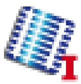
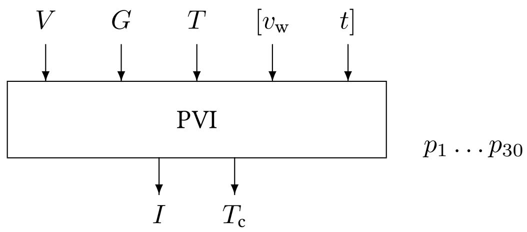
Block PVI

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 / °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 / °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 eV, a-Si $\approx$ 1.75 eV)
	9	Coefficient of short-circuit current density c_ph / V^{-1}
	10	Temperature coefficient of short-circuit current c_t / $\mathrm{V}^{-1}\,\mathrm{K}^{-1}$
	11	Coefficient of saturation current density (Shockley diode) c_s / $\mathrm{A\,m}^{-2}\,\mathrm{K}^{-3}$
	12	Coefficient of saturation current density (Recombination diode) c_r / $\mathrm{A\,m}^{-2}\,\mathrm{K}^{-5/2}$
	13	Series resistance parameter r_s / $\Omega\,\mathrm{m}^2$
	14	Parallel resistance parameter r_p / $\Omega\,\mathrm{m}^2$
	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 / $\mathrm{J\,kg}^{-1}\mathrm{K}^{-1}$
	27	Nominal operating cell temperature NOCT / $^\circ$C
	28	Initial value of cell temperature / $^\circ$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

$$\begin{aligned} j = j_\mathrm{ph} \quad &- \quad j_\mathrm{s}\left(\exp\left(\frac{q(V_\mathrm{c}+jr_\mathrm{s})}{\alpha kT}\right)-1\right) \\ &- \quad j_\mathrm{r}\left(\exp\left(\frac{q(V_\mathrm{c}+jr_\mathrm{s})}{\beta kT}\right)-1\right) - \frac{V_\mathrm{c}+jr_\mathrm{s}}{r_\mathrm{sh}} \end{aligned}$$

where

r_s	Series resistance parameter of the cell / Ω m^2
r_sh	Shunt resistance parameter / Ω m^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 (1.6021×10^{-19}As)
k	Boltzmann constant (1.3854×10^{-23}JK^{-1})

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

$$\begin{aligned} V &= V_\mathrm{c} N_\mathrm{s} \\ I &= j A_\mathrm{c} N_\mathrm{p} \end{aligned}$$

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

$$j_\mathrm{ph} = (c_\mathrm{ph} + c_\mathrm{t} T)\, G$$

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

$$\begin{aligned} j_\mathrm{s} &= c_\mathrm{s} T^3 \exp\left(-\frac{qV_\mathrm{gap}}{kT}\right) \\ j_\mathrm{r} &= c_\mathrm{r} T^{5/2} \exp\left(-\frac{qV_\mathrm{gap}}{2kT}\right) \end{aligned}$$

where

c_s	Coefficient of saturation current density / $\mathrm{A\,m^{-2}\,K^{-3}}$
c_r	Coefficient of saturation current density / $\mathrm{A\,m^{-2}\,K^{-5/2}}$
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

$$m_\mathrm{mod} N_\mathrm{mod} c_\mathrm{mod} \frac{\mathrm{d}T}{\mathrm{d}t} + P_\mathrm{el} = \dot{Q}_\mathrm{G} - \dot{Q}_\mathrm{r} - \dot{Q}_\mathrm{c}$$

where

m_mod	Mass of a PV module / kg
c_mod	Specific heat of a PV module $\mathrm{J\,kg^{-1}\,K^{-1}}$
P_el	Electrical power output of the generator / W
$\dot{Q}_\mathrm{G}$	Insolation on the whole generator / W
$\dot{Q}_\mathrm{r}$	Losses through radiation / W
$\dot{Q}_\mathrm{c}$	Losses through convection / W

The absorbed insolation is modeled by

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

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

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

where

ϵ	Emission factor
σ	Stefan-Boltzmann Constant (5.6697×10^{-8}Wm^{-2}K^{-4})
T_a	Ambient temperature / K

Losses through convection are given by

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

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

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

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 temperatur T_a – of a PV module in NOCT mode is calculated from the equation

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

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

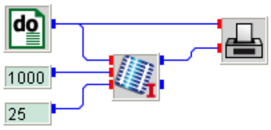
The PVI block can simulate the backward characteristics of a module, if the Bishop parameters a, V_{br}, and m are known. In this case the two-diode-model equation is expanded by the Bishop term

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

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.

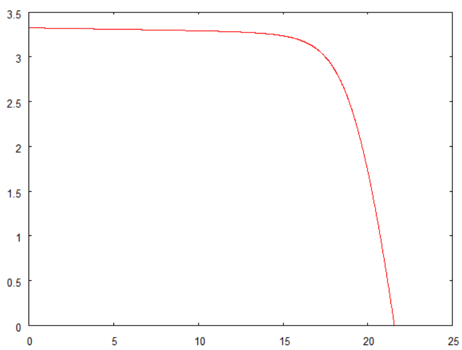
Remarks It is possible to use the one-diode model by setting $c_r = 0$. Parameters for about 5000 modules are given in standard parameter .bp files and can be used in the PVI block's entity editor.

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/m^2, respectively.

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



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