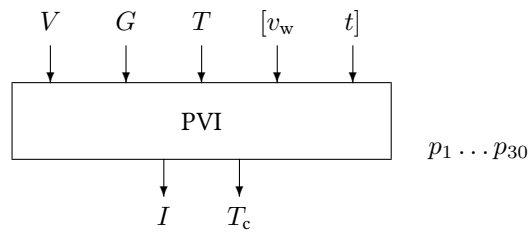


Block PVI

The PVI block calculates the output current and the temperature of a crystalline photovoltaic generator, depending on PV generator voltage, global radiation on the generator plane, ambient temperature, and wind speed.



Name	PVI
Function	se0001
Inputs	3 ... [5]
Outputs	2
Parameters	30
Strings	0 ... [1]
Group	S

Inputs

- 1 Voltage V / V
- 2 Global radiation on the generator plane G / W m^{-2}
- 3 Temperature T / $^{\circ}\text{C}$
- 4 Wind speed close to the generator v_w / m s^{-1}
- 5 Time t / s

Outputs

- 1 Current I / A
- 2 Cell temperature T_c / $^{\circ}\text{C}$

Parameters

- 1 Mode
 - 0 The cell temperature is given by input 3.
 - 1 The cell temperature depends on the thermal parameters of the PV modules and the inputs of the block; initial value of the cell temperature is given by parameter number 28.
 - 2 The difference between cell temperature and ambient temperature is a linear function of the global radiation (input 2) on the basis of NOCT.

2	Number of cells in series per module N_s
3	Number of cells in parallel N_p
4	Number of modules in series M_s
5	Number of modules in parallel M_p
6	Area of a single cell A_c / m^2
7	Area of a single module A_m / m^2
8	Band gap E_g / eV (c-Si $\approx 1.12 \text{ eV}$, a-Si $\approx 1.75 \text{ eV}$)
9	Coefficient of short-circuit current density c_{ph} / V^{-1}
10	Temperature coefficient of short-circuit current $c_t / \text{V}^{-1} \text{K}^{-1}$
11	Coefficient of saturation current density (Shockley diode) $c_s / \text{A m}^{-2} \text{K}^{-3}$
12	Coefficient of saturation current density (Recombination diode) $c_r / \text{A m}^{-2} \text{K}^{-5/2}$
13	Series resistance parameter $r_s / \Omega \text{m}^2$
14	Parallel resistance parameter $r_p / \Omega \text{m}^2$
15	Diode ideality factor α
16	Diode ideality factor β
17	Bishop parameter a
18	Bishop parameter m
19	Bishop parameter V_{br} / V
20	Module tolerance plus / %
21	Module tolerance minus / % (< 0)
22	Characteristic module length ℓ_m / m
23	Module mass m_m / kg
24	Absorption coefficient a
25	Emission factor ϵ
26	Specific heat of a module $c_m / \text{J kg}^{-1} \text{K}^{-1}$
27	Nominal operating cell temperature NOCT / $^{\circ}\text{C}$
28	Initial value of cell temperature / $^{\circ}\text{C}$
29	Error tolerance of voltage (or current) of a single cell in the numerical iteration to solve the two-diode-model equation
30	Maximum number of iterations to solve the two-diode-model equation

Strings

1	Product ID
---	------------

Description The model of the PV module has two parts: an electrical model (the “two diode model”) and a thermal model based on an energy balance.

Electrical model The relationship between voltage V_c / V of a crystalline silicon solar cell and current density $j / A m^{-2}$ is given by the two-diode-model equation

$$j = j_{ph} - j_s \left(\exp \left(\frac{q(V_c + jr_s)}{\alpha kT} \right) - 1 \right) - j_r \left(\exp \left(\frac{q(V_c + jr_s)}{\beta kT} \right) - 1 \right) - \frac{V_c + jr_s}{r_{sh}}$$

where

r_s Series resistance parameter of the cell / Ωm^2

r_{sh} Shunt resistance parameter / Ωm^2

α Diode parameter (should be set to 1 in case of the standard two diode model)

β Diode parameter (should be set to 2 in case of the standard two diode model)

T Cell temperature / K

q Charge of an electron ($1.6021 \times 10^{-19} As$)

k Boltzmann constant ($1.3854 \times 10^{-23} JK^{-1}$)

Hence, the operating point of the PV generator is given by

$$V = V_c N_s$$

$$I = j A_c N_p$$

where

A_c Area of a single cell / m^2

N_s Number of cells in series (whole generator)

N_p Number of cells in parallel (whole generator)

The light-generated current density $j_{ph} / A m^{-2}$ is proportional to the global radiation $G / W m^{-2}$ on the generator plane and is assumed to be linearly dependent on the cell temperature T / K

$$j_{ph} = (c_{ph} + c_t T) G$$

where

c_{ph} Coefficient of light-generated current density / V^{-1}

c_t Temperature coefficient of light-generated current density / $V^{-1} K^{-1}$

The dependence of the saturation current densities j_s and j_r on temperature is given by

$$\begin{aligned} j_s &= c_s T^3 \exp\left(-\frac{qV_{\text{gap}}}{kT}\right) \\ j_r &= c_r T^{5/2} \exp\left(-\frac{qV_{\text{gap}}}{2kT}\right) \end{aligned}$$

where

c_s	Coefficient of saturation current density / $\text{A m}^{-2} \text{K}^{-3}$
c_r	Coefficient of saturation current density / $\text{A m}^{-2} \text{K}^{-5/2}$
V_{gap}	Band gap (Silicon 1.12 V). The dependence of the band gap on cell temperature is neglected.

Thermal model The thermal model is based on an energy balance

$$m_{\text{mod}} N_{\text{mod}} c_{\text{mod}} \frac{dT}{dt} + P_{\text{el}} = \dot{Q}_{\text{G}} - \dot{Q}_{\text{r}} - \dot{Q}_{\text{c}}$$

where

m_{mod}	Mass of a PV module / kg
c_{mod}	Specific heat of a PV module $\text{J kg}^{-1} \text{K}^{-1}$
P_{el}	Electrical power output of the generator / W
$\dot{Q}_{\text{G}}$	Insolation on the whole generator / W
$\dot{Q}_{\text{r}}$	Losses through radiation / W
$\dot{Q}_{\text{c}}$	Losses through convection / W

The absorbed insolation is modeled by

$$\dot{Q}_{\text{G}} = aG(t)A_{\text{mod}}N_{\text{mod}}$$

The coefficient a of absorption is assumed to be constant. Losses through radiation are modeled by

$$\dot{Q}_{\text{r}} = 2\epsilon A_{\text{mod}} N_{\text{mod}} \sigma (T^4 - T_{\text{a}}^4)$$

where

ϵ	Emission factor
σ	Stefan-Boltzmann Constant ($5.6697 \times 10^{-8} \text{Wm}^{-2} \text{K}^{-4}$)
T_{a}	Ambient temperature / K

Losses through convection are given by

$$\dot{Q}_c = 2\gamma A_{\text{mod}} N_{\text{mod}} (T - T_a)$$

In case of free convection the heat loss coefficient γ is set to

$$\gamma_f = 1.78 (T - T_a)^{1/3}$$

forced convection is modeled through

$$\gamma_w = \frac{4.77 v_w^{0.8} (\ell_{\text{mod}} N_{\text{mod}})^{-0.2}}{1 - 0.17 v_w^{-0.1} (\ell_{\text{mod}} N_{\text{mod}})^{-0.1}}$$

with wind speed v_w . In case of mixed convection γ is set to

$$\gamma = \sqrt[3]{\gamma_f^3 + \gamma_w^3}$$

NOCT mode According to U.S. standards the nominal operating cell temperature is defined as the temperature of a PV module operated in its maximum power point under 800 W/m^2 irradiance at an ambient temperature of 20°C and a wind speed of 1 m/s .

The **overtemperature** – i. e., the temperature difference between module temperature T_m and ambient temperature T_a – of a PV module in NOCT mode is calculated from the equation

$$\Delta T = T_m - T_a = (T_{\text{NOCT}} - 20^\circ\text{C}) * G_t / 800 \text{ W/m}^2$$

where T_{NOCT} denotes the nominal operating cell temperature, and G_t the irradiance in the module plane.

Please notice that the small temperature dependency as a function of ambient temperature (of about 5 % per 100°C) is neglected in this mode.

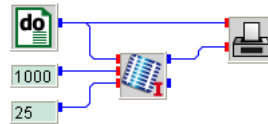
Backward characteristic The **PVI** block can simulate the backward characteristics of a module, if the Bishop parameters a , V_{br} , and m are known. In this case the two-diode-model equation is expanded by the Bishop term

$$\frac{V_c + j r_s}{r_{\text{sh}}} \left(1 + a \left(1 - \frac{V_c}{V_{\text{br}}} \right)^{-m} \right)$$

If all three Bishop parameters are set to zero, the **PVI** block suppresses negative currents, i. e., if $I < 0$ then I is set to zero.

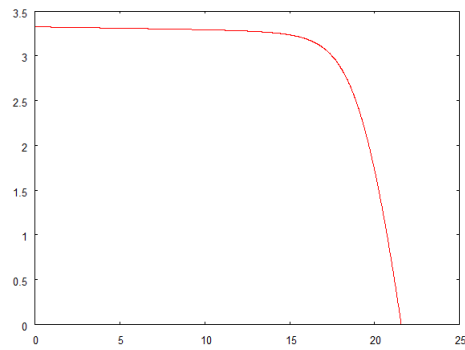
Remarks It is possible to use the one-diode model by setting $c_r = 0$. Parameters for about 5000 modules are given in standard parameter .bp files and can be used in the **PVI** block's entity editor.

pvi.vseit



A **DO** block is used to vary the voltage of a PV module from 0 to 25 V in steps of 0.01 V. To simulate standard test conditions two **CONST** blocks are used to set the module temperature to 25 °C and the radiation to 1000 W/m², respectively.

The **PLOT** block displays the I - V curve for STC.



See also Blocks **PVV**, **PVDET1**, **PVDET2**, **PVFIT1**, **PVFIT2**.