ENERGY SIMULATION VALIDATION

SolarEdge Designer Review

SolarEdge Technologies Inc.

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Task and objective: Perform validation and evaluate performance of SolarEdge Designer web-based solar energy modeling software under specified conditions.

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1 EXECUTIVE SUMMARY

This report presents DNV GL's technical assessment of the photovoltaic (PV) energy simulation capabilities of SolarEdge Designer, a web-based software application that enables SolarEdge customers to model the performance of PV systems installed with SolarEdge products. The objective was to confirm that Designer is capable of producing energy estimates comparable to PVsyst, a solar energy modelling software commonly used in solar project financing.

The present study is comprised of a thorough review of five of SolarEdge's test cases from SolarEdge's internal validation work as well as an independent comparison of two additional systems prescribed by DNV GL. The seven test cases were selected, in part, to provide variation in site configuration (e.g. tilt angle, layout), technology and geographical location. DNV GL notes that this review's comparison was performed on the energy estimates from the two software applications alone and does not include any comparisons to measured field data.

The results of the comparison show that SolarEdge Designer was capable of estimating system energy to within 1% of a comparable PVsyst model on an annual basis for all seven test cases examined (see Table 1-1). The SolarEdge energy estimates were slightly lower, on average, with respect to PVsyst by approximately 0.2% annually. On an hourly basis, SolarEdge Designer exhibited an average bias of -0.2% and a variability of approximately 0.8% with respect to PVsyst. Moreover, a detailed breakdown of Designer's performance at intermediate steps along the sequence of energy estimation steps also confirmed good agreement and general process consistency with PVsyst.

In conclusion, DNV GL considers the alignment between Designer's energy estimation process and PVsyst to be remarkably good, and that SolarEdge Designer is likely to perform similarly well for systems configured similarly to the test cases reviewed here. DNV GL notes that the results herein are based on shade-free sites.

Table 1-1: Final annual energy estimate results [MWh] comparison

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	51.14	39.94	4.95	13.16	29.26	13.94	12.01	-
Designer	51.08	39.85	4.94	13.22	29.28	13.91	11.93	-
Residual	-0.1%	-0.2%	-0.3%	0.4%	0.1%	-0.2%	-0.7%	-0.2%

2 INTRODUCTION

SolarEdge (the "Customer") has engaged DNV GL Energy USA, Inc. (hereafter "DNV GL") to perform a technical assessment of the SolarEdge Designer PV simulation software application ("Designer"). Designer is a web-based application that enables SolarEdge customers to model solar PV systems via their web browsers.

DNV GL understands that SolarEdge intends for Designer to be used by customers and installers of SolarEdge products to estimate energy generation potential for roof-mounted solar energy systems and to assist their customers in selecting the most optimal components for a particular installation.

2.1 Objective & Scope

The scope of this study is to evaluate the energy estimation process only and excludes any review of Designer's other features, including its user interface or the recommendations Designer makes for configuring the input parameters of a simulation and equipment selection. The objective of this study is to confirm that Designer can produce energy estimates under certain conditions comparable to PVsyst. DNV GL notes that validation against real energy production measurements and financial implications of any specific results produced by Designer is beyond the scope of review.

2.2 Approach

There are several key stages in simulating the energy production process of any PV system which include: calculation of solar geometry, transposition from horizontal to plane-of-array irradiance, estimation of irradiance reduction effects, conversion from irradiance to electricity, conversion by the inverter, and estimation of various losses throughout. A reasonable approach for evaluating the validity of an energy estimation tool is to compare results from the tool under evaluation with PVsyst at these various stages of the simulation process both to confirm similarity of results and to identify potential discrepancies. This was the approach taken by DNV GL in this study.

SolarEdge had, prior to this engagement, conducted their own internal validation assessment using a framework that similarly referenced PVsyst as the benchmark. In this study, SolarEdge simulated a number of PV systems to determine how Designer would perform under various configurations. While the test cases varied in geographical location, installed equipment, and electrical layout, it fell short of being a controlled parametric study. Given the alignment between the methodologies used in SolarEdge's previous validation work and DNV GL's typical approach, DNV GL felt it was appropriate to base this assessment on an independent review of a subset of SolarEdge's original test cases along with two additional PV systems prescribed by DNV GL.

2.3 Comparison with PVsyst

PVsyst is a widely-used, commercially-available PV power plant simulation tool offered as a desktop software application. While no software can exactly predict the outcome of a complex, real-world process, PVsyst has long been an industry-standard. It includes robust mathematical models for each of the critical steps in the PV power modelling sequence, including options for experts to prescribe heuristic adjustments that can account for secondary mechanisms such as Module Quality Factor and monthly soiling. Designer follows a comparable sequence of calculations to PVsyst and can also provide users a breakdown of the energy losses at each simulation stage. Comparisons between applications were made primarily for the final output energy at an annual interval, but secondary comparisons at intermediate stages of the simulation as well as at higher temporal resolution were also made to pinpoint the sources of discrepancies. For this study, version 6.73 of PVsyst was used in all test cases.

3 TEST CASES

It was not within the scope of this study to perform a controlled parametric study, whereby DNV GL would methodically iterate through combinations of input values to explore the sensitivity and performance of Designer over a range of probable parameterizations. Nevertheless, there is value in conducting the validation over as diverse a set of input conditions as reasonable in order to demonstrate Designer’s general viability. From a list of 15 systems provided by SolarEdge, DNV GL selected five test cases using the following considerations:

- Geographic location: certain meteorological traits (temperature, humidity) and certain properties of the solar resource (traversal path in sky, seasonal variation of cloudiness) will need to be well captured by any good model; having diversity in location can help expose deficiencies in these critical calculation steps

- Array orientation: this factor is critical to the calculation of plane-of-array irradiance from horizontal (transposition) as well as irradiance reduction factors (incidence angle modifiers); for systems with panels tilted in multiple directions, proper handling of irradiance mismatch is essential

- Module and Inverter models: Designer supports only SolarEdge-branded inverters and optimizers but does not place any explicit limitation on the type of modules that can be used in a simulation; Designer includes a database of module datasheet and modelling parameters sourced from Photovoltaikforum, a source that DNV GL has not qualified for this study

In addition to the 5 systems selected from SolarEdge’s internal validations, DNV GL also independently designed and modelled two additional systems in PVsyst to compare against Designer, bringing the total number of PV systems reviewed in this study to seven. DNV GL’s principal motivations for adding the additional systems were to reinforce the independence of this study and to augment the final sample size. Secondarily, one of the two additional systems prescribed by DNV GL was specifically designed to have multiple array orientations, since all other test cases consisted only of single-orientation designs. While testing one system does not represent a statistically significant evaluation of multi-orientation accuracy, it serves as a check that such a common system configuration is supported by Designer to an acceptable degree. A list of the final test cases used in this study is presented in Table 3-1.

After submitting the data request to SolarEdge, DNV GL registered a new user account on the SolarEdge Designer website where the seven Designer models created by SolarEdge were made available. Via this web interface, DNV GL had access to the user-configurable model inputs, including the site location, solar resource, installed equipment, and electrical layout for each PV system. Likewise, SolarEdge also provided the corresponding PVsyst models for the five systems they had originally created, including all files necessary for DNV GL to load, review, and rerun the energy simulation as well as to export the 8760 hourly data of the final and intermediate results.

Table 3-1: Design specifications of the study's seven test cases

Location	Capacity [kWdc]	DC/AC	Tilt angle	Azimuth angle	Module	Inverter*	Optimizer*
Melbourne	35.6	1.3	33	310	PM096B00_330	SE27.6K	P800p
Miami	24.7	1.2	21	180	JKM 325P-72	SE20KUS	P850
Mumbai	3.1	1.4	15	160	JAM6-60-260/Si	SE2200H	P505
Rome	21.6	1.4	33	210	MVX245-60-5-7B1	SE16K	P730
Seattle	11.0	1.2	38	180	BSM c- Si M 60plus S EU56117_V1_275 Wp	SE9KUS	P730
Phoenix	8.3	1.4	17	268	JAM6-60-260/Si	SE6000H	P505
Fort Meyers	8.3	1.4	15	297/117	JAM6-60-260/Si	SE3000H	P505

* only SolarEdge products are available for use in Designer

4 RESULTS

A single simulation was performed using each of the two applications for each of the seven test cases (14 total simulations). The monthly and total annual energy production estimates for all test cases is presented in Table 4-1. When comparing the results from Designer to PVsyst, DNV GL defines the residual or the disparity as (*Designer* – *PVsyst*) and the relative disparity as ((*Designer*/*PVsyst*) – 1) throughout this study. Among the test cases considered, the average residual in total annual energy produced was approximately -0.2% of PVsyst's estimated annual production—indicating that Designer's annual production estimates were very slightly lower than PVsyst's corresponding results for these test cases. The monthly results comparison reveals some variability in the agreement between Designer and PVsyst over the course of a year, but also shows that the discrepancies were relatively minor.

In addition to the monthly and total annual energy results, DNV GL also computed descriptive statistics to describe the agreement between Designer and PVsyst at the hourly time interval. Similar to the definition of the relative disparity, all relative measures are normalized to PVsyst's results. Three statistical metrics are used in this study and are defined below:

- Mean Bias Error (MBE) is calculated by taking the arithmetic mean of the residuals for any output variable in a given sample (e.g., 8760 hourly data points will be averaged to determine the MBE over a one-year period); the MBE quantifies the persistent error between Designer and PVsyst;

Table 4-1: Comparison of PVsyst and Designer energy estimates [MWh] for all seven test cases

Site		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Melbourne	PVsyst	5.76	4.93	5.13	3.71	2.88	2.49	2.87	3.41	4.23	4.90	5.23	5.61	51.14
	Designer	5.77	4.93	5.13	3.70	2.87	2.47	2.85	3.40	4.22	4.90	5.23	5.61	51.08
	Residual	0.2%	0.1%	-0.0%	-0.3%	-0.5%	-0.6%	-0.6%	-0.4%	-0.2%	-0.1%	-0.1%	0.1%	**-0.1%**
Miami	PVsyst	3.00	3.08	3.77	3.84	3.62	3.25	3.64	3.53	3.27	3.28	2.86	2.81	39.94
	Designer	3.00	3.07	3.76	3.83	3.61	3.24	3.64	3.52	3.26	3.27	2.85	2.80	39.85
	Residual	-0.1%	-0.4%	-0.1%	-0.2%	-0.3%	-0.3%	-0.1%	-0.3%	-0.3%	-0.3%	-0.3%	-0.2%	**-0.2%**
Mumbai	PVsyst	0.43	0.43	0.51	0.50	0.49	0.36	0.30	0.31	0.37	0.43	0.41	0.40	4.95
	Designer	0.43	0.43	0.51	0.50	0.49	0.36	0.30	0.31	0.37	0.43	0.41	0.40	4.94
	Residual	-0.2%	-0.2%	-0.2%	-0.3%	-0.2%	-0.4%	-0.4%	-0.5%	-0.3%	-0.2%	-0.3%	-0.4%	**-0.3%**
Rome	PVsyst	1.51	1.89	2.71	2.71	3.20	3.19	3.43	3.20	2.60	2.17	1.49	1.18	29.26
	Designer	1.51	1.89	2.71	2.71	3.20	3.19	3.43	3.20	2.60	2.17	1.49	1.18	29.28
	Residual	0.1%	-0.1%	0.1%	-0.0%	0.1%	0.2%	-0.0%	0.1%	0.2%	0.1%	0.1%	-0.3%	**0.1%**
Seattle	PVsyst	0.45	0.71	1.02	1.41	1.47	1.51	1.79	1.68	1.39	0.86	0.52	0.36	13.16
	Designer	0.45	0.71	1.02	1.42	1.48	1.52	1.79	1.69	1.39	0.87	0.52	0.36	13.22
	Residual	0.9%	0.4%	0.5%	0.8%	0.4%	0.9%	0.2%	0.5%	0.3%	0.8%	-0.4%	-1.1%	**0.4%**
Phoenix	PVsyst	0.73	0.83	1.16	1.42	1.58	1.58	1.49	1.41	1.23	1.03	0.80	0.68	13.94
	Designer	0.73	0.83	1.16	1.41	1.58	1.58	1.49	1.41	1.22	1.03	0.79	0.68	13.91
	Residual	-0.5%	-0.5%	-0.2%	-0.5%	-0.0%	0.1%	0.1%	0.1%	-0.5%	-0.3%	-0.8%	-0.6%	**-0.2%**
Ft Meyers	PVsyst	0.80	0.84	1.14	1.16	1.27	1.18	1.16	1.21	0.92	0.88	0.75	0.71	12.01
	Designer	0.79	0.84	1.13	1.15	1.26	1.17	1.15	1.20	0.91	0.88	0.74	0.71	11.93
	Residual	-1.0%	-0.2%	-0.6%	-0.9%	-0.9%	-0.7%	-0.6%	-0.8%	-0.5%	-0.5%	-0.9%	-0.6%	**-0.7%**

- Mean Absolute Error (MAE) is calculated by taking the arithmetic mean of the absolute value of the residuals for any output variable (note that a valid MAE is always non-negative);

Root Mean Square Error (RMSE) is calculated by taking the square root of the arithmetic mean of the square of the residuals for any output variable; the RMSE is a measure of the spread of the errors about its average in-sample bias and is always non-negative; high RMSE values indicate more scatter and variability.
Table 4-2 presents the descriptive statistics describing the agreement between Designer and PVsyst at an hourly level over a one-year period. The results show that the MBE between Designer and PVsyst at the hourly level was approximately equal to the disparity of the total annual energy for every test case. The average MBE and RMSE across the seven test cases are approximately -0.2% and 0.8%, respectively, of the average hourly production from PVsyst.

Table 4-2: Descriptive statistics of the 8760 hourly estimates for all seven test cases

Site	MBE [Wh]	MBE [%]	MAE [Wh]	MAE [%]	RMSE [Wh]	RMSE [%]
Melbourne	-6	-0.1%	32	0.5%	70	1.2%
Miami	-11	-0.2%	11	0.2%	23	0.5%
Mumbai	-2	-0.3%	2	0.3%	3	0.6%
Rome	-0.1	-0.0%	8.3	0.3%	16.5	0.5%
Seattle	6.7	0.4%	7.6	0.5%	14	0.9%
Phoenix	-6.9	-0.4%	7.1	0.5%	13.3	0.8%
Ft. Myers	-8.8	-0.6%	8.9	0.7%	16.2	1.2%
Average	-	-0.2%	-	0.4%	-	0.8%

4.1 Loss tree comparison

The following section presents the comparisons between Designer and PVsyst for each of the key stages in the energy production simulation process. Since values computed in each step of the simulation inherit and build on values computed in the preceding steps, discrepancies in later stages can become progressively larger due to cascading errors, so the conclusions that can be reached become weaker as more discrepancies are identified.

4.1.1 Solar Resource and Geometry

SolarEdge Designer includes a convenient feature that automatically recommends several reference weather data sets ranked by the proximity of the weather station to a given project site. A user may use the weather data recommended by this feature or elect to upload hourly meteorological data sourced from elsewhere.

SolarEdge has informed DNV GL that the meteorological data provided by Designer’s native weather selection feature relies on meteorological data measured at a monthly interval. Meteorological data, including Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), Direct Normal Irradiance (DNI), and ambient air temperature, are effectively up-sampled from the monthly records using a series of computations that include various stochastic models.

DNV GL notes that Designer’s weather data procurement feature was beyond the scope of this review. Instead, hourly weather data (8760 points per year) were obtained from Meteonorm for each of the seven test cases and used as the “typical year” weather input for both Designer and PVsyst.

Table 4-3 presents the total annual global horizontal insolation from each test case in two units. Using the same weather file in both applications ensured that the models started with the same conditions and on equal footing. Having equivalent weather inputs also enabled more compelling and meaningful comparisons to be made at the next stages of the simulation.

Table 4-3: Annual total and daily average global horizontal insolation used by each test case

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers
GHI [MWh/m^2]	1.53	1.75	1.84	1.40	1.19	2.07	1.75
GHI [kWh/m^2/day]	4.19	4.79	5.04	3.84	3.26	5.67	4.79

4.1.2 Irradiance Transposition

Quantifying the magnitude of irradiation that is incident on and transmitted through the module stack and onto the solar cell requires multiple computational steps. Transposition is the calculation of the incident irradiance on a tilted plane from the horizontal irradiance data and is the first of the computational steps.

According to documentation provided by SolarEdge, Designer utilizes the Perez model [1,2] for irradiance transposition. This popular model is one of several transposition models available in PVsyst; therefore, all simulations in this study were set to use the Perez transposition model. DNV GL notes that Designer can only model fixed-tilt systems, so trackers cannot be simulated in Designer at the moment.

In principle, the Perez transposition model divides irradiance into three components: direct beam, sky diffuse, and ground diffuse. Because there are very few weather data sources that include measurement of these auxiliary quantities, it is typical to use a mathematical model to estimate diffuse irradiance as well. However, regardless of which transposition model is chosen, PVsyst uses the Erbs [3] diffuse estimation model while Designer uses DIRINT [4]. Fortunately, some sources of irradiance data, like Meteonorm, include pre-computed estimates of DHI along with GHI. Using Meteonorm allowed the circumvention of the diffuse model and the need to reconcile the choice of implementation, as both Erbs and DIRINT have strengths and weaknesses. The ground diffuse component of irradiance is partially a function of the specified albedo for the site. The value of albedo (a value between 0 and 1) is fixed at 0.2 in Designer and user-defined in PVsyst; therefore, all test cases have been parameterized with an albedo equal to 0.2 to be consistent. The results of the transposition step are displayed on Table 4-4.

Table 4-4: Percentage change from horizontal irradiance to plane-of-array irradiance

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	5.2%	6.8%	5.3%	13.5%	11.0%	-1.6%	-2.4%	-
Designer	5.2%	6.8%	5.2%	13.6%	11.0%	-1.6%	-2.3%	-
Residual	0.0%	0.0%	-0.1%	0.1%	0.0%	0.0%	0.1%	0.0%

The errors between PVsyst and Designer were essentially negligible for the transposition step in all cases, validating that SolarEdge has properly implemented the Perez transposition model in Designer. Furthermore, while Designer’s implementation of the DIRINT model for diffuse irradiance estimation was not specifically reviewed, the successful implementation of the Perez model has given DNV GL confidence that other open-source models are likely to have also been correctly implemented elsewhere in Designer.

4.1.3 Incidence Angle

Light rays can be thought to be hitting the surface of a module at anywhere between 0° and 90° angles. However, the transmittance of irradiation through the module is a function of the angle of incidence (AOI) and the materials in the stack and therefore ought to be captured by a model. By default, both Designer and PVsyst implement the ASHRAE model to calculate the incident angle modifier (IAM). The ASHRAE model has only one input parameter b_0 that has a default value of 0.05 with no units. While this parameter can be modified in PVsyst, it is immutable in Designer. In this study, the default parameterization of the ASHRAE model was used in all PVsyst runs. The results of the reflection-loss calculation step can be seen on Table 4-5.

Table 4-5: Percent loss from incidence angle reflection

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	-3.0%	-3.0%	-3.0%	-2.9%	-2.9%	-3.5%	-3.5%	-
Designer	-3.3%	-3.3%	-3.3%	-3.5%	-3.1%	-3.6%	-3.6%	-
Residual	-0.3%	-0.3%	-0.3%	-0.6%	-0.2%	-0.1%	-0.1%	-0.3%

While there were no large errors between PVsyst and Designer for any of the test cases, the results do reveal a bias across all test cases showing Designer to be consistently overestimating the reflection loss with respect to PVsyst. DNV GL notes that the inability to specify the b_0 parameter restricts the number of cases in which the default ASHRAE model can be accurate to reality. PVsyst not only permits changing the value of b_0, but the user may also specify their own custom model, i.e., one measured in a laboratory. Yet while the impact of IAM models on annual yields may not seem substantial, a bankable energy assessment tool ought to have more flexibility.

4.1.4 Irradiance losses

Up until this point in the energy estimation process, irradiance has been assumed to be travelling uninhibited from the sky above. In reality, there are a number of ways by which the incident irradiance can be attenuated:

1. Horizon shading (sunset over mountain ridge)
2. Near shading (tree, chimney, modules in the row ahead)
3. Soiling (dust, soot, bird droppings)
4. Snow
5. Spectral mismatch

At the time of writing, the version of Designer tested had not yet implemented any models for these mechanisms of irradiance attenuation. As such, all test cases were modelled in PVsyst to be free of any shading, soiling, and mismatch with respect to the AM 1.5 reference for the solar spectral distribution. [5] DNV GL anticipates that the usage of a robust shading model will benefit Designer users, who are likely to design systems atop commercial or residential properties that are susceptible to shading losses.

4.1.5 Irradiance to Electricity Conversion

Once the effective irradiance has been determined, it is combined with air temperature and wind speed to form the inputs to a series of models that will convert everything into dc energy. According to SolarEdge documentation provided to DNV GL, the first computational step taken by Designer is to determine the nominal dc energy obtained using the module efficiency measured under Standard Test Conditions (STC), with a temperature of 25°C, an irradiance of 1000 W/m^2, and at a spectrum equal to AM 1.5. The nominal dc energy calculated at this step can be seen on Table 4-6. At this stage in the energy simulation process, the residuals show good agreement between Designer and PVsyst, with an average residual from across all test cases approximately equal to -0.2%. In these idealized cases with no irradiance loss, Designer has shown the ability to model the effective radiance available to a solar cell to well within 1% of PVsyst on an annual level.

Table 4-6: Nominal DC energy at STC efficiency

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	56.0	44.9	5.9	14.4	32.6	16.4	13.7	-
Designer	55.7	44.8	5.9	14.4	32.6	16.3	13.7	-
Residual	-0.5%	-0.4%	-0.1%	-0.2%	0.0%	-0.1%	0.0%	-0.2%

Next, Designer must correct for the fact that module efficiency varies with irradiance level. The exact relationship between irradiance and efficiency varies from module to module and is typically parameterized by coefficients determined from laboratory measurements. PVsyst employs a one-diode model to simulate a solar cell's equivalent circuit and relies on empirical coefficients to accurately calculate a module's electrical efficiency under various irradiance and cell temperature conditions. DNV GL has not reviewed any literature describing Designer's algorithms nor any source code in detail, but the sequences of the steps described by available documentation suggests that Designer's algorithm for calculating module power is comparable to that of PVsyst. Table 4-7 shows the results of applying the correction to account for low-irradiance performance. The residuals once again reveal close agreement between Designer and PVsyst.

Table 4-7: Percent loss due to irradiance corrections to STC

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	-0.9%	-0.5%	-0.4%	-1.6%	-0.8%	-0.3%	-0.5%	-
Designer	-0.8%	-0.5%	-0.5%	-1.2%	-0.8%	-0.4%	-0.7%	-
Residual	0.1%	0.0%	-0.1%	0.4%	0.0%	-0.1%	-0.2%	0.0%

In addition to irradiance, temperature also influences the conversion efficiency of PV modules. Documentation from SolarEdge revealed that Designer computes the cell temperature based on effective irradiance, air temperature, and wind speed in a manner identical to PVsyst. This temperature model has two coefficients parameterizing a given system's rate of conductive and convective heat transfer. The value of the conductive heat transfer term (U_C) is automatically selected by Designer based on the choice of mounting—with a value of 20 given for flush mounted systems and 29 for tilted fixtures. The convective heat transfer term (U_V) is set to zero, effectively ignoring any cooling effect winds may exert. In windy locations, the choice to ignore wind cooling would likely result in an underprediction of annual energy with all things being equal. The results of the temperature correction to the nominal power are presented in Table 4-8. The average residual across all test cases is approximately 0.2%.

Table 4-8: Percent loss due to temperature corrections to STC

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	-3.7%	-7.7%	-12.4%	-2.1%	-5.5%	-12.3%	-10.3%	-
Designer	-3.2%	-7.6%	-12.2%	-2.1%	-5.4%	-12.2%	-10.2%	-
Residual	0.5%	0.1%	0.2%	0.0%	0.1%	0.1%	0.1%	0.2%

4.1.6 Miscellaneous DC Losses

The next step in the modelling sequence is to calculate the optimizer efficiency loss based on module power, string current, and SolarEdge optimizer model. This modelling step is only necessary when optimizer technology is installed. The results presented in Table 4-9 show very good agreement between Designer and PVsyst and their handling of optimizer efficiency loss calculation.

Table 4-9: Percent loss due to optimizer efficiency

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	-0.6%	-0.8%	-1.4%	-0.8%	-0.8%	-0.6%	-0.6%	-
Designer	-0.6%	-0.7%	-1.2%	-0.7%	-0.8%	-0.6%	-0.6%	-
Residual	0.0%	0.1%	0.2%	0.1%	0.0%	0.0%	0.0%	0.1%

Due to slight variations in manufacturing, panels of the same model and factory batch can have slightly different output powers. This difference is expressed on some module datasheets as power bin tolerance that sets bounds between which the actual power of a module lies. In Designer, this loss term is automatically generated in the background, but is hidden beyond a normal user's control. On the other hand, modification of this Module Quality Factor (MQF) term is not restricted in PVsyst. In fact, DNV GL's own standard operating procedures for energy assessments leverage the MQF term in PVsyst frequently as a heuristic adjustment for various phenomena that do not yet have a dedicated model to capture its impact on energy production. Table 4-10 presents the results of the intermediate MQF derate calculation step.

Table 4-10: Percent loss due to module power tolerance and quality

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	0.7%	0.7%	0.7%	0.5%	0.7%	0.7%	0.7%	-
Designer	0.7%	0.7%	0.4%	0.4%	0.8%	0.5%	0.5%	-
Residual	0.0%	0.0%	-0.3%	-0.1%	0.1%	-0.2%	-0.2%	-0.1%

DC ohmic losses occur when current flows through imperfectly conducting wires, characterized by their resistance. Since the resistance of the wire is related to its cross-sectional area and length, small-diameter or long wires have larger resistance than large-diameter or short wires, respectively. For a given resistance, power loss increases proportionally with the square of the current. However, Designer only considers wire length and not the diameter of the conductor in its automated calculation of dc ohmic loss. DNV GL has preferred to make this percentage loss estimate independently in our energy estimates and enter a percentage loss under STC conditions into PVsyst; however, this type of discretion cannot be exercised in Designer by a basic user. The results of this calculation step are presented in Table 4-11.

Table 4-11: Percent loss due to ohmic resistance in dc conduits

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.7%	-
Designer	-0.8%	-0.8%	-0.7%	-0.6%	-0.8%	-1.0%	-0.8%	-
Residual	0.0%	0.0%	0.1%	0.2%	0.0%	-0.2%	-0.1%	0.0%

Furthermore, the final dc energy results culminating at the input node of the inverter(s) are presented in Table 4-12. The results show that even after all the miscellaneous dc losses incurred after the initial conversion to electricity, agreement was still remarkably good with an average of -0.1% residual between Designer and PVsyst across all the test cases.

DNV GL understands that SolarEdge is incorporating support for Light-induced degradation (LID), though this feature was not available during the evaluation by DNV GL. LID is a phenomenon whereby the capacity of a newly manufactured PV module is quickly attenuated to a steady-state level below the nameplate value upon initial exposure to sunlight in the field. Prior to inversion to ac, the total dc generation is usually further derated in the simulation by the estimated impact of LID, which is usually manifest in the first weeks or months after field deployment. Because LID is modelled as a direct reduction in dc capacity, DNV GL would expect that this is a relatively straightforward update to the SolarEdge calculation process.

DNV GL notes that, because the SolarEdge system incorporate dc-dc optimizers on each PV module, the effects of electrical mismatch between modules are essentially eliminated. As such, SolarEdge Designer does not have a corresponding input to mimic the inputs screen of PVsyst. These losses are thus omitted from both Designer and PVsyst for the seven test cases.

Table 4-12: Annual energy production after DC losses [MWh]

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	53.1	40.9	5.0	13.7	30.3	14.2	12.2	-
Designer	53.1	40.8	5.0	13.8	30.3	14.2	12.2	-
Residual	0.1%	-0.3%	-0.4%	0.5%	0.0%	-0.3%	-0.2%	-0.1%

4.1.7 Inverter Power Conversion

The inverter is tasked with converting DC power into AC power. To do this, an inverter must modulate the dc array voltage until it coincides with the maximum power voltage of the connected array, subject to limitations of the operation and efficiency of a given inverter. SolarEdge inverters, which are used exclusively in Designer, are fixed voltage inverters modelled using SolarEdge's own datasheets and inverter efficiency curves. It is possible that these are the same manufacturer supplied modelling coefficients referenced by PVsyst. The results from the inversion step is presented below in Table 4-13.

Table 4-13: Percent loss from inverter efficiency

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	-1.9%	-2.1%	-0.9%	-3.7%	-2.1%	-0.8%	-0.8%	
Designer	-1.9%	-2.1%	-1.0%	-3.7%	-2.1%	-1.0%	-1.2%	
Residual	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.2%	-0.4%	-0.1%

Inverter clipping describes the condition when the instantaneous dc generation of a PV system exceeds the total rated capacity of the installed inverters. In the absence of grid curtailment or limits, the maximum power output of a system is capped by the combined rating of the inverters. Proper handling of inverter clipping is contingent on the accuracy of the inverter datasheet and of the results from previous simulation steps. Table 4-14 shows the results from the application of inverter clipping losses. Except for Melbourne, the disparities were essentially zero for this step. This represents the final simulation step taken by Designer; thus, any transformers or loads downstream of the inverters, including ohmic losses incurred between the output of inverters and the revenue meter at the point-of-interconnection, are not considered by Designer. The exclusion of these ac-side calculations are deleterious for modelling utility-scale power plants, but may be acceptable for systems metered directly at the inverters.

Table 4-14: Percent loss from inverter clipping

	Melbourne	Miami	Mumbai	Seattle	Rome	Phoenix	Ft Meyers	Average
PVsyst	-1.8%	-0.3%	-0.8%	-0.6%	-1.3%	-1.0%	-0.6%	
Designer	-2.0%	-0.3%	-0.8%	-0.6%	-1.3%	-1.0%	-0.6%	
Residual	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.0%

4.1.8 Other inputs and losses

In Section 4.1, DNV GL has noted aspects of the energy estimation process where Designer had either elected to set coefficients automatically for certain models that could otherwise be user-defined or neglect certain calculations all together. DNV GL notes that systems which require customizing any of the following parameters should consult with SolarEdge:

- Systems which utilize modules that specify a customer IAM profile
- Systems requiring a custom albedo value to address variations in reflectivity of different roof surfaces
- Systems where the prevalence of wind may result in higher convective cooling than assumed by the default value

5 CONCLUSIONS

DNV GL has performed a comparison of the energy estimation process between Designer and PVsyst. DNV GL's present study comprised of a thorough review of seven test cases selected, in part, to provide variation in site configuration (e.g. tilt angle, layout), technology, and geographical location. The results produced by both Designer and PVsyst were compared at various intermediate modelling steps (i.e., POA irradiance, electricity conversion, inverter input, inverter output) as well as at the final energy meter. The results were compared on an hourly, monthly and annual basis both to confirm similarities and to assess any disparities between applications. DNV GL also notes that the comparison was performed on the output of the two software applications alone and did not include comparisons to measured field data, so DNV GL is unable to comment on Designer's fidelity to real PV systems.

The seven sites were selected to be representative of roof-mounted, fixed-tilt, shade-free installations in several climates. For the cases evaluated, the results of the comparison indicate that SolarEdge Designer was capable of estimating system energy to within 1% of a comparable PVsyst model on an annual basis.

The SolarEdge energy estimates were slightly lower, on average, with respect to PVsyst by approximately 0.2% annually. The hourly and monthly variations have been provided to identify any daily or seasonal bias that may exist in the model. On an hourly basis, the Solar Edge model showed an average MBE and RMSE of -0.2% and 0.8%, respectively. On a monthly basis, SolarEdge Designer was reasonably consistent with the annual results, but some degree of residual variability over an entire year was observed. Moreover, a breakdown of Designer's performance at intermediate steps along the loss tree of a simulation also confirmed good agreement and general process consistency with PVsyst.

In conclusion, DNV GL considers the alignment between Designer's energy estimation process and PVsyst to be good and expects SolarEdge Designer to perform similarly well for other fixed-tilt and shade-free PV systems using SolarEdge inverters and optimizers.

6 REFERENCES

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