A Study of the Feasibility of Projects using Grid Enhancing Technologies and Reconductoring with Advanced Conductors

Submittal to California Independent System Operator by Southern California Edison in compliance with Cal. Senate Bill 1006 (2023-2024)

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SOUTHERN CALIFORNIA EDISON®

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Introduction

This document summarizes the studies Southern California Edison (SCE) conducted to comply with the requirements of "Electricity: transmission capacity: reconductoring and grid-enhancing technologies," Cal. Senate Bill 1006 (2023-2024), referred to as "Senate Bill 1006" or "SB 1006."[1]

SB 1006 requires SCE, as a Transmission Operator, to submit the completed studies to the California Independent System Operator (CAISO) for review as part of its annual transmission planning process, by January 1, 2026.

The studies are intended to identify opportunities where grid-enhancing technologies (GETs) and reconductoring with advanced conductors may be able to "quickly and cost effectively increase transmission capacity" to connect new renewable or zero-carbon resources as California strives to accomplish 100% of retail electricity supply being met with zero-carbon resources by December 31, 2045.[2]

SCE and the CAISO have considered GETs as potential alternatives in past annual transmission planning processes.[3] This document reflects SCE's ongoing commitment to enhancing the capacity, flexibility, and safety of its transmission system, by continuing to incorporate GETs alongside traditional transmission projects as part of its established portfolio of solutions. SCE describes its methodologies for the three specified GETs in SB 1006 – dynamic line rating (DLR) systems, advanced power flow control (APFC) systems, and topology optimization (TO) – as well as its study methodology for reconductoring with advanced conductors.

SCE provides CAISO with nine potential candidate projects for DLR systems and 58 potential candidate projects for reconductoring with advanced conductors, including information on feasibility, cost, ratings, implementation timelines, and other relevant details. This document concludes with two reconductoring with advanced conductor projects submitted in this report and through the CAISO 2025-2026 Transmission Planning Process Request Window.

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[1] For the full text of Senate Bill 1006, see Bill Text: CA SB1006 | 2023-2024 | Regular Session | Chaptered | LegiScan

[2] Cal. Senate Bill 1006 (2023-2024)

[3] The CAISO's 2024-2025 Transmission Plan states that they "support appropriate application and deployment of these technologies, and has considered them on a case-by-case basis as potential alternatives in the past annual transmission planning processes." Additionally, "The ISO will continue to evaluate and consider opportunities for GETs in the annual transmission planning process. This is now required under FERC Orders No. 1920 and 1920-A. In addition, FERC Order No. 2023 requires transmission providers to consider opportunities to deploy GETs in the resource interconnection process."

Grid Enhancing Technologies Feasibility Study

SCE considered topology optimization (TO), advanced power flow control (APFC) systems, and dynamic line rating (DLR) systems in its GETs study. SCE leveraged its existing Annual Transmission Reliability Assessment (ATRA), the CAISO Transmission Planning Process (TPP), and the CAISO TPP Transmission Economic Assessment to fulfill the SB 1006 requirement of studying for the feasibility of using GETs. SCE's ATRA evaluates transmission system performance under various planning scenarios in compliance with NERC TPL-001-5.1, and resulted in 81 violations studied for TO and APFC.[4]

The information shared below is subject to change with each SB 1006 study submittal as SCE considers industry best practices, new tools, and new information.

Topology Optimization (TO)

Topology Optimization (TO) involves reconfiguring SCE's system to mitigate power flow violations on the Bulk Electric System (BES).

Methodology

The analysis began with reliability assessment results that identified power flow issues. To address a thermal overload during planning events P0-P7, candidate lines in the local area were systematically simulated as out-of-service, one at a time, to explore alternative system configurations. If a reconfiguration mitigated the thermal overload while supporting normal operating conditions, the resulting system became a base case for further evaluation.

Then, the base case was evaluated using power flow simulations to ensure the ability of the power system to withstand the loss of any single major component (like a transmission line, transformer, or generator) and system stability. Short-circuit analyses were also conducted to verify that the new topology would not create equipment rating violations at substations. Only configurations that supported normal operating conditions and passed all reliability analyses would be considered as viable Topology Optimization solutions.

Results

SCE did not identify any TO solutions that could achieve one or more of the purposes identified in SB 1006. Very few instances were identified where an additional line outage could mitigate a thermal overload caused by P0-P7 contingencies using emergency ratings, and only one instance was found under normal ratings as shown in Table 1. In all cases where TO might be applicable, cost-effective mitigations such as Remedial Actions Schemes (RAS) or system operational adjustments consistent with SCE's system and design standards, are already in place.

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[4] NERC TPL-001-5 is the Transmission System Planning Performance Requirement that SCE is required to comply with. It can be found here: https://www.nerc.com/globalassets/standards/reliability-standards/tpl/tpl-001-5.1.pdf.

Table 1: Topology Optimization Candidate with Future Mitigations via RAS

Overloaded Facility	Post Contingency Loading (%)	Contingency	Case	Mitigation
North of Lugo System				
P1 (single element outage)				
Lugo-Calcite 230 kV T/L	113.80%	Lugo-Pisgah 230 kV T/L	2040 Summer peak	The overload is caused by excess generation flowing to Lugo from Pisgah and Calcite. Electrically disconnecting Lugo from Pisgah resolves this overload. Taking out either Calcite-Pisgah 230 kV or Lugo-Calcite 230 kV Electrically disconnects Lugo from Pisgah, and the excess generation flows toward Cima and Eldorado. Future Calcite CRAS mitigates this overload and will be operational in 2028.

Advanced Power Flow Controllers (APFC)

Advanced Power Flow Controllers (APFC) are hardware and software that can actively manage power flow, pushing or pulling electricity to manage congestion and improve reliability.

Methodology

System performance violations in the 2025-2026 TPP reliability analysis were reviewed to determine if these could be addressed by redistributing power flows, as opposed to traditional solutions such as reconductoring, transformer upgrades, or new line construction. For each violation, APFC suitability was assessed by evaluating three criteria: network topology (i.e., the presence of alternative transmission paths where flows could be shifted), projected loading levels, and system operability constraints.

Where APFC deployment was considered technically feasible, conceptual solutions were modeled in steady-state power flow simulations to test their effectiveness and robustness across multiple contingency scenarios. This included examining potential benefits in normal and emergency conditions and confirming whether the devices could operate within their current, voltage, and control range limitations. Practical implementation factors were also evaluated, such as space availability at substation for controller installation, integration with protection system, and compatibility with existing operational practices.

Results

No transmission lines were suitable for APFC deployment to achieve one or more of the purposes identified in SB 1006. Common limitations identified through the evaluation process included insufficient alternative routing options to meaningfully redistribute power, device current limitations that constrained effectiveness, and substation site constraints that restricted deployment. All applicable cases as shown in Table 2 already have mitigations in place through

Remedial Actions Schemes (RAS) or system adjustments consistent with SCE's system and design standards.

Table 2: Advanced Power Flow Controller Candidates with Existing Mitigations via RAS or System Adjustments

Overloaded Facility	Post Contingency Loading (%)	Contingency	Case	Mitigation
North of Lugo System				
P1 (single element outage)				
Calcite-Pisgah 230 kV T/L	113.60%	Calcite-Lugo 230 kV T/L	2035 Spring Offpeak	Future Calcite CRAS
Lugo-Calcite 230 kV T/L	113.80%	Lugo-Pisgah 230 kV T/L	2040 Summer peak	Future Calcite CRAS
Kramer-Sandlot 230 kV T/L	121.00%	Coolwater-Kramer 230 kV No.2 T/L	2040 Summer peak	Kramer CRAS
Coolwater-Kramer 230 kV T/L	113.00%	Kramer-Sandlot 230 kV T/L	2035 Summer peak	Kramer CRAS
Kramer-Victor 230 kV No.2 T/L	109.40%	Kramer-Victor 230 kV No.1 T/L	2027 Summer peak	Mojave Desert RAS
Kramer-Victor 230 kV No.1 T/L	109.40%	Kramer-Victor No.2 230 kV T/L	2027 Summer peak	Mohave Desert RAS
P6 (multiple element outage)				
Coolwater-Kramer 230 kV T/L	126.80%	Coolwater-Tortilla 115 kV T/L Kramer-Sandlot 230 kV T/L	2035 Summer peak	Kramer CRAS
Kramer-Sandlot 230 kV T/L	103.20%	Coolwater-Tortilla No. 1 115 kV T/L Coolwater-Tortilla No. 2 115 kV T/L	2035 Summer peak	Kramer CRAS
Main System				
P1 (single element outage)				
Calcite - Lugo 220 kV T/L	106%	El Dorado - Lugo 500 kV T/L	2035 Spring Offpeak	Future Calcite CRAS
Calcite - Lugo 220 kV T/L	105%	Lugo - Victorville 500 kV T/L	2035 Spring Offpeak	Future Calcite CRAS
P6 (multiple element outage)				
Ellis - Johanna 220 kV T/L	118%	Imperial Valley – North Gila 500 kV, Ellis - Santiago 220 kV T/Ls	2027 Summer peak	Import from SDG&E or dispatch BESS
Barre (W) - Ellis No.1 220 kV T/L	117%	Barre - Lewis 220 kV, Barre (W) - Ellis No.2 220 kV T/Ls	2027 Summer peak	Increase import from SDG&E and/or system redispatch per SOB-04
Johanna - Santiago 220 kV T/L	110%	Loss of Ellis - Santiago 220 kV, Imperial Valley - North Gila 500 kV T/Ls	2027 Summer peak	Increase import from SDG&E and/or system redispatch per SOB-04
Antelope - Whirlwind 500 kV T/L	116%	Vincent - Whirlwind 500 kV, Antelope - Windhub 500 kV T/Ls	2040 Summer peak	System redispatch per SOB-04

Antelope - Vincent No.2 500 kV T/L	109%	Vincent - Whirlwind 500 kV, Antelope - Vincent No.1 500 kV T/Ls	2040 Summer peak	Tehachapi CRAS
Midway - Whirlwind 500 kV T/L	103%	Antelope - Windhub 500 kV, Antelope - Whirlwind 500 kV T/Ls	2030 Summer peak	System redispatch per SOB-04
Moorpark - Santa Clara No.1 220 kV T/L	104%	Pardee - Santa Clara 220 kV, Moorpark - Santa Clara No. 2 220 kV T/Ls	2035 Summer peak	System redispatch per SOB-04 or upgrading terminal equipment
Hinson - Lighthipe 220 kV T/L	105%	Harbor - Hinson 220 kV, Del Amo - Hinson 220 kV T/L	2040 Winter peak	System redispatch per SOB-04
Lighthipe - Mesa 220 kV T/L	105%	Alamitos - Del Amo 220 kV, Del Amo - Hinson 220 kV T/Ls	2040 Summer peak	System redispatch per SOB-04
P7 (common structure outage)				
Lighthipe - Mesa 220 kV T/L	102%	La Fresa - Laguna Bell 220 kV, La Fresa - Mesa 220 kV T/Ls	2040 summer peak	Preemptively dispatching available BESS resources and demand response

Dynamic Line Rating *(DLR) Systems*

Dynamic Line Rating (DLR) is hardware or software that more accurately determines the thermal limits of existing lines based on real-time environmental conditions.

Methodology

SCE focused on lines identified in CAISO's 2024-2025 TPP Economic Assessment for congestion and curtailment to determine where DLR could provide the highest benefits. Transmission lines with existing static rating limitations, such as series capacitors, were excluded from the analysis.[5] SCE then applied a data-driven analysis of historical weather conditions to identify the potential of DLR to increase line capacity.

It should be noted that the California Public Utilities Commission's Decision on SCE's 2025 General Rate Case did not approve DLR funding and has encouraged SCE to pursue a DLR pilot program in a separate application to the Commission or through its Electric Program Investment Charge (EPIC) program.[6]

Results

This resulted in nine out of eleven candidate circuits, which are summarized in Table 3. Table 3 is provided as a starting point for CAISO's review as part of its annual transmission planning process for economic, reliability, and policy goals. The Laguna Bell-Mesa No.1 and No. 2 transmission lines exhibited low or negative capacity changes under DLR conditions, indicating they may have limited suitability for DLR applications; however, they are included in Table 3 to share the results.

[5] The 2024-2025 TPP Economic Assessment Detailed Results can be found here: https://stakeholdercenter.caiso.com/InitiativeDocuments/Appendix-G-Draft-2023-2024-Transmission-Plan.pdf

[6] For more information on EPIC, visit: https://www.sce.com/regulatory/regulatory-information/epic.

Table 3: SCE Transmission Lines Identified as Potential Dynamic Line Rating System Candidates

#	Line Name	Voltage (kV)	Full Year		Summer Peak (June - September 4 - 9 pm)	
			Average % Capacity Change DLR Over Static	% Time DLR > Static	Average % Capacity Change DLR Over Static	% Time DLR > Static
1	Cool Water-Kramer	115	14.6	70.0	18.4	80.3
2	Lugo- Victor No.1	230	26.3	90.5	27.3	95.4
3	Lugo- Victor No.2	230	26.3	90.4	27.2	95.3
4	Lugo- Victor No.3	230	25.9	90.0	26.8	94.9
5	Lugo- Victor No.4	230	25.9	90.0	26.8	94.9
6	Lugo-Pisgah No.1	230	27.9	89.9	22.6	90.3
7	Lugo-Pisgah No.2	230	27.2	88.7	21.9	89.8
8	Laguna Bell-Mesa No.1	230	-1.1	37.9	8.3	80.4
9	Laguna Bell-Mesa No.2	230	-1.0	38.1	8.5	80.6
10	Eldorado-Cima-Pisgah No.1	230	44.3	98.2	27.1	98.0
11	Eldorado-Cima-Pisgah No.2	230	43.9	98.1	26.9	97.9

The scope and costs to fully implement DLR for a given transmission facility requires a detailed engineering assessment of factors such as physical terrain, asset conditions, potential sensor placements, and other specific solution requirements.

High-level cost and timeline estimates are provided below based upon vendor surveys and utility benchmarks and experience. The estimates do not include other necessary efforts – such as system integration (e.g., EMS, cybersecurity) and ongoing O&M – to fully operate the DLR product.

- Initial installation cost: $50,000 - $500,000 per line (based on vendor and solution selection)
- Initial installation timeline: 1 - 2 years per line (depending on transmission facility characteristics)

The wide range in installation cost estimate is due to vendor selection, detailed design, and engineering must be confirmed to arrive at a final scope and costs for each line listed.

Reconductoring with Advanced Conductors

Advanced conductors are wires capable of operating at higher temperatures with low sag and increased load-carry capabilities.

SCE has a demonstrated track record of deploying advanced conductors on its systems prior to the SB 1006 studies. Over the past decade, the company has reconductored hundreds of miles of transmission lines with this technology, enhancing system capacity, flexibility, and reliability.

Methodology

SCE completed a comprehensive review of its Bulk Electric System (BES), as defined under North American Electric Reliability Corporation (NERC) standards and operated by the CAISO, to identify which of its transmission lines can be reconductored with advanced conductors to achieve one or more of the purposes listed in SB 1006. The review applied a stepwise screening process:

- Transmission lines already operating at SCE's highest circuit breaker rating, those with series capacitor installations, and underground segments were excluded because these elements limit potential capacity gains.
- Lines already utilizing High-Temperature Low-Sag (HTLS) conductors, or with HTLS projects currently planned or in progress, were also excluded.

Results

Applying the screening criteria resulted in 56 candidate projects, which are summarized in the table below. These projects would serve as a starting point for CAISO's review as part of its annual transmission planning process for economic, reliability, and policy goals. Table 4 should be used with several notable items in mind:

1) The Cost Estimate column displays robust variability, because the risks of each project are unknown without detailed analysis performed to account for environmental constraints, construction contingencies, and other unexpected circumstances. SCE used estimates meant to reflect the potential costs and schedule including estimated risks and contingencies.
2) The wide ranges seen in the Cost Estimate and Potential Implementation Time columns are due to the range of project size. Most potential projects are substation to substation, while some are only segments of circuits or even a single span. Figures in both columns may increase significantly due to unforeseen factors and should not be used for decision making without additional detailed scoping.
3) Construction conditions typically cause a transmission project to take longer than anticipated. Construction on bulk transmission lines typically occurs between October and March due to environmental constraints and system availability. Storm systems and atmospheric rivers can greatly impact construction schedules. For instance, a five-year project may consist of three years for design and procurement, then two construction seasons that equate to an overall 24 calendar months, but only 12 months of actual construction.

Table 4: SCE Transmission Lines Identified for Potential Reconductoring with Advanced Conductors

#	Circuit Name	kV	Cost Estimate Range ($M)	Approximate Conductor Rating (Amps)[7]	Potential Implementation Time (Years)
1	ALAMITOS-BARRE NO.1	230	$76-$131	[redacted]	6
2	ALAMITOS-BARRE NO.2	230	$36-$62		5
3	ALAMITOS-CENTER	230	$57-$97		5
4	ALAMITOS-LIGHTHIPE	230	$59-$101		5
5	ANTELOPE-MAGUNDEN NO.1	230	$207-$386		7
6	ANTELOPE-MAGUNDEN NO.2	230	$207-$386		7
7	CENTER-DEL AMO	230	$30-$52		5
8	CENTER-MESA	230	$58-$100		5
9	CENTER-OLINDA	230	$93-$160		6
10	CIMA-ELDORADO-PISGAH NO.1	230	$382-$710		10
11	CIMA-ELDORADO-PISGAH NO.2	230	$383-$713		10
12	DEL AMO-HINSON	230	$57-$98		5
13	DEL AMO-LAGUNA BELL	230	$67-$125		5
14	EAGLE ROCK-GOULD	230	$35-$60		5
15	EL NIDO-LA CIENEGA	230	$1-$2		4
16	EL NIDO-LA FRESA NO.3	230	$19-$34		5
17	EL NIDO-LA FRESA NO.4	230	$19-$34		5
18	ELDORADO-MEAD NO.1	230	$77-$132		6
19	ELDORADO-MEAD NO.2	230	$77-$132		6
20	GOLETA-SANTA CLARA NO.1	230	$172-$322		7
21	GOLETA-SANTA CLARA NO.2	230	$172-$322		7
22	GOODRICH-GOULD	230	$42-$73		5
23	GOODRICH-MESA	230	$42-$73		5
24	HARBORGEN-HINSON	230	$8-$17		5
25	HINSON-LA FRESA	230	$26-$45		5
26	HINSON-LIGHTHIPE	230	$21-$40		5
27	KRAMER-VICTOR NO.1	230	$131-$244		6
28	KRAMER-VICTOR NO.2	230	$131-$244		6
29	LA CIENEGA-LA FRESA	230	$42-$79		5
30	LEWIS-VILLA PARK	230	$19-$34		5
31	LIGHTHIPE-MESA	230	$64-$111		5
32	LUGO-PISGAH NO.1	230	$233-$434		8
33	LUGO-PISGAH NO.2	230	$232-$432		8
34	MAGUNDEN-PASTORIA NO.1	230	$102-$191		6
35	MAGUNDEN-PASTORIA NO.2	230	$102-$191		6

[7] Conductor rating is redacted due to Critical Energy/Electrical Infrastructure Information (CEII) restrictions.

36	MAGUNDEN-PASTORIA NO.3	230	$102-$191	[redacted]	6
37	MAGUNDEN-SPRINGVILLE NO.2	230	$173-$323	[redacted]	7
38	MESA-RIO HONDO NO.1	230	$52-$89	[redacted]	5
39	MESA-RIO HONDO NO.2	230	$52-$89	[redacted]	5
40	MESA-VINCENT NO.1	230	$180-$307	[redacted]	7
41	MESA-WALNUT	230	$73-$126	[redacted]	5
42	MIRA LOMA-OLINDA	230	$85-$146	[redacted]	6
43	PADUA-RANCHO VISTA NO.2	230	$69-$119	[redacted]	5
44	MIRA LOMA-RANCHO VISTA NO.1	230	$31-$55	[redacted]	5
45	PADUA-RANCHO VISTA NO.1	230	$69-$119	[redacted]	5
46	MIRA LOMA-VISTA NO.1	230	$77-$132	[redacted]	6
47	MIRA LOMA-VISTA NO.2	230	$77-$132	[redacted]	6
48	MIRA LOMA-WALNUT	230	$99-$169	[redacted]	6
49	MOORPARK-SANTA CLARA NO.1	230	$89-$167	[redacted]	6
50	MOORPARK-SANTA CLARA NO.2	230	$89-$167	[redacted]	6
51	OLINDA-WALNUT	230	$32-$55	[redacted]	5
52	PARDEE-PASTORIA-WARNE	230	$10-$20	[redacted]	5
53	PARDEE-VINCENT NO.1	230	$160-$273	[redacted]	7
54	RIO HONDO-VINCENT NO.1	230	$161-$275	[redacted]	7
55	RIO HONDO-VINCENT NO.2	230	$3-$6	[redacted]	5
56	IVANPAH-BAKER-COOLWATER-DUNN SIDING-MOUNTAIN PASS	115	$327-$609	[redacted]	9

Proposed Reconductoring with Advanced Conductors Projects in the 2025-2026 TPP

SCE submitted two new reconductoring with advanced conductor projects in the 2025-2026 TPP. Both projects were identified as reliability-driven solutions to address thermal overloads. These projects also fulfill several intents of reconductoring with advanced conductors as stated SB 1006, such as increasing transmission capacity and increasing reliability. While a summary of the projects is provided below, SCE encourages the reader to refer to its 2025-2026 TPP submission for the complete analysis and project recommendations.

Table 5: Transmission Lines Proposed to be Reconductored with Advanced Conductors in SCE's 2025-2026 TPP

Line Name	Need	Proposed Solution	Benefits
Pardee-Santa Clara 230 kV	Line overloads	Reconductor 40 mi with high-temperature low sag (HTLS) conductor; Replace four (4) 230 kV, 1200 A disconnect switches at Santa Clara with 3,000 A equivalents	Increase the line rating to 2,180 A (Emergency); Resolves overloads
Santa Clara - Vincent 230 kV	Line overloads	Reconductor 40 mi with HTLS conductor; Replace four (4) 230 kV, 1,200 A disconnect switches at Santa Clara with 3,000 A equivalents	Increase the line rating to 2,180 A (Emergency); Resolves overloads

Closing

SCE is committed to improving the efficiency and reliability of its BES and enabling more renewable energy and zero-carbon resources to come online. This requires SCE to take proactive steps towards mitigating potential system issues identified in its ATRA, including expanding its menu of solutions to include new technologies, such as GETs and reconductoring with advanced conductors. All potential candidate projects and the corresponding information for each, such as cost and implementation time, are provided as initial high-level guides and require detailed engineering and scoping to further determine feasibility. SCE looks forward to working further with CAISO to refine feasibility, cost, and timing of any projects that may help to cost-effectively benefit the ISO-controlled transmission system. The Pardee-Santa Clara and Santa Clara-Vincent reconductoring projects were identified as reliability-driven projects and are being simultaneously submitted to CAISO as part of the 2025-2026 TPP.

SCE looks forward to opportunities to pilot GETs to close the gap between theory, planning, and real-world operationalization and improve the methodologies used in this study to develop a clearer understanding of how more GETs can be operationalized.

Consistent with the requirements of SB 1006, SCE's evaluation of GETs and reconductoring with advanced conductors will be completed on a recurring basis. The GETs study will be completed every two years, with the next evaluation to take place in 2027. The reconductoring with advanced conductors study will be completed every four years, with the next evaluation to take place in 2029.