Energy Extraction Characteristic Study of Solar Photovoltaic Cells and Modules

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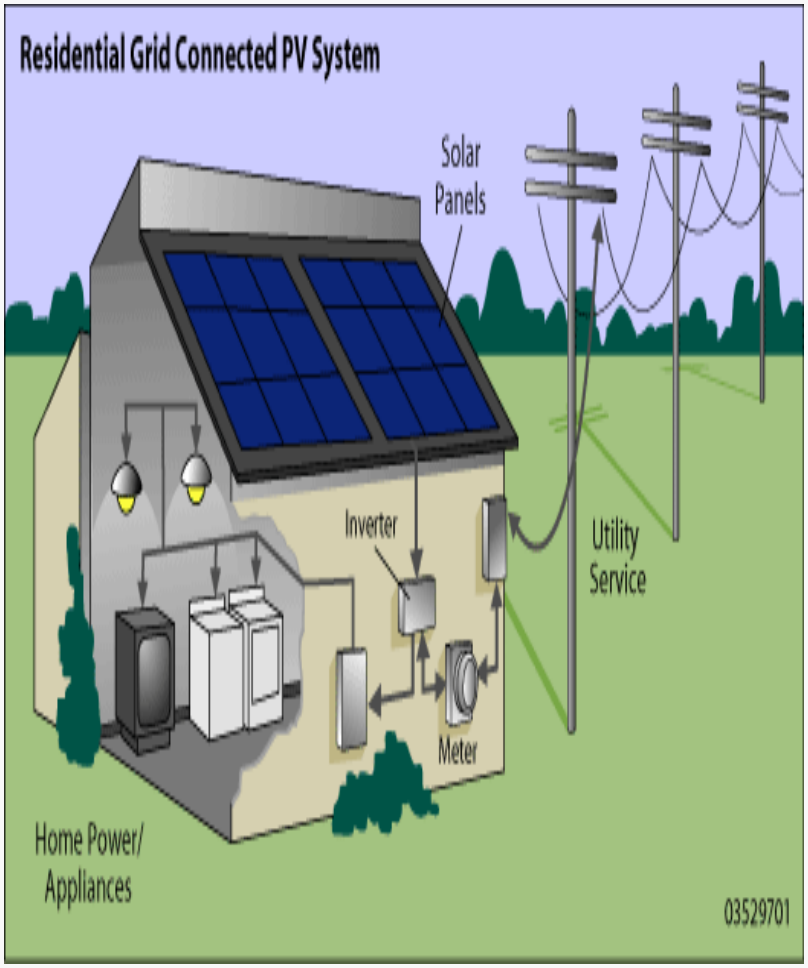
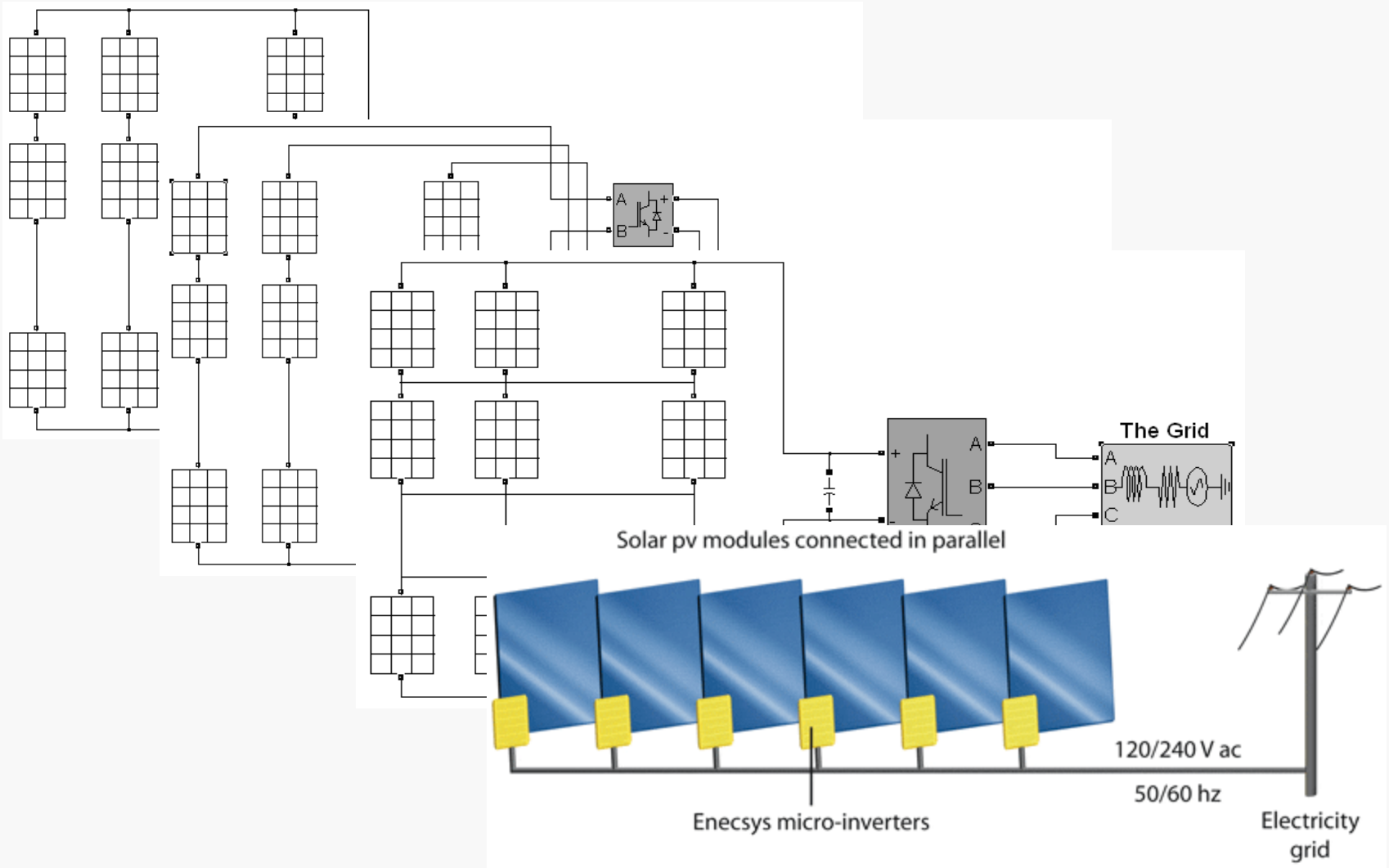
Solar Photovoltaic Power Generation Systems

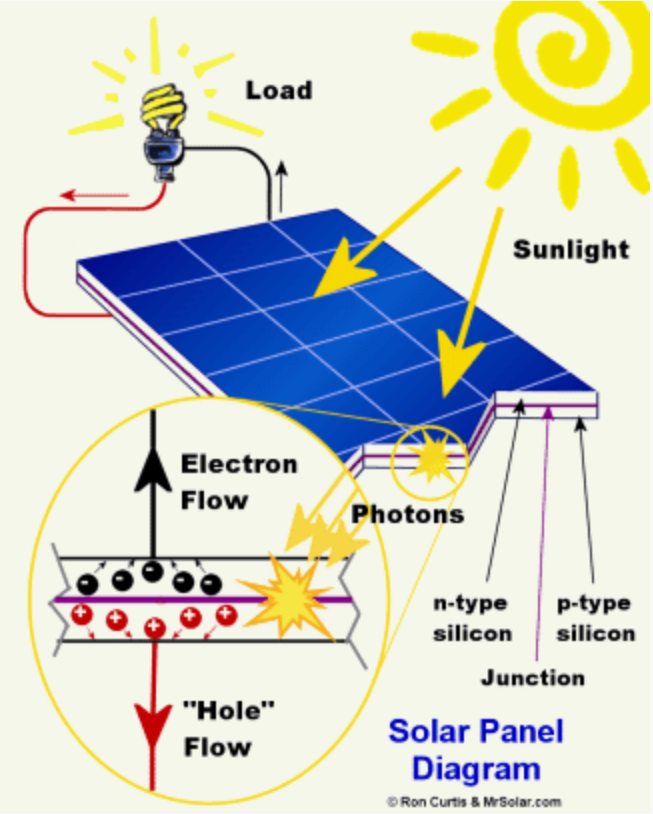


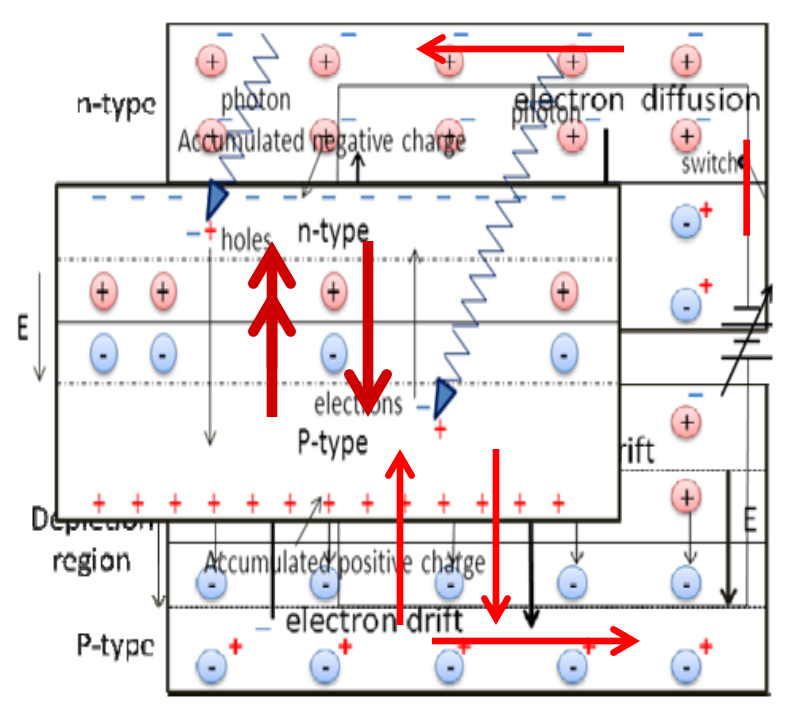
PV System Integrations



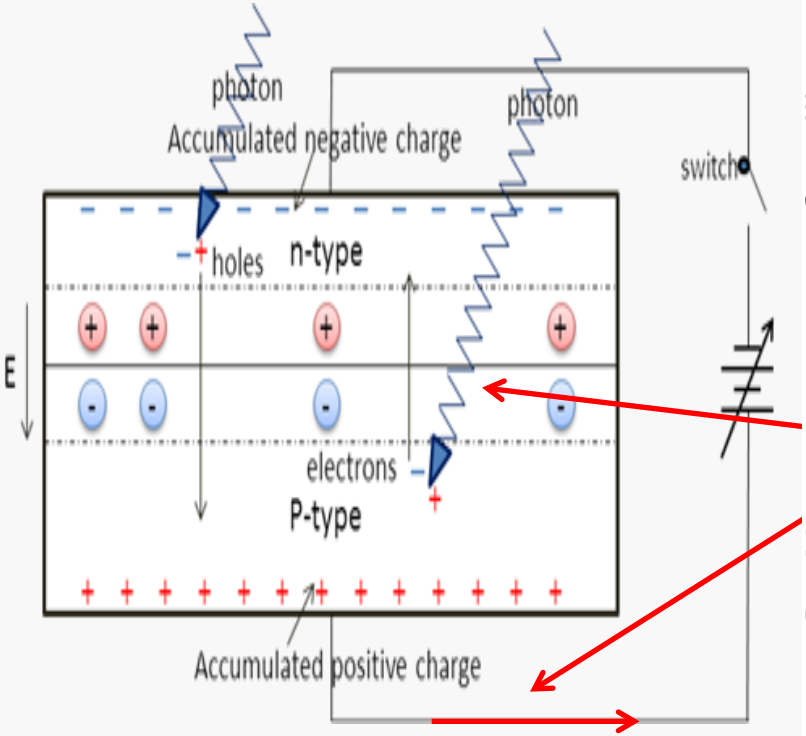
Energy extraction efficiency, reactive power, reliability.

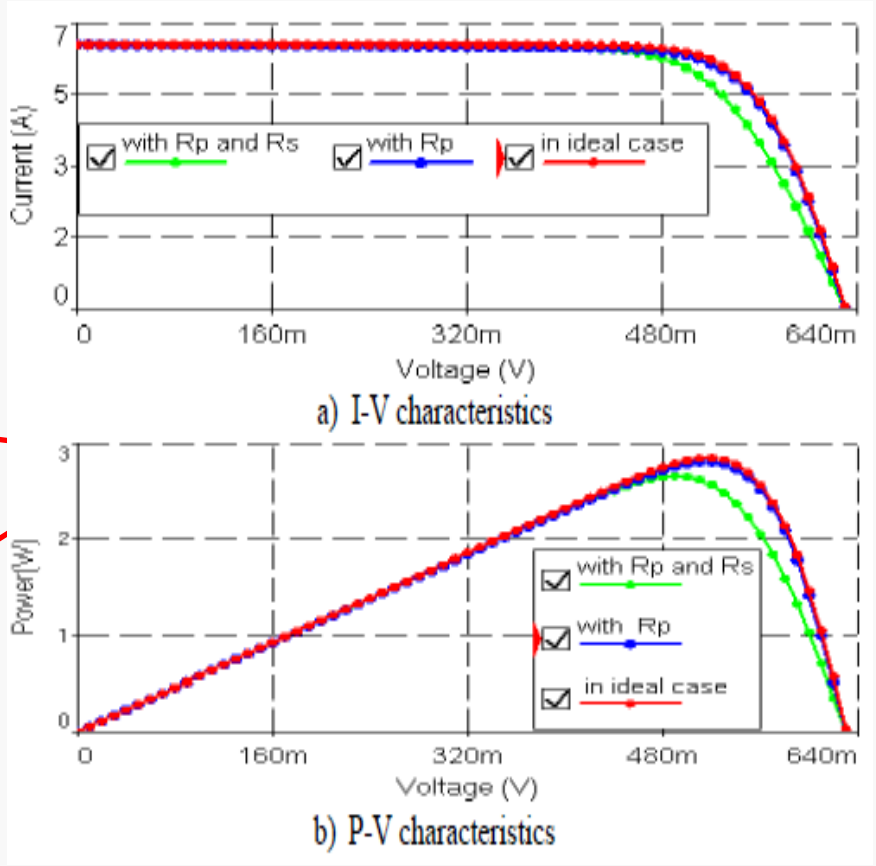
Semiconductor physics and electric power system



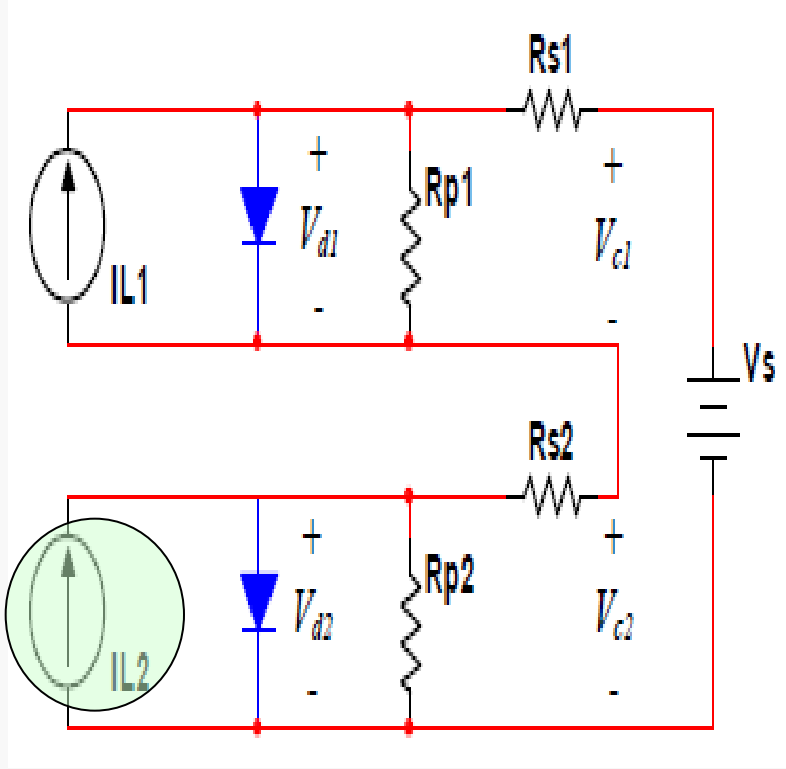


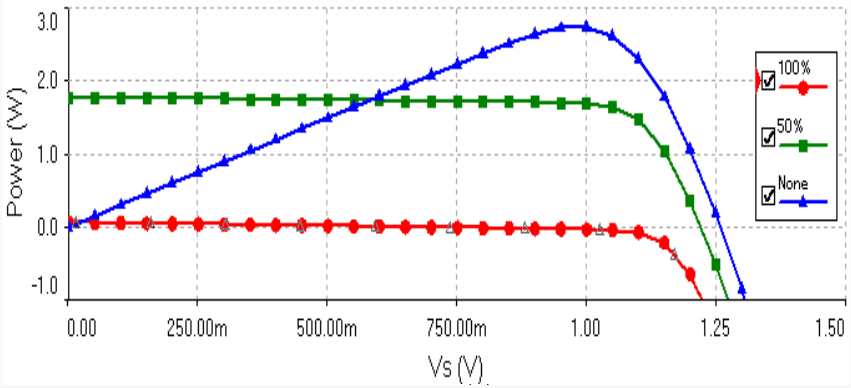
Solar PV Cell Equivalent Circuit

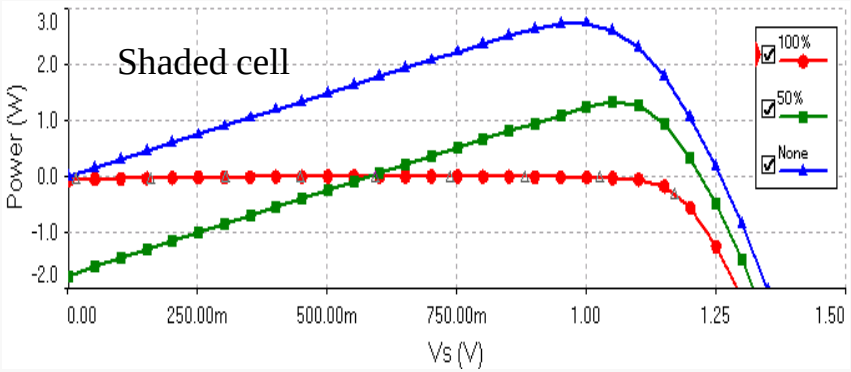




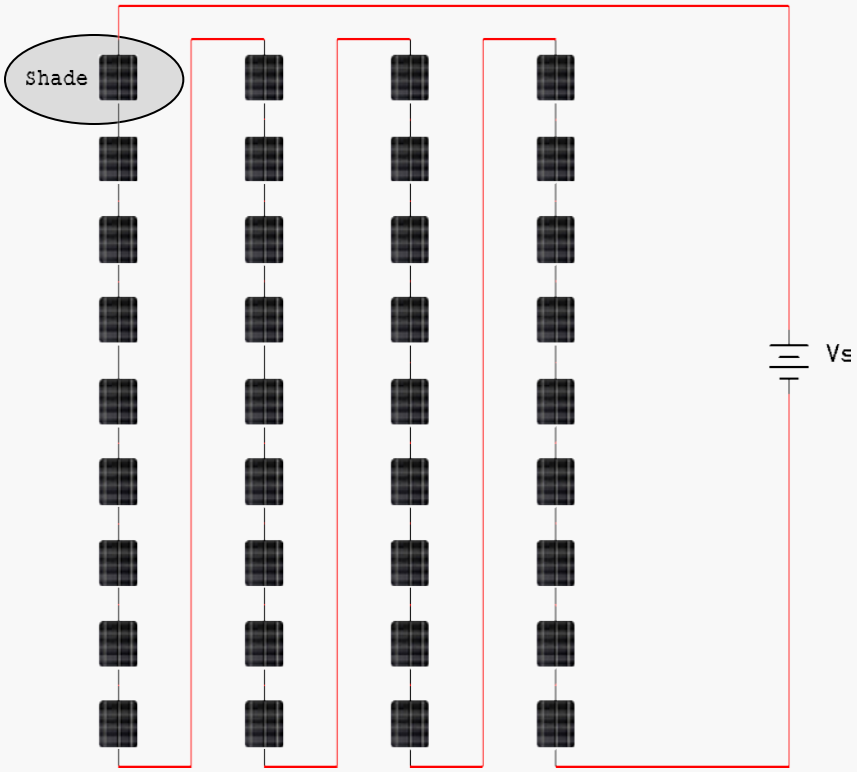
Two series PV cells under uneven shading condition

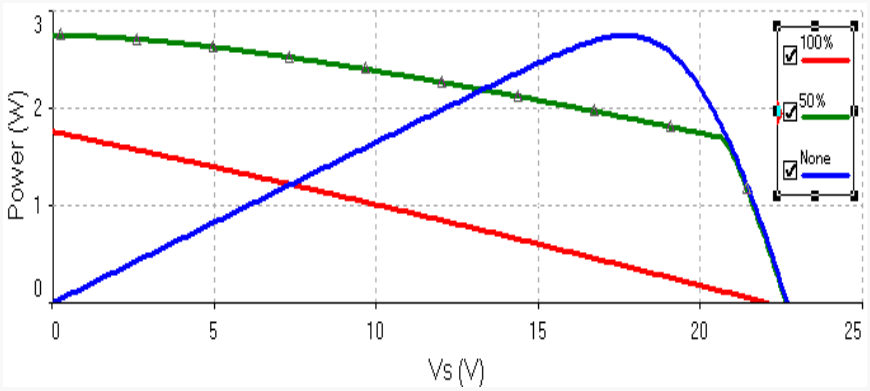


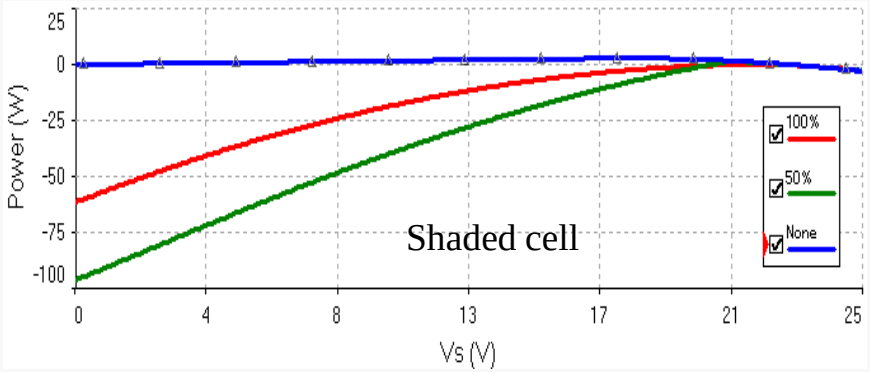


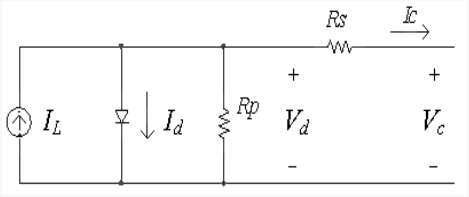


PV Module under one shaded cell condition

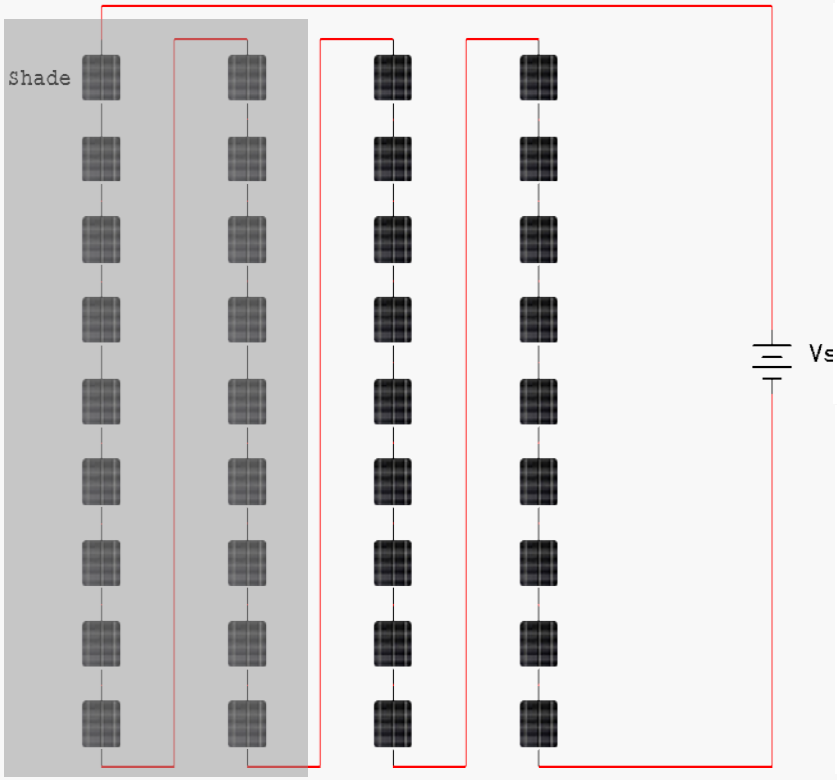


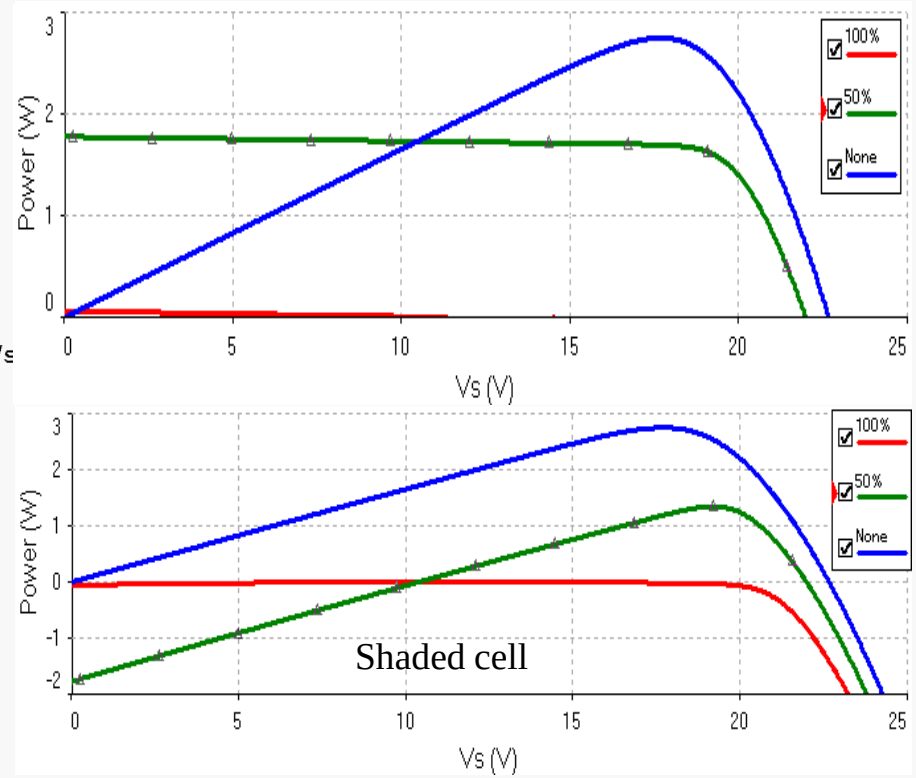


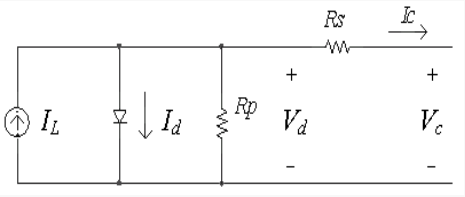




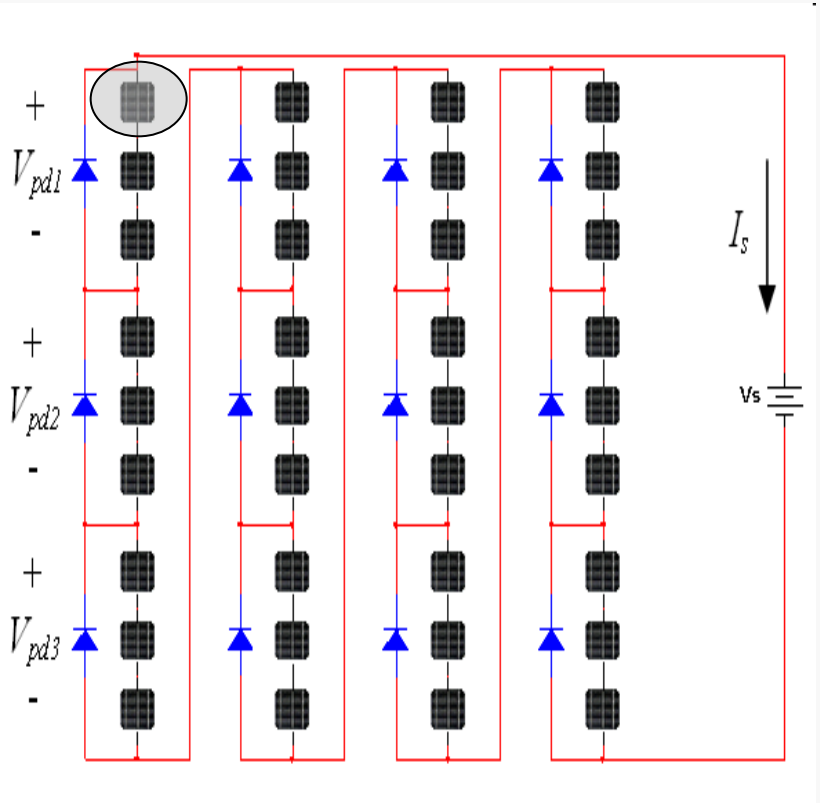
PV Module under 18 shaded cells within a module

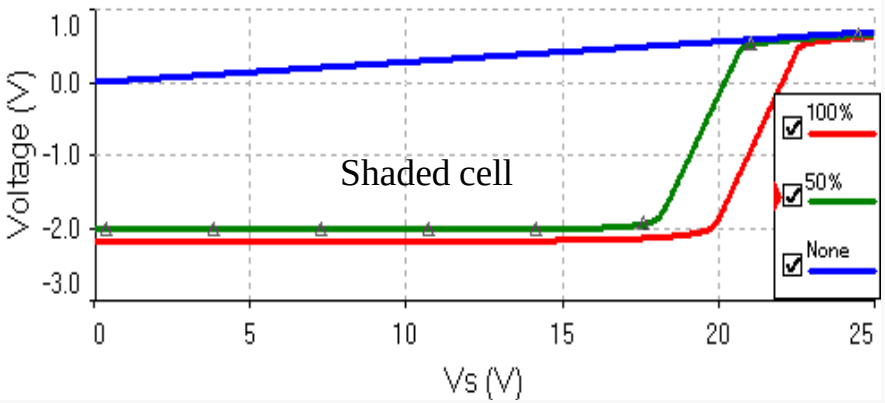


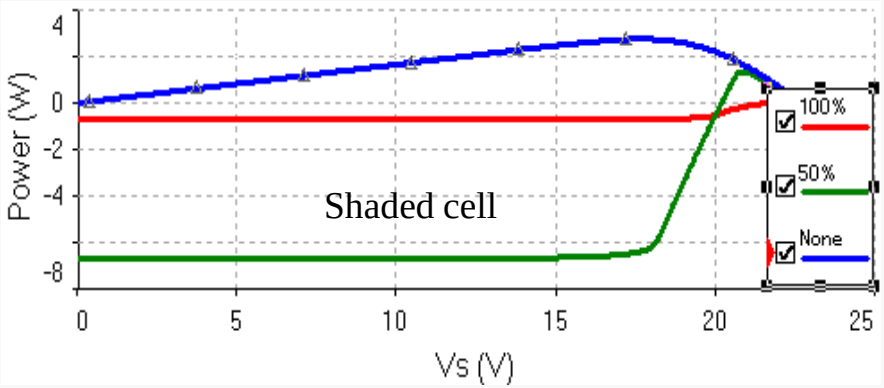




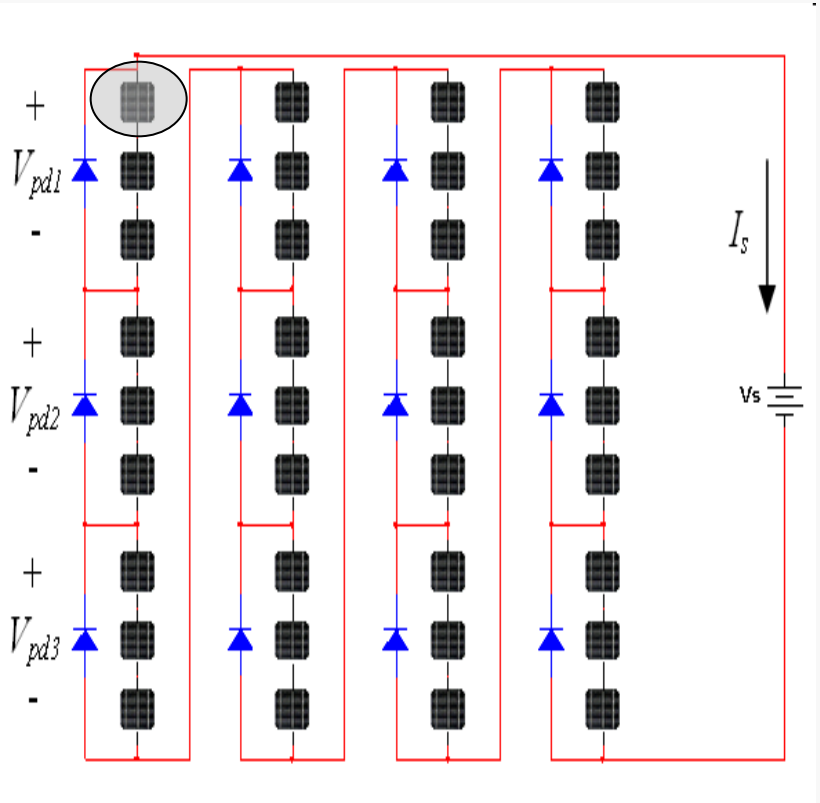
One bypass diode for each three cells

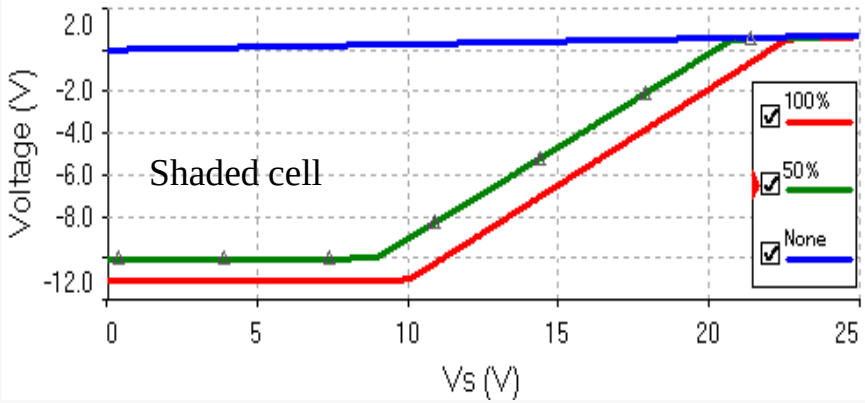


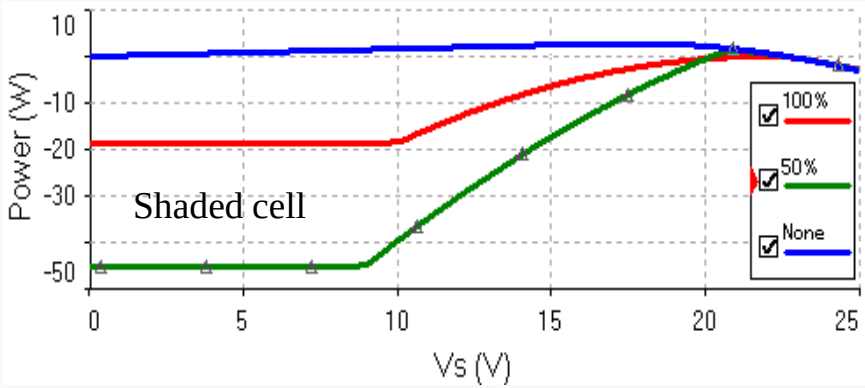


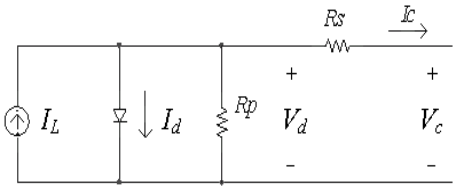


One bypass diode for each 18 cells









Numerical algorithm for PV simulation

- **Model:**

  Cell: $I_{ci} = (1 - p_{ij}) I_L - I_0 \left(e^{qV_{dij}/(mkT)} - 1 \right) - V_{dij} / R_p$, $V_{cij} = V_{dij} - I_{ci} \cdot R_s$

  Bypassed cell group: $V_{pdi} = V_{ci1} + V_{ci2} + \mathrm{K} + V_{ci(n-1)} + V_{ciL}$

  Output current/voltage: $I_s = I_{ci} + I_0 \left(e^{-qV_{pdi}/(mkT)} - 1 \right)$

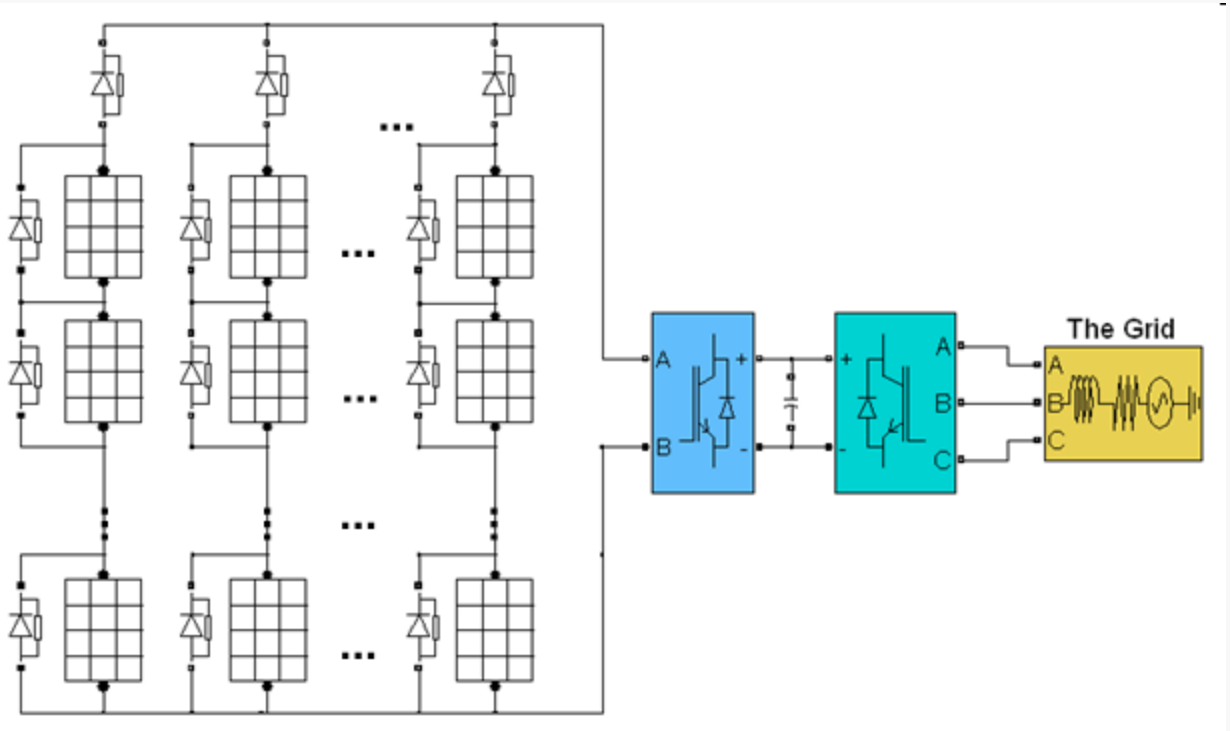
  $V_s = V_{pd1} + V_{pd2} + \mathrm{K} + V_{pd(M-1)} + V_{pdM}$

- **Algorithm:**
  - Obtain a system of N=L×M equations

    $f_1 \left(V_{d1}, \mathrm{L}\ , V_{dN} \right) = 0 \quad \mathrm{L} \quad f_N \left(V_{d1}, \mathrm{L}\ , V_{dN} \right) = 0$

  - Apply Newton-Rephson algorithm
- **Validation:** PSpice simulation compared with numerical computation

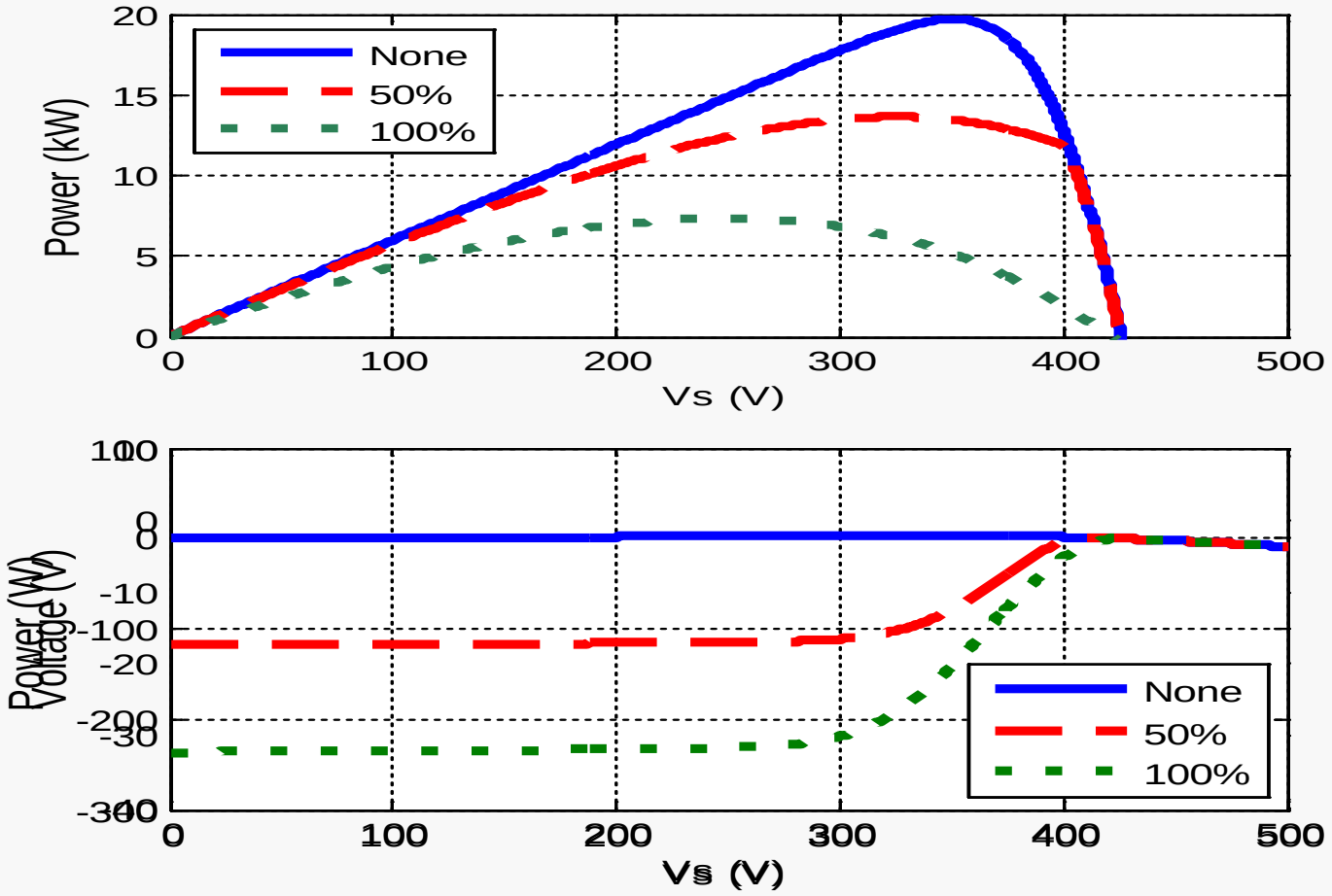
PV array with bypass diodes



- **A bypass diode** for each module
- **A blocking diode** at the top of each string to prevent a shading or malfunctioning string from withdrawing current from the rest strings that are wired together in parallel.

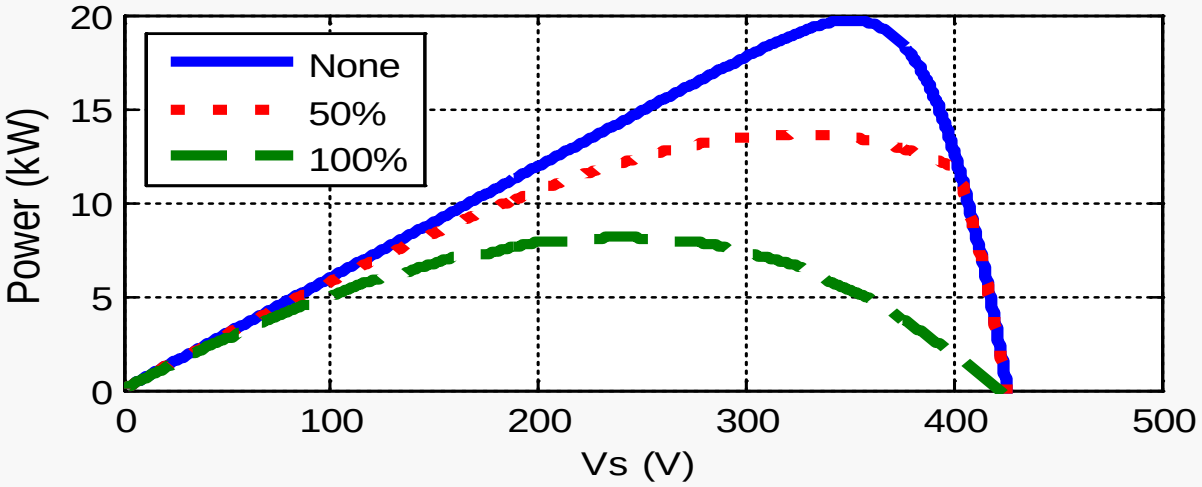
PV array without bypass diodes

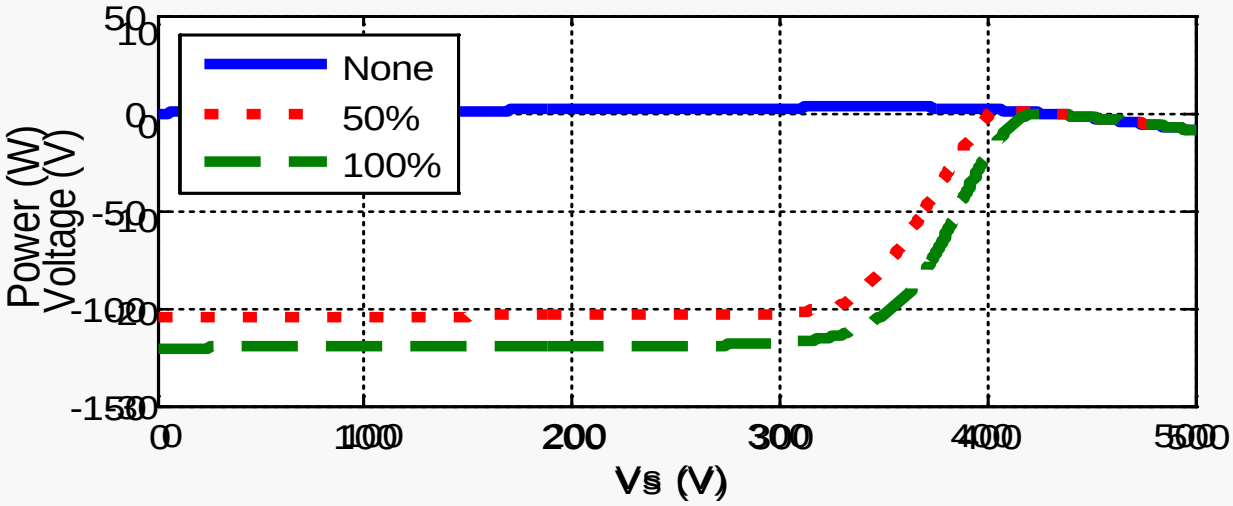
- 20 by 10 PV array
- 10 shaded modules in the 1st string, 9 shaded modules in the 2nd string, 1 shaded module in the **last string**
- Each shaded module has one shaded cell



PV array with a bypass diode for each module

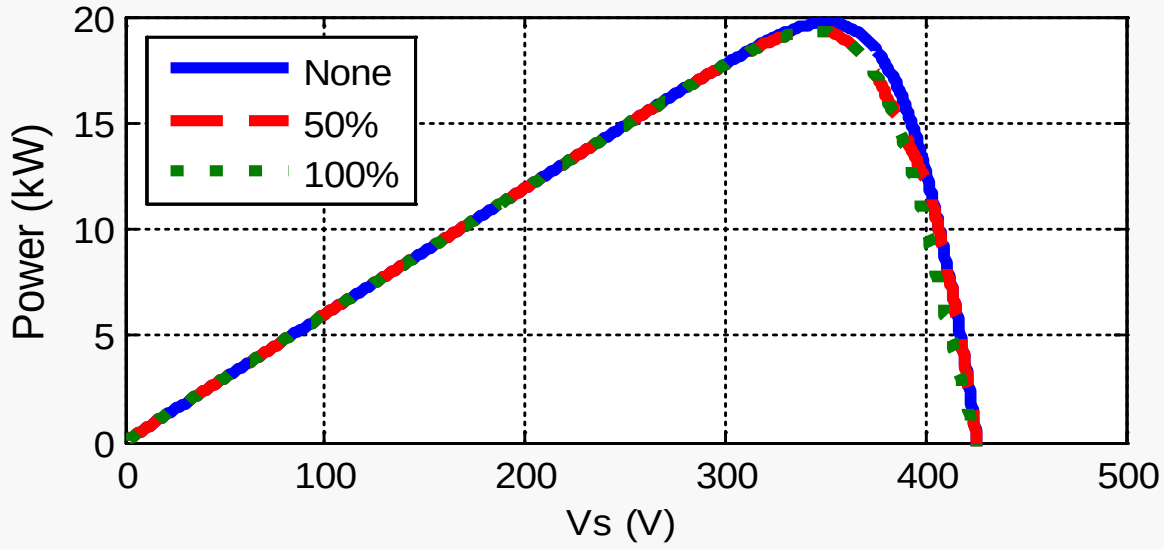
(same condition)

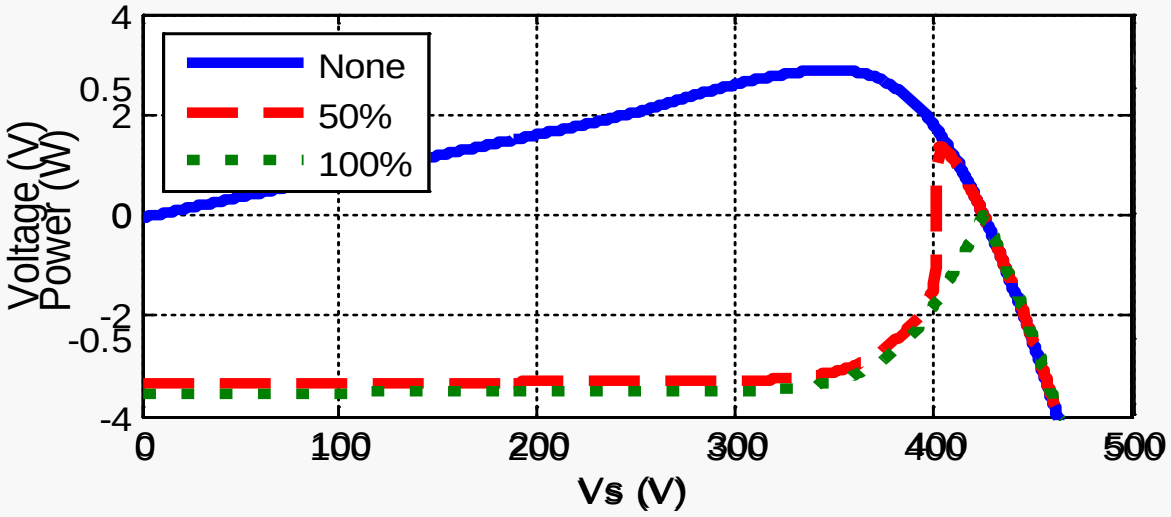




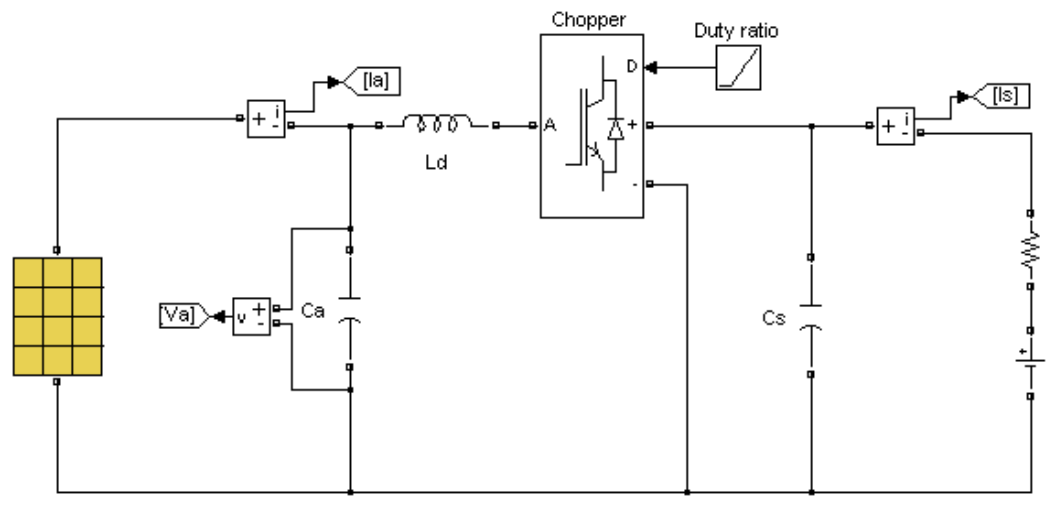
PV array with a bypass diode for each cell

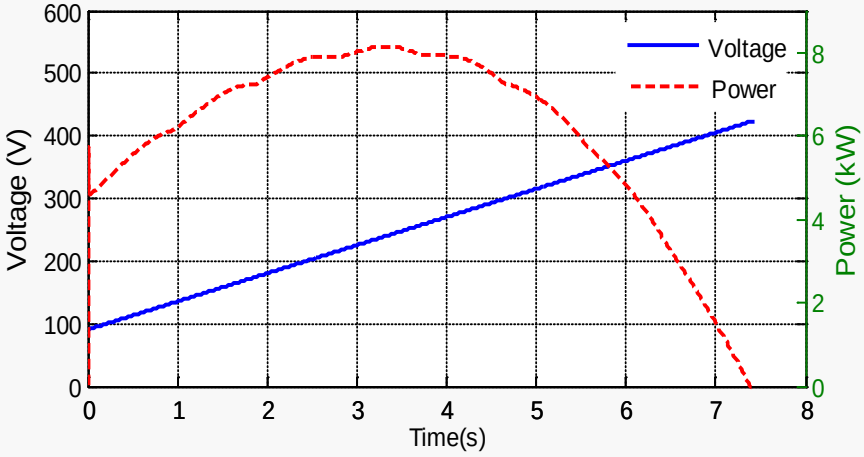
(same condition)

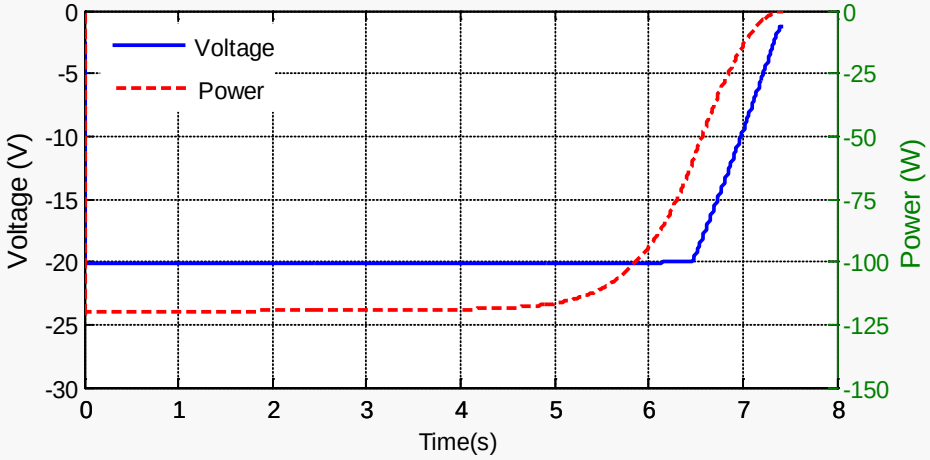




Virtual Transient Experiment







a bypass diode for each module

Conclusions

- **Under uneven shading conditions:**
  - a high current through the parallel resistors of the shaded cells,
  - a high reverse terminal voltage on each shaded cell, and
  - a high absorbing power by each shaded cell, depending on the voltage applied to PV cells or modules.
- **Using bypass diodes:**
  - the less the PV cells within a bypass diode group, the smaller the reverse voltage over shaded cells and the less the shaded cells absorb power.
- **For a solar PV array:**
  - if no bypass diodes applied, the PV array characteristics can be shifted considerably by shaded cells depending on how many strings contain shaded cells and how many shaded cells are in each string.
  - If each PV cell has a bypass diode, the influence of the shaded cells is significantly reduced → **a new PV module concept**.
- **The models and Newton-Rephson algorithm are suitable for transient analysis of power converter controlled solar PV systems.**