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Transmission System Reliability in the Face of Climate Change

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SUMMARY

Utilities are faced with the need to better understand their vulnerability to climate change and how to mitigate the resulting risks. With respect to transmission systems, it is anticipated that climate change will be accompanied not only by higher temperatures and humidity, resulting in higher peak system loads, but also by more frequent periods of relatively high load. This would render the transmission system potentially more vulnerable to reliability challenges[1] despite system strengthening to accommodate high peak loads and address resiliency; and the derating of equipment forced by higher temperatures. Furthermore, should increases in the frequency and amplitude of strong winds, lightning strikes and rain that might accompany climate change, this would affect equipment reliability and could lead to widespread failure bunching as adverse weather affects large areas. Finally, asset degradation resulting from higher temperatures, in particular the degradation of transformer insulation, would increase failure rates.

To better understand the risks posed by climate change, we used existing reliability models to predict whether longer periods of high load and worse weather would affect transmission system reliability. To accomplish this, we projected future values of temperature and humidity for the years 2030, 2050 and 2080, assuming a conservative climate change pathway (the 90th percentile prediction for Representative Concentration Pathway (RCP 8.5): this analysis therefore represents a stress test. We also assumed that the system will be strengthened, as necessary to maintain its current non-probabilistic design criteria at the higher loads forecast. These criteria spell out the contingencies the transmission system must be able to withstand without load drop resulting from thermal overloads or area substation isolation.

KEYWORDS

Transmission, reliability, probabilistic modeling, Monte Carlo, simulation, climate change, RCP, IPCC.

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[1] This paper focuses on transmission system reliability, a system performance measure, rather than resilience, a system characteristic [1].

Introduction

Like other utilities, Con Edison is engaged in efforts to better understand its vulnerability to climate change and how to mitigate the resulting risks [2, 3]. Climatic effects are of considerable importance to transmission system reliability. They impact load patterns that could affect the entire system or large parts of it and could also result in failure bunching - the occurrence of multiple failures within a short period of time because of an increase in equipment failure rates in adverse weather or as a result of high loads coupled with subsequent secondary failures [4]. A risk of particular concern is the effect of more frequent and longer heat waves resulting in periods of higher load. Climate change might also be accompanied by an increase in the frequency and intensity of lightning and extreme weather events and asset degradation driven by higher temperatures. While equipment will be replaced or added to increase capacities and ratings to accommodate higher peak loads, changes in the frequency and duration of heat waves, coupled with a possibly greater frequency and intensity of adverse weather, could affect system reliability.

To examine these issues, we used our transmission system reliability model [5], together with projected temperature and humidity data for various climate change pathways. The results from sensitivity analyses will also be presented to show how asset degradation, and more severe summer weather will also affect transmission system reliability if capacity and ratings are not increased. We would note that the focus of the work described here is on the direct effects of climate change on transmission system reliability in summer. There will be secondary effects too as a result a transition to electric heating in winter and the charging of electric vehicles and a consequent change in the diurnal variation in load. These secondary effects are not addressed here. We would note that the vulnerability of the transmission system infrastructure in Con Edison’s service territory to severe weather events, lessened by the fact that many power lines lie underground and substations were reinforced to guard against flood and storm damage after the storm surge that accompanied tropical storm Sandy in 2012. Subsequent studies are expected to consider the effect of severe weather on systems where a substantial part of the energy is generated by wind and solar energy. In addition, subsequent studies will evaluate how longer, and more frequent heat waves might affect the availability of demand response programs or other non-wires solutions; the effect of load changes in winter; and the occurrence of the “warm arctic/cold-continent weather pattern or other extreme events” [7].

Models and Data

The model employed is a 2024 reliability model for Con Edison’s transmission system. This system comprises 438 miles of overhead circuits operating at 138, 230, 345 and 500 kilovolts, 727 miles of underground circuits operating at 69, 138 and 345 kilovolts, 38 transmission substations and 63 area substations. All these are modeled together with ~ 10,000 pieces of equipment. This model is described elsewhere [6]. The model is embedded in a sequential Monte Carlo simulation, the failure of equipment and its restoration to service being followed over time. As the failure rates prevailing at any time are determined for each piece of equipment by the prevailing weather and prior events, the simulation will ascertain if a particular vulnerability to climate change has a significant effect on system reliability. In this study, the age, condition of equipment, failure rates and outage durations in future years are assumed to be consistent with present assumptions.

The load and temperature data used are taken from the test scenarios for Con Edison’s Climate Change Vulnerability Study [2]. Sets of predicted temperature and humidity data were developed from Global Climate Model predictions, bias-corrected and downscaled as described.

Specifically, the high- end projection (90th) were developed for Representative Concentration Pathway[2](RCP) RCP 8.5 in the near, intermediate and long terms. Specifically, we used:

- Predictions for 2024.
- A 90th percentile case for RCP 8.5 in 2030.
- A 90th percentile case for RCP 8.5 in 2050.
- A 90th percentile case for RCP 8.5 in 2080.

These sets of data were selected to present analyses based on very conservative predictions that are unlikely to occur. As we assumed that load relief and upgrades to system capacity and equipment ratings will be undertaken to supply the anticipated peak demand at prevailing temperatures, it is the pattern—the frequency and duration—of heat waves and periods of high load that is of interest rather than the absolute values of temperature and load, etc. The changes anticipated are illustrated in Figure 1.

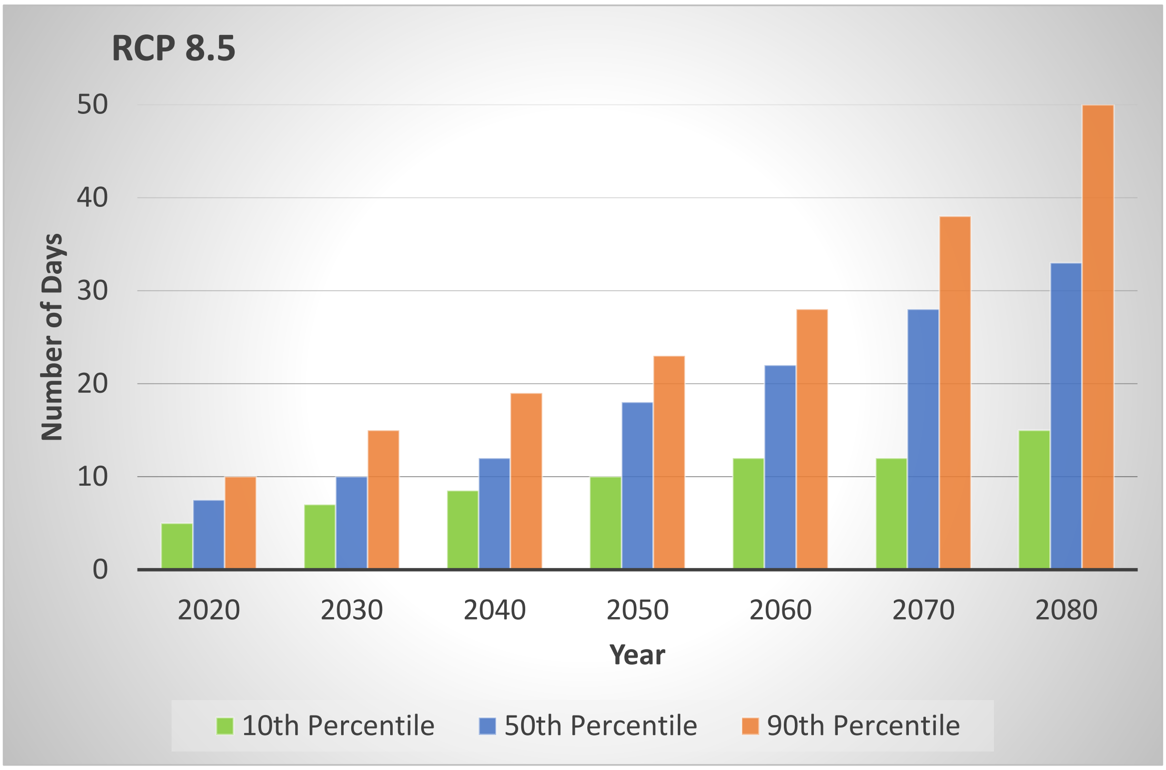

Figure 1 : Projection of The Average Number of Days per Year with Maximum Summer Air Temperatures Exceeding 95°F in Central Park, NY [3]

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[2] Representative Concentration Pathways are pathways used for climate modeling and research that describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases emitted in the years to come. RCP8.5 is the United Nations Intergovernmental Panel on Climate Change's (IPCC) basis for a worst-case climate change scenario.

[3] Extracted from data presented in Figure 7, reference [2].

Excluding extreme events such as hurricanes, historically rain has been shown to be associated with an increase in bus and disconnect switch faults and the unwanted opening of circuit switchers.[4] Frozen precipitation is also associated with an increase in the unwanted opening of breakers. The role of lightning strikes in causing faults and precipitating relay protection scheme mis-operation is transparent and addressed in the model. However, as there is less certainty as to changes in the frequency and amplitude of lightning strikes, sensitivity analyses were performed assuming a 50 % increase in lightning strike frequency and 20 % increase in amplitude by 2080. For rain, we assumed a 20 % increase in rain days, on which more than 0.5 in. of rain falls, by 2080.[5]

Predictions

The frequencies of severe heat waves[6]; the percentage of days where the value of the Temperature Variable (TV)[7] is or exceeds 86ºF (30ºC); and the percentage of hours in which transmission system load exceeds 80 % of peak load are presented for the cases modeled in Figure 2.

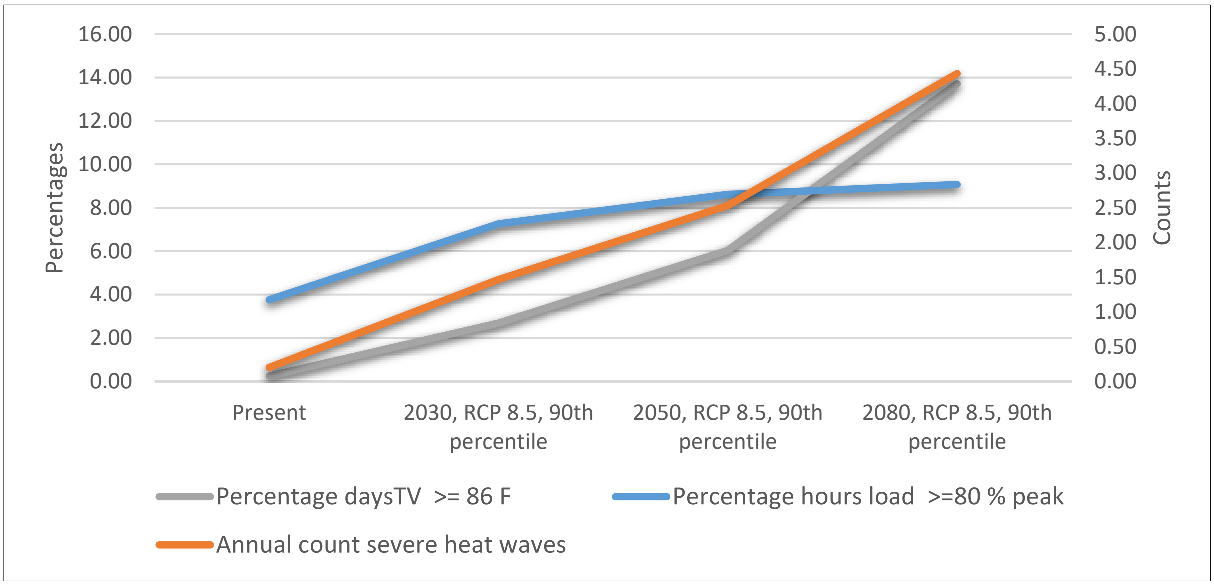

Figure 2 : Heat Waves and Loads, 2024-2080

The predicted frequencies of load drop and challenges[8] to the reliability of transmission system in summer[9] for the cases modeled, and expressed relative to the base-case predictions made for 2024 are presented in Figure 3. In the 2024 model, the weather data used are those from 2007-2016. The predictions suggest that while, more frequent heat waves and high loads will occur, and the frequency of reliability challenges to transmission system will increase throughout the period studied, little

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[4] Capacitors are more likely to undergo unwanted isolation in heat waves.

[5] As per Appendix [1] to [2].

[6] A severe heat wave is defined here as a period in which the value of the Temperature Variable—an index that considers the persistence of heat and humidity over several days [1]—is greater than or equal to 86ºF.

[7] Temperature variable is calculated using the weighted time integration of the highest daily recorded 3-hour temperature and humidity over a 3-day period. The reference TV for Con Edison is 86°F (30ºC), which approximates a heat index of 105°F (40.55ºC).

[8] A challenge is an event that if not mitigated will require that load be dropped.

[9] This study does not address the possible switch to electric power for heating and thus the effect of high winter loads and inclement winter weather on transmission system reliability.

increase in the load drop frequency occurs in the near- and intermediate term. However, by 2080, a 16 % increase in the predicted summer load drop frequency occurs. In the absence of other changes, this increase in the predicted load drop frequency can be addressed using the measures now used to ensure transmission system reliability. These mitigation measures could include topological changes (such as the addition of devices to isolate faults quickly) and upgrading of equipment (e.g., replacing electro-mechanical relays with microprocessors in relay protection schemes).

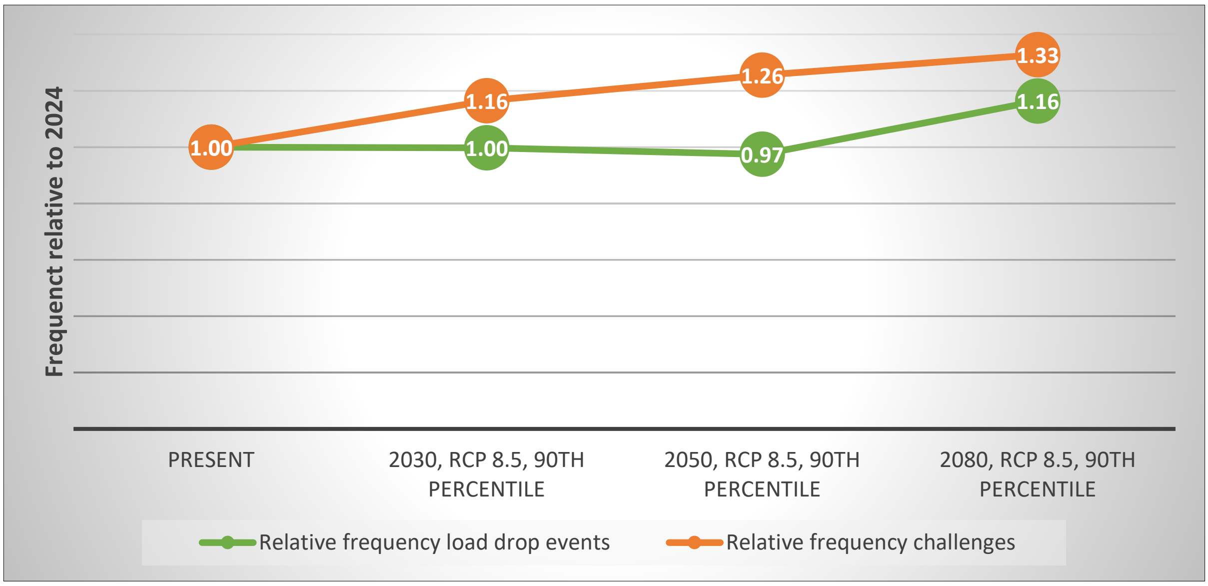

Figure 3 : Predicted Relative Frequency of Load Drops and Challenges, 2024-2080

The types of equipment associated with the predicted causes of load drop in the various cases are presented in Table 1. It appears that, ignoring asset degradation associated with increased temperatures and weather effects, no statistically significant change in the causes of load drop occurs results from of increases in load and heat wave in climate change.[10]

Table 1

Types of Equipment Associated with the Causes of Load Drop

Equipment	**Present**	**2030, RCP 8.5, 90th percentile**	**2050, RCP 8.5, 90th percentile**	**2080, RCP 8.5, 90th percentile**
Breaker	6	4	5	4
Bus	4	4	4	3
Circuit switcher	4	5	5	4
Disconnect switch	2	1	2	2
Generator	0	1	2	2
Lines	46	43	46	44
Transformer fails	37	41	36	40

While changes in the frequency and duration of high load periods seem to have no immediate effect on transmission system reliability, we note that the concern raised in the vulnerability report [2] that with the higher temperatures expected with climate change, equipment and in particular transformers, and

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[10] A Chi-test shows a 15 % probability that the predictions could result in the absence of any changes in the types of equipment that fail or mis-operate.

their electrical insulation, would age faster. Transformers are of particular concern to system reliability because of the time required to replace such equipment. To investigate how the accelerated aging of transformers might affect transmission system reliability, we made predictions based on the assumption that the effect of aging on a transformer's failure rate doubled.[11] Predictions for this stress test are presented in Table 2. These predictions compare the frequency of load drop to the predictions made for 2024 and include predictions made for cases with and without the accelerated aging of transformers and two cases where transformers are replaced pro-actively. The latter two cases are not intended to provide an optimal approach to the mitigation of asset degradation but rather to demonstrate that the rather pronounced adverse effect of climate change on degradation can be readily mitigated.

We conclude that if left unchecked, the accelerated aging of transformers would increase the frequencies of load drop, but the pro-active replacement of transformers will mitigate this effect.

Table 2

Load Drop Frequencies for 2080, RCP 8.5, 90th Percentile Case with Asset Degradation

Case	Relative frequency summer load drop events
Base case: no accelerated degradation	1.16
Accelerated degradation	1.54
Accelerated degradation with the pro-active replacement of transformers with high hazard rates	1.48
Accelerated degradation with the pro-active replacement of transformers older than 30 years or with high hazard rates	1.07

Considering the hypothetical increase in the frequency and intensity of lightning strikes and rain, in Table 3 we show summer load drop frequency predictions made using a data set with: a 50 % increase in lightning strike frequency; a 20 % increase in amplitude; and a 20 % increase in rain days by 2080, over that experienced in the period 2007-2016. We assumed this increase in strike frequency as there is no consensus regarding the effect of climate change on lightning strikes. As expected, with increasing severe weather, the predicted frequency of load drop events increases but only slightly. It must be noted that this conclusion reflects the major operational[12] and design changes made subsequent to earlier extreme weather events.

Table 3

Load Drop Frequencies for 2080, RCP 8.5, 90th Percentile Case, with Worse Weather

Case	Relative frequency summer load drop events	Events to which lightning contributes (%)	Events to which rain contributes (%)
Base case: no accelerated degradation	1.16	6.38	0.13
Worse weather	1.22	8.44	0.25

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[11] This modeling of transformer failure rates makes use EPRI PTX Transformer Fleet Management software, dissolved gas analysis data, transformer age and the count of abnormal events to which the transformer has been subjected is described elsewhere [6].

[12] Operational measures include that assuming that a major transmission line is already unavailable and planning operations and generation accordingly

Finally, we examine the consequences of loads being higher than those for which the system had been designed or rated—of inadequate load relief or unanticipated temperatures being encountered that results in equipment being derated. We used the 2080 RCP 8.5 90th percentile case and assumed that loads are 10 % higher than those for which the system had been designed or rated. A comparison of load drop predictions is presented in Table 4. A 13 % increase in the load drop frequency is predicted where peak loads are 10% higher than has been designed for (or temperatures are such that a further unanticipated 10 % derating of equipment will be required).

Table 4

Load Drop Frequencies for 2080, RCP 8.5, 90th Percentile Case with Inadequate Load Relief

Case	**Relative frequency load drop events**
Base case: adequate load relief	1.16
Inadequate load relief or equipment ratings	1.29

Conclusions

We concluded that:

- The increase in the load drop frequency will be small in the near- and intermediate term. By 2080, however, we predict a 16 % increase in the summer load drop frequency if the worst-case climate change scenario is assumed and if no action is taken. We expect, however, this potential for increased load drop frequency can be dealt with using the same measures now used to address transmission system reliability.
- If left unchecked, the accelerated aging of transformers might pose reliability problems, but the pro-active replacement of transformers will mitigate this.
- The load drop frequency would increase if peak loads are higher than are designed for. For example, we predict an additional 13 % increase in load drop frequency if loads are 10 % higher than those anticipated or unanticipated temperatures require a 10 % derating of equipment.
- The load drop frequency would increase with more severe summer weather but not markedly, but this analysis does not include hurricane events. Susceptible transmission and distribution substations have been reinforced to guard against storm surge damage.

These conclusions suggest that no immediate action is required and that the anticipated adverse effect of climate change can be mitigated readily. That said, we will continue to monitor the impacts of climate change, obtaining new climate data periodically and using the best available science to review our models. We will also explore how the adoption of new and improved technologies such as energy storage, advanced power-flow control devices, high-power delivery systems, advanced sensors and advanced protection systems [8] and the incorporation of distributed energy resources can enhance reliability. Finally, we note that with the development of our climate change implementation plan, we have now made designing for climate change impacts part of our engineering process.

BIBLIOGRAPHY

[1] Con Edison, “Climate Change Vulnerability Study”, December 2019 (https://www.coned.com/-/media/files/coned/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-vulnerability-study.pdf?la=en)

[2] Con Edison, “Climate Change Implementation Plan”, Case Nos. 19-E-0065 and 19-G-0066, Submitted to the New York State Public Service Commission, December 29 2020 (https://www.ny.gov%2Fpublic%2FCommon%2FViewDoc.aspx%3FDocRefId%3D%257BF59D306D-F332-4669-B023EFE980F65E9%257D&usg=AOvVaw2K8DOeI5X0t5iefVcmXvKm).

[3] Hasan, R., Viele, M, Winters, W. and Allen, D. J., “Optimization of Transformer Sparing and Replacement Strategies Using Probabilistic Simulation”, PID-233, 2020 IEEE International Conference on Power Systems Technology, 14-16 September, 2020.

[4] Hasan, R., Viele and Allen, D. J., “Con Edison Transmission System Reliability Model”, CIGRE-197, 2019 CIGRE Canada Conference, Montreal, Quebec 16-19 September 2019.

[5] EPRI, “Exploring the Impacts of Extreme Events, Natural Gas Fuel and Other Contingencies on Resource Adequacy”, 3002019300, January 2021.

[6] IEEE Power & Energy Society, “Resilience Framework, Methods, and Metrics for the Electricity Sector”, Technical Report PES-TR83, October 2020.

[7] Hasan, R., Viele, M, Winters, W. and Allen, D. J., “The Probabilistic Modeling of Common-Cause Failures and Failure Bunching in a Transmission System Reliability Model”, CIGRE-313, 2020 CIGRE Canada Conference, Toronto, Ontario 19-22 October 2020.

[8] O’Reilley, Chris, King, Tom, et al. 2021. Electricity Transmission System Research and Development: Hardware and Components. In Transmission Innovation Symposium: Modernizing the U.S. Electrical Grid, U.S. Department of Energy.