DOE Office of Electricity TRAC Peer Review



PROJECT SUMMARY

Demonstration of Advanced Monitoring and Data Analytics of Power Transmission Lines

ORNL, LineVision, and Xcel Energy outfitted 3 transmission lines with advanced non-contact sensors (EMF and LiDAR) to monitor for 12 months and collect data from conductors to determine power market efficiencies gained from Dynamic Line Ratings (DLR) as well as planning efficiencies achieved from novel conductor health assessments.

PRINCIPAL INVESTIGATORS Dr. Zhi Li, R&D Staff Member, Oak Ridge National Lab Jonathan Marmillo, VP Product, LineVision Inc. Kristine Engel, Applications Engineer, LineVision Inc.

WEBSITE www.ornl.gov www.linevisioninc.com

The Numbers

DOE PROGRAM OFFICE: **OE** – Transformer Resilience and **Advanced Components (TRAC)**

FUNDING OPPORTUNITY: AOP

LOCATIONS: Minnesota, Wisconsin, Colorado

PROJECT TERM: 01/01/2021 to 06/30/2022 **PROJECT STATUS:**

Incomplete, **Ongoing**

AWARD AMOUNT (DOE CONTRIBUTION): \$500,000

AWARDEE CONTRIBUTION (COST SHARE): \$350,000 LineVision Subcontract

Executive Summary

- ORNL, Xcel Energy, and LineVision have been engaged in a project to demonstrate Dynamic Line Ratings (DLR) and Conductor Asset Health assessments with non-contact sensor technology.
- Sensors were installed on lines in MN, WI, and CO.
- Average DLR exceeded static reference ratings by 9–33% in winter months and 26– 36% in summer months at the monitored sites; Available on monitored lines over 85% of the time.
- The impact to Xcel Energy, and utilities in general, is more transmission capacity available today to integrate renewable energy via a cost-effective technology. Utilizing DLR will provide a significant increase in capacity and greater flexibility in operations,
- Ongoing analysis to evaluate the impacts of Dynamic Line Rating with power flow simulations on Xcel lines in MISO.
- Conductor Asset Health reports show that monitored conductors have not experienced significant annealing and not lost tensile strength, but identified sag discrepancies warranting investigation.



Innovation Update

Non-Contact LiDAR & EMF Sensor

Technologies



Patented Technology:

- > Electromagnetic Field (EMF) Power Flow Monitoring
- > LiDAR Conductor Position Monitoring



Scanning LiDAR:

- > Continuously measures conductor position
- > Full catenary shape determined and conductor sag & blowout calculated

Simplified Installations

- > No outages
- > No live-line work

Industry Best Accuracy & Analytics

> Data on all conductor phases

> Any tower, any voltage, any conductor

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> IEEE & CIGRE standards based

LineAware

Real-time field verified information and alerts on conductor motion allows operators and risk managers to protect asset health, system reliability and public safety.

Output:

- > Each phase conductor sag
- > Each phase conductor blowout
- > Line loading, current
- > Icing & galloping alerts
- > Anomalous motion alerts
- > Local ambient weather conditions



LineRate

Increases the transfer capacity on existing transmission lines with Dynamic Line Ratings.

Output:

- > Dynamic Line Rating
- > Conductor temperature
- > Forecasted line ratings, time-configurable
- > Emergency ratings (STE, LTE, Load–Dump)

FERC Order No. 881 Requires:

> Transmission providers implement ambient adjusted ratings on the transmission lines over which they provide transmission service that are impacted by air temperatures.



> RTOs and ISOs are required to implement the systems and procedures necessary to allow electronically updated transmission line ratings least hourly.

> FERC will continue to explore the implementation of Dynamic Line Ratings in a new docket AD22-5-000.

LineHealth

Create a conductor digital twin and prioritize the repair and replacement of lines that are most critical based on the module's estimation of remaining conductor life.

Inputs:

- > Historical SCADA
- > Historical weather data
- > Engineering design information
- > LineVision sensor measurements

Output:

- > Thermal aging analysis and loss of tensile strength from annealing
- > Projected conductor end of life
- > Conductor elongation damage evaluation: designed vs actual sag
- > Operating limit recharacterization
- > Rated breaking strength evaluation
- > Sag discrepancies
- > Galloping & icing event analysis



Conductor Sag (ft)

Dynamic Line Ratings - MN & WI



DLR to Static Line Rating Comparison

<u>Line</u>	<u>Winter Static</u> <u>Rating</u>	<u>Average Winter</u> Dynamic Rating	<u>% Increase</u>	<u>Summer Static</u> <u>Rating</u>	<u>Average</u> <u>Summer</u> Dynamic Rating	<u>% Increase</u>
0817/3303 RPO-GMT	1460	1594	9.2%	1076	1451	34.8%
3101 ASK-ECL*	2000	3661	83.0% *	1994	3358 Minim	68.4% *

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* Line 3101 ASK-ECL is clearance-limited by other spans along the line which are not monitored by LineVision.

Dynamic Line Ratings – CO



DLR-Static Rating Comparison

<u>Line</u>	<u>Winter Static</u> <u>Rating</u>	<u>Average</u> <u>Winter</u> <u>Dynamic</u> <u>Rating</u>	<u>% Increase</u>	<u>Summer</u> Static Rating	<u>Average</u> <u>Summer</u> Dynamic Rating	<u>% Increase</u>	
7109 DANI-MSST	3257	4081	25.3%	2868	3715	29.5%	
5115 DANI-SRDG	2086	2562	22.8%	1849	2338	26.4%	
5113 DANI-MSST	2112	2798	32.5%	1860	2536	36.3%	

Asset Health Comparison – Colorado

	Line 5113			Line	e 5115	Line 7109			
	Site 9b	Site 11b	Site 9b	Site 10	Site 10	Site 11b	Site 8	Site 9a	Site 11a
Maximum Conductor Temperature Calculated	223 F	215 F	111 F	108 F	107 F	109 F	107 F	114 F	114 F
Strength Reduction due to Thermal Annealing	0%	0%	_	0%	0%	_	0%	0%	0%
Sag Increase Observed - Design	0.0 ft (0.0%)	-2.1 ft(- 4.2%)	-0.5 ft(- 0.4%)	0.7 ft (2.0%)	-2.1 ft (- 6.1%)	0.2 ft (0.4%)	0.9 ft (5.5%)	4.8 ft (4.3%)	0.2 ft (0.6%)
Revised Projected Max Operating Temperature	212 F (no change)	212 F (no change)	212 F (no change)	184 F	212 F (no change)	207 F	188 F	142 F	207 F



Phase by Phase Sag Discrepancy Observed

Site 3 has a difference in absolute sags



Sag/Temp for SG 188 XCEL - Site 3 (V3) from January 26, 2021 to June 28, 2021

Left Phase -4.0 ft (-2.2%)

Middle Phase -7.8 ft (-4.3%)

Right Phase O ft (0.0%)

Max Sag Exceeds the Designed Value





Elevated Temperature Detected

Line 5113 conductor temperature has likely exceeded annealing



DLR and Xcel's Carbon Commitment

Xcel will take a multi-pronged approach to achieving its carbon commitments. Increased transmission capacity in the form of new transmission lines and optimization of existing lines will allow for increased renewable generation and dynamic use of existing assets.

- A National Renewable Energy Laboratory study found that to reach 80% renewable electricity in the United States, a 56%–105% increase in long-distance transmission capacity would be required[1]. Grid enhancing technologies can double the capacity on existing power lines right now.[2] New transmission is needed, but DLR can be strategically leveraged and make immediate impacts.
- In areas where moderate or strong winds are common, the use of a DLR monitoring system can increase the achieved power flow capacity of overhead conductors by 5–25% when compared to an SLR for 80–90% of the time (results vary across different lines and geographic regions)[3].



^[1] T. Mai, et al. Renewable electricity futures for the United States IEEE Trans. Sustain. Energy, 5 (2014), pp. 372-378 ^[2] T. Bruce Tsuchida, Stephanie Ross, and Adam Bigelow, The Brattle Group, "Unlocking the Queue With Grid-Enhancing Technologies," February 1, 2021. ^[3] Dynamic Line Rating Systems for Transmission Lines Topical Report (U.S. Department of Energy, April 25, 2014).





Acronyms

- **DLR = Dynamic Line Rating**
- SLR = Static Line Rating
- EMF = Electromagnetic Field
- LiDAR = Light Detection and Ranging
- MISO = Midcontinent Independent System Operator

THANK YOU



U.S. DEPARTMENT OF OFFICE OF ELECTRICITY

Field Data - Minnesota & Wisconsin

Line O817/33O3 RPO-RRK – DLR Heatmap

0	1648	1629	1587	1508	1547	1466	1336	1371	1468	1481	1499	1549
1	1660	1635	1604	1499	1548	1448	1328	1374	1464	1464	1490	1541
2	1657	1647	1609	1511	1519	1435	1330	1406	1425	1453	1483	1553
3	1658	1635	1627	1486	1510	1419	1322	1391	1427	1446	1508	1560
4	1679	1610	1621	1471	1525	1416	1323	1368	1450	1412	1506	1589
5	1689	1611	1637	1482	1544	1412	1296	1321	1454	1369	1489	1590
6	1648	1598	1665	1497	1563	1394	1271	1301	1440	1369	1497	1597
7	1609	1590	1648	1532	1559	1365	1236	1314	1395	1357	1528	1587
8	1594	1580	1631	1549	1562	1344	1237	1317	1380	1370	1549	1573
9	1572	1550	1613	1571	1555	1358	1241	1299	1373	1373	1554	1572
10	1542	1554	1579	1592	1556	1339	1227	1292	1351	1363	1562	1550
11	1517	1560	1555	1602	1561	1337	1242	1303	1338	1370	1522	1531
12	1584	1553	1545	1591	1587	1362	1264	1321	1332	1361	1524	1522
13	1583	1568	1559	1564	1589	1365	1284	1303	1350	1384	1516	1514
14	1539	1556	1577	1540	1592	1388	1317	1322	1364	1399	1539	1457
15	1541	1518	1556	1554	1593	1395	1352	1334	1373	1402	1535	1449
16	1593	1507	1554	1561	1568	1389	1358	1354	1365	1413	1528	1476
17	1634	1543	1583	1519	1551	1389	1366	1389	1351	1400	1485	1485
18	1653	1536	1597	1481	1503	1348	1342	1340	1394	1401	1464	1521
19	1679	1529	1631	1492	1478	1331	1331	1298	1404	1407	1475	1573
20	1721	1528	1638	1522	1503	1388	1336	1278	1410	1421	1464	1567
21	1712	1566	1630	1530	1502	1424	1340	1334	1436	1431	1478	1571
22	1654	1606	1605	1521	1509	1436	1343	1342	1451	1457	1501	1542
23	1647	1619	1586	1531	1531	1449	1347	1356	1450	1477	1512	1544
	January	ebruary	March	April	May	June	vlut	August	tember	October	vember	cember
		ιĹ.				Mo	nth		Sep	~	°Z	De

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Field Data – Colorado

Line 7109 – DLR Heatmap

Hour

с. L				Mo	onth	2000	Sept	0	Nov	Dec
bruary	March	April	May	hue	ylut	August	ember	tober	ember	ember
4253	4325	4103	4000	4000	4108	3889	3851	3919	4000	4211
4229	4326	3957	3854	3943	4016	3834	3770	3944	3967	4177
4115	4279	3797	3695	3840	3815	3681	3708	3981	3938	4188
4184	4205	3751	3633	3539	3553	3536	3515	3950	4001	4177
4135	4234	3746	3494	3379	3423	3481	3473	3852	3893	4144
3846	4165	3750	3544	3367	3405	3511	3538	3767	3789	4108
3915	4098	3719	3699	3374	3307	3418	3440	3791	3663	4024
4113	4011	3672	3723	3535	3142	3396	3424	3747	3627	3972
4236	3906	3705	3747	3558	3108	3311	3414	3728	3608	3987
4325	3836	3722	3850	3471	3258	3434	3340	3678	3539	3985
4364	3762	3780	3823	3380	3359	3422	3474	3514	3571	3845
3932	3684	3800	3566	3389	3334	3528	3520	3494	3530	3783
3751	3696	3801	3426	3416	3317	3483	3514	3404	3517	3836
4070	3731	3837	3378	3252	3223	3412	3452	3439	3551	4021
4106	3788	3866	3494	3116	3144	3287	3445	3619	3731	4128
3943	3991	3930	3605	3158	3121	3293	3546	3896	3937	4324
4153	4142	4070	3774	3521	3422	3564	3839	4023	4032	4511
4252	4125	4118	3797	3808	3673	3712	3866	4041	4050	4496
4211	4137	4122	3785	3855	3813	3740	3827	4015	4096	4431
4197	4177	4148	3766	3854	3937	3810	3860	3999	4073	4434
4228	4213	4217	3881	3932	4043	3830	3835	3975	3996	4314
4156	4223	4278	4045	3997	4105	3864	3865	3926	4019	4210
4086	4289	4245	4096	4017	4085	3810	3908	3910	4043	4156
4074	4305	4143	4080	3998	4097	3861	3916	3931	4060	4133
	4074 4086 4156 4228 4197 4211 4252 4153 3943 4106 4070 3751 3932 4364 4364 4325 4236 4113 3915 3846 4113 3915 3846 4113 3915 3846 4113	407443054086428941564223422842134197417742114137425241254153414239433991410637884070373137513696393236844364376243253836423639064113401139154098384641654135423441844205411542794229432642534325	407443054143408642894245415642234278422842134217419741774148421141374122425241254118415341424070394339913930410637883866407037313837375136963801393236843800436437623780432538363722423639063705411340113672391540983719384641653750413542343746418442053751411542793797422943263957425343254103	40744305414340804086428942454096415642234278404542284213421738814197417741483766421141374122378542524125411837974153414240703774394339913930360541063788386634944070373138373378375136963801342639323684380035664364376237803823432538363722385042363906370537474113401136723723391540983719369938464165375035444135423437463494411542793797369542294326395738544253432541034000YungYungYungYung	4074 4305 4143 4080 3998 4096 4289 4245 4096 4017 4156 4223 4278 4045 3997 4228 4213 4217 3881 3932 4197 4177 4148 3766 3854 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4070 3774 3521 3422 3564 3943 3991 3930 3605 3158 3121 3293 4106 3788 3866 3494 3116 3144 3287 3932 3684 3800 3556 3389 3334 3528 3932 3684 3800 3566 3389 3334 3528 4364 3762 3780 3823 3380 3359<td>4074 4305 4143 4080 3998 4097 3861 3916 4086 4289 4245 4096 4017 4085 3810 3908 4156 4223 4278 4045 3997 4105 3864 3865 4228 4213 4217 3818 3932 4043 3830 3855 4197 4177 4148 3766 3854 3937 3810 3860 4211 4137 4122 3785 3855 3813 3740 3827 4252 4125 4118 3797 3808 3673 3712 3866 4153 4142 4070 3774 3521 3422 3546 3839 4106 3788 3866 3494 3116 3144 3287 3445 4070 3731 3837 3378 3252 3223 3412 3422 3932 3684 3800 3366 3317 3483 3514 3932 3684 3762 3780<!--</td--><td>4074 4305 4143 4080 3998 4097 3861 3916 3931 4086 4289 4245 4096 4017 4085 3810 3908 3910 4156 4223 4278 4045 3997 4105 3864 3865 3926 4228 4213 4217 3811 3992 4043 3830 3865 3926 4197 4177 4148 3766 3854 3937 3810 3860 3999 4211 4137 4122 3785 3855 3813 3740 3827 4015 4252 4118 3777 3886 3675 3712 3866 3996 4106 3788 3866 3494 3116 3144 2287 3445 3619 4106 3788 3866 3494 3116 3317 3483 3514 3404 3932 3686 3801 3426 3316 3327 3445 3619 4106 3788 3866 3292<</td><td>4074 4305 4143 4080 3998 4097 3861 3916 3931 4060 4086 4289 4245 4096 4017 4085 3810 3908 3910 4043 4156 4223 4278 4045 3992 4043 3830 3835 3975 3996 4128 4213 4217 3881 3932 4043 3830 3835 3975 3996 4197 4177 4148 3766 3854 3937 3810 3860 3999 4073 4221 4137 4122 3785 3855 3813 3740 3827 4015 4096 4133 4142 4070 3774 3521 3422 3564 3899 4023 4032 4166 3788 3866 3494 3116 3144 3227 3445 3519 3731 4006 3788 3806 3894 3150 3171 3483 3514 3404 3517 3932 3664 3801</td></td></td>	4074 4305 4143 4080 3998 4097 3861 4086 4289 4245 4096 4017 4085 3810 4156 4223 4278 4045 3997 4105 3864 4228 4213 4217 3881 3932 4043 3830 4197 4177 4148 3766 3854 3937 3810 4211 4137 4122 4153 3937 3810 3740 4252 4125 4118 3797 3808 3673 3712 4153 4142 4070 3774 3521 3422 3564 3943 3991 3930 3605 3158 3121 3293 4106 3788 3866 3494 3116 3144 3287 3932 3684 3800 3556 3389 3334 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3292<</td><td>4074 4305 4143 4080 3998 4097 3861 3916 3931 4060 4086 4289 4245 4096 4017 4085 3810 3908 3910 4043 4156 4223 4278 4045 3992 4043 3830 3835 3975 3996 4128 4213 4217 3881 3932 4043 3830 3835 3975 3996 4197 4177 4148 3766 3854 3937 3810 3860 3999 4073 4221 4137 4122 3785 3855 3813 3740 3827 4015 4096 4133 4142 4070 3774 3521 3422 3564 3899 4023 4032 4166 3788 3866 3494 3116 3144 3227 3445 3519 3731 4006 3788 3806 3894 3150 3171 3483 3514 3404 3517 3932 3664 3801</td></td>	4074 4305 4143 4080 3998 4097 3861 3916 4086 4289 4245 4096 4017 4085 3810 3908 4156 4223 4278 4045 3997 4105 3864 3865 4228 4213 4217 3818 3932 4043 3830 3855 4197 4177 4148 3766 3854 3937 3810 3860 4211 4137 4122 3785 3855 3813 3740 3827 4252 4125 4118 3797 3808 3673 3712 3866 4153 4142 4070 3774 3521 3422 3546 3839 4106 3788 3866 3494 3116 3144 3287 3445 4070 3731 3837 3378 3252 3223 3412 3422 3932 3684 3800 3366 3317 3483 3514 3932 3684 3762 3780 </td <td>4074 4305 4143 4080 3998 4097 3861 3916 3931 4086 4289 4245 4096 4017 4085 3810 3908 3910 4156 4223 4278 4045 3997 4105 3864 3865 3926 4228 4213 4217 3811 3992 4043 3830 3865 3926 4197 4177 4148 3766 3854 3937 3810 3860 3999 4211 4137 4122 3785 3855 3813 3740 3827 4015 4252 4118 3777 3886 3675 3712 3866 3996 4106 3788 3866 3494 3116 3144 2287 3445 3619 4106 3788 3866 3494 3116 3317 3483 3514 3404 3932 3686 3801 3426 3316 3327 3445 3619 4106 3788 3866 3292<</td> <td>4074 4305 4143 4080 3998 4097 3861 3916 3931 4060 4086 4289 4245 4096 4017 4085 3810 3908 3910 4043 4156 4223 4278 4045 3992 4043 3830 3835 3975 3996 4128 4213 4217 3881 3932 4043 3830 3835 3975 3996 4197 4177 4148 3766 3854 3937 3810 3860 3999 4073 4221 4137 4122 3785 3855 3813 3740 3827 4015 4096 4133 4142 4070 3774 3521 3422 3564 3899 4023 4032 4166 3788 3866 3494 3116 3144 3227 3445 3519 3731 4006 3788 3806 3894 3150 3171 3483 3514 3404 3517 3932 3664 3801</td>	4074 4305 4143 4080 3998 4097 3861 3916 3931 4086 4289 4245 4096 4017 4085 3810 3908 3910 4156 4223 4278 4045 3997 4105 3864 3865 3926 4228 4213 4217 3811 3992 4043 3830 3865 3926 4197 4177 4148 3766 3854 3937 3810 3860 3999 4211 4137 4122 3785 3855 3813 3740 3827 4015 4252 4118 3777 3886 3675 3712 3866 3996 4106 3788 3866 3494 3116 3144 2287 3445 3619 4106 3788 3866 3494 3116 3317 3483 3514 3404 3932 3686 3801 3426 3316 3327 3445 3619 4106 3788 3866 3292<	4074 4305 4143 4080 3998 4097 3861 3916 3931 4060 4086 4289 4245 4096 4017 4085 3810 3908 3910 4043 4156 4223 4278 4045 3992 4043 3830 3835 3975 3996 4128 4213 4217 3881 3932 4043 3830 3835 3975 3996 4197 4177 4148 3766 3854 3937 3810 3860 3999 4073 4221 4137 4122 3785 3855 3813 3740 3827 4015 4096 4133 4142 4070 3774 3521 3422 3564 3899 4023 4032 4166 3788 3866 3494 3116 3144 3227 3445 3519 3731 4006 3788 3806 3894 3150 3171 3483 3514 3404 3517 3932 3664 3801

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Field Data – Minnesota & Wisconsin

		Line 3101						
	Site 1a	Site 1b	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Maximum Conductor Temperature Calculated	166F	162F	164 F	147 F	163 F	164 F	170 F	170 F
Strength Reduction due to Thermal Annealing	0%	0%	0%	_	0%	0%	0%	0%
Sag Increase Observed – Design	1.8 ft (2.8%)	-1.1 ft (- 2.5%)	0.2 ft (1.3%)	0.0 ft (0.0%)	-0.4 ft (- 3.4%)	0.9 ft (6.6%)	2.3 ft (1.3%)	-1.6 ft (- 2.4%)
Revised Projected Max Operating Temperature	149 F	198 F (no change)	185 F (from 198 F)	212 F (no change)	212 F (no change)	159 F	184 F	212 F (no change)