SCE Microturbine Generator Testing Program

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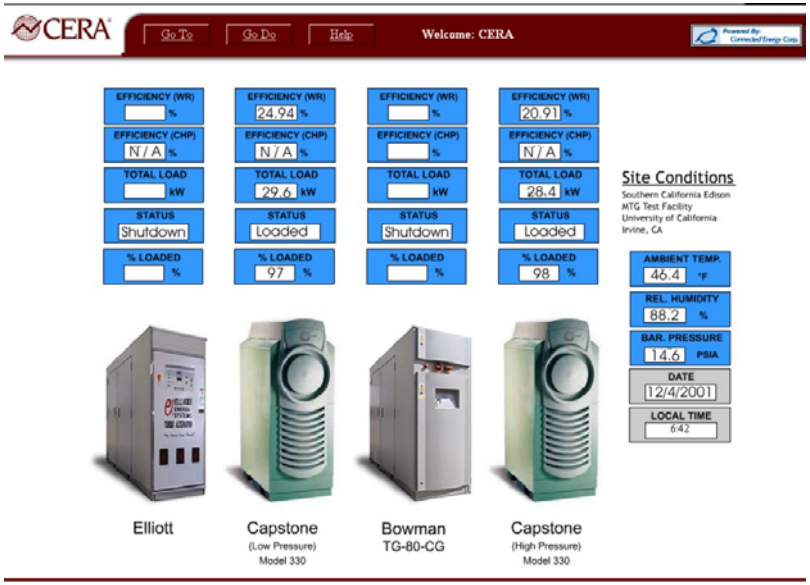
DOE Peer Review of Microturbine & Industrial Gas Turbine Programs
March 13, 2002
Fairfax, VA

SCE Microturbine Generator (MTG) Testing Program

Goal & Objectives:

Goal: determine the performance, reliability, operability, availability, maintainability, and overall characteristics of commercially available MTGs.

Objectives: compare MTGs' actual performance to performance specifications and industry/other standards, such as emissions.



Accomplishments:

- $3.0 million program in progress since 1996
- 12 MTGs tested or in test
- Two to four more MTGs expected for testing
- Completed machine performance tests on 8 MTGs
- Completed initial electrical behavior testing
- Over 44,000 hours of testing
- Implemented "live" browser enabling technology

DOE Program Manager: Debbie Haught

SCE Program Manager: Stephanie Hamilton

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SCE's MTG Program

Goal & Objectives:

Goal: determine the performance, reliability, operability, availability, maintainability, and overall characteristics of commercially available MTGs.

Objectives: compare MTGs' actual performance to performance specifications and industry/other standards, such as emissions.

Collaborations: DOE, CERTS, EPRI, CEC, CERA, UCI, Connected Energy, GE, SNL, ORNL, MTG mfgrs.

Accomplishments:

- $3.0+ million program in progress since 1996; results have driven improvements to MTGs and program builds public awareness
- 12 MTGs tested or in test; two to four more MTGs expected for testing
- Over 48,000 hours of testing
- Completed machine performance tests on eight MTGs
- Completed initial electrical behavior testing
- Numerous site tours, presentations, papers

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SCE MTG Test Bed at University of California at Irvine (UCI)

- 4 test bays
- 400 amp 480 volt service
- 100 psig natural gas with ability to blend for lower Btu testing
- Cogen heat dissipation ability
- 80 kW load banks for stand alone and “micro grid” testing
- Electronic data acquisition and instrumentation for gas & electric
- Veteran two-person testing crew
- Standardized testing procedures
- Ability to do specialized/custom testing

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Desirable Attributes vs. Test Parameters

- ATTRIBUTES
  - Heat rate 12,000 to 16,000 BTU/kWh
  - Good Part Load Performance
  - Emissions < 9 ppm
  - Power Quality < IEEE 519
  - Noise < 70 dBa
  - Endurance = 40,000 hours
  - Installation = Easy & Cheap

- TEST PARAMETERS
  - Overall unit efficiency
  - Net Power Output
  - Emissions
  - Power Quality
  - Noise
  - Endurance
  - Ease of Installation
  - Operability
  - Maintainability

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Data Acquisition System

Parameter	Measuring Instrument
• Electrical Energy Produced	• 3-phase electrical meter with pulse output module
• Fuel Consumed (Gas Flow)	• Gas flow meter
• Fuel Temperature	• Resistance Thermal Detector (RTD)
• Gas Pressure	• Pressure transducer
• Water Flow	• Water flow meter
• Boiler Air Temperature – Inlet and Outlet	• Thermocouple
• Water Temperature – Inlet and Outlet	• RTD
• Power Quality Snapshots	• BMI 7100 and BMI 8010 power quality meters
• Ambient Temperature	• Temperature Probe
• Relative Humidity	• Solid State IC
• Barometric Pressure	• Barometric pressure transducer

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Testing Schedule & Status: 03/01/02

Capstone "B" 30 kW	Jan-97	958	Completed
Capstone "B" 30 kW	Jan-97	967	Completed
Capstone 10 Pack	Apr-97	26	Completed
Capstone "C" 30 kW	May-97	3,794	Completed
Capstone "C" 30 kW	Jul-97	2,079	Completed
Bowman 35 kW	Feb-99	100	Completed
Bowman 60 kW	Jun-99	60	Completed
Capstone HP 30 kW	Apr-99	18,881	Operating
Parallon 75 kW	Jun-00	5,806	Completed
Capstone LP 30 kW	Aug-00	12,341	Operating
Bowman 80 kW	Jun-01	3,424	Operating
Total		48,436	

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Capstone 30 kW Description

- Model 330 rated output: 30 kW at ISO
- 480 VAC, 3-phase, 60 Hz
- Recuperated single stage radial flow compressor and turbine on a single shaft, integrated with generator
- Equipped with a low NOx combustor
- Not equipped with a waste heat recovery boiler
- Fourth generation unit
- One unit only capable of grid connect
- One unit capable of stand alone and grid connect operation

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Capstone 28 kW Results

- Several overspeed trips were resulting from flame control algorithm; Capstone remotely downloaded revised control system software; no overspeed trips since software revised
- Reliable operation following resolution of overspeed
- Comparing manufacturer's efficiency and heat rate claims with test results converted to a common basis, resulted in testing results consistent with claims as shown below @ 70°F, about sea level, and LHV:

	(tested)	(claimed)
Efficiency	23.7% ± 0.45%	24.5% ± 0.5%
Heat rate	14,415 BTU/kWh	13,931 BTU/kWh

Capstone 28 kW Results

- Total Harmonic Distortion (THD) requirements specified by IEEE 519 were met:
  - Voltage THD: 1.6% measured average < 5% IEEE 519
  - Current THD: 5.87% measured average < 8% IEEE 519
- Noise measurement taken at 2m due to site conditions, e.g. obstructions and site compressor noise. Noise measured 70 dBA @ 2m, consistent with manufacturer's claim, 65 dBA, 10m.
- Emissions test results met SCAQMD requirements:

Manufacturer Claim	SCAQMD Standard (Rule 1303)	Test Results
NOx: < 9ppm (0.023 lb/hr)	NOx: 0.2 lb/hr	0.0031 lb/hr
No Claim	CO: 11.0 lb/hr	0.11 lb/hr

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Grid Impact Testing

- Uncovers problems potentially hindering grid interconnection of DG
- Testing needed to determine:
  - Power quality
  - Protection/ anti-islanding issues
  - Interconnection standards/rules
  - Dynamic behavior so simulation models can be built

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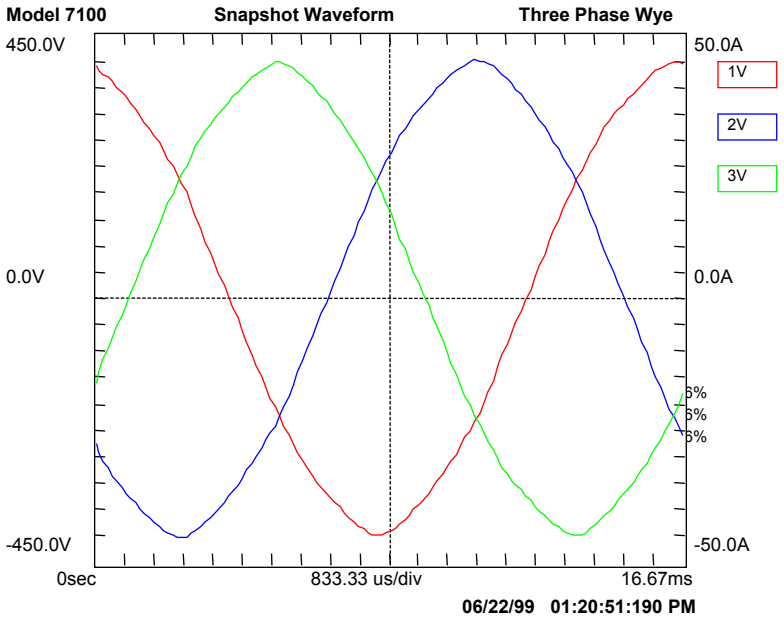
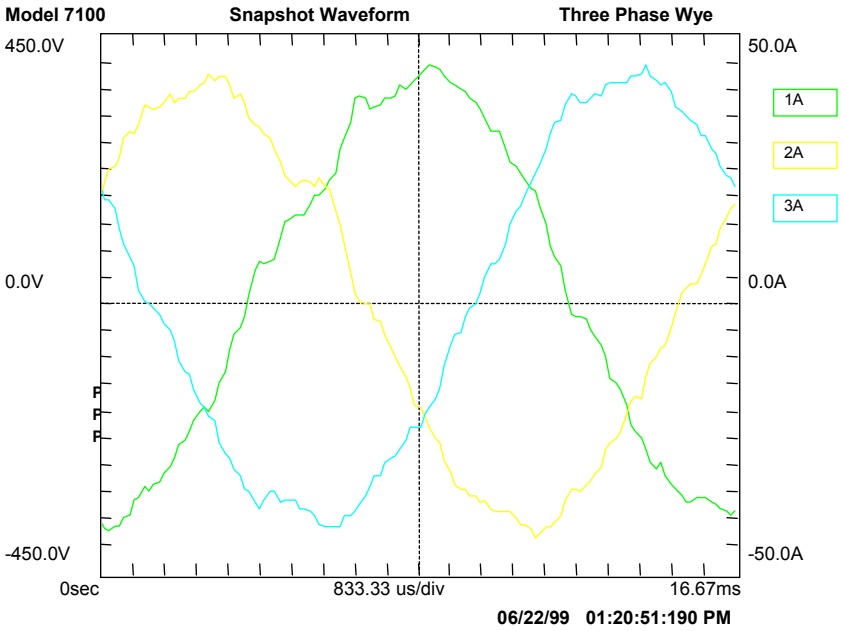
Capstone Voltage & Current Waveforms

Voltage Waveform Snapshot



Current Waveform Snapshot



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Dynamic Testing

- Tests to observe the behavior of MTGs when interconnected with the utility grid
- Tests conducted at the SCE test bed
- Power ramping tests in both grid-connected and stand-alone modes (slow dynamics)
- SCE working with ORNL, SNL and GE to define additional testing to obtain data for fast dynamic models
- Data helps build models to simulate operation of the MTGs in a distribution system

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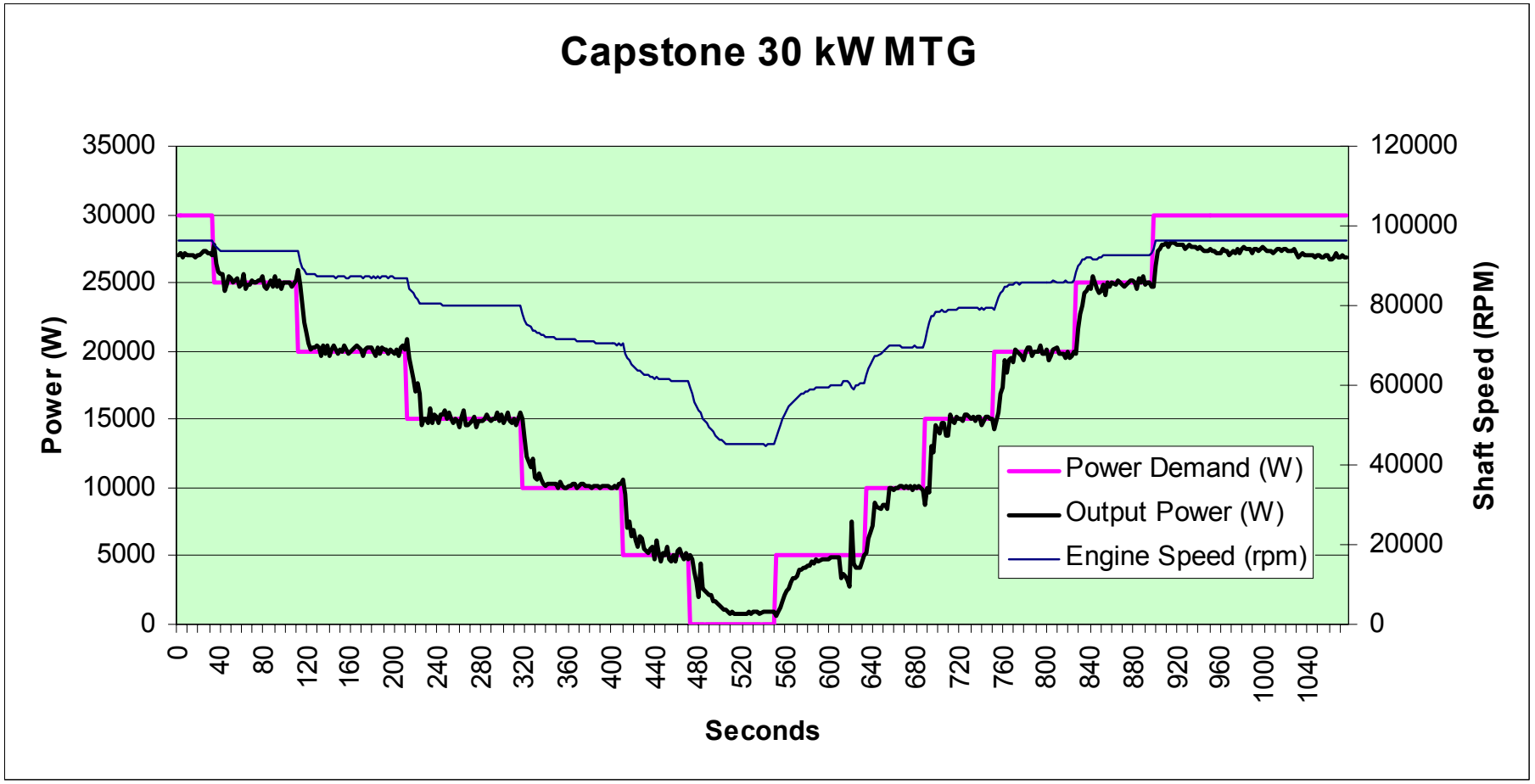
Capstone Grid Connect Tests



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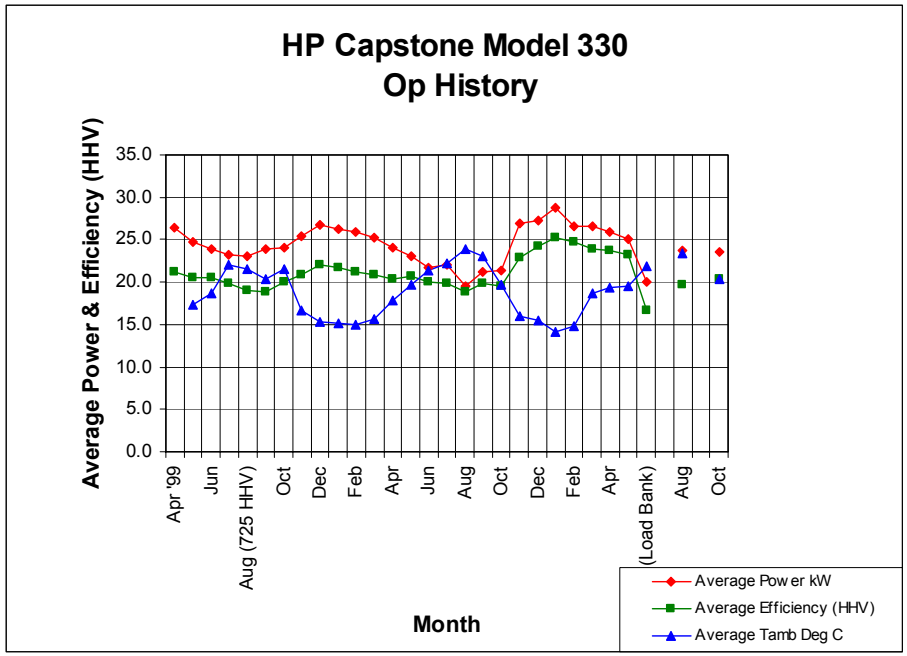
“New” Capstone 30 kW from “Old” Capstone 28 kW



- DPC [digital power controller] was upgraded Oct 2000 – this MTG became a different machine:
  - Higher net power output by 2 kW max, just over 7%.
  - Increased machine efficiency
- Two DPCs have been replaced on this machine due to failure. In both cases, failure was due to too high power supply voltage 16+ vs. nominal is 13.8 VDC. Capstone reports no other similar failures.

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Honeywell 75 kW Description

- Parallon™ 75 kW at ISO
- 275 AC with Honeywell transformer option added to boost to 480 VAC, 3-phase, 60 Hz at site
- Recuperated single stage radial flow compressor and turbine on a single shaft, integrated with generator
- Not equipped with a heat recovery boiler – option is available
- Grid parallel or stand-alone operation
- Internal gas compressor

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Bowman 80 kW CHP Description

- Bowman 80 kW at ISO
- 480 VAC, 3-phase, 60 Hz
- Recuperated single stage radial flow compressor and turbine on a single shaft, integrated with generator
- Integrated heat recovery boiler
- In grid parallel operation
- Will test stand-alone operation

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Summary of Testing Results: 3/07/02

- 1997 Testing of Capstone units (Beta, Charlie – pre-commercial)
  - Did not meet manufacturer's expectations
  - First & second generation units
  - Began testing "next generation" in 1999
- 1998 No MTGs commercially available to purchase and test
- 1999 Testing of Bowman units (pre-commercial)
  - Did not meet manufacturer's expectations
  - First generation units;
  - Began testing "next generation" in 2001
- 1999 Testing of High Pressure Capstone unit
  - Met manufacturer's claims
  - Fourth generation unit
  - Began testing "next generation" in 2000

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Summary of Testing Results: 03/07/02 (continued)

- 2000
  - Capstone high pressure unit's DPC upgraded and replaced resulting in higher power output and increased efficiency
  - Began testing low pressure Capstone and Honeywell
- 2001
  - Initial results for Capstone both LP and upgraded HP
  - Honeywell results
  - Performed electrical characterization on Capstones and Honeywell
  - Began testing Bowman
  - Elliot returned to UCI test site and testing to resume
- 2002
  - Begin testing of Ingersoll-Rand (I-R)
  - Seek other MTGS, such as Capstone 60 kW, Turbec 100 kW CHP
  - Test "new models" from Bowman & I-R
  - Finalize results for Capstones and Bowman

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Future testing -- Elliott 80 kW

- Elliott 80 kW at ISO
- 480 VAC, 3-phase, 60 Hz
- Recuperated single stage radial flow compressor and turbine on a single shaft, integrated with generator
- Not equipped with a heat recovery boiler – option is available
- Grid parallel or stand-alone operation

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Future testing -- Ingersoll-Rand 70 kW

- Ingersoll-Rand 70 kW at ISO
- 480 VAC, 3-phase, 60 Hz
- A dual shaft recuperated MTG:
  - A radial flow compressor and gasifier turbine on one shaft
  - A radial flow power turbine on the other shaft
  - The power turbine drives the reduction gear and induction generator for grid parallel-only operation
- Heat recovery boiler option available
- Internal gas compressor

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Future Testing - Capstone 60 kW Description

- Capstone 60 kW at ISO
- 480 VAC, 3-phase, 60 Hz
- Recuperated single stage radial flow compressor and turbine on a single shaft, integrated with generator
- Not equipped with a heat recovery boiler – option is available
- Grid parallel or stand-alone operation

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Selected Quotes regarding program, tours, presentations

"This is really cool!" Hugh Anderson, Investment Banker, Banc of America Securities

"No one else is even close!" Don Baker,TVA manager

"Far exceeded our expectations!" Chris Hunter, Johnson & Johnson, worldwide strategic engineering manager

"Edison's contributions to these technological advances is commendable," Karen Johanson, ISO BOD

"Your discussion of most recent results was of great interest to participants," Gil Rodgers & Steve Taub, Directors, CERA Distributed Energy Summit

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Connected Energy Corp.

ENABLING DISTRIBUTED UTILITIES

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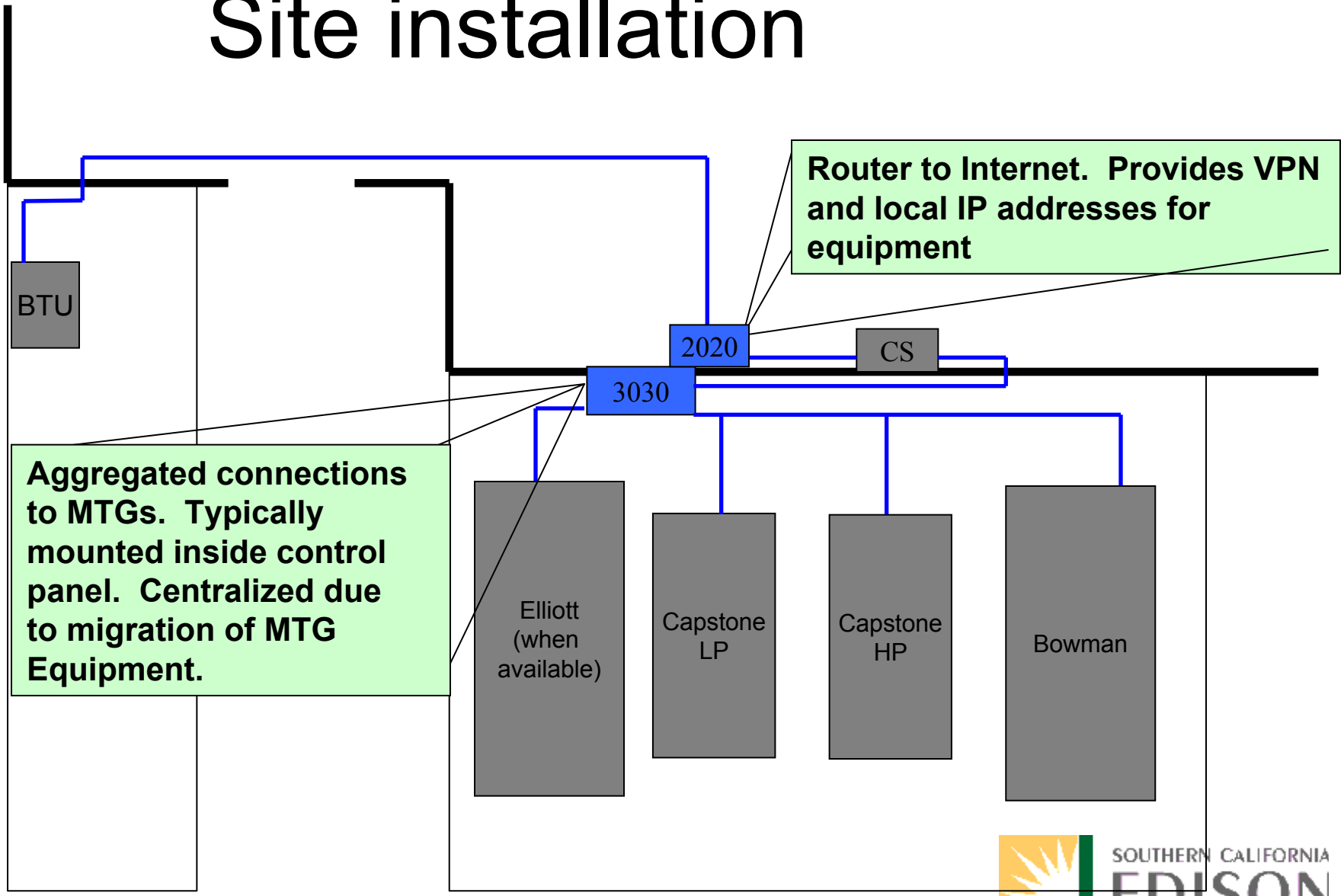
Blue lines = installed Wiring

Site installation



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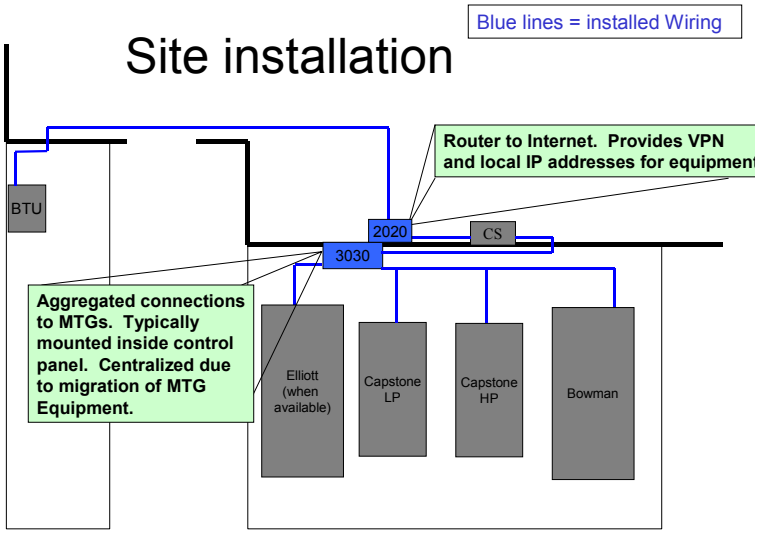
“3030” box at SCE MTG Test Bed



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Questions?


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