Edgecumbe Performance Test Report

29/05/2024

INFRATEC

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Contents

1. Introduction

Part of Infratec's Testing and Commissioning scope in the EPCC for Edgecumbe Solar Farm is to conduct a performance test. The performance test methodology is set out in EPCC contract schedule 15 Part 2 and the referenced parts of IEC 61724-1:2021 and IEC 61724-2:2016.

The purpose of this performance test is to compare the actual performance of the Edgecumbe solar farm against the modelled performance of the solar farm. A secondary purpose is to determine if there is any performance shortfall due to Infratec's workmanship for Infratec's scope in the EPCC.

The performance test is for the whole solar farm and is bounded by the revenue meter of the solar farm. The performance test is a performance ratio test, and the performance ratio target is 96 % of the P50 As-Built PVSyst model Performance Ratio, when using on-site meteorological measurements during the performance test as the meteorological input to the PVSyst model.

2. Methodology

The performance test method specified in the EPCC contract is based on the performance testing methodology in IEC 61724, but to determine the performance ratio target the output of the As-Built PVSyst model was used with an input of filtered measured irradiance and temperature during the performance test. The high-level methodology is specified in EPCC contract schedule 15 Part 2 (included in Appendices) and the IEC 61724 standard. In addition, a methodology document was prepared and shared with Lodestone, covering the performance test methodology for Edgecumbe in detail. The lessons learnt from Kaitaia performance test have been incorporated in the test methodology that will be followed for Edgecumbe, where relevant. The performance test methodology document is included in the appendices.

The test data was retrieved from Lodestone's Octavian EDS historian. Data was retrieved for every 3 second period during the performance test (as per the Class A sampling interval in IEC 61724).

Filtering of data is explained in detail in the clarifications section below and evidence of this filtering methodology being followed can be seen in the provided python filtering script ("data_processing_v3-Edgecumbe (final).py"). The python script used for Edgecumbe was modified from the one used for Kaitaia to output the filtered data into excel spreadsheet format at each stage of the data filtering process. These files have been provided separately and provide further evidence of the functioning of the script. Infratec used python version 3.10 with the following libraries / modules imported to run the script:

- Pandas library
- NumPy module
- Tqdm library
- Datetime module
- Matplotlib library

The performance test was started after commissioning of the solar plant was complete and all plant was functioning correctly. Plant outages and equipment failures that occurred during the performance test have been noted in this report and are managed as per the EPCC contract. Associated data is filtered according to this document.

2.1 Methodology Clarifications

The IEC 61724 standard gives flexibility around certain parts of the methodology. Below is a list of further methodology clarifications.

- Total duration of the performance test must be at least 14 consecutive days. There may be less than 14 days' worth of data used for the performance test if periods are legitimately required to be excluded.
- Data collected for all points used for performance testing on a three (3) second sampling interval.
- In-plane irradiance is the average of the two in-plane irradiance sensors.
  - If either sensor measurement is faulty the other sensor value is used
  - If both sensors are faulty these periods have been excluded.
- Global Horizontal irradiance for PVSyst is the average of the two global horizontal irradiance sensors.
  - If either sensor measurement is faulty the other sensor value is used
  - If both sensors are faulty these periods have been excluded.
- Ambient temperature used for PVSyst is the average of the two sensors.
  - If either sensor measurement is faulty the other sensor value is used
  - If both sensors are faulty these periods have been excluded.
- Missing or bad data periods for irradiance / temperature and AC output power / energy will be excluded.
- Periods where the trackers go into the stow position have been excluded.
- Any periods where there is AC curtailment due to the network or not being fully dispatched have been excluded.
- Irradiance sensors and PV modules will <u>not</u> be cleaned before or during the performance test but will be checked for unacceptable uncleanliness. The soiling on both panels and irradiance sensors has been assumed to be the same, thus soiling loss was set to 0% on the PVSyst Model for the performance test.
- If any of the inverters are curtailed, these periods will be excluded.
- Periods of constrained operation will be excluded in the performance test.
- PVSyst requires Global Irradiance as the irradiance input when creating a custom meteorological file for a tracking system. So Global Irradiance was used in the performance test rather than In-Plane Irradiance specified in the EPCC contract.
- Data filtering methodology
  - Filtering at the 3 second level was done for:
    - Point of Connection Limitation – both 23.7 MW and 26.34 MVA. Periods where real power or apparent power was greater than 99.8% of point of connection ratings were excluded.
    - Inverters Constraining
      - Inverter were considered constrained if their apparent power output was greater than 99.8% of the maximum power rating considering how many power modules were available for operation as reported by the inverter. Each power module is rated at 1.0975 MVA.
    - High wind speed resulting in Wind Stow
      - Periods of wind stow were detected by checking the wind sensors readings against the tracker controller settings. If both wind speed readings were over 40 km/hr (11.11 m/s) for two consecutive 3 second readings (i.e. 6 seconds in total), then wind stowing was assumed until the wind speed measured by both sensors dropped below 38 km/hr (10.55 m/s) for 300 seconds.
  - Averaging to 1 minute data
    - Then data was averaged into minutes from the remaining (filtered) 3 second periods.
    - One-minute periods were excluded if there were less than 5 valid data points in that 1-minute period.
  - Filtering and averaging to 15-minute data:
    - Only periods with 15 x 1-minute data points remaining after 3 second filtering were used.

    - Irradiance was filtered as per Table 1 in IEC 61724-2:2016, and Target Reference Condition (TRC) was selected to be 700 W/m^2. 15-minute periods that did not fall within the acceptable irradiance range (<0.5xTRC or >1.2xTRC) were excluded.
    - Temperature was filtered as per Table 1 in IEC 61724-2:2016, and 15-minute periods excluded.
    - Power was filtered as per Table 1 in IEC 61724-2:2016, and 15-minute periods excluded.
- Any 15-minute datapoint that had a POA irradiance less than 450 W/m^2 was excluded as well.
- All remaining 15-minute periods of averaged value data after filtering were used for the performance test. Each valid 15-minute period was simulated as an hour period in PVSyst.
- The Design Performance Ratio was calculated using the bifacial performance ratio calculation specified in IEC 61724-1 by taking the sum of energy in the PVSyst output file (from the PVSyst simulation) and dividing the sum of energy by the amount of unconstrained DC energy that would be produced in the same timeframe at STC and correcting with the front and rear irradiance seen on the panels.
- The Actual Performance Ratio was calculated using the actual energy measurements from site and the same calculation methodology as Design Performance Ratio.

3. Sensors and Accuracy

The two NIWA weather stations installed on-site at Edgecumbe (WSTAT211 and WSTAT231) were used. IEC 61724 specifies the number and class of sensors required for a solar farm based on solar farm size shown in Table 4 of IEC 61724-1, this table was followed.

These two weather stations were installed by NIWA and are owned by Lodestone.

The following sensors and instrumentation were used as part of the performance guarantee testing:

- Revenue & Power Quality Meter - ION 8650
- Irradiance Sensor Global Horizontal – Class A – Hukseflux SRA30-M2-D1
- Irradiance Sensor Plane of Array – Class A - Hukseflux SRA30-M2-D1
- Temperature Sensors – Class A - Lufft WS501-UMB
- Wind Sensor - Lufft WS501-UMB
    a. Note wind sensors were only used to determine if the tracking modules ever went into a stow or partial stow position.

Datasheets for the sensors can be found in Lodestone Documentation.

3.1 Sensor validation

Prior to the performance test beginning, NIWA completed site acceptance testing on the weather stations and associated sensors. The site acceptance testing used reference readings (where possible) to check the accuracy of installed sensors. Irradiance sensors were calibrated prior to installation on site and suitable checks were conducted after installation to validate sensor readings.
Infratec also completed an analysis prior to beginning the performance test to check that sensor readings were sensible and correlated well. Correlations between similar sensor readings was checked after the 3 second data was filtered and averaged into 1-minute data points. The main reason for doing this was to avoid using bad data in the correlation calculations.

3.1.1 Irradiance Sensors

The Class A Irradiance sensors site acceptance testing was completed by NIWA on 22nd February 2024, see site acceptance report and calibration certificates in the Appendices.

The two Global Irradiance sensors and the two In-Plane Irradiance sensors have been correlated against each other as a further check.

Global Irradiance Sensors

Over the performance test period the data from the two sensors had a correlation co-efficient of 0.983.

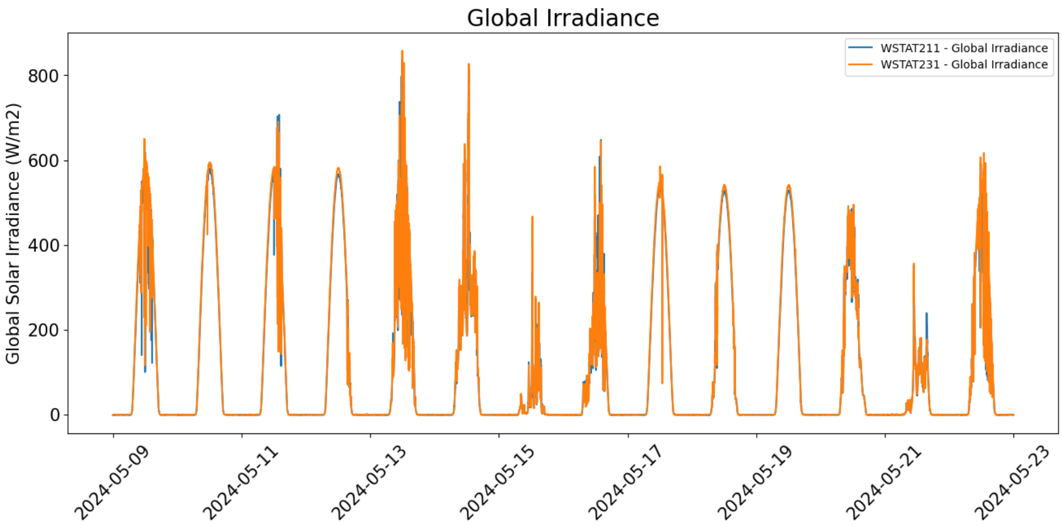

Figure 1: Trend of Global Irradiance Data over test period

As Infratec was not going to clean the solar modules and the irradiance sensors for the performance test, the irradiance sensor cleanliness was checked to ensure that irradiance sensors were not more soiled than the modules. Images of the irradiance sensors taken before the start of the performance test can be seen in Figure 2 and Figure 3 below.

Figure 2: Uncleaned Global Horizontal Irradiance Sensor 1

Figure 3: Uncleaned Global Horizontal Irradiance Sensor 2

As the Global Horizontal Irradiance sensors measurements are the main driving factor for the performance test, a further check was completed to correlate their measurements with the POA sensors with the solar array between -1 degrees to +1 degrees tilt (horizontal). As can be seen in Figure 4 below, the global horizontal and POA sensors at each weather station location correlate extremely well.

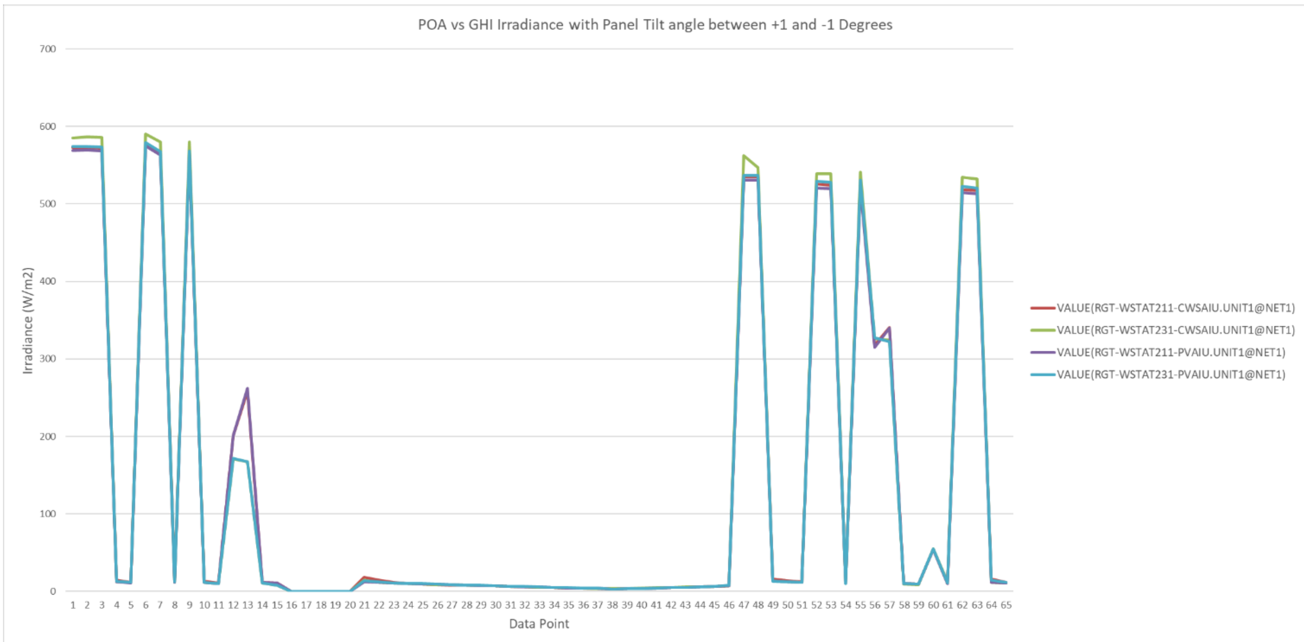

Figure 4: Comparison of Irradiance Sensors

In-Plane Irradiance Sensors

Over the performance test period the data from the two sensors had a correlation co-efficient of 0.923.

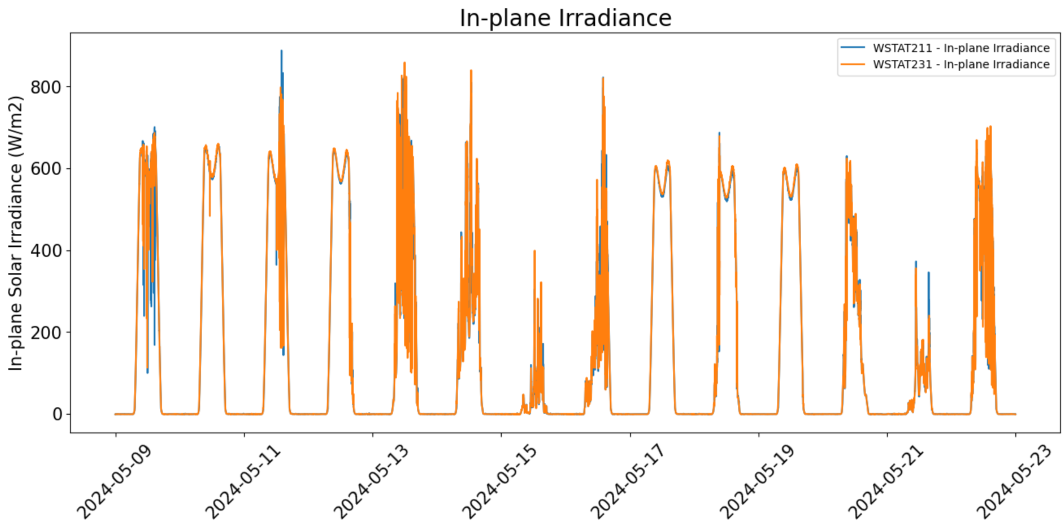

Figure 5: In-plane irradiance over test period

During the performance test, Lodestone informed Infratec one of the POA irradiance down sensors was deemed unacceptably dirty and instructed Infratec site personnel to clean this sensor (see Figure 6 below). Lodestone also requested that all other irradiance sensors be checked at the same time.

Figure 6: Dirty POA down sensor on near MVS 1

Despite Infratec's intention to not clean the irradiance sensors during the performance test, based on the discussion noted above, all POA sensors were cleaned. The sensors were cleaned on 15th May 2024, which was 6 days into the performance test.
Images of the uncleaned Plane of Array up irradiance sensors can be seen in Figure 7 and Figure 8 below.
Images of the cleaned Plane of Array irradiance sensors can be seen in Figure 9 and Figure 10.

Figure 7: Uncleaned POA Irradiance up Sensor 1

Figure 8: Uncleaned POA Irradiance up Sensor 2

Figure 9: Cleaned POA Irradiance up Sensor 1

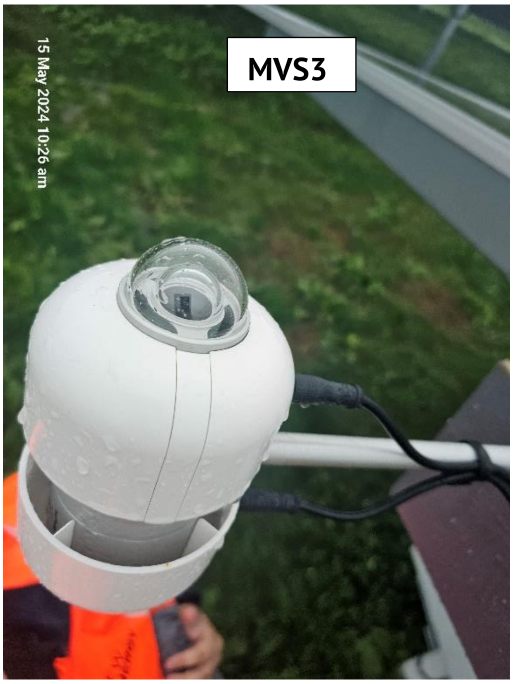

Figure 10: Cleaned POA Irradiance up Sensor 2

3.1.2 Temperature Sensors

The ambient temperature sensors site acceptance testing was completed by NIWA on 22nd February 2024, see the NIWA final installation report and calibration certificates in the Appendices.

Over the performance test period the data from the two sensors had a correlation coefficient of 0.979.

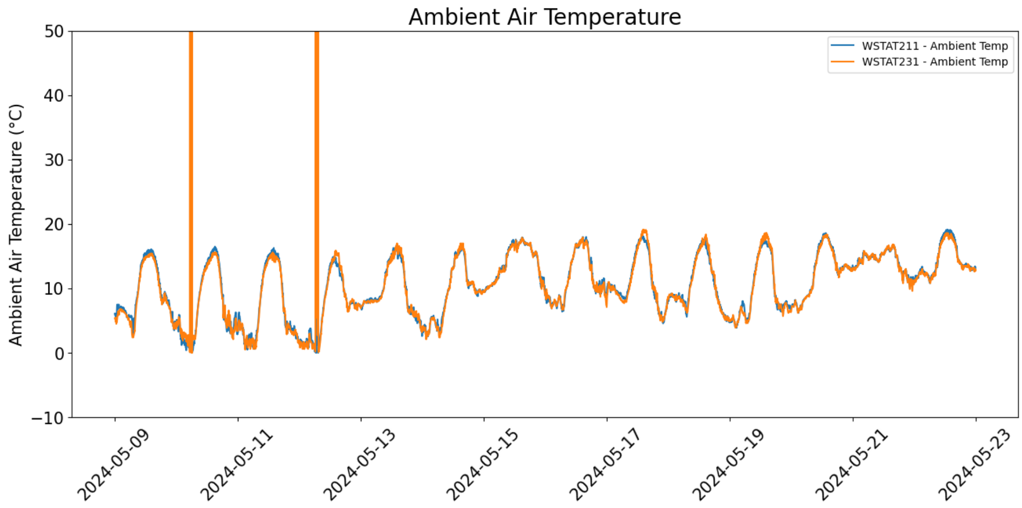

Figure 11: Trend of Ambient Temperature Data over Test Period

Also notice that the ambient temperature readings from both weather station sensors had erroneous measurement spikes in the early stages of the performance test. Upon further investigation Infratec has confirmed that no work was done on the weather stations during the performance test period, which could have explained the reason for these spikes. Infratec does not know the exact cause of these spikes, however, we suspect that the cause may be intermittent communications failures between the sensors and the weather station or between the weather station and SCADA.
It is clear from the trend though, that the sensors provided reliable readings throughout the performance test aside from these anomalies. These spikes will be filtered out by the filtering method specified in section 2.1.

3.1.3 Revenue and Quality Meter

The revenue meter and power quality meter were calibrated by Metering Equipment Provider (MEP) AccuCal Ltd on 27th February 2024. See Appendices for calibration certification.

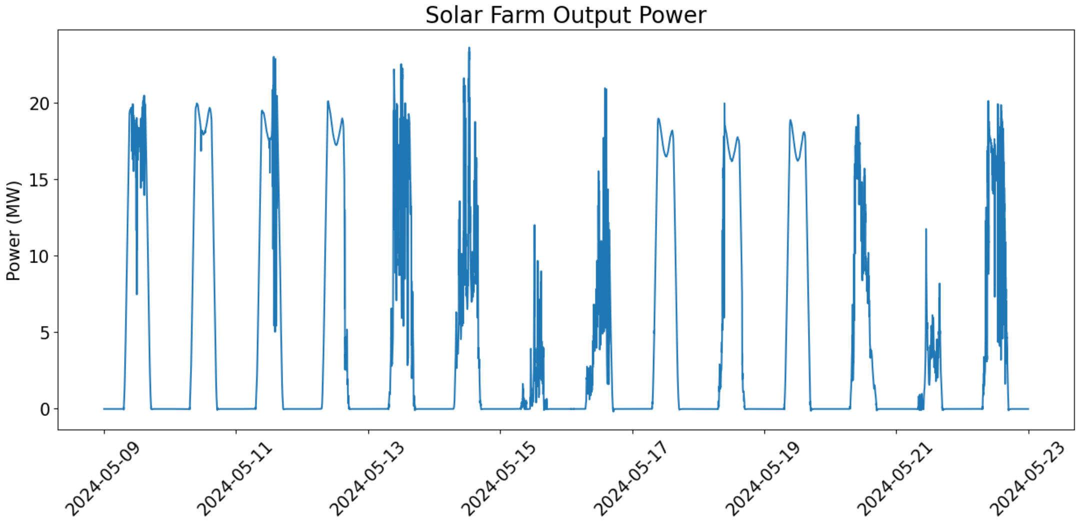

Figure 12: Solar Farm Output Power Over Test Period

3.1.4 Wind Sensors

The wind sensor site acceptance testing was completed by NIWA on 22nd February 2024, see the NIWA final installation report and calibration certificates in the Appendices.

Over the performance test period the data from the two sensors had a correlation co-efficient of 0.749.

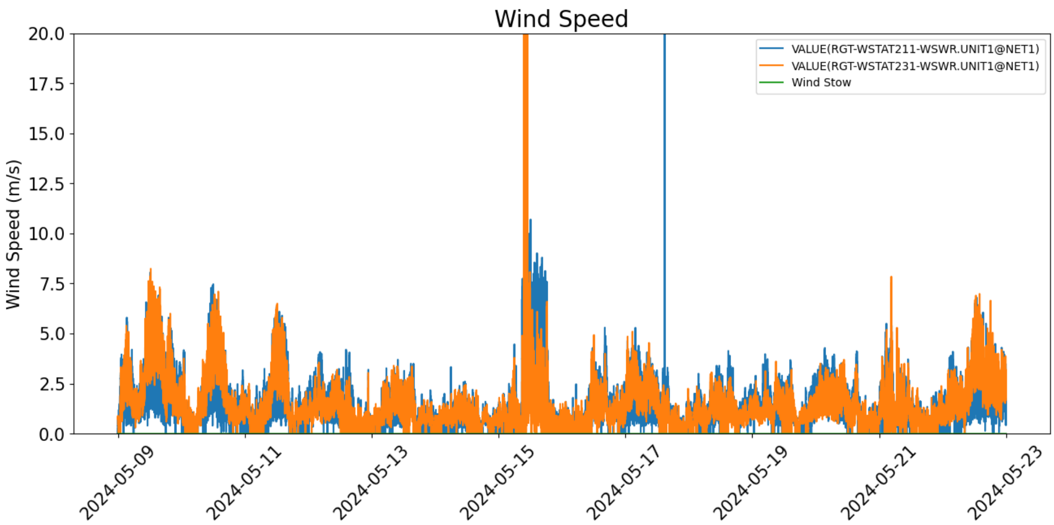

Figure 13: Trend of Wind Speed data over test period

Note that in Figure 13 the wind speed sensor of both weather stations had large spikes in measurements that occurred at different times. Apart from these spikes the two sensors correlate well enough. To mitigate the large spikes for the wind stow filtering the wind stow filter required both measurements to be above the wind stow threshold for two consecutive readings (i.e. 6 seconds).

4. Performance Test and Results

4.1 Test Period

The 14-day performance test was conducted from 09/05/2024 12:00am to 22/05/2024 23:59pm.

4.2 Test Data

The test data was recorded from Lodestone's Octavian EDS historian. Data was retrieved for every 3 second period during the performance test (as per the Class A sampling interval in IEC 61724). The data recorded over the performance test period is included along with this report to allow for auditing, this includes indication of periods that were filtered.

After filtering there were 156 x 15-minute datapoints used for the performance test. For filtering method see the Methodology Clarifications section.

4.2.1 Irradiance

The Global Irradiance sensors were used to record the irradiance during the performance test, due to PVSyst requiring a Global Irradiance input for creating a custom meteorological file for a tracking system.

The Target Refence Condition (TRC) was selected to be 700 W/m^2. This value was selected as at the STC value of 1000 W/m^2 the solar farm is typically constrained due to the high DC to AC ratio. This TRC value means that average global horizontal irradiance below 350 W/m^2 and above 840 W/m^2 were excluded from the performance test. Despite the lower global horizontal irradiance value being 350 W/m^2, any Plane of Array irradiance readings below 450 W/m^2 were also excluded, as per the recommended minimum irradiance in Table 2 of IEC 61724-2 Table 2.

The average Global Horizontal Irradiance for the data inputted into PVSyst was 484 W/m^2.

The average POA irradiance for the data inputted into PVSyst was 587 W/m^2.

4.2.2 Temperature Sensors

The ambient air temperature sensors on the two weather stations were used to record the ambient air temperature to input into PVSyst to create the custom meteorological file.

The average temperature on-site during the test period was 14.7 ˚C.

4.2.3 Inverter Constrained Operation

Periods of inverter constraints / forced outages were detected using the filtering methodology and these periods were excluded from the performance test. A trend of when the inverters were detected as constrained can be seen below in Figure 14. The majority of the periods where the inverters are showing as being constrained in Figure 14 occurred when there was no generation from the PV plant i.e. outside daylight hours when all inverter modules are unavailable. There were a few periods where inverters were constrained during daylight hours, but these periods occurred when irradiance was insufficient to produce an output from the inverter(s). This can be seen more clearly in Figure 15, which shows the site output power and inverter constraints on the same graph.

There were no inverter faults noted throughout the performance test.

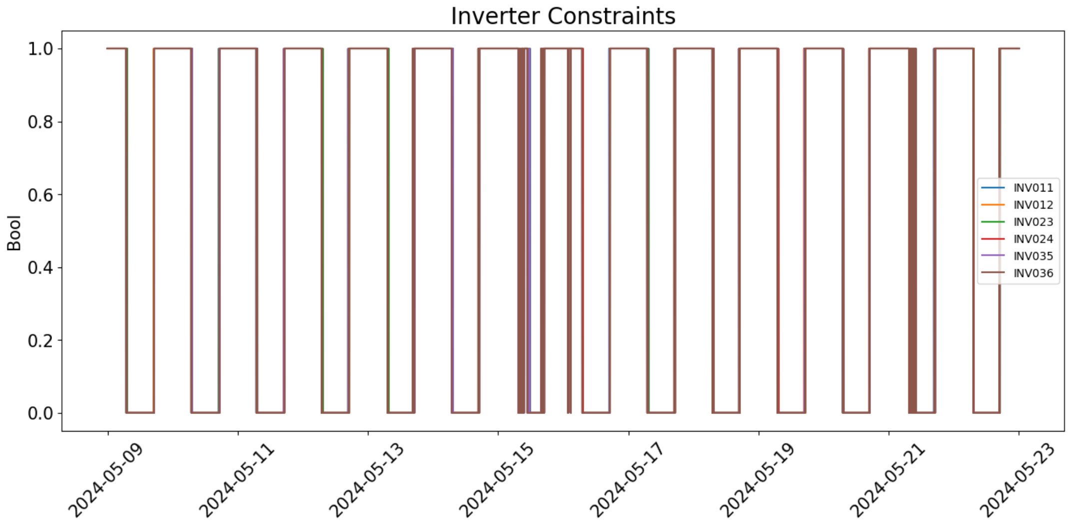

Figure 14: Trend of detected inverter constraints

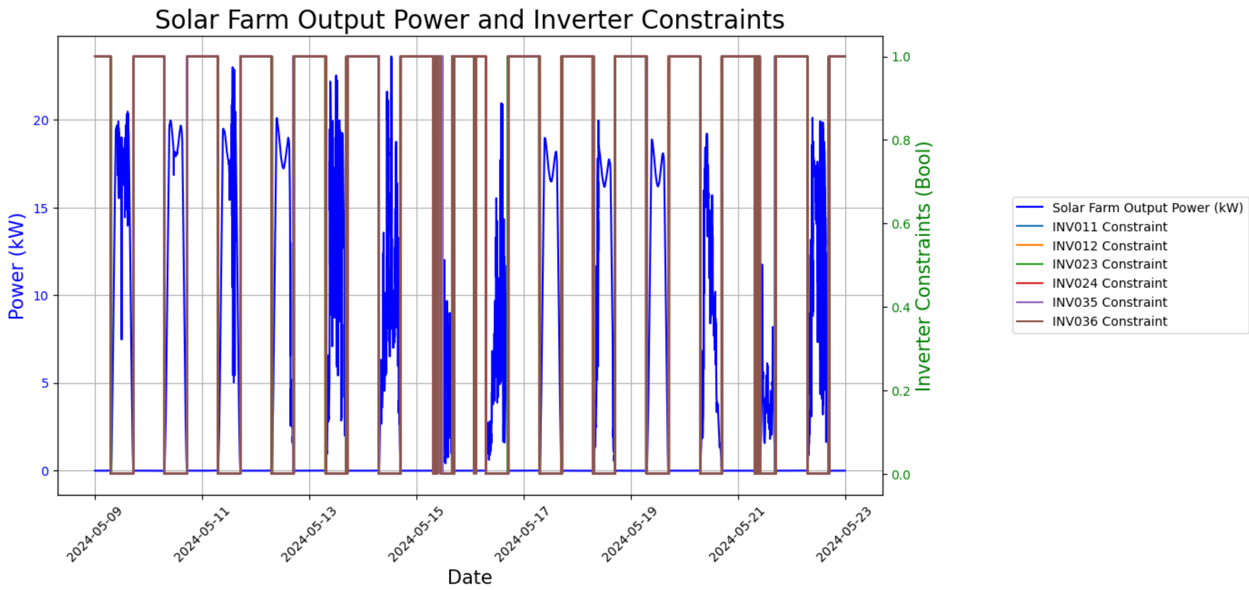

Figure 15: Trend of Site Output Power and Inverter Constraints

4.2.4 Wind Stow

There was no wind stow conditions detected throughout the performance test, as both wind sensors were never above the wind stow threshold simultaneously.

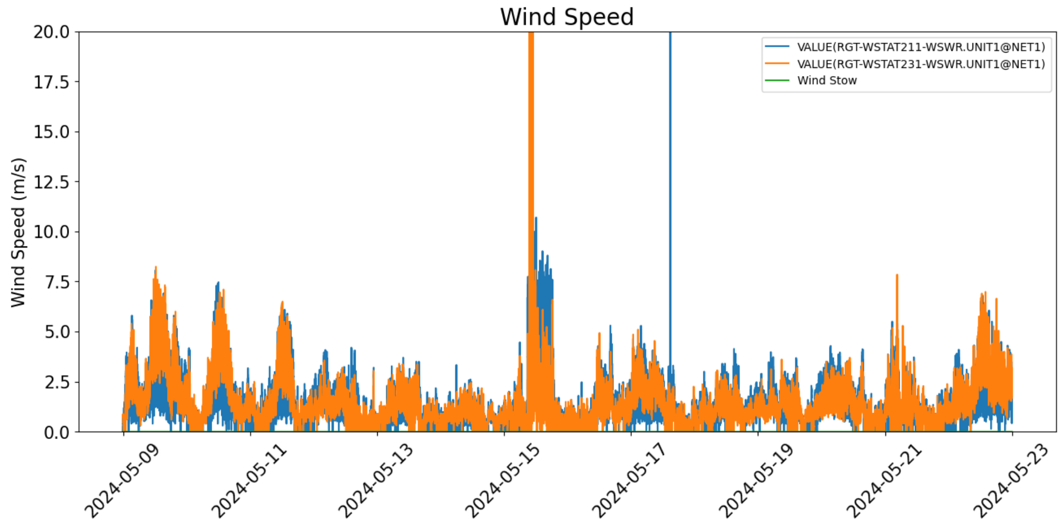

Figure 16: Wind sensor measurements throughout the performance test

4.3 Maintenance, Outages, and Issues During Test

There were some plant alarms, component faults and other notable changes during the performance testing period.
For each fault, Infratec was notified by Lodestone via email and where appropriate, Infratec attended faults once notification was received. Aside from the faults listed below, no other issues were noted.

The dates provided for the faults that occurred during the performance testing period are not the actual fault date or time, but rather indicate the date on which Lodestone notified Infratec of the fault. The date/time that each fault was resolved are mentioned where known.

Inverter status was also being monitored to determine if an inverter was out of service. None of the inverters presented any faults during the performance test period.

Table 1 Below lists all the noted plant component faults and other notable changes that occurred during the performance test period:

Table 1: List of noted plant faults and changes during performance testing period

Item	Notification Date	Plant component(s) affected	Issue Description [and Resolution]
1	13/05/2024	Tracker field 5 TCUs 50, 51, 54, 62 & 64	Wind alarms. Tracking stalling at +12 degrees. [Trackers were power cycled and resumed normal operation on Sunday 12th May at 14:15]
2	15/05/2024	Tracker field 5 TCUs 49, 50, 51, 54, 56, 57, 63 & 64	Comms error between NCU 5 and TCUs. TCUs not reporting correct position to SCADA.
3	15/05/2024	Two combiner boxes in tracker field A linked to either inverter 1 or 2	The 2 combiner boxes were disconnected prior to the start of the performance test on 09/05/2024. [They were both reconnected on 13/05/2024 at 13:45]
4	15/05/2024	Plane of Array Irradiance (POA) sensors on PV tables	Lodestone instructed Infratec site representative to clean the down POA sensor near MVS1 and to check all other POA irradiance sensors on 15/05/2024 (6 days into the performance test). Infratec site personnel cleaned the POA irradiance sensors mounted on the PV array tables near MVS1 and MVS3 on 15/05/2024.
5	20/05/2024	Several TCUs located in field arrays C, F and D	TCUs reporting incorrect tilt angle positions to SCADA. Trina representative has confirmed that the trackers are physically tracking correctly, but SCADA is not displaying correct positions.

It was noted prior to commencing the performance test that irradiance sensors are not to be cleaned as we assumed them to be as soiled as the PV panels, so soiling losses were set to 0% in PVSyst. However, Lodestone instructed Infratec site personnel to clean the POA down irradiance sensor mounted on the PV tables near MVS1, as it was deemed unacceptably dirty (see Figure 6). Lodestone also requested that Infratec check the cleanliness of all other POA irradiance sensors at the same time. Infratec site personnel subsequently cleaned all the POA irradiance sensors mounted on the PV arrays (not the POA sensors mounted on the weather stations).
If anything, the cleaning of the POA irradiance sensors during the performance test; while still leaving soiling losses at 0% in PVSyst; would make it more difficult for Infratec to meet the target performance ratio, as it would result in the PVSyst performance ratio being slightly higher than it should be.

The filtering of data does not account for individual tracker faults, so the TCU faults noted in Table 1 above would not have been filtered out during the data filtering process.

It should be noted that all the issues listed above would have made it more difficult for Infratec to meet the target performance ratio, as the actual plant output would have been reduced because of these issues. Despite this, Infratec have run the performance ratio calculation including all the data recorded during the periods when these faults were present.

No other site maintenance or activities were conducted during the performance testing period that would affect the performance of the solar farm.

4.4 PVSyst Modelling

PVSyst version 7.4 was used for the performance test. The Edgecumbe PVSyst model used for the performance test was "Lodestone 4_PT (2024-04-08)".

The input file used to create the custom meteorological file is supplied along with this report. The PVSyst output file from the performance test is also included. Note that as 15-minute data points were used as hourly inputs into PVSyst, datapoints with the same day and hour as a previous data point were pushed forward to the next free day without a valid data point in that hour.

The only changes made to the PVSyst model were setting soiling losses to 0% and increasing the AC output power limitation to 23.7 MW from 23 MW. No changes were made to the soiling losses in the PVSyst model to account for the cleaning of the POA sensors during the performance test period. Ideally, the soiling losses should have been increased to account for the difference in the level of soiling between the POA irradiance sensors and the PV modules, but Infratec have left soiling losses at 0%.

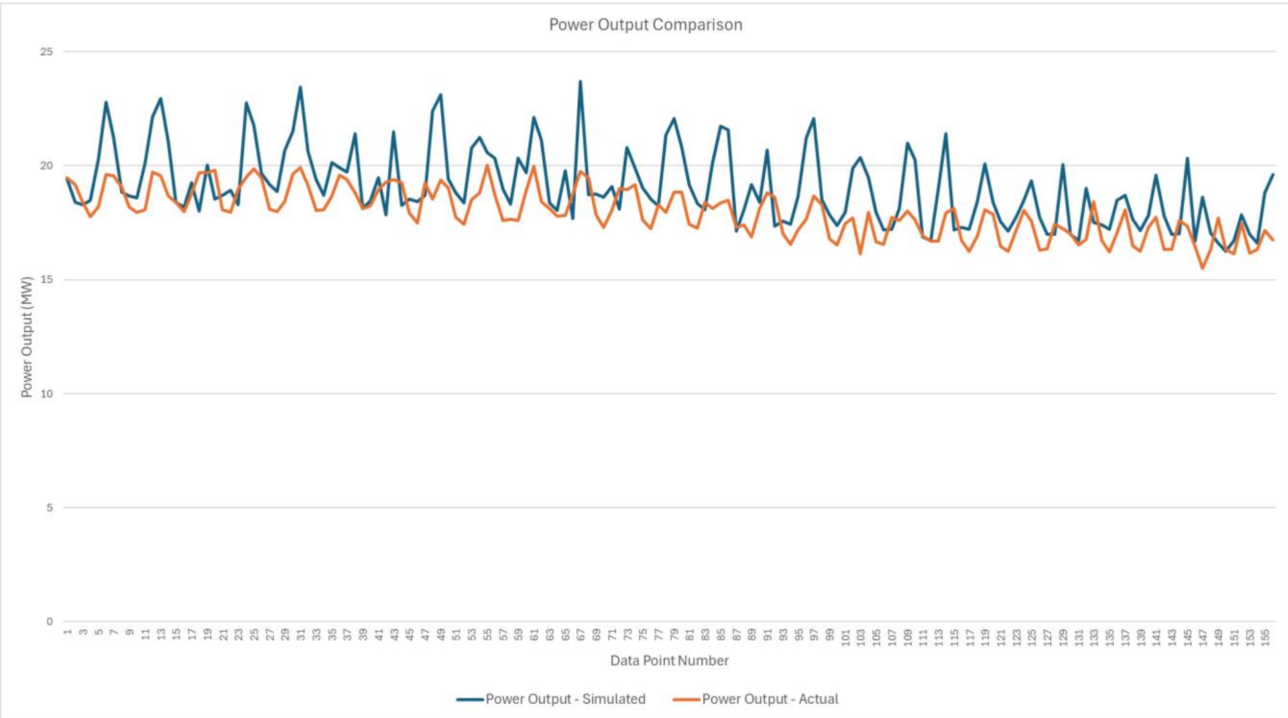

Figure 17: Power Output Comparison of Actual and Simulated

As shown in Figure 17 the actual power output and the simulated power are fairly well correlated.

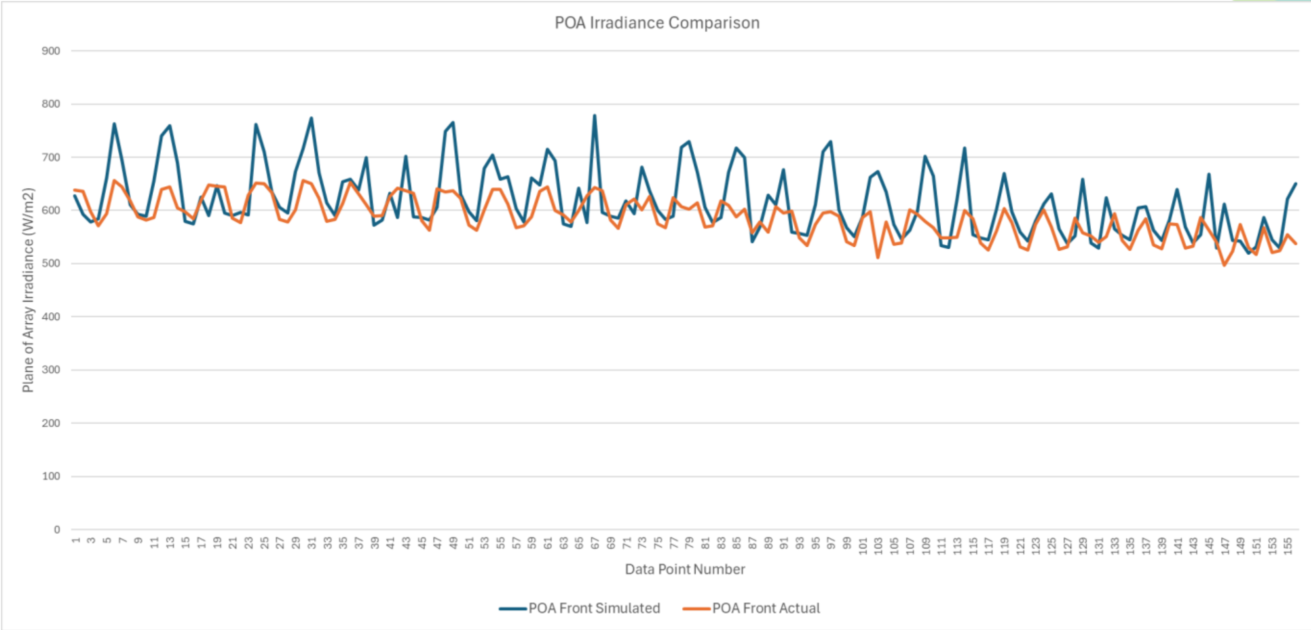

Figure 18: Plane of Array Comparison of Actual and Simulated

As shown in Figure 18 the actual Plane of Array irradiance and the simulated irradiance are correlated reasonably well.

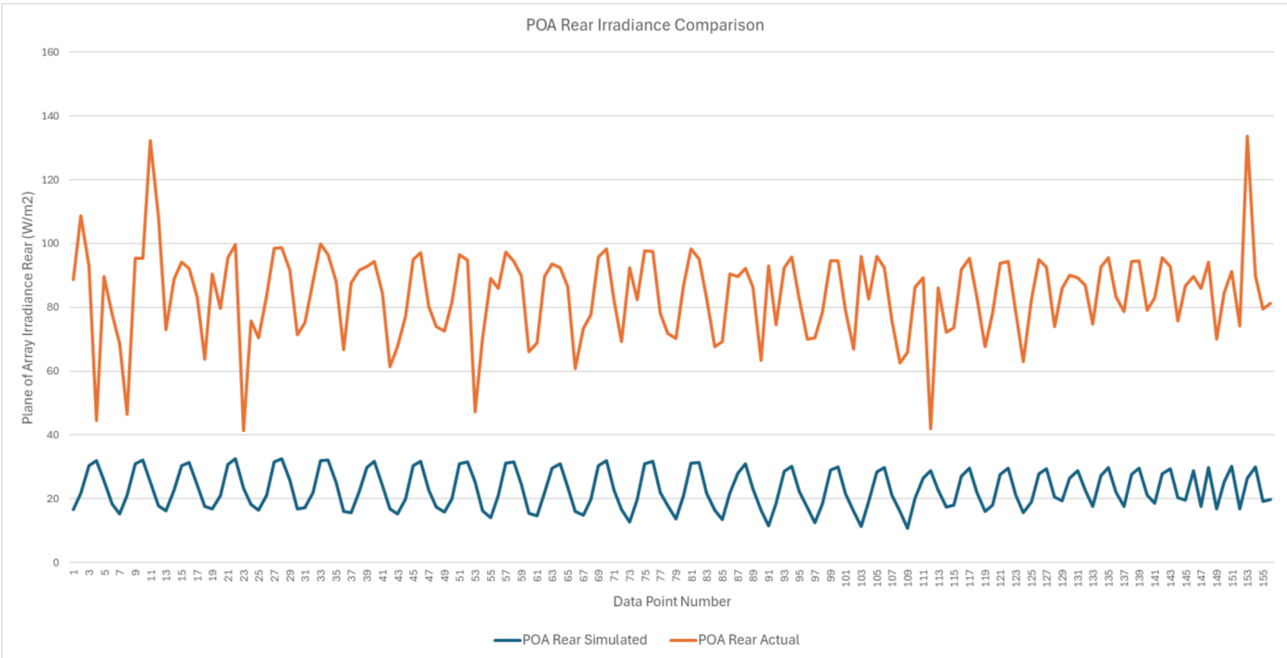

Figure 19: Plane of Array Rear Irradiance Comparison

As shown in Figure 19 the actual measured rear irradiance is significantly higher than the simulated value. This is likely because of the location of the rear POA sensor, which is on the end of the array row meaning it receives more rear irradiance than the average panel down the array due to shading and the ground near these sensors having more albedo due to the construction traffic killing the grass. This can be seen in the images in the next section.

4.5 Performance Metrics

The Actual Bifacial Performance Ratio calculated for the test period is 0.8867 and the PVSyst Design Biafical Performance Ratio calculated for the test period is 0.9195. These performance ratios were calculated using the bifacial performance ratio formula in IEC 61724.
When calculating the above performance ratios, Infratec did not exclude data points from the periods when there were combiner boxes isolated and TCU issues on site. Instead, we opted to run the performance ratio calculation with all the collected data, which would have only made it more difficult to meet the target performance ratio.

The actual albedo was not as built in the PVSyst model due to the location of the up and down irradiance sensors being in areas where the grass / ground was more reflective due to the construction activities, as seen below in Figure 20, Figure 21, Figure 22 and Figure 23. As was done for Kaitaia, the view factor assumed in PVSyst was used to correct the actual rear irradiance in the actual bifacial performance ratio calculation.

Figure 20: No grass beneath Weather Sation at MVS1

Figure 21: Ground beneath Weather Station at MVS3

Figure 22: Ground conditions beneath POA down sensor - MVS1

Figure 23: Ground conditions beneath POA down sensor - MVS3

5. Conclusion

The 14-day performance test was conducted from 9 May 2024 12:00am to 22 May 2024 23:59pm. From the valid data collected during that period, the Asbuilt PVSyst Model Bifacial Performance Ratio was calculated as 0.9195 and the Asbuilt Actual Bifacial Performance Ratio calculated as 0.8867 (96.4% of 0.9195). The lower limit for determining a Performance Ratio Shortfall as defined in the EPCC Schedule 15 is 96% of 0.9195, therefore Infratec has successfully passed the Edgecumbe performance test. Actual Bifacial Performance Ratio is ~3.6% less than the simulated value, this is roughly the same as the irradiance sensor accuracy which is 3% for a Class A sensor.

APPENDIX A. EPPC Schedule 15 Part 2

APPENDIX B. Instrumentation Documentation

APPENDIX C. Performance Test Methodology Document