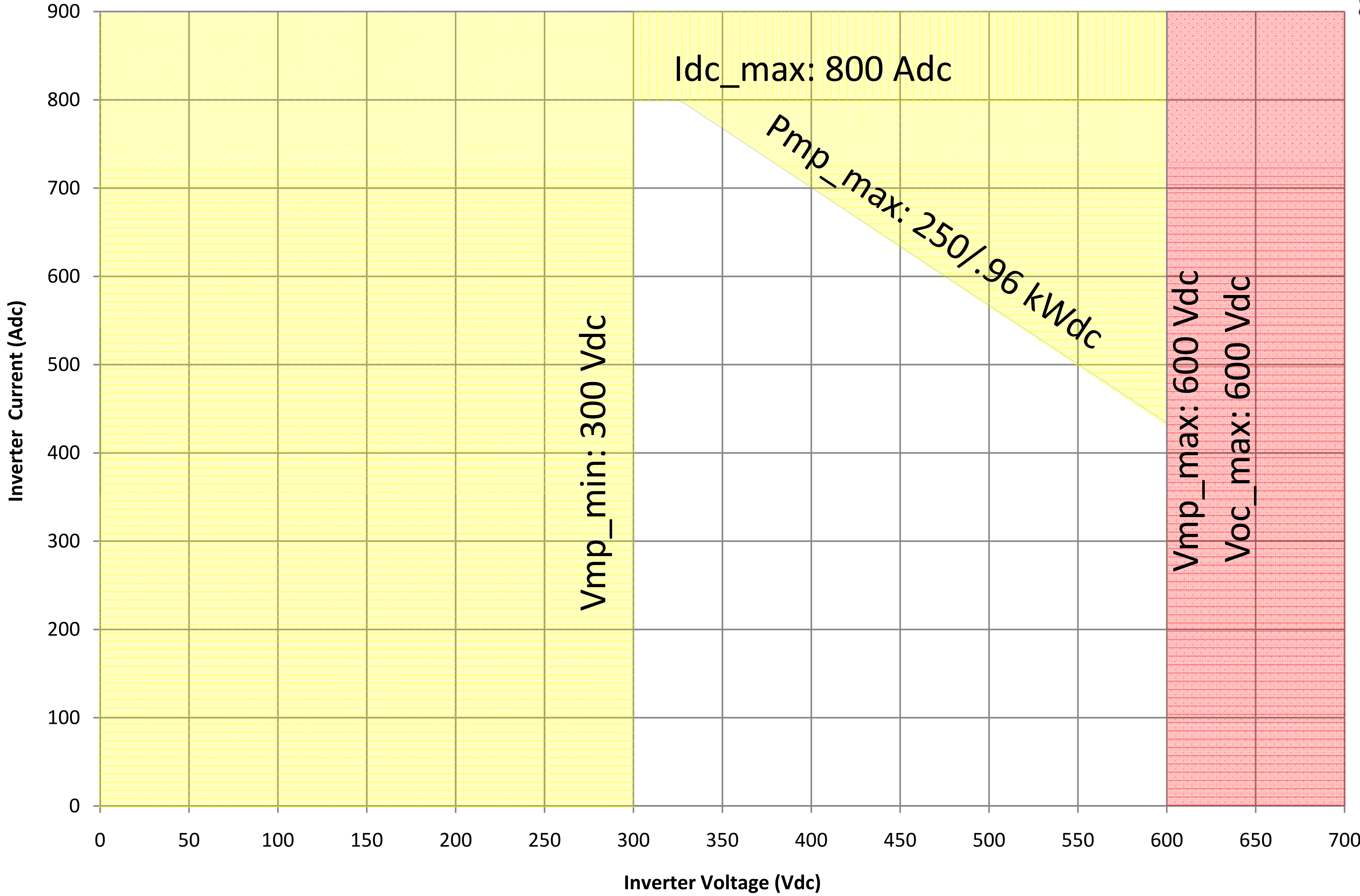
5 kW Inverter Window with Array



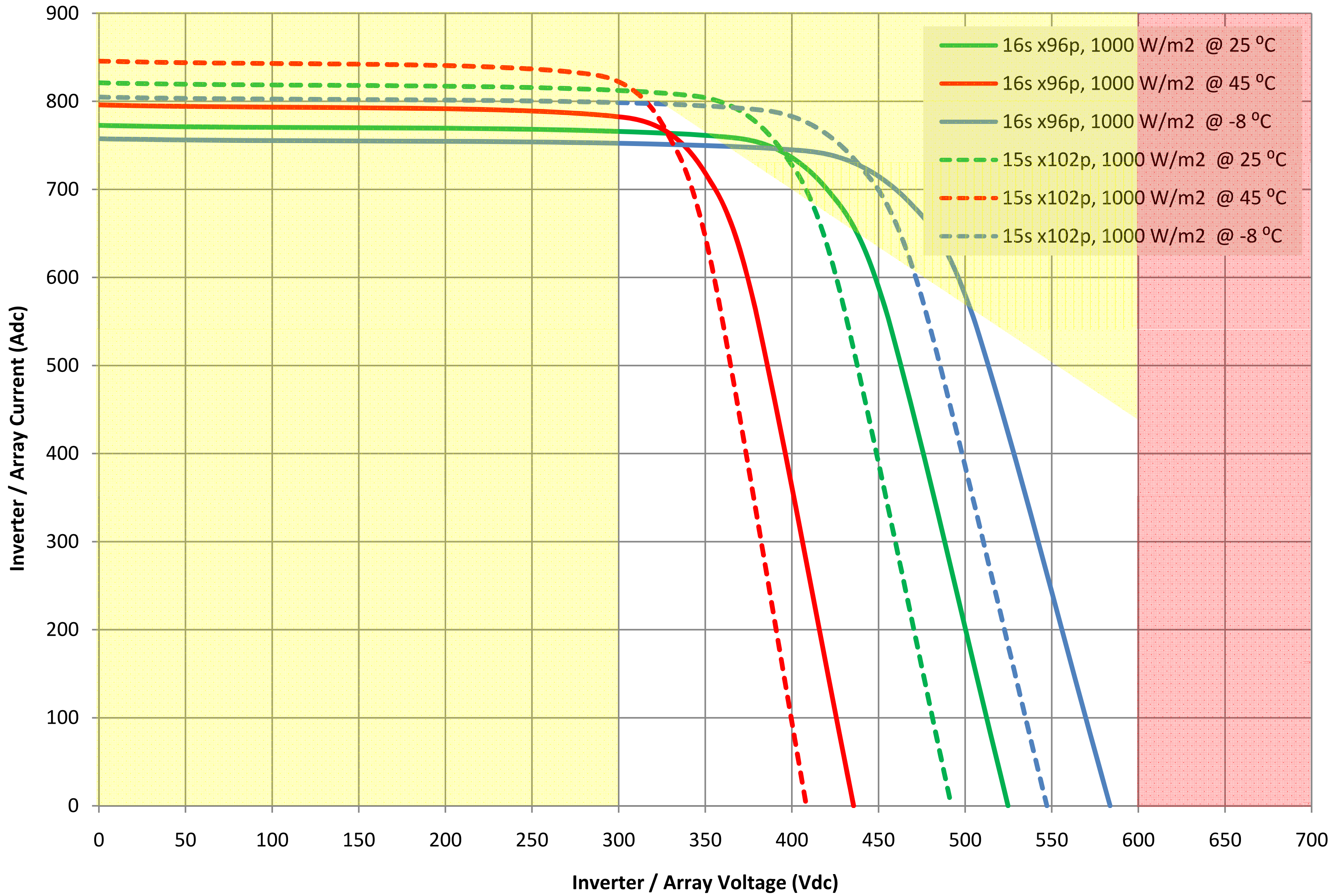
250 kW example

- Module data remains the same
- Inverter data (250 kW inverter)
  - Pmax: 250 kWac
  - Voc_max: 600 Vdc
  - Vmp_max: 600 Vdc Vmp_min: 200 Vdc
  - Idc_max: 800 Amps
  - η_cec: 97%, η_max_avg: 96.5 %
- Results
  - Maximum number of modules = 1,527 (CEC method)
  - 16 Series x 96 Parallel = 1,536
  - 15 Series x 102 Parallel = 1,530

250 kW Inverter Operating Window



250 kW Inverter Window with Array



Conclusions

- First order array to inverter optimizations can be done using basic parameters and simple equations
  – One or two optimal array configurations can be determined for most array / inverter combinations
  – Mounting structure and array layout likely dictates final choice.
- CEC rebate structure effectively limits maximum array size for a given inverter
  – This works well for sunny climates but limits optimal inverter utilization in low insolation areas
- Detailed optimizations require modeling software and good weather data, e.g. PVSyst, NREL TMY data