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An Analysis on the Economic Impacts of Dynamic Line Ratings on a Congested Transmission Line in Southwest Power Pool

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SUMMARY

In December 20, 2017, LineVision, Southwest Power Pool (SPP) and American Electric Power (AEP) entered into a Three-Party Research Agreement and Non-Disclosure Agreement to work together on a transmission line monitoring and dynamic line rating (DLR) project to study the possible economic, operational, and reliability improvements that DLR technologies offer. The primary question to be addressed was how much financial benefit might DLR provide if it were able to impart a reduction on system congestion. On February 1st, 2018 a LineVision V2 transmission line monitoring and dynamic line rating system was installed under the 161kV Siloam Springs - Siloam Springs City transmission line in AEP's Arkansas service territory. On three separate days in March 2018, the monitored transmission line experienced congestion in the real-time market and was binding and/or breached for multiple intervals totaling 300 minutes. During these times, the LineVision monitoring system was computing the transmission line's true transfer capacity as determined by DLR, which was above the line's static operating limit during all of these times. SPP performed an economic study and ran a duplicate instance of their five-minute market (Real Time Balancing Market) using the DLR values to determine what the financial impact would have been if the DLR had been used in lieu of the line's static rating. The results showed that the market savings from the reduction in congestion could have been up to $18,000 during this period.

KEYWORDS

Dynamic Line Ratings, DLR, EMF, Transmission Line Monitoring, Congestion, Market Efficiency

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1. Introduction

On December 20, 2017, LineVision, Southwest Power Pool (SPP) and American Electric Power (AEP) entered into a Three-Party Research Agreement and Non-Disclosure Agreement to jointly work together on a transmission line monitoring and dynamic line rating (DLR) project for a period of approximately one year. SPP, as the project sponsor, was interested in learning about the possible economic, operational, and reliability improvements that dynamic line rating technologies can provide and AEP supported the project with permitted DLR monitoring of a transmission line within their Southwestern Electric Power Company (SWEPCO) service territory along with technical and field engineering resources.

On February 1, 2018, LineVision and AEP field service technicians met at the installation site and the team installed a LineVision V2 non-contact transmission line monitoring and dynamic line rating system. This ground-based equipment utilizes electromagnetic field (EMF) sensors to measure and determine various conductor parameters that include:

1. Circuit current (amps)
2. Conductor sag and vertical clearance from ground
3. Average conductor temperature for the monitored stringing section
4. Ambient temperature at the monitored site
5. Dynamic (Thermal) Line Rating - Normal (or steady-state) rating

These parameters, as determined by the monitoring system during the study period of March 3rd to March 14th, 2018, are shown below in Figures 3, 4 and 5.

The system consisted of three electromagnetic field (EMF) monitors, two of which were installed near the mid span of the target line and one adjacent to the eastern tower structure. The monitors utilize NEMA 4x enclosures mounted on top of galvanized steel pipes and sit approximately five feet above ground level. The steel posts were secured into the ground by mixing a concrete footing with a depth of approximately two feet. Each monitor is battery powered, continually recharged by a photovoltaic panel and transmits EMF data to LineVision via a secure cellular connection.

The monitors measure the amplitude-component of the magnetic field emitted by the transmission line to determine the amount of power flowing on the line. The vector-component of the magnetic field is also measured and analyzed to determine the conductor's position and thus its sag/clearance. Based upon the sag exhibited by the conductor, its temperature is calculated. The system considers the ambient weather conditions along with additional variables in IEEE Standard 738-2012, the Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors [1], to ultimately determine the DLR. The scientific methodologies used have been described in further details in a previous CIGRE publication [2].

2. Installation Site

The target line was an ideal site for a DLR analysis as the entire transmission line was encompassed by a short 2.1 mile section. Given that the transmission line was only a single stringing section, a full path-rating was able to be provided by one monitoring system.

Line Name: Siloam Springs - Siloam Springs City
Location: Siloam Springs, AR, see Figure 1.
Total Length: 2.1 Miles, see Figure 2.
Conductor Type: 2-Conductor Bundled 397.5 ACSR Ibis
Voltage Level: 161kV
Installation Site: Between Structures 10 and 11

Figure 1: Installation location in northwest Arkansas, USA.

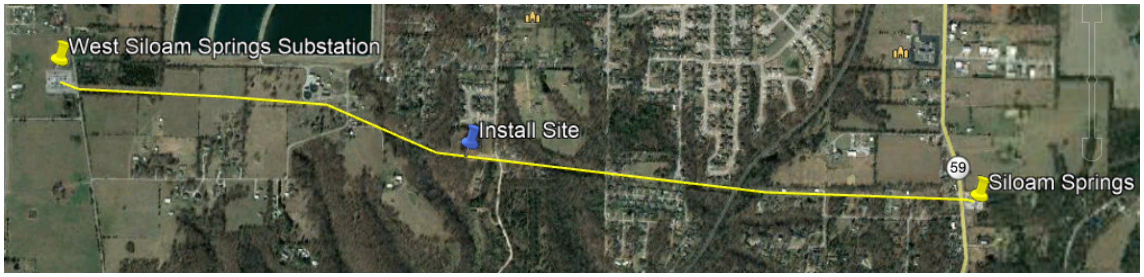

Figure 2: Overview of the Target Line and Installation Site

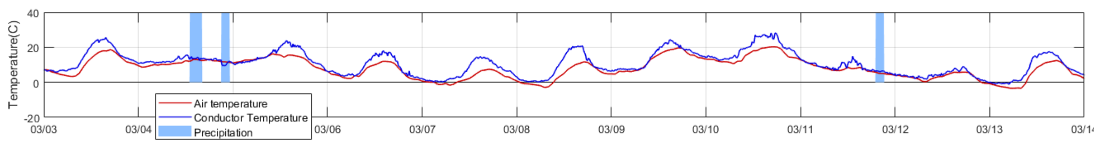

Figure 3: Conductor temperature plotted during the DLR study period with ambient temperature and periods of precipitation

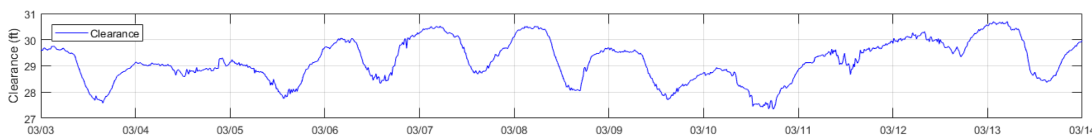

Figure 4: Conductor clearance / sag plotted during the DLR study period

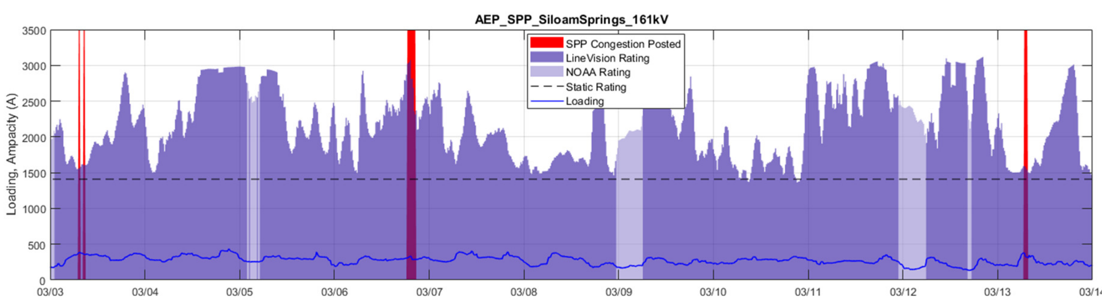

Figure 5: DLR plotted during the study period along with the analyzed times of market congestion shown with red highlights. Note that during all periods of congestion the DLR was above the static rating for the target line.

3. Economic Analysis

An economic analysis was performed to determine the impact of DLR had it been applied in the SPP market on the Siloam Springs – Siloam Springs City 161kV transmission during known congested periods. This line is the monitored element of an existing SPP contingency / monitored flowgate pair.

SPP market data [3] indicates the transmission line was binding and/or breached throughout three intervals of time on the days of March 3, March 6, and March 13, 2018, as shown in Tables 1 through 3. Dynamic line rating data was also captured by the LineVision DLR sensors and is shown in the tables below along with the shadow price. The DLR was well above the static rating and the effective limit used by the market for all instances of the binding/breached state.

Date	Conductor Normal DLR (amps)	State	Shadow Price	Monitored Facility
03/03/2018 07:15	1871.51	BREACHED	-1466.258	LN SILOAM - SILSPRNG
03/03/2018 07:20	1917.57	BREACHED	-897.362	LN SILOAM - SILSPRNG
03/03/2018 07:25	1917.57	BREACHED	-966.61	LN SILOAM - SILSPRNG
03/03/2018 07:30	1917.57	BREACHED	-747.696	LN SILOAM - SILSPRNG
03/03/2018 07:35	1917.57	BREACHED	-656.207	LN SILOAM - SILSPRNG
03/03/2018 07:40	1883.37	BINDING	-90.434	LN SILOAM - SILSPRNG
03/03/2018 07:45	1883.37	BINDING	-95.119	LN SILOAM - SILSPRNG
03/03/2018 08:10	2337.04	BINDING	-53.205	LN SILOAM - SILSPRNG
03/03/2018 08:15	2055.50	BINDING	-92.581	LN SILOAM - SILSPRNG
03/03/2018 08:30	2000.44	BINDING	-312.799	LN SILOAM - SILSPRNG
03/03/2018 08:35	2000.44	BINDING	-501.198	LN SILOAM - SILSPRNG
03/03/2018 08:40	2076.37	BINDING	-55.802	LN SILOAM - SILSPRNG
03/03/2018 08:45	2076.37	BINDING	-282.5	LN SILOAM - SILSPRNG
03/03/2018 08:50	2076.37	BINDING	-38.773	LN SILOAM - SILSPRNG
03/03/2018 09:00	1989.11	BINDING	-4.819	LN SILOAM - SILSPRNG
03/03/2018 09:00	1989.11	BINDING	-4.819	LN SILOAM - SILSPRNG
03/03/2018 11:00	2249.06	BINDING	-191.165	LN SILOAM - SILSPRNG

Table 1: Real-time market congestion on the target line on March 3, 2018, lasting for 85 minutes.

Date	Conductor Normal DLR (amps)	State	Shadow Price	Monitored Facility
03/06/2018 18:25	2320.37	BREACHED	-724.46	LN SILOAM - SILSPRNG
03/06/2018 18:30	2281.82	BREACHED	-746.777	LN SILOAM - SILSPRNG
03/06/2018 18:35	2281.82	BREACHED	-1199.162	LN SILOAM - SILSPRNG
03/06/2018 18:40	2281.82	BREACHED	-1403.069	LN SILOAM - SILSPRNG
03/06/2018 18:45	2514.76	BREACHED	-1275.102	LN SILOAM - SILSPRNG
03/06/2018 18:50	2514.76	BREACHED	-1398.183	LN SILOAM - SILSPRNG
03/06/2018 18:55	2514.76	BREACHED	-1497.638	LN SILOAM - SILSPRNG
03/06/2018 19:00	3124.43	BREACHED	-1486.633	LN SILOAM - SILSPRNG
03/06/2018 19:05	3124.43	BREACHED	-1378.38	LN SILOAM - SILSPRNG
03/06/2018 19:10	3124.43	BREACHED	-1499.175	LN SILOAM - SILSPRNG
03/06/2018 19:15	2328.72	BREACHED	-1212.996	LN SILOAM - SILSPRNG
03/06/2018 19:20	2328.72	BREACHED	-1497.48	LN SILOAM - SILSPRNG
03/06/2018 19:25	2328.72	BREACHED	-1452.112	LN SILOAM - SILSPRNG
03/06/2018 19:30	2736.45	BREACHED	-1416.502	LN SILOAM - SILSPRNG
03/06/2018 19:35	2736.45	BREACHED	-1492.9	LN SILOAM - SILSPRNG
03/06/2018 19:40	2736.45	BREACHED	-1222.028	LN SILOAM - SILSPRNG
03/06/2018 19:45	2578.59	BREACHED	-1462.454	LN SILOAM - SILSPRNG
03/06/2018 19:50	2578.59	BREACHED	-1493.69	LN SILOAM - SILSPRNG
03/06/2018 19:55	2578.59	BREACHED	-1243.732	LN SILOAM - SILSPRNG
03/06/2018 20:00	2271.90	BREACHED	-1245.742	LN SILOAM - SILSPRNG
03/06/2018 20:05	2271.90	BREACHED	-1131.03	LN SILOAM - SILSPRNG
03/06/2018 20:10	2271.90	BREACHED	-1408.96	LN SILOAM - SILSPRNG
03/06/2018 20:15	2860.70	BREACHED	-1240.677	LN SILOAM - SILSPRNG
03/06/2018 20:20	2860.70	BREACHED	-898.997	LN SILOAM - SILSPRNG
03/06/2018 20:25	2860.70	BREACHED	-998.562	LN SILOAM - SILSPRNG
03/06/2018 20:30	2411.16	BINDING	-112.166	LN SILOAM - SILSPRNG
03/06/2018 20:35	2411.16	BINDING	-268.716	LN SILOAM - SILSPRNG
03/06/2018 20:40	2411.16	BINDING	-18.51	LN SILOAM - SILSPRNG
03/06/2018 20:45	3199.14	BINDING	-73.22	LN SILOAM - SILSPRNG
03/06/2018 20:55	3199.14	BINDING	-193.414	LN SILOAM - SILSPRNG

Table 2: Real-time market congestion on the target line on March 6, 2018, lasting for 155 minutes.

Date	Conductor Normal DLR (amps)	State	Shadow Price	Monitored Facility
03/13/2018 06:45	1995.21	BREACHED	-1414.058	LN SILOAM - SILSPRNG
03/13/2018 06:50	1995.21	BREACHED	-1444.55	LN SILOAM - SILSPRNG
03/13/2018 06:55	1995.21	BREACHED	-1343.793	LN SILOAM - SILSPRNG
03/13/2018 07:00	2070.12	BREACHED	-1374.562	LN SILOAM - SILSPRNG
03/13/2018 07:05	2070.12	BREACHED	-739.856	LN SILOAM - SILSPRNG
03/13/2018 07:10	2070.12	BINDING	-512.574	LN SILOAM - SILSPRNG
03/13/2018 07:15	2111.07	BINDING	-496.192	LN SILOAM - SILSPRNG
03/13/2018 07:20	2111.07	BINDING	-499.219	LN SILOAM - SILSPRNG
03/13/2018 07:25	2111.07	BINDING	-349.723	LN SILOAM - SILSPRNG
03/13/2018 07:30	2047.28	BINDING	-464.476	LN SILOAM - SILSPRNG
03/13/2018 07:35	2047.28	BINDING	-270.666	LN SILOAM - SILSPRNG
03/13/2018 07:40	2047.28	BINDING	-375.969	LN SILOAM - SILSPRNG

Table 3: Real-time market congestion on the target line on March 13, 2018 lasting for 60 minutes

To determine the economic benefit, the five-minute market (RTBM) was duplicated using the dynamic line ratings data in lieu of the market effective rating used during the indicated intervals. A comparison was then made of the original market rating vs dynamic case total operating cost using Equation 1. The variables due to DLR are shown as Incremental Energy and Ancillary Service Costs.

Equation (1): RTBM Operating Cost Calculation

RTBM Operating Cost = (Startup Cost) + (No Load Cost) + (Incremental Energy Cost) + (Ancillary Service Cost) + (Transaction Costs)

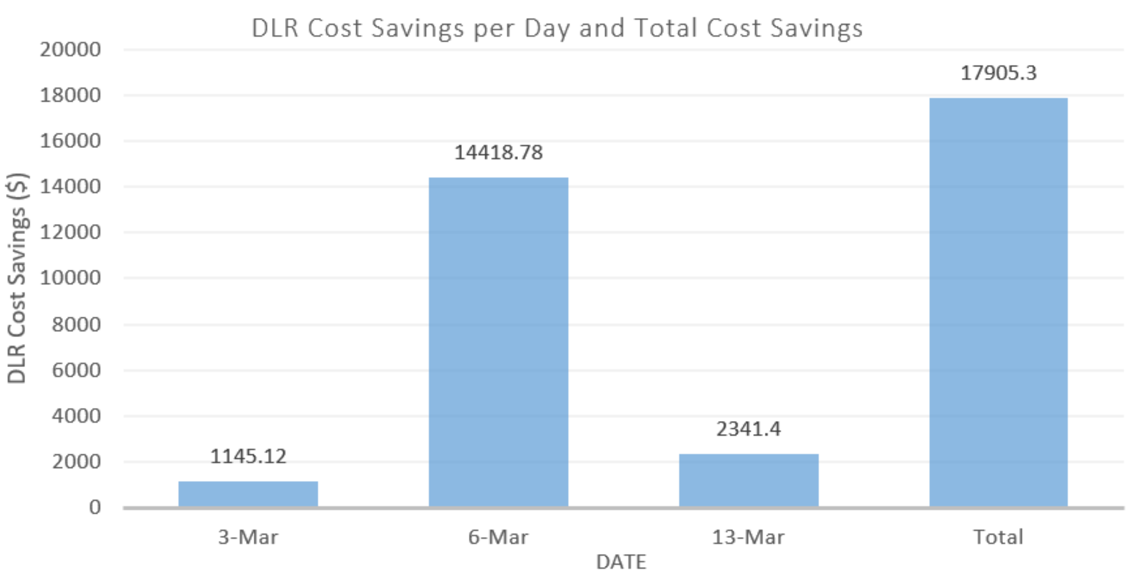

Figure 6: DLR Cost Savings per Day and Total Cost Savings

4. Conclusion

The results in Figure 6 show that the savings due to DLR could have been up to $18,000 over the intervals totaling 300 minutes as shown in Tables 1 through 3. It should be noted that the savings calculation only took the five-minute RTBM market savings into account and does not include cost savings that would have likely occurred from re-running the day-ahead market's unit commitment and various intra-day reliability unit commitment studies. Had DLR been used, a different unit commitment would have been expected to result in more substantial savings

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[3] Southwest Power Pool Real-Time Balancing Market Binding Constraint Historical Information. https://marketplace.spp.org/pages/rtbm-binding-constraints#%2F2018%2F03