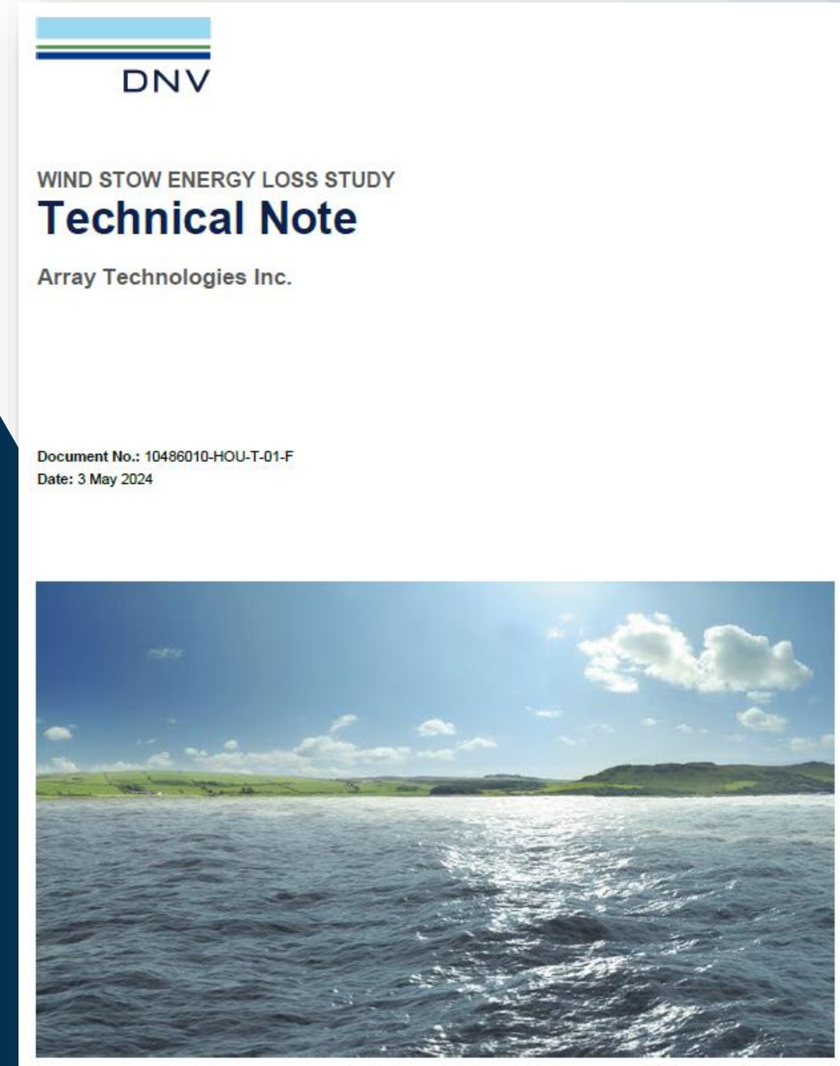
ARRAY

DNV Wind Study Webinar

October 29, 2024


DNV

WIND STOW ENERGY LOSS STUDY

Technical Note

Array Technologies Inc.

Document No.: 10486010-HOU-T-01-F
Date: 3 May 2024

ARRAY

ARRAY Introduction

1,000+
employees globally

$1.577B
in revenue in 2023

200+
issued patents

30+ Years
of solar experience

ARRAY

ARRAY's Strong Track Record of Delivering Power Across the Globe

68+ GW Delivered Globally

ARRAY

Tracker Solution Portfolio

We offer an evolving suite of tracker products all powered by **SmarTrack™** software

Multi-Row

DuraTrack®

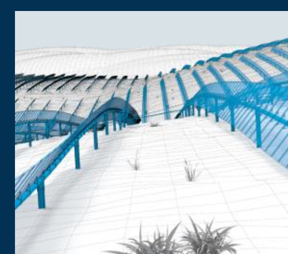
"Gold standard in solar tracking"

Best project returns
Fastest installation
Dependable in extreme weather
Zero scheduled maintenance

OmniTrack™

"All the benefits of DuraTrack plus more"

Enhanced N/S terrain flexibility
Minimized site grading and civil works permitting
Premier solution for unlevel site terrain



SkyLink

"Wireless, all-weather, string powered DC control system"

PV-string powered brushless DC motor
Zigbee wireless communication
Eight-row linked architecture
Reduced trenching, zero batteries

Dual-Row

H250

"STI's legacy sought after tracker with a strong global reputation"

Lower upfront CapEx

Established presence in Europe, South America, and South Africa

Ideal for sites with irregular boundaries, highly angled blocks, or fragmented project areas

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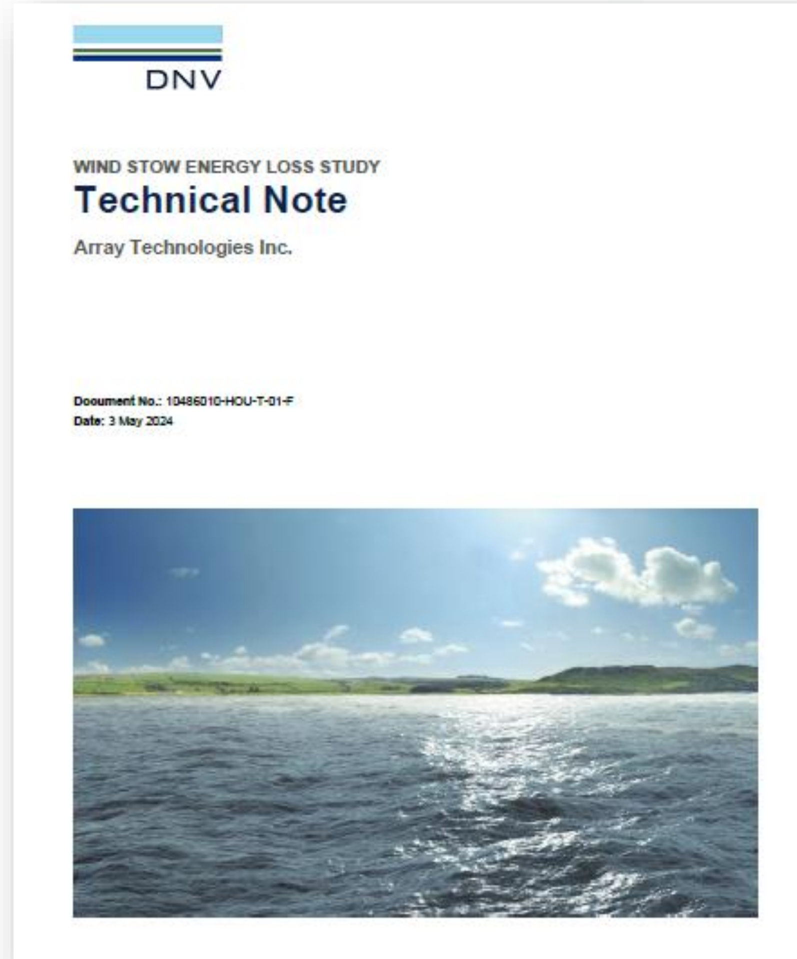
ARRAY's Partnership with DNV

Wind stow study collaboration and overview

- ARRAY developed a general methodology and software to model wind stow and its energy loss impacts using high resolution wind data
- DNV reviewed ARRAY's methodology, intermediate results, and final energy losses for each parameter set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DNV supports developers, owners, operators, lenders, investors, and equipment manufacturers, globally

Solar and storage project development

Solar and storage project engineering

Solar and storage asset operation and management

Solar measurements, resource data, and forecasting

Solar and storage technology reviews and testing

Solar and storage software tools

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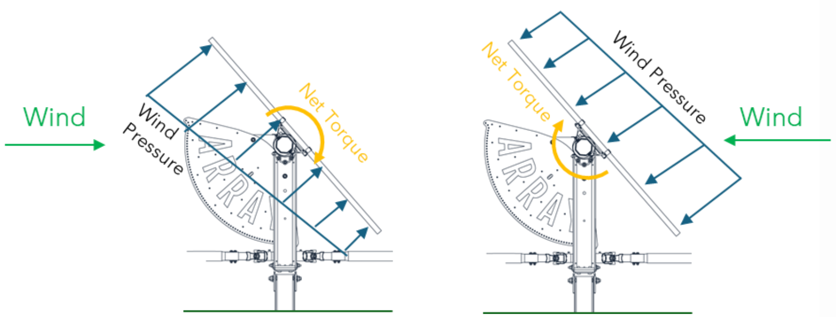
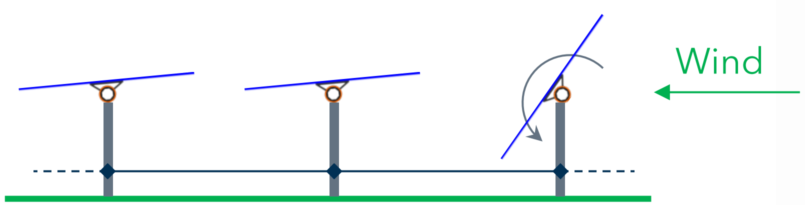
ARRAY Passive Wind Stow

Passive Wind Stow

ARRAY DuraTrack® and ARRAY OmniTrack™ do not require any active monitoring (i.e. sensors, specialized controls, communications) to respond to high wind events.



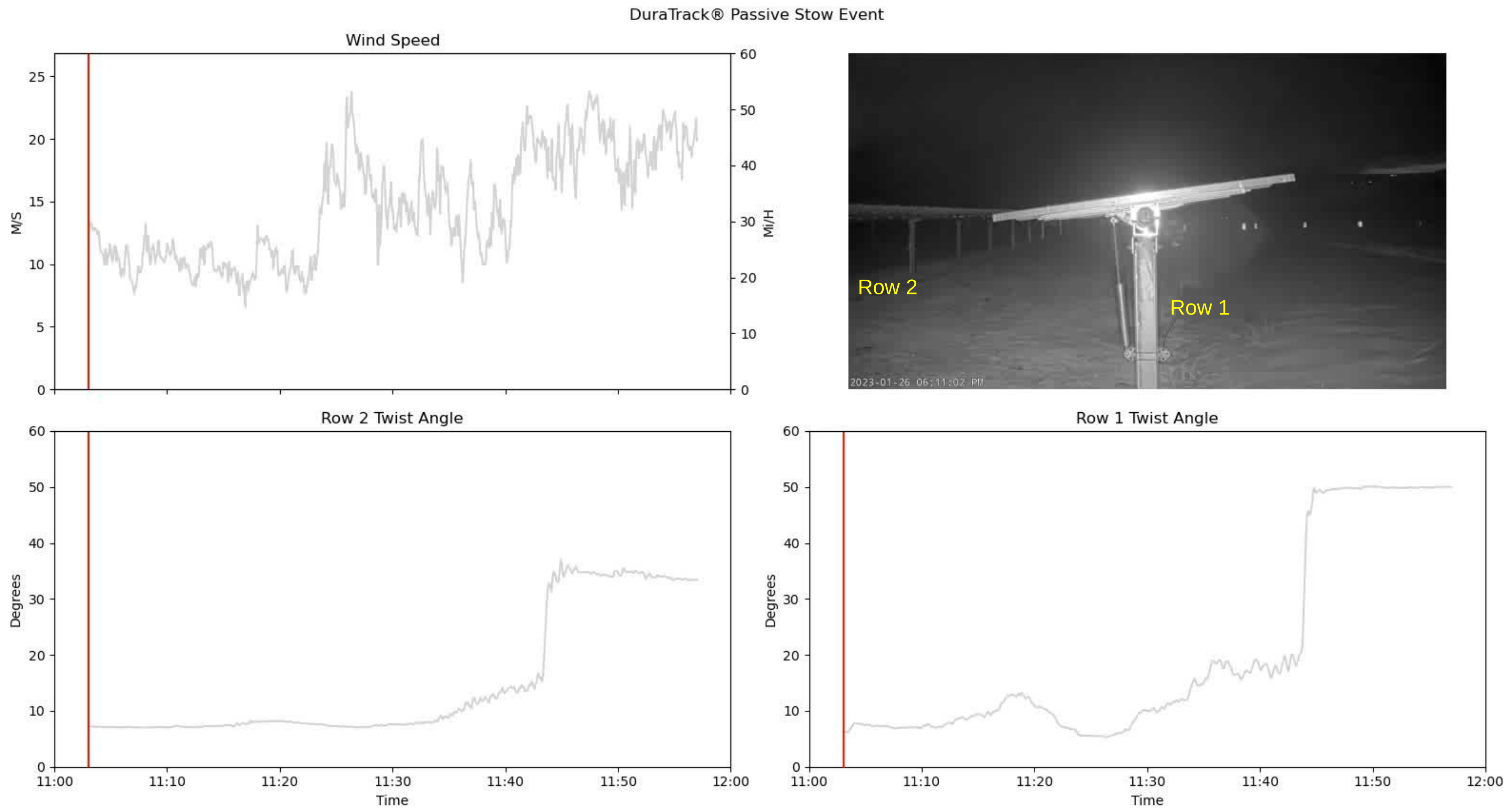


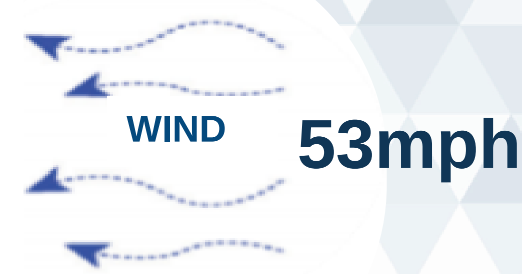
- Nonuniform wind pressure on a tilted tracker creates net torque pushing the tracker toward maximum tilt in the direction it is already facing.
- Patented Gear Box design includes a torsion limiting clutch that supports the pressure and keeps the tracker at its position up to predetermined torque threshold.
- If the torque threshold is exceeded, the clutch in the Gear Box allows the tracker to move to maximum tilt.
- Each row can respond independent of other rows connected to it through the driveline. Only individual rows that experience wind pressure exceeding the clutch thresholds will move to stow.

Passive Wind Stow

- At maximum tilt, the row is supported by stops in each bearing. The stops distribute the wind pressure to each of the foundations. This results in a very rigid structure that is not susceptible to dynamic torsional excitation.
- Typically, exterior rows will move to maximum tilt first, providing a wind barrier for interior rows. Rows that are not affected by the wind pressure will continue tracking normally.
- Stowed rows will automatically realign with the unaffected rows at either the end of tracking in the evening or the start of tracking in the morning.
- Depending on the time of day, some stowed rows may immediately resume tracking out of phase with the other rows and may become realigned (in phase) within a few minutes.

Passive Wind Stow Response in Action





Confidential Under Array Technologies MNDA

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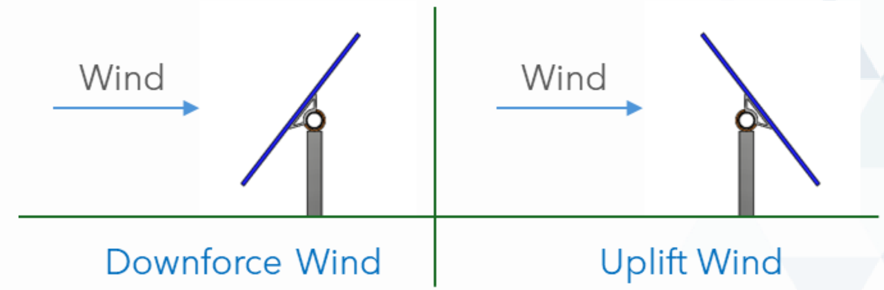
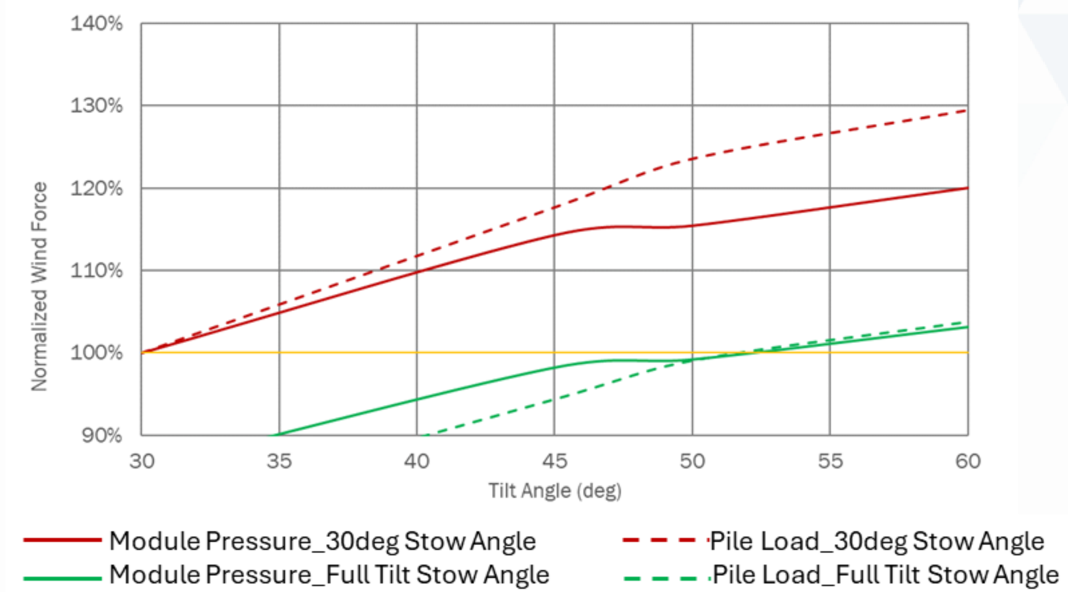
Design

Tracker designs should always consider worst case loading scenarios.

- For highest reliability, trackers should be designed to be at full tilt angle in either direction under every condition.
- Foundation and module mounting designs should consider any wind speeds (up to site design maximum) while the modules are positioned in either direction at maximum tilt.
- If the tracker structure is not designed to take maximum wind force at full tilt, and the tracker remains at high tilt angles during a severe weather event, then the structure can be overstressed, putting it at risk of damage.





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Stow Angle Dilemma

ACTIVE Wind Stow + Active Snow Stow+ Pro-Active Hail Stow

Stow Priority	Conflict Potential			
	Snow	Flood	Hail	Wind
Snow		NO*	NO	YES*
Flood	NO*		NO*	NO*
Hail	NO	NO*		YES*
Wind	YES*	NO*	YES*	

PASSIVE Wind Stow + SmarTrack Automated Snow Response + SmarTrack Hail Alert Response

Stow Priority	Conflict Potential			
	Snow	Flood	Hail	Wind
Snow		NO*	NO	NO
Flood	NO*		NO*	NO*
Hail	NO	NO*		NO
Wind	NO	NO*	NO	

* Assumes tracker is tall enough to eliminate need of low tilt flood stow
* Assumes tracker is not designed for high wind at high tilt

ARRAY DuraTrack with Passive Wind Stow is designed to eliminate stow conflict
► Designed for full wind in any direction at high tilt

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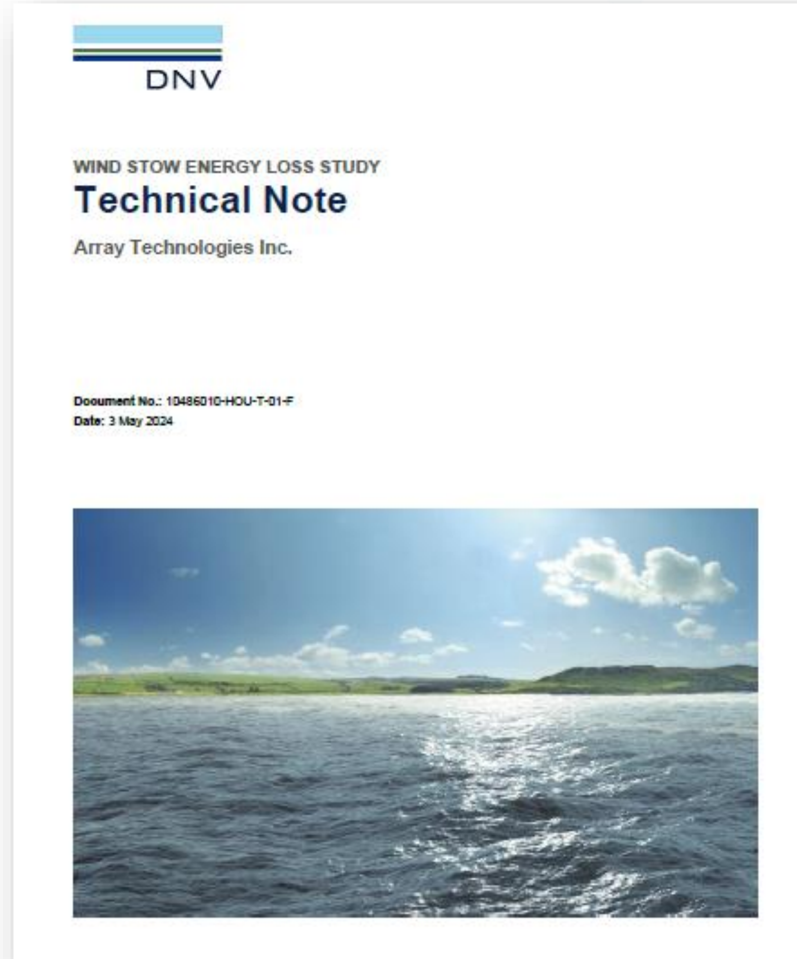
Wind Stow Energy Loss Study

DNV

Wind Stow Study Overview

A new method of calculating energy loss due to wind stow

- ARRAY developed a general methodology and software to model wind stow and its energy loss impacts
- Chose wind stow parameters that correspond to typical projects using active stow
- Each parameter set roughly corresponds to a typical wind stow method (i.e., active or passive)
- Calculations applied to two fictitious projects
- 1 minute or better wind data
- 5-minute energy simulation
- DNV reviewed ARRAY's methodology, intermediate results, and final energy losses for each parameter set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Analyzed Stow Strategies

Parameters representing a variety of different stow methods

- **A:** ARRAY's passive wind stow method
- **B, C:** Two active stow strategies selected by ARRAY based on industry knowledge
- **D:** DNV provided one active stow strategy to model for comparison purposes

Note: Stow parameters vary widely based on tracker design and project-specific design and conditions

Modeled Scenarios and Results*

Case	Parameter Source	Active/ Passive	Relaxation Time (min)	Stow Angle (deg)	Windspeed Thresholds
A	ARRAY	Passive	N/A	52	Exterior rows: 3 s gust > 36 - 150 mph (direction dependent) Interior rows: 3 s gust > 42 - 150 mph (direction dependent)
B	ARRAY	Active Logic 1, all-row	20	25	Instantaneous speed > 37.3 mph OR 1 minute average > 26.1 mph
C	ARRAY	Active Logic 2, tiered	N/A	60	Exterior rows + 25% interior rows: vec. Norm. 3 m > 21 mph (exit 16 mph) All rows: vec. Norm. 3 m > 25 mph (exit 20 mph)
D	DNV	Active Logic 2, tiered	30	60	25% rows: 3 s gust > 30 mph All rows: 3 s gust > 35 mph

*Note: 3 s gust -> 10 m (30 ft); Instantaneous -> 10 m (30 ft); Vector normal - 3 m (10 ft)

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Stow Modeling Parameters

Key parameters modeled in the active stow strategies:

- Wind velocity thresholds and wind direction
- Stow arrangement
  - How many and which rows go into stow
- Stow dwell time
  - How long the system stays in stow before exiting (time-based or wind speed based)
- Stow position
  - Stow tilt angle and direction (East or West)
- Multiple stow levels
  - In some cases, there is more than one stow trigger parameter

Modeled Scenarios and Results*

Case	Parameter Source	Active/ Passive	Relaxation Time (min)	Stow Angle (deg)	Windspeed Thresholds
A	ARRAY	Passive	N/A	52	Exterior rows: 3 s gust > 36 - 150 mph (direction dependent) Interior rows: 3 s gust > 42 - 150 mph (direction dependent)
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D	DNV	Active Logic 2, tiered	30	60	25% rows: 3 s gust > 30 mph All rows: 3 s gust > 35 mph

*Note: 3 s gust -> 10 m (30 ft); Instantaneous -> 10 m (30 ft); Vector normal - 3 m (10 ft)

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Modeled Stow Cases

1) Passive stowing tracker (Array DuraTrack) – individual rows stow to 52deg tilt when torque threshold wind speed is exceeded

2) Active stowing #1 – all rows within plant stow to predetermined stow angle when wind threshold is exceeded; single level threshold wind speed

3) Active stowing #2 – all exterior rows & 25% of interior rows stow to predetermined stow angle when wind threshold is exceeded; two level threshold wind speed

Types of stow cases modeled

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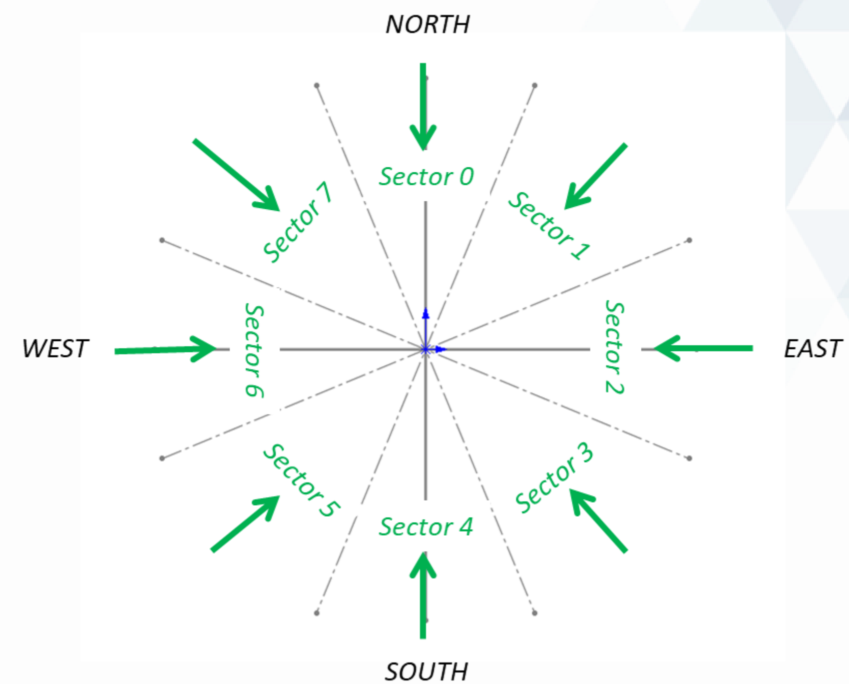
Passive Wind Stow Model

Case A – ARRAY passive stow model

- ARRAY's passive stow occurs when the pressure induced by wind is high enough for the clutch mechanism to slip
  - Independent clutch mechanism for every row
  - Purely mechanical function (no electronics, sensors, or signals)
- Passive stow thresholds depend on direction and row location
- For exterior rows:
  - Sectors 1, 2, 3, and 5, 6, 7: 35 – 60 mph
  - Sectors 0 and 4: 150 mph threshold
- For interior rows:
  - 17% of rows slip along with exterior rows
  - All other interior rows remain tracking
  - Slipped rows shield remaining rows
- These parameters are based on ARRAY wind tunnel and NREL field testing
- Slipped rows continue tracking but lag the unslipped rows



Passive stow wind sectors

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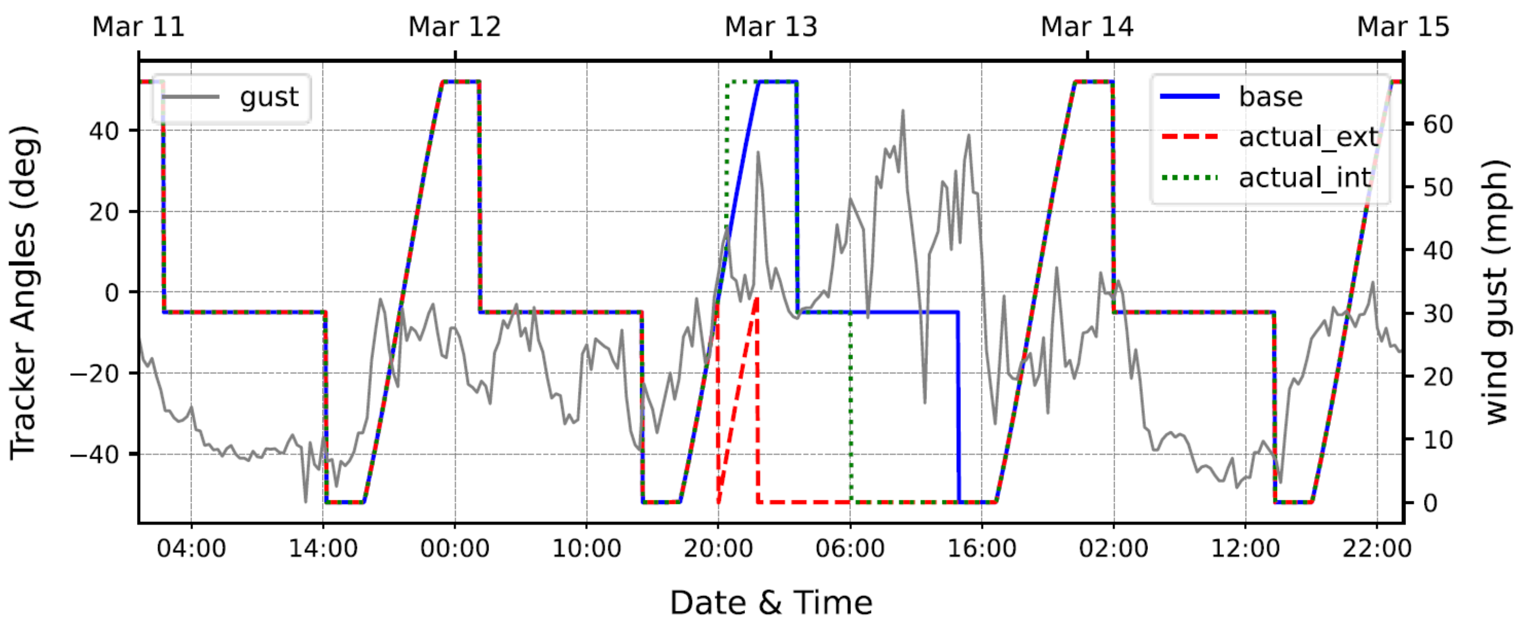
Module Angle Calculations

Passive stow tracking angles – Case A, ARRAY passive stow model



Key Takeaway:
<u>Low</u> frequency of stow due to wind speed with passive wind stow capabilities

Case A Stow Parameters

Exterior Wind Speed Threshold (mph)	Interior Wind Speed Threshold (mph)	Which Rows Stow at This Level?	Stow Angle
36-150	42-150	Exterior Rows + 17% Interior Rows	52° Facing Wind

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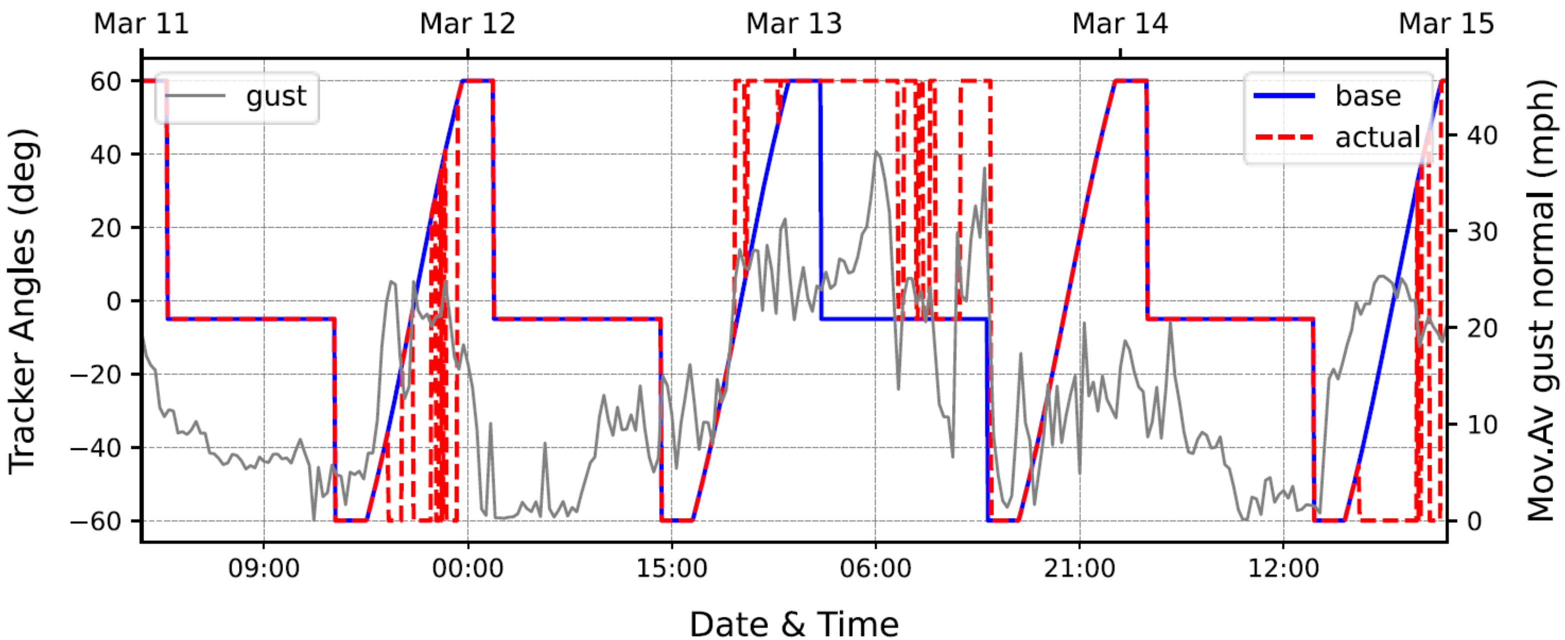
Module Angle Calculations

Active stow tracking angles for Case C



Key Takeaway:
High frequency of stow due to wind speed with active wind stow

Case C Stow Parameters

Stow Trigger Wind Speed (mph)	Stow Exit Wind Speed (mph)	Which Rows Stow at This Level?	Stow Angle
21	16	All Exterior Rows + 25% Interior Rows	60° Facing Wind
Stow trigger and stow exit wind speeds are 1min average at 3 meters, vector normal components			

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Wind Data Processing

Two wind data sets were utilized in the model

- Site 1: California. Annual average wind speed of 14.3 mph
  - Wind speed and direction sampled every 10 seconds
  - Two anemometers located 30 feet above ground level
- Site 2: Nevada. Annual average wind speed of 7.7 mph
  - 1-minute peak wind speed, 1-minute average wind speed, and 1-minute average direction
  - Anemometer and mounted 10.5 feet above ground level
- The wind data processed for the different stow methods including
  - Instantaneous wind speed
  - Moving average wind speed
  - Vector normal wind speed
  - 3-second gust wind speeds
- ARRAY extracted the maximum value over each 5-minute window for use in the stow and energy models

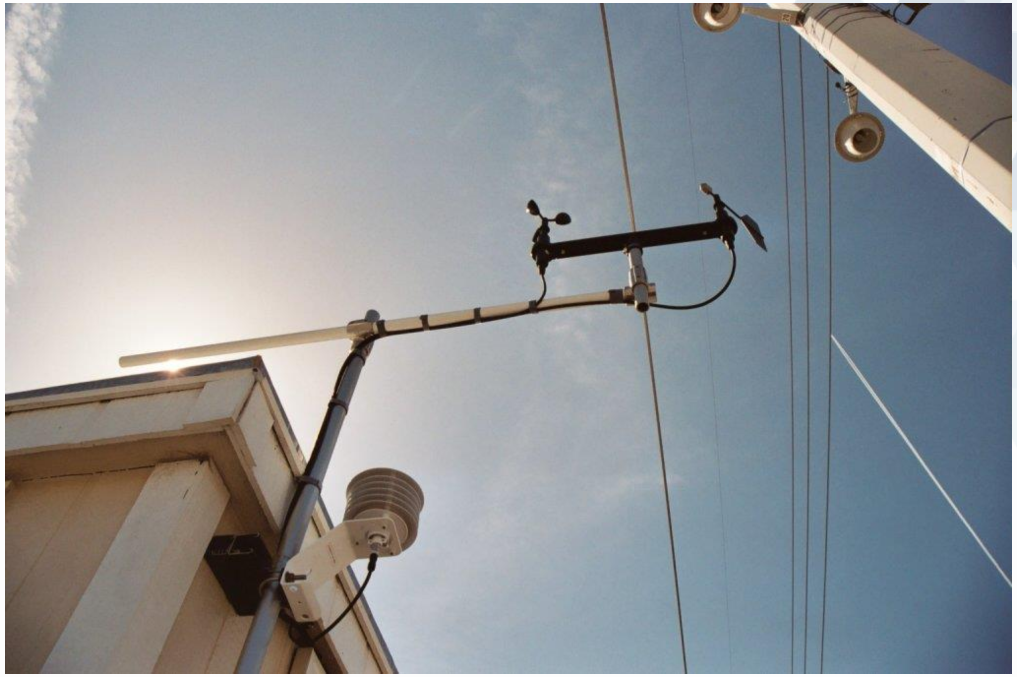

Image source: Andreas, A.; Stoffel, T.; (2006). Nevada Power: Clark Station; Las Vegas, Nevada (Data); NREL Report No. DA-5500-56508; http://dx.doi.org/10.5439/1052547

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Energy Model

- ARRAY used the PlantPredict platform to model the project per Table 2-2
  - Sub-hourly time resolution and user-specified tracker angles
- Backtracking disabled
- 5-minute global horizontal irradiance and ambient temperature data from NREL NSRDB PSM3 model
- PlantPredict was used for non-stow energy and tracker angles for each 5-minute time stamp
- Tracker angles were input into PlantPredict to calculate stow energy values
- The difference between the non-stow energy and the stow energy for each scenario results in the energy lost due to stowing

Modeled Project Parameters

Parameter	Value
Module	First Solar Series 7 7530A
Nominal module rating	530 W
Total DC capacity	200 MW
Inverter loading ratio	1.25
Ground cover ratio	40%
Backtracking	False
Exterior rows	121
Interior rows	3379
Row length	108 modules (131 meters)

Model Results

Energy loss results for different stowing methods

Modeled Scenarios and Results*

Case	Parameter Source	Active/ Passive	Relaxation Time (min)	Stow Angle (deg)	Windspeed Thresholds	Energy Loss at Site 1	Energy Loss at Site 2
A	ARRAY	Passive	N/A	52	Exterior rows: 3 s gust > 36 - 150 mph (direction dependent) Interior rows: 3 s gust > 42 - 150 mph (direction dependent)	**0.1%**	**0.0%**
B	ARRAY	Active Logic 1, all-row	20	25	Instantaneous speed > 37.3 mph OR 1 minute average > 26.1 mph	**4.3%**	**3.2%**
C	ARRAY	Active Logic 2, tiered	N/A	60	Exterior rows + 25% interior rows: vec. Norm. 3 m > 21 mph (exit 16 mph) All rows: vec. Norm. 3 m > 25 mph (exit 20 mph)	**4.2%**	**0.7%**
D	DNV	Active Logic 2, tiered	30	60	25% rows: 3 s gust > 30 mph All rows: 3 s gust > 35 mph	**2.6%**	**1.9%**

*Note: 3 s gust -> 10 m (30 ft); Instantaneous -> 10 m (30 ft); Vector normal - 3 m (10 ft)

Lower losses from passive stow are due to:

- Active stow wind thresholds are lower than passive stow
- Passive stow is dependent on wind direction
- Only 17% of interior rows stow in passive stow model

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DNV Review Summary

- ARRAY tracker angle calculations are correct
- Methods for processing measured wind data into wind data for use in stow models are consistent with industry standards
- The use of 5-minute time steps improves the accuracy of the wind stow loss calculations
- The choice of modeling software and project assumptions are reasonable
- Energy losses from passive stow cases were lower than the active stow cases:
    - 0.0% - 0.1% for passive stow
    - 0.7% - 4.3% for active stow
- Evolving industry trends in module sizes, site terrain, row lengths, and custom algorithms may impact future trends in tracker designs and stow parameters.

Best Practices

- Acquire wind data that is directly relevant to stow strategies (correct time resolution, height)
- Acquire at least 12 months of data
- In windier environments also acquire data at 10 m
- Use range of power law exponents to account for uncertainty in surface roughness
- Wind stow loss calculations occur on the DC side, but comparisons should account for inverter and plant controller clipping, storage
- Adjust modeling assumptions as industry trends evolve
    - Uneven terrain, hail/flood stow, diffuse irradiance optimization
- Developers, IEs, OEMs, other parties should align on each project-specific wind stow strategy

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Key Learnings and Recommendations

- Energy losses due to active wind stowing can be significant and should be accounted for by site developers, investors, and owners
    - Most energy production calculations do not account for wind stow losses
- Using hourly wind data can lead to inaccuracy in predicting stow losses
- In the early stages of new PV projects, install a wind measurement station onsite to get high resolution wind data for stow loss analysis – especially for medium to high wind sites
- ARRAY's patented Passive Wind Stow reduces energy production loss caused by wind stow because:
    - Only the precise number of rows that "need" to stow will stow
    - Stowing reaction time is effectively zero
    - Stowed rows can continue to track out of phase immediately after stowing (depending on time of day that stowing occurs)

Note: While DNV does account for wind stow losses in its energy assessments, many production calculations from developers, EPCs, and IEs do not account for stow losses.

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Questions:

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