Original Research Article

Solar star projects SAM version 2017.9.5 PVwatts version 5 model case study & validation

hosted by
Turkish JournalPark ACADEMIC

Burak Ömer Saraçoğlu

Orhantepe Mahallesi, Tekel Caddesi, Geziyolu Sokak, 34865 Dragos, Kartal, Istanbul, TURKEY

ARTICLE INFO

ABSTRACT

Very Large Photovoltaic Solar Power Plants (VLPVPPs) are a major revolutionary step up not only for economies of scale, but also for %100 renewable power Global Grid. Their designs and investments should be performed in an environmentally friendly, fair, open to very large to small private investors, transparent and reducing relative income inequality approaches. Their investments will easily be possible with new investment models (%0 interest load, %100 private equity, open investment for ordinary people, project developers, private companies etc. with a constraint-based shareholder structuring). These revolutionary investment models will play an important and game changing role. VLPVPPs' early engineering and investment analysis can be performed in many software. Therefore, validation and verification efforts of those software in advance on the operational PVPPs are essential. This research study aims to present a validation and verification accomplishment of the Solar Star Projects (597 MW$_{AC}$, 747.3 MW$_{DC}$) (Solar Star I: 318 MW$_{AC}$, 397.8 MW$_{DC}$ & Solar Star II: 279 MW$_{AC}$, 349.5 MW$_{DC}$) in Antelope Valley near Rosamond, Kern and Los Angeles counties, California, United States with the PVWatts Version 5 model of the National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) Version 2017.9.5. The location and resource, system design data and information on the Solar Star Projects (I & II) are presented based on open source information and personal communications. The Solar Star Projects SAM software models' are simulated on a personal computer (PC) (Windows 10 Pro, Intel(R) Core(TM) i5 CPU 650 @ 3.20 GHZ, 6,00 GB RAM) with the internet connection. The results of eight simple simulations, one parametric simulation and one stochastic simulation are compared with the actual generation data by the help of some statistical performance measures (e.g. annual model/actual: 100,0%, annual model/actual: 100,1%, absolute maximum forecast error 39.276 MWh, mean absolute error 11.554 MWh, geometric mean absolute error 8.924 MWh, mean square error 2.662.330.229 MWh, root mean square error 51.597 MWh).

1. Introduction

Very Large Photovoltaic Solar Power Plants (VLPVPPs) are the key elements of %100 renewable power grids [1]. They have a major advantage, *economies of scale*, amongst all other PV power plant sizes (i.e. large, medium, small). They will also help other proposed models such as *green roof* for cities, that can help plantation and animal wildlife, urban farming, noise reduction, air quality improvement, heat island prevention, rain water harvesting, storm water managing, and flood control [2-4]. Their investments won't be difficult with new investment models (0% interest load, 100% private equity, open investment for ordinary people, project developers, private companies, etc. with some constraint-based shareholder structuring) (e.g. Halal

investment, Islamic investment), that will also help the income inequality reduction on the World, as in today's conditions (Figure.1) [5-12]. This research study aims to build the preliminary foundations of the VLPVPPs' design, engineering and investment processes.
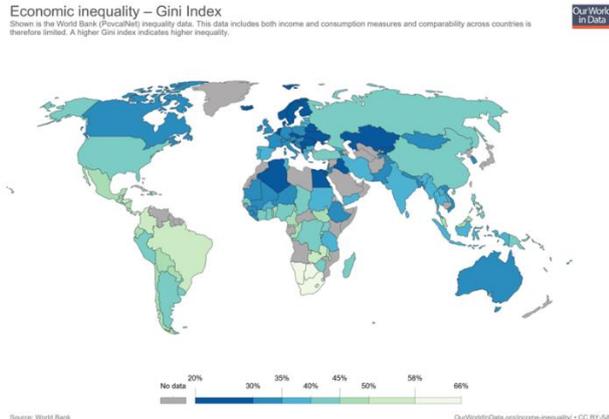

Figure 1. GINI index (World Bank estimate) [11, 12]

The VLPVPP's design and engineering process isn't much different from the photovoltaic solar power plants' (PVPPs) design and engineering process. The PV design software is important in this design and engineering process. There are many free and commercial off-the-shelf PV software alternatives (e.g. the German Ministry for Economic Affairs and Energy FreeGreenius [13], the National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) [14-17]). They have their own models and algorithms for their calculations and simulations. Thus, their validation and verification research studies and publications are necessary and important in the literature. Moreover, these validation and verification research studies and publications will guide the solar design and engineering teams in their real-life projects. These research studies and publications will also help at first templatization and then automatization of the solar power plant design and engineering process. This research study focuses on the NREL SAM software for the PV design and engineering process [14-17]. The rest of this work is organized as follow: in Section 2, the robust uncertainty modelling of output power and rotational speed of electric motors are realized. In Section 3, the mechanical structural analysis under the stochastically modelled variables of electric motors, and modelling the torque uncertainty via a case study is implemented. In Section 4, a conclusion explaining the contributions of this work is briefly drawn.

The NREL SAM's research, development, deployment & demonstration (RD^3) efforts have integrated for as such the model RD^3 processes, the weather data sources RD^3 processes, the component parameter databases RD^3 processes by many institutions such as the National Renewable Energy Laboratory (NREL), the University of

Wisconsin (UW), the Sandia National Laboratories, and the California Energy Commission (CEC) under the main RD^3 funding organization, the U.S. Department of Energy (DOE) [14-23]. The NREL SAM has some performance models to calculate the power output in several technologies (i.e. photovoltaic, concentrating photovoltaic, concentrating solar power) and some financial models to calculate some financial metrics (i.e. net present value, payback period) [14, 24, 25]. Many researchers (i.e. Paul Gilman, Henry Price, Michael J. Wagner, Guangdong Zhu, Aron P. Dobos) have contributed and developed these models [14, 24, 25]. There are 41 versions and updates (Version 1.1 August 10, 2007 to Version 2017.9.5 Revision 2, SSC Version 180: October 30, 2017) [17]. This research study addresses the latest NREL SAM software release (Version 2017.9.5, 64 bit, updated to revision 2 SSC Version 180: Windows 64-bit Visual C++) and the latest PVWATTS model version (PVWatts V5) [14, 17, 24, 26].

There are several PV cell technologies (i.e. monocrystalline silicon: Mono-Si or sc-Si, cadmium telluride: CdTe) with different cell efficiencies (i.e. 46.0%; 27.6%; 26.6%; 25.8%) in the photovoltaic solar power industry. One of the most advanced and concise presentation of the PV cell technologies by the A.T. Kearney Energy Transition Institute in Paris, France and the best research cell efficiencies by the National Center for Photovoltaics (NCPV) at the NREL in Colorado, the U.S.A., are shown in Figure 2 and Figure 3 [27-31]. This research study investigates the monocrystalline silicon (Mono-Si or sc-Si) PV cell technology, which is a mature PV technology ("*widely deployed commercial scale projects*"), on the commercial on the grid PV solar power plant basis [27-31].
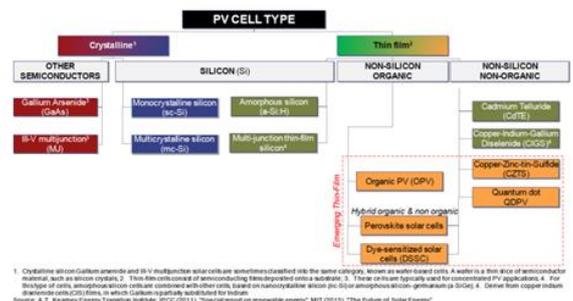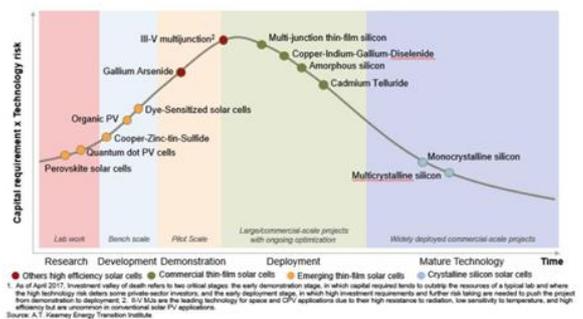

Figure 2. Solar PV technology maturity curve (left), classification of solar PV cells (right) [27-29]

There are many monocrystalline silicon (Mono-Si or sc-Si) PV panel (module) manufacturers on the global market (i.e. Canadian Solar- Canada, Hanwha Q CELLS-South Korea, JA Solar-China, Jinko Solar-China, Trina Solar-China, SunPower-USA, Yingli-China). This research study presents the SunPower's utility scale technology application, the Solar Star Projects (597 MW$_{AC}$, 747.3 MW$_{DC}$) (Solar Star I: 318 MW$_{AC}$, 397.8 MW$_{DC}$ & Solar Star II: 279 MW$_{AC}$, 349,5 MW$_{DC}$) (BHE Renewables, LLC) (SunPower Corporation's max price 130,390 USD in December 2007, min price 3.92 USD in July 2012 at Nasdaq) [32-47].

There are six main contributions of this paper. Firstly, this research paper presents a very organized validation and verification effort of the PVWatts V5 model on the NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 like some previous validation and verification studies [48]. Secondly, it presents the SunPower's Mono-Si PV technology and its application of the largest PV plant in the U.S.A. and the 6th largest one in the World by the end of 2017, the Solar Star Projects (I & II) [32-46, 49]. Thirdly, the current study contributes the efforts to develop the VLPVPPs in Africa, America, Caucasus, Middle East and North Africa (MENA) and World. Also, it helps the kick-off of their new investment models. Fourthly, the results of this research study will contribute to the Global Grid Prediction Systems (G^{2}PS), the Global Grid Electricity Demand Prediction System (G^{2}EDPS), and the Global Grid Peak Power Prediction System (G^{2}P^{3}S) [50–54]. Fifthly, it contributes to the city district and urban planning topic. Finally, it helps the war against climate change and environmental pollution.
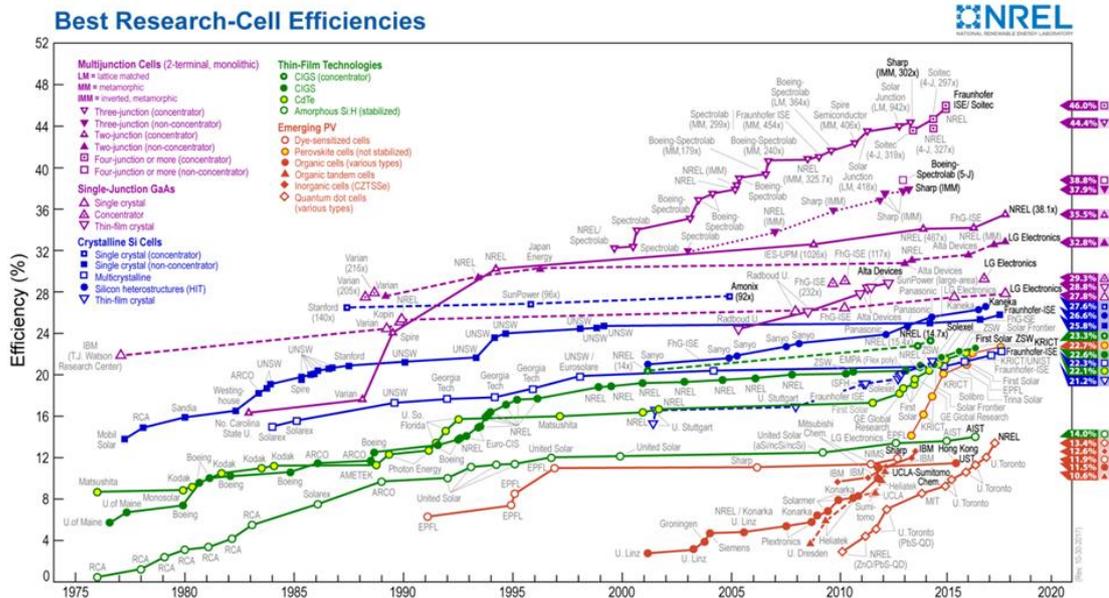

Figure 3. The NREL NCPV best research-cell efficiencies "*This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO.*" [30- 32]

2. Solar Star Projects (Solar Star I & Solar Star II)

The Solar Star Projects were constructed between 2013 and 2015. It is placed on approximately 12.95 km^2 (3200 acres) privately owned land. The location of the Solar Star Projects in Antelope Valley near Rosamond, Kern and Los Angeles counties, California, United States is characterized as "*little rain and high winds, dust control efforts are at the forefront of construction development and execution*" [55].

2.1. Location and resource (Actual & Model)

Earth Pro 7.1.5.1557 [56] are as follows (open Solar Star Projects.kmz) (Figure 4):

Solar Star 1 (318 MW$_{AC}$, 397,8 MW$_{DC}$):

34°50'26.55"N, 118°25'51.81"W; 34°49'35.09"N, 118°25'51.58"W; 34°49'34.98"N, 118°25'20.78"W; 34°49'8.82"N, 118°25'20.67"W; 34°49'8.96"N, 118°24'52.36"W; 34°49'18.71"N, 118°24'52.73"W; 34°49'26.57"N, 118°24'56.69"W; 34°50'23.16"N, 118°25'43.52"W; 34°50'26.63"N, 118°25'47.93"W; 34°48'40.77"N, 118°24'47.28"W; 34°48'17.38"N, 118°24'46.93"W; 34°48'17.43"N, 118°24'35.46"W; 34°48'40.92"N, 118°24'35.66"W; 34°48'17.18"N, 118°24'18.48"W; 34°48'17.02"N, 118°24'7.15"W; 34°48'24.08"N, 118°24'7.21"W; 34°48'24.15"N, 118°24'10.80"W; 34°48'28.95"N, 118°24'10.85"W; 34°48'28.98"N, 118°24'18.55"W; 34°48'17.41"N, 118°23'46.79"W; 34°48'17.38"N, 118°22'46.17"W; 34°48'17.38"N, 118°22'46.17"W; 34°49'8.54"N, 118°22'46.54"W; 34°49'8.19"N, 118°23'57.63"W; 34°49'3.55"N, 118°23'57.58"W; 34°49'3.54"N, 118°24'0.78"W; 34°48'53.80"N, 118°24'0.71"W; 34°48'53.75"N, 118°24'11.57"W; 34°48'43.48"N,

118°24'11.00"W;   34°48'43.70"N, 118°23'47.02"W;
34°48'43.67"N,   118°22'40.03"W;   34°48'44.08"N,
118°21'43.21"W;   34°49'8.81"N, 118°21'43.31"W;
34°49'8.62"N,   118°22'40.42"W;   34°49'10.22"N,
118°23'49.30"W;   34°49'20.16"N, 118°23'49.33"W;
34°49'20.05"N,   118°24'13.54"W;   34°49'10.09"N,
118°24'13.48"W;   34°49'15.97"N, 118°24'21.11"W;
34°49'15.96"N,   118°24'34.23"W;   34°49'29.28"N,
118°24'49.43"W;   34°49'59.38"N, 118°24'49.73"W;
34°49'59.54"N, 118°24'21.63"W.

Solar Star 2 (279 MW$_{AC}$, 349,5 MW$_{DC}$):
34°50'15.67"N,   118°26'34.09"W;   34°50'15.67"N,
118°26'24.87"W;   34°50'13.98"N,   118°26'22.86"W;
34°50'14.16"N,   118°25'58.01"W;   34°50'0.72"N,
118°25'57.96"W;   34°49'34.91"N,   118°26'0.18"W;
34°49'34.71"N,   118°26'55.94"W;   34°49'58.93"N,
118°26'56.08"W;   34°49'59.00"N,   118°26'38.09"W;

34°50'8.02"N,   118°26'38.26"W;   34°50'8.06"N,
118°26'33.98"W;   34°49'10.79"N,   118°20'39.89"W;
34°49'10.65"N,   118°21'8.26"W;   34°49'35.07"N,
118°21'8.37"W;   34°49'35.10"N,   118°20'52.60"W;
34°50'29.78"N,   118°20'52.19"W;   34°50'29.74"N,
118°21'25.45"W;   34°50'53.62"N,   118°21'24.96"W;
34°50'54.51"N,   118°22'11.88"W;   34°51'19.41"N,
118°22'12.06"W;   34°51'20.85"N,   118°21'9.40"W;
34°51'45.81"N,   118°21'9.26"W;   34°51'46.17"N,
118°20'9.12"W;   34°51'22.15"N,   118°20'8.96"W;
34°51'22.24"N,   118°20'39.91"W;   34°50'52.52"N,
118°22'15.70"W;   34°50'32.39"N,   118°22'15.34"W;
34°50'32.58"N,   118°22'42.89"W;   34°50'52.50"N,
118°22'43.81"W.

The location information is gathered and verified on the open source publications and also by personal communication with Mr. Matt Campbell (Vice President, Power Plant Products, SunPower®) [56–58].

Figure 4. Solar Star Projects location: Solar Star 1 (318 MW$_{AC}$, 397,8 MW$_{DC}$) in chartreuse color, Solar Star 2 (279 MW$_{AC}$, 349,5 MW$_{DC}$) in cyan color (according to the literature review, location officially confirmed) (generated by Microsoft Office Excel 2007 [59], Paint.NET.4.0.16 [60], Google Earth Pro 7.1.5.1557 [56])

There are two different weather files for the Solar Star Projects in this study. The first weather file is the standard library file of the NREL SAM Version 2017.9.5, Lancaster Gen Wm Fox Field weather file (USA CA Lancaster Gen Wm Fox Field TMY3.csv) (SAM, Location and Resource) (Table 1, Figure 5). The second weather file is downloaded from the NREL National Solar Radiation Database (NSRDB) (34.82_-118.37_psm_satellite_60_tmy.csv) (open SolarStarProjectsSaracoglu.sam) (SAM, Location and

Resource) (Table 1, Figure 6) (see [61, 62]). The bird fly distance between the Solar Star Projects location and the Lancaster Gen Wm Fox Field weather file station is approximately 13 km. The NSRDB weather file covers the Solar Star Projects site. There are uncertainties in the weather files such as "*hourly broadband solar resource data uncertainty, Plane-of-Array (POA) upto ± 20%*" (see [63]). Henceforth, there is a model and actual (real life) observation major mismatch with the weather data.

Table 1. Location and Resource.

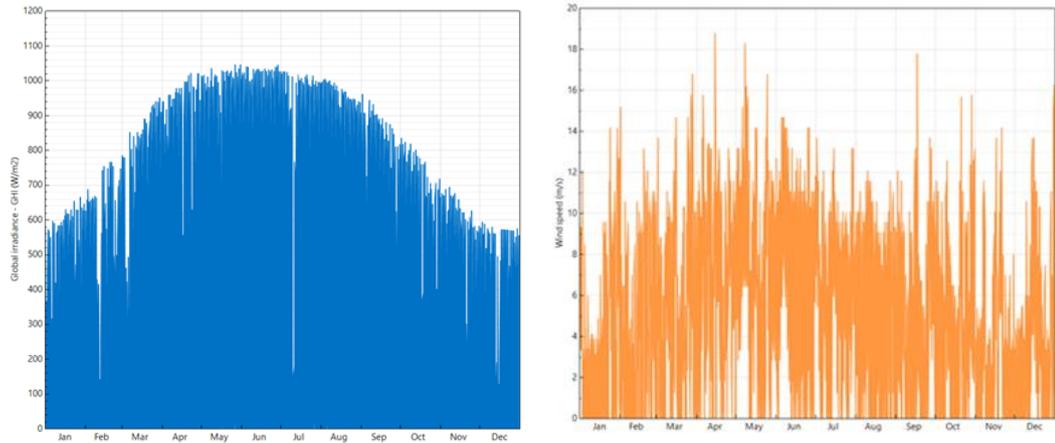| Simulations	Solar Resource Library	Station ID	Latitude	Longitude	Core References
Simulation A	USA CA Lancaster Gen Wm Fox Field (TMY3).csv	723816	34.733 °N	-118.217 °E	[15]
Simulation B	34.82_-118.37_psm_satellite_60_tmy.csv	188819	34.81 °N	-118.38 °E	[61, 62]

Figure 5. USA CA Lancaster Gen Wm Fox Field (TMY3).csv global irradiance-GHI(W/m2) (left), wind velocity (m/s) (right), (Source: open SolarStarProjectsSaracoglu.sam, Paint.NET.4.0.16 [60])
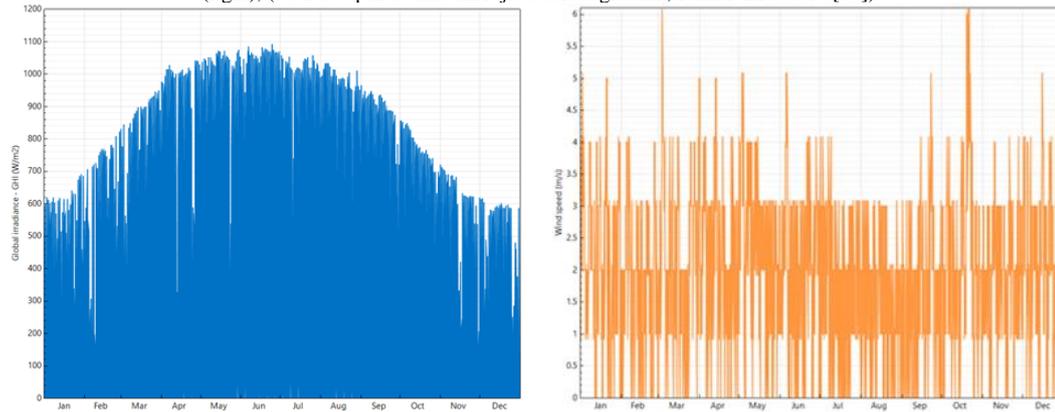

Figure 6. 34.82_-118.37_psm_satellite_60_tmy.csv global irradiance-GHI(W/m2) (left), wind velocity (m/s) (right), (Source: open SolarStarProjectsSaracoglu.sam, Paint.NET.4.0.16 [60])

2.2. System Parameters

The Solar Star Projects' direct current (DC) capacity and alternating current (AC) capacity is respectively found as 747.3 MW$_{DC}$ and 597.0 MW$_{AC}$ (Solar Star I: 318.00 MW$_{AC}$, 397,76 MW$_{pDC}$, Entity Code: SSCA, NERC Code: NCR11424 & Solar Star II: 279,00 MW$_{AC}$, 349.53 MW$_{pDC}$, Entity Code: SSXX, NERC Code: NCR11432) [64- 66], in contrast with 586.0 MW$_{AC}$, 749.0 MW$_{DC}$ [67, 68], and 579.0 MW$_{AC}$, 747.0 MW$_{DC}$ in some references [47, 69, 70, 71, 72, 73].

As a result, the DC:AC ratio is manually calculated as 1,25176 on the PVWatts V5, NREL SAM Version 2017.9.5 Revision 2.

The total 1,72 million (Solar Star I: 914.400 & Solar Star II: 803.520) incrementally installed SunPower E20-435 watt monocrystalline silicon modules (panels), which enables Maxeon® cell technology on the modules, with the SunPower® Oasis® Power Plant SunPower® C1 Single Axis Trackers (Solar Star I: 1.270 & Solar Star II: 1.116) technology occupies totally 3.200 acres (approximately 1295 hectares and 13 km^2) [47, 64, 65, 67] (Table 2).

The Solar Star I & II Project's completion are respectively in January 2015 and in November 2014 [47].

Table 2. Solar Star Projects Construction & Grid Connection Milestones Based On [67]

Milestones	Date	Duration from Start (months/years)
Construction Begins	January 2013	-
Synchronized With Grid	October 2013	10
57 MW in-service	December 2013	12
170 MW in-service	April 2014	16
465 MW in-service	November 2014	21
586 MW in-service	June 2015	30
Commercial Operations	July 2015	31

The SunPower® E-Series monocrystalline silicon panels, which have the high performance anti-reflective glass module cover, have a 20% solar panel efficiency (SunPower® E20) [74- 78].

Each 1 MW power block integrates with an inverter [79]. 424×750 kW inverters, 212×transformers (step up to 34.5 kV) and 2×175 MVA transformers (step up to 230 kV) are equipped in the Solar Star I [64]. 750 kW and 1500 kW inverters, 186×transformers (step up to 34.5 kV), 1×225 MVA transformer (step up to 230 kV) and 1×71 MVA transformer (step up to 230 kV) are equipped in the Solar Star II [65]. The inverters' efficiencies are taken as %97.5≤ (%98)

according to the weighted inverter efficiency in the catalogue of the SunPower™ Oasis™ C1 Power Plant [80] (see also [81, 82], and for the explanations of the peak efficiency and the weighted inverter efficiencies such as California Energy Commission efficiency and European efficiency, see [83, 84]).

Henceforth, the model and actual (real life) system parameters are summarized in Table 3 and Table 4. There is a model and actual (real life) observation major mismatch in the system parameters section, because of the configuration and the equipment issues.

Table 3. System Parameters.

SAM Model Parameters	SAM Model Value	SAM Model Unit	Actual	Core References
System nameplate size	747300	kWdc	747,3 MW_{DC}	[64,65,66]
Module type	Premium	-	SunPower E20 435-watt monocrystalline silicon modules	[47, 64,65, 67]
DC to AC ratio	1,25176	-	-	
Inverter efficiency	98%	-	[a]SMA, ABB with an efficiency of about 98%	[80]

[a]Personel communication: Matt Campbell in the SunPower.

Table 4. Module type.

SAM Module Type	SAM Approximate Nominal Efficiency	SAM Module Cover	SAM Temperature Coefficient of Power
Standard (crystalline Silicon)	15%	Glass	-0.47 %/°C
[a,b]Premium (crystalline Silicon)	19%	Anti-reflective	-0.35 %/°C
Thin film	10%	Glass	-0.20 %/°C

[a]Premium (crystalline Silicon): "*The "premium" option is appropriate for modeling high efficiency (~18-20 %) monocrystalline silicon modules that have anti-reflective coatings and lower temperature coefficients.*" [26]. [b] SunPower® E20 solar panel efficiency: 20% [74, 75].

2.3. Orientation

The Solar Star Projects is a single axis tracking project (SunPower® Oasis® Power Plant SunPower® C1 Single Axis Trackers) [67] (see [80] for the details of the SunPower® C1 Single Axis Trackers, "*a 45 degree rotation*" by Mr. Matt Campbell). The active tracking system operates daily in the east (in the morning) to west (in the evening) motion of the Sun. There isn't any tilt information found in the open sources, hence it might be a horizontal single axis tracker (HSAT) [85], instead of a horizontal tilted single-axis tracker or horizontal single axis tracker with tilted modules (HTSAT) [85, 86]. The digital photos prove also this assumption [47, 87-89]. As a consequence, the tilt angle isn't taken as 32° in winter, 56° in spring and fall, and 80° in summer or approximately 35° as the latitude according to the general guidance in the PV literature [90-93], but according to the SAM developers and experts guidance [94]. It utilizes the SunPower® TMAC[TM] Advanced Tracker Controller (see [95]).

There is not any ground coverage ratio (GCR) information of the Solar Star Projects found in the open sources, hence it is calculated and estimated according to the measurements on the Google Earth Pro 7.1.5.1557 and the information in the catalogues and documents of the SunPower® (A/B =

approximately 1.70 m / 4.70 m measurement = 0.3617, actual A = 2,067 mm, measurement accuracy: 1.70 m / 2.067 m = %82.25) (see [96, 97]).

The readers should note the following design issues on the PVWatts V5, NREL SAM Version 2017.9.5 Revision 2:

- "Self-shading is a reduction in the array's output caused by shading of neighboring rows of modules at certain times of day." [98]

- "Backtracking is a tracking algorithm that rotates the array toward the horizontal during early morning and late evening hours to reduce the effect of self shading. The one-axis tracking algorithm assumes a rotation limit of ±45 degrees from the horizontal." [98]

- "Tilt, degrees": "Applies only to fixed arrays and arrays with one-axis tracking." [98]

- "The array's tilt angle in degrees from horizontal, where zero degrees is horizontal, and 90 degrees is vertical and facing the equator (in both the southern and northern hemispheres." [98]

- "Azimuth, degrees": "Applies only to fixed arrays with no tracking." [98]

- "An azimuth value of zero is facing north, 90 degrees = east, 180 degrees = south, and 270 degrees = west, regardless

of whether the array is in the northern or southern hemisphere." [98]

- "Ground coverage ratio (GCR)": "The ratio of the photovoltaic array area to the total ground area for arrays with one-axis tracking." [98]

Henceforth, the model and actual (real life) system parameters are summarized in Table 5 and there is a model and actual (real life) observation minor mismatch in the orientation.

Table 5. Orientation Parameters.

Model Parameters	Model Value	Actual	References
Array type	[a]1-Axis Backtracking	SunPower® Oasis® Power Plant SunPower® C1 Single Axis Trackers	[61]
Tilt	0		[47, 87-89]
Azimuth	[b]----- (180)	-	
Ground coverage ratio (GCR)	0,36	-	

[a]Backtracking is selected due to SunPower® TMAC[TM] Advanced Tracker Controller [95]. [b]-----(180): Azimuth, degrees: Its value is 180° in the SAM file, however it does not make any difference in the SAM calculations because of the 1-axis tracking and the 1-axis backtracking array type

2.4. Losses

There are 10 system losses elements of a PVWatts Version 5 model of the NREL SAM Version 2017.9.5. These are the soiling loss, the shading loss, the snow loss, the mismatch loss, the wiring loss, the connections loss, the light-induced degradation loss, the nameplate rating loss, the age loss and the availability loss. The short definitions of them are as follows [99]:

- Soiling Loss: "due to dust, dirt, and other foreign matter on the surface of the PV module that prevent solar radiation from reaching the cells."

- Shading Loss: "PVWatts calculates self-shading losses for one-axis trackers, so you should not use the shading loss to account for self-shading with the one-axis tracking option. The default value of 1% represents an array with no shading."

- Snow Loss: "Reduction in the system's annual output due to snow covering the array."

- Mismatch Loss: "Electrical losses due to slight differences caused by manufacturing imperfections between modules in the array that cause the modules to have slightly different current-voltage characteristics."

- Wiring Loss: "Resistive losses in the DC and AC wires connecting modules, inverters, and other parts of the system."

- Connections Loss: "Resistive losses in electrical connectors in the system."

- Light-Induced Degradation Loss: "Effect of the reduction in the array's power during the first few months of its operation caused by light-induced degradation of photovoltaic cells."

- Nameplate Rating Loss: "Nameplate rating loss accounts for the accuracy of the manufacturer's nameplate rating. Field measurements of the electrical characteristics of photovoltaic modules in the array may show that they differ from their nameplate rating."

- Age Loss: "Effect of weathering of the photovoltaic modules on the array's performance over time"

- Availability Loss: "Reduction in the system's output cause by scheduled and unscheduled system shutdown for maintenance, grid outages, and other operational factors."

The soiling loss value of the Solar Star Projects is identified and determined according to the general PV literature. Its site description is found such as "*little rain and high winds, dust control efforts*", and taken dust control actions such as "*grass was preseeded prior to construction, majority of the project land was not graded, reseeding took place as needed to encourage growth of vegetation*" [55], "*average performance loss due to soiling in dry climates occurs at a rate of 0.0011 kWh/kWp/day without rainfall. This equates to an annual energy loss of between 2-6% depending on the region and environment*" [100] and the climatic conditions [101-106].

The shading loss value of the Solar Star Projects is identified and determined according the guiding sentence in SAM help manual "*so you should not use the shading loss to account for self-shading with the one-axis tracking option*" [99] and according to the general PV literature.

The snow loss value of the Solar Star Projects is identified and determined according the climatic conditions such as "*average annual snowfall: 2 inch, 50,8 mm*", "*an average of 21.6" of snow (0 cm)*" [101-108].

The mismatch loss value of the Solar Star Projects is identified and determined according the sentences "*Research has demonstrated that the voltage mismatch associated with current module tolerance standards (±5% normal distribution) will result in a loss in system power of approximately 0.5% (Bucciarelli mismatch). Consequently, the SunPower Systems Electrical Engineering group recommends 0.5% for module voltage mismatch loss and 0.3% for string current mismatch, resulting in a total mismatch of 0.8%.*" [109, 110].

The wiring loss value of the Solar Star Projects is identified and determined according to the general PV literature "*DC Wiring derating factor: 0,98*" and "*AC Wiring derating factor: 0,99*" [110-112].

The connections loss value of the Solar Star Projects is identified and determined according the according to the general PV literature [111, 112].

The light-induced degradation loss value of the Solar Star Projects is identified and determined according the catalogues and documents of the SunPower® as "*no light-induced degradation*" [97, 113, 114] and to the general PV literature "*initial degradation of 2.6% ± 1.3%*" [111, 112, 115-118].

The nameplate rating loss value of the Solar Star Projects is identified and determined according the general PV literature [111, 112, 119].

The age loss value of the Solar Star Projects is identified and determined according the catalogues and documents of the

SunPower® as "*conventional panel linear warranty, 95% for first 5 years, −0.4%/yr. to year 25, 0.25%/yr degradation*", "*panel degradation rates in the industry may range from -0.25% per year to -1,00% per year*" [97, 120-122] and "*in the range of 0.3 to 0.8% per year*" [115, 118].

The availability rating loss value of the Solar Star Projects is identified and determined according the investors service documents of the credit ratings corporations such as "*Solar Star achieved an average availability of 87.6% for 2016 due to a combination of transformer outages and the subsequent repair and replacement work that transpired during the year.*" [123- 127].

There is a model and actual (real life) observation major mismatch in the losses.

Table 6. PVWATTS SAM Losses

Losses	SAM Default Value Case (%)	Most Possible Value Case (%)	Reasonable Minimum Value Case (%)	Reasonable Maximum Value Case (%)	Core References
[a]Soiling	[a]2	[a]3	[a]2	[a]6	[100,128]
[a]Shading	[a]3	[a]2	[a]1	[a]3	[99]
Snow	0	0	0	0	[107,108]
[a]Mismatch	[a]2	[a]0,8	[a]0,15	[a]3	[109-112]
[a]Wiring	[a]2	[a]2	[a]1	[a]5	[110-112,129,130]
[a]Connections	[a]0,5	[a]0,5	[a]0,3	[a]1	[111,112]
Light-Induced Degradation	1,5	0	0	4	[97,115,116,118]
[a]Nameplate Rating	[a]1	[a]1	[a]0,15	[a]5	[111,112,119]
[a]Age	[a]0	[a]0,4	[a]0,25	[a]1,25	[97,115,118,120-122]
[a]Availability	[a]3	[a]10	[a]5	[a]15	[124-127]
[b,c]Total system losses	14,08	18.40	9,53	36,32	

[a]Losses: These values are preliminary estimated indicative values to find and calculate the total system losses. They are not checked, crosschecked and confirmed by any methods or means, so that they may not be compatible with the power plant, the methods and the software. As a consequence, please do not use any of these values in any of scientific, engineering and commercial studies without any further investigations. In short, the readers should not take into account these losses in their studies, because it will be investigated in future studies. [b]Total system losses = 100%×{1-[(1-Soiling ÷ 100%)×(1-Shading÷100%)×(1-Snow÷100%)×(1-Mismatch÷100%)×(1-Wiring÷100%)×(1-Connections÷100%)×(1-Light-induced degradation÷100%)×(1-Nameplate÷100%)×(1-Age÷100%)×(1-Availability÷100%)]}, [c]Total system losses: The readers may take and use this total system losses value in their analysis, because this study shows that they are reasonable enough for the engineering analysis of this power plant (most possible value case (%)) under the current study's conditions and assumptions only (e.g. weather file, configuration).

2.5. Shading

The shading is taken into account within the losses inputs section ("Shading"), so that this shading losses option is disabled. The explanation of this shading is given as "*The shading losses represent a reduction of the solar radiation incident on the array due to shadows on the array created by nearby objects such as trees and buildings. SAM assumes that the entire array is uniformly shaded. You can specify hourly beam shading losses and a single sky diffuse shading loss in the Edit Shading window*." [131].

2.6. Curtailment and availability

The curtailment and availability is taken into account within the losses inputs section ("Availability"), so that this curtailment and availability option is disabled. The explanation of this curtailment and availability is given as

"*Use curtailment and availability losses to represent reductions in the system's output or complete system outages for maintenance, forced outages due to grid constraints, or other situations that prevent the system from operating as designed.*" [132].

3. Results and Discussion

The annual output data of the Solar Star I power plant and the Solar Star II power plant are gathered on the official records [133, 134]. The monthly generation (megawatt hours) data of the Solar Star I power plant are presented between March 2014 to November 2017 [133]. The monthly generation (megawatt hours) data of the Solar Star II power plant are presented between March 2014 to November 2017 [134]. There is not any generation data of the Solar Star I power

plant in Feb 2015 [133]. Three annual output data sets of the Solar Star Projects are generated by the summation of the annual output data of the Solar Star I and II power plants and the arithmetic mean (simple mean, mean, average) of the monthly data per annum during the data preprocessing studies of this analysis. The first data set of the Solar Star Projects covers all month data set (March 2014 to November 2017) with the arithmetic mean operation (4 years) (acronym: AYMDS). The second data set of the Solar Star Projects eliminates Feb 2015 amongst all month data set with the arithmetic mean operation (4 years) (acronym: FYMDS). The third data set of the Solar Star Projects eliminates all month data set before the full capacity installed (before June 2015) with the arithmetic mean operation (2 years) (acronym: TYMDS). The monthly data sets (kilowatt hours) are presented in the Figure 7. The simulation results of the Solar Star Projects are calculated by three different simulation approaches on the PVWatts V5 model on the NREL SAM Version 2017.9.5 Revision 2, SSC Version 180. These simulations are the one by one simple simulation (acronym: OSS), the parametric simulation (acronym: PS) and the stochastic simulation (acronym: SS). The SAM simulations of the Solar Star Projects are performed on a personal computer (PC) (Windows 10 Pro, Intel(R) Core(TM) i5 CPU 650 @ 3.20 GHZ, 6,00 GB RAM) with internet connection. The monthly simulation results are given in the Figure 7.

3.1. Simulations & Parametric Simulations & Stochastic Simulations

There is only one NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 file with eight model sheets created (SolarStarProjectsSaracoglu.sam) in this study. The titles of the model sheets in the NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 file are AS for the Simulation A Station ID 723816 with the losses of the SAM default value case, AMP for the Simulation A Station ID 723816 with the losses of the most possible value case, ARMIN for the Simulation A Station ID 723816 with the losses of the reasonable minimum value case, ARMAX for the Simulation A Station ID 723816 with the losses of the reasonable maximum value case, BS for the Simulation B Station ID 188819 with the losses of the SAM default value case, BMP for the Simulation B Station ID 188819 with the losses of the most possible value case, BRMIN for the Simulation B Station ID 188819 with the losses of the reasonable minimum value case, BRMAX for the Simulation B Station ID 188819 with the losses of the reasonable maximum value case.

The model and actual (real life) observation mismatches are presented in Table 7 common for all of the simulations.

The simulation report summary of the PVWatts V5 model on the NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 on a personal computer (PC) (Windows 10 Pro, Intel(R) Core(TM) i5 CPU 650 @ 3.20 GHZ, 6,00 GB RAM) with internet connection is given in Table 8.

Table 7. PVWATTS SAM Model & Actual Mismatches

Mismatch (Discrepancy)	Expected Effect Size & Intensity	Note
Weather Files	Major	[a] Unknown and unconfirmed actual, operation or site data and information
System Design, System Parameters	Major	[a] Unknown and unconfirmed actual, operation or site data and information
System Design, Orientation	Minor	[a] Unknown and unconfirmed actual, operation or site data and information
System Design, Losses	Major	[a] Unknown and unconfirmed actual, operation or site data and information

[a]Unknown and unconfirmed actual, operation or site data and information: The data and information of the actual, operation or site can not be gathered during this study. They will be tried to be gathered in the future studies.

Table 8. PVWATTS SAM Simulation Report

Model	Total time (ms)	SSC time (ms)	Errors	Warnings	Notices	Annual energy (year 1)(kWh)	Capacity factor (year 1) (%)	Energy yield (year 1) (kWh/kW)
[a]AS	79	78	0	0	0	1.665.812.352	25.4	2.229
[b]AMP	357	301	0	0	0	1.583.815.040	24.2	2.119
[c]ARMIN	87	86	0	0	0	1.742.346.496	26.6	2.332
[d]ARMAX	80	79	0	0	0	1.235.953.024	18.9	1.654
[e]BS	65	64	0	0	0	1.645.686.784	25.1	2.202
[f]BMP	66	65	0	0	0	1.563.837.568	23.9	2.093
[g]BRMIN	70	69	0	0	0	1.726.448.640	26.4	2.310
[h]BRMAX	67	66	0	0	0	1.220.201.728	18.6	1.633

[a]AS: Simulation A Station ID 723816 with the losses of the SAM default value case. [b]AMP: Simulation A Station ID 723816 with the losses of the most possible value case. [c]ARMIN: Simulation A Station ID 723816 with the losses of the reasonable minimum value case. [d]ARMAX: Simulation A Station ID 723816 with the losses of the reasonable maximum value case. [e]BS: Simulation B Station ID 188819 with the losses of the SAM default value case. [f]BMP: Simulation B Station ID 188819 with the losses of the most possible value case. [g]BRMIN: Simulation B Station ID 188819 with the losses of the reasonable minimum value case. [h]BRMAX: Simulation B Station ID 188819 with the losses of the reasonable maximum value case.

3.2. SAM results and actual generation comparison

There is only one NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 file with eight model sheets in this study (SolarStarProjectsSaracoglu.sam). The monthly comparative simulation results are given in the Figure 7. The comparative simulation results per month are given in the Figure 8.

The following forecast accuracy metrics amongst all of the forecast accuracy metrics such as the prediction scale-dependent error metrics, the percentage error metrics, the relative error metrics, the scale-free error metrics according to literature are used in this research study (see [48, 50–54, 135–140]).

Forecast Errors (scale-dependent error):
$$e_t = Actual_t - Predicted_t \tag{1}$$

Absolute Forecast Errors (scale-dependent error):
$$|e_t| = e_t \tag{2}$$

Mean Absolute Error (MAE) (scale-dependent error):
$$MAE = \frac{1}{n}\sum_1^n |e_t| \tag{3}$$

Geometric Mean Absolute Error (GMAE) (scale-dependent error):
$$GMAE = (\prod_{i=1}^n |e_t|)^{1/n} \tag{4}$$

Mean Square Error (MSE) (scale-dependent error):
$$MSE = \frac{1}{n}\sum_1^n e_t^2 \tag{5}$$

Root Mean Square Error (RMSE) (scale-dependent error)
$$RMSE = MSE^{1/2} \tag{6}$$

Absolute Percentage Errors (APE) (percentage error):
$$APE_t = \frac{(|Actual_t - Predicted_t|)}{(Actual_t)} \tag{7}$$

Minimum Absolute Percentage Error (MinAP) (percentage error):
$$MinAP = min(APE_t) \tag{8}$$

Maximum Absolute Percentage Error (MAP) (percentage error):
$$MAP = max(APE_t) \tag{9}$$

Mean Absolute Percentage Error (MAPE) (percentage error):
$$MAPE = \frac{1}{n}\sum_1^n (APE_t) \tag{10}$$

Symmetric MAPE (percentage error):
$$SMAPE = \frac{1}{n}\sum_1^n \left(\frac{|Predicted_t - Actual_t|}{\left(\frac{(|Predicted|_t + |Actual_t|)}{2}\right)}\right) \tag{11}$$

Relative Error (relative error):
$$r_t = \frac{e_t}{e^*_t} \tag{12}$$

Median Relative Absolute Error (MdRAE) (relative error):
$$MdRAE = median(|r_t|) \tag{13}$$

Geometric Mean Relative Absolute Error (GMRAE) (relative error):
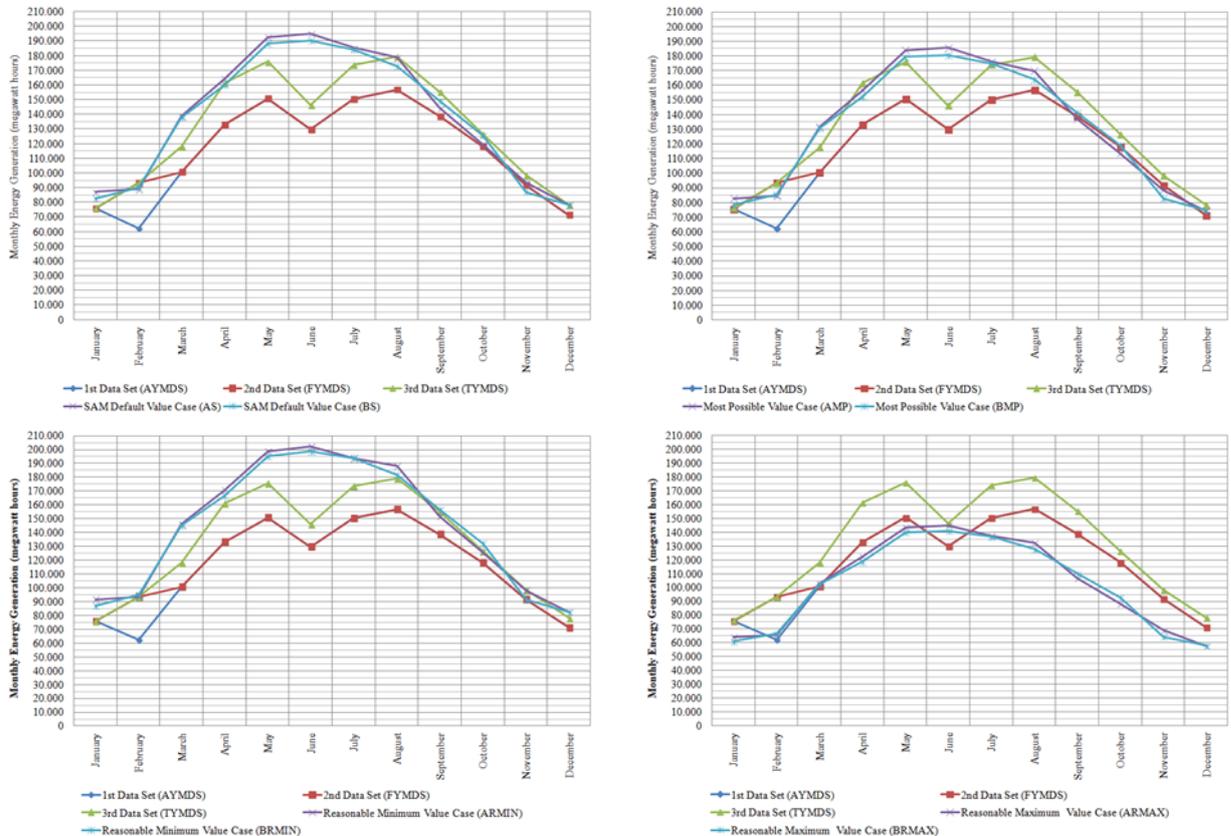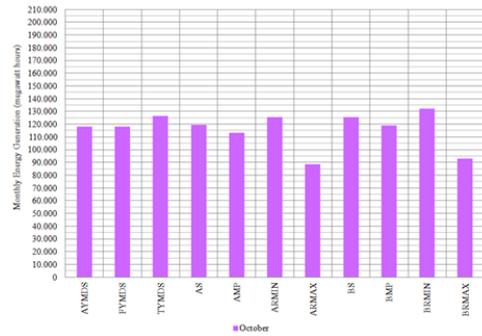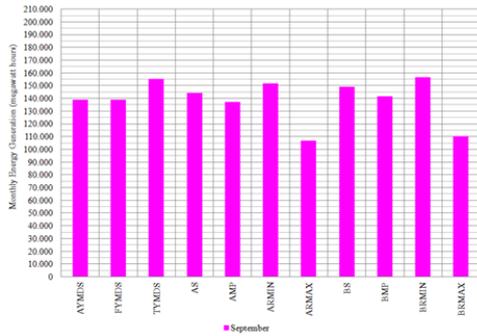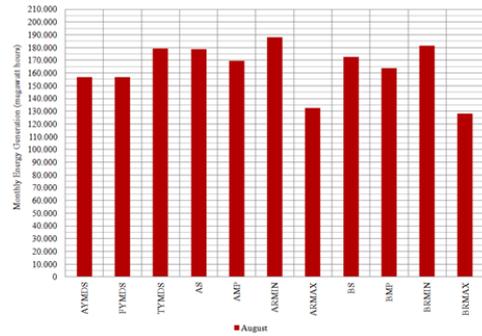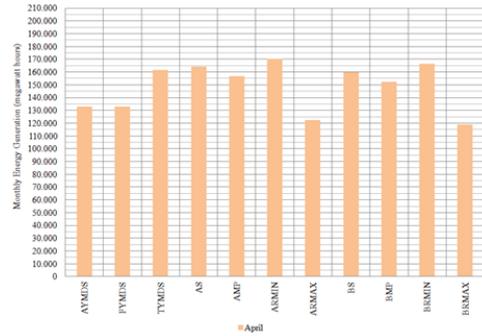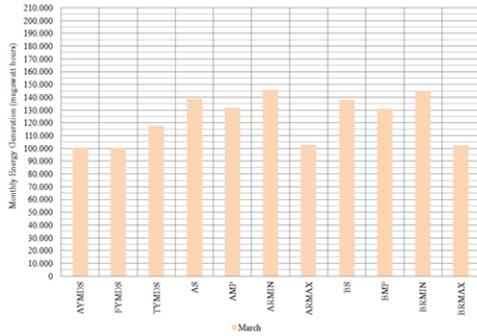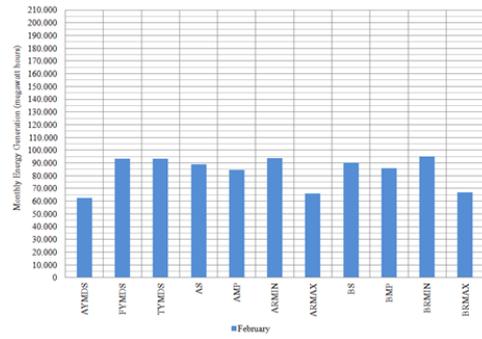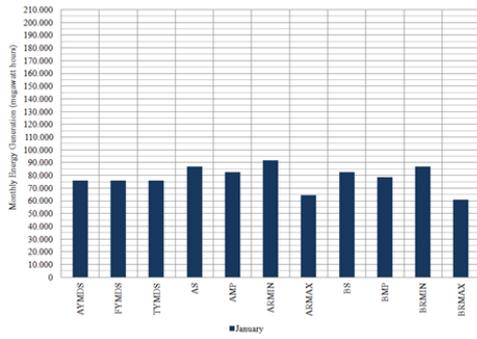$$GMRAE = (\prod_{i=1}^n |r_t|)^{1/n} \tag{14}$$

Figure 7. SAM Results and Actual Generation Comparison (Source: open SolarStarProjectsSaracoglu.sam, Paint.NET.4.0.16 [60])
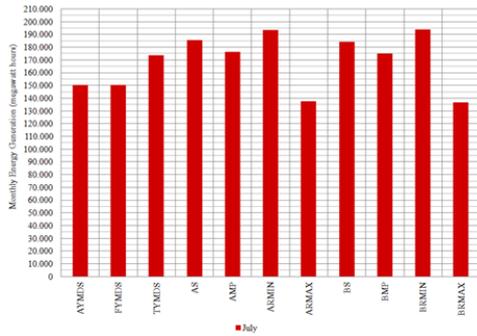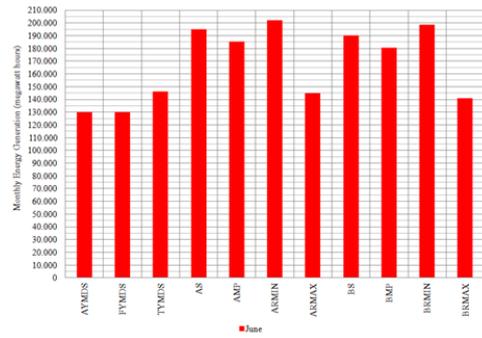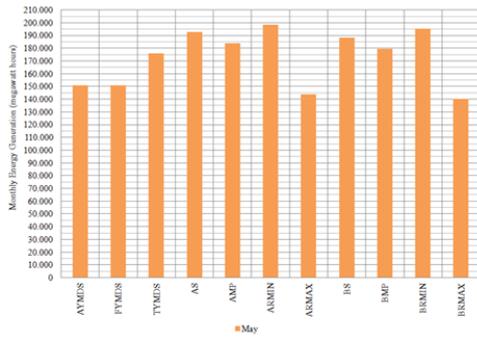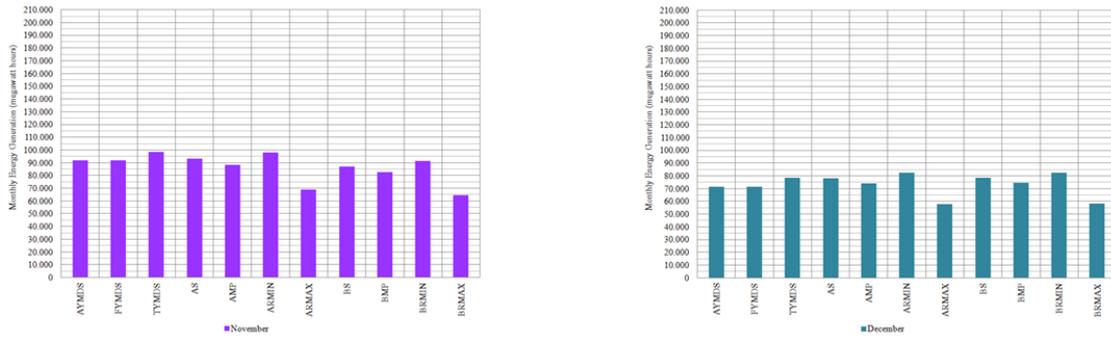
Figure 8. SAM Results and Actual Generation Comparison Per Month (Source: open SolarStarProjectsSaracoglu.sam, Paint.NET.4.0.16 [60])

The simulation and actual generation comparison of the Solar Star Projects is summarized in the following sentences for only the case of the best performed annual total model/actual (annual model/actual: 100,1%) with regards to the TYMDS (the full capacity installed (before June 2015) with the arithmetic mean operation). The readers should visit the electronic supplementary files for the other models. In the AMP (Simulation A Station ID 723816 with the losses of the most possible value case) with regards to the TYMDS (the full capacity installed (before June 2015) with the arithmetic mean operation), the maximum forecast error (e_t) is observed in September (18.241 MWh). The minimum forecast error (e_t) is observed in June (-39.276 MWh). The absolute maximum forecast error ($|e_t|$) is observed in June (39.276 MWh). The absolute minimum forecast error ($|e_t|$) is observed in July (2.249 MWh). The mean absolute error (MAE), the geometric mean absolute error (GMAE), the mean square error (MSE) and the root mean square error (RMSE) are respectively 11.554 MWh, 8.924 MWh, 2.662.330.229 MWh and 51.597 MWh. The minimum absolute percentage error (MinAP), the maximum absolute percentage error (MAP) and the mean absolute percentage error (MAPE) are respectively 0,01 (July); 0,27 (June) and 0,09. The maximum model/actual is in June (126,9%). The absolute minimum model/actual is in July (101,3%). The absolute maximum model/actual is in June (126,9%). The most accurate prediction according to model/actual is in annual total (100,1%). As a result, the simulation results below 5,0% absolute model/actual is in April (97,0%), May (104,6%), and July (101,3%) are good enough monthly predictions. The simulation results between 5,0% and 10,0% absolute model/actual is in January (108,7%), February (90,4%), August (94,7%) and December (94,9%) are moderate monthly predictions. The simulation results above 10,0% absolute model/actual is in March (111,8%), June (126,9%), September (88,3%), October (89,6%), and November (90,0%) are poor monthly predictions. The annual simulation result is very good prediction (100,1%) in this model. There is not any seasonal similarity in the

performance of these predictions. Finally, the AMP (Simulation A Station ID 723816 with the losses of the most possible value case) with regards to the TYMDS (the full capacity installed (before June 2015) with the arithmetic mean operation) PVWatts V5 model on the NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 performance is very good on the annual (yearly) basis, however the monthly prediction performances are not very good in their current form.

The parametrics simulation of the PVWatts V5 model on the NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 are only performed on the AMP (Simulation A Station ID 723816 with the losses of the most possible value case) NREL SAM sheet with only "User-specified total system losses" in this study (SolarStarProjectsSaracoglu.sam). The minimum and maximum values are taken based on the total system losses (%18.4) of the most possible value case. The range is defined as %1,0 below and above of the total system losses (Start value: %17.4 to End value: %19.4) with an increment of %0.1 (Increment: %0.1) in the parametrics simulation. As a result, there are 21 number of simulations in the parametrics simulation. There is only one output, "monthly AC system output" in this analysis.

The parametrics simulation and actual generation comparison of the Solar Star Projects is summarized in the following sentences for only the case of the best performed annual total model/actual (annual model/actual: 100,0%) with regards to the TYMDS (the full capacity installed (before June 2015) with the arithmetic mean operation). The "AC system output: run 12" with "User-specified total system losses" of %18.5 presents the best performance. The readers should visit the electronic supplementary files for the other models. In the AMP (Simulation A Station ID 723816 with the losses of the most possible value case) parametrics simulation "AC system output: run 12" with regards to the TYMDS (the full capacity installed (before June 2015) with the arithmetic mean operation), the maximum forecast error (e_t) is observed in September (18.241 MWh). The minimum forecast error (e_t) is observed in June (-39.048 MWh). The

absolute maximum forecast error ($|e_t|$) is observed in June (39.048 MWh). The absolute minimum forecast error ($|e_t|$) is observed in July (2.032 MWh). The mean absolute error (MAE), the geometric mean absolute error (GMAE), the mean square error (MSE) and the root mean square error (RMSE) are respectively 11.561 MWh, 8.896 MWh, 2.654.840.296 MWh and 51.525 MWh. The minimum absolute percentage error (MinAP), the maximum absolute percentage error (MAP) and the mean absolute percentage error (MAPE) are respectively 0,01 (July); 0,27 (June) and 0,09. The maximum model/actual is in June (126,7%). The absolute minimum model/actual is in July (101,2%). The absolute maximum model/actual is in June (126,7%). The most accurate prediction according to model/actual is in annual total (100,0%). As a result, the simulation results below 5,0% absolute model/actual are in April (96,9%), May (104,4%), and July (101,2%) are good enough monthly predictions. The simulation results between 5,0% and 10,0% absolute model/actual are in January (108,6%), February (90,3%), August (94,6%) and December (94,8%) are moderate monthly predictions. The simulation results above 10,0% absolute model/actual is in March (111,6%), June (126,7%), September (88,1%), October (89,5%), and November (89,8%) are poor monthly predictions. The annual simulation result is very good prediction (100,0%) in this model. There is not any seasonal similarity in the performance of these predictions. The parametrics simulation of this study doesn't make any much difference to its prediction performance.

The stochastic simulation of the PVWatts V5 model on the NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 are only performed on the AMP (Simulation A Station ID 723816 with the losses of the most possible value case) NREL SAM sheet with only "User-specified total system losses" in this study (SolarStarProjectsSaracoglu.sam). The mean (mu) value of the selected normal distribution is taken based on the total system losses (%18,4) of the most possible value case. The standard deviation of the selected normal distribution is defined as %1,0 with a number of samples of 100 and seed value of 0 for randomization in the stochastic simulation. There are three outputs, "Annual energy (kWh), Capacity factor (%), First year (kWh/kW)" in this analysis.

The stochastic simulation and actual generation comparison of the Solar Star Projects is summarized in the following sentences for only the case of the best performed annual total model/actual (annual model/actual: 99,99%) with regards to the TYMDS (the full capacity installed (before June 2015) with the arithmetic mean operation). The best performance of the "Annual energy (year 1) (kWh)" with "User-specified total system losses" is observed in 6th sample. Its "Capacity factor (%)" and "First year (kWh/kW)" are respectively %24.2 and 2.117 kWh/kW. The readers should visit the electronic supplementary files for the other models. The stochastic simulation of this study doesn't make any much difference to its prediction performance. The results of the stochastic simulation of this study is presented in Figure 9.
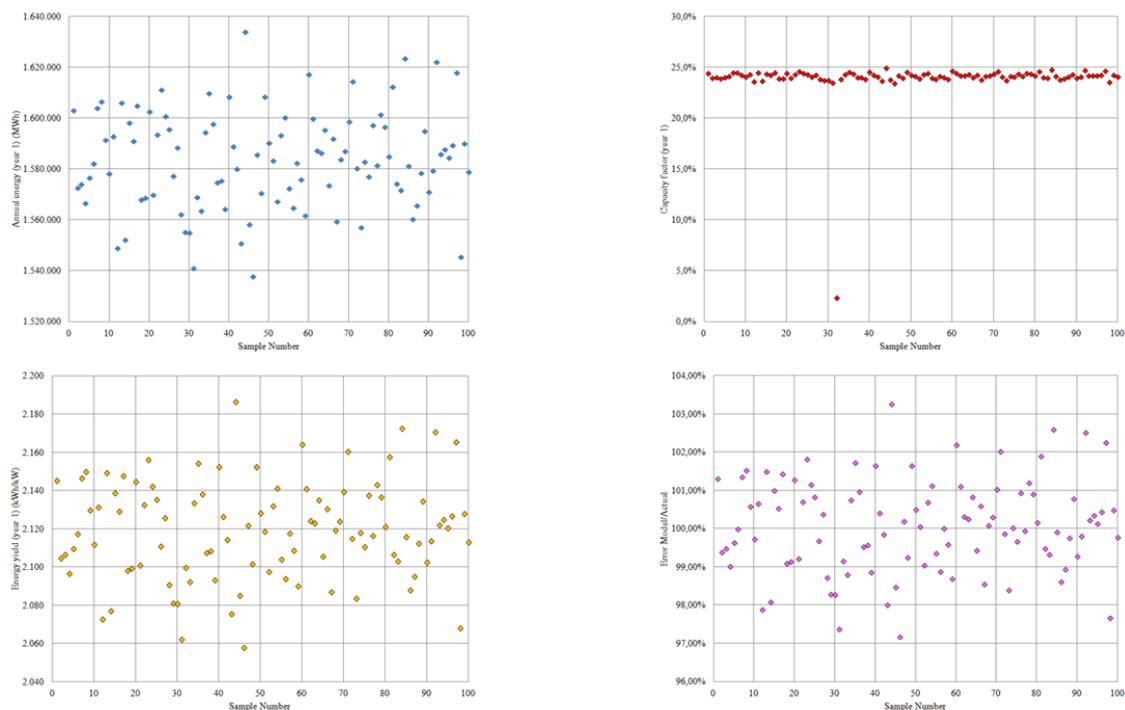

Figure 9. SAM Stochastic Simulation Results (Source: open SolarStarProjectsSaracoglu.sam, Paint.NET.4.0.16 [60])

4. Conclusion

This research study shows a validation and verification effort of the PVWatts V5 model on the NREL SAM Version 2017.9.5 Revision 2, SSC Version 180 performance models at the Solar Star Projects (I & II) power plants with a known possible PVWatts variations as much as the annual errors of "±3% or less" up to "±10%" [26, 141, 142]. There are some major mismatch and minor mismatch modeling weaknesses in this research study. It is very well realized that a mismatch free modelling of a PV power plant is almost impossible considering all time frames (e.g. minutely, half hourly, hourly, weekly, monthly). Henceforth, the acceptable prediction accuracy ranges must be defined and decided in these kinds of the research efforts. These prediction accuracy ranges will be studied in some future research papers.

This research paper also contributes to the research, development, demonstration and deployment (RD^3) efforts of the VLPVPPs in Africa, America, Caucasus, Middle East and North Africa (MENA) and World, the Global Grid Prediction Systems (G^2PS), the Global Grid Electricity Demand Prediction System (G^2EDPS), and the Global Grid Peak Power Prediction System (G^2P^3S) [50–54].

In the future research studies, the exact configuration and equipment and all generation data in all time frames (hourly, half hourly, minutely) of the Solar Star Projects will be tried to be gathered from the engineering, procurement, construction (EPC) companies, the official state organizations, the operators, and the owners. The detailed photovoltaic (PV) of the up to date NREL SAM version shall be built up and run to understand the SAM performance models in the following research studies. Furthermore, the confirmations of all model inputs and outputs are tried to be taken from the EPC companies, the official state organizations, the operators, and the owners. For instance, the shading loss will be revisited and investigated (e.g. %2 or %0 or %1) according to the statement of "*PVWatts calculates self-shading losses for one-axis trackers, so you should not use the shading loss to account for self-shading with the one-axis tracking option. The default value of 1% represents an array with no shading.*" [99] and site reevaluations on the digital photos and satellite images. At last, the answers to some questions such as the causes of differences between the simulation and actual values, or the problems in the operation phases are tried to be given in the following studies.

Acknowledgment

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