NEC 690

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Intro

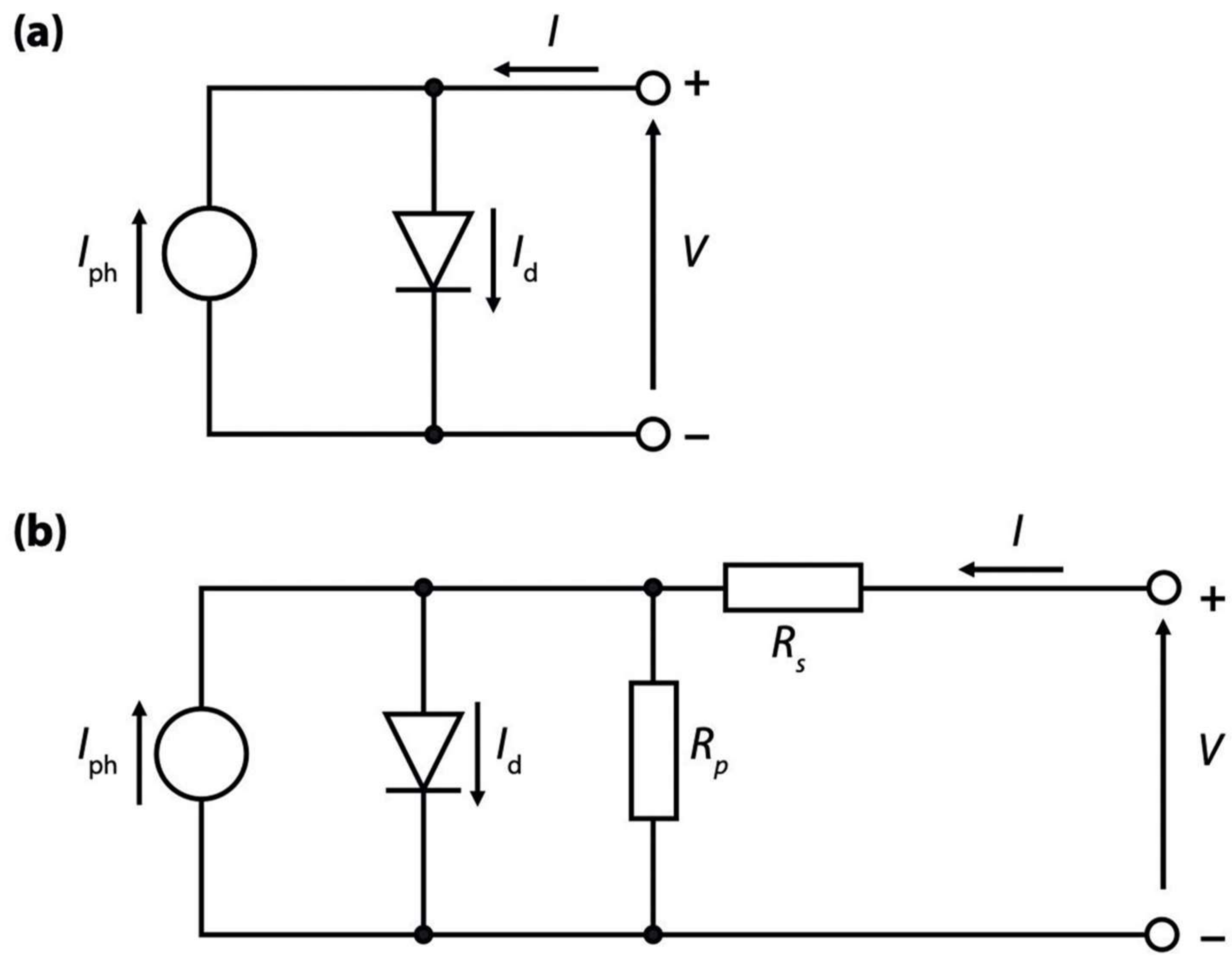
Breaker & Fuse

What is NEC 690?

- Solar photovoltaic systems of all sizes
- Pairs with NEC Article 691 for utility-scale projects
- Considerable calculation requirement details
- Significant changes in 2014, 2017, and 2020 Codes
- All numeric references here are based on 2020 NEC

Behavior of a PV Module

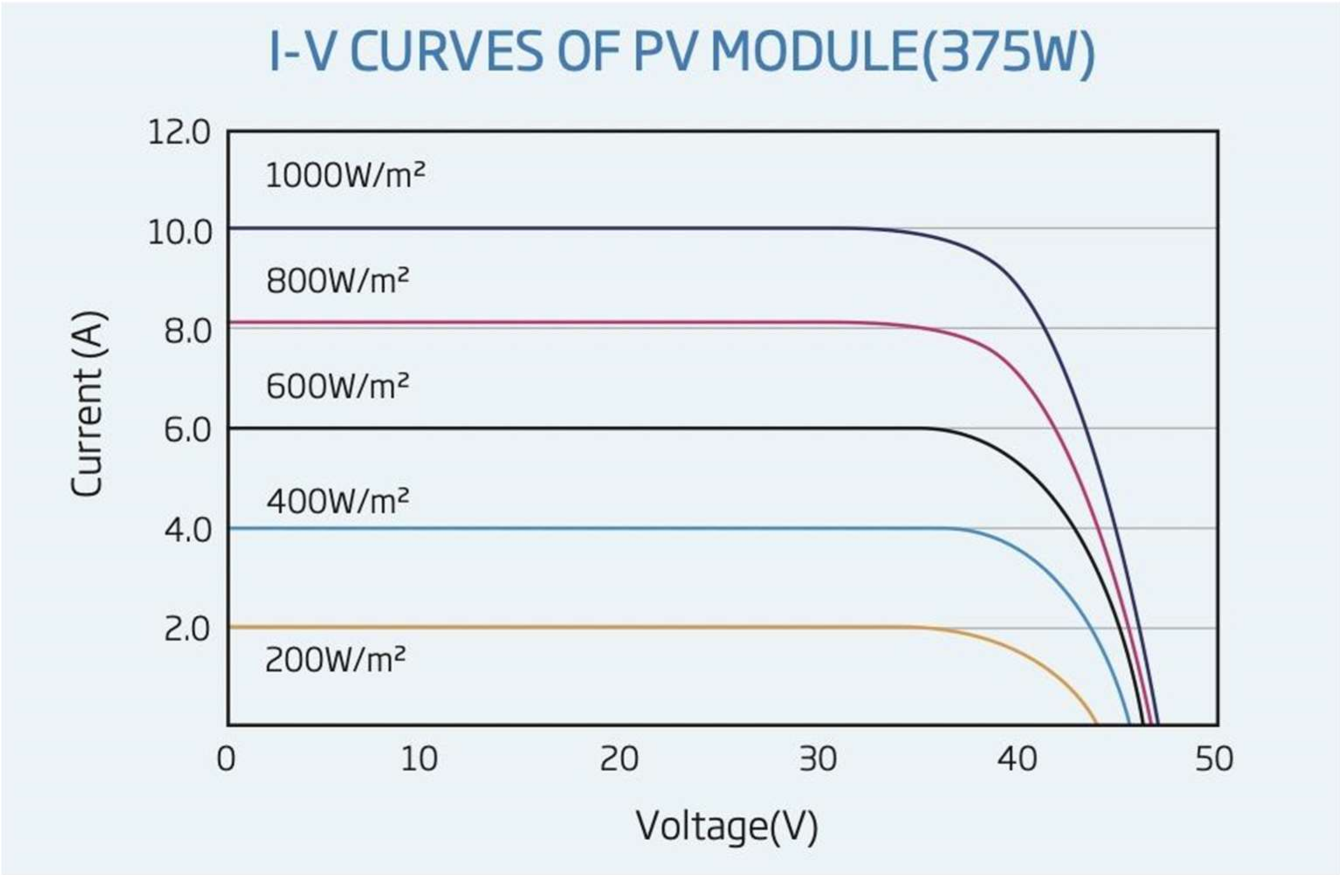
- Modules behave in a complicated way
- Current source with a diode in parallel is ideal
- Real modules have "shunt" and "series" resistance
- Module data is usually reported at STC
  - Standard Test Conditions
  - 1000 W/m^2 irradiance (typical solar noon direct sun)
  - 25 Celsius cell temperature



Source: [UT Delft]

Behavior of PV Modules (Continued)

- Although many clients will be interested in operating parameters, engineers and NEC 690 are generally only considered with worst-case behavior: Open-Circuit Voltage and Short Circuit Current



Source: Trina Solar (Typical)

Open-Circuit Voltage Calculations (Basic)

- NEC 690.7 describes the calculation for maximum Voc
- Based on temperature-corrected manufacturer data
- Voltage increases as temperature decreases
- ASHRAE extreme annual mean minimum is recommended
- Connections in series up to 600V, 1000V, or 1500V

$$V_{oc,max} = V_{oc,ref}(1 + \beta(T_c - T_{ref}))$$

ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	345	350
Power Output Tolerance-P_{MAX} (W)		
Maximum Power Voltage-V_{MPP} (V)	38.2	38.4
Maximum Power Current-I_{MPP} (A)	9.04	9.13
Open Circuit Voltage-V_{OC} (V)	46.3	46.5
Short Circuit Current-I_{SC} (A)	9.55	9.60
Module E°ciency η_m (%)	17.4	17.6

STC: Irradiance 1000W/m^2, Cell Temperature 25°C, Air Mass AM1.5.
*Measuring tolerance: ±3%.

Example

$$V_{oc,max} = V_{oc,ref}(1 + \beta(T_c - T_{ref}))$$

Low temperature assumed as 0 Celsius and typical correction factor

46.3 * (1 + .0028 (25 - 0)) = 49.541V

We could put 30 modules in series on a 1500V system

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Short Circuit Current Calculations (Monofacial)

- NEC 690.8 describes the maximum short circuit current calculation
- For monofacial (one-sided) modules, this is just 125% of the STC current
- Note that this 125% multiplier is NOT the same as the 125% multiplier for ampacity

$$I_{sc,max} = 1.25\, I_{sc,ref}$$

Source: Solar Power World Online

Short Circuit Current Calculations (Bifacial)

- NEC 690.8 in the 2020 NEC does not address bifacial modules (two-sides of sunlight absorption)
- The 2023 NEC will have a reference to bifacial, but it will not be very helpful for design
- Bifacial modules can produce 25-30% additional peak short circuit current over monofacial modules of the same wattage

$$I_{sc,max} = 1.56\, I_{sc,ref}$$

Example

Monofacial: 1.25 * 9.55 = 11.9375 A

Bifacial: 1.56 * 9.55 = 14.898 A

*Remember, this does not consider any additional multipliers for ampacity

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Historical Site-Specific Modeling

- In the 2020 NEC, both open-circuit voltage and short circuit current are permitted to be calculated using detailed irradiance-temperature behavior
- This only applies to projects over 100kW
- Site-specific modeling can yield substantially reduced worst-case behavior

$$I_{sc} = \frac{G}{G_{ref}} I_{sc,ref} \left(1 + \alpha(T_c - T_{ref})\right)$$

$$V_{oc} = N_s kT\gamma \, ln\left(\frac{I_{sc}}{I_0} + 1\right)/q$$

Risk and Site-Specific Modeling

- NEC 690 doesn’t give much direction on site-specific modeling
- There is no clear time frame of interest or required design margin
- Electrical engineers should carefully consider the design and the interests of stakeholders when designing such a project
- Much like Neher-McGrath calculations for ampacity, site-specific modeling can yield significant improvements but must be done with great detail to ensure a satisfactory design

Additional NEC 690 Considerations

- 690.8(B) requires conductors to be sized as if loads are continuous
- 690.9 requires overcurrent protection devices to be rated for 125% of the maximum current
- 690.9 does not require overcurrent protection where conductors are rated for the maximum current
- 690 Part V covers grounding requirements, but module performance may be impacted if the system isn't negatively grounded due to PID losses

Conclusions

- Most of the requirements in NEC 690 are similar to any other electrical project
- A lack of standardization in the solar industry in the past has created confusion, but the latest editions of the NEC will help with this problem
- For the time being, electrical engineers need to make careful choices when modeling beyond the basic methods of the NEC

Questions?