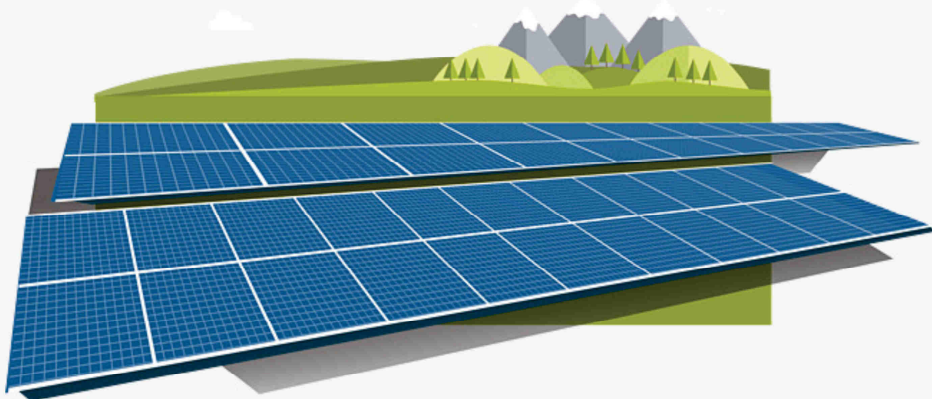





# Modelagem e Controle de Sistemas Fotovoltaicos

## Aula 02 - P1 - Introdução à Energia Solar Fotovoltaica



Prof. Heverton Augusto Pereira  
heverton.pereira@ufv.br



# Histórico

1800	<i>Descoberta do Selênio (Se) (Berzelius)</i>
1820	<i>Preparação do Silício (Si) (Berzelius)</i>
1840	<i>Efeito Fotovoltaico (Becquerel)</i> 
1860	<i>Efeito Fotocondutivo no Se (Smith)</i> <i>Retificador do Ponto de Contato (Braun)</i>
1880	<i>Efeito Fotovoltaico no Se (Adams &amp; Day)</i> <i>Células Fotovoltaicas de Se (Fritts/Uljanin)</i>
1900	<i>Fotosensitividade em Cu-Cu<sub>2</sub>O (Hallwachs)</i>

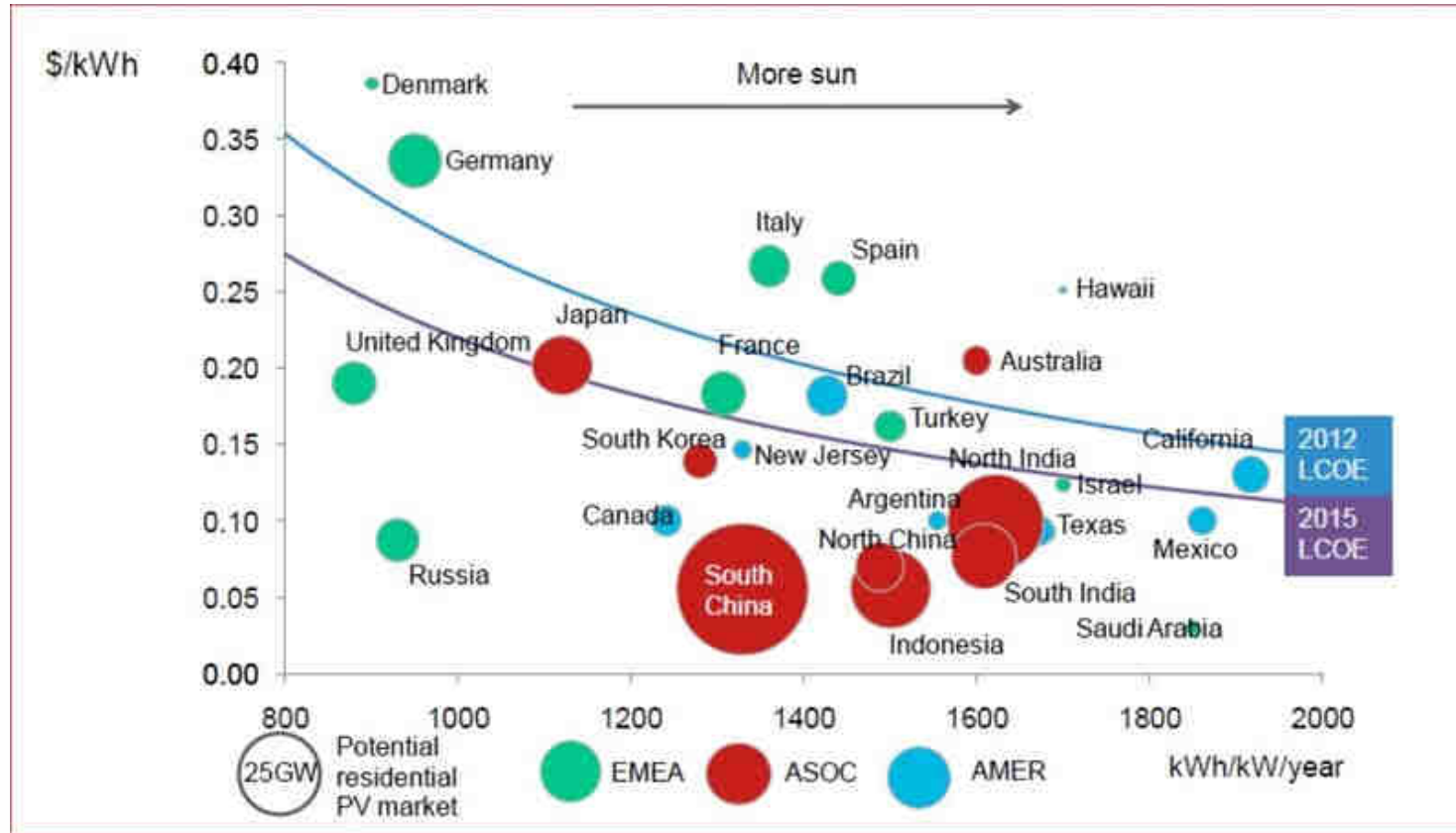
# Histórico

1910	<i>Efeito Fotovoltaico com Barreira de Potencial (Goldman &amp; Brodsky)</i>	
1920	<i>Monocristal a partir do Si Fundido (Czochralski)</i>	
	<i>Retificador de Cu-Cu<sub>2</sub>O (Grondahl)</i>	
1930	<i>Célula Fotovoltaica de Cu-Cu<sub>2</sub>O (Grondahl &amp; Geiger)</i>	
	<i>Teoria de Bandas em Sólidos (Strutt/Brillouin/Kronig &amp; P)</i>	
	<i>Teoria de Células com Barreiras V e H (Schottky et al)</i>	
1940	<i>Teoria da Difusão Eletrônica (Dember)</i>	
	<i>Aplicações Fotométricas (Lange)</i>	
	<i>1% eficiência em Células de Sulfeto de Tálcio (TI<sub>2</sub>S) (Nix &amp; Treptow)</i>	
1950	<i>Crescimento de Células Fotovoltaicas com Junção (Ohl)</i>	
	<i>Teoria de Junções p-n (Shockley)</i>	

# Aplicações

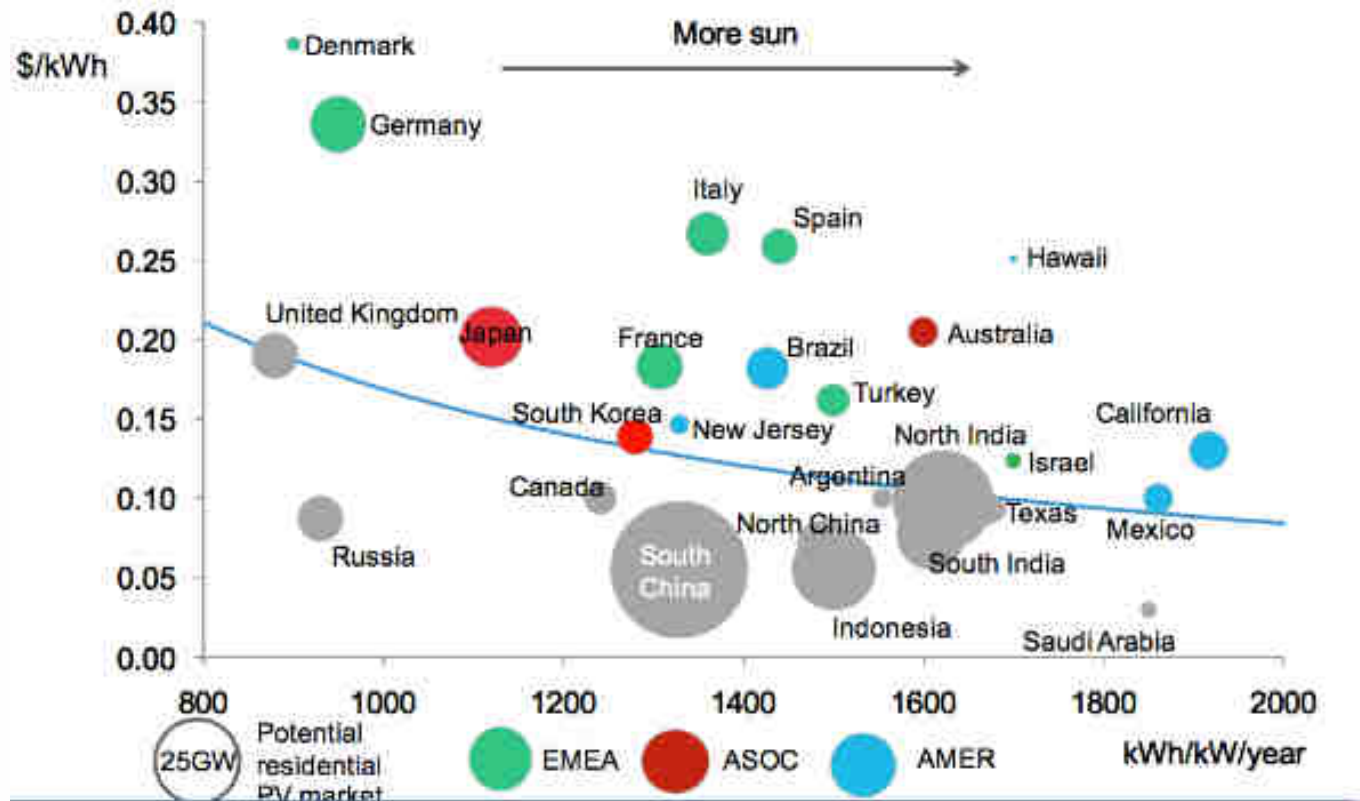


# “Grid parity”



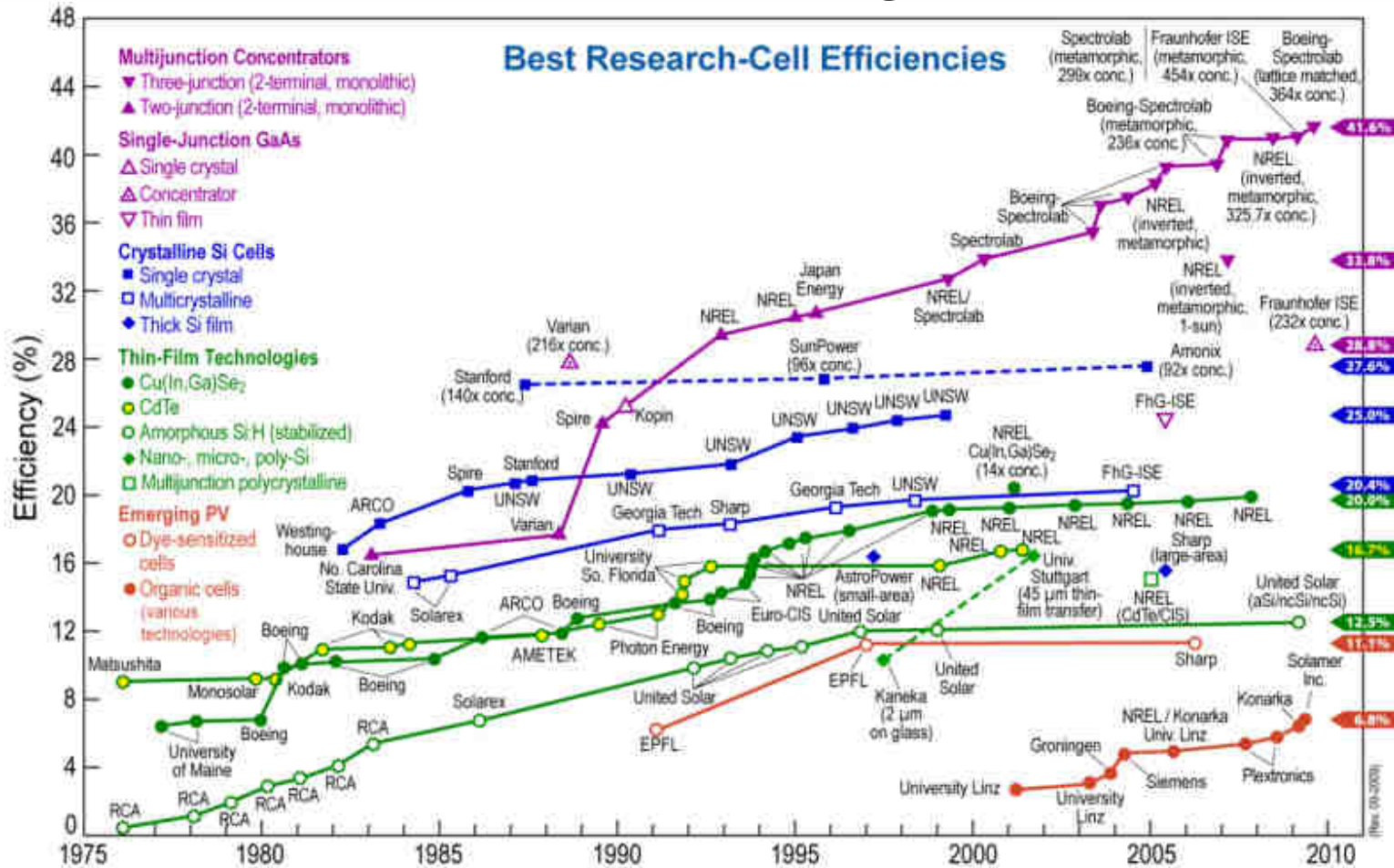
Fonte: Bloomberg

# “Grid parity” da energia solar: 2020



Fonte: Bloomberg

# Tecnologias



# Tipos de Células

1. Silício cristalino – monocristalino e policristalino
2. Silício amorfo
3. Telureto de Cádmió – CdTe
4. Disseleneto de Cobre Índio (CIS – CuInSe<sub>2</sub>)
5. Arsenieto de Gálio – GaAs
6. Células de Multi-Junção
7. Corantes

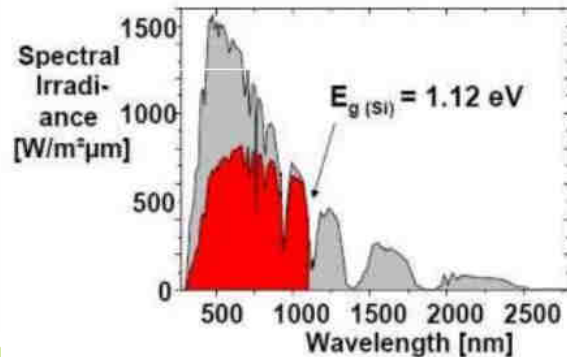
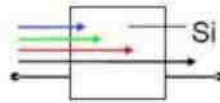


# Tipos de Células

$d = 37 \mu\text{m}$ ,  $\eta = 20.2 \%$ ,  $A = 4 \text{ cm}^2$



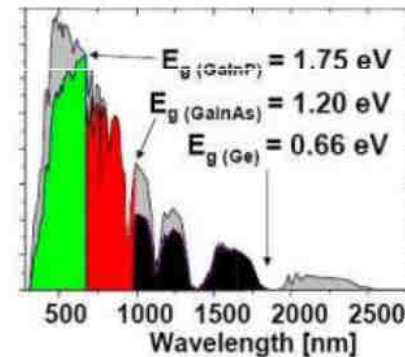
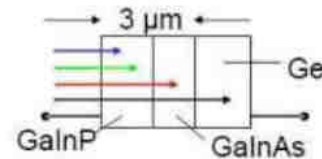
Monocrystalline Silicon



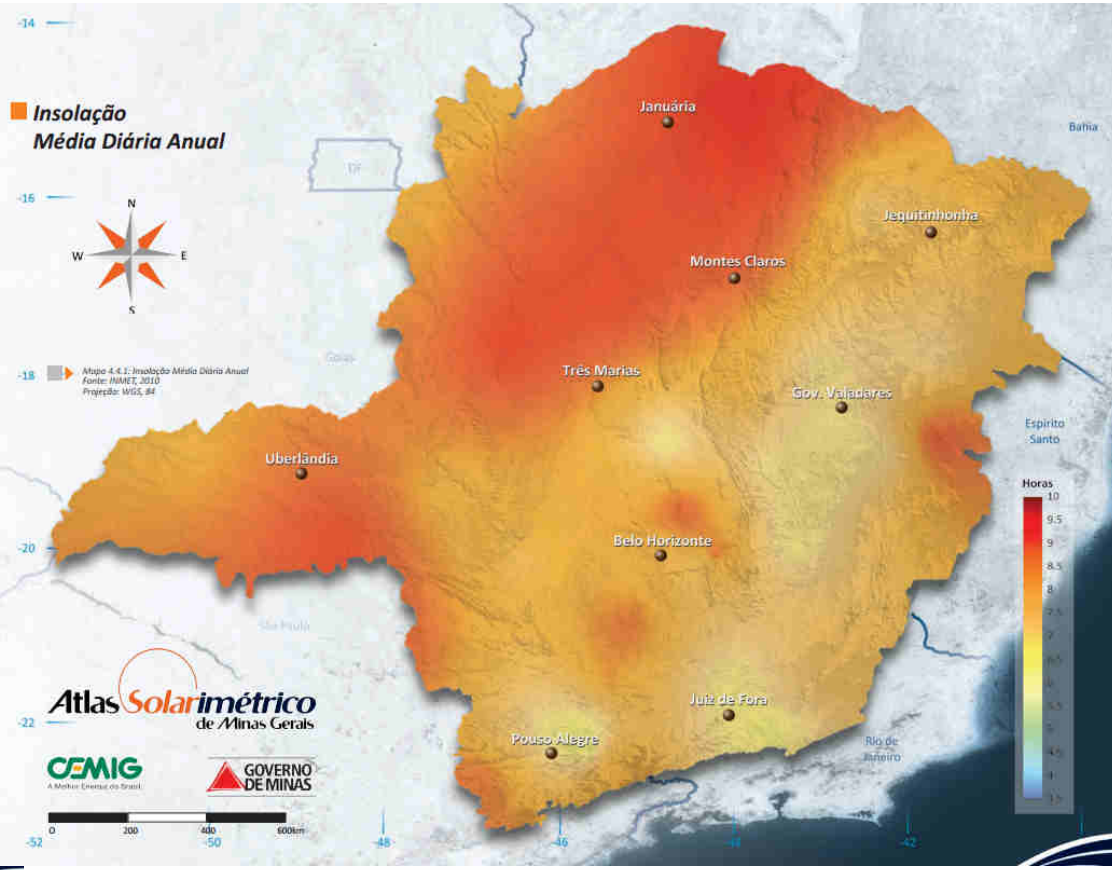
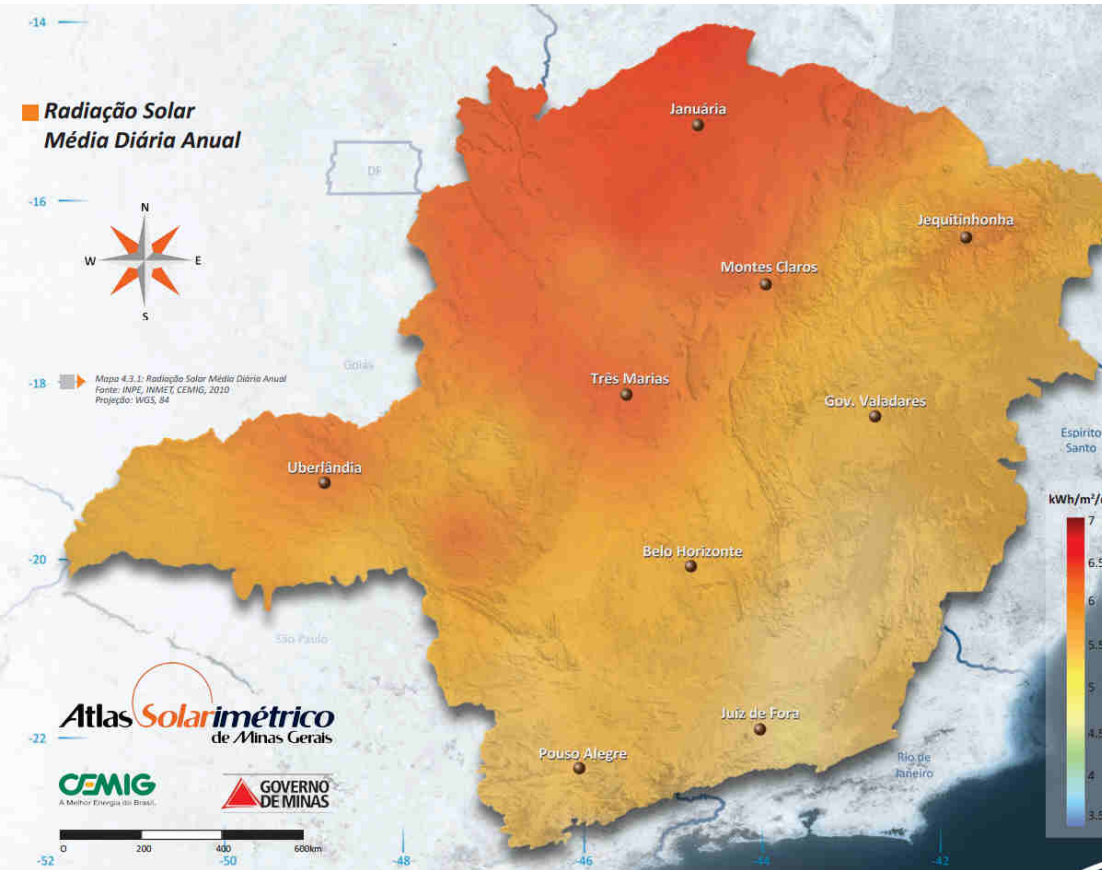
$d = 99 \mu\text{m}$ ,  $\eta = 20.3 \%$ ,  $A = 1 \text{ cm}^2$



Multicrystalline Silicon

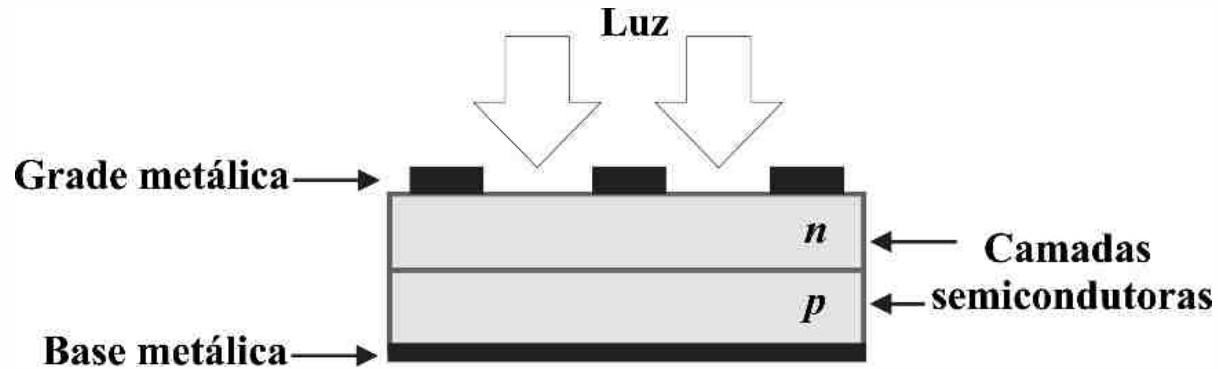


# Radiação Solar e Insolação Média



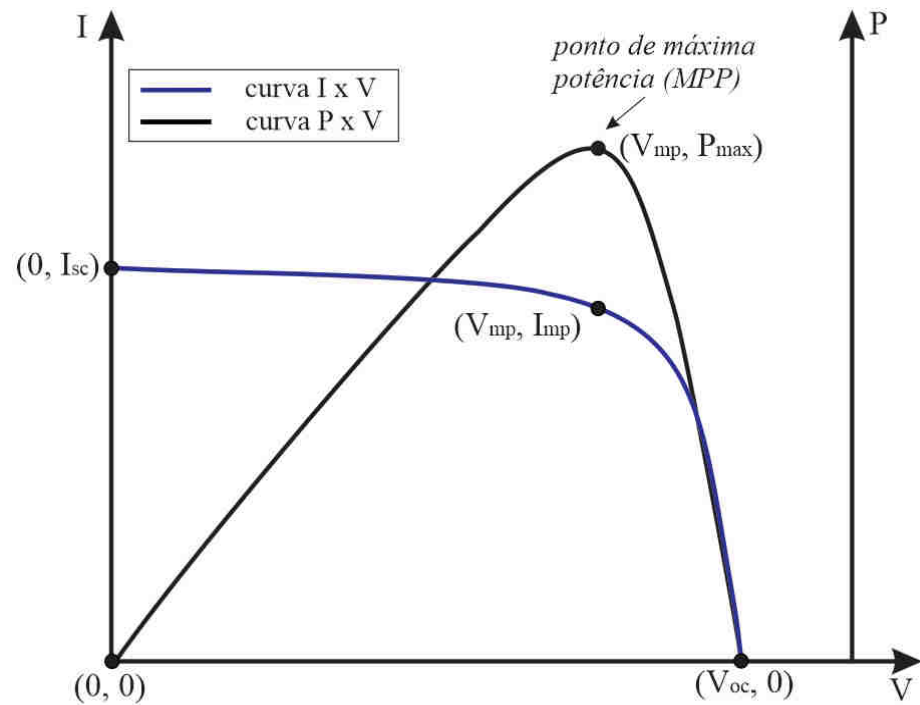
Fonte: <http://www.cemig.com.br/>

# Modelo e Simulação de Módulos Fotovoltaicos

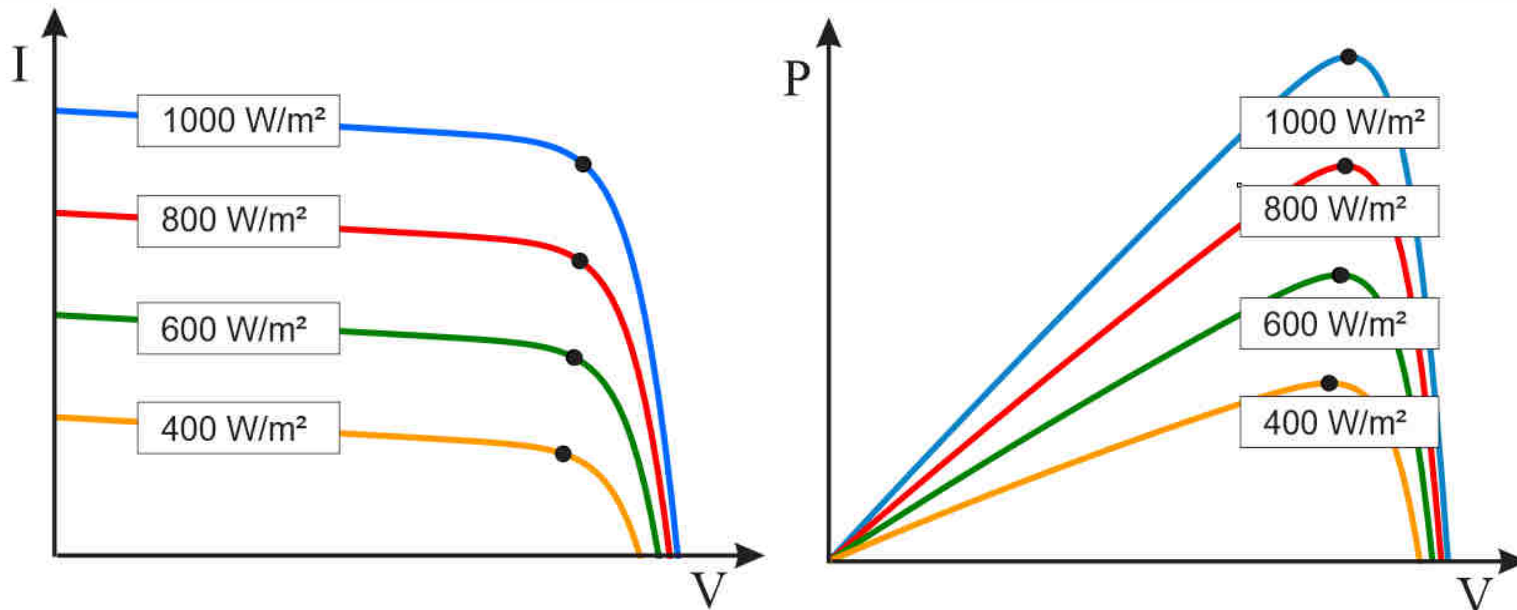


VILLALVA, M. G.; GAZOLI, J. R.; FILHO, E. R. Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays. IEEE Trans. Power Electron., v. 24, n. 5, p. 1198-1208, 2009.

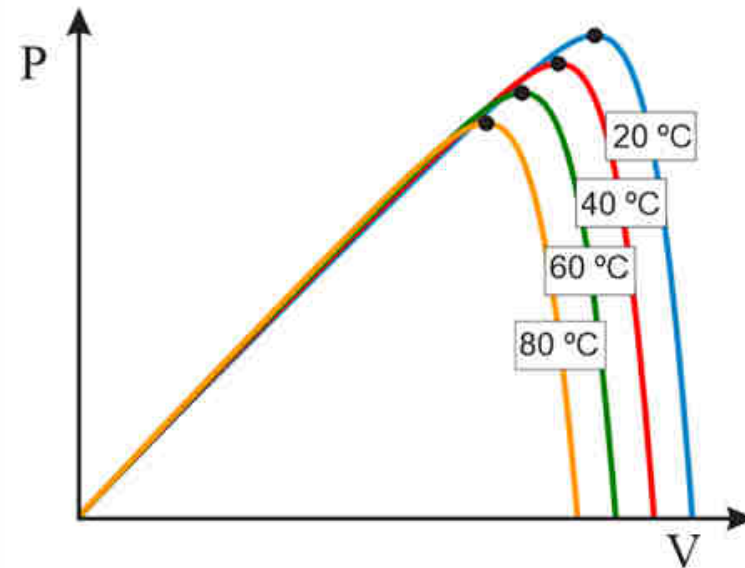
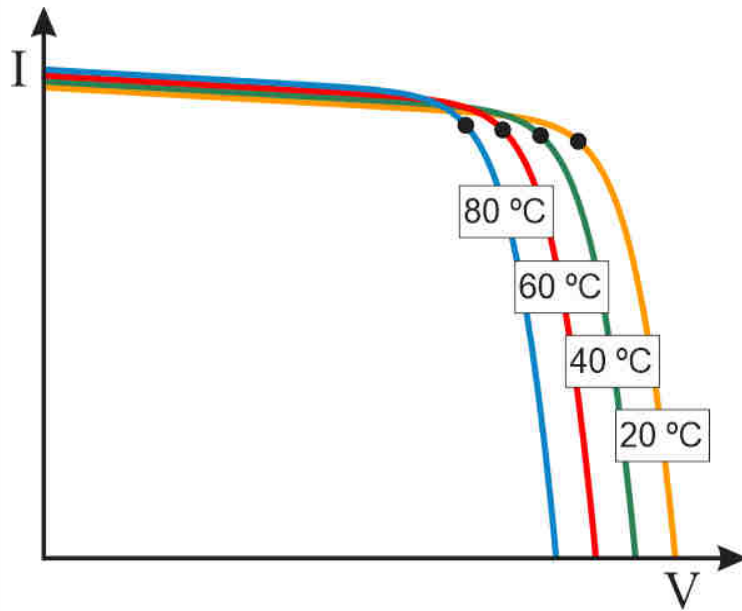
# Módulo Fotovoltaico: Curvas Características



# Módulo Fotovoltaico: Curvas Características

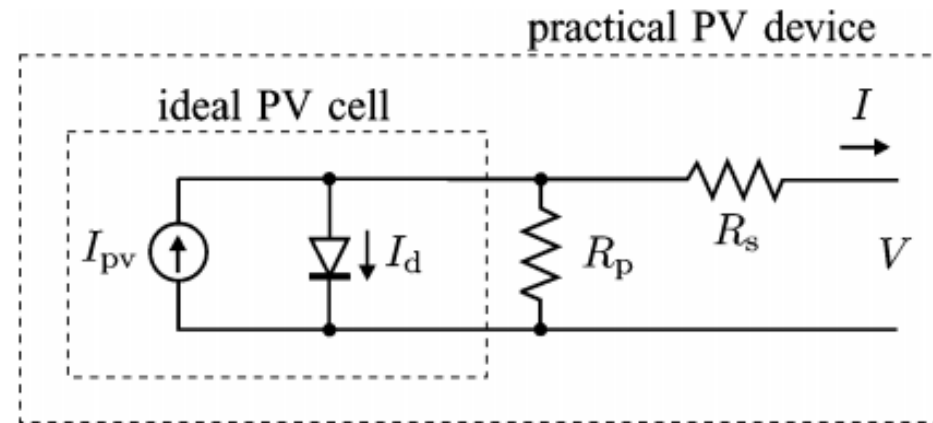


# Módulo Fotovoltaico: Curvas Características



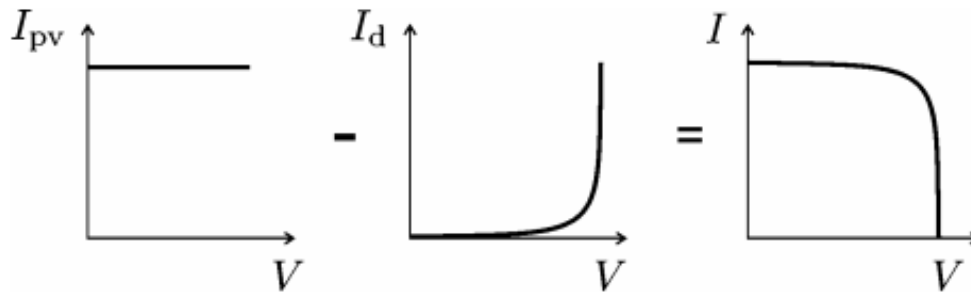
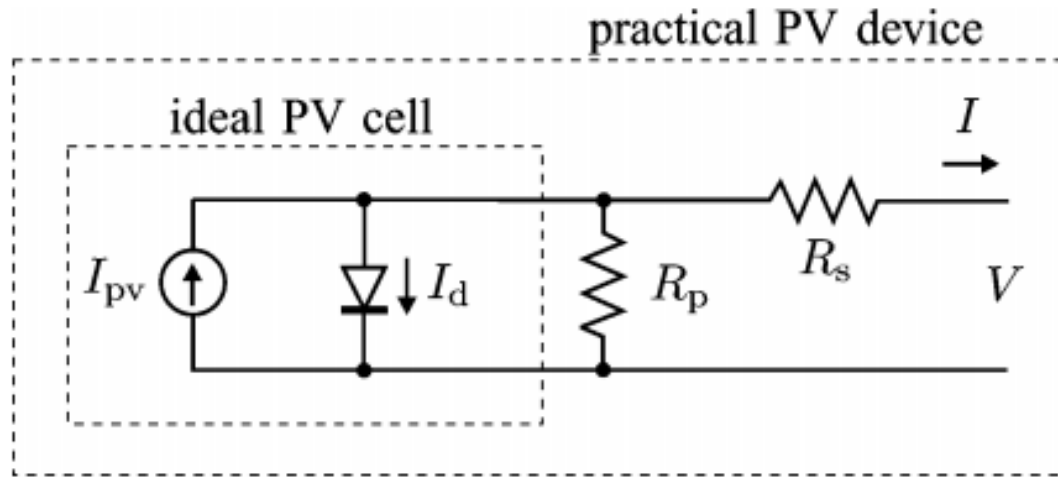


 Isto é um módulo fotovoltaico....



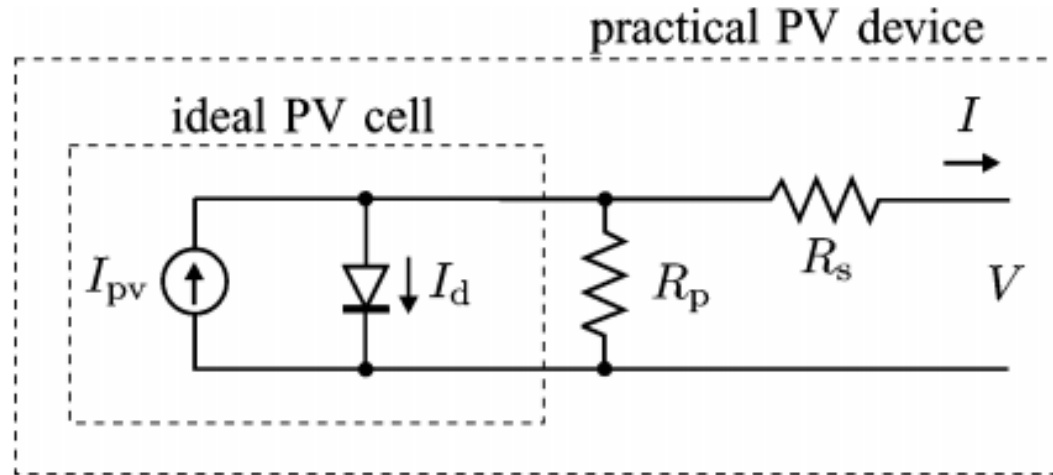
 Isto é um modelo do módulo fotovoltaico.

# Modelo Matemático de Célula Fotovoltaica



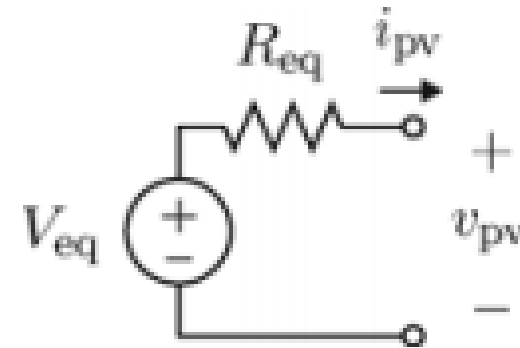
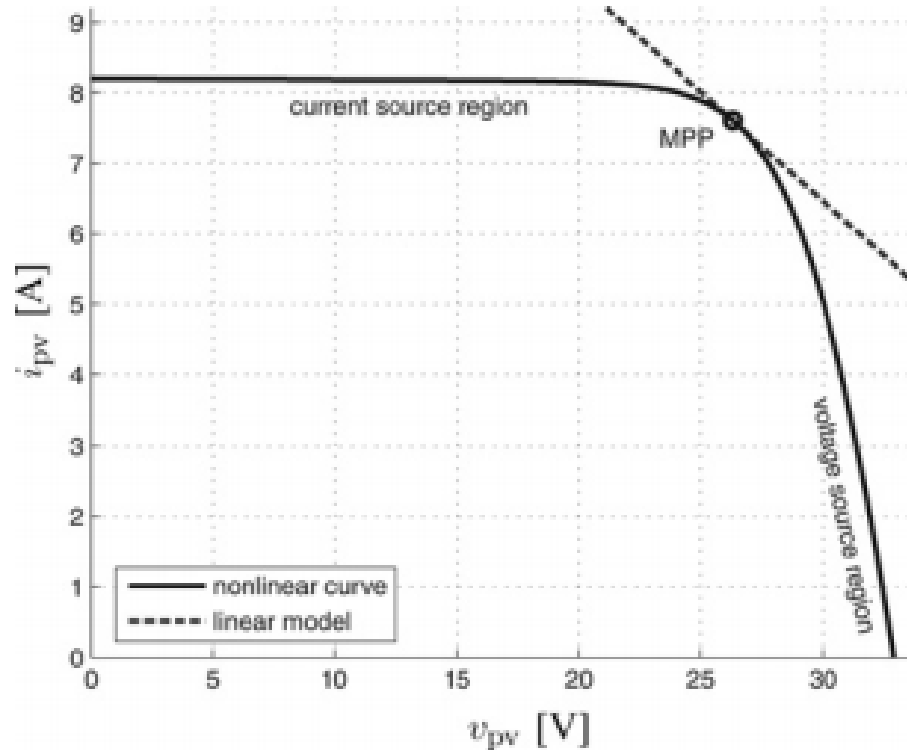


# Modelo Matemático de Célula Fotovoltaica



$$I = I_{pv} - I_0 \left[ \exp \left( \frac{V + R_s I}{V_t a} \right) - 1 \right] - \frac{V + R_s I}{R_p}$$

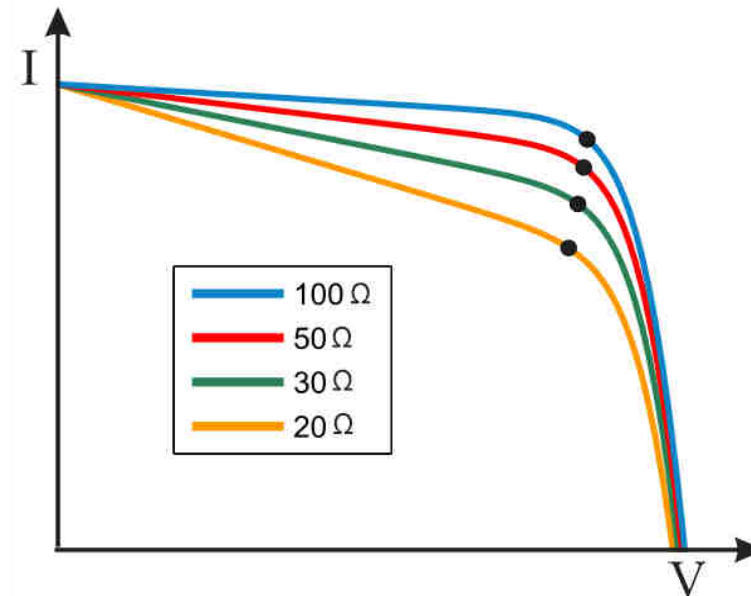
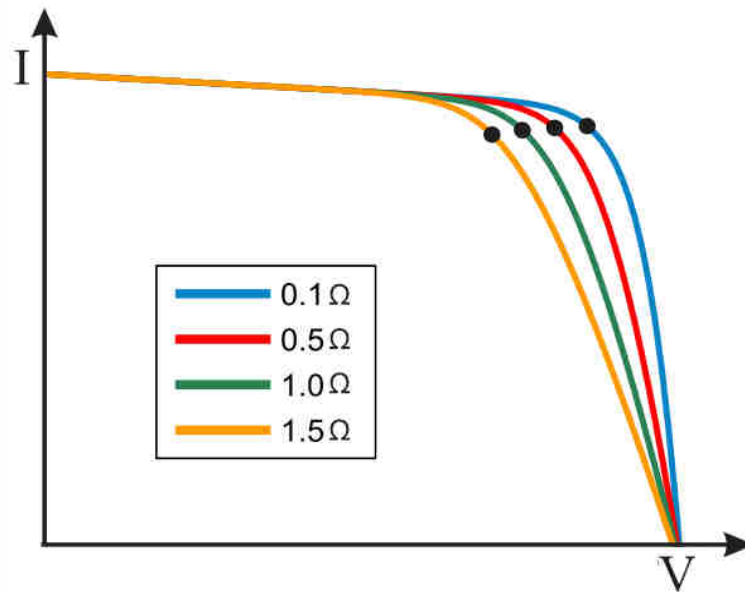
# Modelo Simplificado



Voltage regulation of photovoltaic arrays: small-signal analysis and control design. M. G. Villalva, T. G. de Siqueira, E. Ruppert F. IET Transactions on Power Electronics (Journal), v. 3, no. 6, 2010.

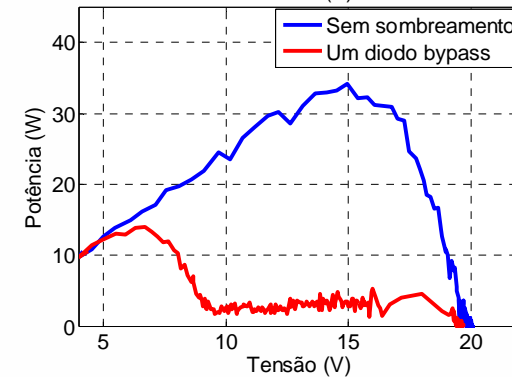
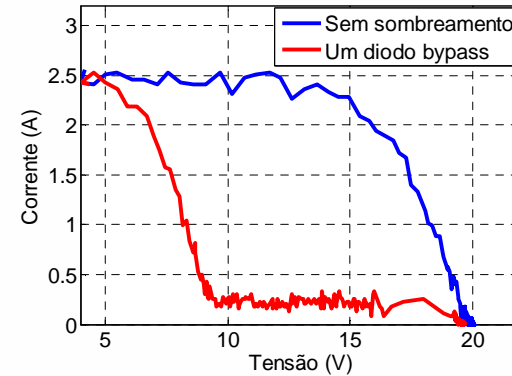
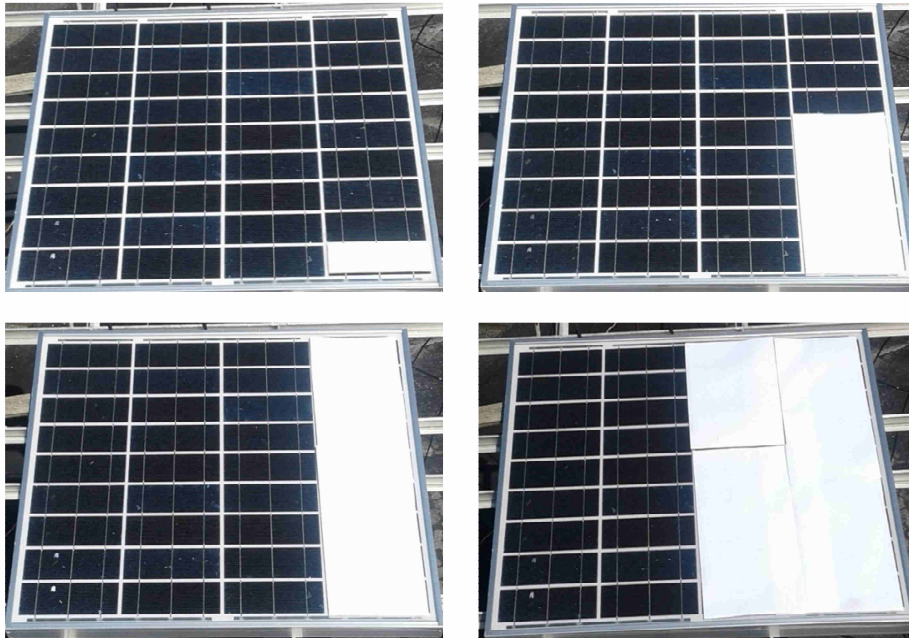
# Fatores que influenciam as curvas características.

- Resistências série e paralelo



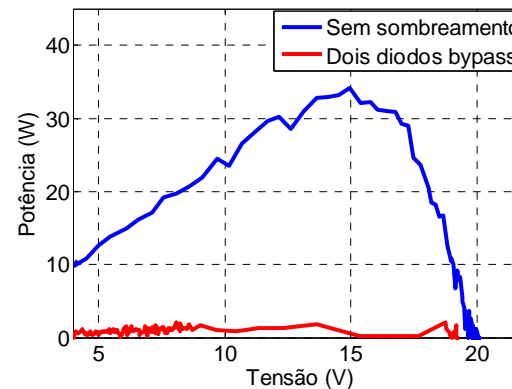
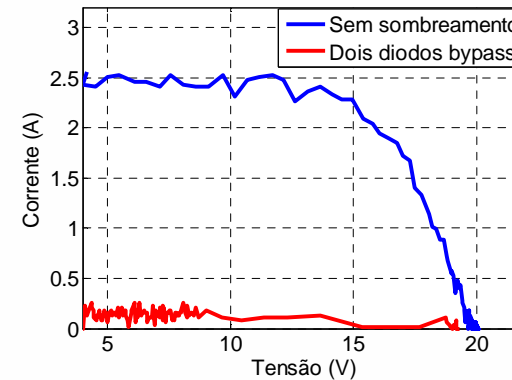
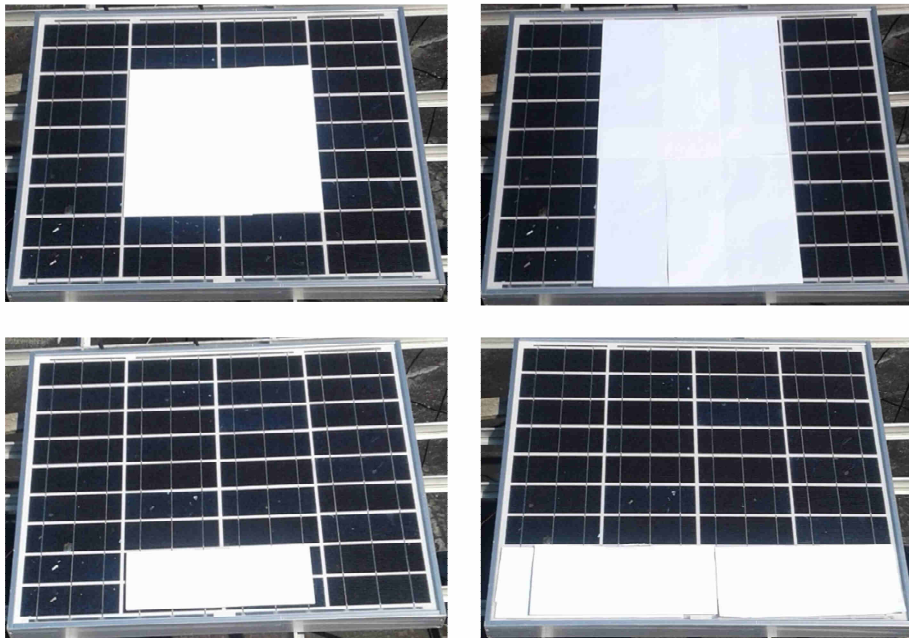
# Módulo Fotovoltaico: Efeito Sombreamento Parcial

- Sombreamento e ação dos diodos *by-pass*.



# Módulo Fotovoltaico: Efeito Sombreamento Parcial

- Sombreamento e ação dos diodos *by-pass*.





[www.gesep.ufv.br](http://www.gesep.ufv.br)



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Estimate - Sistemas  
Fotovoltaicos



<https://play.google.com/store/apps/details?id=br.developer.gesep.estimate>



# Obrigado!

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**Heverton Augusto Pereira**

Prof. Departamento de Engenharia Elétrica | UFV

Coordenador da Gerência de Especialistas em Sistemas Elétricos de Potência | Gesep

Membro do Programa de Pós-Graduação em Engenharia Elétrica | PPGEL/CEFET-MG

E-mail: [heverton.pereira@ufv.br](mailto:heverton.pereira@ufv.br)