



Sunfolding NREL High Wind Test Site Project

Cooperative Research and Development Final Report

CRADA Number: CRD-19-00808

NREL Technical Contact: Jeroen van Dam

**NREL is a national laboratory of the U.S. Department of Energy
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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5000-89769
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Cooperative Research and Development Final Report

Report Date: April 22, 2024

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Sunfolding

CRADA Number: CRD-19-00808

CRADA Title: Sunfolding NREL High Wind Test Site Project

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

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Daphne Adam, daphne.adam@sunfolding.com

Sponsoring DOE Program Office(s): Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Office (SETO)

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	\$85,000.00
Year 2, Modification #1	\$.00
Year 3, Modification #2	\$.00
Year 4, Modification #3	\$.00
TOTALS	\$85,000.00

Executive Summary of CRADA Work:

Wind speeds at the NREL National Wind Technology Center (NWTC) vary dramatically from summer to winter. Wind speeds are low over the summer and high over the winter. The data collected from this site will allow validation of the survivability of the Sunfolding tracker under high wind events, increased understanding of the dynamic behavior of the Sunfolding tracker at different wind speeds.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assists laboratory in achieving programmatic scope,
- Uses the laboratory's core competencies, and/or
- Enhances U.S. competitiveness by utilizing DOE developed intellectual property and/or capabilities.

Summary of Research Results:

The initial high wind test site development was covered under Bailment: BAE-18-196. The CRADA was developed shortly thereafter to allow better protection of the generated data.

Original CRADA Tasks

Overall Project Management

NREL completed the NEPA process and developed a Safe Work permit for the construction activities. As part of the project management task NREL would review monthly financial information, host Sunfolding employees, and perform Designated Area Representative (DAR) duties related to safety.

Site monitoring

Sunfolding initially installed four sections of PV trackers (piers were installed for a total of six trackers) at site 1.9 of the NREL Flatirons Campus (Figure 1 and Figure 2). NREL installed two cameras at the site (Figure 5 and Figure 6). NREL also has a PZT camera installed on the M-2 Meteorological tower which could be directed at the Sunfolding site during high wind events (Figure 7). All video cameras would maintain a two week circular buffer.

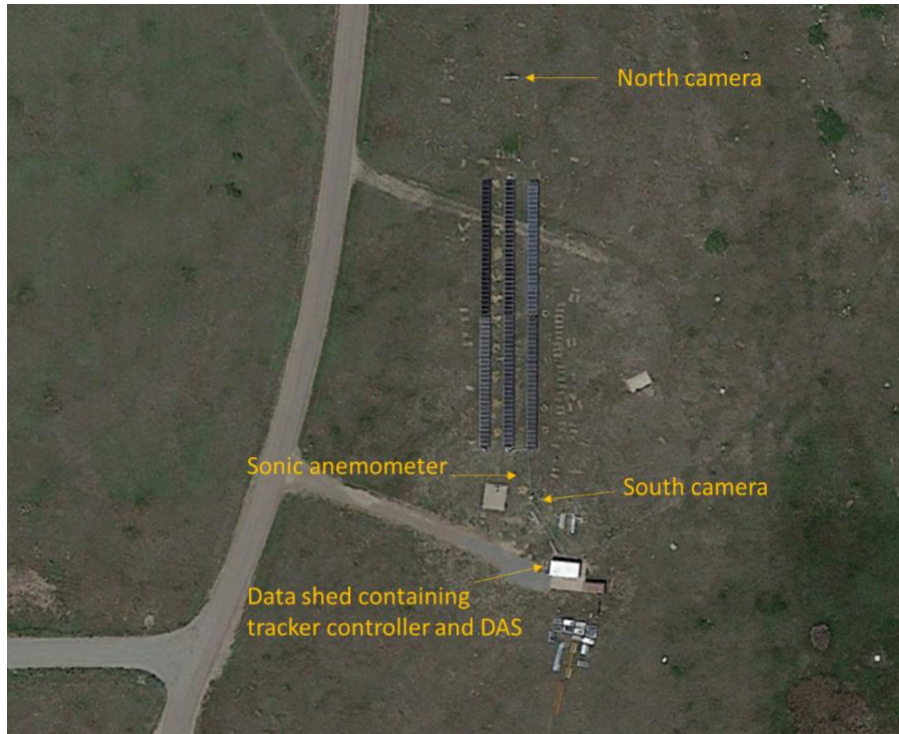
NREL added a short meteorological tower with a Sonic anemometer and accelerometers were installed on the trackers (Figure 8). An EtherCAT based Data acquisition system was installed in the nearby datashed (Figure 9).



Figure 1. Location of Sunfolding installation at the Flatirons Campus (indicated with green, blue lines are Campus boundaries) (Source: Google Earth)



Figure 2. Initial array installation



**Figure 3. Satellite view of the Sunfolding site layout at the Flatirons Campus (June 2021)
(Background photo source: Google Earth)**



Figure 4. Sunfolding test array with sonic anemometer in the foreground (Photo: Jerry Hur, NREL))



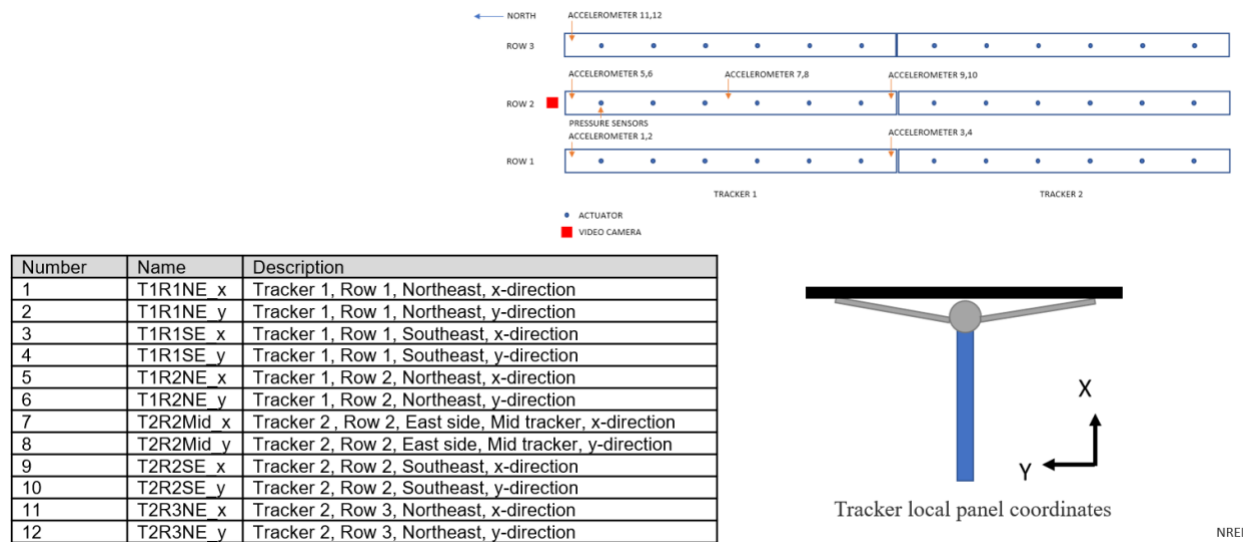
Figure 5. View from permanent North camera (Source: NREL)



Figure 6. View from Permanent South Camera (Source: NREL)



Figure 7. View from M2 PZT camera (Source: NREL)

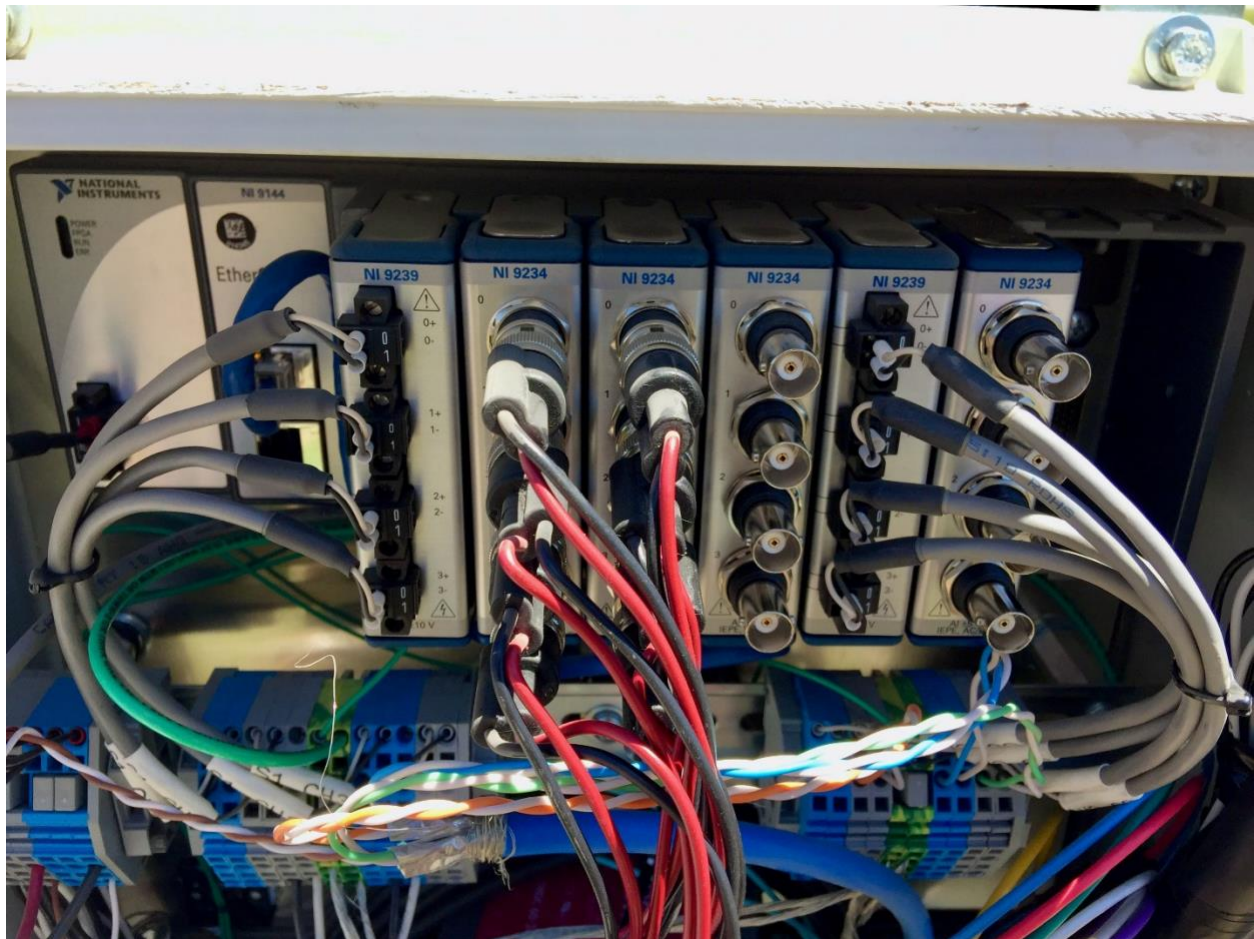


NREL

Figure 8. Initial accelerometer layout

Table 1. Data acquisition channel list

Channel Name	Description	Units
T1R1NE_x	Accelerometer IEPE AC Coupled, Tracker 1, row 1, Northeast, x-direction	g
T1R1NE_y	Accelerometer IEPE AC Coupled, Tracker 1, row 1, Northeast, y-direction	g
T1R1SE_x	Accelerometer IEPE AC Coupled, Tracker 1, row 1, Southeast, x-direction	g
T1R1SE_y	Accelerometer IEPE AC Coupled, Tracker 1, row 1, Southeast, y-direction	g
T1R2NE_x	Accelerometer IEPE AC Coupled, Tracker 1, row 2, Northeast, x-direction	g
T1R2NE_y	Accelerometer IEPE AC Coupled, Tracker 1, row 2, Northeast, y-direction	g
T1R2Mid_x	Accelerometer IEPE AC Coupled, Tracker 1, row 2, Middle, x-direction	g
T1R2Mid_y	Accelerometer IEPE AC Coupled, Tracker 1, row 2, Middle, y-direction	g
T1R2SE_x	Accelerometer IEPE AC Coupled, Tracker 1, row 2, Southeast, x-direction	g
T1R2SE_y	Accelerometer IEPE AC Coupled, Tracker 1, row 2, Southeast, y-direction	g
T1R3NE_x	Accelerometer IEPE AC Coupled, Tracker 1, row 3, Northeast, x-direction	g
T1R3NE_y	Accelerometer IEPE AC Coupled, Tracker 1, row 3, Northeast, y-direction	g
WindSpeed3D	RM Young Sonic Anno 3D wind speed	m/s
WindDirection	RM Young Sonic Anno Wind Direction	deg
ElevationAngle	RM Young Sonic Anno Elevation angle	deg



**Figure 9. NREL's EtherCAT based data acquisition system used for the Sunfolding project.
(Source: Jerry Hur, NREL)**

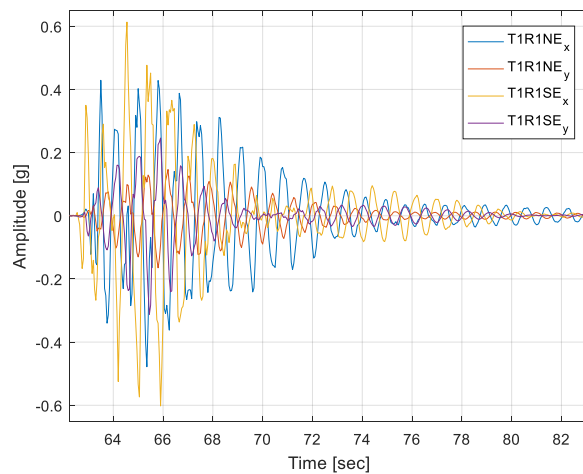


Figure 10. Initial results from accelerometers used for system frequency identification

Mod 1& Mod 3 tasks:

Task 1: Ongoing monitoring

This task provides continuation of monitoring by collecting data with the data acquisition system and cameras through April 2020. NREL will check in on the camera system and data acquisition system to assure data collection is ongoing, will note and resolving any issues with either system. NREL will check on the installation on a weekly basis and inform Sunfolding of any unusual items. NREL will install the tie downs if requested by Sunfolding. NREL will support visiting Sunfolding personnel if needed.

Throughout the CRADA period NREL would periodically check to assure data acquisition was ongoing and signals were still valid. If signal issues were observed NREL would touch base with Sunfolding to assess whether repair was desired. NREL would also report any kind of observations of tracker behavior such as errors reported by the tracker controller. In those cases Sunfolding would either send out resources or provide written instructions to NREL to resolve any issues.

Throughout the CRADA period ~ 10 minute data files of 20Hz data as well as 24 hours long 1Hz files and ten minute statistics (mean, max, min, stdev) were collected amounting to ~ GB. Data collection would be stopped between hardware installations and to facilitate software updates to the DAS PC.

Data was uploaded to the FTP site upon request for analysis by Sunfolding.

In July 2022 NREL removed the instrumentation.

NREL's role was limited to collecting and providing the data to Sunfolding for its own use. NREL did not perform analysis on the data. During the project, Sunfolding verbally stated it used the data to inform its design iterations, as also described under task 2. However, Sunfolding did not share any analysis with NREL and subsequently ceased operations, and any results were no longer obtainable.

Task 2: Response to high wind events

Throughout the duration of the CRADA after major wind events (winds typically exceeding ~40 mph) NREL staff would go the site for inspection of the array. If damage was detected this would be documented and reported to Sunfolding. Sunfolding would either provide written repair instructions or instruction on how to secure the installation to avoid further damage, providing time for a Sunfolding crew to come out and perform repairs. NREL would also secure any video footage of the high wind event to the NREL server and upload the video to the FTP site for Sunfolding's use.

On December 22, 2020, a high wind event, peaking out at 111mph (50m/s) was experienced and the configuration at the time consisting of AX1 actuators, Z-purlins and dampers survived this event without any notable damage.

There were several instances where high wind events resulted in damage. Sunfolding used the data generated under this CRADA to inform design decisions and evolved the design over time. In the end three distinct generations of hardware were installed and tested.

Through the work at NREL the team assessed that the addition of dampers to all of the generations resulted in substantially improved dynamic behavior, and dampers are now included in the build of all project sites. Partially by utilizing the data from NREL, the team was able to design, build, and test later generations (AX1 and AX2) that were substantially more resilient in high wind conditions (both static and dynamic) than the earlier A90 generation that was initially installed at NREL.



Figure 11. Screenshot of video under high wind. Note the early A90 generation of technology without dampers on top left showing deformed shaped due to dynamics under high wind (compare with Figure 5)

In some cases, the team assessed early stage versions of new concepts at HWTS and due to failures at the site, made the decision to pivot the design in a different direction or to discontinue R&D work altogether. See Figure 11 for a locked actuator based R&D tracker that underperformed; this design was never deployed to a customer site.



Figure 12. R&D prototype of locked actuator for extremely high wind applications. The concept showed some promise but needed extensive re-design due to results at HWTS.

Task 3: Adding accelerometers

This task allows for the installation of 8 more accelerometers on one of the installed trackers. NREL will provide the instrumentation. Sunfolding will determine the location and orientation of the accelerometers to be added.

Figure 13 shows the layout of the additional accelerometer that NREL installed. Figure 14 shows a close up of one of the sets of accelerometers. Once installed NREL performed so called end-to-end checks to assure proper installation and configuration.

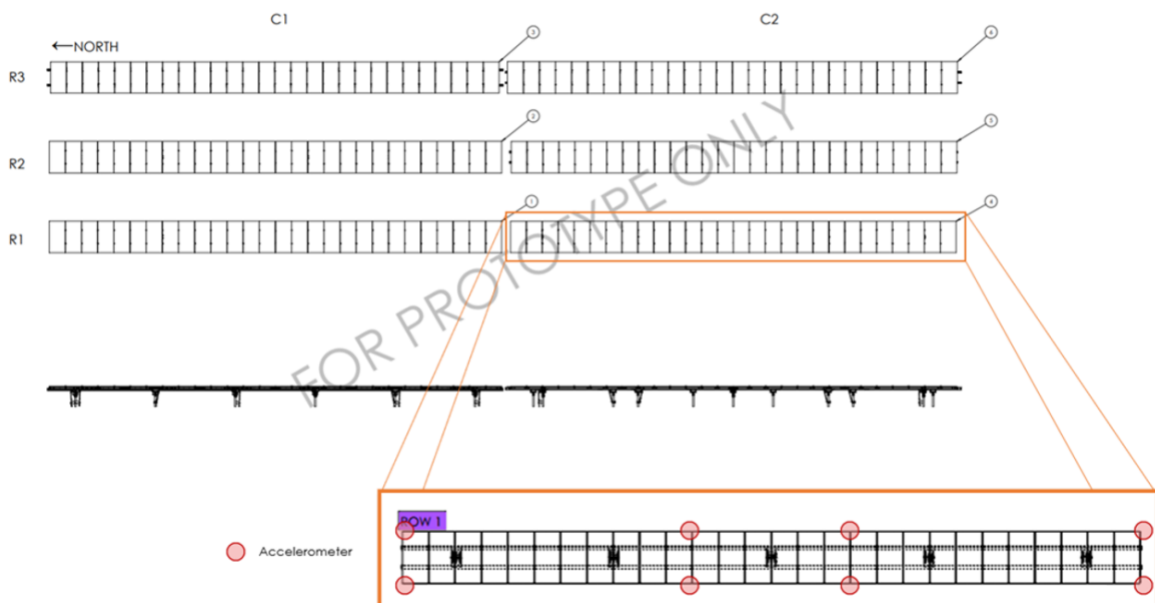


Figure 13. Instrumentation layout for added accelerometers as provided by Sunfolding



Figure 14. Close up of one of the biaxial accelerometer installations

Task 4: Site remediation

After project completion the site will need to be restored to pre-project conditions. This will involve removal of the array hardware and some site remediation which may include reseeded. NREL will provide the re-seeding requirements if needed and provide contact information for contractors that have performed such work at the NREL Flatirons campus before. Sunfolding shall coordinate restoration activities with NREL EH&S.

Site remediation was performed July 5-20, 2023. All the hardware was removed, metals were recycled and the piers were dug out of the ground and disposed of. The ground was leveled in preparation of reseeded which per NREL's request was delayed till September 2023 for better anticipated results.



Figure 15. Excavator working on pier removal



Figure 16. Site 1.9 after equipment removal and prior to reseeding

Task 5: Project management

Throughout the project NREL assured compliance of the project with project management requirements as well as site safety procedures. This activity covered time spend on financial management, safe work permits, visitor hosting, as well as the final CRADA report. The project was executed without any safety incidents and within budget. This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Article X.

Subject Inventions Listing:

None.

ROI #:

None.