TYPE 562: SIMPLE GLAZED OR UNGLAZED PHOTOVOLTAIC PANEL

General Description

Type562 models either a glazed or unglazed photovoltaic array, basing its performance calculation on a user provided overall array efficiency. Efficiency may be constant, variable, provided as a function of cell temperature and incident radiation in an external file or provided for reference conditions along with coefficients that describe the effect of cell temperature and incident radiation changes. This model is appropriate for PV arrays that are connected to a load through a maximum power point tracking device since the efficiency of the Type562 PV is not dependent upon load voltage.

Nomenclature

η	[0..1]	The overall efficiency of the photovoltaic array.
$\eta_{T,coef}$	[0..1]	A coefficient that describes the change in photovoltaic array efficiency as a function of cell temperature.
$\eta_{I,coef}$	[0..1]	A coefficient that describes the change in photovoltaic array efficiency as a function of incident solar radiation.
T_{PV}	[°C]	The PV cell temperature
I_T	[kJ/hr.m^2]	The total amount of solar radiation incident on the PV collector surface.
T_{ref}	[°C]	Cell temperature at the conditions under which the reference PV efficiency was measured.
$I_{T,ref}$	[kJ/hr.m^2]	The total amount of solar radiation incident on the PV collector surface at the conditions under which the reference PV efficiency was measured.
η_{ref}	[0..1]	The overall efficiency of the photovoltaic array under reference conditions.
IAM	[0..1]	The combined incidence angle modifier for the PV cover material.
IAM_{beam}	[0..1]	The incidence angle modifier for the PV cover for beam radiation.
$IAM_{diffuse}$	[0..1]	The incidence angle modifier for the PV cover for diffuse radiation.
IAM_{ground}	[0..1]	The incidence angle modifier for the PV cover for ground reflected radiation.
I_{beam}	[kJ/hr.m^2]	The beam radiation incident on the PV surface.
$I_{diffuse}$	[kJ/hr.m^2]	The diffuse radiation incident on the PV surface.
I_{ground}	[kJ/hr.m^2]	The ground reflected radiation incident on the PV surface.
$\theta_{diffuse,effective}$	[degrees]	The effective incidence angle of diffuse solar radiation on the PV surface.
β	[degrees]	The slope of the PV surface.
$\theta_{ground,effective}$	[degrees]	The effective incidence angle of ground reflected solar radiation on the PV surface.
$\dot{P}_{pv}$	[kJ/hr.m^2]	The power generated by the PV
$(\tau\alpha)_n$	[0..1]	The transmittance absorptance product of the PV cover for solar radiation at a normal angle of incidence.
A	[m^2]	The PV surface area.
$\dot{Q}_{abs}$	[kJ/hr.m^2]	The rate at which energy is absorbed by the PV array
$\dot{Q}_{top,conv}$	[kJ/hr.m^2]	The rate at which the PV loses energy convectively off its top surface.
$\dot{Q}_{back,conv}$	[kJ/hr.m^2]	The rate at which the PV loses energy convectively off its back surface.
$\dot{Q}_{top,rad}$	[kJ/hr.m^2]	The rate at which the PV loses energy radiatively off its top surface.

$\dot{Q}_{back,rad}$	[kJ/hr.m^2]	The rate at which the PV loses energy radiatively off its back surface.
$h_{conv,top}$	[kJ/hr.m^2.K]	The convective heat transfer coefficient for the top surface of the PV.
$h_{rad,top}$	[kJ/hr.m^2.K]	The radiative heat transfer coefficient for the top surface of the PV.
$h_{conv,back}$	[kJ/hr.m^2.K]	The convective heat transfer coefficient for the back surface of the PV.
$h_{rad,back}$	[kJ/hr.m^2.K]	The radiative heat transfer coefficient for the back surface of the PV.
$T_{amb,top}$	[°C]	The temperature to which the PV convectively loses energy off its top surface.
$T_{amb,back}$	[°C]	The temperature to which the PV convectively loses energy off its back surface.
T_{sky}	[°C]	The temperature to which the PV radiatively loses energy off its top surface.
$T_{rad,back}$	[°C]	The temperature to which the PV radiatively loses energy off its back surface.

Detailed Description

Type562 includes four modes of calculating PV performance depending on available data. In the first mode, the user must provide a constant overall efficiency of the array as a parameter to the model. In the second mode of operation, the user provides efficiency information for reference conditions as well as coefficients that describe how the overall efficiency changes with cell temperature and incident solar radiation. In the third mode, Type562 takes the array efficiency as a time dependent input. In the final mode, efficiency information is provided as a function of incident radiation and ambient temperature in an external data file.

In mode 2, the overall efficiency of the PV is calculated based on equation 562.1.

$$\eta = \left(1 + \eta_{T,coef}\left(T_{PV} - T_{ref}\right)\right)\left(1 + \eta_{I,coef}\left(I_T - I_{T,ref}\right)\right)\eta_{ref} \qquad \text{(Eq 562.1)}$$

In mode 4, the efficiency is read from an external data file using the TRNSYS Data Reading routine. The external file syntax must conform to the standard TRNSYS data file format. That is to say that in the case of Type562, the first line of the data file must contain at least one value of solar radiation, specified in kJ/hr.m^2. The second line must contain at least one value of PV cell temperature, specified in degrees C. The subsequent lines much each contain a single value of the PV efficiency that corresponds to a single pair of solar radiation and PV cell temperature. An example data file has been provided with this component in the "\trnsys16\TESS Models\SampleCatalogData\" directory and has been reproduced for reference at the end of this document. As with all calls to the TRNSYS Data routine, Data is able to interpolate in multiple dimensions within the range of independent variable values present in the file. In the case of Type562's call to the Data routine, the independent variables are solar radiation and PV cell temperature. The TRNSYS Data routine is not able to extrapolate beyond the data range present in the file. If a value above or below the range is given, Data will return the values that correspond to the maximum or the minimum of the range and will print a warning to the TRNSYS list file and simulation log files.

In modes 1 and 3, the overall PV efficiency is given either as an input or as a parameter to the model.

Incidence Angle Modifiers

Type562 is designed to be able to model PV arrays that either have or do not have a transparent cover material protecting the PV material from ambient conditions. If a cover is specified, Type562 requires

that the user enter information about the cover material's refractive index, thickness, thermal conductivity, and extinction coefficient. If a cover is included, Type562 calculates incidence angle modifiers in order to come up with the solar radiation absorbed by the PV cells themselves. The overall incidence angle modifier is a weighted average of the component incidence angle modifiers and is given by equation 562.1

$$IAM = \frac{IAM_{beam}(I_{beam}) + IAM_{diffuse}(I_{diffuse}) + IAM_{ground}(I_{ground})}{I_{beam} + I_{diffuse} + I_{ground}} \quad \text{(Eq 562.2)}$$

The individual IAM values are provided to Type562 by the TRNSYS "tau-alpha" routine. For more information on this routine, please refer to the Component Formulation section (Chapter 3) of the main TRNSYS documentation set. This routine takes number of covers, radiation angle of incidence, cover thickness – extinction coefficient product, cover material index of refraction, absorber surface absorptance, and cover reflectance to diffuse radiation as arguments. It returns an overall transmittance absorptance product for the cover system. For diffuse and ground reflected radiation, effective angles of incidence (proposed by Brandemuehl [1]) are used.

$$\theta_{diffuse,effective} = 59.68 - 0.1388\,\beta_{surface} + 0.001497\,\beta_{surface}^2 \quad \text{(Eq 562.3)}$$

$$\theta_{ground,effective} = 90 - 0.5788\,\beta_{surface} + 0.002693\,\beta_{surface}^2 \quad \text{(Eq 562.4)}$$

PV Array Performance

Type562 performs the energy balance shown schematically in Figure 1 to predict the power delivered by the photovoltaic array.

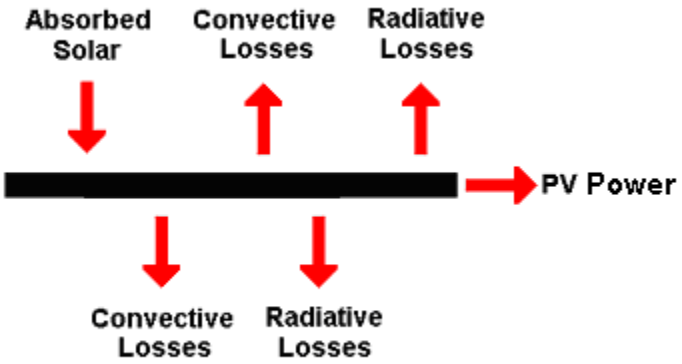


Figure 1: PV Energy Balance

The various terms in the energy balance are as follows: The power generated by photovoltaic array is given by equation 562.5

$$\dot{P}_{pv} = (\tau\alpha)_n\ IAM\ \dot{I}_T\ \eta\ A \quad \text{(Eq 562.5)}$$

The absorbed solar energy is given by equation 562.6

$$\dot{Q}_{abs} = IAM\ \dot{I}_T\ A \quad \text{(Eq 562.6)}$$

The amount of energy lost convectively from the top surface of the PV is

$$\dot{Q}_{top,conv} = h_{conv,top}\ A\left(T_{PV} - T_{amb,top}\right) \quad \text{(Eq 562.7)}$$

The amount of energy lost through radiation from the top surface of the PV is

$$\dot{Q}_{top,rad} = h_{rad,top}\ A\left(T_{PV} - T_{sky}\right) \quad \text{(Eq 562.8)}$$

The amount of energy lost convectively from the back surface of the PV is

$$\dot{Q}_{back,conv} = h_{conv,back}\ A\left(T_{PV} - T_{amb,back}\right) \quad \text{(Eq 562.9)}$$

The amount of energy lost through radiation from the back surface of the PV is

$$\dot{Q}_{back,rad} = h_{rad,back}\ A\left(T_{PV} - T_{rad,back}\right) \quad \text{(Eq 562.10)}$$

The only unknown in the above equations is the cell temperature at which the PV is operating. Type562 performs an iterative search, repeatedly guessing and modifying the PV cell temperature until the various terms of the energy balance sum to 0.