Demonstration & Value Proposition of Utility Integrated Power Electronics

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SOUTHERN CALIFORNIA EDISON

Energy for What's Ahead℠

Southern California Edison (SCE) is one of the nation's largest electric utilities

15 MILLION RESIDENTS

5 MILLION CUSTOMER ACCOUNTS

50,000 SQUARE-MILE SERVICE AREA

1.4 MILLION POWER POLES

724,000 TRANSFORMERS

1,360 MW ENERGY STORAGE CONTRACTS

3,500 MILES OF OVERHEAD POWER LINES REPLACED WITH INSULATED WIRE

118,000 MILES OF OVERHEAD DISTRIBUTION & TRANSMISSION LINES

6,090 POLES UPGRADED TO FIRE-RESISTANT

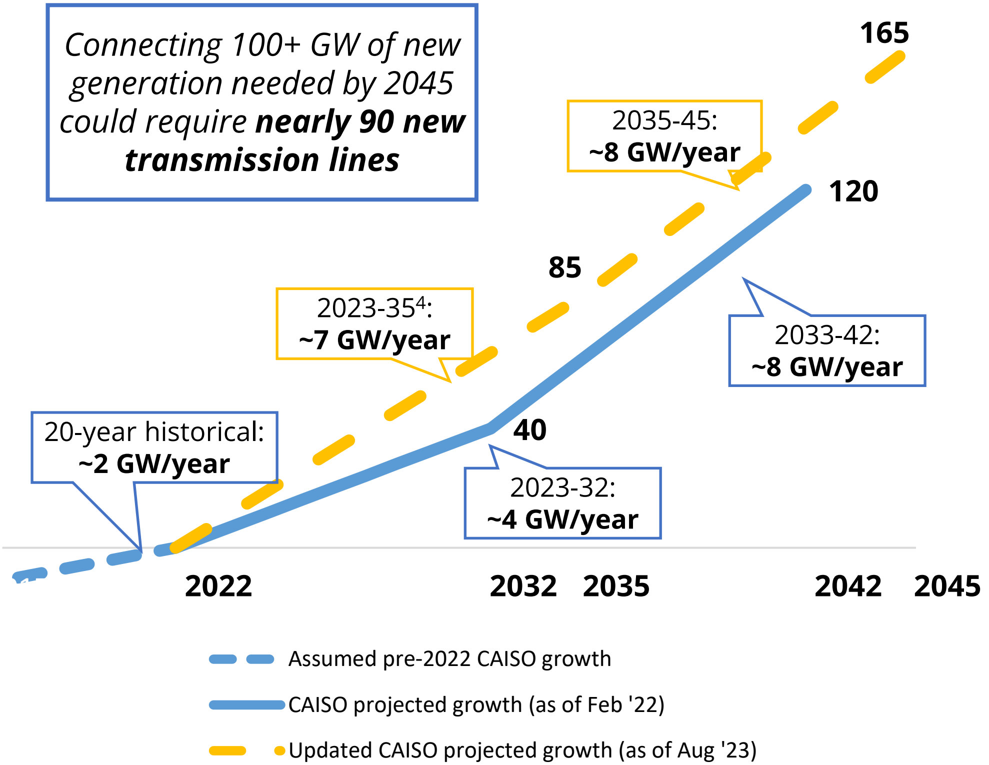
Countdown 2045: Grid Expansion Estimates

To meet 2045, SCE needs to build at 10x current rate for dist. & 4x for trans. Incremental improvement no enough!

TRANSMISSION

New CAISO transmission capacity needed

Connecting 100+ GW of new generation needed by 2045 could require ***nearly 90 new transmission lines***



DISTRIBUTION

SCE distribution projects needed

	Planned in next 10 years (2023-2032)	Incremental for *Countdown* (2033-2045)
New substations[1]	~10	~75
Substation expansions[1]	~45	~300
New circuits[1]	~130	~1300

SCE Distribution in 2045…
- **~25% larger distribution system**
- ~90% average circuit utilization
- Many service transformers and wires upgraded

Projects SCE is working on

SCE is laying the ground work to incorporate Power Electronics in the grid.

- **DC Transmission For Increased Capacity**
  - Solid State Power Substation (SSPS) – conversion of a Subtrans line from AC to DC to increase power throughput.
  - Valuation Proposition
- **DC as a Service**
  - Medium Voltage DC power Supply (MVDCPS) – applicable to DCFC and data centers
  - Proposed as utility owned device.
- **Transportation Electrification Projects**
  - Swift Electrification of Transit – EPIC 4
  - Extreme Fast Charge (XFC) – EPRI/NREL DOE project
  - High Power Charging Lab – eTRUC Facility
- **Distribution Transformers**
  - Early stage demo with EPRI IncubatEnergy Lab
  - Support for next phase hosted at SCE EDEF Facility.

Solid State Power Substation (SSPS)

Conversion of 66 kVAC line to 65kV DC to increase capacity within existing right-of-way

Project Scope

Installation of a medium-voltage direct current (MVDC), modular multi-level converter (MMC) at an A and B-substation to create a DC-link. SSPS will provide reliable capacity upgrades to better integrate higher penetrations of DER, provide real and reactive power management, bi-directional (reverse) flow capabilities, enhanced protection, monitoring capabilities, and enable hybrid AC/DC topologies in the future.

Project Objectives

- Increase electric power delivery 1.5x in existing right-of-way through the construction of a solid-state power substation delivering medium-voltage direct current (MVDC)
- Demonstrate enhanced power quality control, protection, improved system operation to support DER integration and service for vehicle/building electrification
- Deliver community benefits for reducing local emissions through electrification and provide resources to facilitate electrification moving forward
- Progress workforce development to support this novel technology implementation, operation and maintenance to facilitate a successful energy transition
- Provide technology and operational support to achieving California's 2045 carbon neutrality goal

SSPS Converter Stations

Solid State Power Substation Converters:

- Provides voltage, phase, and frequency control including harmonics
- Allows for hybrid service topologies to customers (i.e., AC and DC)
- Capable of riding through system faults and disruptions (e.g., HVRT, LVRT)
- Enables dynamic coordination of fault current and protection for both AC and DC distribution systems and networks
- Provides bidirectional power flow control between sub-transmission and distribution systems while buffering interactions between the two

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Energy for What's Ahead

Value Stacks for Financial Analysis

How can we value a $166M project for 65MW increased Capacity? → TIME

- As a direct comparison to a traditional power transformer, Power Electronics are up to 5x more expensive. However, this does not capture the value proposition.
- Traditional build out is time consuming & likely bandwidth limited → 10x / 4x
- Customer will have to use alternative means to meet those requirement, likely natural gas for residential and commercial heating or diesel/gasoline for transportation.
- What value does accelerating electrification provide?

At macro level –> Incremental energy delivery cost is $130/MWH, Average commercial cost → $157/MWH

Benefit Stack

- **Assume 5 yr differential in serving on 65 MW of load – 1.3 TWH**
- **Self Generation Cost Differential - $418M → New Customer Benefits**
- **Lost revenue for renewable generators - $150M → Generators Benefit**
- **Additional Capacity Utilization - $40M → All Customers Benefit**
- **Carbon emissions - $41M → All of Society Benefit**
- **Power Quality / System Stability - $46M → Customers on Circuit Benefit**
- **Efficiency value ~ $1.7M / year → All Customers Benefit**

Potential Value Stack for MVDC		
Energy Estimation		
Incremental Capacity (MW)		65
Load Factor		0.45
Time Acceleration vs New Line (yrs)		5
Total Energy (MWH)		**1,281,150**
Unserved Generation Cost		
SCE 2024 Gen Purchase rate ($/MWH)	$	117
Lost Revenue for Generator ($MM)	$	150
SCE Delivery Rate ($/MWH)	$	157
SCE Delivery Charge ($MM)	$	201
Total Utility Billing	**$**	**351**
Self Generation Cost- Diesel - $/kWh	$	0.60
Total Self Generation Cost ($MM)	$	769
Value Difference ($MM)	**$**	**418**
Unserved Load Value - Utility Delivery Charges		
Energy Mix (Commerical / EV)		0.7
EV Charge Rate ($/kWH)		0.173
Value of unserved EV load ($MM)	$	155
Average Commercial Rate ($/kWh)		0.157
Value of unserved Building Load ($MM)	$	60
Sub-Total	**$**	**215**
Emissions / Carbon Value		
Diesel Emissions (MT CO2 / MWH)		0.93
Natural gas (MT CO2 / MWH)		0.35
SCE Average emission (MT CO2 / MWH)		0.2
Saved CO2 Emissions		712,319
Average CO2 Cost 2028-2032 ($/MT CO2)		58
Carbon Value ($MM)	**$**	**41**
Reactive Power Value		
Reactive Power Capability (MVAR)		184
STATCOM Cost ($/VAR)		0.25
Value of STATCOM ($MM)	**$**	**46**

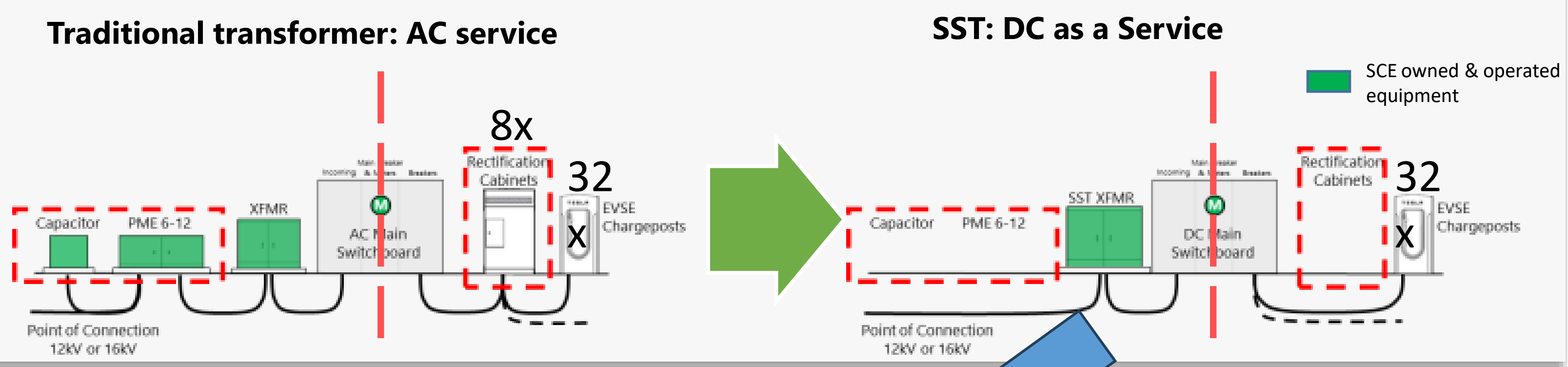
SST for DC as a Service (DCaaS)

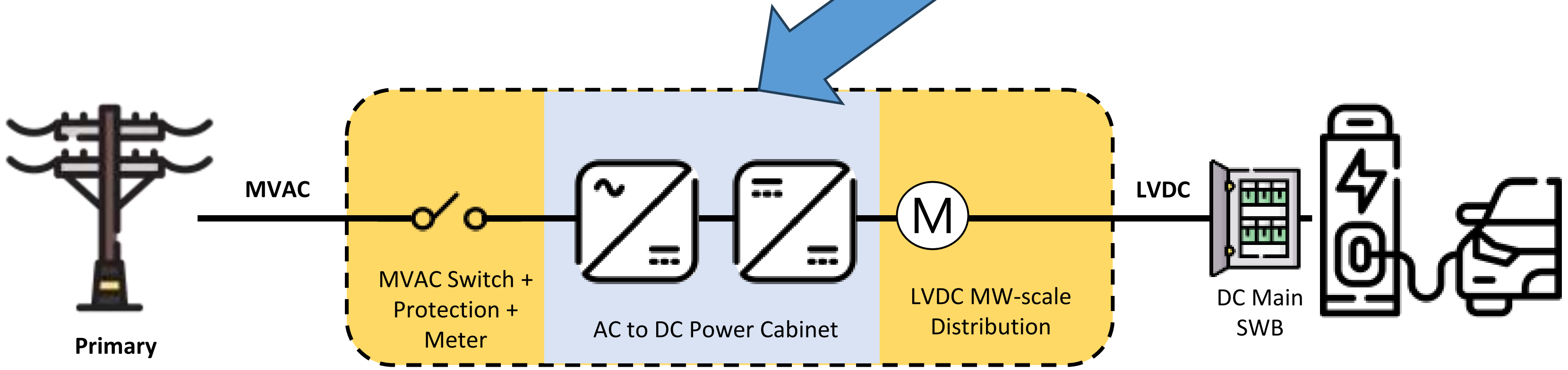
Power Electronics can reduce footprint and accelerate TE

Current EV service paradigm

The multiple utility owned components required (switch, Capacitor, Transformer) to service electric vehicle (EV) charging stations inhibit rapid deployment of EV charging stations, due to cost and footprint. Since Transportation Electrification is a pillar to achieve the State of California and SCE emission goals, delays in EV adoption caused by lack of charging infrastructure is a problem for achieving statewide goals.

Targeted use case: 4000A @ 480V servicing DC Fast Charging customer





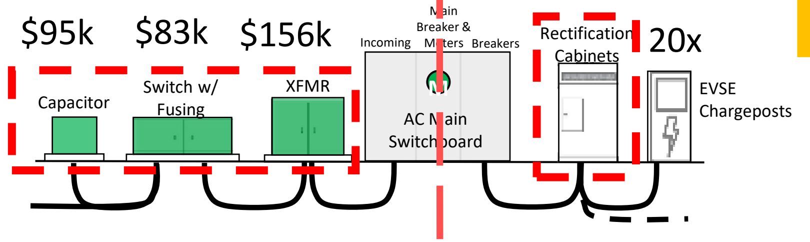
Concept of Utility owned and operated Medium Voltage DC Power Supply

Concept of Customer owned and operated Electric Vehicle Supply Equipment (EVSE)

Commercial EV – Existing AC Architecture

Targeted use case: 2 MW DC capacity for DC Fast Charging customer

Traditional transformer: AC service		Cost of Utility Equipment & Rectification Cabinets	
UTILITY OWNED, AND OPERATED	CUSTOMER OWNED, AND OPERATED	UTILITY OWNED, AND OPERATED	CUSTOMER OWNED, AND OPERATED
$95k $83k $156k	5x $54-142k; 20x	$95k Cap $83k Switch +$156k XFMR ~ $334k Total[1]	$572k Rec. Cab. +143k Indirect +$105k Const. ~ $820 k Total[2]



SCE Implications

Separation of functions into separate boxes creates inefficiencies in space, construction, and project management. EV developer cost is high and can only be amortized over that single site.

Design Basis:

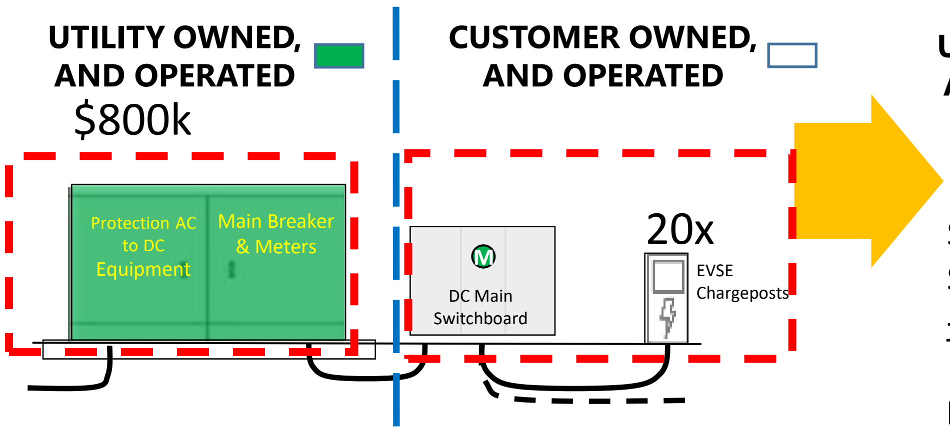
- **Utility Equipment:** Cap, Switch, and XFMR all on separate pads with clearance requirements take up significant site footprint. Note Capacitor not always required, deployed when SCE engineering determines that the circuit requires Volt/Var support, typical for 1500 kVA+ sites
- **Rectification:** Customer owned and operated rectification cabinets. To be conservative, assume material cost is 80% of total cost, consistent with site data of material versus total cost. Not considering Chargeposts / Dispenser costs
- **$334k Utility Cost + $820k Customer Cost = $1,154k Total Cost**

1. Cost based on SCE 2024 standard units cost. ~1/3 of cost can be allocated to construction costs
2. Average from rectifier source is $286/kW for price. Assuming indirect cost of 20%.

Commercial EV – SCENARIO: DC as a Service (DCaaS)

Targeted use case: 2 MW Utility provided DC service to customer at ~1500 VDC @ 1333A

Equipment: Medium Voltage DC Power Supply	**Cost of Utility Equipment & Rectification Cabinets**



UTILITY OWNED, AND OPERATED

$800k MVDCPS
$200k Indirect
+$105k Construct
$1,105k Total
Net Increase ~$800k

CUSTOMER OWNED, AND OPERATED

-$572k Rec. Cab.
-$70k const
-$50k indirect
+$40k Dispenser.
Net Reduction ~$650k

New System Implications

Equipment cost may be at parity or even lower for the new design. Additions of Buck circuit in Dispenser and DC Switchboard may lead to a premium of 1.2x traditional system cost. However, the benefit of smaller footprint expanding deployment base, there is good potential that the technology is cost competitive with traditional service.

Assumptions:

- **Utility Equipment:** MVDCPS – included switch, metering, and power conversion in single footprint.
- **Rectification:** Functionality incorporated into the MVDCPS
- **Unknowns: Cost of DC switchboard, dispenser availability.**
- **+800k in Utility cost - $650k in customer cost = $150k from cost parity**

EPIC 4: Swift Electrification of Transit (SET)

SCE Implications

The project aim to incorporate solid state power electronics to demonstrate the benefit to load growth.

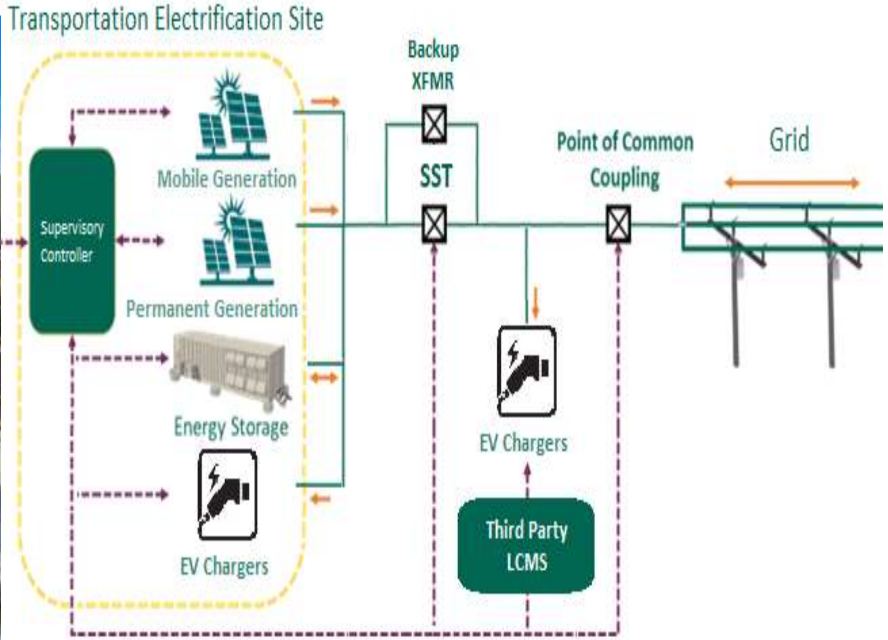
Swift Electrification of Transit (SET)

This project aims to accelerate electrification by exploring Vehicle to grid integration with energy storage systems to provide backup power and grid services.

Key objectives include:

- **Expediting charging infrastructure deployment through energy storage, dynamic charge management, and grid constraint management.**
- **Reducing land acquisition needs by optimizing service point sizing based on real-world loads and storage capabilities.**
- **Ensuring EV charging infrastructure resilience during outages with microgrid controllers and dynamic charge management.**

SET project is releasing an RFP to procure an SST to facilitate



Benefit Stack

- ➢ **EV charging stations trigger new Dist. Circuit with 2+ year lead time**
- ➢ **Deploying solutions to allow faster connection delivers same value evaluation as SSPS**
- ➢ **Multiple years of early connection provide benefit to both EV customers and all customers by improving affordability**

Extreme Fast Charging & eTRUC

SCE is supporting EPRI/NREL in testing SST for DCFC

SCE Implications

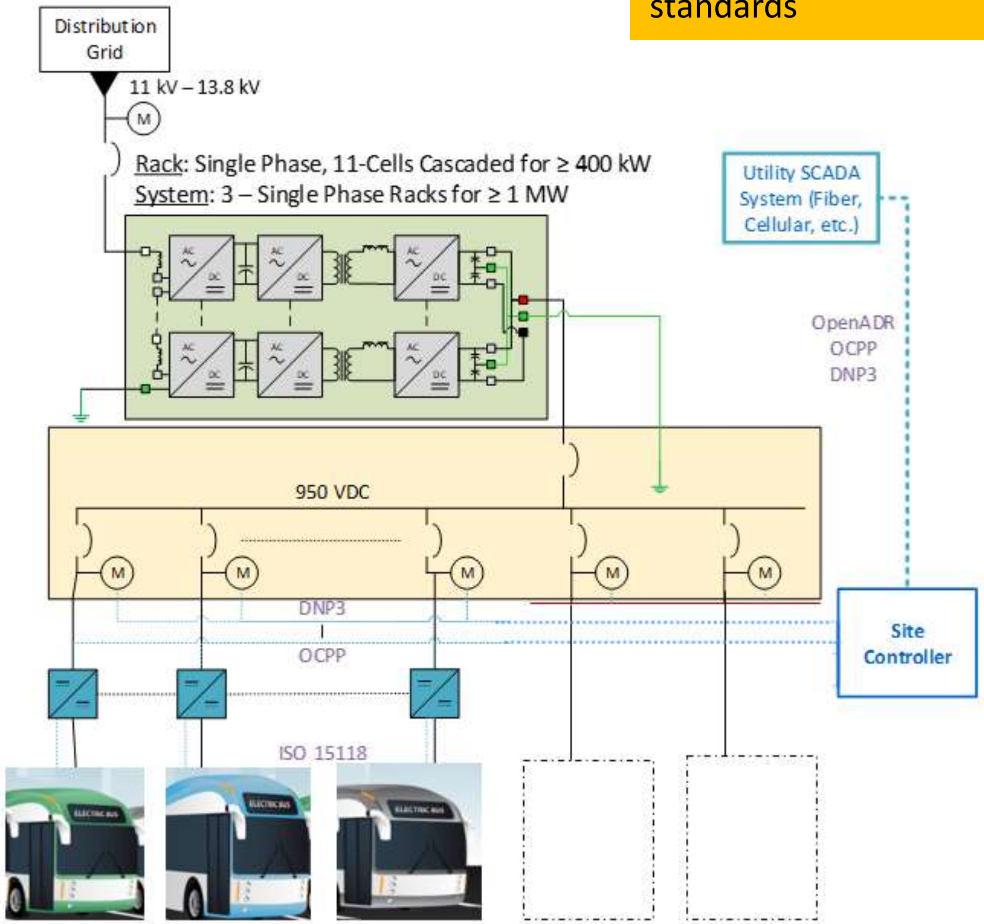
Project aligns with vision of DCaaS. Facilitate demonstration of feasibility of technology and development of processes & standards

Overall Objective

Develop and demonstrate medium voltage Silicon Carbide (SiC) based AC/DC conversion equipment and the DC-DC head unit for use in extreme fast charging (XFC) equipment of simultaneously charging multiple light duty plug-in electric vehicles.

Project Highlights & SCE's interest:

- **Architecture aligns with SCE's DCaaS vision**
- **SCE has been providing technical support for the project**
- **Currently, EPRI prepping to test MVDCPS at NREL**
- **SCE plans to test the MVDCPS at its Electric Vehicle Technical Center in Pomona, CA**
- **SCE will utilize its eTRUC High Power Charging Lab (HPCL) to test medium voltage converter.**



HPCL – High Power Charging Lab, eTRUC

Overview

The electric truck utilization center (eTRUC) Advance Transportation Research Center (ATRC) is a facility available to third parties and vehicle/charging industry manufacturers to support high quality electric refueling infrastructure.

Site Highlights:

- **Connection to 12kV distribution circuit**
- **2.5 MVA interconnection**
- **Large open space with trenching to allow flexible test setup**
- **Keysight test instrumentation with AC & DC emulators**

Solid State Distribution Transformer

Distribution Solid State Transformer for FITT FOA

Overview

EPRI led Field demonstration to install at appropriate test site a flexible and innovative solid state transformer design. The goal is to advance and accelerate the commercialization of this novel device through R&D, use case economic analysis, laboratory evaluation, and field testing at multiple utilities.

Benefits:

- **Voltage Regulation for Voltage Optimization**
- **Power Factor Correction**
- **DC Bidirectional Bus**
- **Protective Device**

Valuation:

- **Quantification of value is less mature for this use case**
- **Power Factor Correction**
- **DC Bidirectional Bus**
- **Protective Device**

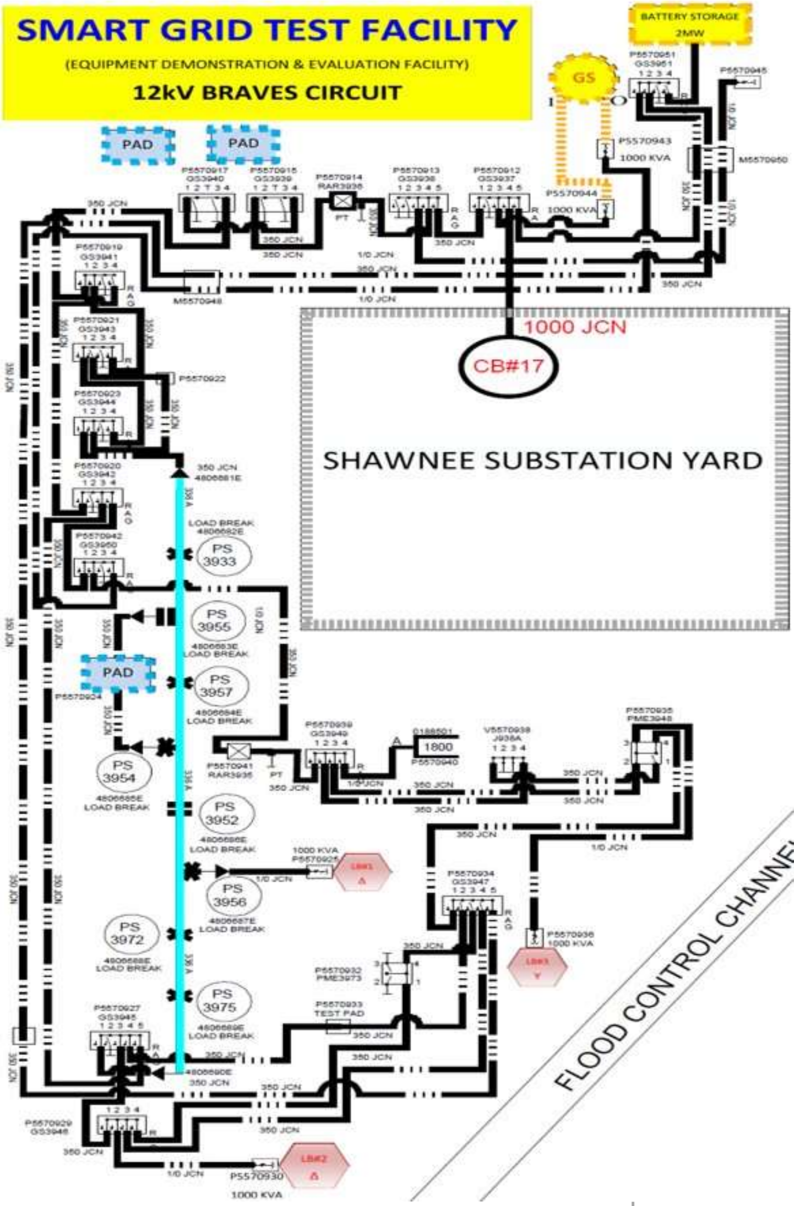
Equipment Demonstration & Evaluation Facility (EDEF)

Overview

EDEF is a facility co-located with an SCE 66/12 kV substation that can facilitate the testing of distribution equipment both overhead and underground on a dedicated test circuit (BRAVES)

Test equipment include:

- **Automatic Reclosers**
- **RAG Switches**
- **Load banks**
- **Capacitor banks**
- **Grid simulators**

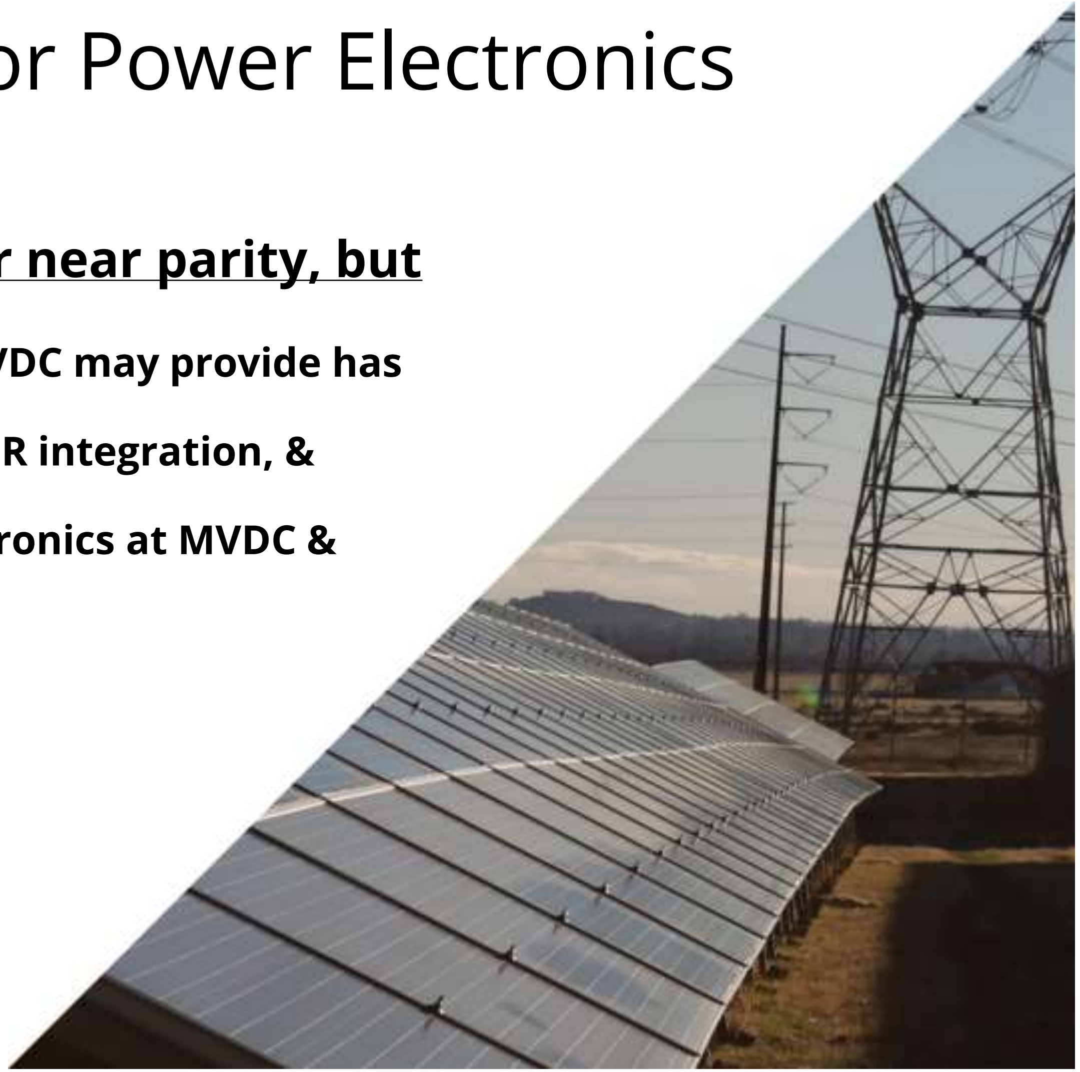


Conclusion

Conclusions on Value Proposition for Power Electronics

With performance from SiC, there are use cases at or near parity, but require the right system level framing to justify.

- **In Sub-Transmission – Faster load growth interconnection for MVDC may provide has significant opportunity value**
- **At Grid Edge – MV to LV DC systems open up EV sites, increase DER integration, & relieve circuit loading when coupled with storage**
- **SCE is supporting demonstration & pilot projects for power electronics at MVDC & LVDC level**
- **Hosting monthly Technical Advisory Working Group.**
- **Testing facilities to support product demonstrations.**
  - Home - SCEIdeas.com**for submission to SCE**
  - eTRUC Laboratory – eTRUC for use of eTRUC High Power Charging Lab



Appendix