CASSYS / PVsyst Comparison

A Model-to-Model Comparison Of Two Grid-Connected PV System Modelling Tools

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Executive Summary

The following document compares two simulation tools, CASSYS and PVsyst, which use similar physical models to predict the performance of grid-connected photovoltaic systems. The comparisons are done with input parameters requiring the use of different radiation and temperature models. The discrepancies between key input parameters are limited progressively in the document by using values calculated by either software where applicable. The agreement between the tools is found to be -0.35% for the energy predicted over an entire year (CASSYS being the more conservative tool) when the inputs to all models are closest to each other. The dominant sources of error for this result are identified and directions for future development are also explored.

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Introduction

Canadian Solar System Simulator (CASSYS) was developed by Canadian Solar Operations and Maintenance for the operational analysis of grid-connected systems. The program features an easy-to-use interface, can be highly automated, and accepts meteorological data averaged at arbitrary time-steps. It enables the prediction of losses incurred due to various events that would impact production (grid outages, snow, etc.). In this document, important intermediary outputs of the simulation tool are checked as calculated by PVsyst (v. 5.64) and CASSYS (v. 1). As different models use different inputs for processing, this report uses various meteorological input files to explore any resultant differences and trace their source. When possible, calculated values from PVsyst are used in CASSYS to eliminate discrepancies to the model inputs. The site layout and system characteristics provided to both programs can be found in the PVsyst report (see Appendix I).

Test Cases and Model Comparisons

The following table summarizes the choices of inputs, the outputs compared and the models they reflect upon. Each input type is devoted its own section wherein, the characteristics and usage of the input are presented in greater detail along with a discussion of the discrepancies between the two programs.

	Test Case Description	**Outputs compared**	**Models**
1	TMY file with Horizontal Global and Diffuse Irradiances	- Plane of Array (POA) Irradiance Components - Near Shading factors (NSF) - Incidence Angle Modifiers (IAM) - Effective POA Irradiance	Sun position Beam Calculation Transposition (Hay) Shading factors Incidence Angle Modifier
2	TMY file with Horizontal Global	- Beam Normal and Horizontal Diffuse - POA Irradiance	Sun position Horizontal decomposition Transposition (Hay)
3	POA Irradiance	- POA Irradiance	Sun position POA to Horizontal de-transposition
4	POA Irradiance (PVsyst recalculated, eliminates outliers)	- POA Irradiance - POA Irradiance Components - Effective Irradiance on the Panel surface	Sun position Horizontal decomposition models Hay Transposition Model Shading factors Incidence Angle Modifier
5	POA Irradiance and Panel Temperature (PVsyst Recalculated, eliminates outliers and uses the same panel temperature for modelling)	- PV Performance and losses - Inverter Performance and Efficiency Curves - Transformer Performance and Efficiency Curves	All of the previous, and PV Array Model Inverter Model Transformer Model

Table 1: Input types, outputs and model comparisons conducted between PVsyst and CASSYS.

Test case 1: Using a TMY File with Global and Diffuse Components of Horizontal Irradiance

Using the same values for horizontal global and diffuse irradiance in both programs allows for the quantification of differences resulting from transposition models.

Comparison of Meteorological file and Input characteristics

A Typical Meteorological Year (TMY) File was used as an input to PVsyst and CASSYS. The TMY file used for simulation was a 3TIER TMY file applicable for the site specified in Appendix I. The chosen inputs and notes regarding their usage by both programs are presented in the table below:

TMY file variable	PVsyst	CASSYS
Time Stamp (Input values are averaged at the ending of the time stated)	Time stamp changed to beginning of hour	Used as provided
Ambient Temperature (°C)	Used as provided	Used as provided
Normal Extra-terrestrial Irradiance ($W \cdot m^{-2}$)	Not used	Not used
Global Horizontal Irradiance ($W \cdot m^{-2}$)	Used as provided	Used as provided
Beam Normal Irradiance ($W \cdot m^{-2}$)	Not used	Not used
Horizontal Diffuse Irradiance ($W \cdot m^{-2}$)	Used as provided	Used with deviation.
Wind Direction (°, respect to North)	Not used.	Not used.
Wind Speed ($m \cdot s^{-1}$)	Used as provided.	Used as provided.

Table 2: List of inputs and their respective usage in PVsyst and CASSYS (Test Case 1: TMY file with global and diffuse components of horizontal irradiance)

Global and diffuse horizontal irradiances were output by both simulation programs to ensure no changes occur from the values provided as input (see Figure 2 to Figure 5) for Test Case 1. Some deviations occur in CASSYS when the Incidence or Zenith Angles get close to 87.5 degrees. These deviations occur because of an attempt to limit the normal beam irradiance to a physically reasonable value (below the clear sky value).

Comparison of Radiation Calculations

The errors discussed here will reflect upon all other test cases and are presented here in some depth as a result.

<u>Plane of Array Irradiance and its components</u>

POA Irradiance and its components are calculated in both programs using the Hay model (described in the CASSYS Physical Models and Engine Guide). See Figure 6 to Figure 9 for results.

The differences in the values below 200 $W \cdot m^{-2}$ occur due to the adjustment in the diffuse irradiance so that the normal beam irradiance stays below the normal extra-terrestrial irradiance, as discussed in the previous section.

The same adjustments cause the values of the diffuse component of plane of array irradiance to vary between the two programs as well. The ground reflected component remains the same for both programs however, since it depends only on the global horizontal irradiance.

Near Shading Factors on Plane of Array components

Shading factors on the three components of POA Irradiance are calculated using the position of the sun, the orientation of the site and the site layout (see Appendix I for details). The shading factor is 1 in the absence of shading and 0 in the case of total shading.

Near Shading Factor on the Beam Component of POA Irradiance

The Near Shading Factor for the Beam component of POA Irradiance has two distinct lines that are formed as a result of the calculations by the two programs (see Figure 10). PVSyst does not calculate the shading factor on a particular component if the component has a value of zero. This is seen repeatedly when comparing direct, diffuse or ground reflect near shading factors (see Figure 10). CASSYS calculates the shading factor regardless of the value of the component. This results in the formation of Pattern 1 (Figure 10), regardless of values calculated by CASSYS.

The non-horizontal line has slight dispersion in Pattern 2 (Figure 10) due to minor differences in the calculation of the Profile Angle by the two programs (the step-wise pattern is due to the use of the cell-based shading effect with 4 cells). The values produced by CASSYS have been checked against the reference material suggested by PVsyst [1] and was found to be in good agreement with the equations provided. For a more detailed view of the equations used, please see the CASSYS Physical Models and Engine Guide.

Near Shading Factor on the Diffuse Component of POA Irradiance

The shading factor applied to the diffuse component of POA Irradiance is expected to be constant throughout the year, as it depends only on the geometry of the system. PVsyst reports this value as 0.9601 and also the value 1 due to the reasons stated in the previous section. The value calculated by CASSYS differs from the one calculated by PVsyst. Using the Tools menu in PVsyst, one can determine the expected value of the shading factor to be 0.976. The value provided in this table does not adjust for the number of rows (the first row will have no shading, so the overall shading factor is lowered by an adjustment factor). The value calculated by CASSYS (0.9703) is close to this adjusted value (0.966); the value calculated by PVsyst during simulation is 0.9601.

Near Shading Factor on the Ground Reflected Component of POA Irradiance

The shading factor applied to the ground reflected component of POA Irradiance is also expected to be constant throughout the year. Both programs calculate the same value (0.1010) however PVsyst sometimes reports the value as 1 due to the reasons stated in the previous section.

Near Shading Factor on the Global POA Irradiance

The factors calculated by PVsyst and CASSYS are compared in Figure 11. The shading factor on global is a sum-product of the three factors and the value of the respective components. The outliers occur because of the differences in the values for diffuse irradiance (see Figure 8) and the corresponding effect it has on the other components. These results in the large difference observed around 0.964 in Figure 11, which is where the global shading factor is close to the diffuse shading factor.

<u>Incidence Angle Modifiers on Plane of Array components</u>

The angle of incidence of beam irradiance calculated by PVsyst and CASSYS are in good agreement (Figure 12), except near sunrise or sunset. This has a minor impact overall because these are times with very low irradiance.

IAM Factor applied to Beam Component of POA Irradiance

The expected IAM curve should display the behaviour of the curve shown in Figure 1. PVsyst only models the IAM when the POA Beam is a non-zero value. Comparing results (Figure 13) shows that there are deviations around the sunset and sunrise cases, or more specifically when the incidence angle or sun zenith angle is close to 87.5 degrees. The calculation of the factors for incidence angles larger than 87.5° is handled similarly in PVsyst and CASSYS (setting it to zero).

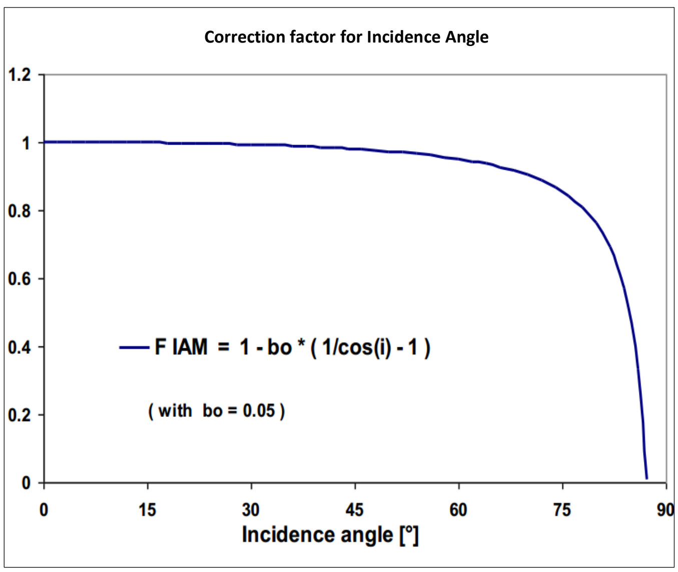

Figure 1: Correction factor for Incidence Angle (Source: Modelling System Losses in PVsyst [2])

IAM Factor applied to Diffuse and Ground Reflected Component of POA Irradiance

Diffuse irradiance is, by its very definition, irradiance that is scattered and can be incident from various angles onto the panel surface. Using an isotropic assumption, the angle of 60° is used as an average angle for the diffuse component of radiation (see Beckman [1]). The same is also used for the ground reflected component. This yields the same IAM factor for both components in CASSYS.

The values for PVsyst are modelled only when the diffuse or ground reflected components are a non-zero value (as discussed earlier). PVsyst (IAM Diffuse: 0.9601) uses a different angle which is close but not equal to the 60° used by CASSYS (IAM Diffuse and Albedo: 0.95) to determine the IAM loss factor for the diffuse component.

For the ground-reflected case, the values for PVsyst assume negative values (-18.985) for all non-zero ground reflected component values leading to the differences observed.

IAM Factor applied to Global POA Irradiance

As observed when comparing the Near Shading factor, when the global IAM factor is closer to the IAM factor on the diffuse or the ground reflected component discrepancies exist between CASSYS and PVsyst. For all other cases, due to the differences in the values and the factors calculated, the net effect causes dispersion around the expected agreement of y = x (see Figure 14).

Global POA after Shading and IAM factors are applied

In Figure 15, the POA Irradiances after Shading and IAM factors are applied by the two programs are compared. The dispersion below 200 $W{\cdot}m^{-2}$ carries over from the previous adjustments made by CASSYS and PVsyst to the diffuse value and other dispersion can be accounted for by the differences in IAM factor and Shading Factor mentioned in the preceding sections.

Summary of Differences over an Entire Year

As a guide, negative values correspond to CASSYS being lower than PVsyst:

Output Variable	**Difference**
Global Horizontal Irradiance	0.00%
Horizontal Diffuse Irradiance	0.03%
Beam POA Irradiance	0.17%
Diffuse POA Irradiance	0.52%
Ground Reflect POA Irradiance	0.00%
Global POA Irradiance	0.31%
Effective Global POA corrected for Shading and IAM	0.02%
Array Production	0.14%
Inverter Production	0.14%
Energy to Grid	0.14%

Table 3: Summary of differences over an entire year's simulation (Test Case 1: TMY file with global and diffuse components of horizontal irradiance)

Test Case 2: Using a TMY File with only Global Horizontal Irradiance

The comparison in this section highlights the difference occurring in radiation processing due to decomposition of Global Horizontal Irradiance, and the Transposition algorithms. The resultant difference from decomposition is within 1% for both components, and in a similar range for the tilted irradiance components calculated through transposition. See Figure 16 to Figure 21. The comparison is summarized in Table 4.

Summary of Difference over an Entire Year

As a guide, negative values correspond to CASSYS being lower than PVsyst:

Output Variable	Difference
Global Horizontal Irradiance	0.00%
Horizontal Diffuse Irradiance	0.46%
Beam POA Irradiance	-0.17%
Diffuse POA Irradiance	1.05%
Ground Reflect POA Irradiance	0.00%
Global POA Irradiance	0.35%
Effective Global corrected for Shading and IAM	-0.02%
Array Production	0.17%
Inverter Production	0.18%
Energy to Grid	0.18%

Table 4: Summary of differences over an entire year's simulation (Test Case 2: TMY file with global horizontal irradiance only)

Test Case 3: Using Global Plane of Array Irradiance calculated by PVsyst from TMY File

The comparison in this section highlights differences resulting from de-transposition and re-transposition of the input global plane of array irradiance. In this case, it is important to highlight that PVsyst modifies the POA irradiance close to the sunrise and sunset times when the horizontal normal is higher than the solar constant. POA irradiance is therefore reduced by PVsyst to the tune of 0.24%.

The difference in the total energy to grid calculated by both programs is 0.18% which predominantly stems from the difference in the global corrected for shading and IAM. See Figure 22 and Figure 23 for details.

Summary of Differences over an Entire Year

As a guide, negative values correspond to CASSYS being lower than PVsyst:

Output Variable	Difference
Global Horizontal Irradiance	-0.15%
Horizontal Diffuse Irradiance	0.34%
Beam POA Irradiance	-0.10%
Diffuse POA Irradiance	0.71%
Ground Reflect POA Irradiance	-0.15%
Global POA Irradiance	0.24%
Effective Global corrected for Shading and IAM	-0.20%
Array Production	-0.02%
Inverter Production	-0.02%
Energy to Grid	-0.03%

Table 5: Summary of differences over an entire year's simulation (Test Case 3: Using POA Irradiance)

Test Case 4: Using Global Plane of Array Irradiance calculated by PVsyst (to eliminate outliers)

The comparisons in this section are conducted with the PVsyst re-calculated plane of array irradiance, from the previous case, to eliminate significant discrepancy resulting from adjustments discussed in the previous section. The horizontal decomposition errors are still present but are within

1% of each other. The observed difference in the overall simulation is -0.21%. See Figure 24 to Figure 28 for details. The differences occurring in other key variables are summarized in Table 6.

Array production comparisons show that the difference is reduced from the previous step (-0.36%) to (-0.19%). The increased power prediction between CASSYS and PVsyst results from different cell temperature values calculated by each program. The cell temperature is directly related to the Irradiance incident upon the cell surface (see Figure 29). To eliminate this effect, the same temperature is used in the next section for both tools.

Summary of Differences over an Entire Year

As a guide, negative values correspond to CASSYS being lower than PVsyst:

Output Variable	**Difference**
Global Horizontal Irradiance	-0.26%
Horizontal Diffuse Irradiance	0.22%
Beam POA Irradiance	-0.37%
Diffuse POA Irradiance	0.50%
Ground Reflect POA Irradiance	-0.26%
Global POA Irradiance	0.00%
Effective Global corrected for Shading and IAM	-0.36%
Array Production	-0.19%
Inverter Production	-0.20%
Energy to Grid	-0.21%

Table 6: Summary of differences over an entire year's simulation (Test Case 4: Using POA Irradiance recalculated by PVsyst)

Test Case 5: POA Irradiance and Panel Temperature (PVsyst Recalculated)

The comparisons in this case are conducted with the corrected global plane of array irradiance as calculated by PVsyst and the panel temperature modelled by PVsyst to ensure that both PV models start from the same set of conditions. Table 7 compares all important output values between the simulation programs including the array losses and production, inverter energy production and the transformer model.

The observed differences are large in scale for values that use array currents as their basis for calculation (Soiling, Module Quality and Mismatch Loss). This discrepancy occurs because of a difference in the calculation during clipping (or power limiting) mode of the inverter. CASSYS uses the current generated by the PV Array after the inverter has limited the input power of the array. This results in similar losses occurring between different clipping periods. It seems that PVsyst may be using current values before the limiting behaviour occurs to calculate losses. Slight differences in the voltage values used to determine the currents may also contribute to the observed errors. This causes the patterns seen in Figure 30, to Figure 32.

The current to which the inverter limits the PV array is also slightly different due to slight differences in the voltage modelling between both simulation tools. CASSYS calculates this current to be slightly higher than PVsyst; but the values are in good agreement when the inverters are not clipping.

This is a dominant cause for the difference observed between the calculated DC-side wiring (or ohmic) losses at the higher range of the chart (see Figure 33).

The difference in the AC ohmic losses results from slightly different AC resistances calculations by both programs.

The Inverter efficiency curve (Figure 35) displays the interpolation technique used to calculate efficiency values along the 8-point efficiency curve used in PVsyst and CASSYS. Both programs use linear interpolation to determine values from the resulting 8-point transfer function ($P_{ACx} = P_{DCx} * Efficiency_X$).

Summary of Differences over an Entire Year

As a guide, negative values correspond to CASSYS being lower than PVsyst:

Output Variable	**Difference**
Global Horizontal Irradiance	-0.26%
Horizontal Diffuse Irradiance	0.22%
Beam POA Irradiance	-0.37%
Diffuse POA Irradiance	0.50%
Ground Reflect POA Irradiance	-0.26%
Global POA Irradiance	0.00%
Effective POA Irradiance corrected for Shading and IAM	**-0.36%**
Soiling Loss	-5.76%
Module Quality Loss	-6.22%
Mismatch Loss	-6.22%
Ohmic Losses DC	-0.89%
Effective Power at the Output of the Array	**-0.34%**
Available Power at Inverter Output	**-0.34%**
Ohmic Losses AC	-0.97%
Energy delivered to the grid	**-0.35%**

Table 7: Summary of differences over an entire year's simulation (Test Case 5: Using POA Irradiance and module temperature recalculated by PVsyst to eliminate outliers and dispersion)

Conclusion

The comparisons between various CASSYS and PVsyst outputs highlight the discrepancies and similarities resulting from the use of different meteorological inputs. The difference between the energy to grid calculated by both programs was in good agreement with the largest discrepancy occurring below 0.5% over an entire year's simulation. The errors in the effective global corrected for shading and IAM are a combination of different shading factors and the irradiance components they are applied to, which is the dominant error over all, but leads to a difference well within 0.5% between the two tools.

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Appendix I. PVsyst Report used for site definition and simulation

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Grid-Connected System: Simulation parameters

Project :

Geographical Site

Situation	Latitude	44.1°N	Longitude	77.2°W
Time defined as	Legal Time	Time zone UT-5	Altitude	75 m
	Albedo	0.10		

Meteo data :

Simulation variant :

Simulation parameters

Collector Plane Orientation	Tilt	28°	Azimuth	0°
99Sheds	Pitch	9.90 m	Collector width	3.96 m
Inactive band	Top	0.00 m	Bottom	0.00 m
Shading limit angle	Gamma	16.19 °	Occupation Ratio	40.0 %
Shadings electrical effect	Cell size	15.6cm	Strings in width	4
Models used	Transposition	Hay	Diffuse	Measured
Horizon	Free Horizon			
Near Shadings	Mutual shadings of sheds	Electrical effect		

PV Arrays Characteristics (6 kinds of array defined)

Array#1 : PV module	Si-poly	Model	**CS6X - 285P**		
		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	18 modules	In parallel	212 strings
Total number of PV modules		Nb. modules	3816	Unit Nom. Power	285 Wp
Array global power		Nominal (STC)	**1088 kWp**	At operating cond.	968 kWp (50°C)
Array operating characteristics (50°C)		U mpp	573 V	I mpp	
Array#2 : PV module	Si-poly	Model	**CS6X - 295P**		
		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	18 modules	In parallel	1220 strings
Total number of PV modules		Nb. modules	21960	Unit Nom. Power	295 Wp
Array global power		Nominal (STC)	**6478 kWp**	At operating cond.	5761 kWp (50°C)
Array operating characteristics (50°C)		U mpp	576 V	I mpp	
Array#3 : PV module	Si-poly	Model	**CS6X - 290P**		
		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	18 modules	In parallel	616 strings
Total number of PV modules		Nb. modules	11088	Unit Nom. Power	290 Wp
Array global power		Nominal (STC)	**3216 kWp**	At operating cond.	2862 kWp (50°C)
Array operating characteristics (50°C)		U mpp	575 V	I mpp	
Array#4 : PV module	Si-poly	Model	**CS6X - 290P**		
		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	18 modules	In parallel	220 strings
Total number of PV modules		Nb. modules	3960	Unit Nom. Power	290 Wp
Array global power		Nominal (STC)	**1148 kWp**	At operating cond.	1022 kWp (50°C)
Array operating characteristics (50°C)		U mpp	575 V	I mpp	

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Grid-Connected System: Simulation parameters (continued)

Array#5 : PV module	Si-poly	Model	**CS6X - 300P**		
		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	18 modules	In parallel	200 strings
Total number of PV modules		Nb. modules	3600	Unit Nom. Power	300 Wp
Array global power		Nominal (STC)	**1080 kWp**	At operating cond.	960 kWp (50°C)
Array operating characteristics (50°C)		U mpp	578 V	I mpp	
Array#6 : PV module	Si-poly	Model	**CS6X - 290P**		
		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	18 modules	In parallel	192 strings
Total number of PV modules		Nb. modules	3456	Unit Nom. Power	290 Wp
Array global power		Nominal (STC)	**1002 kWp**	At operating cond.	892 kWp (50°C)
Array operating characteristics (50°C)		U mpp	575 V	I mpp	
Total	Arrays global power	Nominal (STC)	**14012 kWp**	Total	47880 modules
		Module area	**91873 m²**	Cell area	83909 m²

Inverter		Model	**Sunny Central 800CP-US (769kW modified)**		
		Manufacturer	SMA		
		Operating Voltage	570-820 V	Unit Nom. Power	769 kW AC
Array#1:		Number of Inverter	1	Total Power	769 kW AC
Array#2:		Number of Inverter	6.0	Total Power	4614 kW AC
Array#3:		Number of Inverter	3	Total Power	2307 kW AC
Array#4:		Number of Inverter	1	Total Power	769 kW AC
Array#5:		Number of Inverter	1	Total Power	769 kW AC
Array#6:		Number of Inverter	1	Total Power	769 kW AC
Total		Number of Inverter	13	Total Power	9997 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	45 °C
Wiring Ohmic Loss	Array#1	5.8 mOhm	Loss Fraction	1.5 % at STC
	Array#2	0.98 mOhm	Loss Fraction	1.5 % at STC
	Array#3	2.0 mOhm	Loss Fraction	1.5 % at STC
	Array#4	5.5 mOhm	Loss Fraction	1.5 % at STC
	Array#5	5.9 mOhm	Loss Fraction	1.5 % at STC
	Array#6	6.3 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC

Array Soiling Losses

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
10.0%	13.0%	6.0%	3.0%	2.0%	1.0%	1.0%	1.0%	1.0%	2.0%	6.0%	9.0%

Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	1.5 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

System loss factors

AC loss, transfo to injection	Grid Voltage	44 kV		
	Wires	115355 m 3x1200 mm²	Loss Fraction	1.5 % at STC
External transformer	Iron loss (24H connection)	41206 W	Loss Fraction	0.3 % at STC
	Resistive/Inductive losses	0.1 mOhm	Loss Fraction	1.5 % at STC

User's needs : Unlimited load (grid)

Appendix II. Comparison charts for Test Case 1: TMY file with Global and Diffuse Horizontal Irradiances

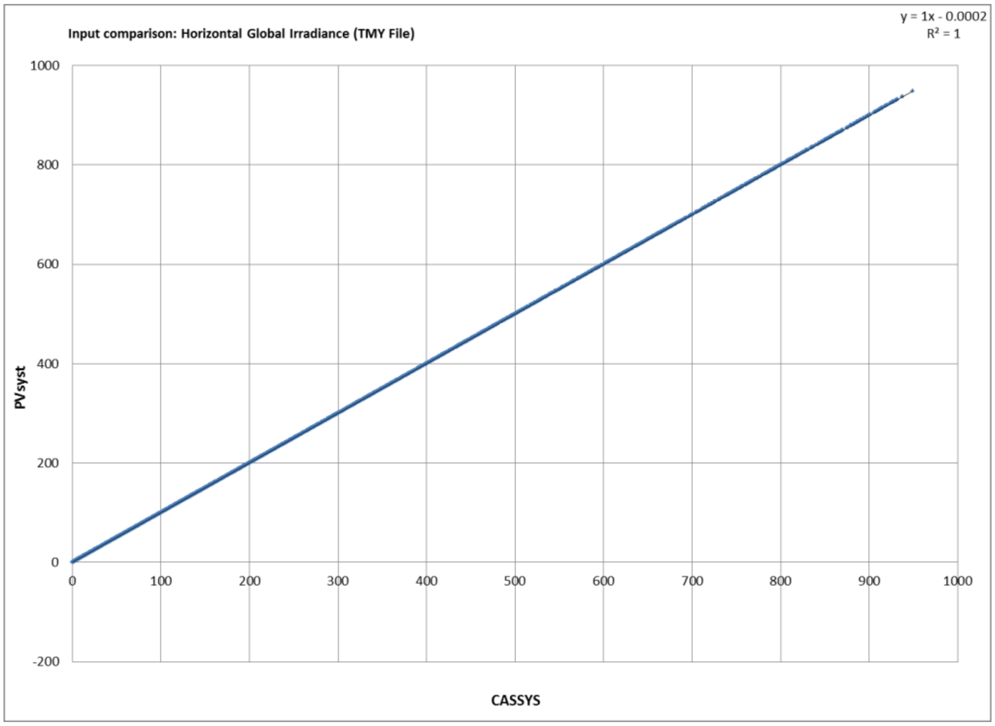

Figure 2: Comparison of Horizontal Global Irradiance (Test Case 1: TMY file with HGlo and HDif)

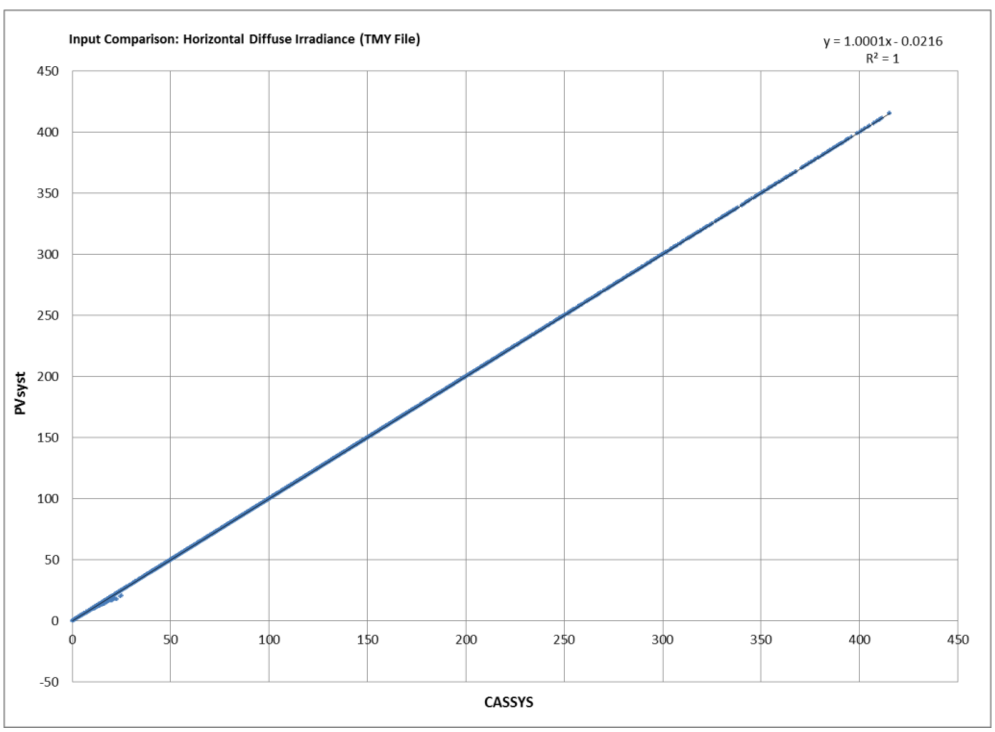

Figure 3: Comparison of Horizontal Diffuse Irradiance (Test Case 1: TMY file with HGlo and HDif)

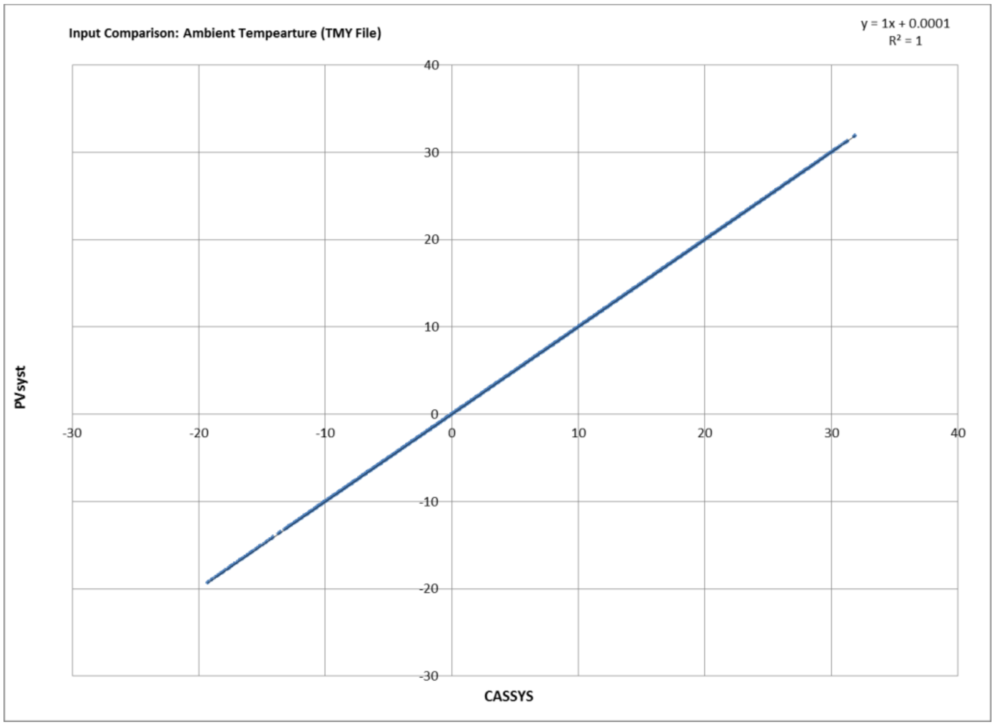

Figure 4: Comparison of Ambient Temperature (Test Case 1: TMY file with HGlo and HDif)

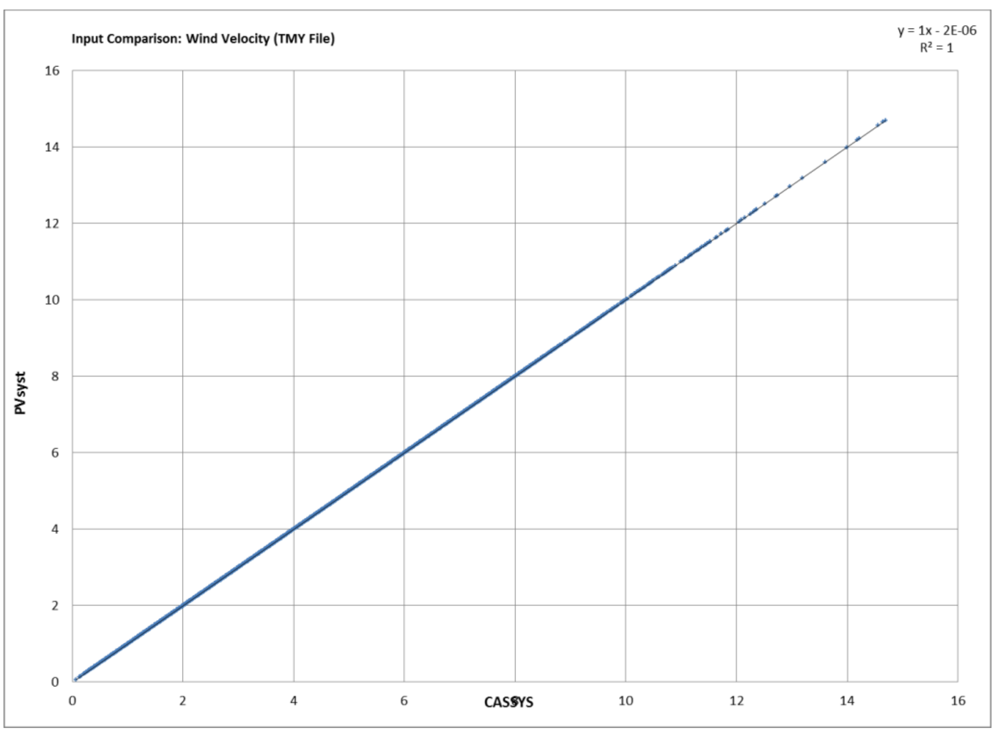

Figure 5: Comparison of Wind Velocity (Test Case 1: TMY file with HGlo and HDif)

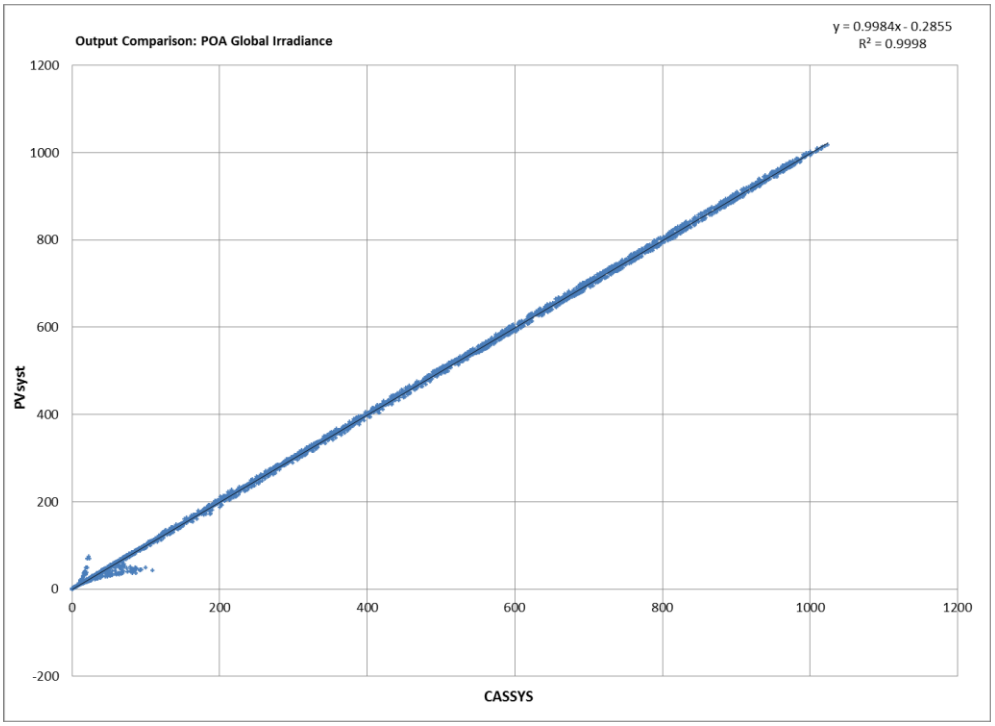

Figure 6: Comparison of POA Global Irradiance (Test Case 1: TMY file with HGlo and HDif)

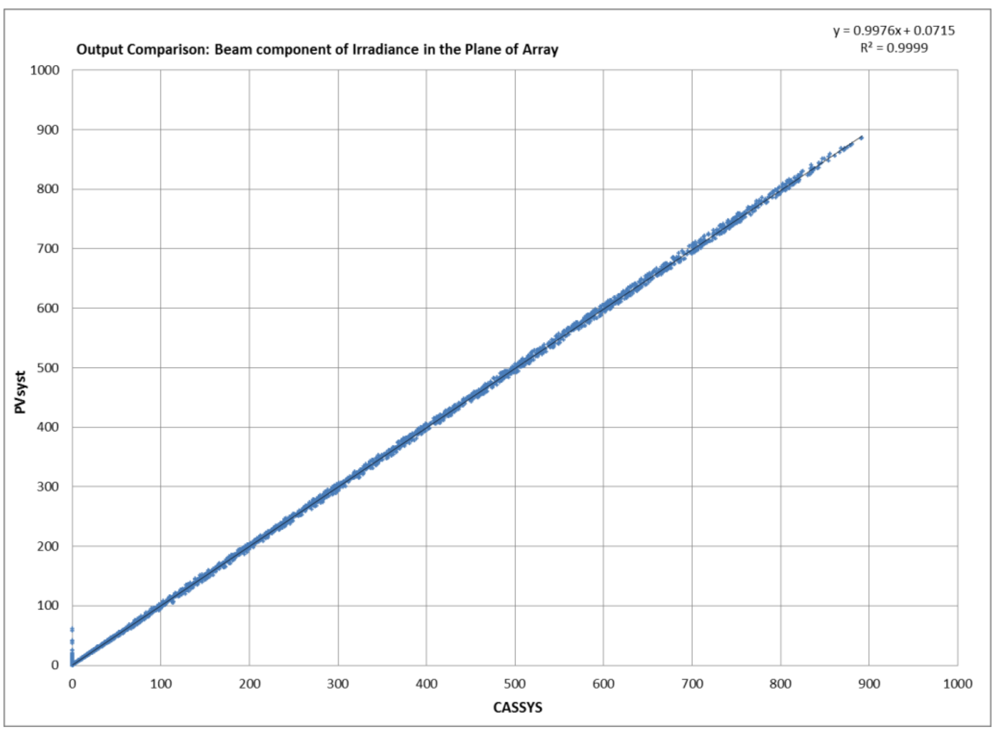

Figure 7: Comparison of POA Beam Irradiance (Test Case 1: TMY file with HGlo and HDif)

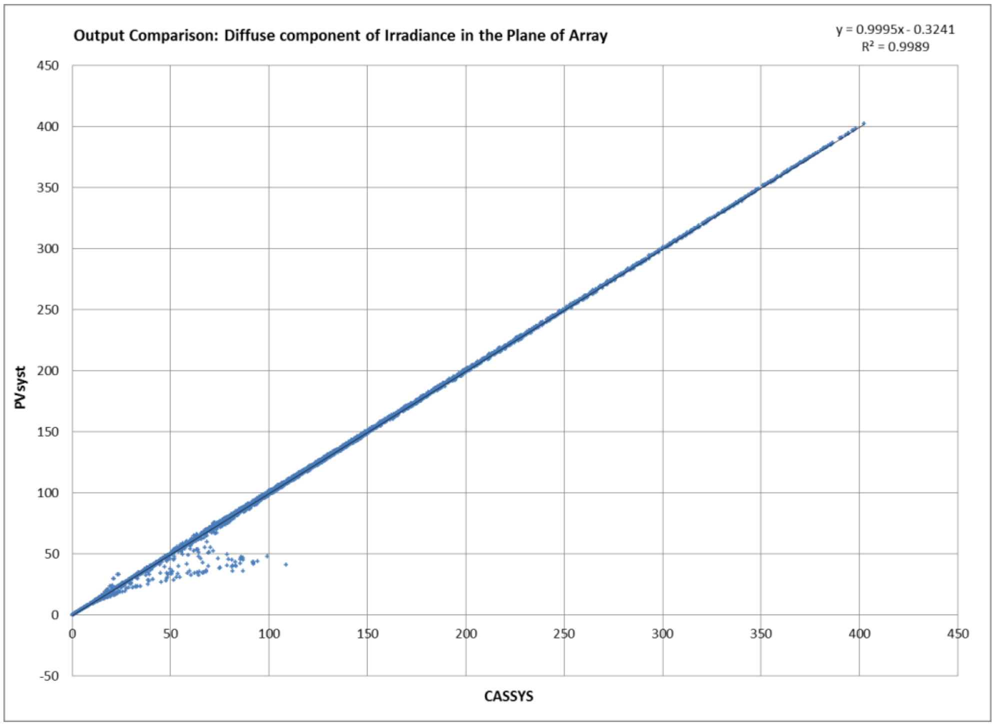

Figure 8: Comparison of POA Diffuse Irradiance (Test Case 1: TMY file with HGlo and HDif)

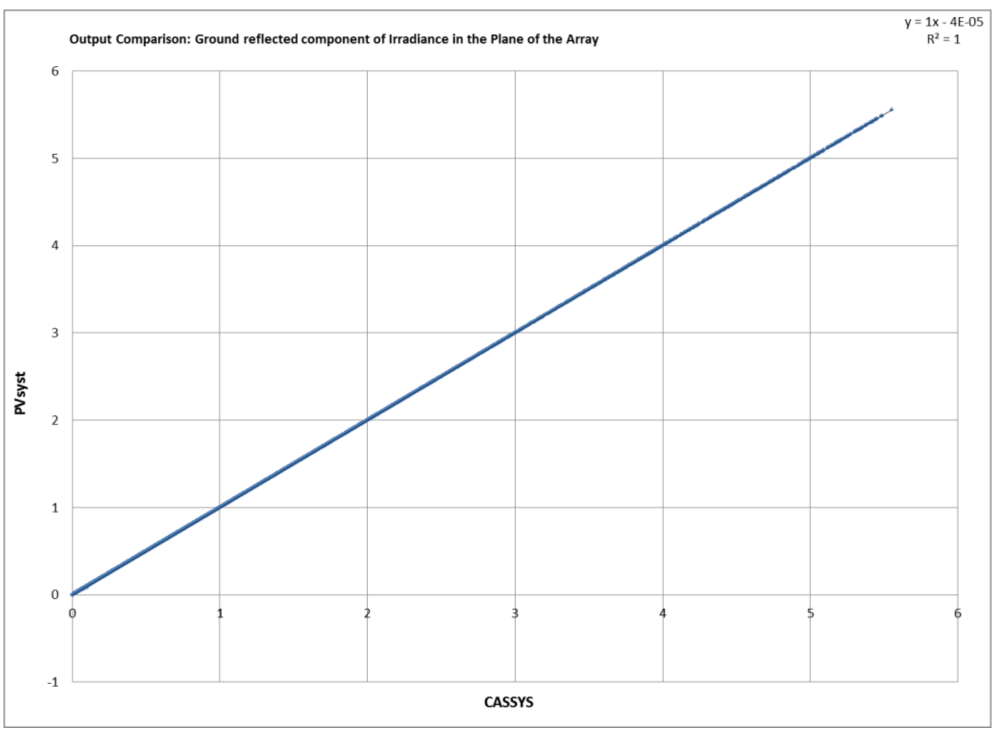

Figure 9: Comparison of POA Ground Reflected Irradiance (Test Case 1: TMY file with HGlo and HDif)

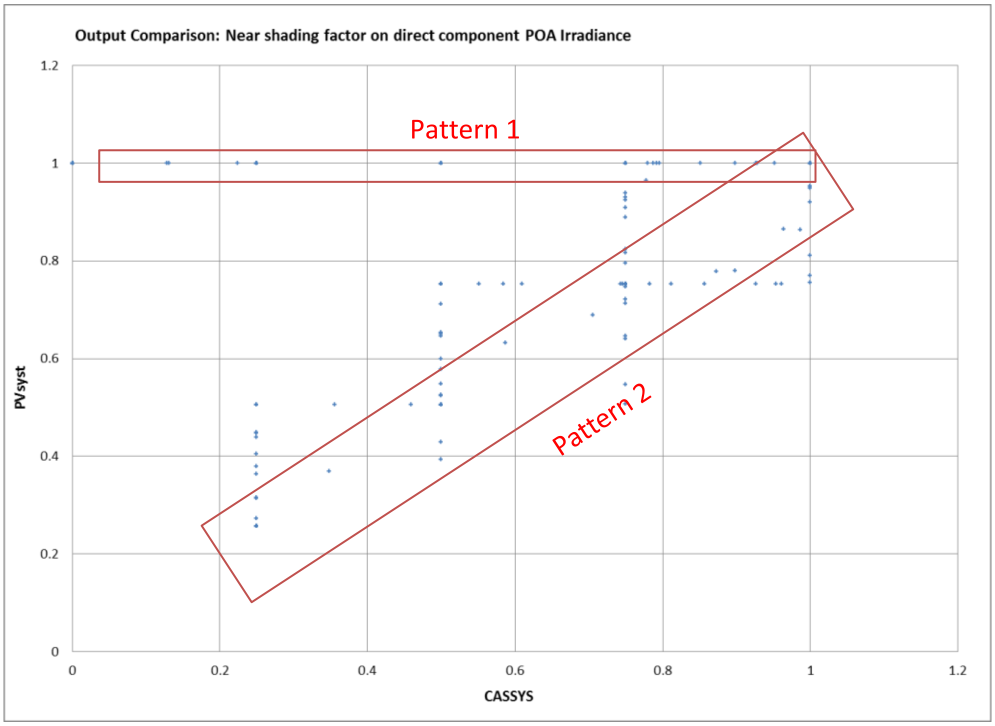

Figure 10: Near Shading Factor on the Direct Component of POA Irradiance (Test Case 1)

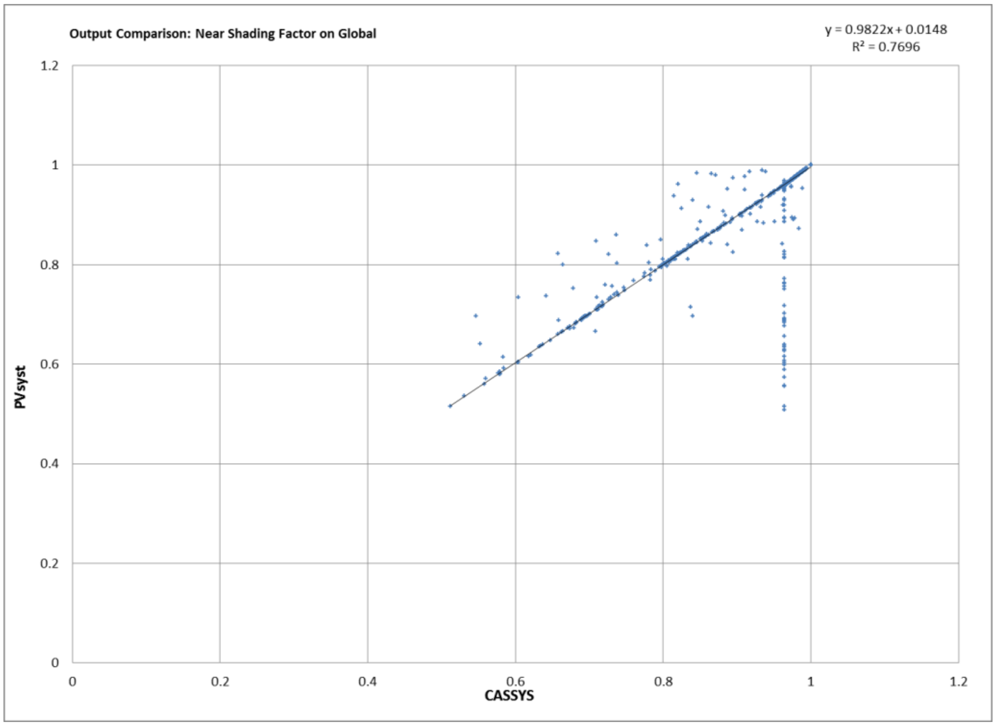

Figure 11: Near Shading Factor on Global POA Irradiance (Test Case 1)

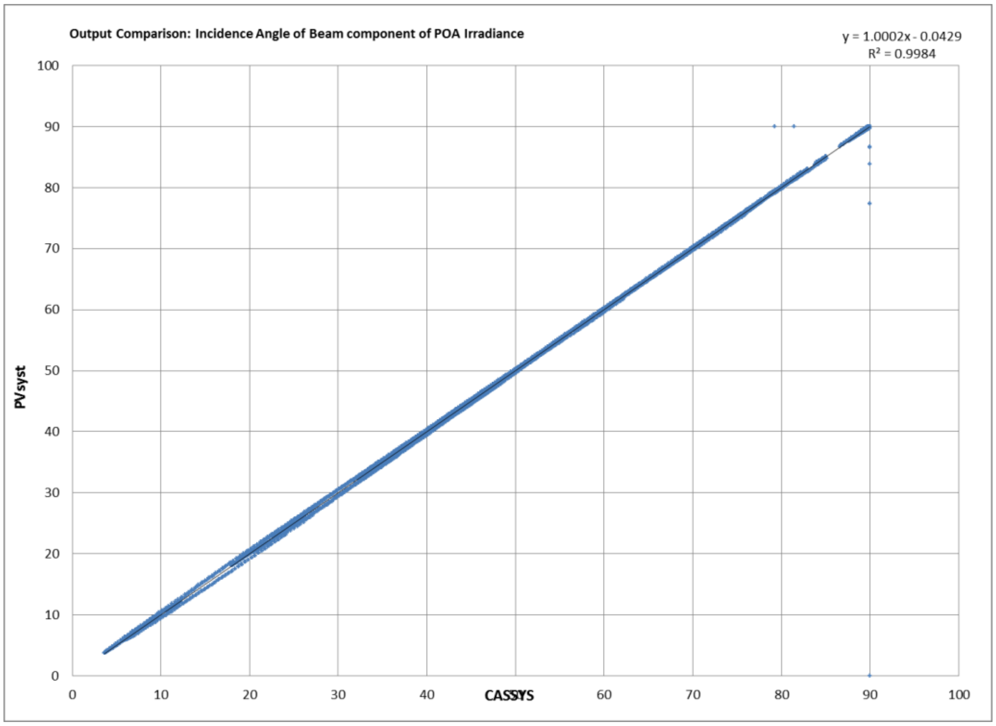

Figure 12: Incidence Angle of the Beam component of POA Irradiance (Test Case 1)

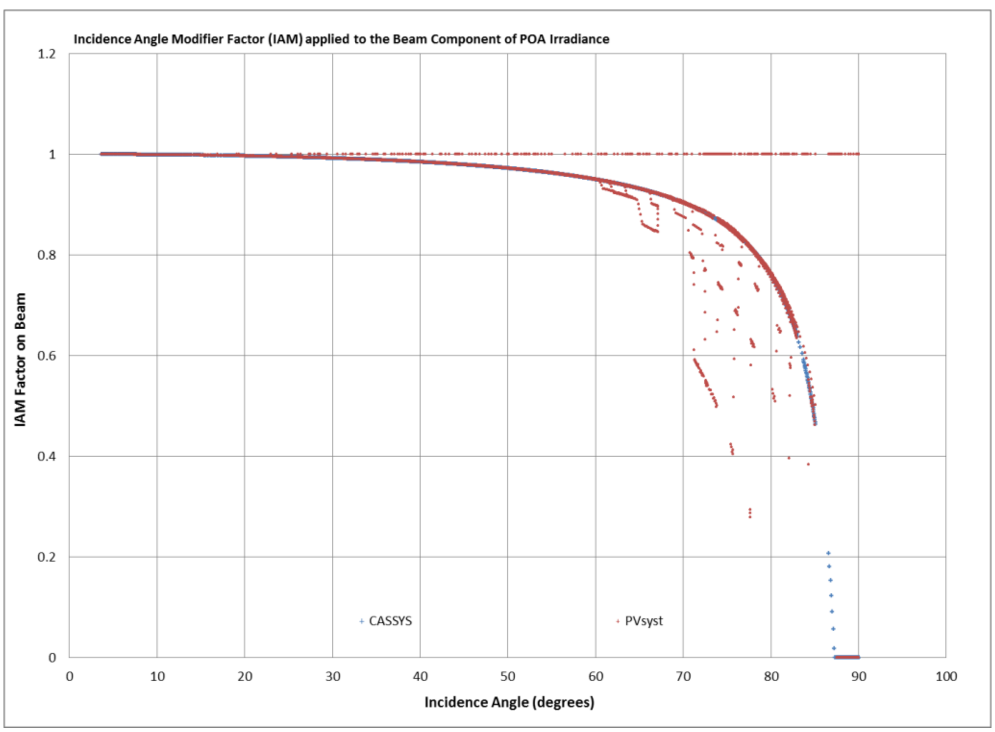

Figure 13: Incidence Angle modifier applied to the Beam component of POA Irradiance (Test Case 1)

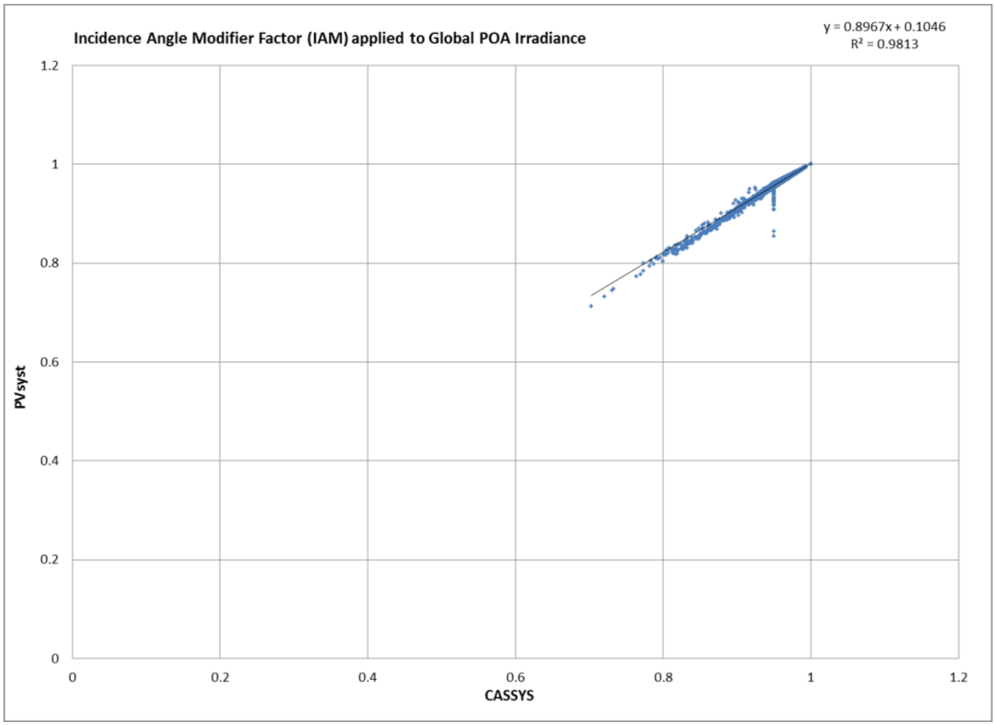

Figure 14: IAM Factor on Global POA Irradiance (Test Case 1)

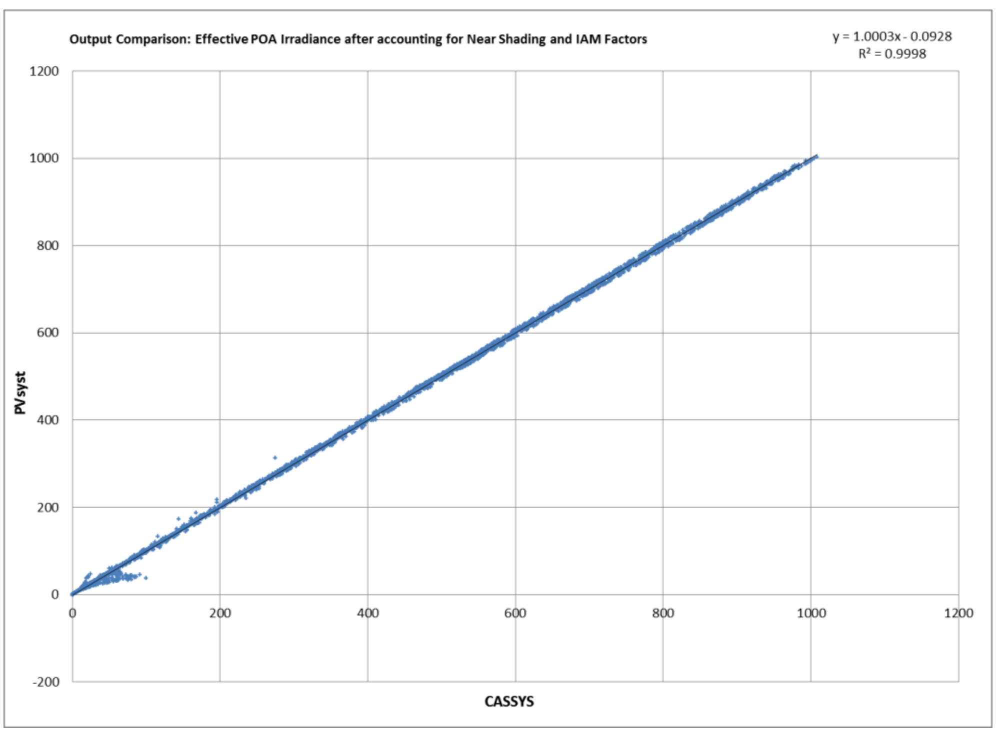

Figure 15: Effective POA Irradiance after accounting for Near Shading and IAM Factors (Test Case 1)

Appendix III. Comparison charts for Test Case 2: TMY file with HGlo

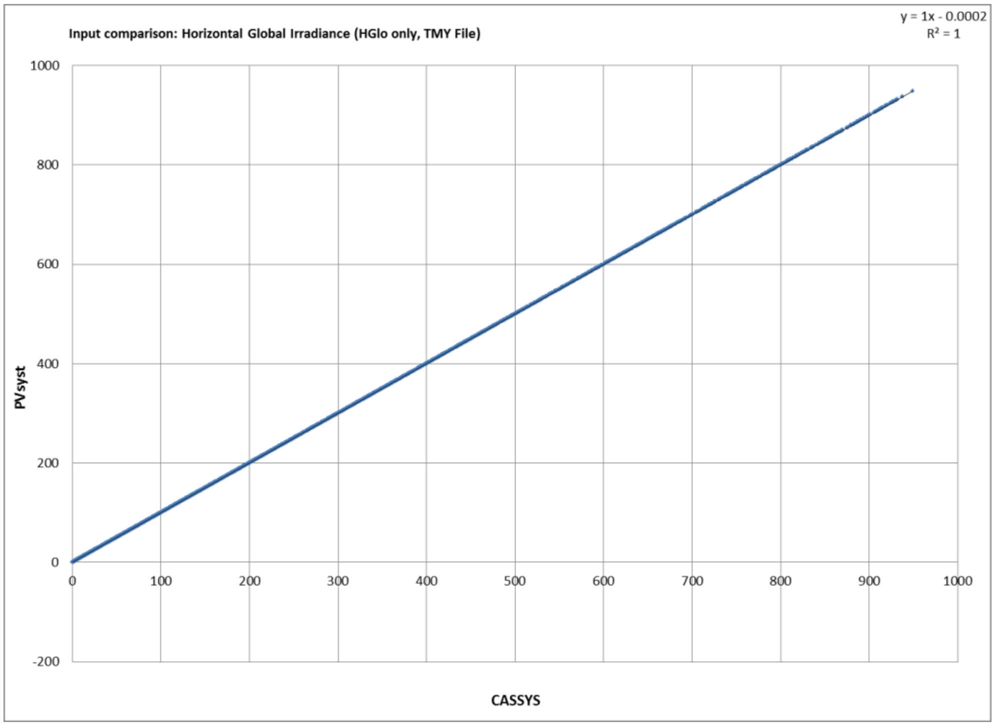

Figure 16: Horizontal Global Irradiance (Input: HGlo only, TMY File, Test Case 2)

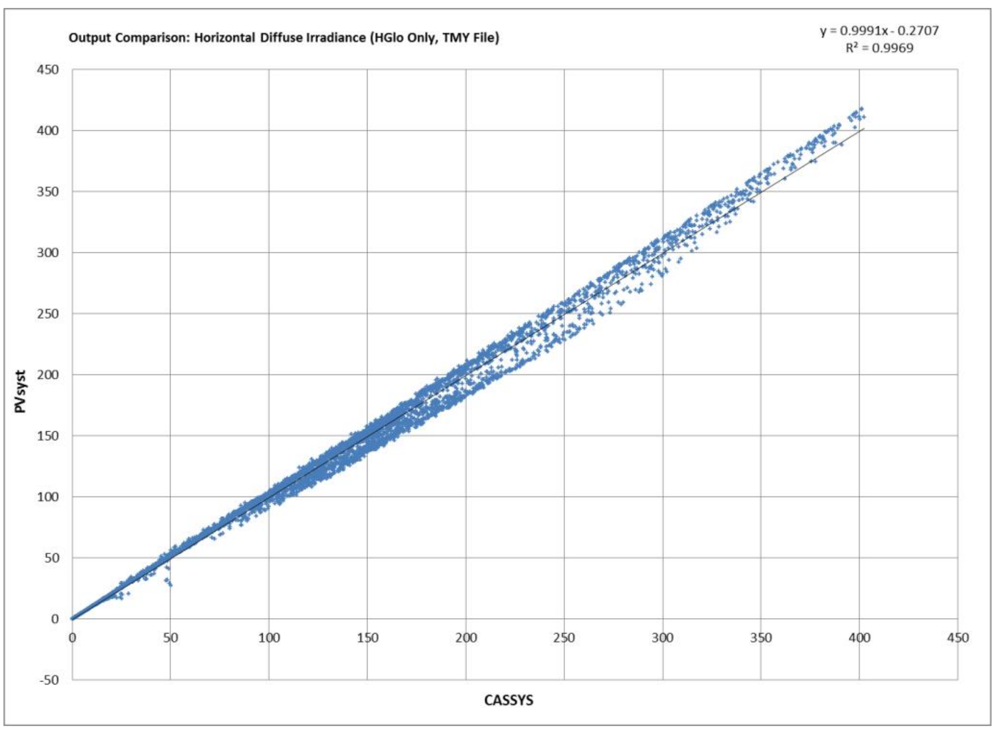

Figure 17: Horizontal Diffuse Irradiance (Input: HGlo only, TMY File, Test Case 2)

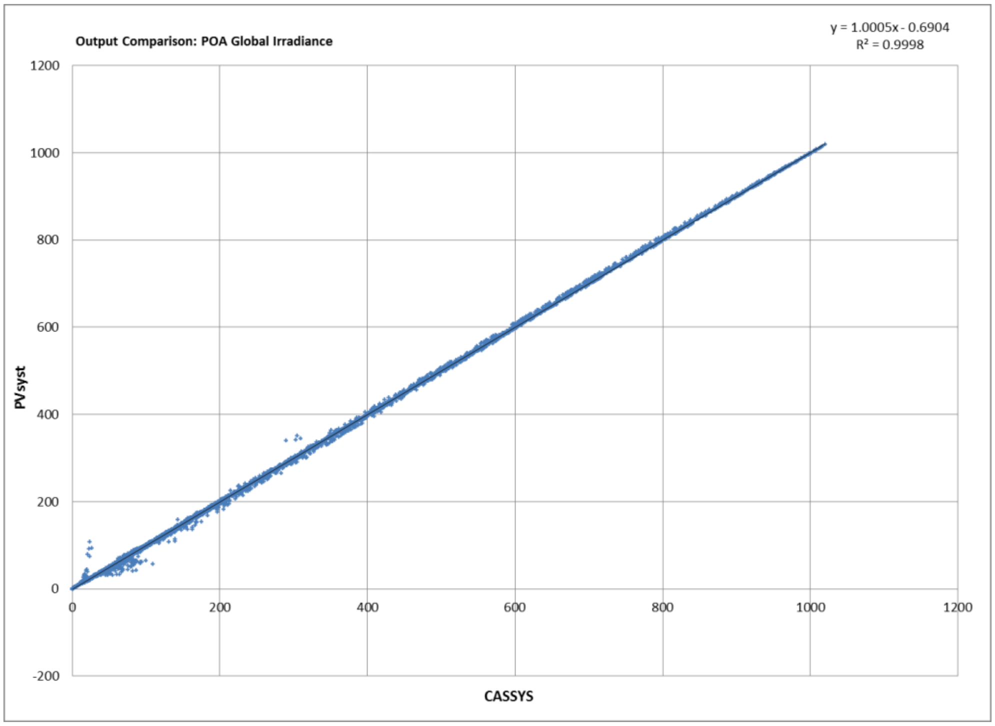

Figure 18: POA Global Irradiance (Input: HGlo only, TMY Input, Test Case 2)

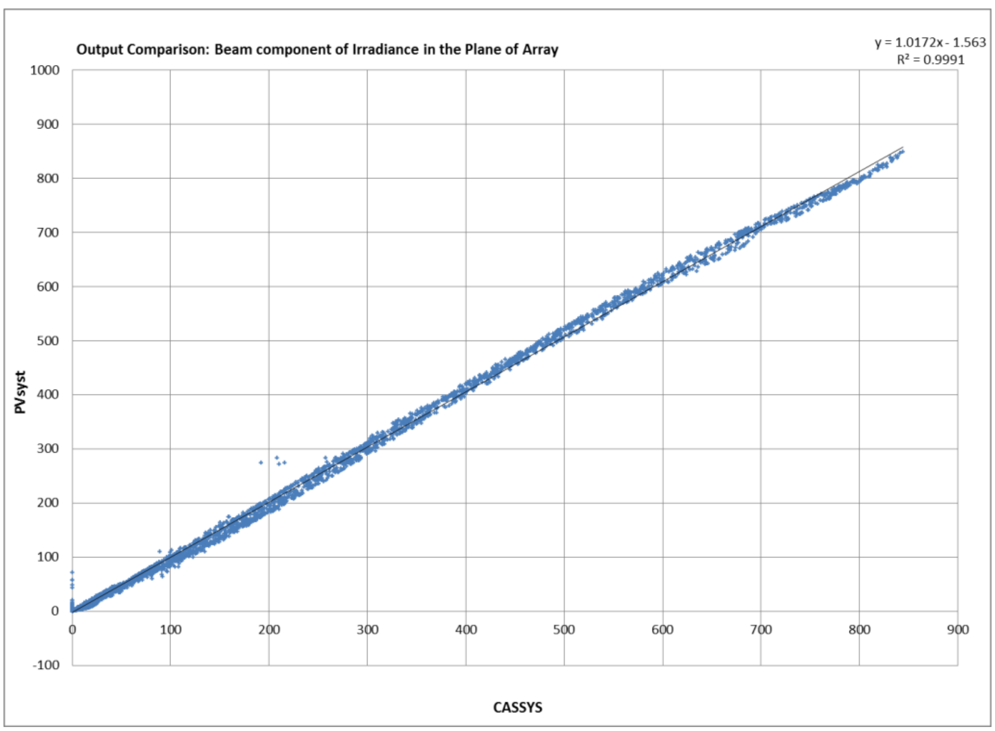

Figure 19: Plane of Array Irradiance Beam Component (Input: HGlo only, TMY file, Test Case 2)

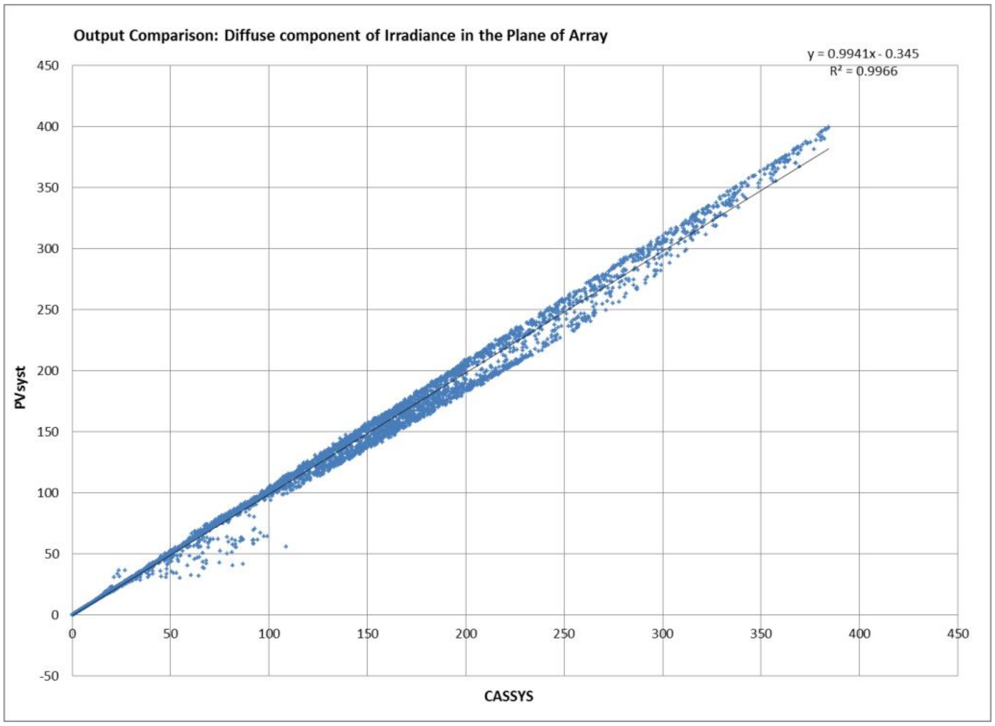

Figure 20: Plane of Array Irradiance Diffuse component (Input: HGlo only, TMY file, Test Case 2)

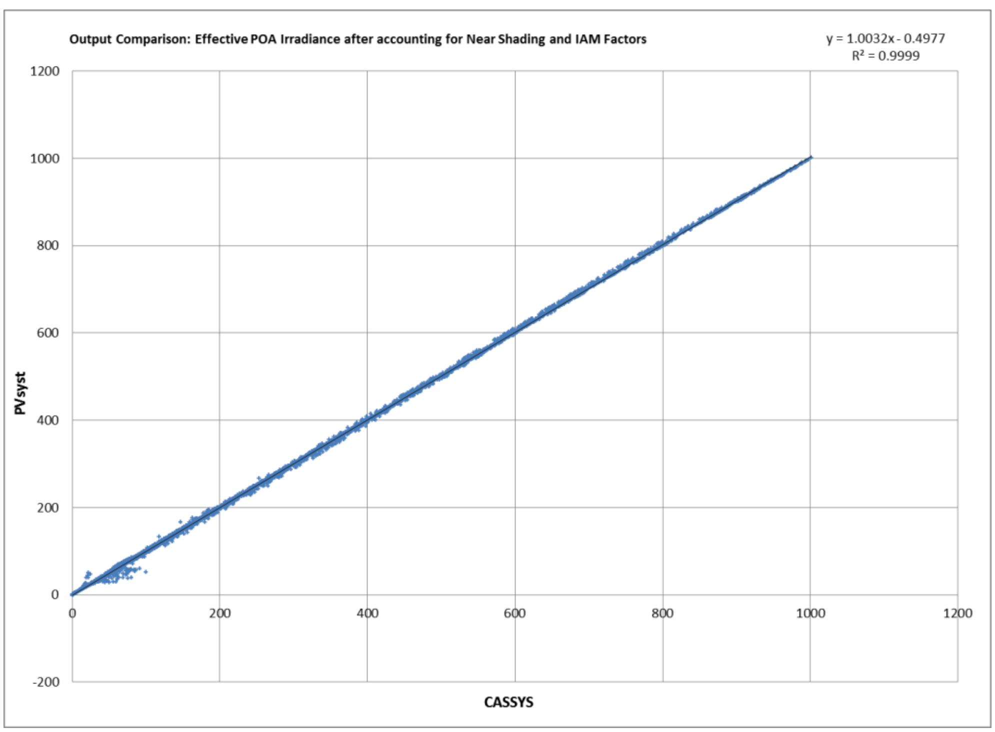

Figure 21: Effective Plane of Array Irradiance reaching the cell (Input: HGlo Only, TMY file, Test Case 2)

Appendix IV. Comparison chart for Test Case 3: Global POA Calculated by CASSYS from TMY

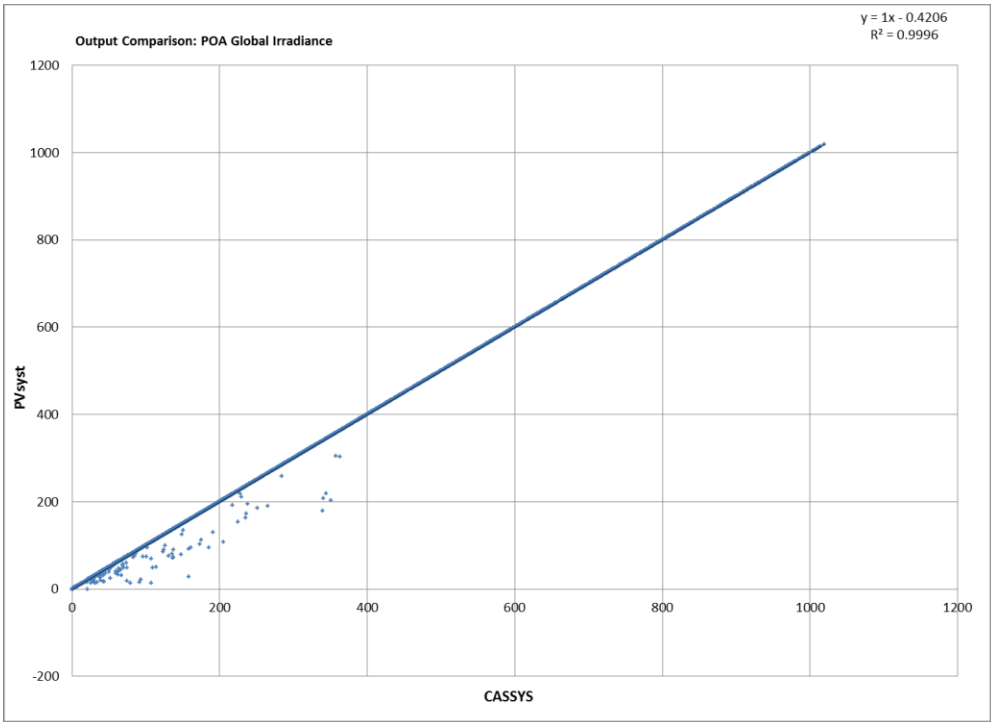

Figure 22: Input/output Comparison - POA Global Irradiance (Test Case 3)

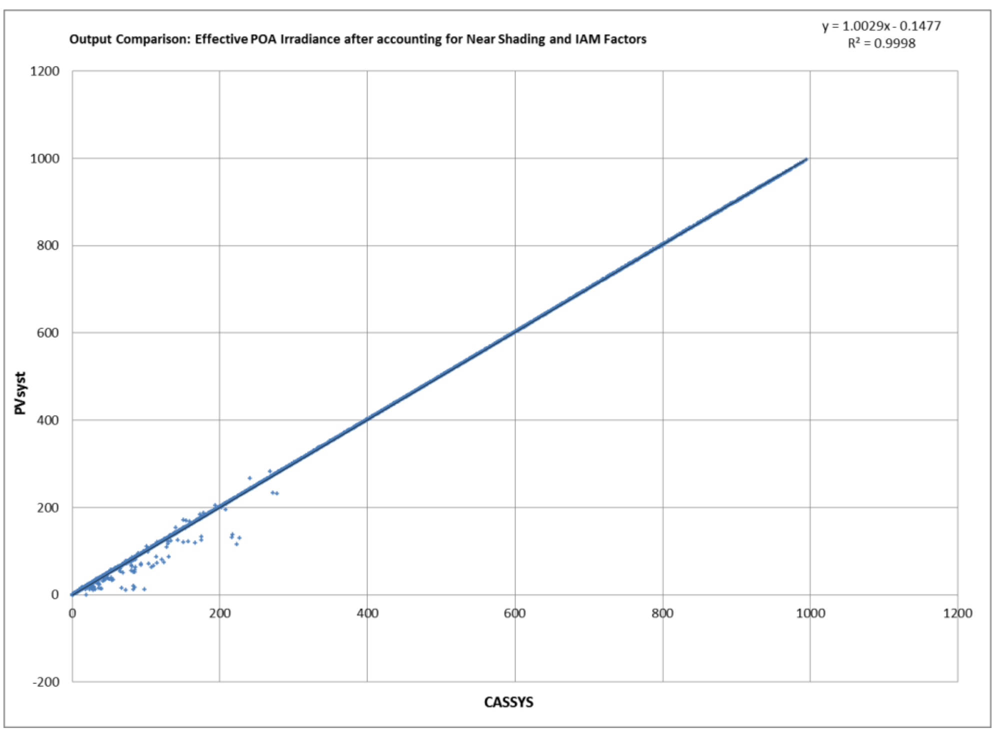

Figure 23: Effective Plane of Array Irradiance reaching the cell (Test Case 3)

Appendix V. Comparison charts for Test Case 4: Global POA re-calculated by PVsyst to eliminate outliers

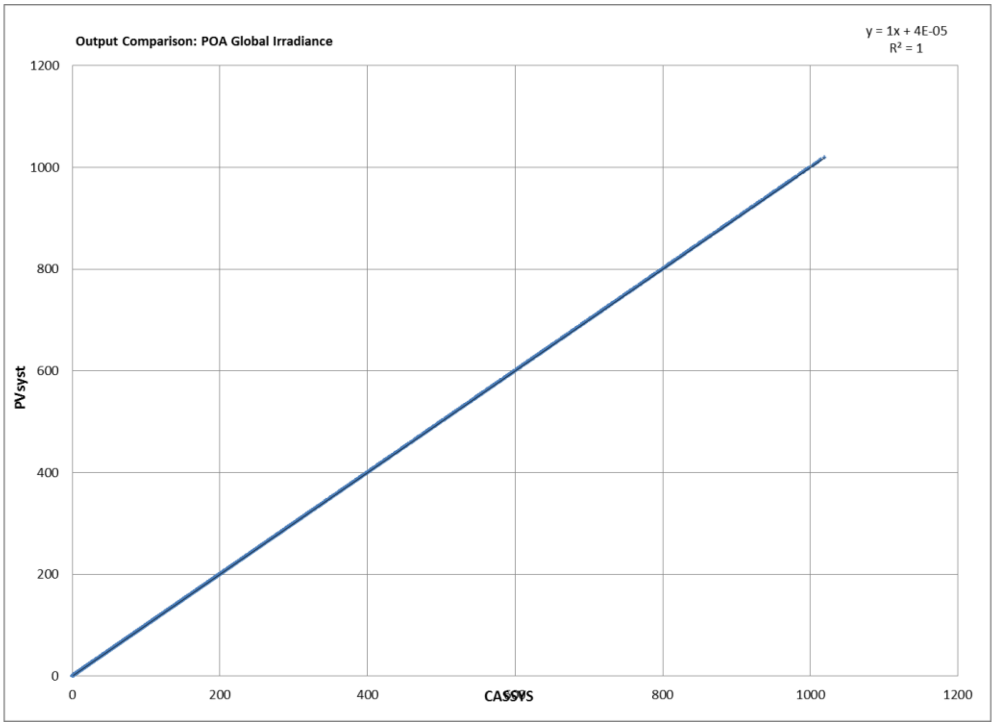

Figure 24: Input/Output Comparison - POA Global Irradiance (Test Case 4)

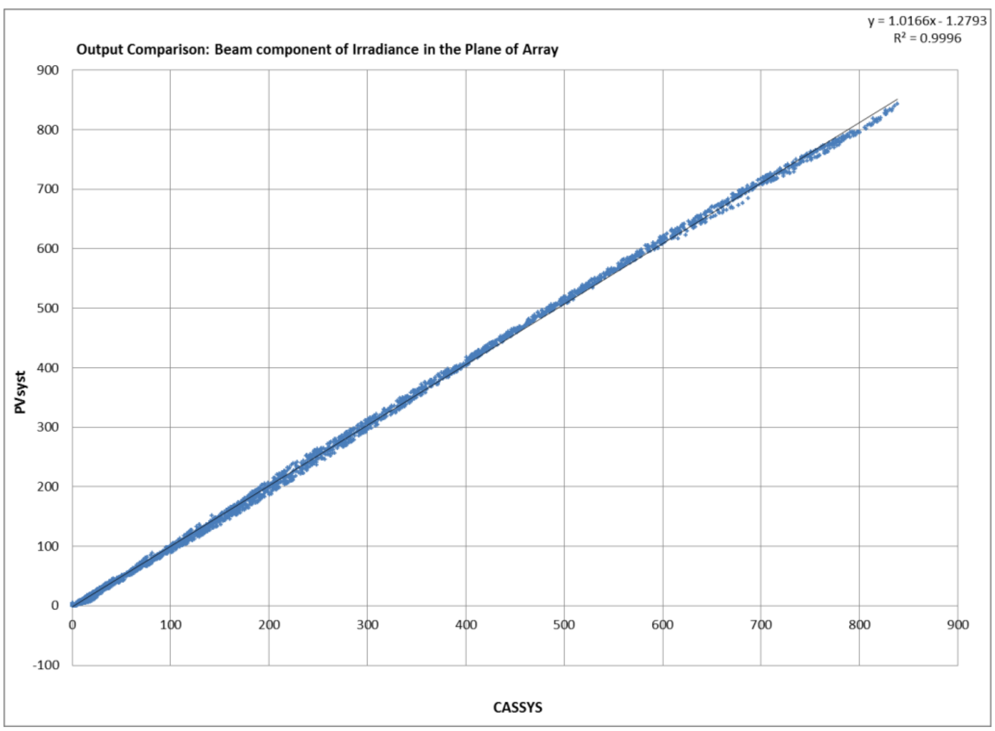

Figure 25: Comparison of Beam Component of POA Irradiance (Test Case 4)

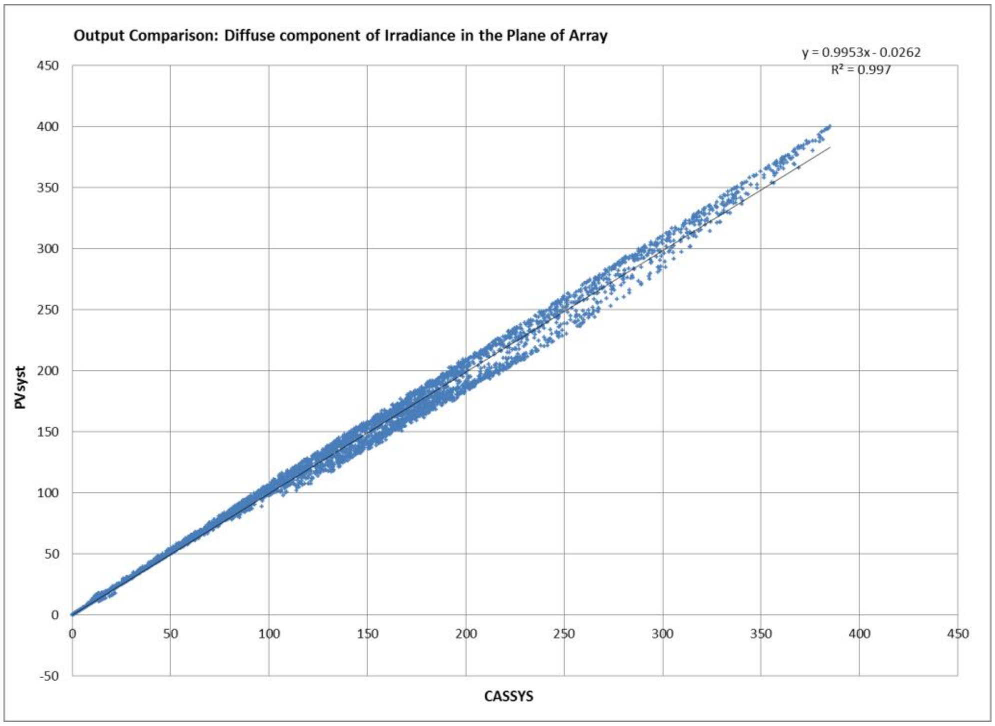

Figure 26: Output Comparison: Diffuse Irradiance in the plane of array (Test Case 4)

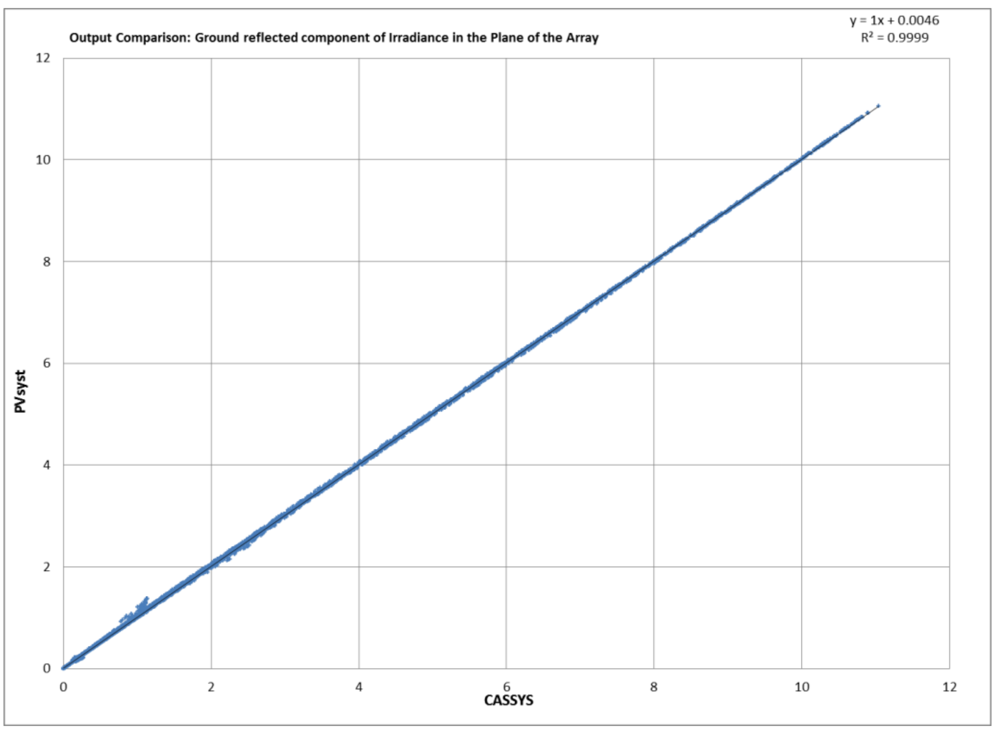

Figure 27: Output Comparison: Ground Reflected Irradiance in the Plane of Array (Test Case 4)

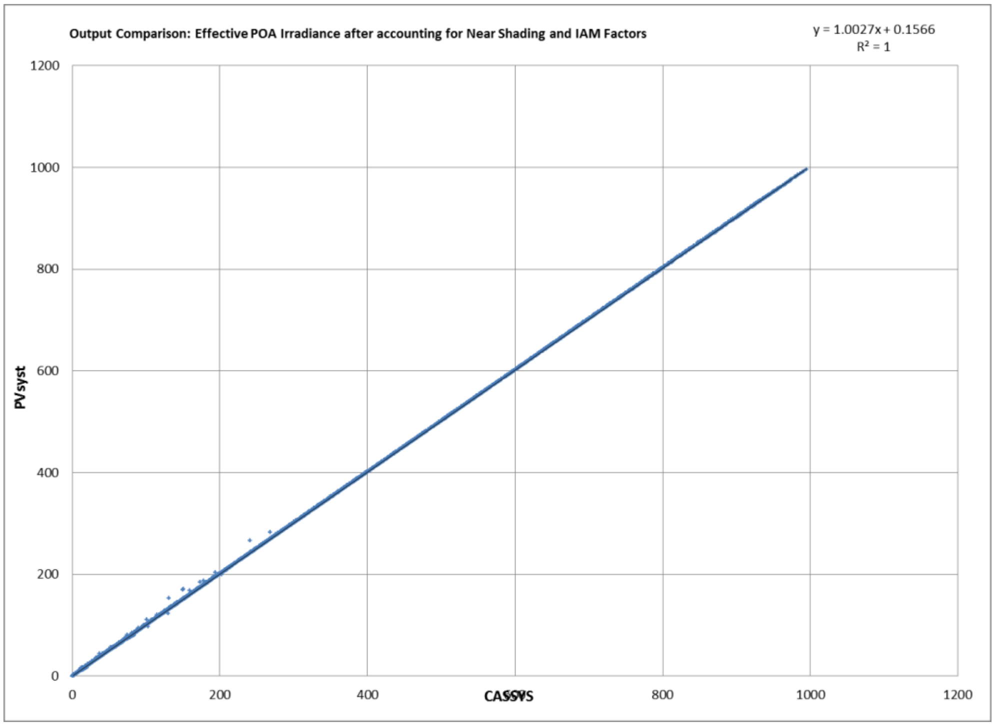

Figure 28: Effective irradiance incident on the cell (Test Case 4)

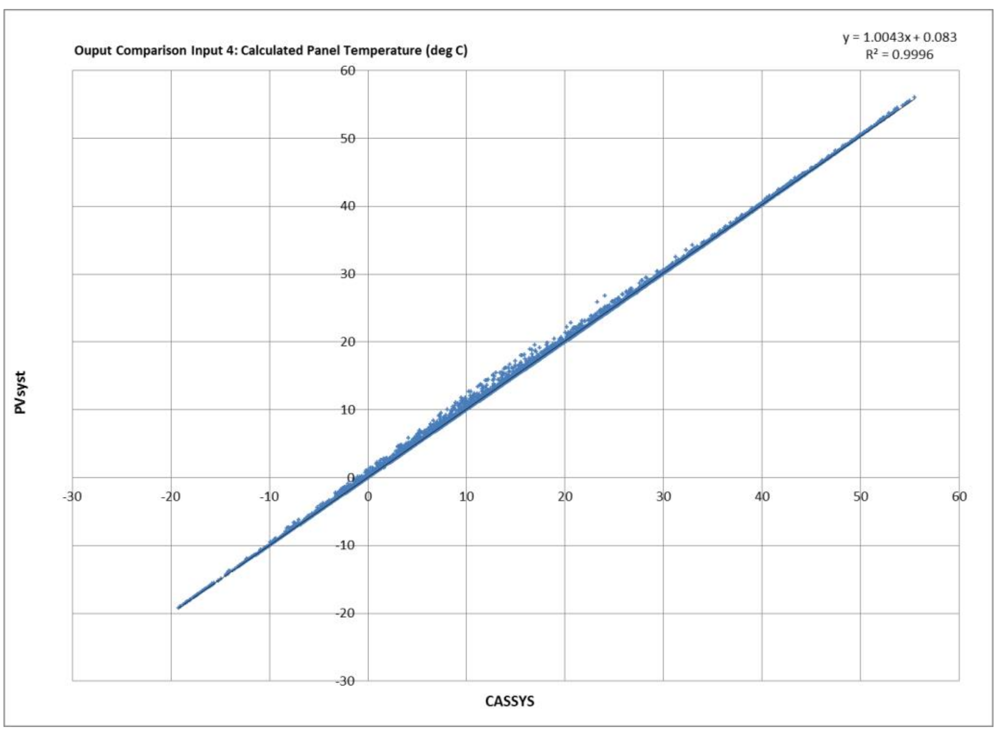

Figure 29: Calculated Panel Temperature (Test Case 4)

Appendix VI. Comparison charts for Test Case 5: PVsyst recalculated POA Irradiance and Panel Temperature

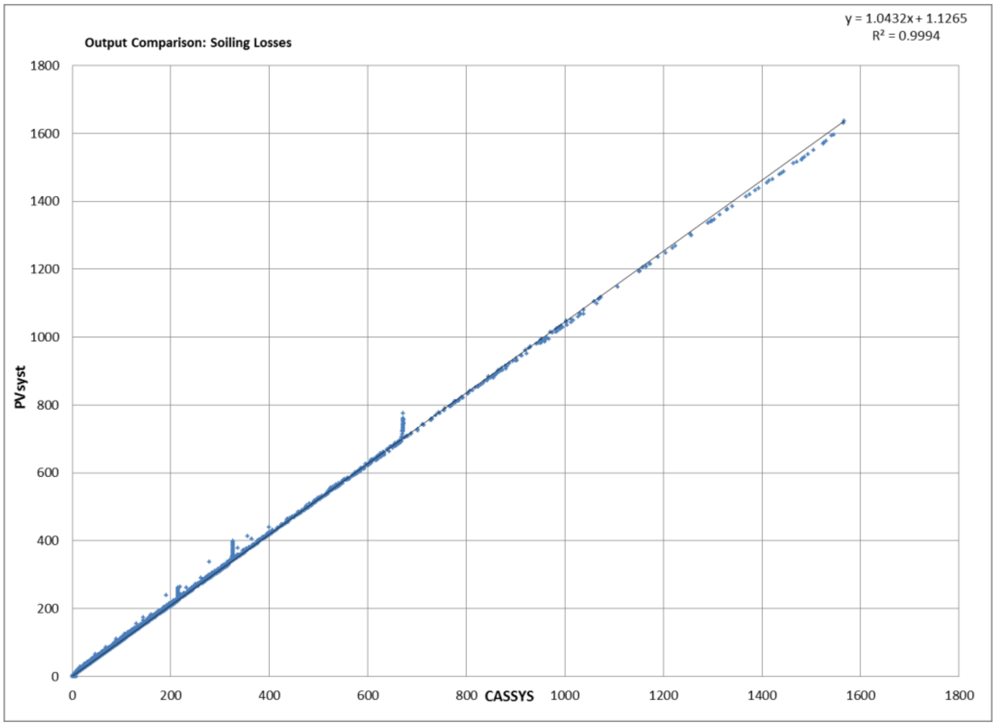

Figure 30: Soiling Losses (Set to different monthly values, Test Case 5)

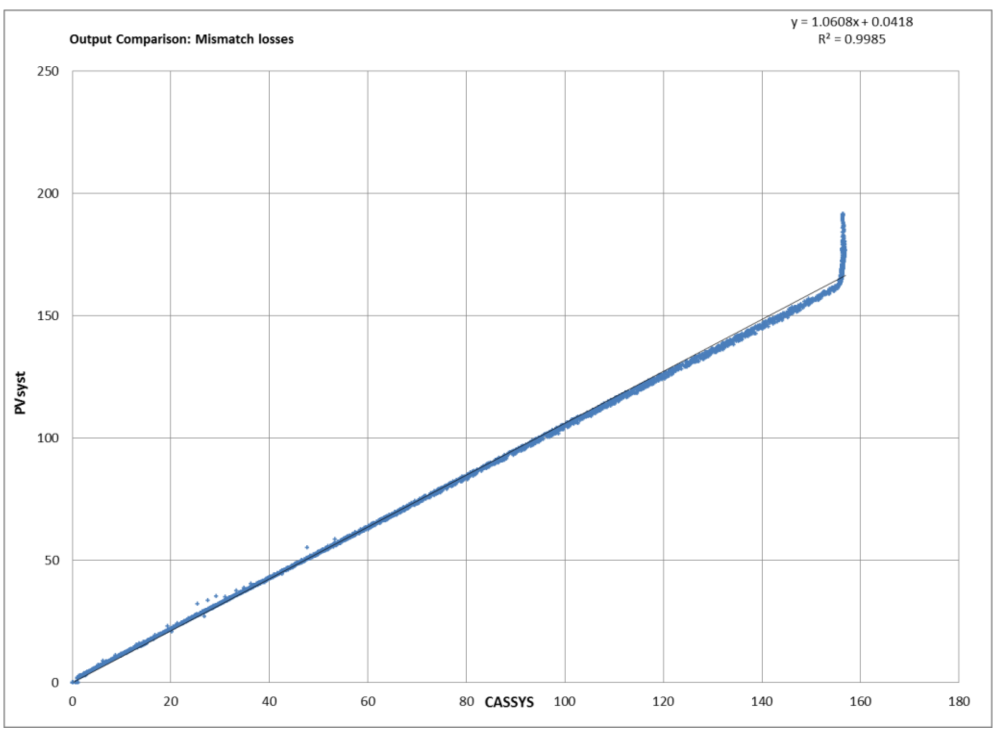

Figure 31: Mismatch losses (Set to 1.5% at STC and Fixed Voltage in both programs, Test Case 5)

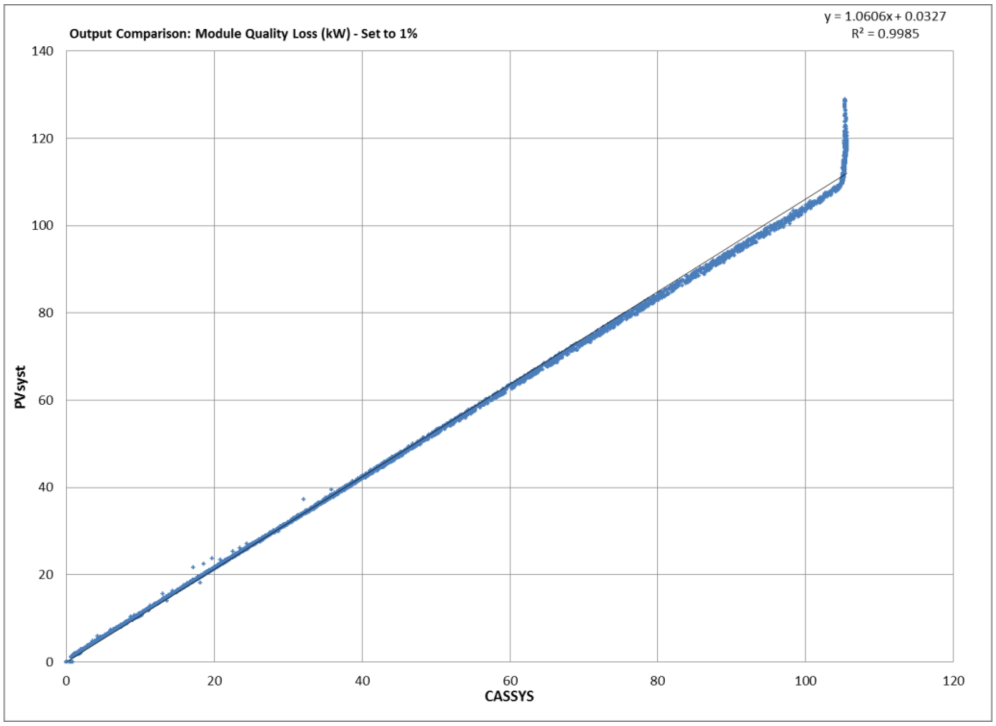

Figure 32: Module Quality Losses (Set to 1%, Test Case 5)

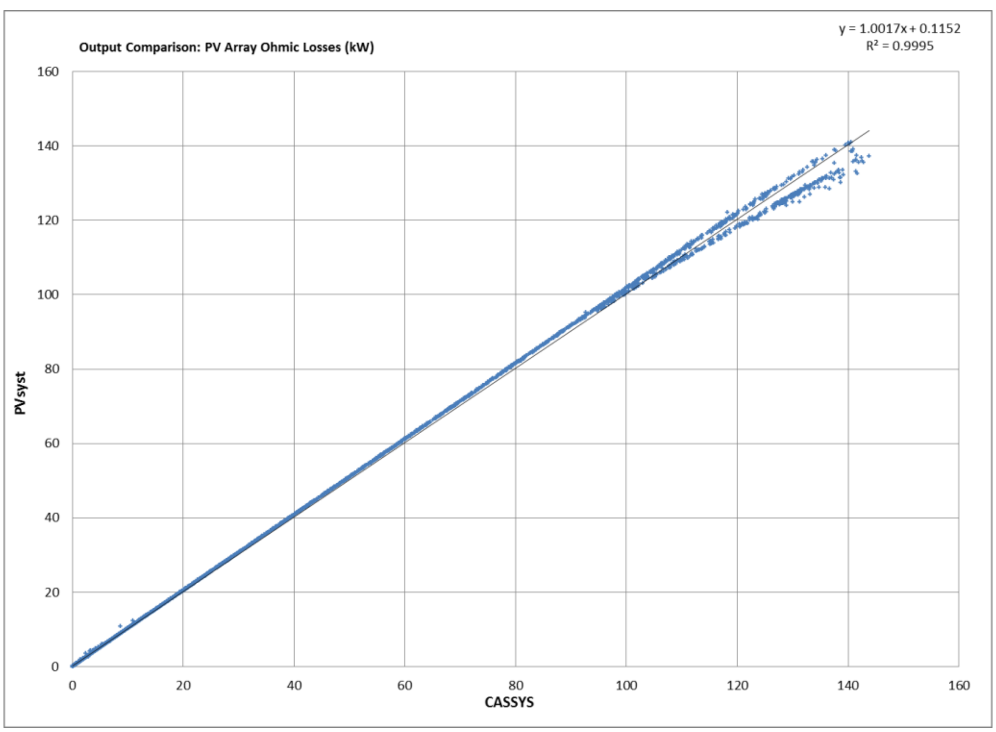

Figure 33: Ohmic Losses at the PV Array (Set to 1% for all sub-arrays, Test Case 5)

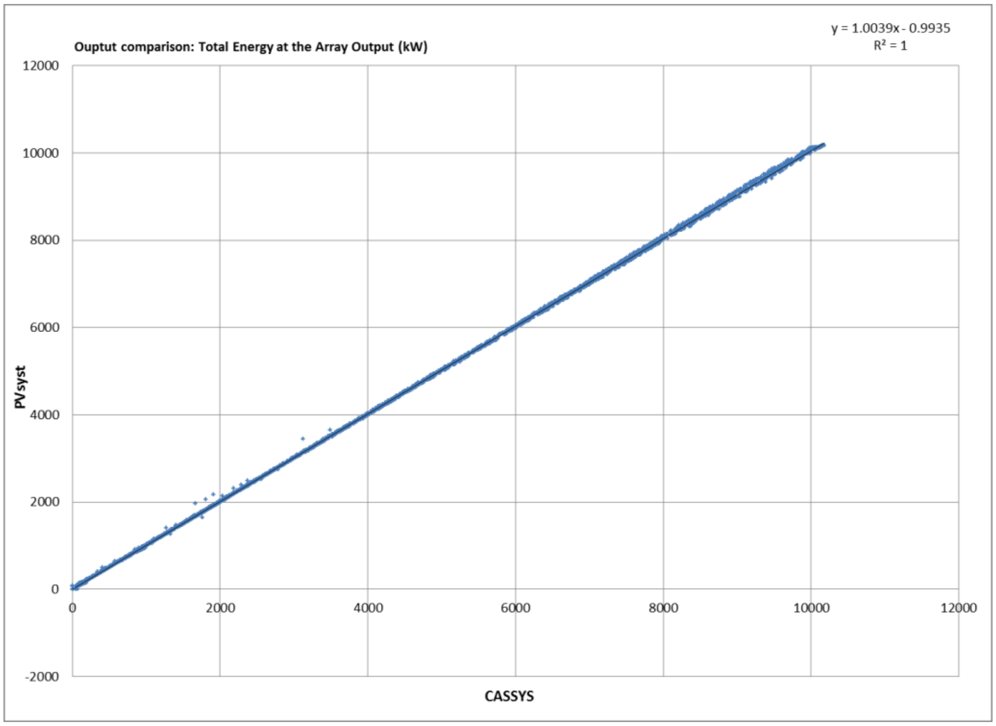

Figure 34: Total Energy at the Output of the Array (Test Case 5)

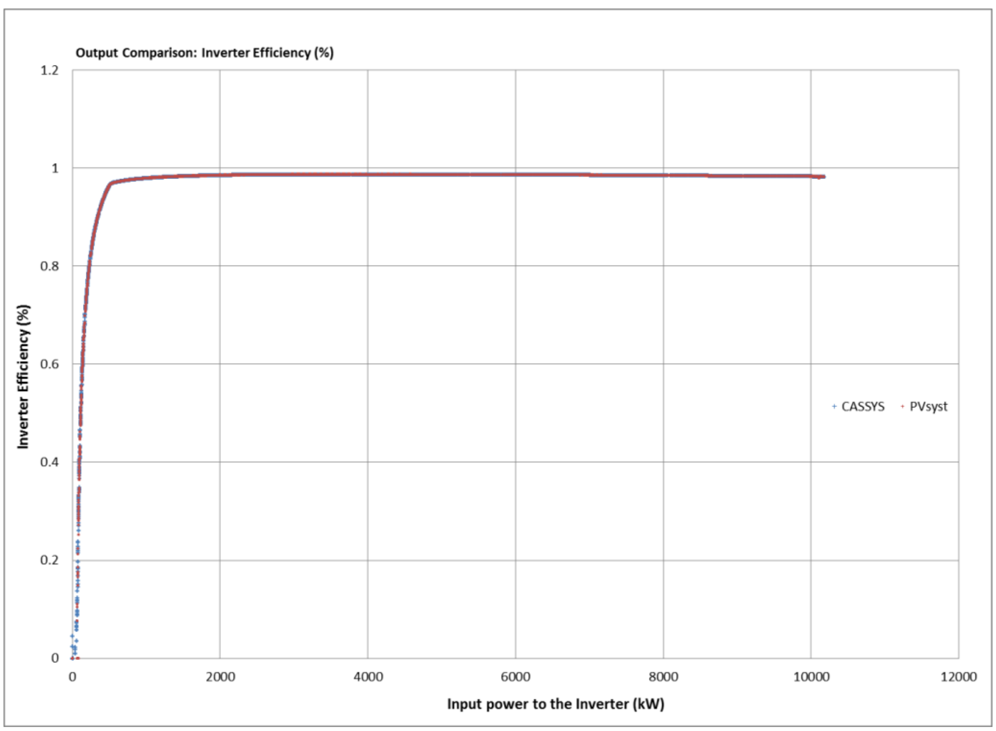

Figure 35: Inverter efficiency curves (Test Case 5)

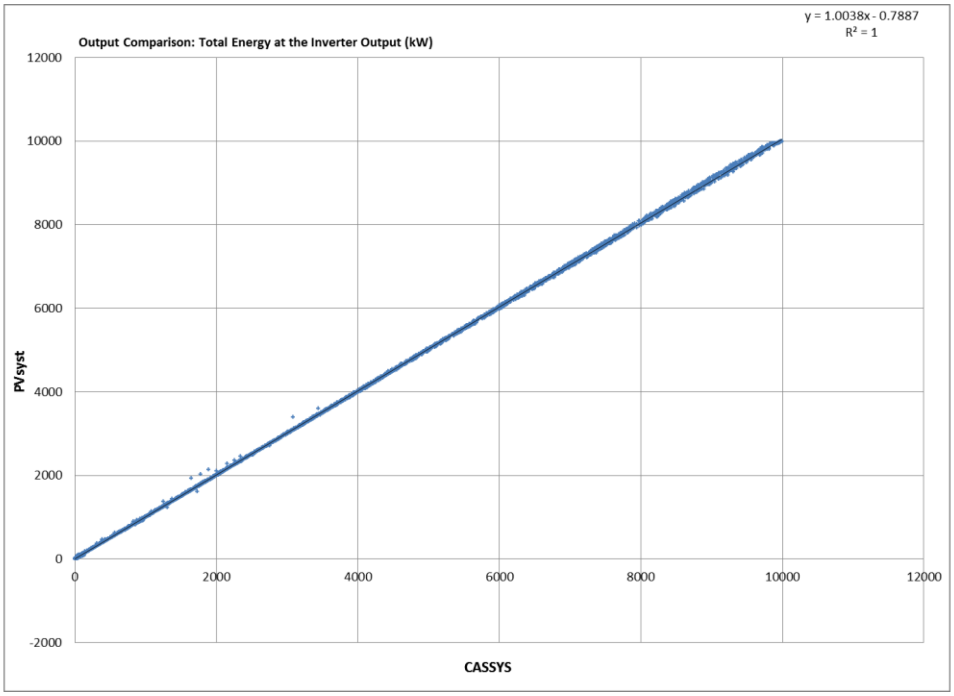

Figure 36: Total Energy at the Inverter Output (Test Case 5)

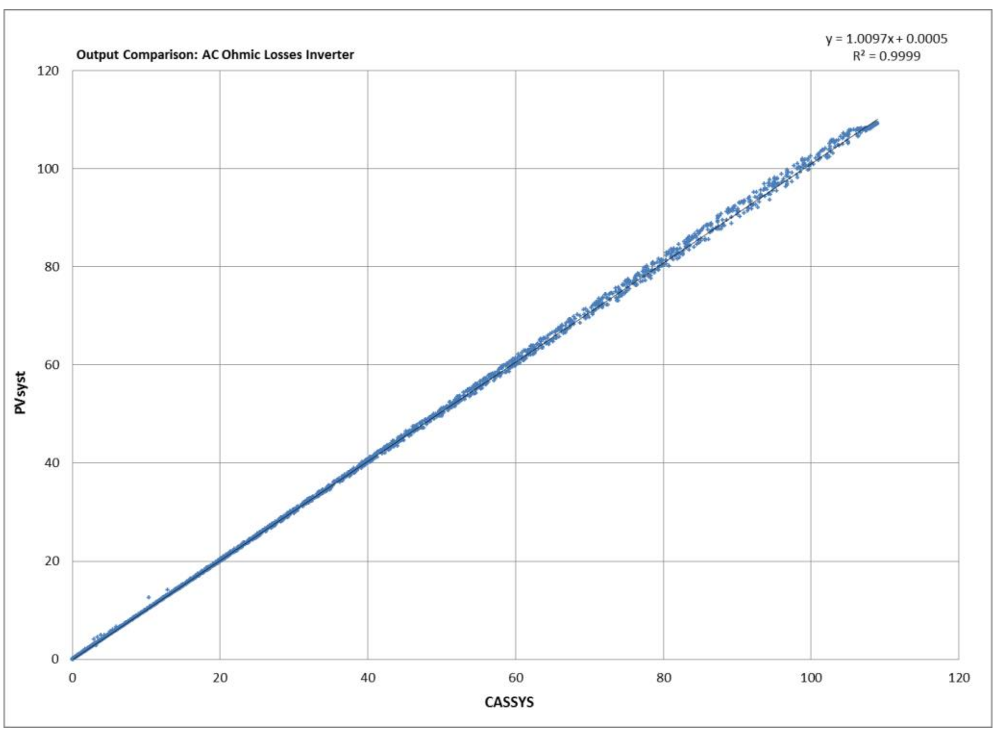

Figure 37: AC Ohmic Losses (Inverter to Transformer, Test Case 5)

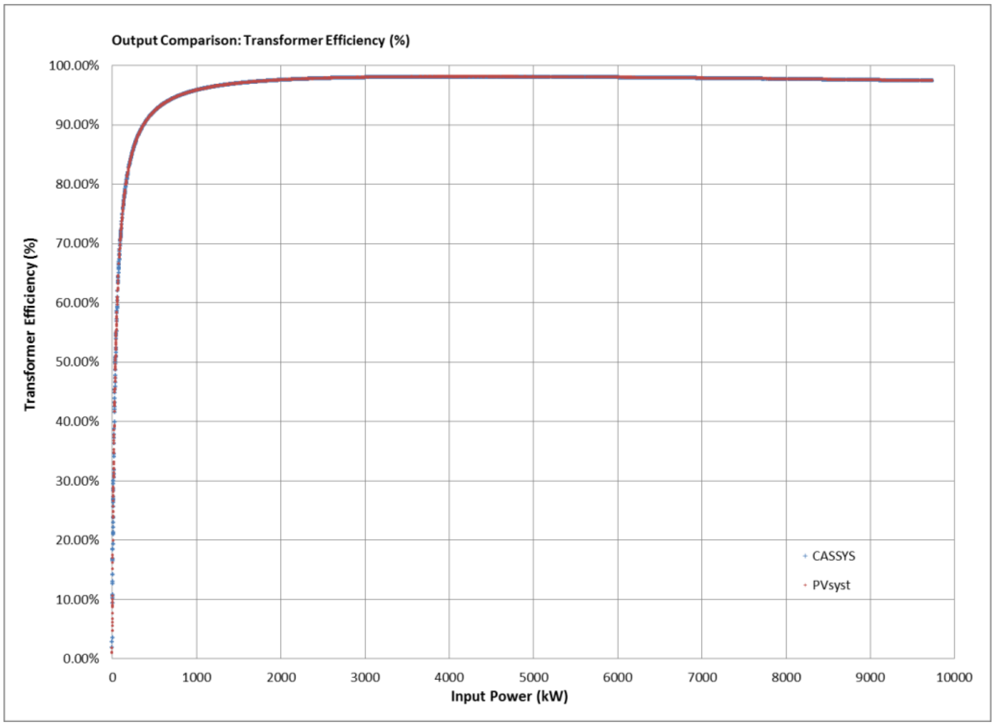

Figure 38: Transformer Efficiency (Test Case 5)

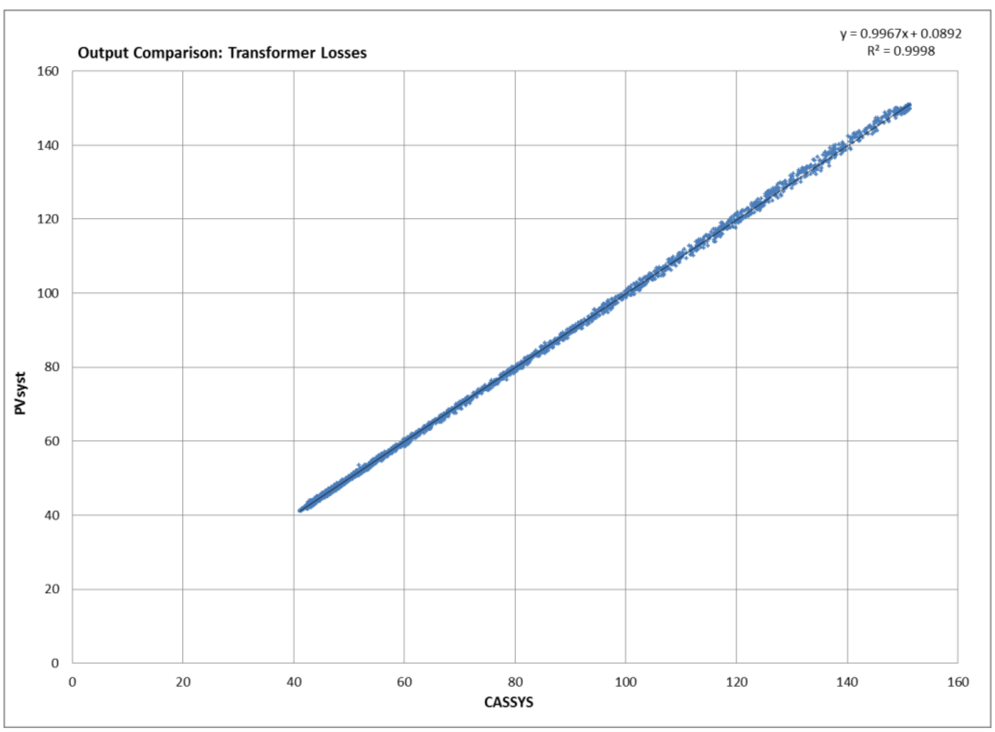

Figure 39: Transformer Losses (Test Case 5)

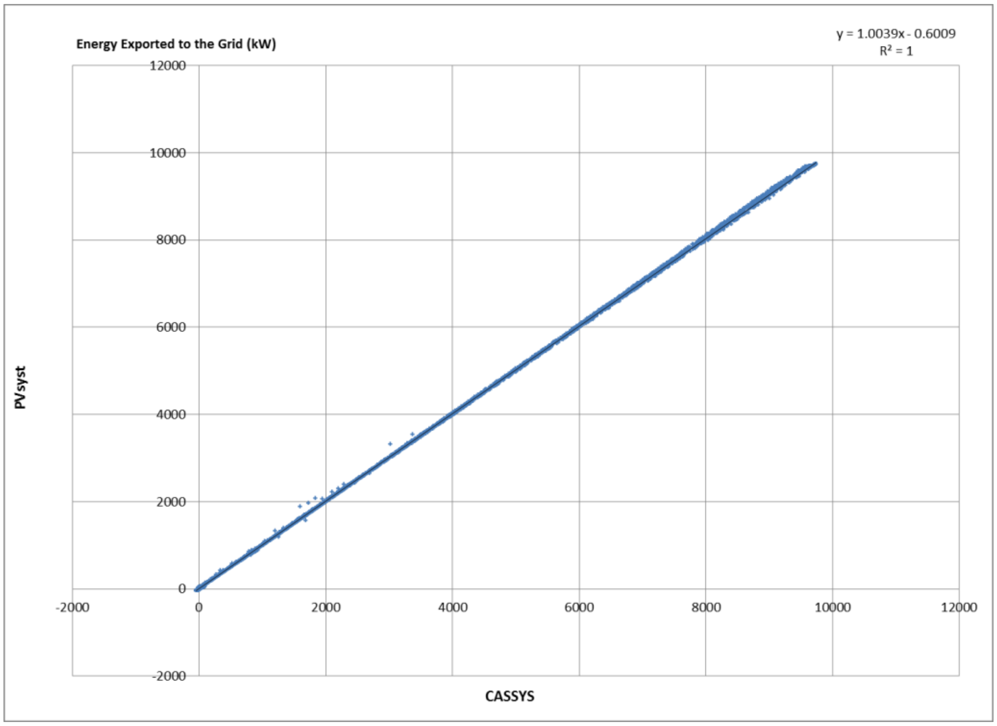

Figure 40: Energy exported to the Grid (Test Case 5)

Bibliography

[1] J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes 2 Ed., New York: Wiley-Interscience Publication, 1991.

[2] A. Mermoud, "Modeling Systems Losses in PVsyst," Universite De Geneve, [Online]. Available: http://energy.sandia.gov/wp/wp-content/gallery/uploads/Mermoud_PVSyst_Thu-840-am.pdf. [Accessed 18 February 2015].