



ERCOT Solar Operations and Forecasting Workshop

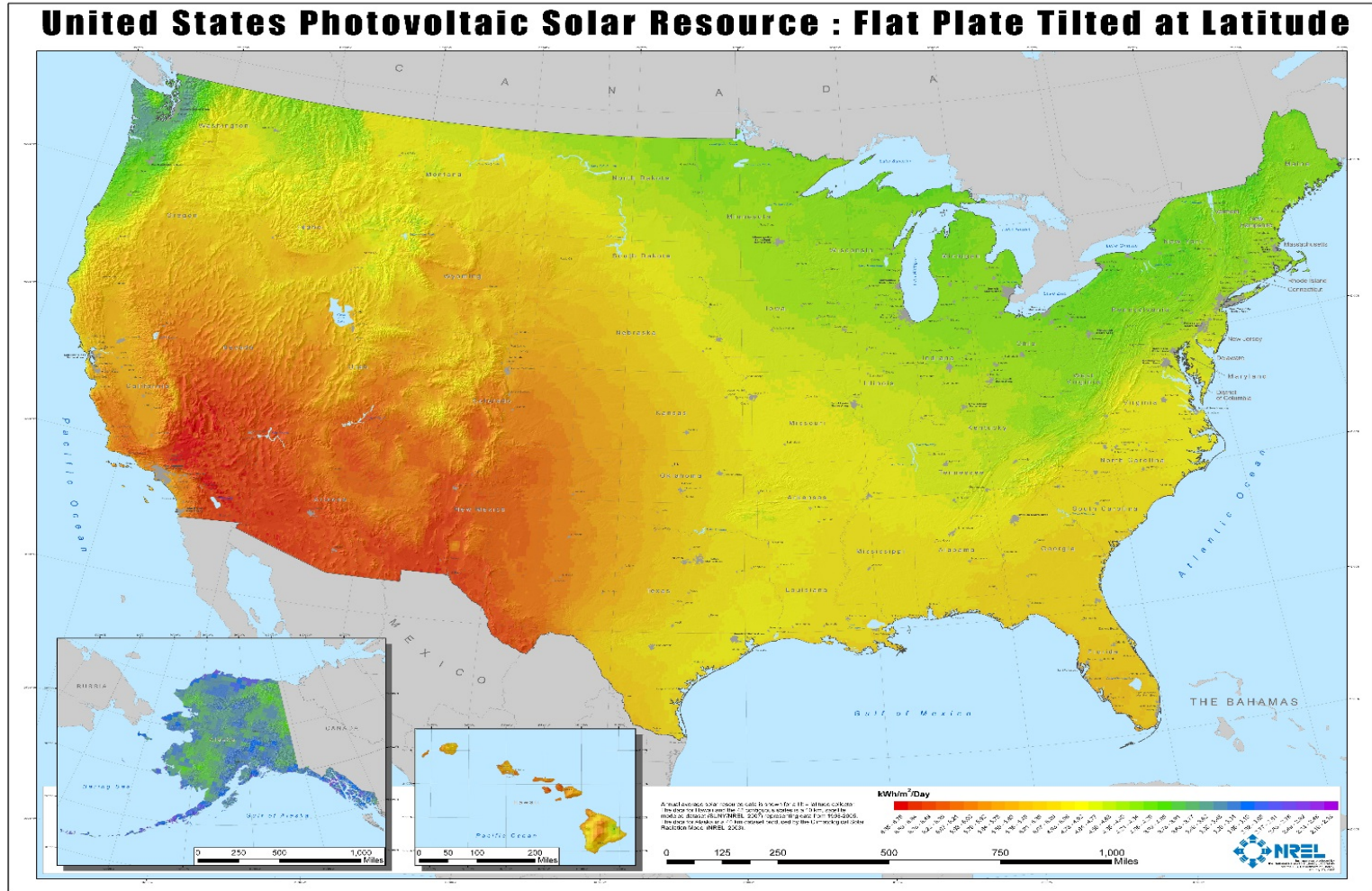
ERCOT Operations Planning Staff

12/6/2016

Outline

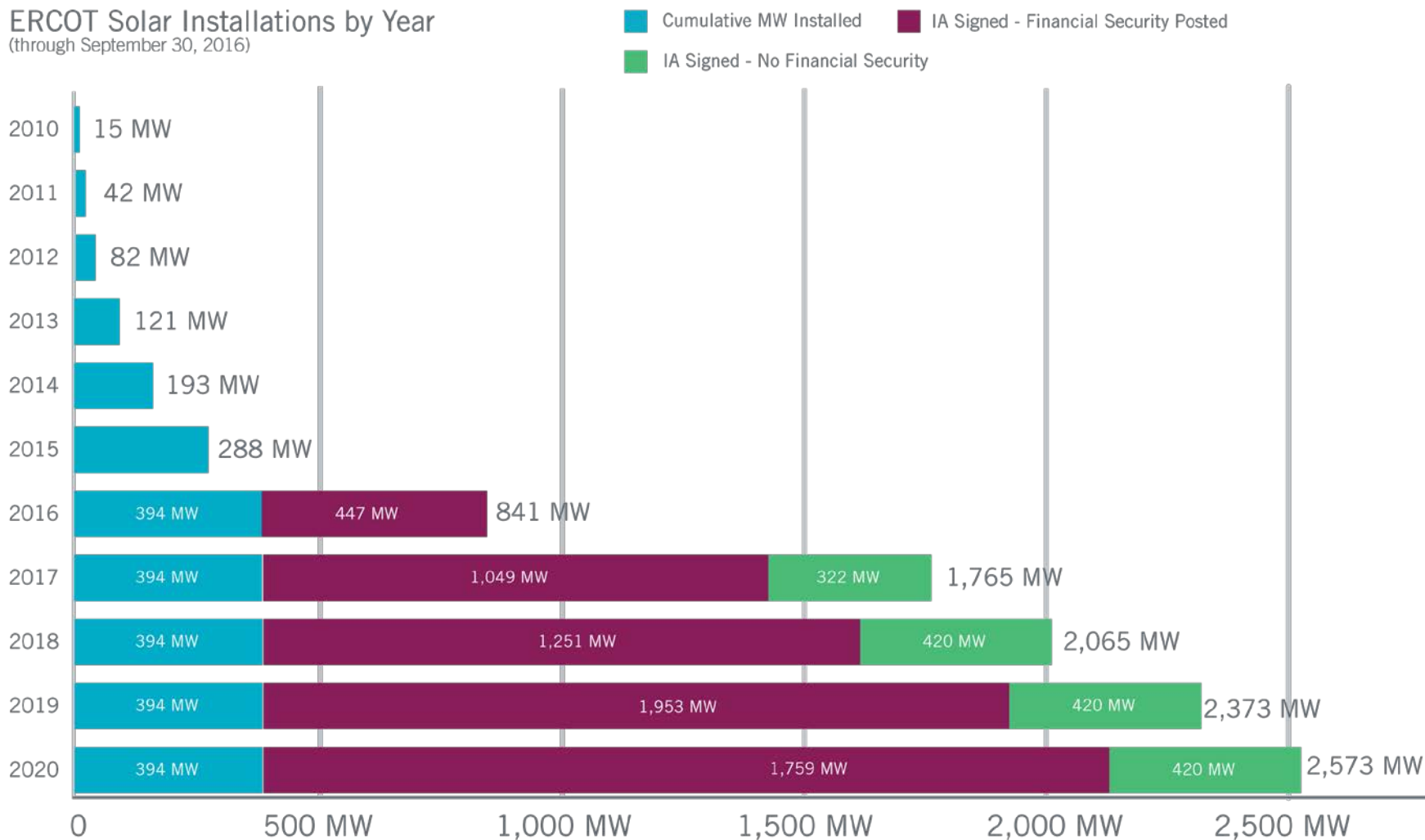
- Outlook of Solar Generation in ERCOT
- Overview of Solar Forecasting
- [NPRR 785](#)
- [RRGRR 007](#) Implementation
- [ICCP Handbook](#) Additions
- [Business Practice Manual](#)
- Operations Under Curtailment Examples
- Number of Inverters Online Telemetry Examples
- MDA Presentation

Solar Potential

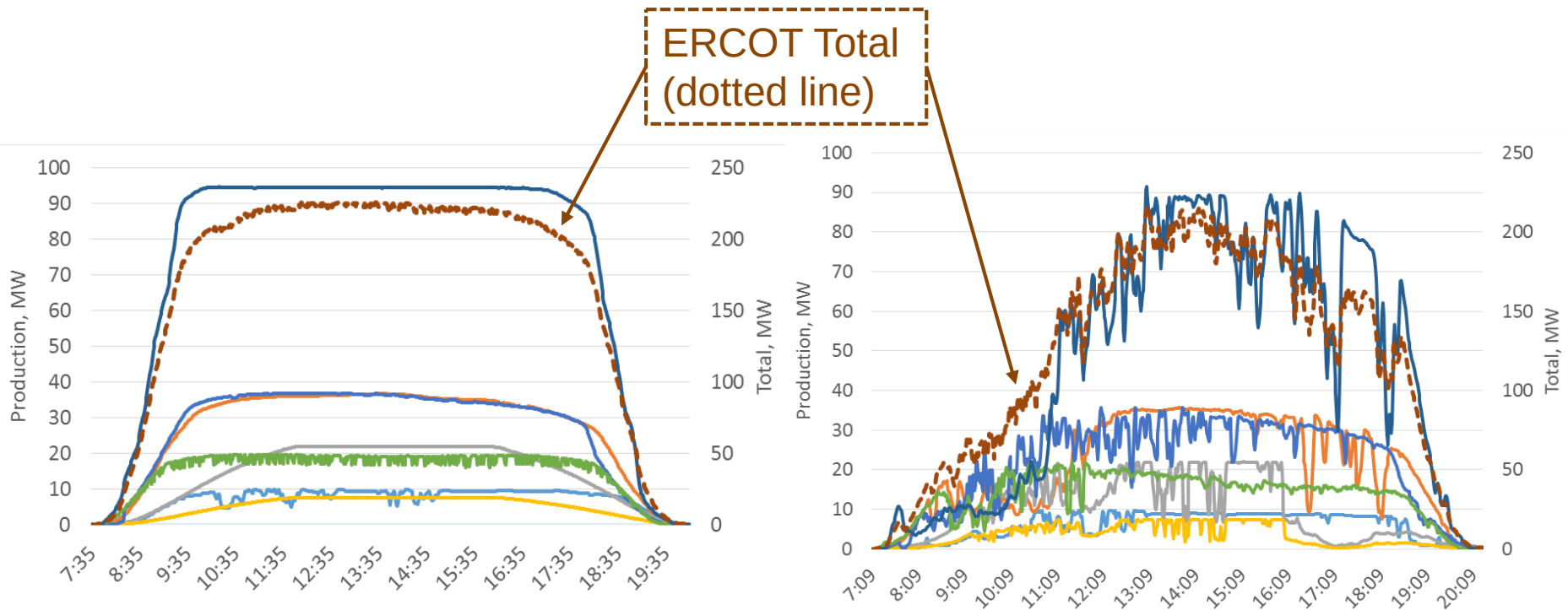


Installed Solar Generation in ERCOT

ERCOT Solar Installations by Year
(through September 30, 2016)



Solar Generation Profile – Sunny vs Cloudy Day



Sunny Day (3/20/2016)

Cloudy Day (8/11/2016)

Solar Forecasting

Daily Solar Report for: October 4, 2016

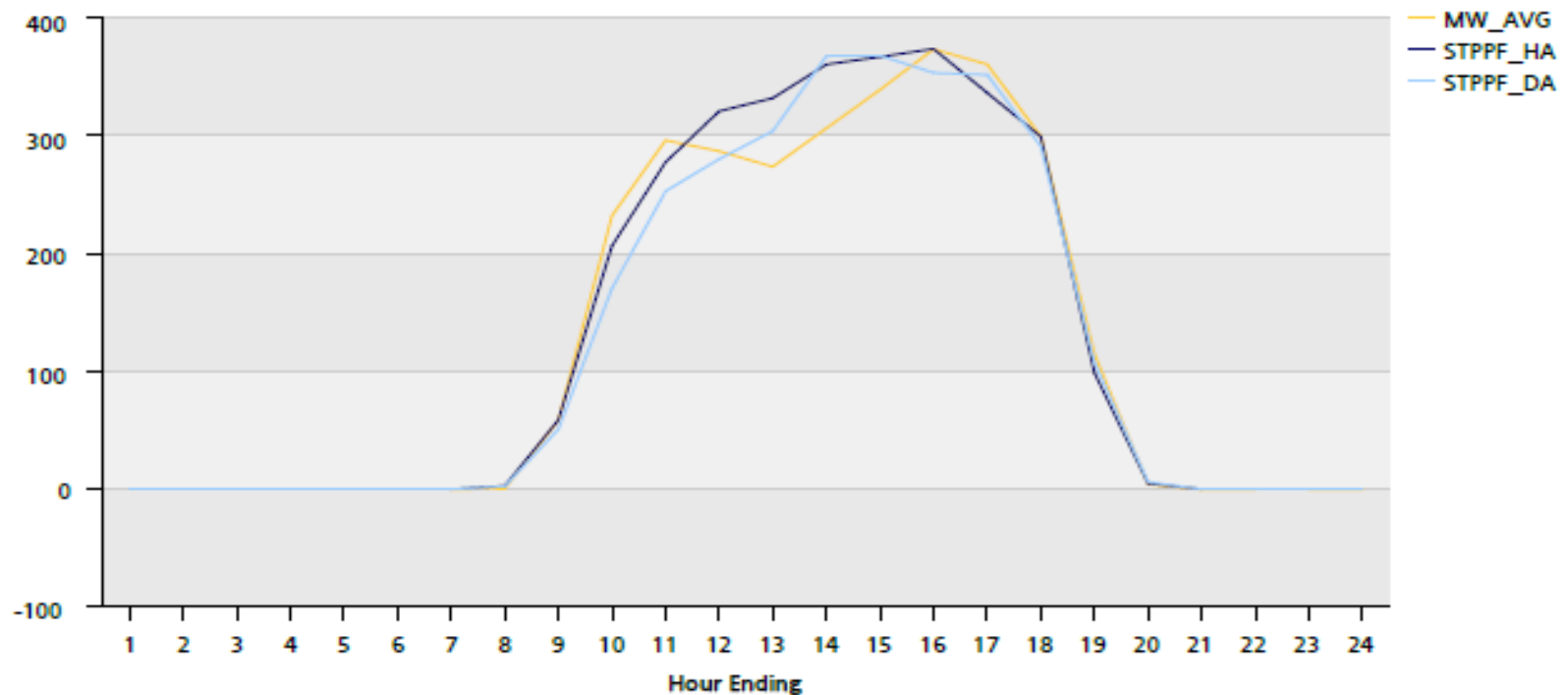
Hour Ahead MAPE: 4.21% Day Ahead MAPE: 4.62%

Hours counted:13

(Only hours above 1 MW are counted)

Current Installed Capacity: 484MW*

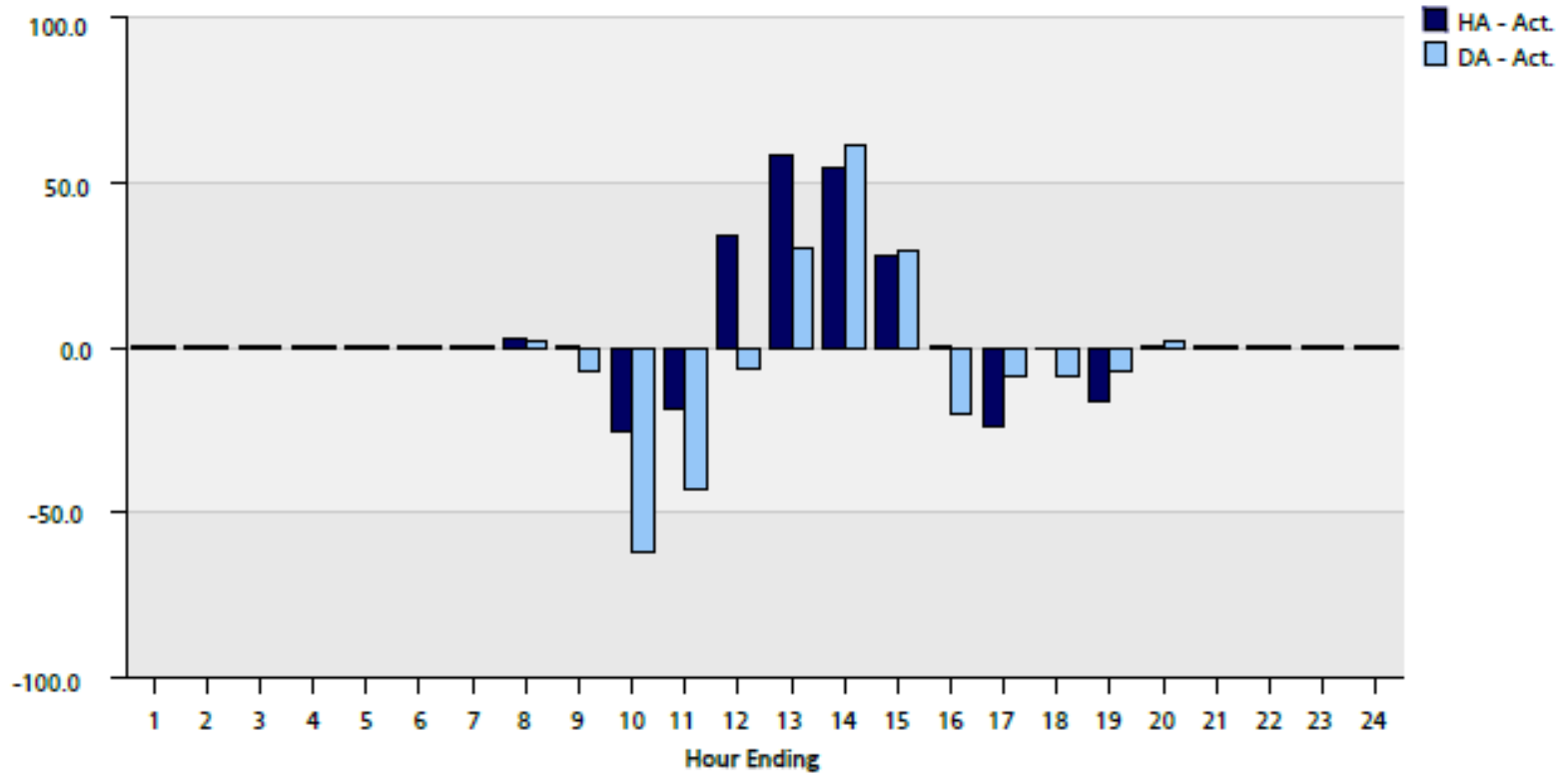
Solar Output vs. Forecasts



Solar Forecasting

October 4th 2016

Solar Forecast Error by Hour (in MW)



Short-Term PhotoVoltaic Power Forecast (STPPF)

- MDA provides a Short-Term PhotoVoltaic Power Forecast (STPPF) to ERCOT for a rolling 168 hour timeframe.
- This process uses information from multiple systems, including:
 - RARF (ex. site geo-location, met tower geo-location)
 - EMS (ex. Resource Status, telemetered site specific meteorological data)
 - Outage Scheduler (ex. derate start/stop dates, derate values)
- When submitting COPs, Solar QSEs must use this STPPF for the applicable 168 hours timeframe. (COP HSL must be $\leq$ STPPF.)
 - Note that NPRR 785, upon approval will only require Solar QSEs to update a COP only when solar farm operating conditions dictate COP HSL to be lower STPPF.

NPRR 785

- Synchronizes Short Term Wind Forecast (STWPF) and Short-Term PhotoVoltaic Power Forecast (STPPF) with Current Operating Plan (COP) of Wind Generation Resources (WGRs) and Photovoltaic Generation Resources (PVGRs)
 - ERCOT will automatically prepopulate every WGR and PVGR's COP with most recent forecast for the next 168 hours.
 - QSEs representing WGRs or PVGRs will be required to either submit a COP with the automatically prepopulated forecast **or submit a lower number** (when solar farm operating conditions dictate COP HSL to be lower than STPPF).

RRGRR 007

- Board approved on 12/8/15
- Should be implemented in early 2017
- Added numerous fields regarding configuration, inverter and panel details.
- Notable Examples
 - Inverter/Panel Layout
 - Inverter Details
 - Model, Manufacturer, count, etc...
 - Panel Details
 - Area, model, manufacturer, count, plane of array, tracking, etc...

Meteorological Telemetry Requirements

- Meteorological telemetry must be telemetered with the specified data units at the refresh rates mentioned below.

TELEMETRY NAME	DATA UNIT	REFRESH RATE
Wind Speed (MPH)	MPH	10s
Wind Direction (DEG)	Degrees (between 0 and 360)	10s
Temperature (TEMP)	°C	10s
Barometric Pressure (PRES)	mbar	10s
Num. Of Turbines <i>Available</i> (NTON) Num. Of Turbines <i>Unavailable</i> (NTOF) Num. Of Turbines <i>Unknown</i> (NTUN)	Integer (Count of turbines)	10s

References:

- [ERCOT and QSE Operations Practices During The Operating Hour \(Section 3.9.1\)](#)
- [ERCOT Nodal ICCP Communications Handbook](#)

ERCOT Business Practices

- Please see section 3.9 of the Business Practice Manual for updates adding in solar resources to have similar requirements to wind.
- Inverter telemetry
 - Number of wind turbines/solar inverters *Available*
 - Number of wind turbines/solar inverters *Unavailable* (“out of service and not available for operation, independent of MW production”)
 - Number of wind turbines/solar inverters *Unknown* (“not able to communicate and whose status is unknown”)

Turbine Availability Telemetry Requirements

- Num. Of Turbines/Inverters Available (NTON)
 - Should indicate count of turbines/inverters that will generate power if the operating conditions are met regardless of what current output from the wind generation resource may be.
 - If a turbine is disconnected from the grid to reach curtailed Base Point, it should be communicated as Available.
- Num. Of Turbines/Inverters Unavailable (NTOF)
 - Should indicate count of turbines/inverters that are offline & not available
 - Turbines/inverters that are under maintenance, or experiencing forced outages (caused by meteorological phenomenon like icing, hurricane, etc.) or mechanical issues) should be communicated as unavailable
- Num. Of Turbines/Inverters Unknown (NTUN)
 - should only be used in the few and temporary occasions when there is a failure with the wind/solar plant's communication system
- Sum of the telemetered number of turbines Available, Unavailable and Unknown should equal the total number of turbines/inverters identified in unit's RARF.

References:

- [ERCOT and QSE Operations Practices During The Operating Hour \(Section 3.9.2\)](#)

ERCOT Business Practices

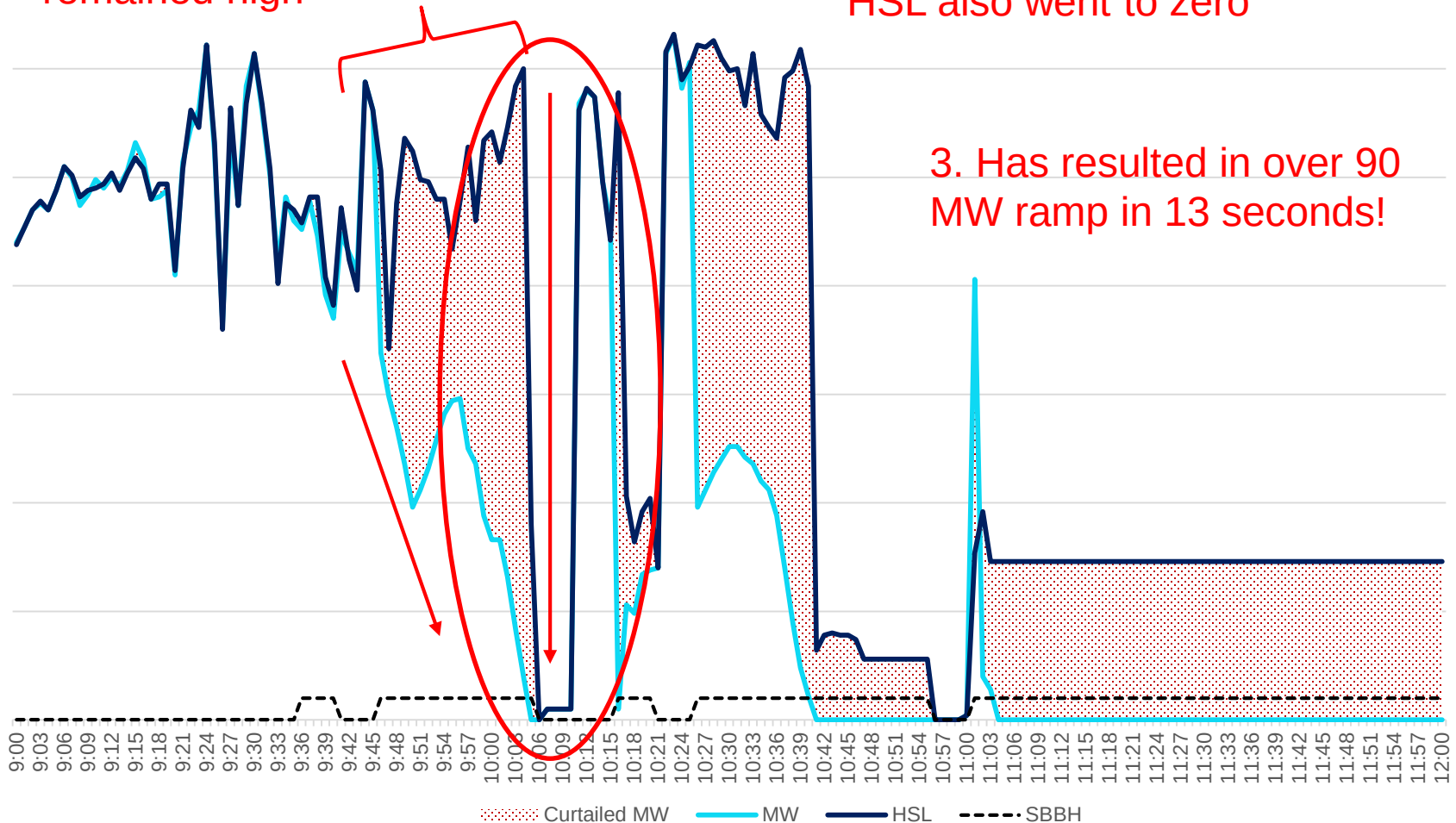
Situation: A Wind Turbine or Solar Inverter's power production is reduced because of...	Expected Availability Status
Maintenance or mechanical issues	Unavailable
Curtailment	Available
Partial or complete high speed cut-out	Available
Partial or complete high/low temperature cut-out	Available
Turbine icing	Unavailable
Zero or near zero output	Available

Incorrect Operations Under Curtailment

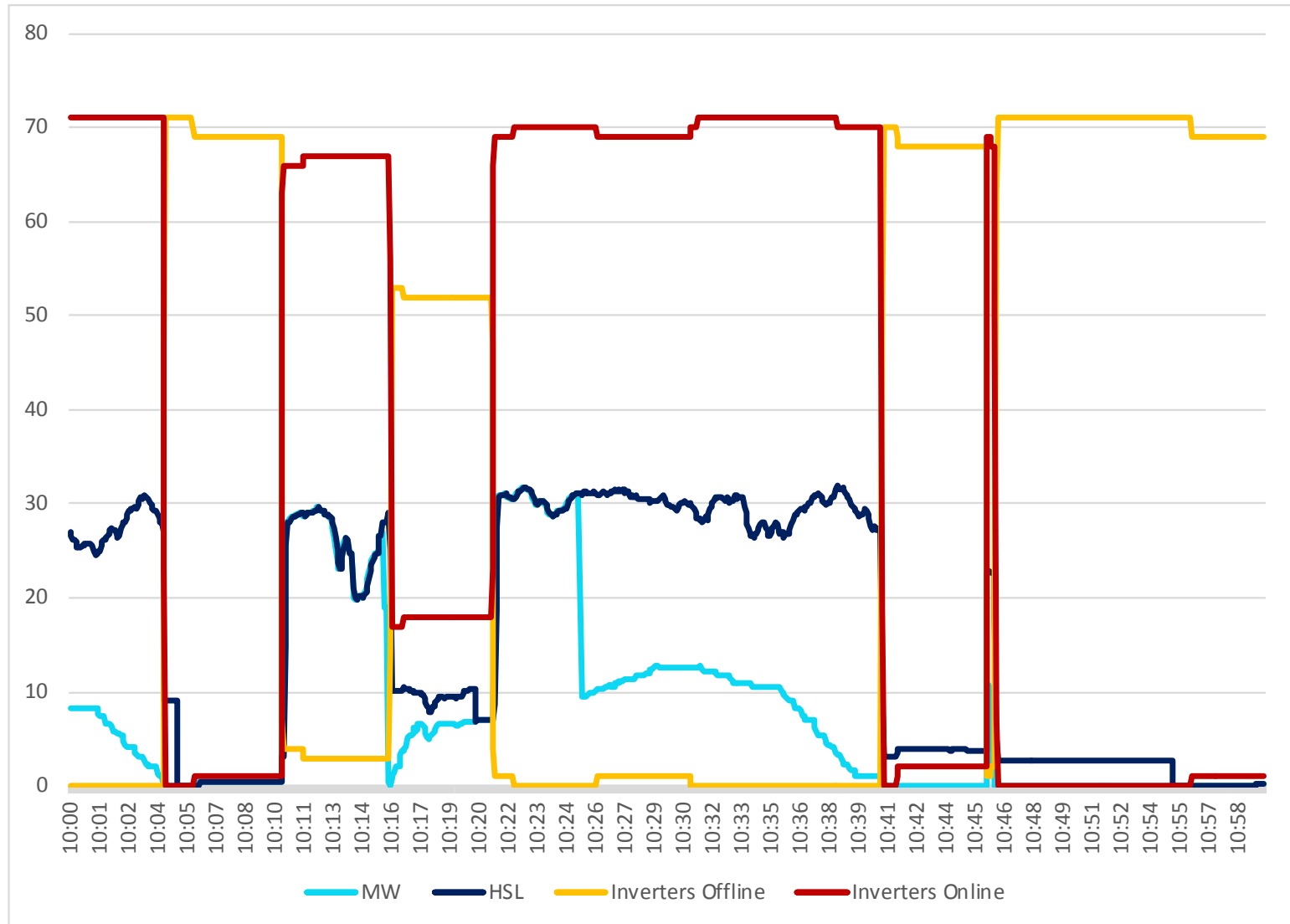
1. Unit was curtailed, HSL remained high

2. Unit was curtailed to zero, HSL also went to zero

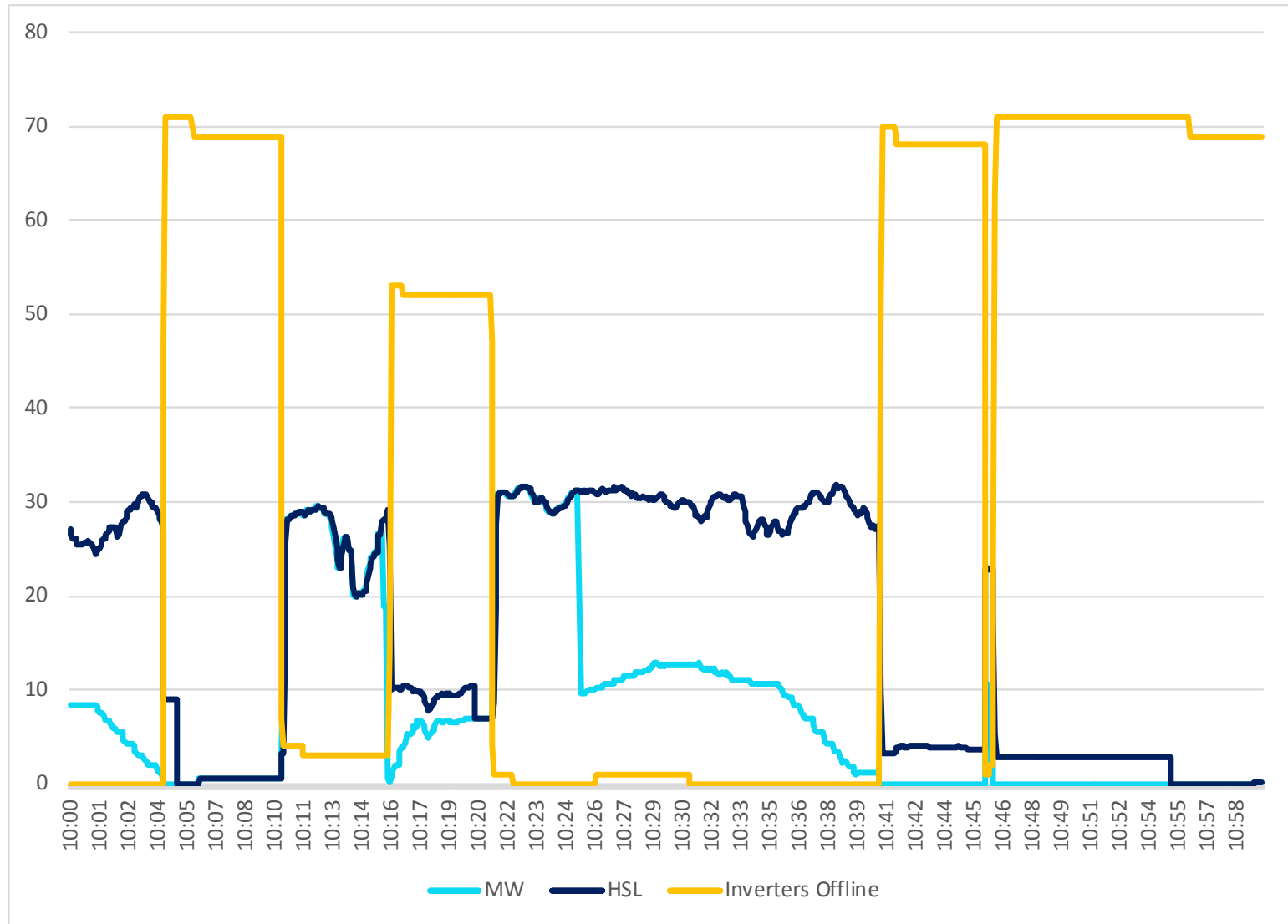
3. Has resulted in over 90 MW ramp in 13 seconds!



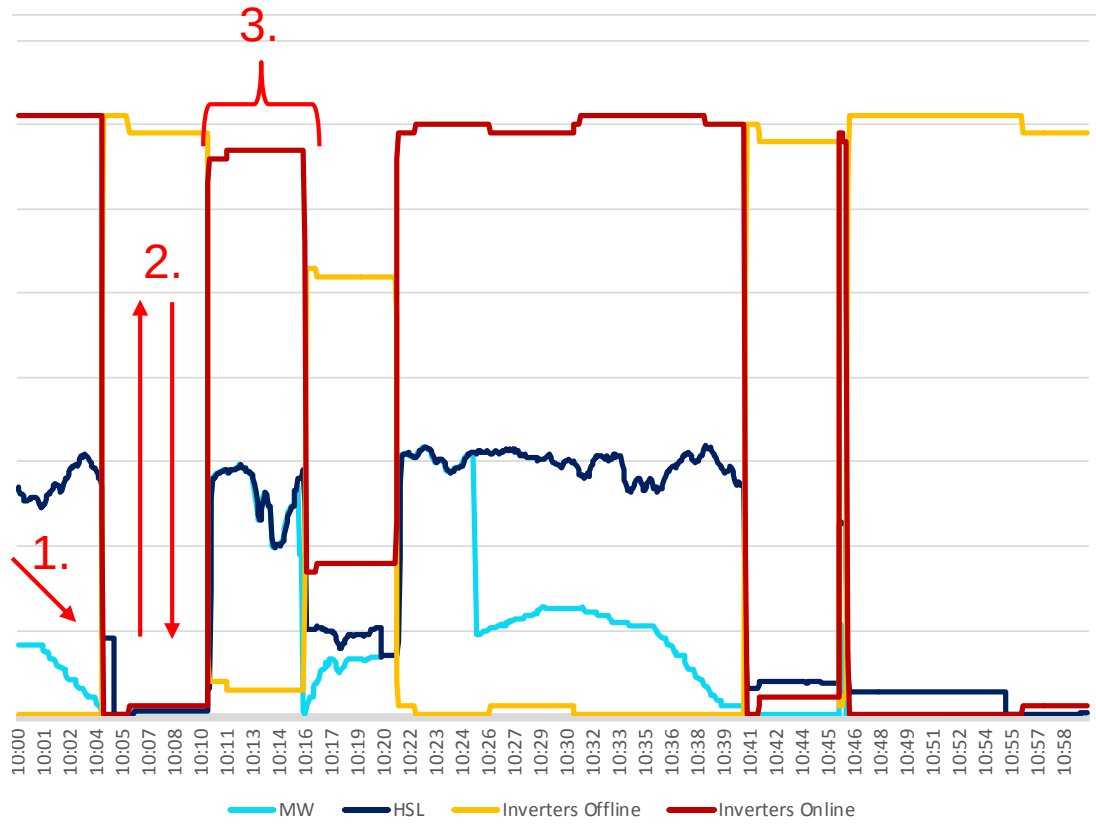
Incorrect Operations Under Curtailment



Incorrect Operations Under Curtailment

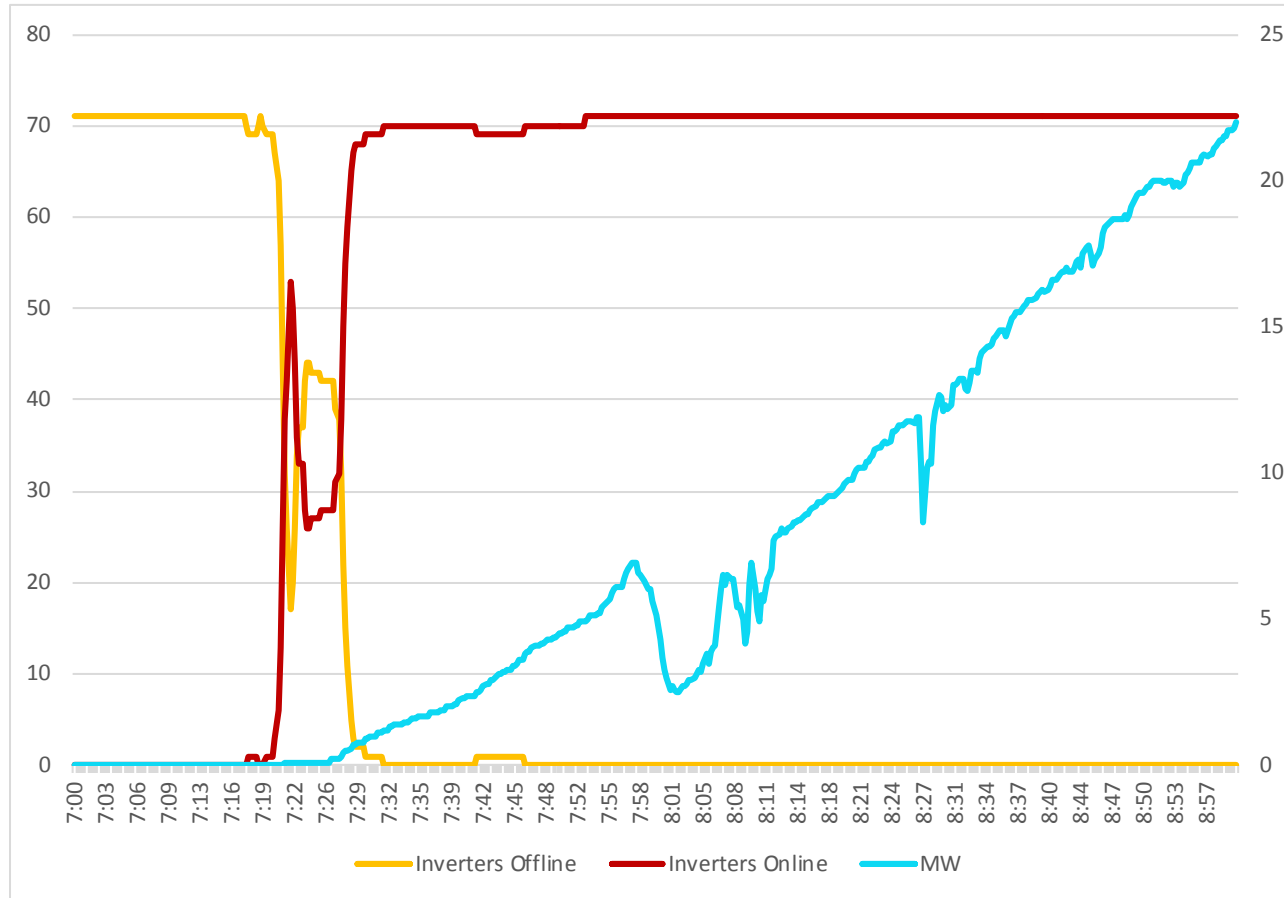


Incorrect Operations Under Curtailment



1. Unit is curtailed to zero MW.
2. Inverters online goes to zero and inverters offline goes up causing the HSL to go to zero.
3. Unit will oscillate in and out of curtailment. this can result in large ramps and affects regulation.

Inverters Online/Offline Example



When the unit is not producing any output, the number of inverters online is zero. This is incorrect.

Inverters should only be considered offline if they are down for maintenance or out due to meteorological phenomenon such as icing.

Transition to MDA Presentation...



WEATHER SERVICES



Telemetry Data Quality Guide for ERCOT Solar QSEs

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Purpose

The purpose of this guide is to illustrate good examples and common problems with PVGR QSE telemetry data to help QSEs diagnose and correct sensor or reporting issues and practices, leading to more good quality data.

Motivation:

Better data quality will improve solar forecasts, allowing more cost-effective grid management.

QSE telemetry data is crucial to high quality forecasts of PVGR-generated power:

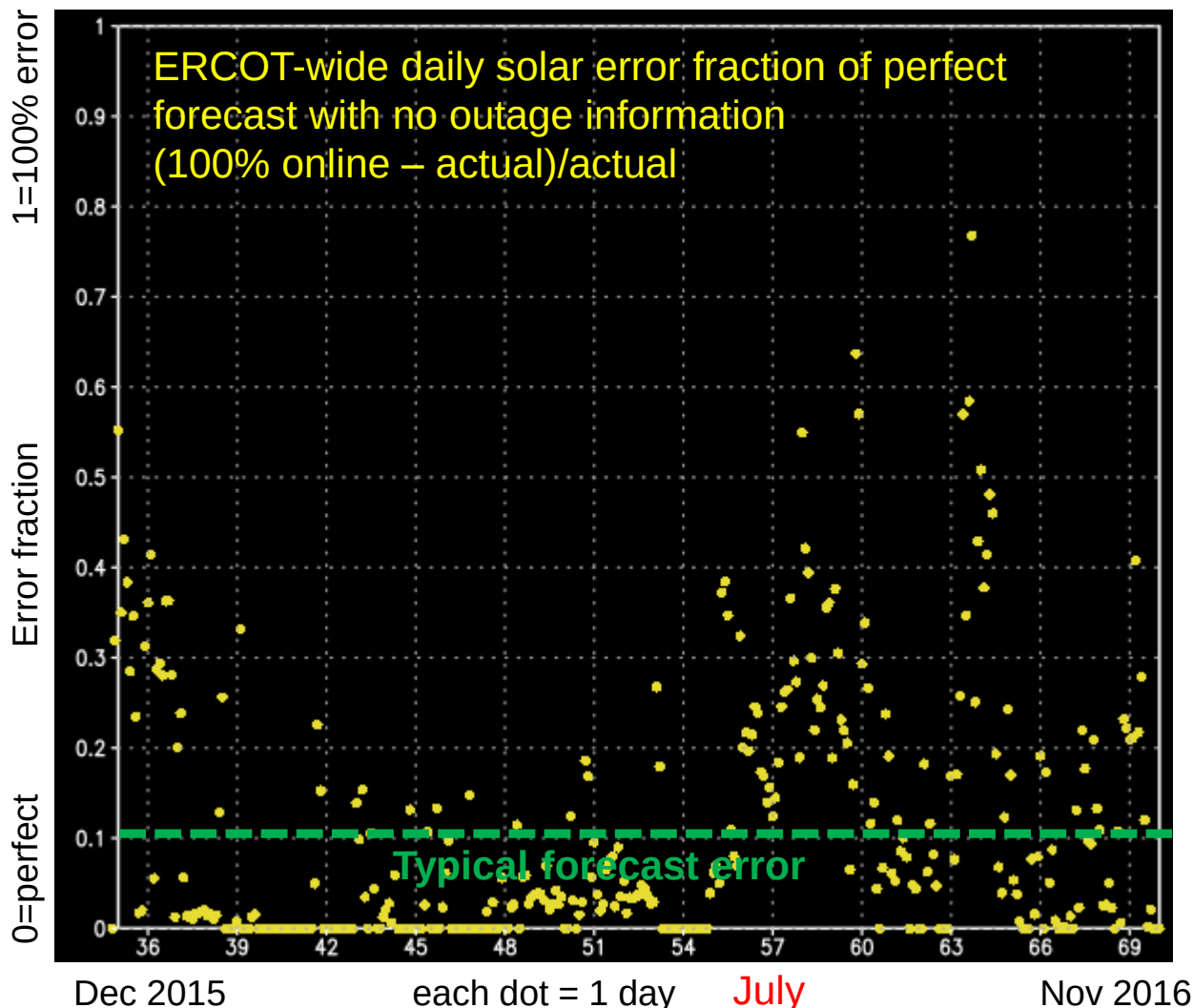
- Ground truth **irradiance** data used to bias correct weather forecast models
- **Power and irradiance** data and other data/information are combined to translate the weather forecast to a power generation forecast specific to each generating unit
- **Power and irradiance data over the past hour** can be used to correct an off-track weather forecast. Poor quality data can cause the wrong “correction”
- **Outage information** must be timely and accurate so that the forecast will know in advance to limit the predicted output and when to lift the limit
- **Inverter status** is used to prorate metered generation in the translation between the weather forecast and the power forecast. This is especially important during the spin-up of new sites until months of fully operating data can be collected

Motivating Example: Outage Information

Outage data is important!

Chart shows daily error a **perfect** forecast would have if *predicted* generation at all sites were not limited by outages (all sites 100% up).

Error shows zero in winter and spring when all sites were fully operating. Many new large sites started testing over the summer. With good outage information, this is fully accounted for in the forecast. If no information were available, errors in this otherwise *perfect* forecast are much larger than typical forecast errors (green line) caused by errors in the weather forecast.



Outage Information

We use the following information in the forecast:

1. Site
2. Time and date of notification
3. Time and date lower limit begins
4. Time and date lower limit ends
5. Limit (MW) (zero if completely off, 20 MW during Part 2 testing, etc.)

Forecasts issued before the notification time (2) cannot account for this information

Forecasts issued after the notification time (2) assume the power is limited to the amount stated

Sometimes the notification (2) arrives after the limit period began (3)

Often, the work is completed early and the site resumes full operation following a revised notification with the same beginning time (3) but an earlier ending time (4). Forecasts issued before the revised notification will assume the site is still limited until the original stated ending time. Forecasts issued after the revised notification will have the correct time for resuming full operation.

Sometimes power is generated greatly exceeding the indicated limit for a brief period

Outage Information – Unplanned Outage Example

Day 1, normal morning ramp up, then sudden shut down to zero just before 10:00 am

Outage notice sent 10:56 am declaring limit of 0 MW from 10am day 1 to end of day 3

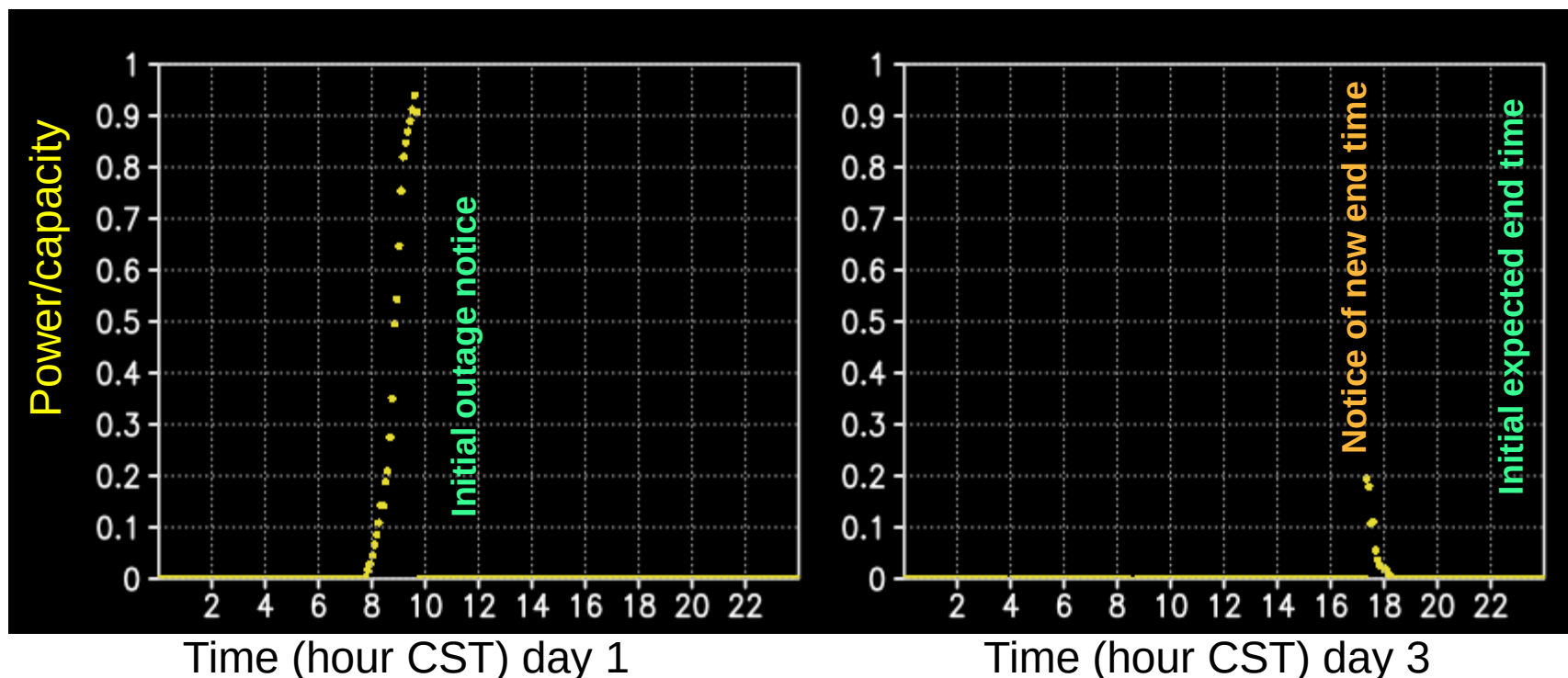
Site restored to full power around 5:00pm on day 3, normal evening ramp down (next day normal)

Updated outage notice sent 4:56 pm day 3 updating the ending time

Good: output as declared (zero)

Better: advanced notice about start/early end if possible

Forecasts issued before 11 am day 1 predict full power, issued before 5pm day 3 predict zero to end of day



Outage Information – Planned Outage Example

Good: outage announced 3 weeks in advance! Scheduled 6:00 am day 1 through 5:00 pm day 4

Not good: site live with power until 2 hours after announced start time

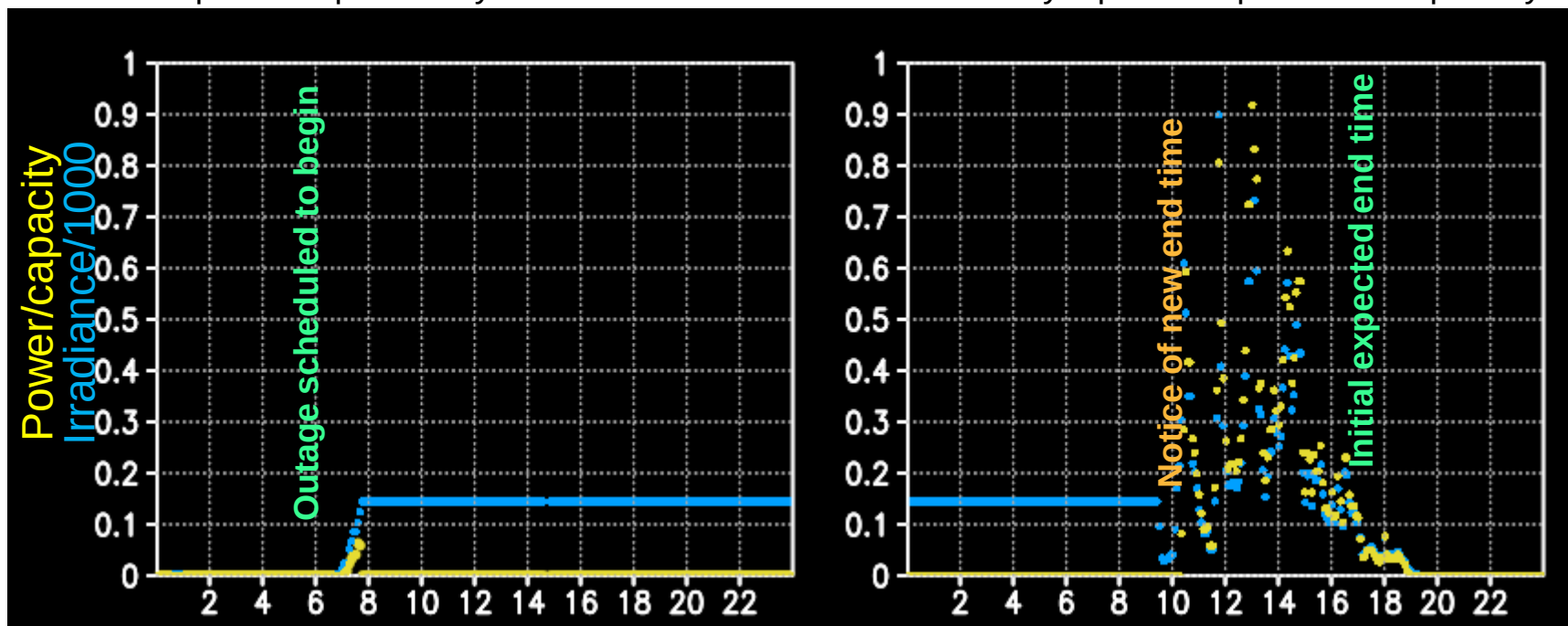
Not good: logger repeated last irradiance value for 73 consecutive hours while site was down

Updated ending time at 9:51 am day 4, declaring outage ended at 9:22 am day 4

Good: output as declared (zero) during outage and full power before and after outage

Not good: early ending not announced in advance and time mismatch (no power until after 10:00am)

Forecasts predict 0 power day 1. Forecasts issued before 10am day 4 predict 0 power until 5pm day 4



Time (hour CST) day 1

Time (hour CST) day 4

Outage Information – Planned Outage Example

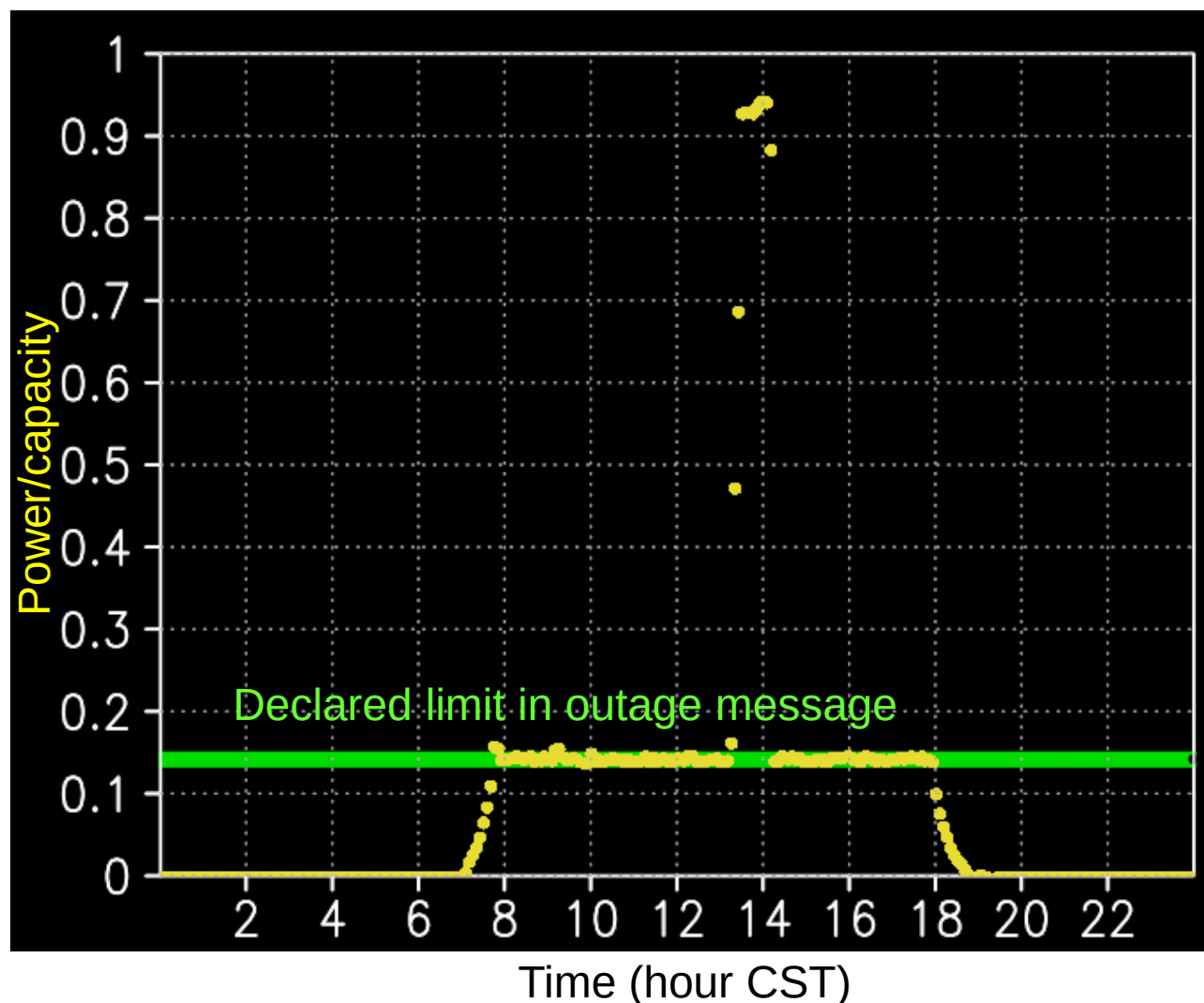
Multi-day limit during site testing

Most days adhered to limit

Some days had periods exceeding limit, with no notification

Example shows site at full power for around 1 hour during period of low limit

Otherwise good – morning ramp up to limit, stays at limit, evening ramp down from limit



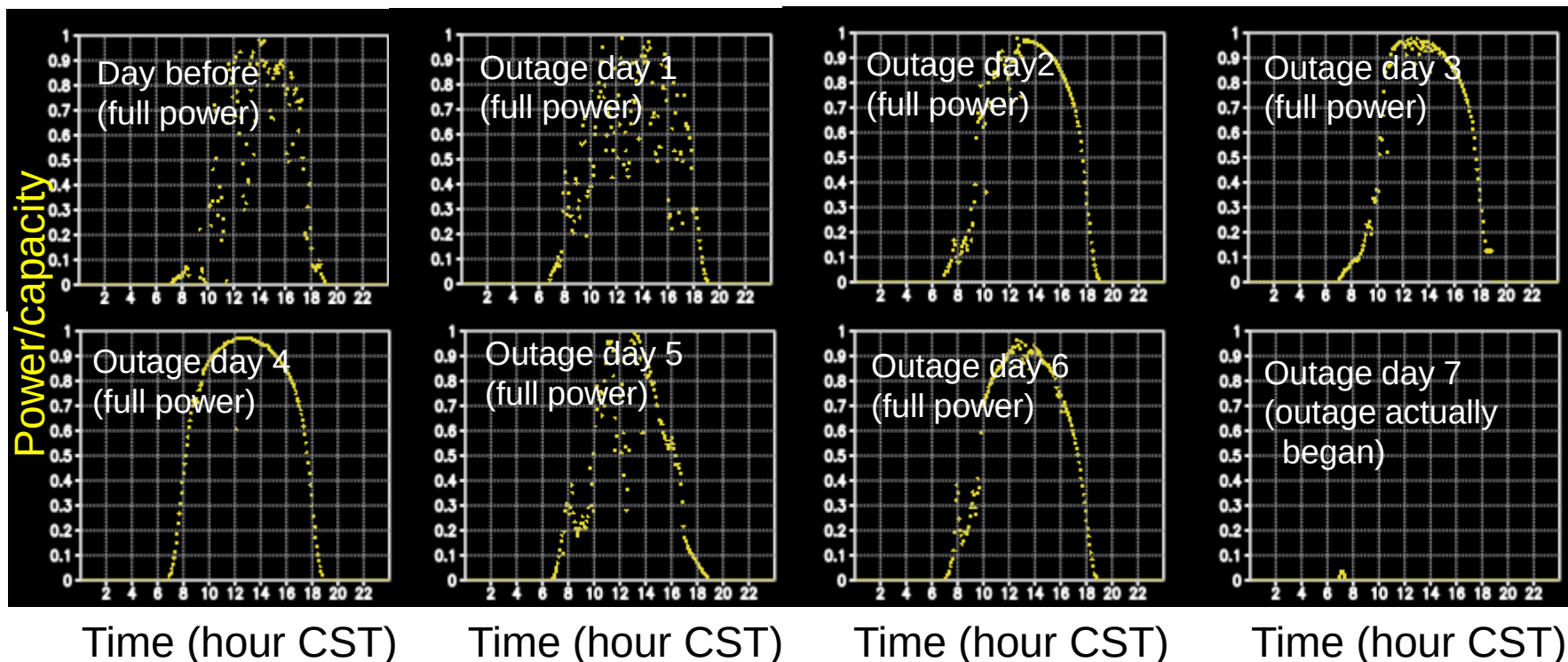
Outage Information – Planned Outage Example

Outage announced 1 week in advance, running for 2 weeks duration

Outage modified 1 day in advance to start 2 hours earlier than originally announced

Outage did not begin until 7th day into scheduled outage period

No notification issued for outage start date

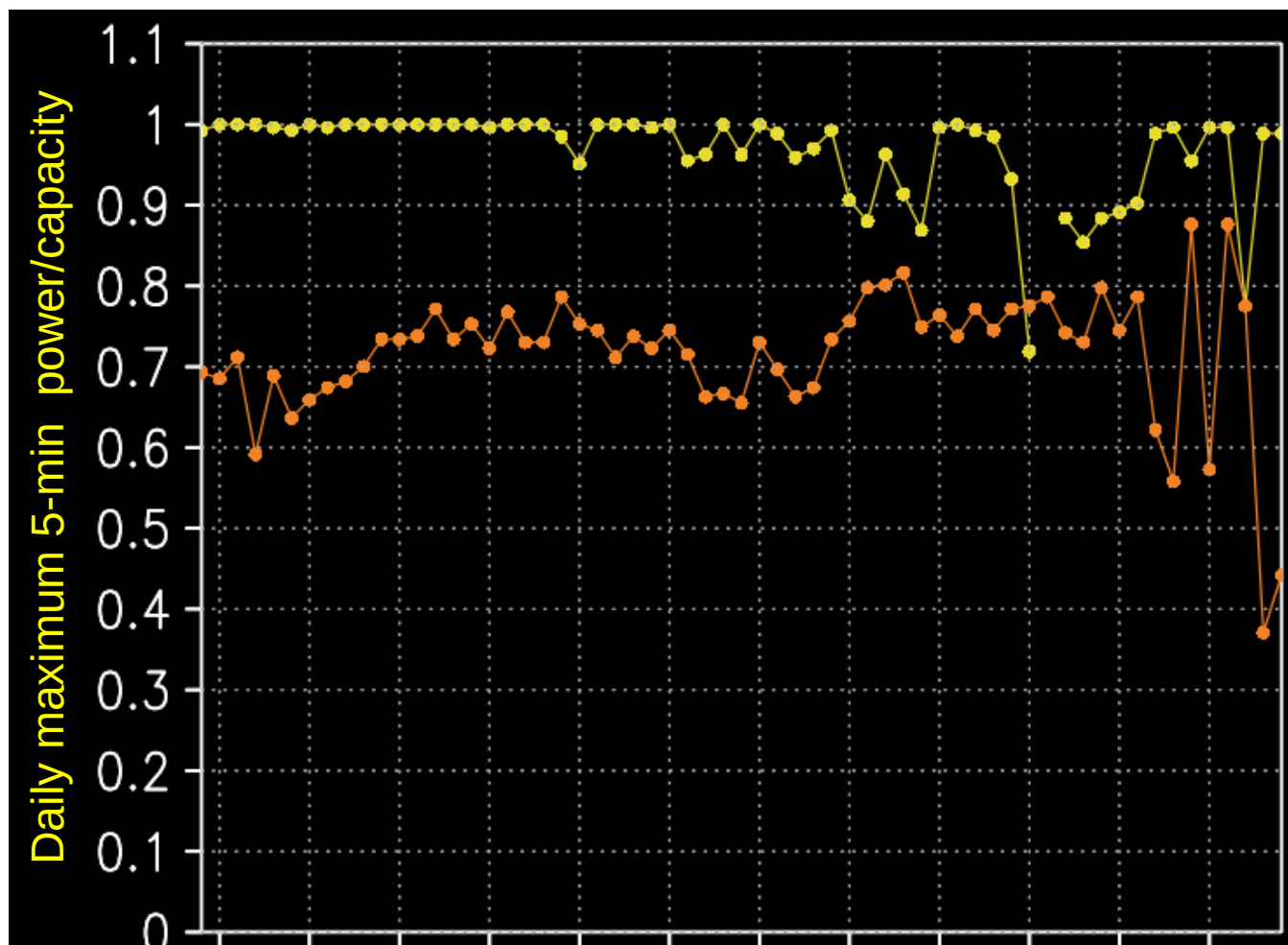


Outage Information – Long-term Reduction

Site appears self-curtailing or not fully available for many months at a time.

Yellow dots=peak 5-minute average power/capacity each day for 2 months.
Orange=same days but for different year.
Dips are cloudy days.
Yellow shows fully operational. Orange shows around 80% operational.

No related outage info provided
Site reported more than 90% of inverters online/operating
No site configuration changes reported



Days (same 2-month periods, two different years)

Outage Information

Most common problems:

- Start of outage differs from start time in notification by 1-2 hours
- Notification of changes to ending time often provide little or no advance notice
- Ending times often differ by 1-2 hours from last stated ending time

Best practice:

- Notify of outage days as much in advance as possible
- Update start time as soon as change is known
- Update ending day/time as soon as change is known
- Avoid exceeding stated limit during most updated stated outage period
- Check logger data to make sure numbers are not “stuck” for duration of outage

Inverter Status Information

We use the following information in power modeling for the forecast:

1. Site and date/time
2. Number of inverters in “on” status
3. Number of inverters in “unknown” status
4. Number of inverters in “off” status

Adding number of inverters on + unknown status + off = TOTAL NUMBER OF INVERTERS

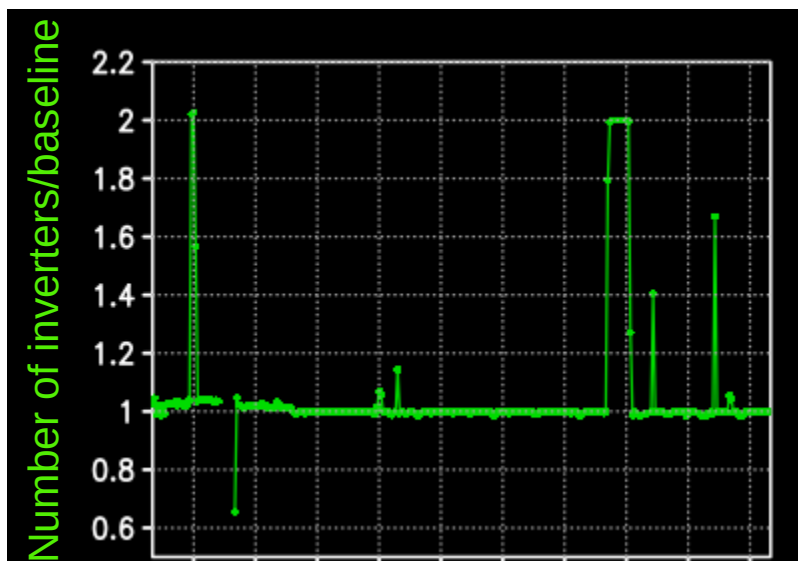
The total number of inverters should never change unless the site has new construction or demolition. If part of the site is offline, the number of inverters “off” increases and number “on” decreases, but the total should be **constant**. This number should match the number listed in the generator forms filed with ERCOT, but in some cases it is not even close.

Forecasts can utilize site recent or past history relating power to irradiance if the fraction of inverters on is **accurately** reported. For example, if a site has 75% of inverters online and 25% offline, the power can be prorated accordingly to convert it to the amount which would have been generated when the site is fully operational. While this is always useful, it is especially important when new sites are coming online for two reasons:

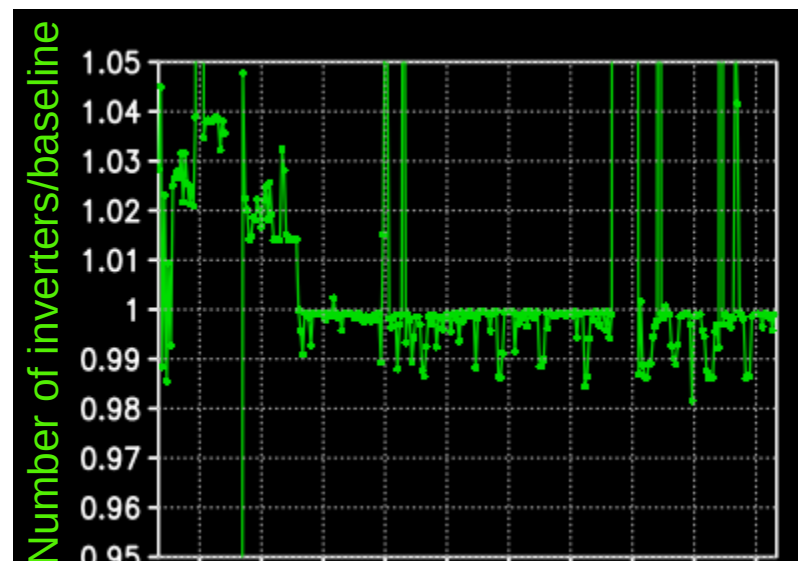
1. There is little site history to work with, and
2. The site is typically testing, so fluctuations in status are frequent

Inverter Count Totals

Some sites do an excellent job of reporting a consistent total number of inverters. Shown here is an example of one that is usually consistent but has some peculiar variations. The plot shows the average number of inverters reported through the daylight period of each day, for every day over a 10-month period, scaled by the correct number the site has. For example, 2 means the daily average was double the correct number, while 0.5 means the daily average was half the correct number, and 1.02 means 2 percent higher than the correct number. The plots on left and right are the same but more zoomed in on the vertical axis in the plot on the right.



Days over 10-month period



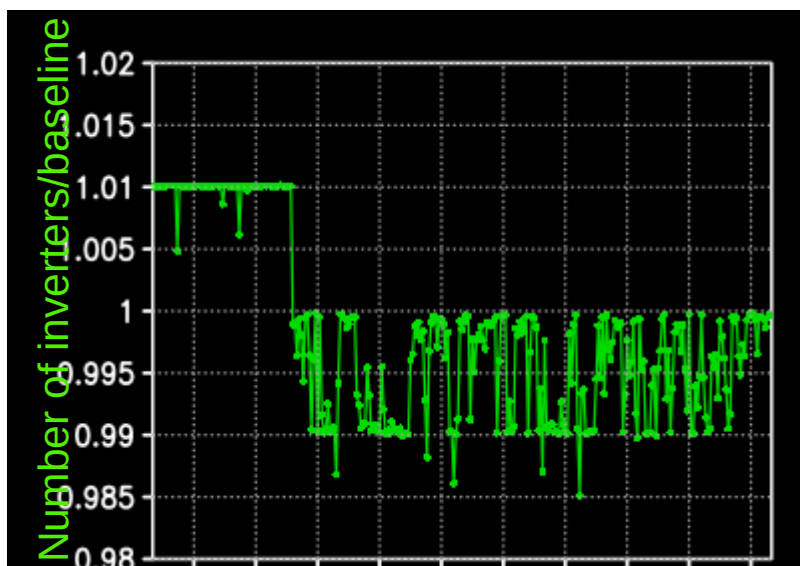
Days over 10-month period

Inverter Count Totals

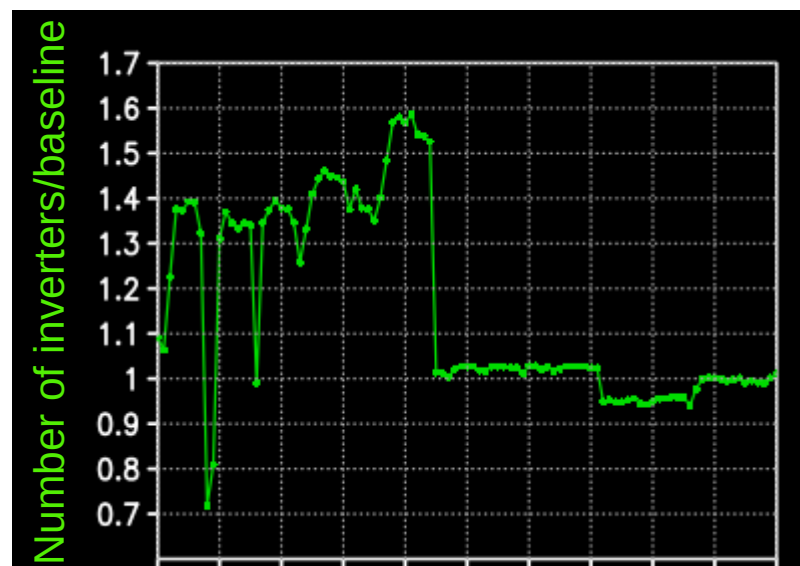
Same type of plot as on previous slide.

Plot on left shows a site which was consistent day to day suddenly dropped 1% of its total inverter count and then began a daily oscillation with another 1% sometimes dropping out.

Plot on right shows a site with wild unrepresentative numbers for a month and a half, then settling into a somewhat consistent pattern within 5% of its baseline level though still fluctuating.



Days over 10-month period

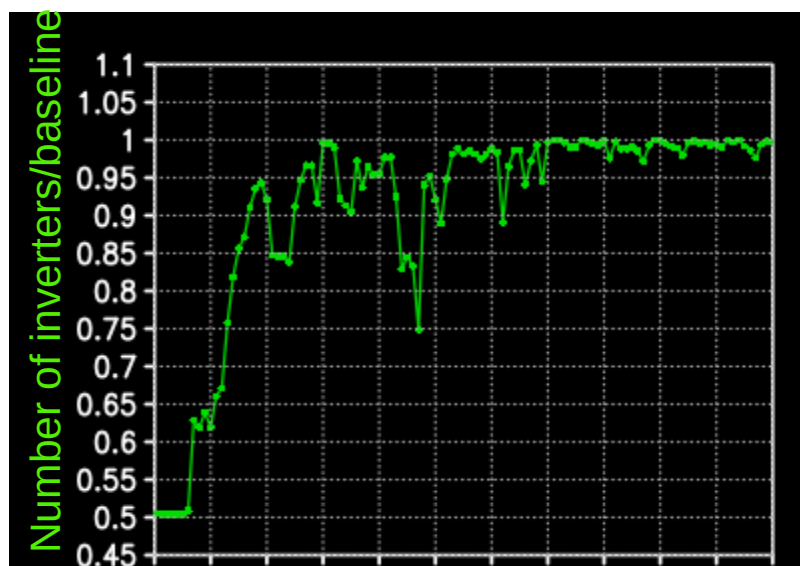


Days over 3-month period

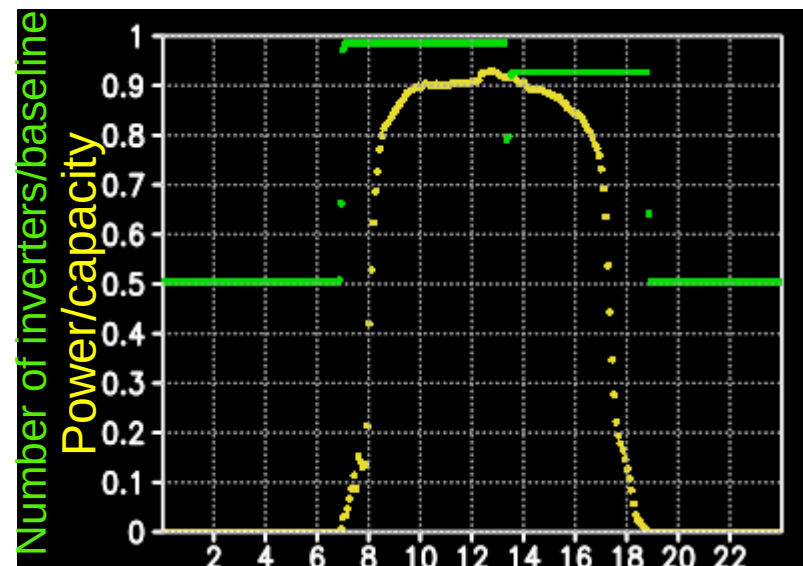
Inverter Count Totals

Plot on left is same type as on previous two slides, showing only half as many inverters were reported in the beginning of the 4-month period, then increasing but not steadily, and finally settling down near the baseline level but still not steady.

Plot on the right shows a single day of inverter count total and power as a fraction of capacity on this sunny day. This site reported only half as many total inverters in any status at night as during the day, and even during the day there was a jump down in the afternoon not related to any jump in power.



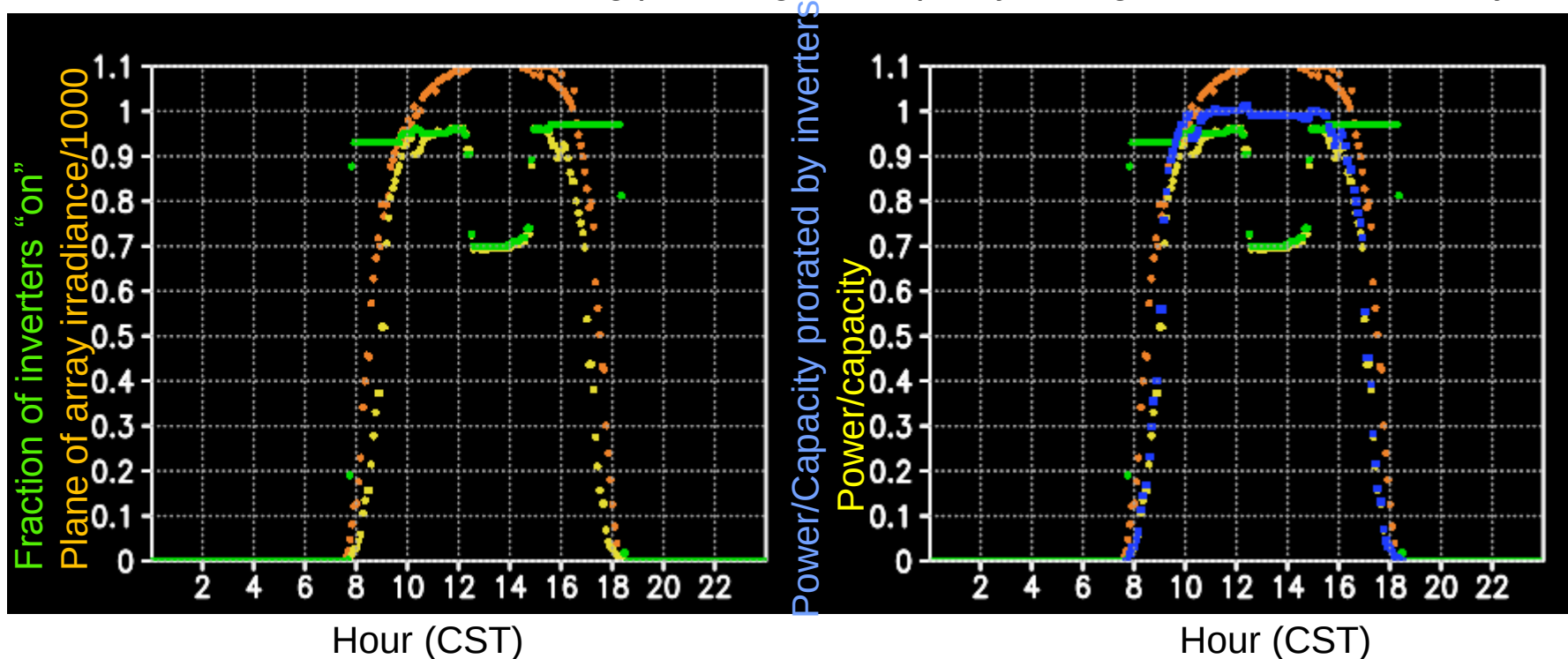
Days over 4-month period



Hour of day (CST)

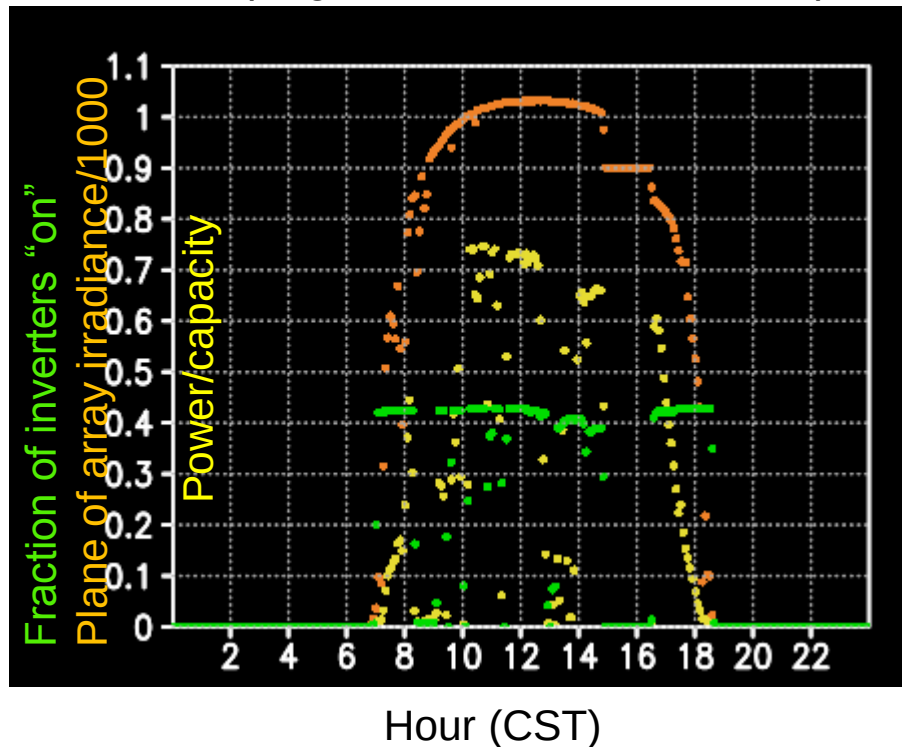
Inverter Status Highly Informative!

Here is a terrific example of perfect reporting and how it is useful. Plot on the left shows fraction of inverters in the “on” status in green, with around 92-97% on most of the day but only 70% on during the middle of the day. Orange shows irradiance – it was a clear day. Yellow shows power/capacity with a dip matching the dip in inverter availability. On the right is the same plot with a blue overlay showing power/capacity when prorated to account for the online inverter fraction – showing power right at capacity through the middle of the day.



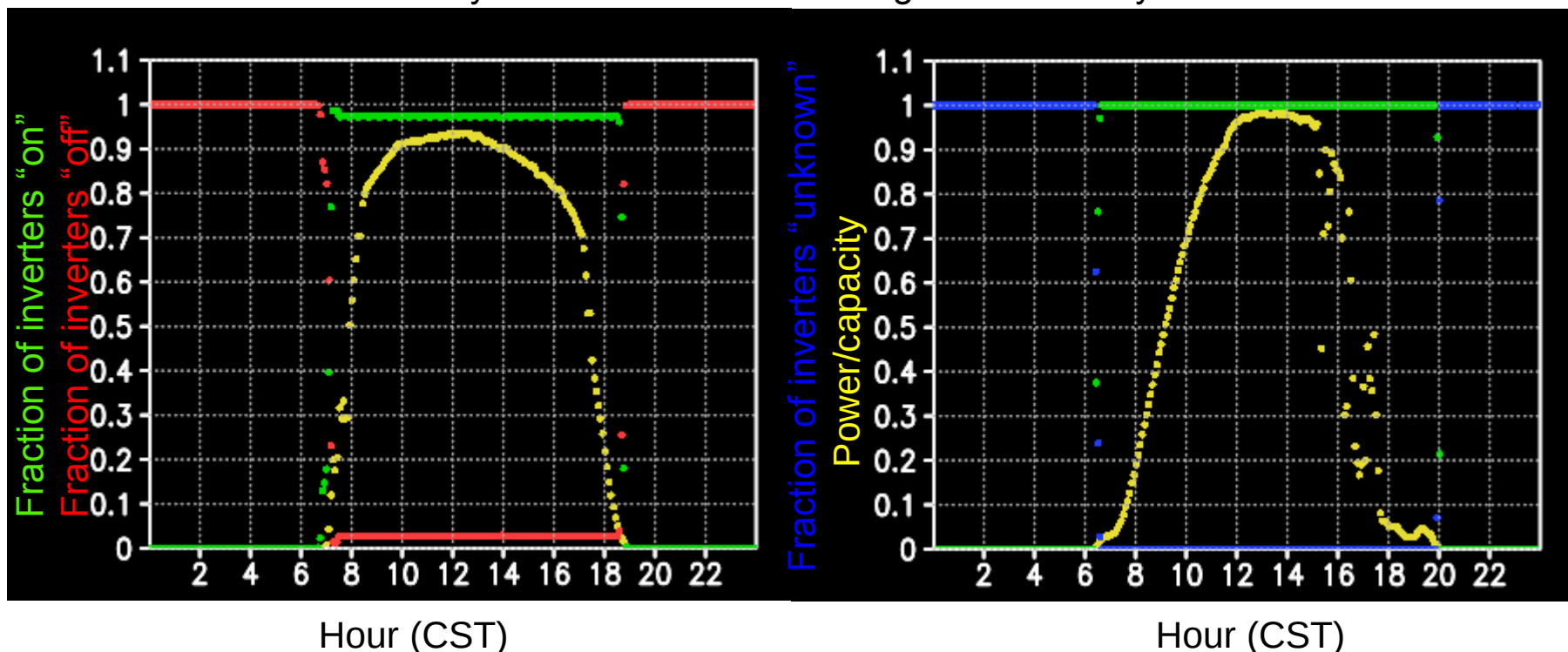
Inverter Status Dubious, Need Better Data

Here is a similar example except the data are not mutually consistent. Again, it is a mostly clear day (orange plane-of-array irradiance). The fraction of inverters online is reported between 40% and 50% most of the day but with notable dips and fluctuations. The reported power is at 30% of capacity around 10:00 am, rising abruptly to 70% of capacity most of the time from 10 to a bit after noon, and overall the fluctuations do not match up against the fluctuations in reported online inverters.



Inverter Status Day and Night

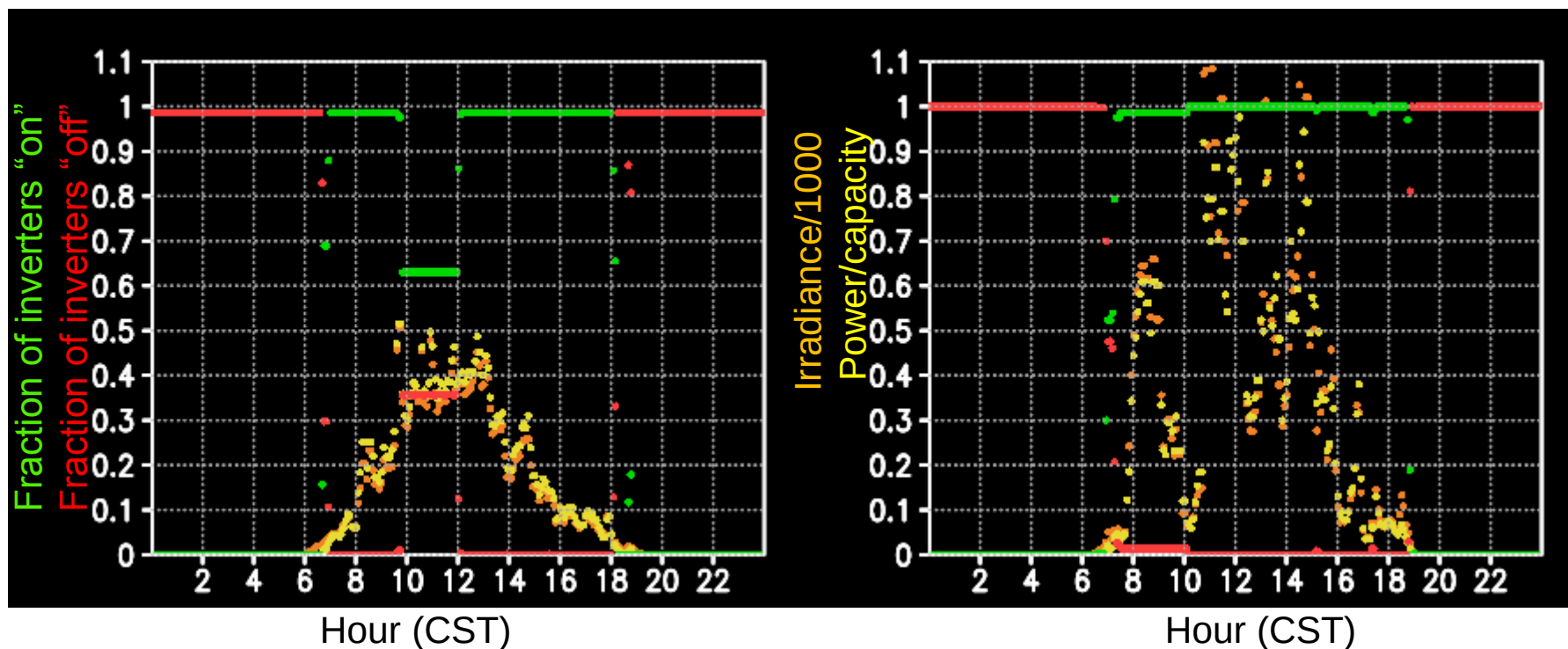
Most days, all sites have been self-consistent about reporting inverter status during the day versus at night. Plot on left shows a site which reports inverters on during the day and off at night. Plot on right shows a site which reports inverters on during the day and in unknown status at night. Sites transition for 15-30 minutes in morning/evening which is faster than the power ramp. Power ramps are consistent with full availability under ramping irradiance. It isn't clear why inverters are not showing full availability at all times.



Inverter Status on Cloudy Day

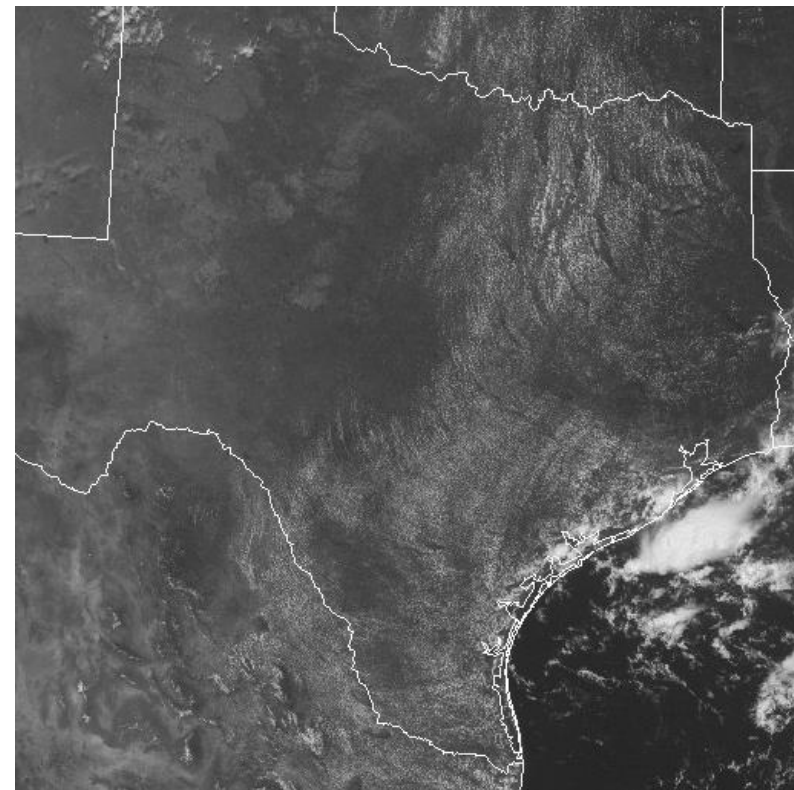
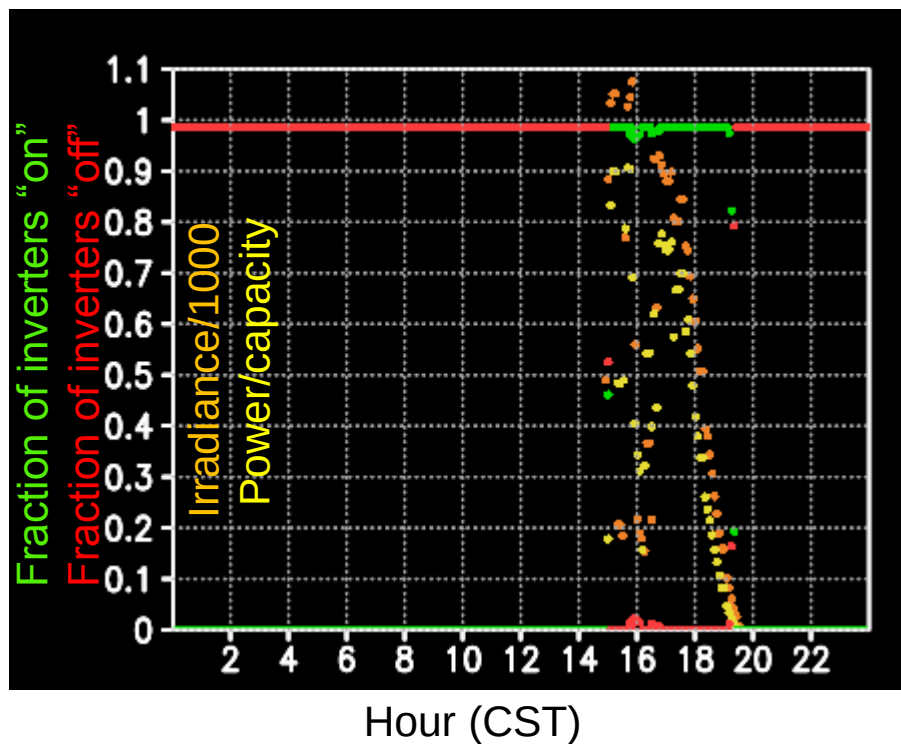
Shown here are two separate cloudy days at the same site.

The day on the left has rather steady cloud cover. Power fraction of capacity follows plane-of-array irradiance closely through the entire day, but more than 1/3 of the inverters are reported as “off” during the middle of the day. This inverter status is inconsistent with the irradiance-power match in the data. The day on the right shows the site nearly entirely online through the entire day and power closely tracking the deep fluctuations in irradiance.



Inverter Status or Outage Unreported?

Here is a day where the site reported zero power until 3:00 pm CST and showed all inverters were offline during that time (plot on left, same type as on previous slide). It also shows zero irradiance during that time. However, satellite imagery (right is for 11:00 am CST) showed a mostly sunny morning to mid-day across all of Texas except near the coast. No outage was reported for this event. Forecast was for a sunny morning, resulting in large error at this site due to the site being down.



Power Information

Power is reported to MDA as 5-minute averages.

This power is checked against plane-of-array irradiance (calculated from global horizontal irradiance [GHI] if only GHI is reported) and it is checked against a calculated clear-sky power. Also, the fraction of inverters online is used in the checks. At some sites, comparison against HSL also is useful while at other sites it does not seem to help.

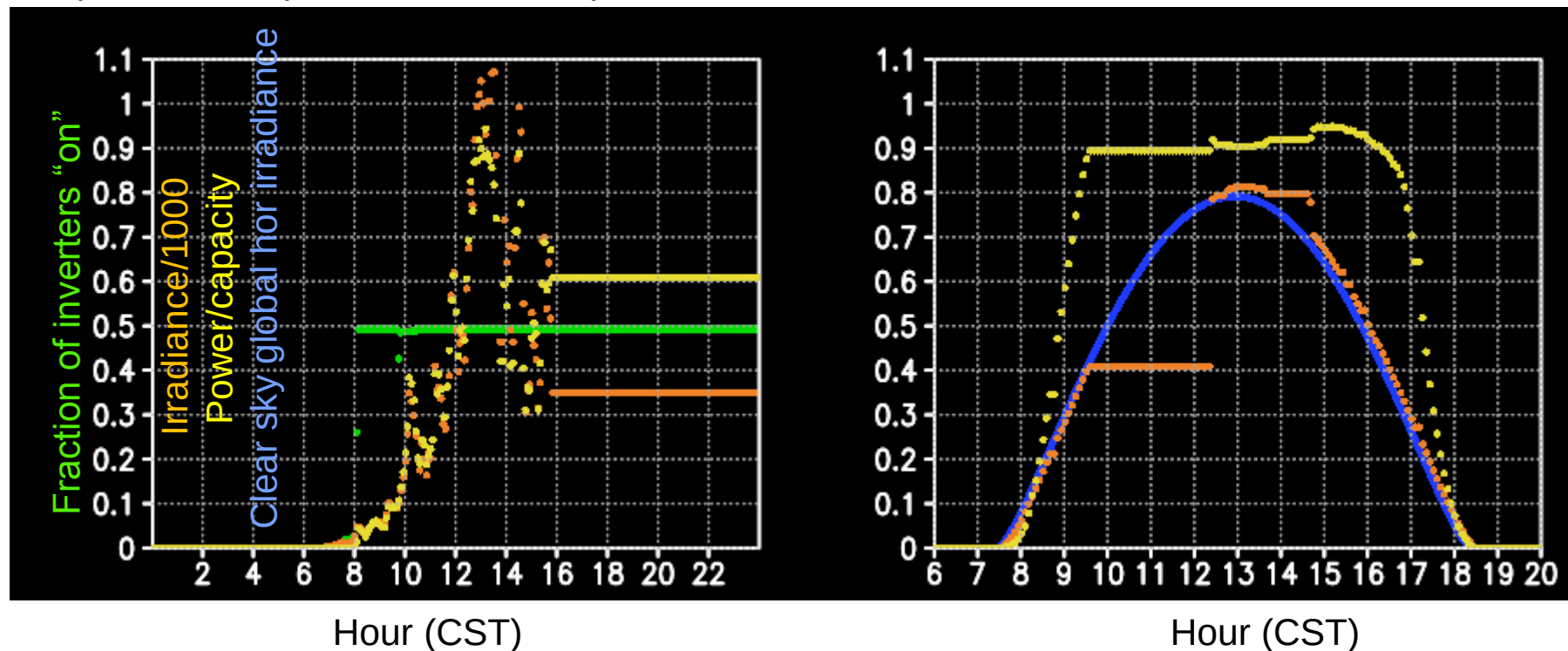
Frequently, the quality control checks show inconsistency, leading us to not utilize the power information at that time. However, often, the power may actually be correct and the other information (irradiance, inverter fraction, etc.) may be incorrect. Unfortunately, it can be difficult to correctly infer which pieces of information are accurate and which not when an inconsistency is found.

Aside from inconsistency with other data, the most common problem with power data is a stuck value. Values can get stuck for 30 minutes or for several days. However, values for short periods could be accurate and appear stuck, making it difficult to distinguish between stuck values and stable values.

It is extremely important to make sure the data logger is not stuck on a value when the actual conditions have changed.

Stuck Logger

Shown here are two examples of a stuck logger. The day on the left is partly cloudy with rapid fluctuations in cloudiness, but the logger gets stuck just before 4:00 pm CST, resulting in repeating the last value of power, irradiance, and inverter status counts until past midnight. The day on the right shows a clear sky day with the logger stuck from 9:30 am CST to 12:20 pm CST and again from 1:40 pm CST to 2:40 pm CST. Clear sky GHI is shown in blue for comparison to reported GHI. Stuck power values are subtle and harder to detect alone.



Irradiance

Some sites report Global Horizontal Irradiance (GHI) – the insolation falling on a horizontal plane.

Other sites report Plane of Array Irradiance (POA) – the insolation falling on a tilted plane where the plane has the same orientation as the solar panels.

These are extremely different with different diurnal shapes on a clear day.

POA can be calculated from GHI through a very complex procedure, which we do. The calculated POA is subject to some assumptions leading to some error typically small under clear conditions but not as small under cloudy conditions. Therefore, it is helpful to have it measured directly.

GHI is not generally back-calculated from POA.

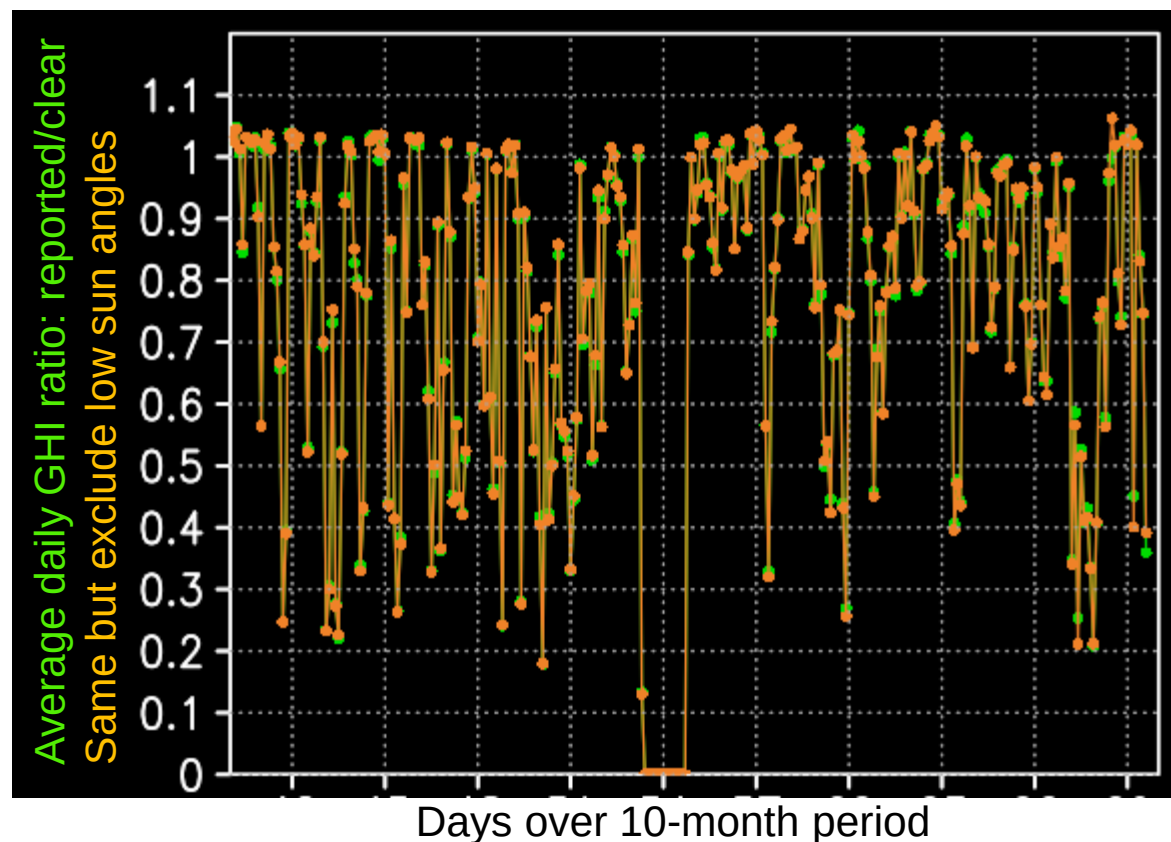
GHI is used for bias-correcting weather forecast model output. POA is used together with measured power generation to translate our forecast POA to a forecast power generation.

POA and GHI also can be complimentary – having both allows additional cross checks in quality control. No ERCOT sites currently report both GHI and POA.

Irradiance – Calibration, Maintenance

Pyranometers are high quality instruments but require periodic recalibration and cleaning annually and more frequent cleaning in locations where dust exposure is likely to cause some soiling. Other irradiance instruments likewise require some regular maintenance.

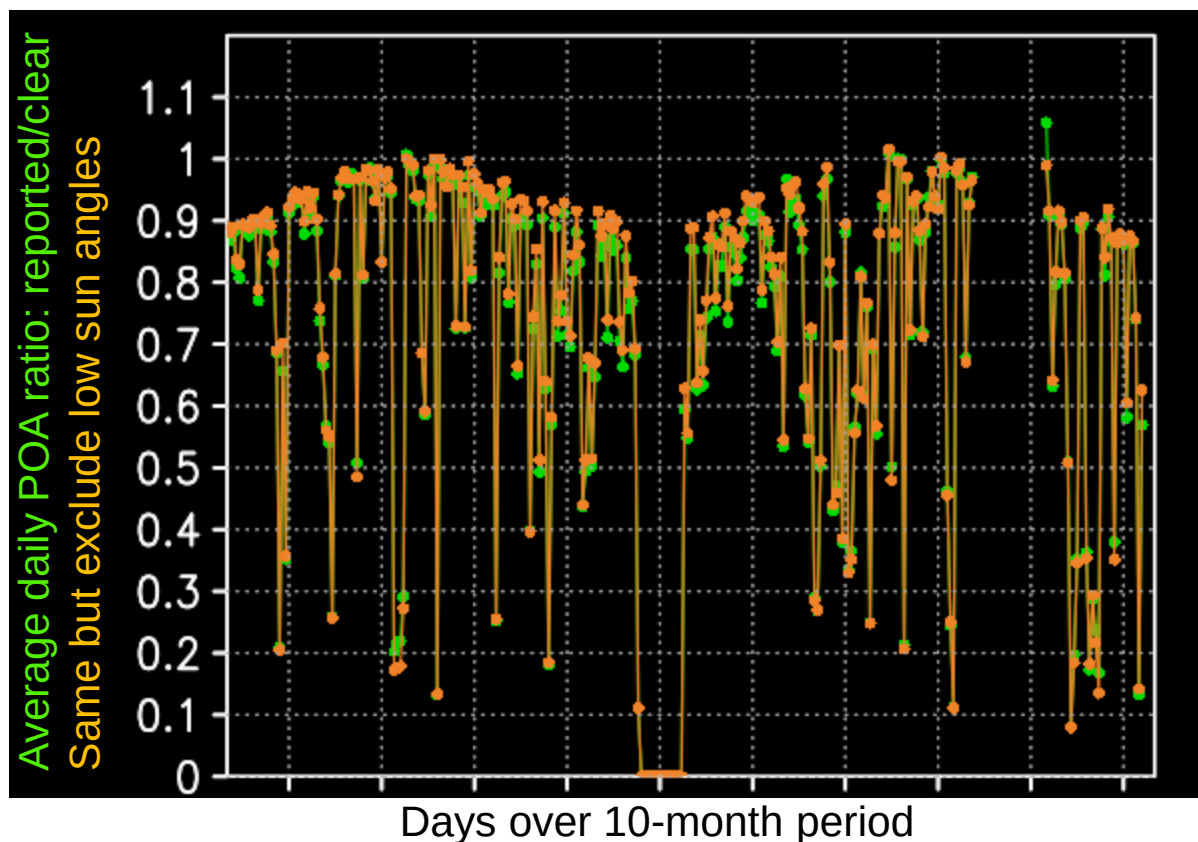
This plot compares reported GHI to calculated clear sky GHI. The calculated values are highly accurate. On cloudy days, the ratio will be less than 1, while on clear days it should be 1.0. The ratio shown is based on the daily average GHI in green and excluding low sun angles in orange. The peak days are close to 1 and stable through a 10-month period, suggesting good calibration and maintenance.



Irradiance – Calibration, Maintenance

This plot shows an example of possible soiling requiring cleaning. This is the same as the previous plot except the site measures plane-of-array rather than GHI. The clear sky calculation may not be as accurate as for GHI both because of assumptions in the calculations for a known plane orientation and because the solar panel orientation itself is estimated. Nonetheless, it shows the peaks have large excursions from 1.0. Low values of the peaks, if those peaks are actually clear sky days, indicate the reported irradiance may be too low. It turns out that the valleys in the plot correspond to dry periods, suggesting soiling on the sensor may be occurring.

Also, it would help if actual tracking angles could be included as additional telemetered data.

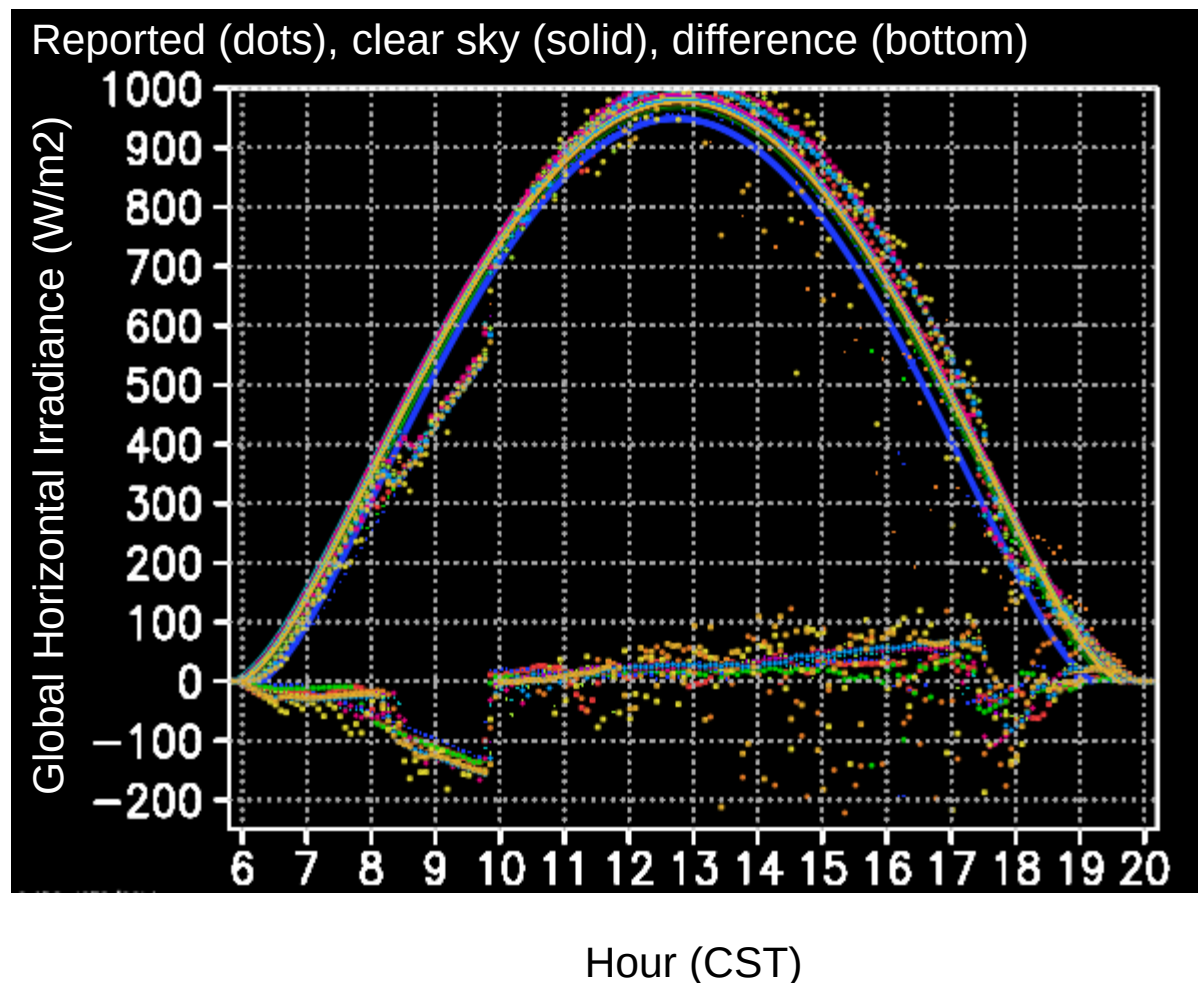


Irradiance – Instrument Siting/Shadow

This site appears to cast a faint but important shadow or veil on the sensor when the sun is to the east.

The plot shows measured GHI with a dip relative to clear sky GHI between 8 and 10 am CST on each of the 11 sunny days plotted. Each day is a different color. The difference grows from zero to around 150 W/m² during the 8 am to 10 am time period, then abruptly corrects back to the clear sky curve.

It is important to make sure that the instrument is not even partly or somewhat shaded except at extremely low sun angle.





WEATHER SERVICES

Thank you

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