TRNSYS Type 835

PV model for the coupling with solar thermal absorber and collector models as PVT model

Documentation

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Contents

This model is based on work of Manuel Lämmle, Axel Oliva, Michael Hermann, Korbinian Kramer and Wolfgang Kramer, published in Lämmle et al. 2017.

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Disclaimer

Nomenclature

A_{PV}	gross area of PV modules or PVT collector [m²]
a	model parameter a for irradiance dependence of PV efficiency calculation [m²/W]
b_0	constant for incident angle modifier IAM [-]
b	model parameter b for irradiance dependence of PV efficiency calculation [-]
c	model parameter c for irradiance dependence of PV efficiency calculation [-]
G	solar irradiance in PV or PVT plane [W/m²]
$P_{\mathrm{el,PV}}$	electrical power output of the PV modules or PVT collector [W]
$p_{\mathrm{el,PV}}$	specific electrical power output of the PV modules or PVT collector [W/m²]
PR_{G}	performance ratio due to loss effects of irradiance [-]
PR_{IAM}	performance ratio due to loss effects of incidence angle [-]
PR_{T}	performance ratio due to PV cell temperature dependence [-]
PR_{tot}	overall performance ratio [-]
$\dot{q}_{\mathrm{th}}$	specific thermal power output of the PVT collector [W/m²]
T_{amb}	ambient air temperature [°C]
T_{cell}	temperature of PV $T_{\mathrm{cell,PV}}$ or PVT $T_{\mathrm{cell,PVT}}$ cells [°C]
$T_{\mathrm{cell,ref}}$	PV cell temperature at reference conditions (usually STC conditions) [°C]
T_{m}	mean fluid temperature of the PVT collector [°C]
U_0	coefficient for radiation dependence of PV module temperature [W/m²K]
U_1	coefficient for wind dependence of PV module temperature [Ws/m³K]
u	wind speed in the PV plane [m/s]
U_{AbsFl}	internal heat transfer coefficient [W/m²K]
β	power temperature coefficient of the PV cells [%/K]
$\eta_{\mathrm{el,PV}}$	overall electrical efficiency of the PV modules or PVT collector, gross area [-]
$\eta_{\mathrm{el,ref}}$	electrical efficiency at reference conditions (usually STC) of the PV modules or PVT collector, gross area [-]
θ	incidence angle of beam radiation [°]

1 Overview

The main idea behind this model is to develop a PV performance model in TRNSYS, which can be coupled to existing models of solar thermal collectors or absorbers for the calculation of the electrical power output of uncovered and covered PVT collectors (see Fig. 1). It is especially developed for the connection with thermal models which are based on the quasi-dynamic model of ISO 9806:2013 (ISO 9806, 2013), e.g. TRNSYS Type 832 (Haller et al., 2013). As the electrical mode of operation has a significant impact on the thermal efficiency, the thermal performance coefficients for the thermal power output calculation of the PVT collector should be determined in MPP mode (Lämmle et al., 2017).

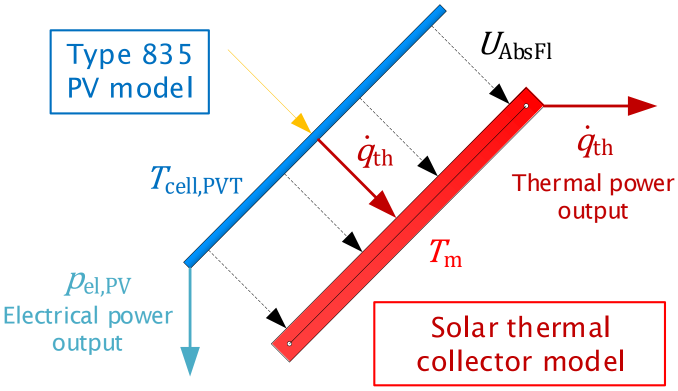

Fig. 1 Coupled PVT-model

As addition, the model includes a PV mode to simulate PV modules based on the same performance model, e.g. for a comparison of electrical yield of a PV module and PVT collectors with use of identical PV cells. The major difference between the calculation of PV modules and PVT collectors in this approach results from the cell temperatures, which are determined by the fluid temperature in PVT collectors and by a steady-state module temperature in PV modules.

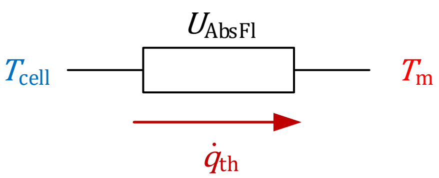

Fig. 2 Thermal network

In case of PVT collectors, the PVT cell temperature $T_{cell,PVT}$ is calculated via an equivalent thermal network with an internal heat transfer coefficient U_{AbsFl}, which connects the PVT cell temperature with the mean fluid temperature T_m of the PVT collector (see Fig. 2), according to the electrical performance model of Lämmle et al. (2017). In case of PV modules the PV cell temperature $T_{cell,PV}$ is calculated by the Faiman model (Faiman, 2008). For details see mathematical description.

2 Parameter, Inputs and Outputs

Parameter

Nr.	Short	Description	Unit
1	Area	Area of the PVT collectors or PV modules (gross area)	m²
2	Eta_ref	electrical efficiency at reference conditions (gross area)	-
3	PVTmode	mode for PV cell temperature calculation 1: PVT - connection to solar thermal fluid temperature 2: PV - stand-alone calculation (Faiman model)	-
4	b0	constant for IAM	-
5	beta	temperature coefficient of solar cell efficiency	%/K
6	Tcell_ref	PV Cell temperature at reference conditions	C
7	Uabsfl	internal heat transfer coefficient connecting cell and fluid temperature (PVT mode: 1)	W/m²K
8	PVmode	mode for the irradiance dependence calculation of the PV efficiency 1: Calculation in MPP according to Heydenreich et al. 2: not defined	-
9	a	model parameter a for PV efficiency (PV mode: 1)	m²/W
10	b	model parameter b for PV efficiency (PV mode: 1)	-
11	c	model parameter c for PV efficiency (PV mode: 1)	-
12	U0	coefficient for module temperature (radiation) (PVT mode: 2)	W/m²K
13	U1	coefficient for module temperature (wind) (PVT mode: 2)	Ws/m³K

Inputs

Nr.	Short	Description	Unit
1	It	Global radiation on PV plane	kJ/hm²
2	Theta	Incidence angle of beam radiation	degrees
3	Tm	mean fluid temperature of the PVT collector	C
4	qth	specific thermal power output of the PVT collector	kJ/hm²
5	u	wind speed in the PV plane	m/s
6	Tamb	ambient air temperature	C

Outputs

Nr.	Short	Description	Unit
1	Pel	Electric power output	kJ/h
2	Tcell	temperature of the PV cell	C
3	EtaPV	total efficiency of PV modules (gross area)	-

3 Mathematical description

The PV model Type 835 can be used for the simulation of:

1) the electrical part of PVT collectors by coupling the PV model with models of solar thermal absorbers or collectors (PVT collector simulation, PVT mode 1), or
2) Stand-alone PV systems (PVT mode 2).

Overall electrical efficiency and electrical power output

The overall (or total) electrical efficiency $\eta_{\mathrm{el,PV}}$ is calculated with:

$$\eta_{\mathrm{el,PV}} = \eta_{\mathrm{el,ref}} \cdot PR_{\mathrm{tot}} \qquad \text{(Eq. 1)}$$

The electrical power output of the PV modules or PVT collector $P_{\mathrm{el,PV}}$ is given by:

$$P_{\mathrm{el,PV}} = \eta_{\mathrm{el,ref}} \cdot PR_{\mathrm{tot}} \cdot G \cdot A_{\mathrm{PV}} \qquad \text{(Eq. 2)}$$

and as specific electrical power output by (Lämmle et al., 2017):

$$p_{\mathrm{el,PV}} = \eta_{\mathrm{el,ref}} \cdot PR_{\mathrm{tot}} \cdot G \qquad \text{(Eq. 3)}$$

where $\eta_{\mathrm{el,ref}}$ is the electrical efficiency at reference conditions (usually STC conditions), PR_{tot} is the overall instantaneous performance ratio, G (or I_T) the global radiation on PV or PVT plane and A_{PV} the PV or PVT area.

The overall instantaneous performance ratio is calculated with (Lämmle et al., 2017):

$$PR_{\mathrm{tot}} = PR_{\mathrm{IAM}} \cdot PR_{\mathrm{T}} \cdot PR_{\mathrm{G}} \qquad \text{(Eq. 4)}$$

The electrical performance model for PV takes into account the following loss effects (performance ratios PR):

- loss effects of incidence angle PR_{IAM}
- loss effects of irradiance PR_{G} and
- PV cell temperature dependence of electrical efficiency PR_{T}.

The major difference between the calculation of PV modules as Stand-alone PV system and PVT collector is given by the cell temperatures, which are determined by the fluid temperature in PVT collectors (PVT mode 1) and by the steady-state module temperature in PV modules (PVT mode 2).

Loss effects of incidence angle

The instantaneous performance ratio due to incidence angle losses PR_{IAM} is calculated with (Duffie and Beckman, 2013):

$$PR_{\mathrm{IAM}} = 1 - b_0 \cdot (1/\cos(\theta) - 1) \qquad \text{(Eq. 5)}$$

where b_0 is the constant for IAM and θ the incidence angle of beam radiation.

Loss effects of irradiance

The instantaneous performance ratio due to irradiance losses PR_{G} is calculated with (Heydenreich et al., 2008):

$$PR_{\mathrm{G}} = a \cdot G + b \cdot \ln(G+1) + c \cdot \left[\left(\ln(G+\mathrm{e})\right)^2/(G+1) - 1\right] \qquad \text{(Eq. 6)}$$

with the model parameters a in m²/W, b and c dimensionless, the global irradiance G in W/m² and the Euler's number e.

PV cell temperature dependence of the electrical efficiency

The PV cell temperature dependence of the electrical efficiency is calculated with (Skoplaki and Palyvos, 2009):

$$PR_{\mathrm{T}} = 1 - \beta \cdot \left(T_{\mathrm{cell}} - T_{\mathrm{cell,ref}}\right) \qquad \text{(Eq. 7)}$$

where β is the power temperature coefficient of the PV cells, T_{cell} the temperature of the PV cells and $T_{\mathrm{cell,ref}}$ the PV cell temperature at reference conditions (usually STC conditions).

PV cell temperature

As described before, the main difference between the calculation of PV modules as Stand-alone PV system and PVT collectors is given by the calculation of the PV cell temperatures.

In case of PVT collectors (PVT mode 1), the PVT cell temperature is calculated with a simple equivalent thermal network with an internal heat transfer coefficient U_{AbsFl}, which connects the PVT cell temperature $T_{\mathrm{cell,PVT}}$ with the mean fluid temperature T_{m} of the PVT collector. In this case, the PVT cell temperature is given by (Lämmle et al., 2016, 2017):

$$T_{\mathrm{cell,PVT}} = T_{\mathrm{m}} + \dot{q}_{\mathrm{th}}/U_{\mathrm{AbsFl}} \qquad \text{(Eq. 8)}$$

where $\dot{q}_{\mathrm{th}}$ is the specific thermal power output of the PVT collector.

In case of PV modules as stand-alone PV system, the PV cell temperature is calculated with (Faiman, 2008):

$$T_{\mathrm{cell,PV}} = T_{\mathrm{amb}} + G/(U_0 + U_1 \cdot u) \qquad \text{(Eq. 9)}$$

where T_{amb} is the ambient air temperature, U_0 the coefficient for radiation dependence of PV module temperature, U_1 the coefficient for wind dependence of PV module temperature and u the wind speed in the PV plane.

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Appendix: Changelog