Instructions for participating in the blind PVPMC modeling intercomparison (PHASE 1 and 2) [updated August 10, 2023]

Disclaimer

By participating in this study and providing your results, we are assuming that we have permission to include them in the comparison and publish the results anonymously; if you include sensitive information in any form or manner, please let us know.

Objectives

The objectives of this blind intercomparison are to:

1. quantify differences among modelers
2. investigate whether some models are more accurate than others
3. see if performance modeling can be improved
4. quantify validity of PV performance models
5. find sources of uncertainty
6. develop workplan to improve functionality and reproducibility

Conclusions and lessons learned in 2021 blind PV performance modeling intercomparison

The 2021 blind PV performance modeling intercomparison had 32 participants from 12 countries and 26 organizations with 29 submissions. The results of the analysis were summarized in a journal article, which is currently under review [1]. The conclusions and lessons learned, extracted from the manuscript [1], include the following:

"

1) *The irradiance transposition models seem to perform well, except the isotropic one.*
2) *Modeling the rear POA irradiance is still challenging with errors exceeding ~ ±100%. However, it should be mentioned that rear POA irradiance represents ~10% or less of the total irradiance.*
3) *Standardization is needed for handling sun position calculations when using time-averaged irradiance measurements.*
4) *Incorporating a radiative loss term in module temperature modeling appears to improve accuracy.*
5) *There is confusion around the U values for Faiman and PVsyst temperature models. Uc and Uv (PVsyst) values should not be used in place of U0 and U1 (Faiman) values.*
6) *Most software and models showed similar results indicating good reproducibility among participants, especially when compared with the 2010 blind modeling study. For example, the spread in estimated energy yield among PVsyst participants is now ~6% compared with ~33% in 2010.*
7) *Uncertainty and variation in derate factors between participants appear to explain most of the differences; it was observed that modelers overestimated the derates resulting in significant power underestimation.*
8) *Human errors are not uncommon. The intercomparison highlighted several errors related to the temperature coefficients and the efficiency across irradiance. There is an opportunity to develop screening tests that can detect such errors, thus assuring stakeholders of the accuracy of the modeling results.*

9) *Modeler skill at understanding, choosing, and using the models and their parameter correctly, and accumulated experience observing various derate mechanisms in operational systems seems to be more important than the PV model itself (see 7 and 8 above).*

Unfortunately, the bifacial PV time-series in this study contained only a handful of rear POA irradiance days. As such, no further analysis has been conducted to investigate the impact of their variations. Depending on data availability, future PVPMC blind modeling intercomparisons will include larger systems, sub-hourly time-series, investigations on rear POA irradiance, and an iterative submission process that would enable a more detailed determination of the uncertainties involved at each step of a PV performance modeling pipeline."

Data availability of 2021 blind PV performance modeling intercomparison

The validation datasets of the 2021 blind PV performance modeling intercomparison are available online in open access at two locations. The first is on the website of the PV Performance Modeling Collaborative at https://pvpmc.sandia.gov/. The second is on the Duramat Data Hub at https://datahub.duramat.org/dataset/pv-performance-modeling-data (doi: https://doi.org/10.21948/1970772) [2].

Scenarios in 2023 blind PV performance modeling intercomparison

Based on the findings, lessons learned, and feedback received from the previous blind modeling intercomparison, four scenarios were identified as shown in Figure 1:

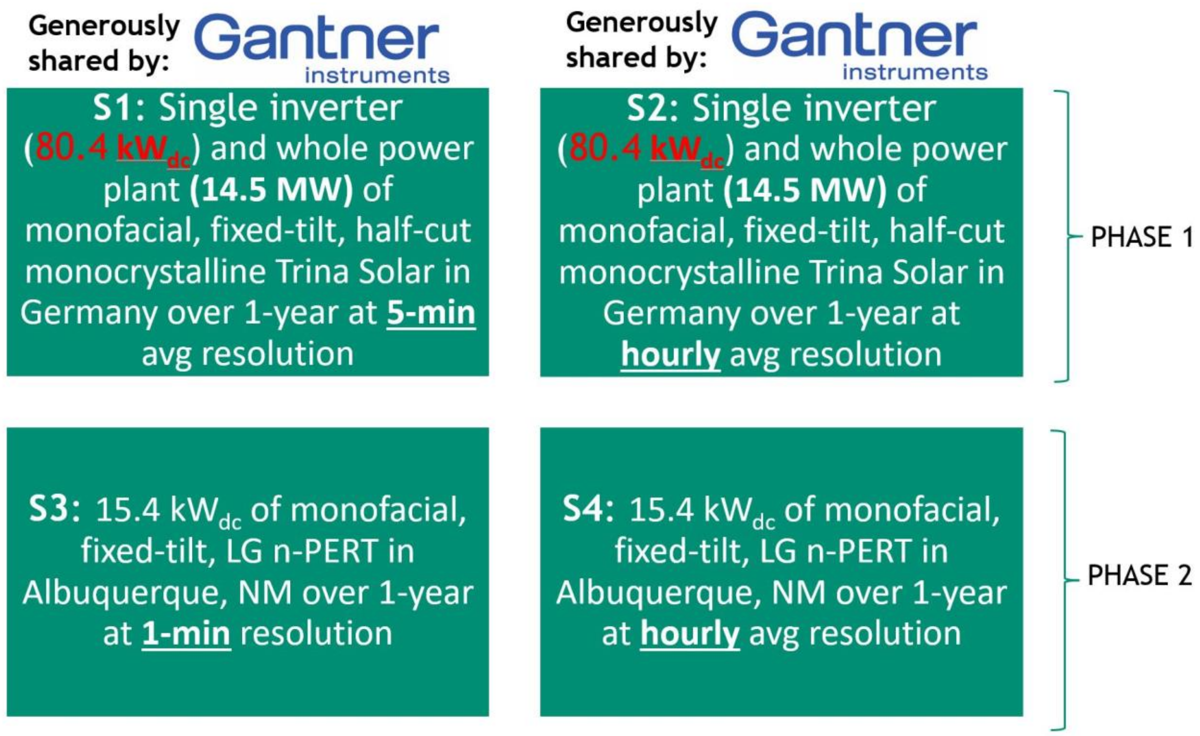


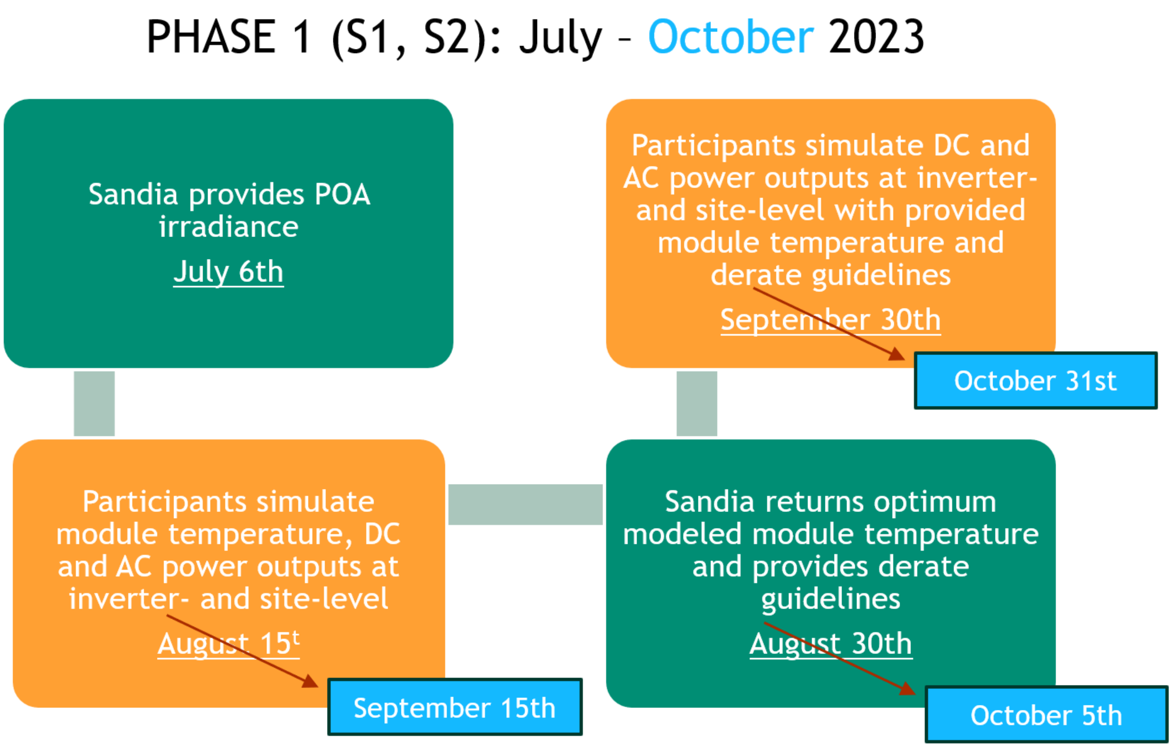
Figure 1: Four blind PV performance modeling scenarios divided into two phases: 1 and 2. Phase 1 will run from July – October 2023 whereas Phase 2 will run from October 2023 – January 2024. S1 and S2 will include inverter- (Inverter no. 14 in Transformer 4) and site-level estimations; these data were generously shared by Gantner Instruments, Juergen Sutterlueti. **Please note that this figure was modified to account for the correct number of strings on Inverter 14 (10 strings – 80.4 kWdc, not 9 strings).**

The scenarios are based on two systems: one in Germany and one in Albuquerque, NM. S1 and S2 are on 5-min and hourly average resolution, respectively. S3 and S4 are on 1-min and hourly average resolution, respectively. While S3 and S4 will only involve DC power only, S1 and S2 will include DC and AC power on the inverter- (1 out of 200 inverters in the plant) and site-level (all 14.5 MW; more details below).

Reporting Results

The four modeling scenarios are described in the following section. To participate one must "copy and paste" their estimates (i.e., POA irradiance [when applicable], module temperature, DC and AC power on inverter_14- and site-level [when applicable]) into the corresponding tabs (S1 – S2 , or S3 – S4) of the PhaseX_Results.xlsx file (the link is on the PVPMC website for Phase 1 and Phase 2). Running all scenarios is optional, but strongly encouraged. In addition to the estimated timeseries, the participants are requested to provide answers with respect to the model/software they used and inputs/assumptions according to the questionnaires at each excel tab.

The Due Date for the submissions varies according to the diagram in Figure 2. Please send the completed PhaseX_Results.xlsx file to Dr. Marios Theristis at mtheris@sandia.gov before the deadlines. If you have any questions after reading all of the documentation please email Marios and he will update the FAQ section of this webpage, as appropriate so everyone can see the same answers.



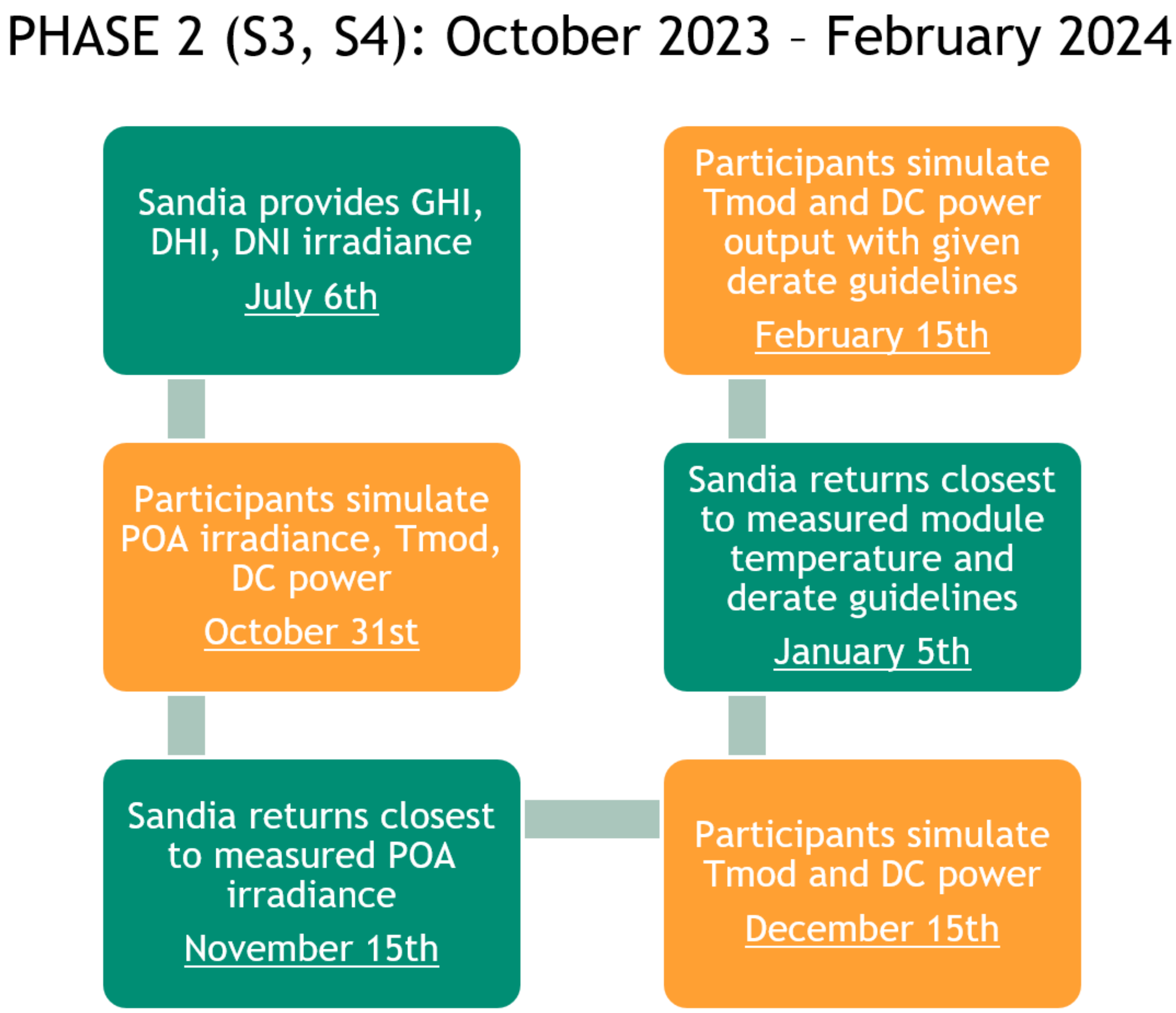


Figure 2: The iterative process of the 2023 blind PVPMC PV modeling intercomparison will enable error propagation at each modeling step and a self-learning experience for all participants. Phase 1 will run from July – October 2023 whereas Phase 2 will run from October 2023 – February 2024. The timeline of this process is also shown underlined. **All Phase 1 deadlines were extended on August 10, 2023.**

The results will be collected and handled by Sandia. Sandia plans to present an anonymized summary of the results at the next PVPMC workshops planned for November 8-9, 2023 in Mendrisio, Switzerland and May, 2024 in Salt Lake City, UT. Upon completion, Sandia would like to prepare a journal article describing the study with all the participants included as co-authors. The authors list will be listed in the order of 1) leading writer(s) and/or organizer(s), 2) execution of most scenarios, 3) contribution to the paper writing, 4) availability of data, 5) provision of feedback. If any of the participants do not wish to have their name included in any publication, please inform mtheris@sandia.gov.

In this intercomparison, **two groups** will be invited as follows:

1) **Open invitation for anyone to participate:** same process as in the 2021 intercomparison through PVPMC's email list.
2) **Software products by invitation only**. Emails will be sent out by Sandia. If your software entity did not receive an invitation, please reach out, we would love to have you on board.

The analysis of Phase 1 and 2 for both groups will be summarized in a manuscript with best practices in PV performance modeling.

Why participate?

- When an approach is tested against known datasets, a bias might be introduced.
- These blind intercomparisons provide an opportunity for PV modelers to test their models and ability.
- Participate in an international collaborative and see how your modeling skills or models compare to others.
- Results are shared with the participants much earlier than any other dissemination efforts.
- Participate in a large collaborative journal article.
- Self-learning exercise: iterative process will allow modelers to understand at which step(s) the error/uncertainty is being introduced.
- Software companies will be able to see where their products stand in comparison with other products.
- Get your company logo and name advertised for free!

Software companies are highly encouraged to also invite their own users to participate. This will create an adequate statistical sample for each software/model and observe variations and similarities in their user estimations allowing the identification of strengths and potential weaknesses. An independent analysis like this one will allow different companies to examine how reproducible their products are.

Note: The performance of a particular model/software in these intercomparisons should not be taken as global proof for its accuracy. Two systems in two locations are not adequate to prove any location- and technology-independent accuracy of a product.

Information regarding the four scenarios

	Scenarios 1-2	**Scenario 3-4**
Site information		
Location	Germany*	Albuquerque, New Mexico
Latitude (approx.)	52.195° N	35.0546 ° N
Longitude (approx.)	13.486° E	106.5401° W
Altitude (m above sea level)	41	1600
Time zone	CET (GMT+1)	MST (GMT-7)
System information		
Commissioning year	2020	2021
Capacity	14.5 MW dc	15.4 kW dc
Inverter	Huawei SUN2000-60KTL-M0	SMA Sunny Tripower 20000TL-US
Monofacial/Bifacial	Monofacial	Monofacial
Technology	Half-cut mono-c-Si	n-PERT
Manufacturer	Trina Solar	LG
Model	Trina TSM-DE06M(II)	LG320N1K-A5 320W LG NeON2
Module nominal power	335 W	320 W
Fixed/Tracked	Fixed	Fixed
DC/AC ratio	1.2	0.77
Tilt Angle	24°	35°
Azimuth	180° (facing South)	180° (facing South)
PV panel configuration	3-Up portrait	2-Up landscape
Total number of PV panels in system	43,344	48
PV panels in series	24	12
PV strings in parallel	1	1
Number of strings	1806	4
Number of inverters	200	1
Number of MPPTs per inverter	6	2
Number of transformers	6	NA
Strings per inverter	7-10**	4
Row spacing (m)	Detailed diagram in Figure 3	4.88
Provided inputs [S1, S2, S3, S4]		
Year of data	2022	2022
Duration	1 year	1 year
Resolution	**S1**: 5-min average data **S2**: Hourly averages reported in the middle of the hour	**S3**: 1-min average data **S4**: Hourly averages reported in the middle of the hour
Front Gpoa (W/m^2)	Yes	No
GHI (W/m^2)	No	Yes
DNI (W/m^2)	No	Yes
DHI (W/m^2)	No	Yes
Tamb (°C)	Yes	Yes
Tmod (°C)	No	No
RH (%)	No	Yes
WS (m/s)	Yes	Yes

Albedo	No	Yes (monthly averages in second tab of meteo data)
Requested modeled results		
	Modeled module temperature (°C)	Modeled POA irradiance (W/m^2)
	Modeled DC power on Inverter 14 of T4 (kW)***	Modeled module temperature (°C)
	Modeled AC power on Inverter 14 of T4 (kW)***	Modeled system DC power (W)
	Modeled DC power for whole site (kW)	
	Modeled AC power for whole site (kW)	

* German location is approximate due to owner confidentiality.

** The string inverters have 6 MPPTs. Therefore, some strings are combined into one MPPT (max of 2 per MPPT). See the table below for more information on the power plant configuration.

*** Inverter 14 (of Transformer 4) consists of 10 strings. See Figures 4-6 for more information.

Power plant configuration for S1-S2

Transformer	Number of inverters with 10 strings	Number of inverters with 9 strings	Number of inverters with 8 strings	Number of inverters with 7 strings	Inverters per transformer	Strings per transformer	Modules per string
1	0	34	0	0	34	306	24
2	8	26	0	0	34	314	24
3	0	33	0	1	34	304	24
4	8	26	1	0	35	322	24
5	0	27	1	1	29	258	24
6	4	26	0	4	34	302	24

**** This plant configuration was edited on August 10, 2023 due to a mismatch in the single line diagrams and actual power plant commissioning.**

Nomenclature

Gpoa – global irradiance on the plane-of-array

GHI – global horizontal irradiance

DNI – direct normal irradiance

DHI – diffuse horizontal irradiance

Tamb – ambient temperature

Tmod – module temperature

RH – relative humidity

WS – Wind speed

SAPM – Sandia Array Performance model

IAM – incidence angle modifier

NMOT – nominal module operating temperature

Filtering

- Consistency of GHI, DHI and DNI using QCRad criteria in *pvlib-pvanalytics*
- When DNI < 0 W/m^2 then DNI = 0 W/m^2
- 1 < GHI < 1300 W/m^2
- 1 < Gpoa < 1300 W/m^2
- 1 < DHI < 800 W/m^2
- 0 < WS < 32 m/s
- -5 < Tamb < 45°C
- 0 < RH < 100%

Plant and array diagrams

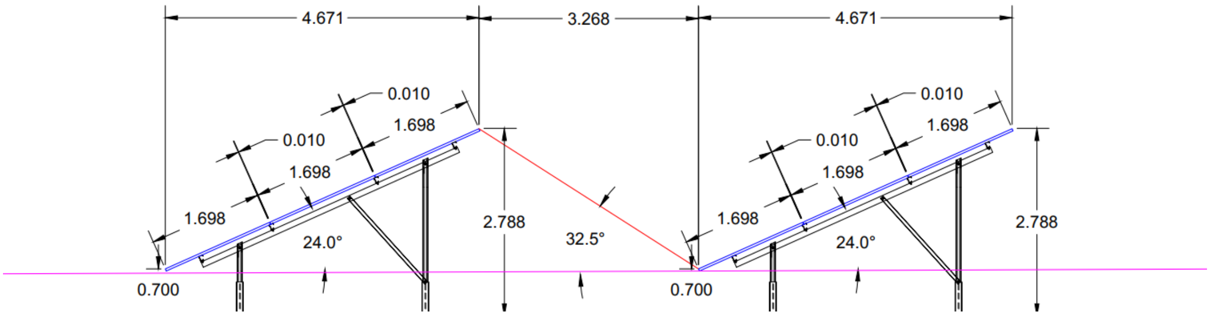


Figure 3: Diagram of S1-S2 PV array dimensions and spacing.

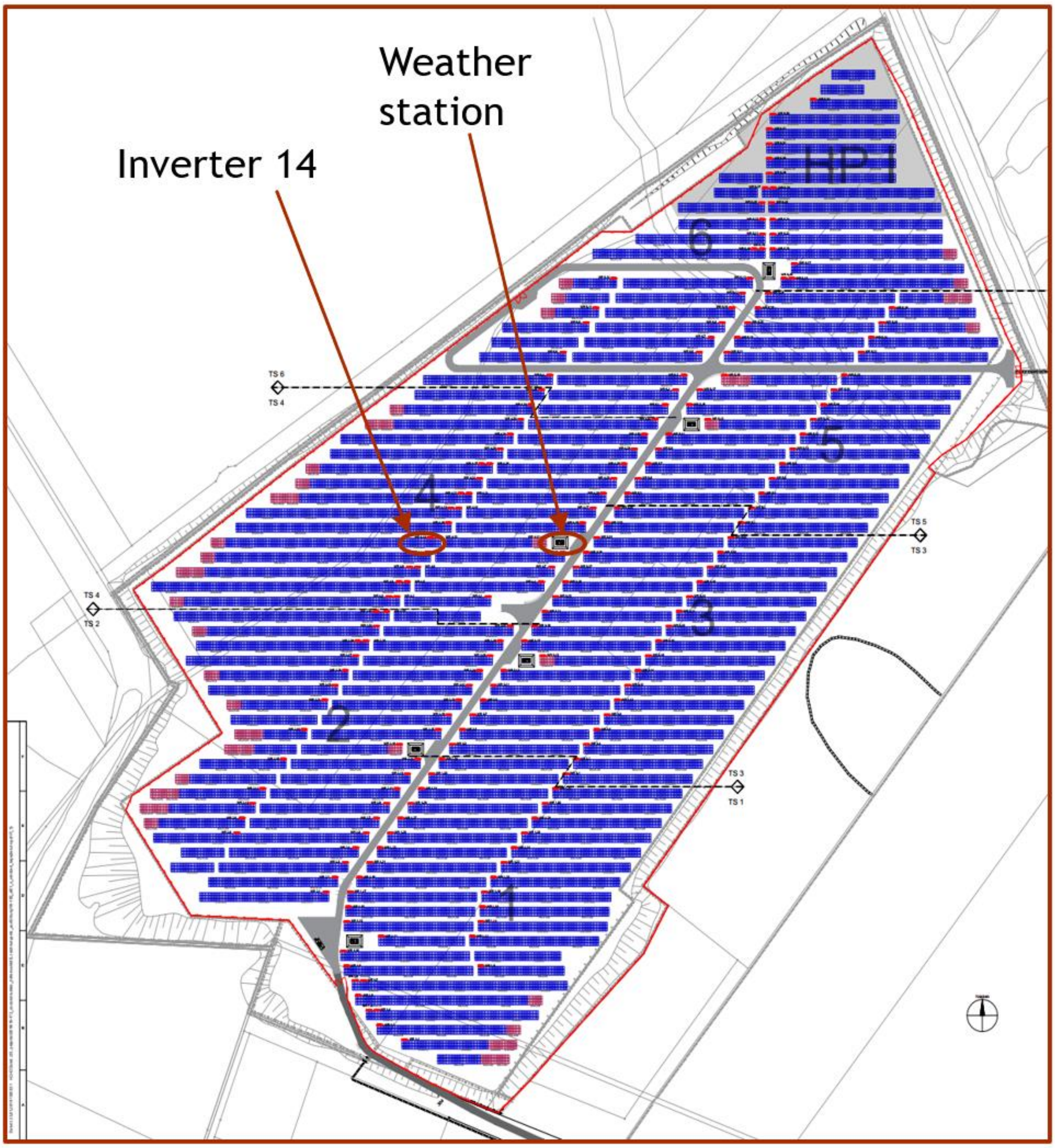


Figure 4: Site view of S1-S2 power plant showing the location of the six transformers. Inverter 14 and weather station are also indicated.

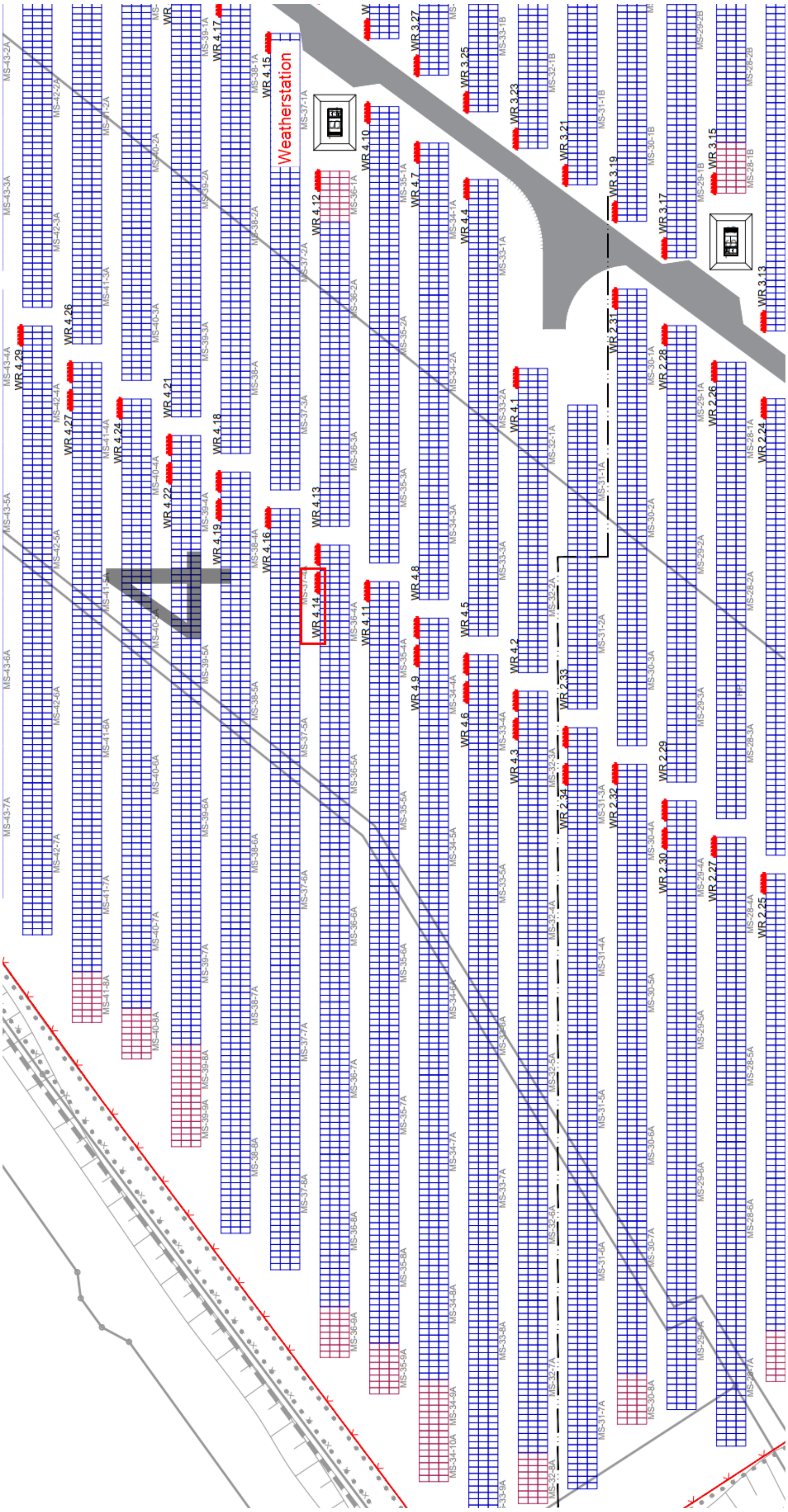


Figure 5: Zooming in to Figure 4 to show finer details of Inverter 14 and weather station.

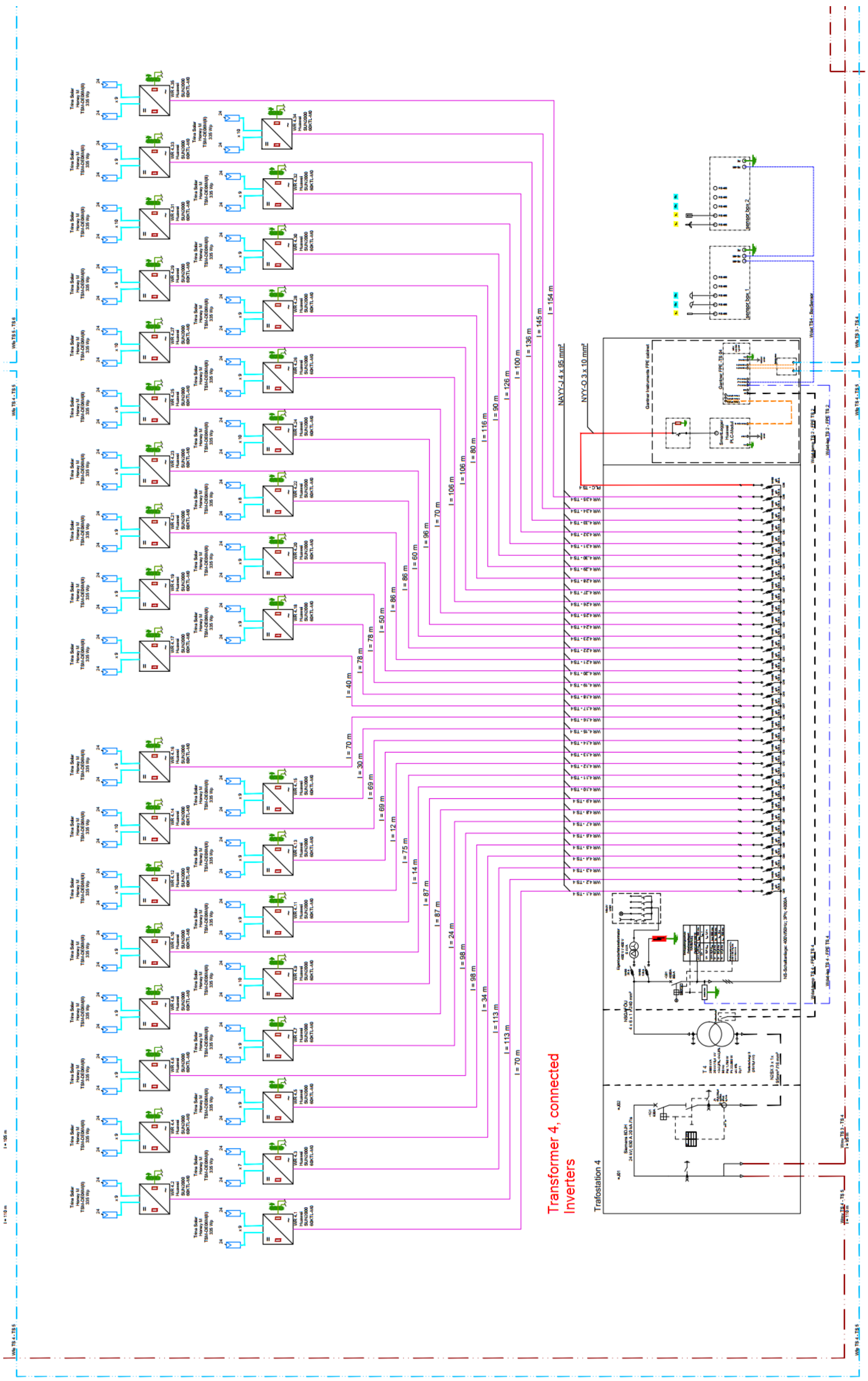


Figure 6: Exemplary single line diagram of Transformer 4 in S1-S2. Inverter 14 consists of 10 strings. Refer to the configuration table for the correct number of strings per inverter for all transformers. Distances should be considered as approximate.

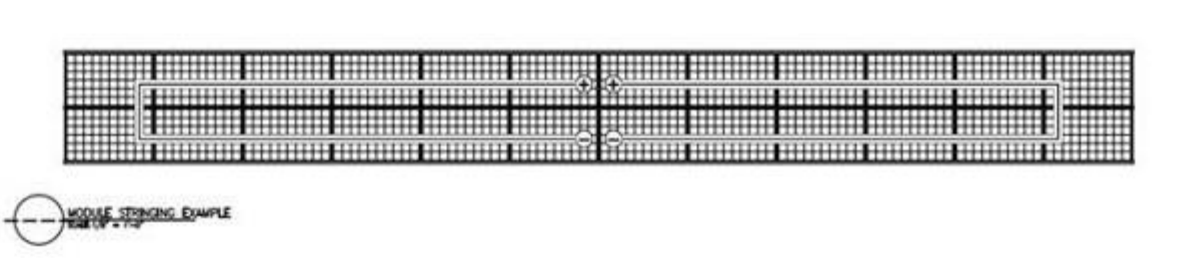


Figure 7: String wiring of modules in S3-S4. The figure displays two out of 4 strings.

References

[1] M. Theristis, *et al.* "Blind photovoltaic modeling intercomparison: a multidimensional data analysis and lessons learned," Progress in Photovoltaics: Research and Applications, 2023.

[2] M. Theristis and J. S. Stein, "PV Performance Modeling - Data and Resources, " in DuraMat Data Hub https://doi.org/10.21948/1970772, accessed in May 25, 2023.