Winter Storm Elliott Peak Study

9/26/2023

A study simulating the conditions experienced during Winter Storm Elliott in December 2022 has been performed by EKPC's Transmission Planning department. In particular, a model of the peak hour that occurred on 12/23/2023 at hour-ending 18:00 EST was developed.

The starting-point model was the 2022/23 winter peak-load model that was developed by EKPC as part of the annual base-case development process in 2022. The actual loads on EKPC's system (see Table 1 below) and generation for EKPC and LGE&KU at the peak of the storm (17:00-18:00 on 12/23/2022) were uploaded into the model. EKPC's total system load in this model for this peak hour is 3,667 MW. Actual transmission-facility outages that were occurring on the EKPC system at that time were included in the model (see Table 2 below) to re-create real-time conditions. Due to the lack of actual load and complete generation information for surrounding utilities, "virtual" generators were placed at various tie buses with set voltages in order to match real-time voltage average values at these tie buses and flows across tie lines as closely as possible across the system. Once this base model that closely approximates actual Winter Storm Elliott conditions ("WSE model") was developed, the virtual generators at the tie buses were locked at their real and reactive power output levels in preparation for performing contingency analysis on the model.

Contingency analysis was performed on the WSE model without any additional generation outages simulated, as well as a scenario where only the Cooper 1 and 2 units were simulated offline, and another scenario where only the LG&E/KU Brown 3 unit was simulated offline. Additional analysis determined that approximately 279MW's of load shed would have been required on EKPC's system during the Cooper 1&2 generation-outage dispatch scenario, 117MW's during the Brown 3 generation-outage dispatch scenario, and 102MW's during the no generation-outage dispatch scenario, in order to achieve contingency voltage levels above 0.92pu, and to alleviate thermal overloads identified during the contingency analysis (see Table 12 below).

Many industrial customers' real time loads were much lower than expected due to the timing of the storm on the Christmas holiday weekend. Therefore, additional studies were performed with the industrial loads connected to the EKPC system at their forecasted extreme winter-peak levels (1-in-10 probability forecast) to identify potential system issues if the storm had occurred on a different day. The total load on the EKPC system increased by 267MW's due to returning industrial customers to forecasted 90/10 loading. With this added load, the total EKPC system load increased to 3,934 MW.

The heat maps below were created using the data from all of the studies to provide an insight to the areas of EKPC's transmission system where potential issues were identified.

Table 1. EKPC System Modeled Load

Load Type	Total MW's
EKPC Native	3256
EKPC on KU	411
KU on EKPC	99
Industrial Increase	267

Table 2. Transmission-Facility Outages

Outage Type	Outage
Planned	Goddard-Oak Ridge 69kV
Planned	Magnolia-Summersville 69kV
Planned	Booneville T-Beattyville Junction 69kV
Planned	Munk Junction-Oakley Noel 69kV
Planned	Glendale-Stephensburg 69kV
Planned	Peytons Store-KU Liberty 69kV
Planned	Keavy #2 Junction-South Corbin 69kV
Planned	Penn capacitor bank 69kV
Unplanned	Munk capacitor bank 69kV
Open for mitigation/relief	Thelma-Jenny Wiley Tap 69kV
Open for mitigation/relief	Somerset KU-Ferguson South tie 69kV

Exhibit 1. No Generation-Outage Dispatch

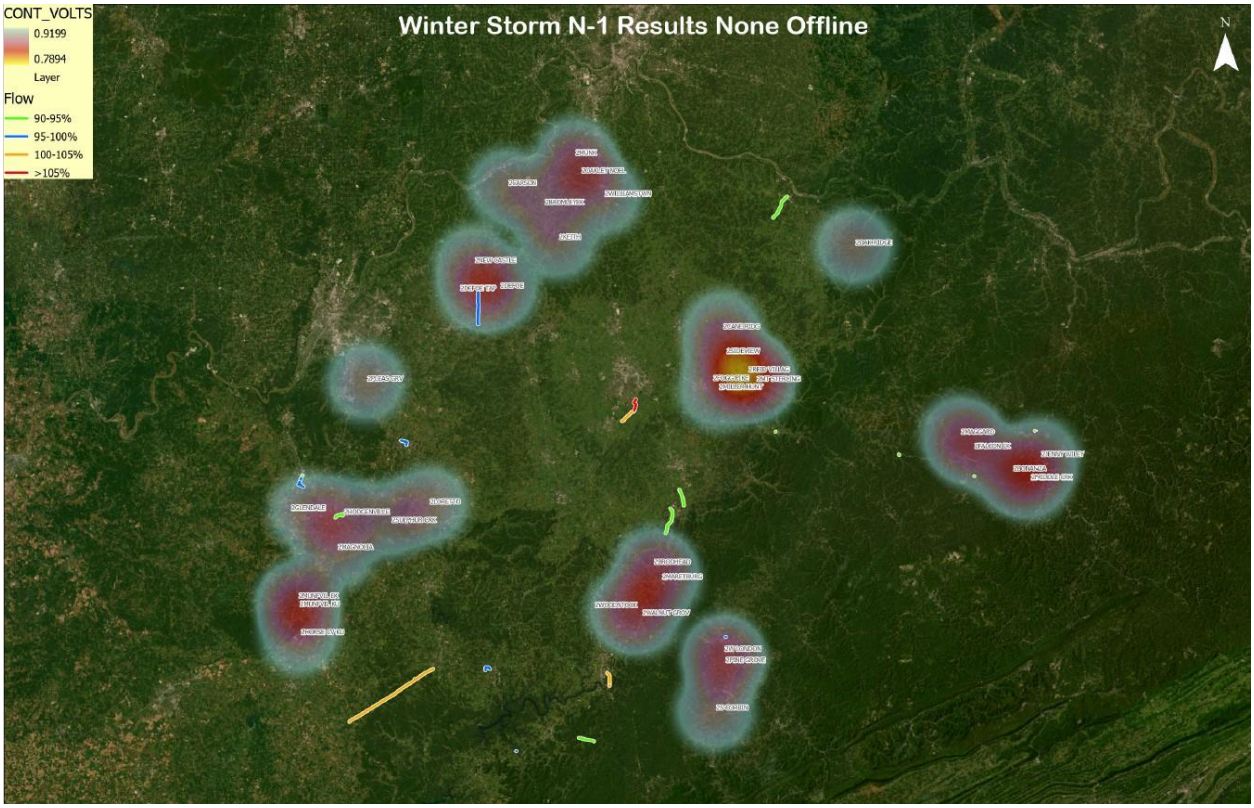

Exhibit 2. No Generation-Outage Dispatch-Industrial Loads at Forecasted Level

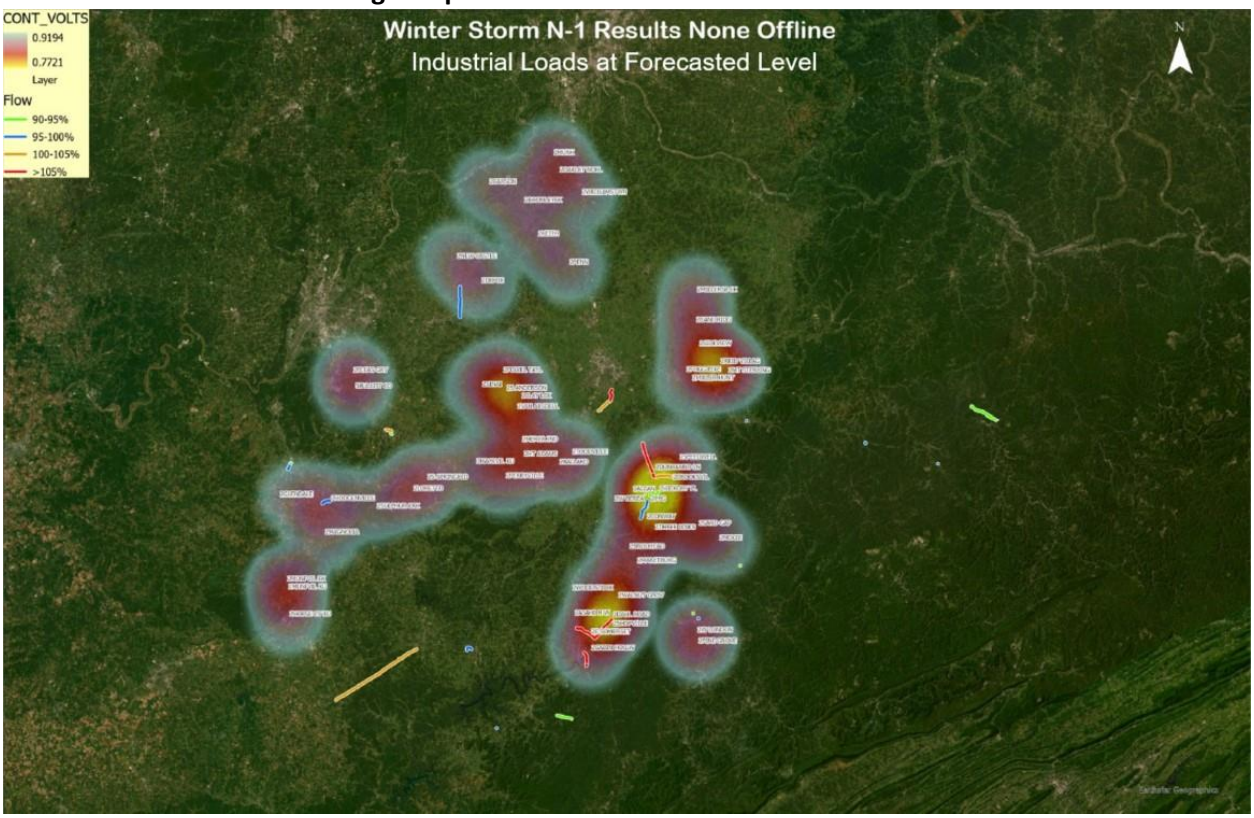

Table 3. No Generation-Outage Dispatch Thermal Overloads:

Lines above 100% of thermal rating	Critical Contingency	Overload %
Fayette-Davis 69kV	Baker Lane-KU Baker Lane 138kV	108.34
AEP Thelma-Thelma 69kV	AEP Dewey-Thelma 138kV	104.04
Cooper transformer 161/69kV	Russel Co-Russel Co Jct 161kV	103.38
Davis-Nicholasville 69kV	Baker Lane-KU Baker Lane 138kV	103.29
Cooper-Somerset 2/1 69kV	Cooper-Somerset 1/2 69kV	102.46
Summer Shade-West Columbia Tap 69kV	Cooper-Russel-Wolf Creek 161kV	100.19

Table 4. No Generation-Outage Dispatch-Industrial Loads at Forecasted Level Thermal Overloads:

Lines above 100% of thermal rating with forecasted load increases	Critical Contingency	Overload %
Fawkes-Duncannon Lane Tap 69kV	Fawkes-West Berea 138kV	119.10
Cooper-Somerset 2/1 69kV	Cooper-Somerset 1/2 69kV	113.26
Cooper transformer 161/69kV	Russel Co-Russel Co Jct 161kV	110.86
AEP Thelma-Thelma 69kV	AEP Dewey-Thelma 138kV	108.79
Fayette-Davis 69kV	Baker Lane-KU Baker Lane 138kV	108.32
Norwood Tap-Shopville 69kV	Brodhead-Three Links Jct 69kV	107.84
Duncannon Lane Tap-Crooksville Tap 69kV	West Berea 69/138kV transformer	107.65
Bardstown Industrial Tap-East Bardstown 69kV	Bullitt Co 69/161kV transformer	103.33
Davis-Nicholasville 69kV	Baker Lane-KU Baker Lane 138kV	103.23
Summer Shade-West Columbia Tap 69kV	Cooper-Russel-Wolf Creek 161kV	102.79
Crooksville Tap-Hickory Plains 69kV	West Berea 69/138kV transformer	102.05

Table 5. No Generation-Outage Dispatch Worst Contingency Voltages:

Bus	Outage	Contingency Voltage	Contingency Voltage With Industrial Load at Forecasted Value
Bromley	Owen Co Jct 1-Bromley EK SS 69kV	0.7894	0.7846
Glendale	Etown KU-Etown 4 69kV	0.8519	0.8435
Keith	Owen County 138/69kV transformer	0.8593	0.8530
Oakley Noel	Gallatin Co-Ghent 138kV	0.8885	0.8860
Brodhead	Brodhead-Three Links Junction 69kV	0.8902	0.8153
Mt Sterling	Hunt-Miller Hunt Tap 69kV	0.8972	0.8897
Shopville	Norwood Tap-Shopville 69kV	1.0038	0.7721
Alcan	Fawkes-West Berea 138kV	0.9748	0.8644

Exhibit 3. Cooper 1&2 Generation-Outage Dispatch

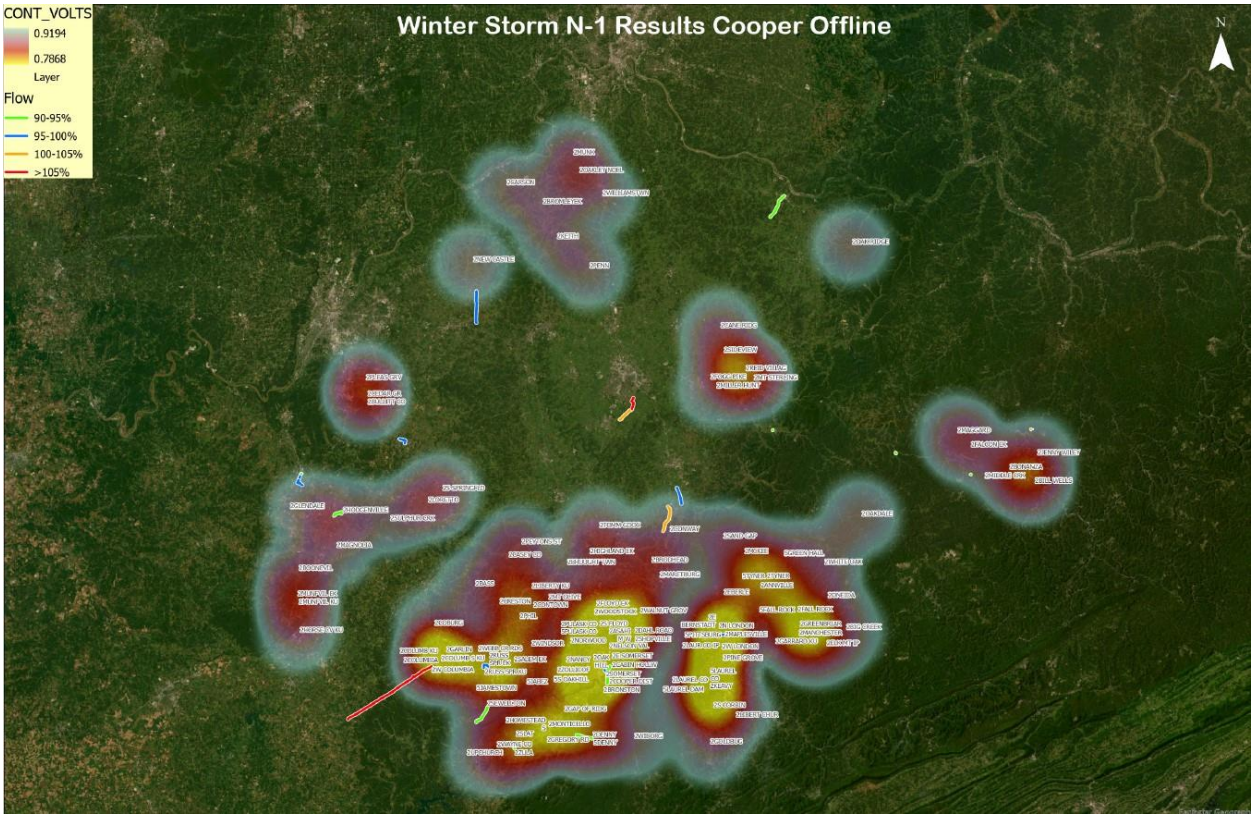

Exhibit 4. Cooper 1&2 Generation-Outage Dispatch-Industrial Loads at Forecasted Level

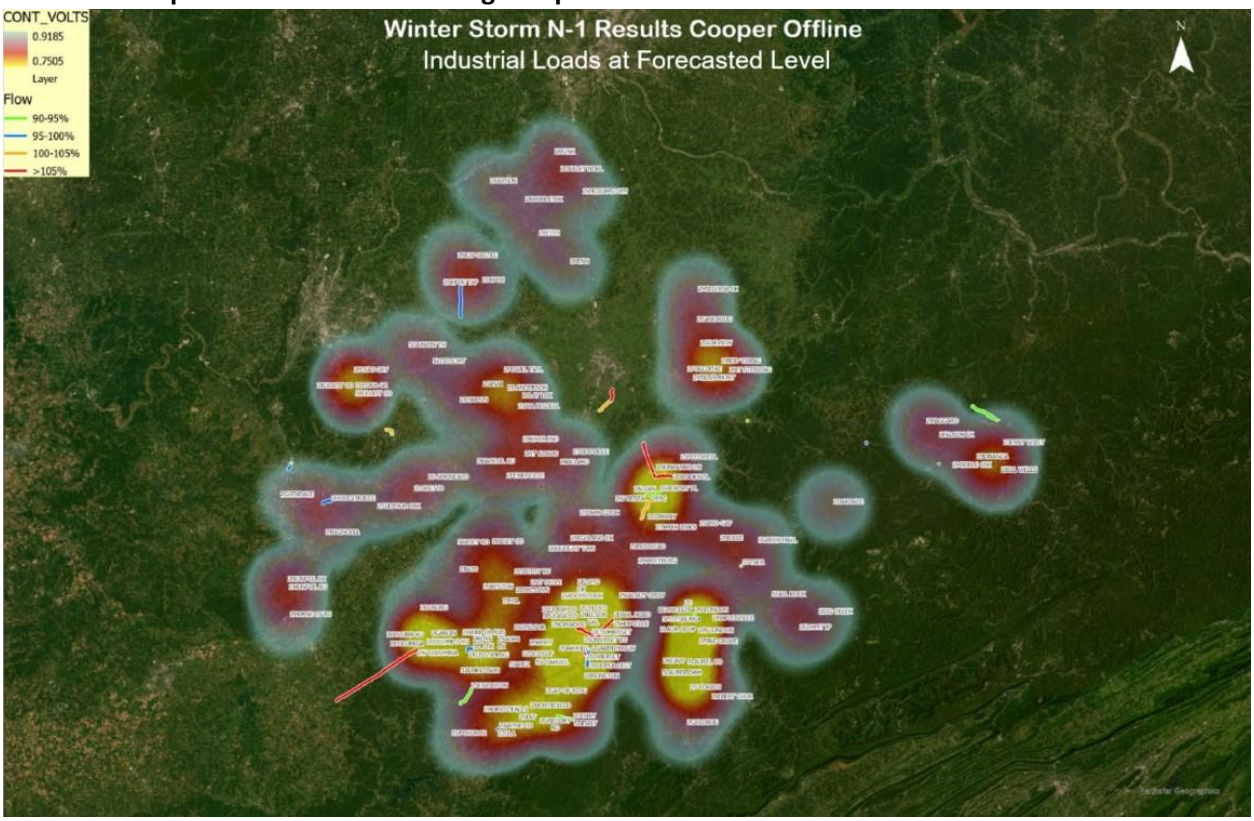

Table 6. Cooper 1&2 Generation-Outage Dispatch Thermal Overloads:

Lines above 100% of thermal rating	Critical Contingency	Overload %
Summer Shade-West Columbia Tap 69kV	Cooper-Russel-Wolf Creek 161kV	109.38
Fayette-Davis 69kV	Baker Lane-KU Baker Lane 138kV	108.32
AEP Thelma-Thelma 69kV	AEP Dewey-Thelma 138kV	104.53
Davis-Nicholasville 69kV	Baker Lane-KU Baker Lane 138kV	103.22

Table 7. Cooper 1&2 Generation-Outage Dispatch-Industrial Loads at Forecasted Level Thermal Overloads:

Lines above 100% of thermal rating with forecasted load increases	Critical Contingency	Overload %
Fawkes-Duncannon Lane Tap 69kV	Fawkes-West Berea 138kV	122.81
Summer Shade-West Columbia Tap 69kV	Cooper-Russel-Wolf Creek 161kV	110.31
Norwood Tap-Shopville 69kV	Brodhead-Three Links Jct 69kV	110.23
Duncannon Lane Tap-Crooksville Tap 69kV	West Berea 69/138kV transformer	110.13
AEP Thelma-Thelma 69kV	AEP Dewey-Thelma 138kV	109.30
Fayette-Davis 69kV	Baker Lane-KU Baker Lane 138kV	108.30
Cooper-Somerset 2/1 69kV	Cooper-Somerset 1/2 69kV	105.26
Crooksville Tap-Hickory Plains 69kV	West Berea 69/138kV transformer	105.12
Bardstown Industrial Tap-East Bardstown 69kV	Bullitt Co 69/161kV transformer	104.11
Davis-Nicholasville 69kV	Baker Lane-KU Baker Lane 138kV	103.17
Cooper transformer 161/69kV	Russel Co-Russel Co Jct 161kV	102.03

Table 8. Cooper 1&2 Generation-Outage Dispatch Worst Contingency Voltages:

Bus	Outage	Contingency Voltage	Contingency Voltage With Industrial Load at Forecasted Value
Bromley	Owen Co Jct 1-Bromley EK SS 69kV	0.7868	0.8346
Brodhead	Brodhead-Three Links Junction 69kV	0.8415	0.7505
Somerset	KU Alcalde-Elihu 161kV	0.8441	0.8484
Glendale	Etown KU-Etown 4 69kV	0.8475	0.8404
Sewellton	Cooper-Russel-Wolf Creek 161kV	0.8637	0.8610
Keith	Owen County 138/69kV transformer	0.8639	0.8523
South Corbin	Farley 161kV tie	0.8775	0.8934
Laurel County Industrial Park	Delvinta-Green Hall Tap 161kV	0.8806	0.9018
Broughtontown	Garrard Co-South Lancaster Tap 69kV	0.8835	0.9584
Oakley Noel	Gallatin Co-Ghent 138kV	0.8880	0.8856
Pine Grove	Brown N-Alcalde-Pineville 345kV	0.8905	0.8988
Mt. Sterling	Hunt-Miller Hunt Tap 69kV	0.8950	0.8859
Jamestown	Russel Co Jct-Wolf Creek HP 161kV	0.8974	0.9052
Pine Grove	Keavy 1 Tap-Pine Grove Tap 69kV	0.8996	0.8985
Shopville	Norwood Tap-Shopville 69kV	0.9724	0.7588
Alcan	Fawkes-West Berea 138kV	0.9603	0.8464
McKee	McKee-Tyner 69kV	0.9234	0.8936
Powell Taylor	KU Fla Tile Tap-Lawrenceburg 69kV	0.9428	0.8993

*some voltages are higher with the increased industrial loading due to generators being increased at ties prior to contingency analysis in order to keep tie voltages at real values

Exhibit 5. Brown 3 Generation-Outage Dispatch

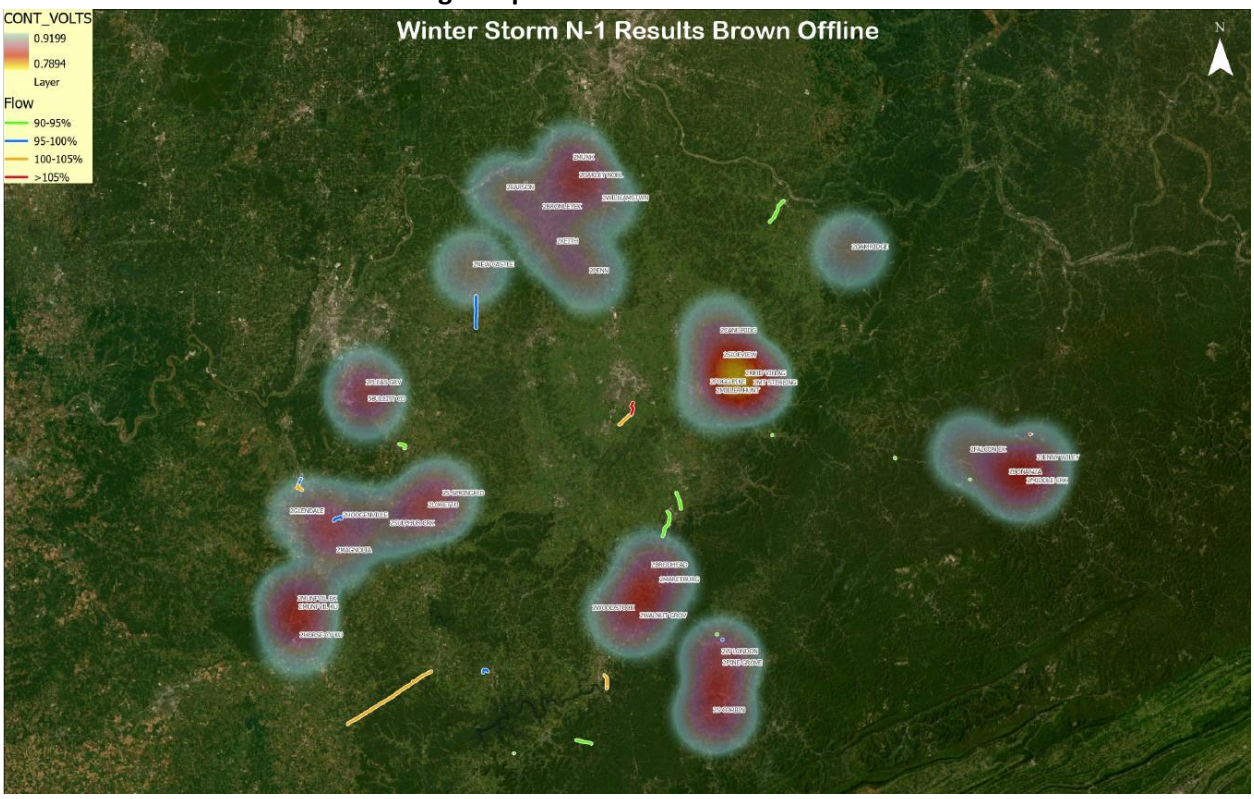

Exhibit 6. Brown 3 Generation-Outage Dispatch-Industrial Loads at Forecasted Level

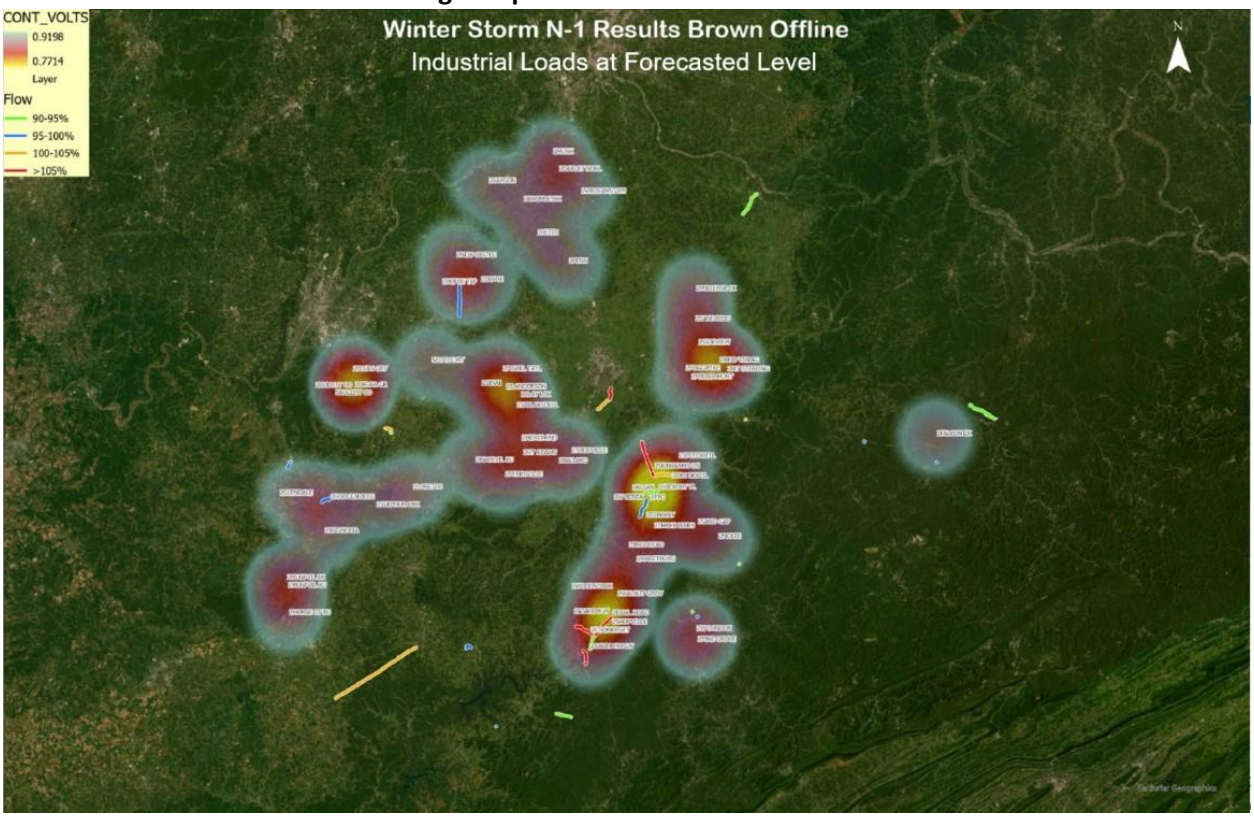

Table 9. Brown 3 Generation-Outage Dispatch Thermal Overloads:

Lines above 100% of thermal rating	Critical Contingency	Overload %
Fayette-Davis 69kV	Baker Lane-KU Baker Lane 138kV	108.33
AEP Thelma-Thelma 69kV	AEP Dewey-Thelma 138kV	106.02
Summer Shade-West Columbia Tap 69kV	Cooper-Russel-Wolf Creek 161kV	103.38
Davis-Nicholasville 69kV	Baker Lane-KU Baker Lane 138kV	103.27
Cooper transformer 161/69kV	Russel Co-Russel Co Jct 161kV	103.08
Cooper-Somerset 2/1 69kV	Cooper-Somerset 1/2 69kV	102.33
TVA Wayne-Wayne 161kV	Russel Co Jct-Wolf Creek HP 161kV	101.45
Etown KU-Tharp Tap 69kV	Rogersville Jct-Rogersville 69kV	100.14

Table 10. Brown 3 Generation Dispatch-Industrial Loads at Forecasted Level Thermal Overloads:

Lines above 100% of thermal rating with forecasted load increases	Critical Contingency	Overload %
Fawkes-Duncannon Lane Tap 69kV	Fawkes-West Berea 138kV	118.50
Cooper-Somerset 2/1 69kV	Cooper-Somerset 1/2 69kV	113.49
Cooper transformer 161/69kV	Russel Co-Russel Co Jct 161kV	110.92
AEP Thelma-Thelma 69kV	AEP Dewey-Thelma 138kV	110.87
Fayette-Davis 69kV	Baker Lane-KU Baker Lane 138kV	108.31
Norwood Tap-Shopville 69kV	Brodhead-Three Links Jct 69kV	107.98
Duncannon Lane Tap-Crooksville Tap 69kV	West Berea 69/138kV transformer	107.07
Summer Shade-West Columbia Tap 69kV	Cooper-Russel-Wolf Creek 161kV	104.22
Davis-Nicholasville 69kV	Baker Lane-KU Baker Lane 138kV	103.19
Bardstown Industrial Tap-East Bardstown 69kV	Bullitt Co 69/161kV transformer	102.34
Crooksville Tap-Hickory Plains 69kV	West Berea 69/138kV transformer	101.27
Etown KU-Tharp Tap 69kV	Rogersville Jct-Rogersville 69kV	100.51

Table 11. Brown 3 Generation Dispatch Worst Contingency Voltages:

Bus	Outage	Contingency Voltage	Contingency Voltage With Industrial Load at Forecasted Value
Bromley	Owen Co Jct 1-Bromley EK SS 69kV	0.7894	0.7838
Glendale	Etown KU-Etown 4 69kV	0.8478	0.8493
Keith	Owen County 138/69kV transformer	0.8628	0.8526
Brodhead	Brodhead-Three Links Junction 69kV	0.8873	0.8121
Oakley Noel	Gallatin Co-Ghent 138kV	0.8883	0.8855
Mt Sterling	Hunt-Miller Hunt Tap 69kV	0.8965	0.8863
Shopville	Norwood Tap-Shopville 69kV	0.9789	0.7714
Alcan	Fawkes-West Berea 138kV	0.9746	0.8633

Table 12. Load Shed to Alleviate Violations

Loads Shed	No Generation Dispatch	Cooper 1&2 Generation Dispatch	Brown 3 Generation Dispatch
Bromley	**X**	**X**	**X**
Somerset	**X**	**X**	**X**
Cabin Hollow		**X**	
S Oakhill		**X**	
Oak Hill		**X**	
Brodhead	**X**	**X**	**X**
Elk Mountain		**X**	
Laurel Co IP #1		**X**	
Oakley Noel	**X**	**X**	**X**
Glendale	**X**	**X**	**X**
Hodgenville	**X**	**X**	**X**
Norwood		**X**	
Coburg		**X**	**X**
Bronston #1		**X**	
Mt Sterling	**X**	**X**	**X**
S Floyd		**X**	
S Corbin		**X**	
Pleasant Grove #1		**X**	
Maggard		**X**	
Williamstown		**X**	
Oak Ridge		**X**	
Nicholasville	**X**	**X**	**X**

Additional analysis was performed in a follow up study to determine what the system would have looked like if all of the out-of-service line sections had been restored.

EKPC is considering various locations for future generation. Additional analysis was performed to investigate the potential impact from the new generation sites on the system, had they been online during the winter storm. The two sites, Liberty and Campbellsville, each represent an installation of RICE engines on the 161kV system, each with an output of 216MW's.

Exhibit 7. No Generation-Outage Dispatch with All Outages Restored

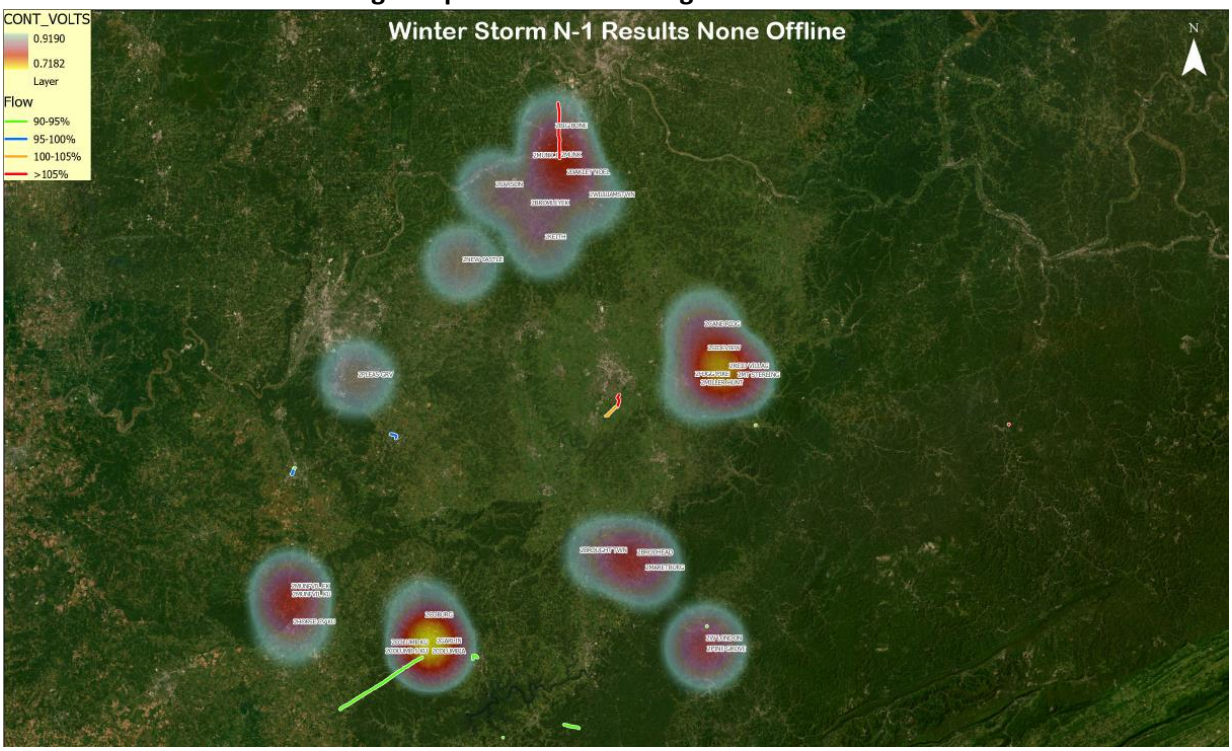

Exhibit 8. Cooper 1&2 Generation-Outage Dispatch with All Outages Restored

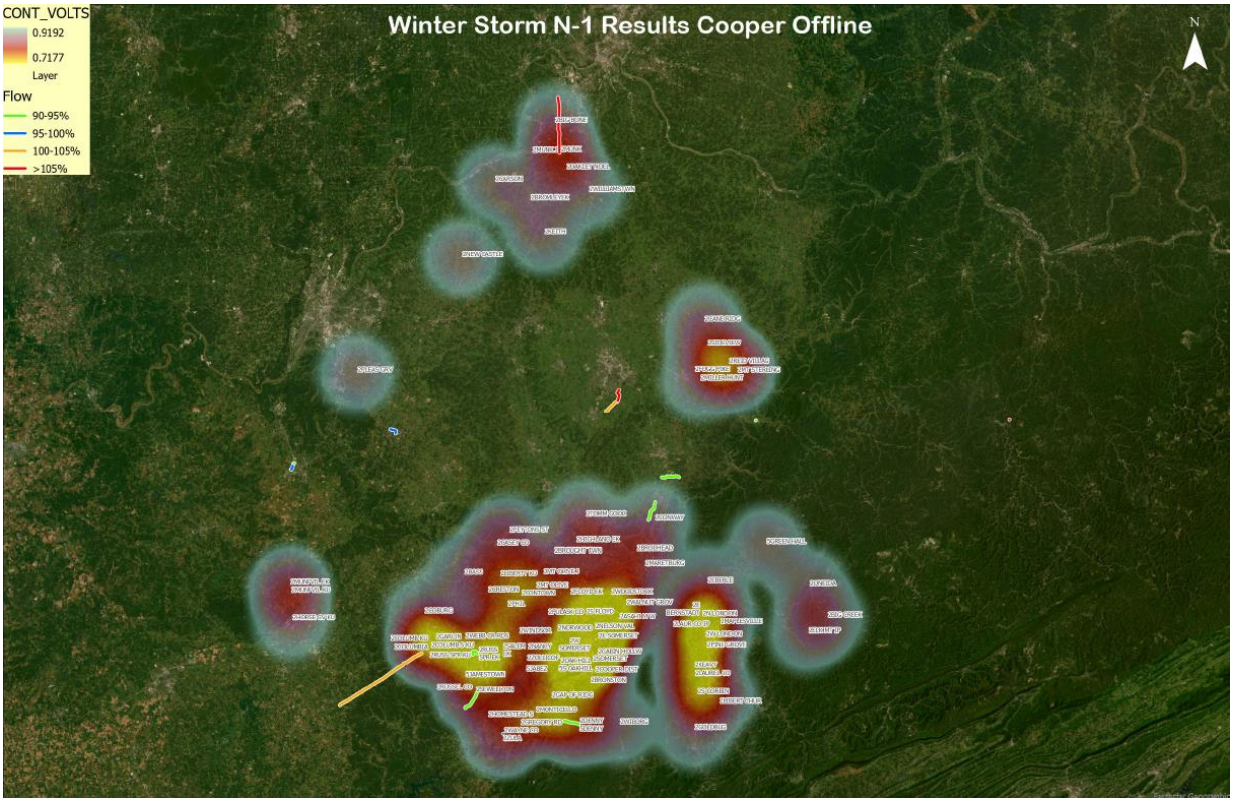

Exhibit 9. Brown 3 Generation-Outage Dispatch with All Outages Restored

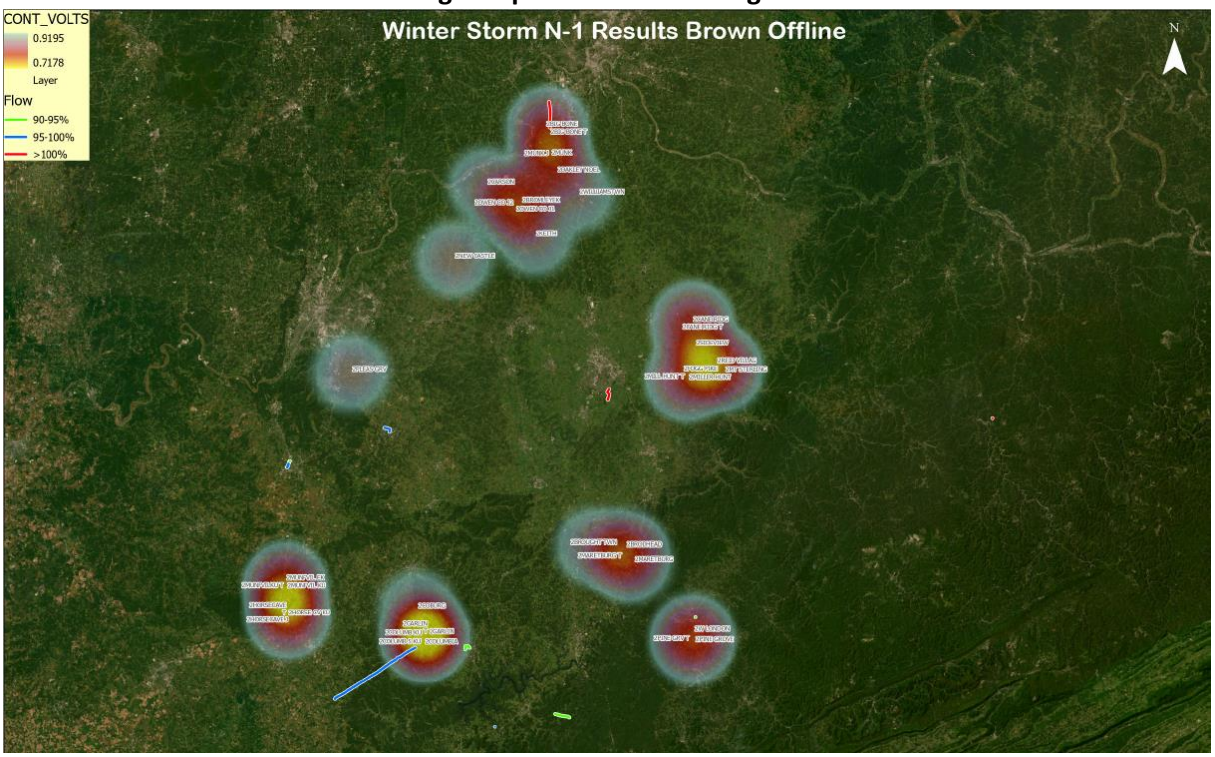

Exhibit 10. Cooper 1&2 Generation-Dispatch with Liberty Generation Site

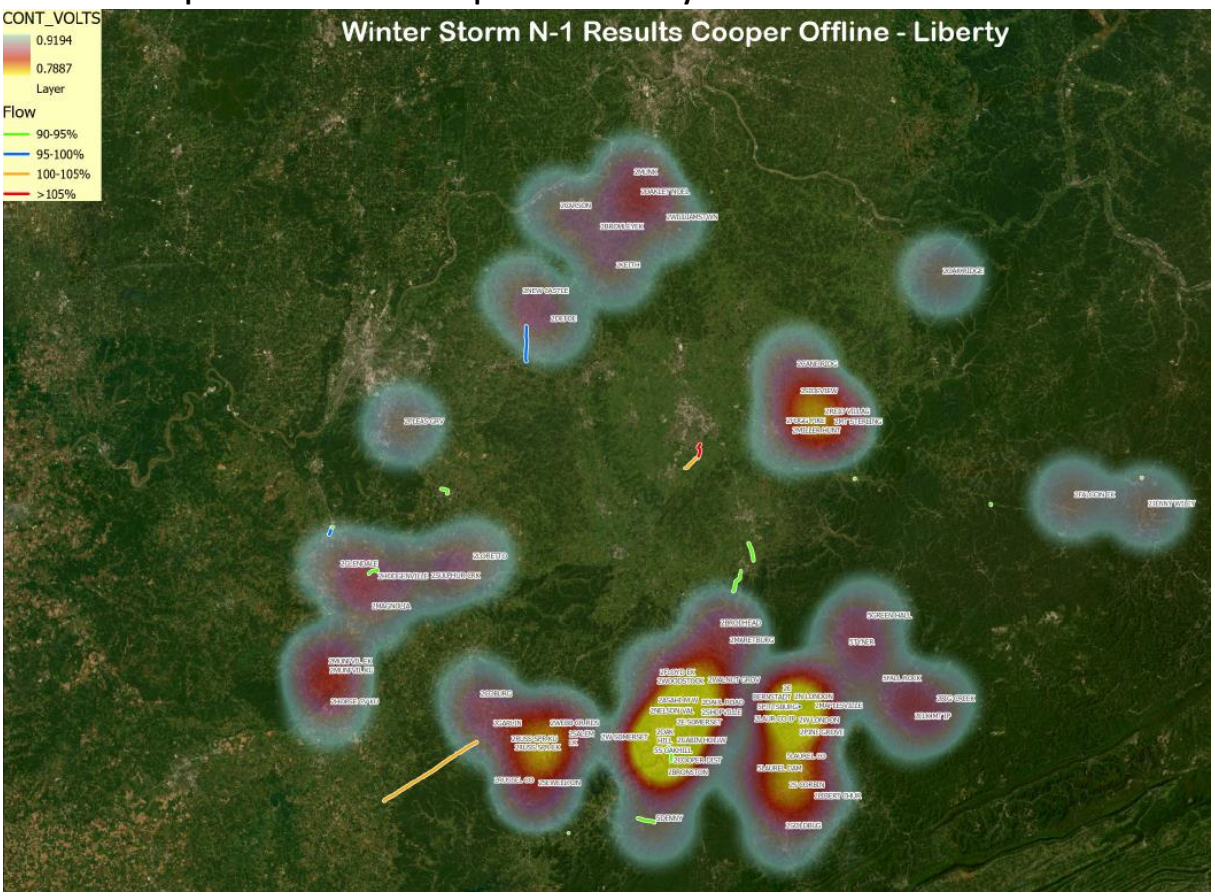

Exhibit 11. Cooper 1&2 Generation-Dispatch with Campbellsville Generation Site

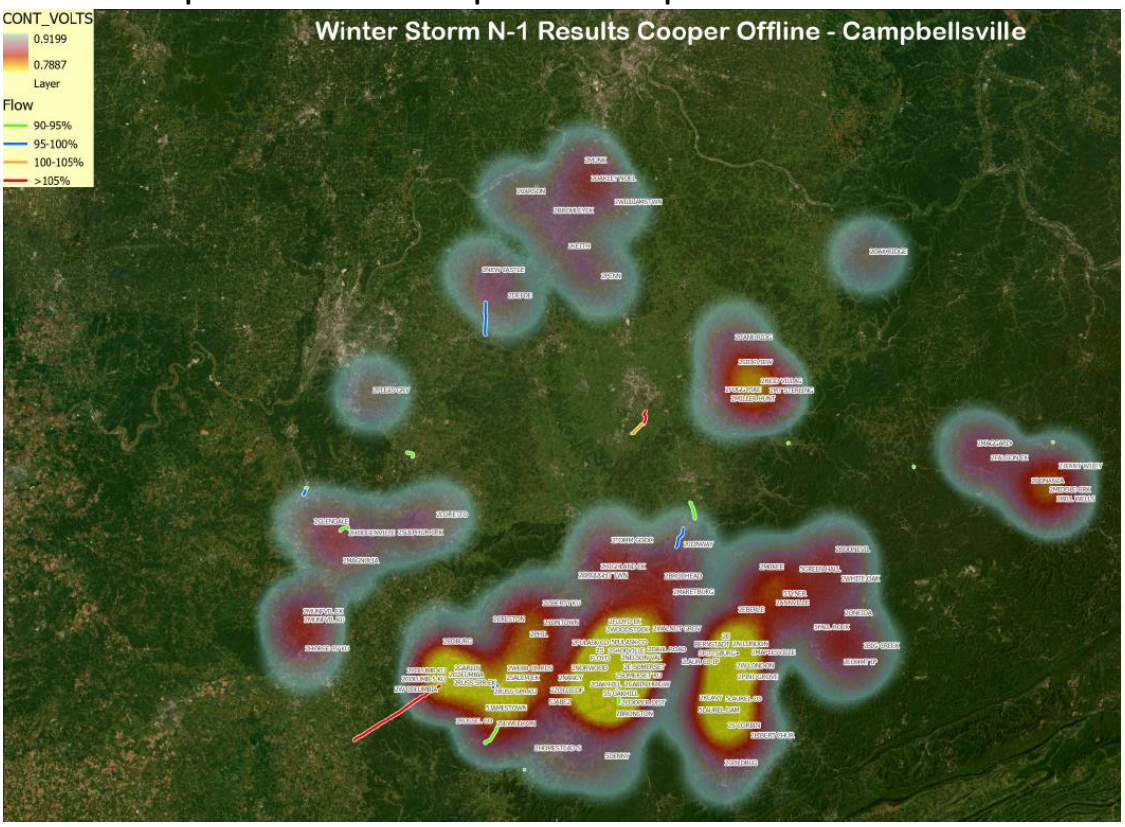

Exhibit 12. Cooper 1&2 Generation-Dispatch with Liberty and Campbellsville Generation Site