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Resiliency Analysis for Climate Hazard Impacts on Distribution System

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SUMMARY

Climate change impacts have been widely documented globally, across the nation, and within California. Loss of snowpack and a rising sea level; longer, more frequent heat waves; and longer, more intense wildfire seasons are being experienced in California. While uncertainties remain about the exact timing and extent of projected impacts, numerous climate-driven hazards represent a clear threat to Southern California Edison's (SCE) transmission, sub-transmission, and distribution electrical facilities and operations. The California Public Utilities Commission opened an Order Instituting Rulemaking to provide guidance to utilities on how to incorporate climate change adaptation into their planning and operations. SCE's need to conduct a Vulnerability Assessment on the assets, operations, and services because of projected climate hazards is driven by Decision 20-08-046 issued by the California Public Utilities Commission on 9/3/2020.

This Climate Adaptation Vulnerability Assessment (CAVA) provides one of the first evaluations of its kind in California for transmission, sub-transmission, and distribution electrical facilities owned and operated by SCE and the grid operational activities that SCE performs. Assets vulnerable to hazards from climate change and assessed in this resiliency analysis, using 2050 as the end point, are presented under five categories: Wildfire, Extreme Heat, Flooding, Sea Level rise, and Debris Flow. This assessment examines how SCE's electrical assets may be impacted by future Wildfire, Extreme Heat, Flooding, Sea Level Rise and Debris Flow hazards and the ability of SCE's electric system and operations to withstand or adapt to these climate hazards.

The effects of flooding, rising sea level, wildfires, and landslides on customers were evaluated by mapping potential substation and distribution equipment outages into the CYME networks for each affected distribution circuit. After the equipment was identified in the model, it was used to identify the total customer impact including the number of customers and total load at risk.

Recovery options were then identified for customers whose equipment was not directly affected by these climate-induced threats. The recovery options were limited to ties to adjacent circuits, new substation circuits, creating new circuit ties, and microgrids. The ties to adjacent circuits were deemed valid if the existing interconnect was available to restore power to a restorable group of customers. Alternate substation circuits were used when the substation was not affected by the hazard under study and there was a clear path to restore service. The alternate circuit ties were investigated if there was a nearby circuit that could restore service. Potential microgrid solutions were explored in scenarios where the affected circuit or substation did not have an available solution using the previous mitigation methods.

Extreme temperature analysis was focused on the distribution substation transformers. The results of this evaluation predicted that many of these transformers would see significant heat waves using the future climate models. These heat waves could cause multiple transformers in proximity to fail in the same heat wave incident. The age and relative health of the transformers were evaluated to project failures in these cases. The hazard analysis predicted transformers from multiple substations, as many as four in proximity may fail during a single heat wave. Recovery solutions were explored for each affected substation to determine how much load could be rolled to the restorable substations utilizing existing circuit ties. The analysis provided the overall capacity that could be transferred, required conductor upgrades, and additional capacity needed for the substation to account for load that was unable to be transferred.

KEYWORDS
Grid Resiliency, Climate Assessment, Distribution Planning, Study Automation

Introduction

Climate change impacts have been widely documented globally, across the nation, and within California. Loss of snowpack and a rising sea level; longer, more frequent heat waves; and longer, more intense wildfire seasons are being experienced in California. While uncertainties remain about the exact timing and extent of projected impacts, numerous climate-driven hazards represent a clear threat to Southern California Edison's (SCE) transmission, sub-transmission, and distribution electrical facilities and operations. The California Public Utilities Commission opened an Order Instituting Rulemaking to provide guidance to utilities on how to incorporate climate change adaptation into their planning and operations. SCE's need to conduct a Vulnerability Assessment on the assets, operations, and services because of projected climate hazards is driven by Decision 20-08-046 issued by the California Public Utilities Commission on 9/3/2020.

Traditionally distribution planning has not accounted for equipment vulnerabilities to climate hazards or the by-products of a changing climate (flooding, wildfire, extreme temperatures). Determining the distribution system resiliency to these climate change events will become critical to future planning. Identifying the vulnerable assets, total impact of losing the vulnerable assets, and how well the current infrastructure may be utilized will become critical to future planning efforts to increase grid resiliency. Also, where existing infrastructure is unable to react, this analysis will be required to determine recovery options that may be implemented to restore as much of the distribution system as possible.

POWER and SCE evaluated climate effects on the utility's transmission and distribution systems, but this paper focuses only on the distribution system. The evaluation determined the substation and distribution equipment at risk and compiled a list of equipment affected by the climate hazard on the distribution network. The goal of the analysis was to determine total effects on customers, available mitigation options, and system upgrades for each climate hazard.

Climate Assessment

Climate hazards may present themselves in various forms. The types of hazards are greatly dependent on the geographical location being investigated, and each will impact the system's infrastructure differently. The climate assessment was conducted to narrow the types of hazards that could affect SCE's system and determine which circuits and types of equipment were vulnerable to these climate hazards. The sections below provide a description of the identified hazards and the potential impacts on SCE's electrical infrastructure.

Extreme Temperature

Climate change is projected to create higher peak temperatures over time, and the duration of these temperatures will increase as well. Equipment exposed to these increased temperatures will operate less efficiently and result in a decreased useful life span. The extreme temperature analysis was projected out to year 2050. The projection was done utilizing 10 global climate models (GCM).

The data from the projection was utilized to determine what equipment would be impacted by the increased temperatures and duration of increased temperatures. The impacted equipment included, distribution service transformers, wood poles (increased rate of decay), distribution substation transformers, and distribution switchgear. The analysis included in this report is restricted to distribution substation transformers. SCE identified vulnerable transformers as equipment being subjected to four-day heatwaves at 104°F or greater. This criterion was derived using historical outage and temperature data available to SCE. Accounting for current transformer replacement programs, SCE identified 89 or ~4% of all transformers that would be impacted by future heatwaves.

Sea Level Rise

SCE investigated the impacts of sea level rise because of polar ice cap and glacier melt from climate change. The investigation also included potential rises because of storm surges on coastal towns. The investigation was done utilizing coastal storm modeling system (CoSMoS) projections under 100-year storm conditions. The projections were done in three time frames, 2030, 2050, and 2070.

The CoSMoS data will provide impacted areas but determining precise water levels is difficult to predict without precise elevations. To determine affected assets SCE made a conservative assumption that any area impacted by rising sea levels would be under two feet of saltwater. Utilizing the two foot flood assumption, the affected assets were determined to be substation control houses (DC batteries, relays, control wiring) and pad-mounted switches, transformers, and capacitor banks.

Flooding

SCE investigated the impacts of flooding because of increased precipitation. The investigation utilized the Federal Emergency Management Agency floodplain data. FEMA floodplains do not readily include flood depth data so a conservative assumption was made that if an asset was located in a floodplain, it would be exposed to at least two feet of flooding. Utilizing the two foot flood assumption the affected assets were determined to be substation control houses (DC batteries, relays, control wiring) and pad-mounted switches, transformers, and capacitor banks.

Wildfire

Climate change is projected to worsen drought conditions in SCE service territory. Leading to higher probabilities for ignition, and more fuel for the fires in dry and dead plant material. For the PUC filing, SCE analyzed fire exposure in the context of non-utility caused ignitions. To project the occurrence of a wildfire happening in a certain area, the analysis utilized historical fire locations, current high fire risk areas (HFRA), soil moisture, relative humidity, and the Keetch-Byram Drought Index. These variables were used to determine scenarios where wildfires would start and burn though a specific area.

The assets vulnerable to wildfire were deemed to be overhead construction and pad-mounted switchgear, and substation equipment. The outage analysis assumed entire areas would be burned. Any substation or vulnerable asset that was included in the burn area was taken out of service. This means only circuits that are not wholly contained in the burn area and only traverse through would not sustain a full outage.

Debris Flow

SCE evaluated future changes in post-fire debris flow risk through a relative debris flow risk metric, calculated from input data for wildfires, precipitation, and landslides. The chosen variables are intended to capture the cascading effect of wildfire burn scars on unstable slopes during heavy precipitation. Wildfires burn vegetation and create hydrophobic soils, driving unstable slopes when rooted vegetation is absent or weakened. Slopes become even more unstable following heavy precipitation, creating conditions conducive to destructive debris flows. Utilizing wildfire hazard data, precipitation data, and landslide susceptibility data, vulnerable areas were identified and analyzed for debris flow. The vulnerable assets included substation equipment, distribution wood poles, and pad-mounted equipment. These were deemed vulnerable to failure because of the significant lateral forces imposed by the fast-moving debris.

Resiliency Analysis

Determining the system's resiliency because of climate impacts is well beyond the scope of typical distribution planning analysis. Many aspects of the analysis required functionality that is not offered in any distribution planning software. The resiliency analysis requires mapping thousands of equipment outages into the distribution model, determining total customer impact, and investigating any viable solutions for the restoring customers utilizing existing distribution infrastructure. There were two approaches used when analyzing the impacts due to loss of vulnerable assets. One was used for the Sea Level Rise, Flooding, Debris Flow, and Wildfire. The other was used on the Extreme Temperature climate hazard.

Study Automation

The resiliency analysis required analyzing thousands of circuits and mapping tens of thousands of outages into the CYME networks. Utilizing the current methods available in CYME, and any other simulation software would create great burden on a planning team. The current planning strategies do not require mapping large quantities of outages, mapping restorable customer groups after equipment failure, and determining recovery options for those customers. Manually running this process could introduces risk of user error. Also, these are going to be new types of planning strategies that will need to be reanalyzed periodically and will be refined over time. Utilizing a manual study process would be time consuming and would greatly limit any additional refinements to the process.

To combat the intense labor burden and accommodate future refinements, the entire resiliency analysis was automated using the CymPy interface with CYME. Automation processes were developed to map all vulnerable equipment outages into the CYME network. Topology searching algorithms were used to identify the groupings of restorable customers, and available tie points to adjacent circuits. The use of topology search algorithms allowed for the automation analysis to be decoupled from the circuit topology. the same algorithm may be applied to any circuit with zero modifications to the algorithm. This functionality is critical to producing effective, efficient, and consistent results.

As with traditional system planning, this resiliency analysis will need to be conducted continuously. The climate models will continually become more accurate as more data becomes available. Analyzing impacts on the electrical grid because of these climate hazards should evolve as well. Implementing study automation allows for a snapshot of the analytical process that may be used during the planning cycle. Allowing for more analysis and innovation as there is no longer wasted effort recreating what has already been done.

Sea Level Rise, Flooding, Debris Flow, and Wildfire

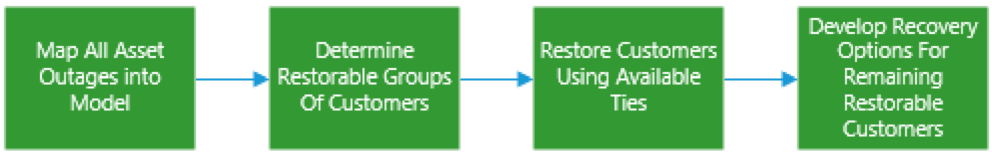

Figure 1 - Climate Hazard Impact Analysis Flow Diagram

Unique scenarios were developed that included assets that have a high probability to be impacted by rising sea levels, flooding, debris flow, and wildfire. The scenarios were separated by geographical area, probability of event causing failure, and future date of analysis (2030, 2050, 2070 etc). Each scenario contained a list of substations, circuits, and distribution assets (poles, pad mounted equipment, overhead equipment, etc.) identified as being vulnerable to the climate hazard. Utilizing the asset GIS identifier, the impacted assets were mapped into the CYME networks and simulated as an outage on the distribution system.

After the outages were mapped into the CYME network the overall circuit impact was evaluated. The evaluation included the following:

1. Total number of customers located on the circuit.
2. Total number of customers electrically disconnected from their source substation because equipment failure.
3. If substation assets were impacted, then the circuit breaker was opened, and all customers connected to the substation were impacted.
4. The maximum group of restorable customers and the total amount of restorable customers were identified. Restorable customers are defined as a group of customers that could be reenergized using an alternative source or path. The maximum group of restorable customers was utilized to determine how may customers could be restored by a neighboring circuit, or with any single mitigation solution option.

To determine the system's resiliency to losing the vulnerable assets, the entire circuit was distributed into groups of customers directly affected by the climate hazard. Existing tie points to adjacent circuits were evaluated to provide restoration to the unaffected customer groupings. Restoration is only possible when a tie switch location is electrically connected to an unaffected customer grouping. Otherwise, these customers would require a mitigation solution, discussed in mitigation development below, to restore service. When evaluating existing tie circuit for restoring unaffected customers the following assumptions were made:

1. If the adjacent circuit could restore load, then all the unaffected customers could be restored.
2. Restoring load would not cause loading or voltage violations based on SCE standards on the adjacent circuit.
3. Restoring load would not cause overloads on the substation transformer feeding the adjacent circuit based on net forecasted load.

After all the customer recovery options were investigated using the existing infrastructure the remaining circuits were analysed to find suitable candidates to investigate further mitigation. Suitable candidates were chosen based on the total customers served and largest groupings of restorable customers that were not restored utilizing the available tie locations. The mitigations were evaluated in the following manner:

1. Completely underground all the impacted assets (pad mounted gear and overhead lines).
2. Create new circuit ties built in a manner that would withstand the climate hazard impact (Larger class poles, elevated pads, or submersible switchgear.)
3. New distribution circuits out of the same substation as the circuit affected by the climate hazard. The path of the new circuit may not pass through an area affected by the climate hazard.
4. Utilizing a mobile microgrid to restore service to customers. This option was utilized if the circuit and substation are isolated from the rest of the network.

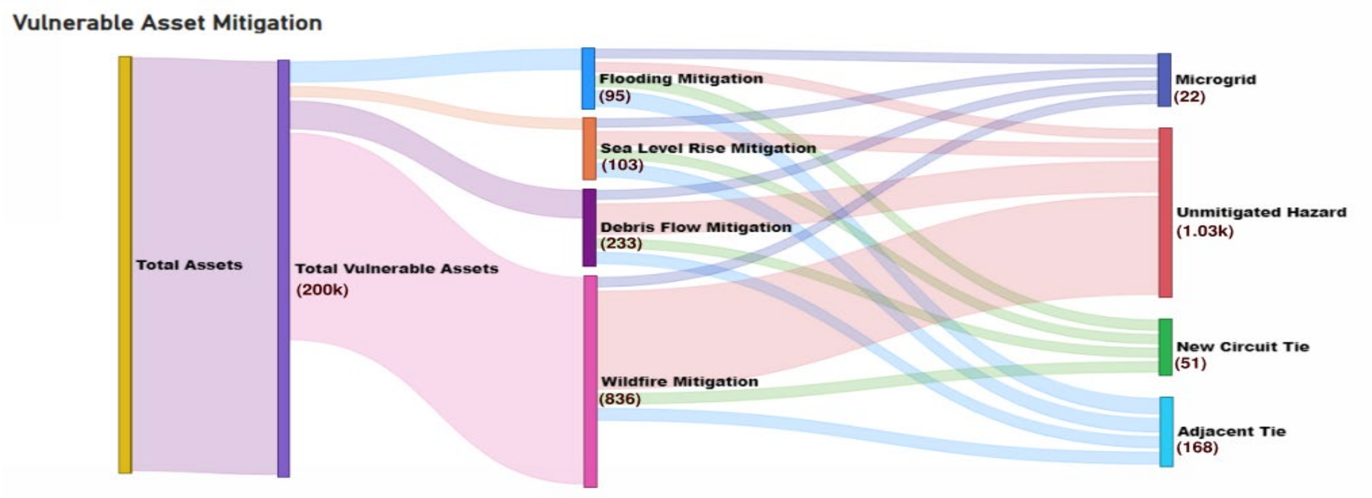

Figure 2 - Vulnerable Asset Mitigation

What mitigation options were available, if any, was largely dependent upon the climate hazard being studied. Debris flow affects areas located near the foothills of mountains which affected mainly pad mounted switchgear and distribution poles. This geographic area also limited the viable recovery options. The distribution system in the area did not have many existing tie locations and limited alternate substation locations to route power from. A rising sea level affects coastal areas and towns, which affected mainly pad mounted switchgear. This geographic area had more available ties which allowed mitigation options to be more readily available. Both geographic locations of these climate hazards effectively box in the affected areas making it very difficult to bring in additional sources to restore customers. The affected vulnerable assets for flooding and wildfire resulted in more mitigation options. These would result in large groupings of restorable customers.

As shown in Figure 1, a mitigation strategy described above could not be developed for all circuits having vulnerable assets. Wildfire and debris flow heavily impacted distribution and substation assets, which caused minimal groupings of restorable customers. For these circuits solely, an equipment hardening strategy would be necessary to mitigate the climate impacts. These hardening strategies would include increasing pad heights of pad-mounted equipment, installing flood barriers around the substations, installing fire wrapped poles and covered conductors, and strategic undergrounding of overhead construction.

Extreme Temperature

The extreme temperature climate analysis found several transformers at substations with a low health index that would be exposed to multiple heat waves. The health index of a transformer is determined using data collected through inspections, age of the asset, and SCE's Dissolved Gas Analysis. The analysis was limited to N-1-1 scenarios since SCE's current planning practices covered all the N-1 contingencies. The resiliency analysis was confined to scenarios where multiple failed transformers were in geographical proximity. These transformers were determined to have a high probability of concurrent failure during heat wave events and are not currently in the queue for replacement. Based on existing data, they would not be replaced within the climate exposure time horizon (2030) completed in this study.

After analyzing the transformer failure data, five unique distribution substation transformer failure scenarios were identified. Each scenario had two to three affected substations in the same sub-transmission system with at least one transformer failure at each affected substation. The transformer failure would effectively lower the loading limits of the substation below the criteria projected load (CPL) for the substation. CPL is the loading limits of the substation accounting for all transformers feeding the distribution circuits. The difference between the new contingency loading limits and the CPL is the amount required be rolled to neighboring substations to avoid dropping customers and alleviate overloads. The neighboring substation's CPL and emergency loading limits were analyzed to determine the amount of load that could be accepted without exceeding the emergency loading limits of the substation transformers. The loading on each circuit was determined using 2030 forecasted CPL for each circuit.

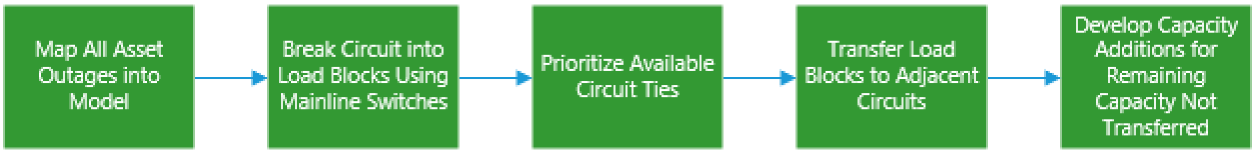

Figure 3 - Extreme Temperature Load Transfer Flow Diagram

The load transfer analysis included all the circuits connected to the affected substation, and all the available ties connected to those circuits. For each circuit that needed to transfer load, the feeder was broken up into load blocks utilizing the existing mainline switches, either pad-mounted or overhead. There are many potential ties for any given circuit, these tie points were prioritized by:

1. Available open capacity of the feeder. Each feeder was limited by the rating of the circuit breaker of 600A.

2. Least opportunities to pick up load. The goal is to first utilize circuit ties with fewer opportunities to pick up load.

The defined load blocks would be transferred to the adjacent circuit until either all the load for the circuit was transferred, the 600A breaker loading limit was reached, the transfer would exceed the emergency loading limits of the conductor, or the adjacent substation transformer exceed its emergency loading limit.

To allow SCE to identify simple conductor upgrade projects this analysis would also be run to ignore the conductor overload criteria while still respecting the 600A breaker loading limits. This analysis would determine the maximum available to transfer load utilizing existing substation capacity. This solution is often more desirable due to the time and cost of adding substation capacity. The conductor loading, and overload length were collected to determine the potential cost to achieve the maximum load transfer utilizing the existing substation capacity

Extreme Temperature Scenario	Substation	Required Offload (MVA)	Load Transferred (MVA)	Max Contingency Excluding Conductor Limitations (MVA)	Required Conductor Upgrades (MI)
Scenario 1	Sub 1-1	31	18	32	4.6
	Sub 2-1	46	9	23	
	Sub 3-1	26	11	14.2	
Scenario 2	Sub 1-2	2	7	N/A	0
	Sub 2-2	7	10	N/A	
Scenario 3	Sub 1-3	52	13	18	3.8
	Sub 2-3	13	10	15	
	Sub 3-3	1	2	N/A	
Scenario 4	Sub 1-4	42	23	26	2.1
	Sub 2-4	50	17	25	
Scenario 5	Sub 1-5	1	9	9	0
	Sub 2-5	11	5	5	

Table 1 - Extreme Temperature Load Transfer Results

The cumulative transferred load and accepted load for each substation included in the analysis was collected. The difference between the amount of load transferred, and the required offload to achieve loading below the emergency loading limit after the outage dictates the load transfer capabilities for each scenario. If the available transfer did not meet the required transfer limits to achieve loading below the emergency loading limits post outage, then further mitigation is required. There are two mitigation options for substations with inadequate ability to transfer their load:

1. Install spare transformers at or near the substation or group of substations.
2. Reconductor the overloaded conductors in tie paths to allow maximum load transfer.

Conclusion

The study discussed in this paper described SCE's beginning process of identifying vulnerable assets and developing future plans to mitigate the potential problems caused by the climate hazards. Tens of thousands of assets were identified as being vulnerable to many climate impacts, including flooding, wildfire, debris flow, and extreme temperatures. Mitigation options utilizing existing infrastructure, creating new circuit ties, and microgrids were analyzed.

This study provided SCE the ability to meet the PUC requirement of determining the impacts and resiliency of the distribution system to predicted climate hazard threats. The analysis was implemented in an efficient and repeatable manner, allowing for future analysis to be repeated and expanded as needed. The results presented actionable mitigation methods to alleviate disturbances to the system to strengthen SCE's resiliency today and in the future.

Planning grid resiliency for climate impacts is going to be increasingly important in the years to come. Understanding where vulnerable assets are, how many there are, and what types of impacts they are vulnerable to will be critical in future planning efforts. When the climate events occur, a massive recovery effort will be required to restore grid functions, leaving many without power for extended periods of time. The number of vulnerable assets is great and getting mitigations in place will not happen quickly. Beginning the planning process of identifying the vulnerable assets will prove critical in ensuring the grid is ready for the climate change grid impacts of tomorrow.

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