MIT Microgrid Campus Upgrade for Improving Resiliency and Reducing Blackouts

Frances P. Boyle, PE, MIT

Wayne Schweidenback, PE, Vanderweil Power Group

Abdel Rahman Khatib, PhD, PE, Schweitzer Engineering Laboratories, Inc.

Motivations, Goals, and Objectives

Frances P. Boyle, PE, MIT

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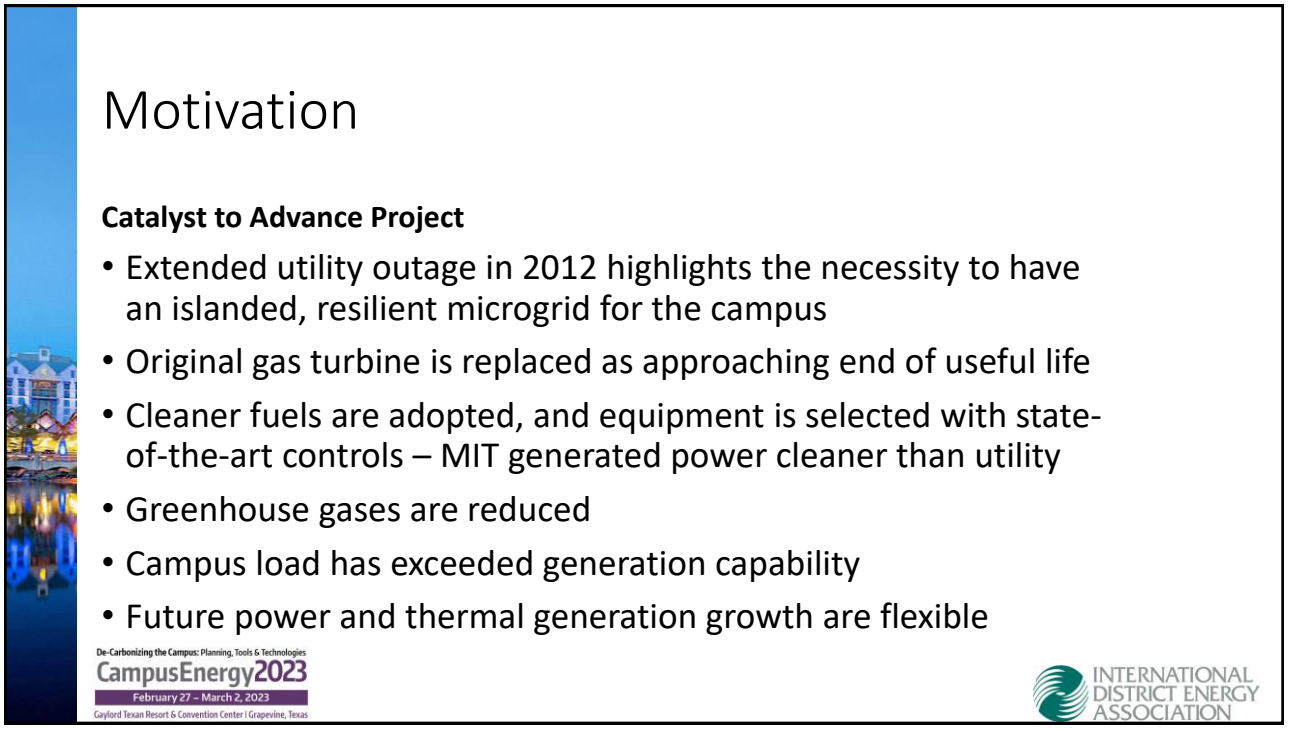

Motivation

Catalyst to Advance Project

- Extended utility outage in 2012 highlights the necessity to have an islanded, resilient microgrid for the campus
- Original gas turbine is replaced as approaching end of useful life
- Cleaner fuels are adopted, and equipment is selected with state-of-the-art controls – MIT generated power cleaner than utility
- Greenhouse gases are reduced
- Campus load has exceeded generation capability
- Future power and thermal generation growth are flexible

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Goals and Objectives

Requirements

- Increase campus electrical system resiliency and reliability
- Relocate critical infrastructure
- Double utility buses and connect to existing buses
- Double distribution buses with electrical protection
- Provide power cleaner than grid
- Create seamless island microgrid
- Support phased construction

Benefits

- Enabled replacement of electrical equipment nearing end of life
- Maximized power to campus
- Expanded campus circuits for future electrification

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MIT Microgrid Electrical Distribution Upgrade

Wayne Schweidenback, PE, Vanderweil Power Group

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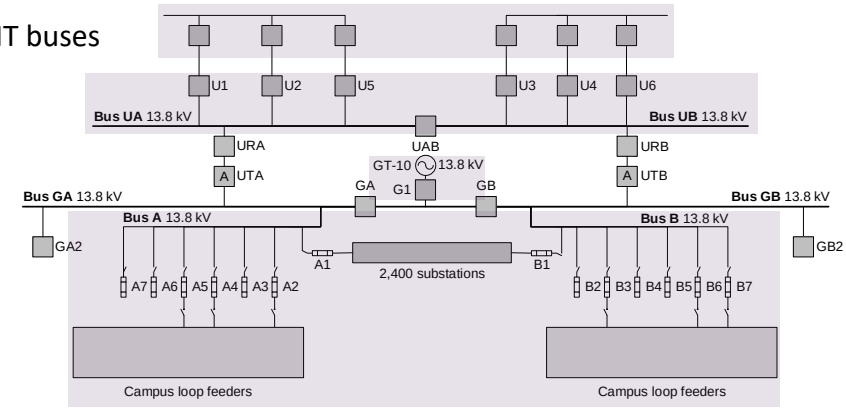
Original Electrical Distribution

Incoming utility

- Six cables – two MIT buses
- Main – tie – main

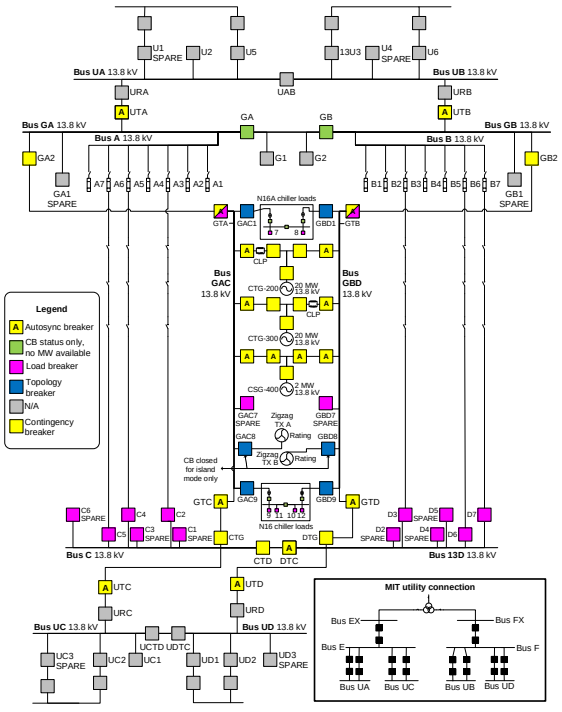
Campus load buses

- Primary cables and manholes, loop feeder with many switches
- Existing gas turbine generator



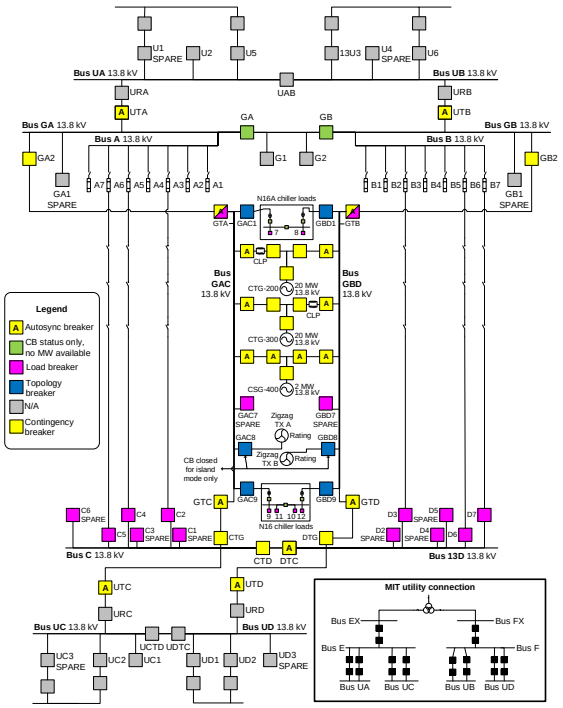
Increase Generation, Redundancy, and Resiliency

- Doubled generation capability
- Reduced campus GHG emissions
- Utility and load buses – duplicated for redundancy



Enhanced Reliability and Cold Start

- Preserved full output of Cogen facility
- Redundant protective relay systems
- Necessary current-limiting device protection
- 2 MW standby diesel generator
- 2 MW roll-up rental generator installed and tested



Relay Control System (RCS)

Abdel Rahman Khatib, PhD, PE, Schweitzer Engineering Laboratories, Inc.

Solution – Power Management System (RCS)

1) Load-shedding system
   - Contingency **(group-based)**
   - Underfrequency **(inertia-based)**
2) Generation control
   - PCC power flow control – **4 intertie to utility**
   - Island autosynchronization – **17 breakers**
   - Voltage and frequency control after islanding – **ISO/droop/ ISO-sharing/voltage droop**
3) Load restoration
   Voltage/frequency/spinning reserve/ time-supervision
4) IDD
   IEEE 1547 + 81RF
5) Cold start
   Step-by-step help

Load-Shedding Priority HMI Example

Description			Status				RESET CLOSE FAIL ALARM		
#	Breaker Number(s)	Description	Breaker Status	Load Bus Connection	43 LS/ NLS 43 L/R	Present Power (MW)	Forced Power (YES NO)	Forced Power (MW)	Load Shed Group Priority
1	13C1	13.8 kV Feeder	Closed	Bus 13C	NLS	2.75	No	1.25	1
2	13C2	13.8 kV Feeder	Closed	Bus 13C	NLS	2.75	No	1.25	1
3	13C3	13.8 kV Feeder	Closed	Bus 13C	LS	2.75	No	1.25	1
4	13C4	13.8 kV Feeder	Closed	Bus 13C	LS	2.75	No	1.25	1
5	13C5	13.8 kV Feeder	Closed	Bus 13C	LS	9.86	No	1.25	1
6	13C6	13.8 kV Feeder	Closed	Bus 13C	LS	11.23	No	1.25	1
7	13D2	13.8 kV Feeder	Open	None	LS	0.0	No	1.25	2
8	13D3	13.8 kV Feeder	Closed	Bus 13D	LS	4.57	No	1.25	2
9	13D4	13.8 kV Feeder	Closed	Bus 13D	LS	3.97	Yes	5.00	2
10	13D5	13.8 kV Feeder	Closed	Bus 13D	LS	8.68	No	1.25	2
11	13D6	13.8 kV Feeder	Closed	Bus 13D	LS	2.98	No	1.25	2
12	13D7	13.8 kV Feeder	Closed	Bus 13D	LS	5.55	No	1.25	2
13	13GTA	13.8 kV Incomer	Open	None	43L	0.0	No	1.25	4
14	13GTB	13.8 kV Incomer	Alarm	None	43R	0.0	No	1.25	4
15	N16A-7	4.16kV Chiller	Closed	Bus 13GAC	_	0.15	No	1.25	3
16	N16A-8	4.16kV Chiller	Closed	Bus 13GBD	_	9.34	No	1.25	3
17	N16-9	4.16kV Chiller	Closed	Bus 13GAC	_	7.55	No	1.25	3
18	N16-10	4.16kV Chiller	Closed	Bus 13GBD	_	10.45	No	1.25	3
19	N16-11	4.16kV Chiller	Closed	Bus 13GAC	_	0.17	No	1.25	3
20	N16-12	4.16kV Chiller	Closed	Bus 13GBD	_	0.17	No	1.25	3
21	13GAC7	future	Open	None	LS	0.17	No	1.25	4
22	13GBD7	future	Open	None	LS	0.17	No	1.25	4

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Load-Shedding Crosspoint HMI Example

Contingency Load Shedding X-Point

	Breaker	13C1	13C2	13C3	13C4	13C5	13C6	13D2	13D3	13D4	13D5	13D6	13D7	13GTA	13GTB	N16A-7	N16A-8	N16-9	N16-10	N16-11	N16-12	13GAC7	13GBD7
N/A	Loss Of Eversource	S	S	S	S			S			I			S									
1	13UTA										I												
2	13UTB										I												
3	13UTC										I												
4	13UTD										I												
5	13G2										I												
6	13G3										I												
7	13G4										I												
8	13GA2 + 13GTA										I												
9	13GB2 + 13GTB										I												
10	13GAC2 + 13G2TAC										I												
11	13GBD2 + 13G2TBD										I												
12	13GAC3 + 13G3TAC										I												
13	13GBD3 + 13G3TBD	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
14	13GAC4 + 13G4TAC										I												
15	13GBD4 + 13G4TBD										I												
16	13GTC + 13CTG										I												
17	13GTD + 13DTG										I												
18	13CTD + 13DTC										I												

Generation Control HMI Example

AUTOMATIC GENERATION CONTROLS

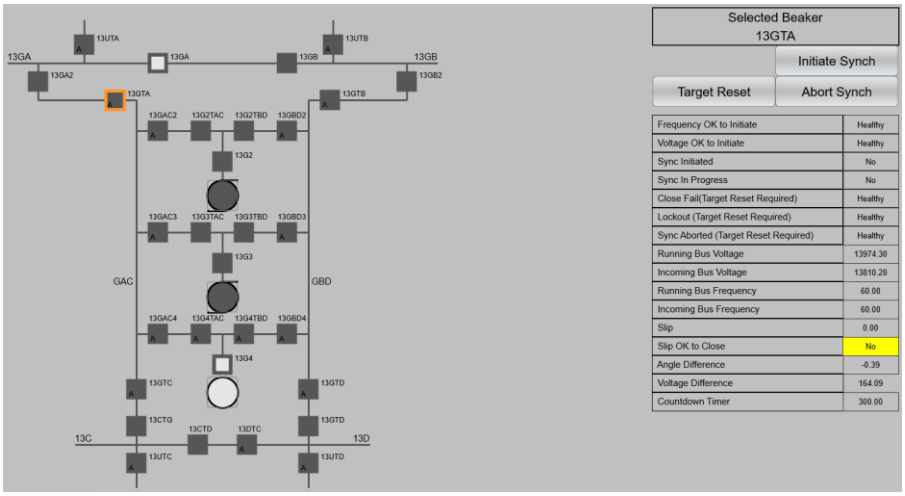
	CONTROL / SETPOINTS						STATUS										ALARMS		
Generator	MW Enable Control	MW Control Mode	MW Base Setpoint	MW Lower Regulation Limit	MW Upper Regulation Limit	ISO Priority	Bus Connection	Generator Islanded	Generator Mode	Breaker Status	Frequency	Present Power	Requested Setpoint	RCS Mode	Under RCS Control	Control In Progress	Min/Max Capacity	Following Error	ISO/Droop Error
CTG-200	Enabled	Regulation	13.50	0.00	21.00	0.00	GAC+GBD	No	Droop	Closed	60.00	8.87	8.83	On	On	Off	Off	Off	Off
CTG-300	Enabled	Regulation	8.00	0.00	21.00	1.00	GAC+GBD	No	Droop	Closed	60.00	5.23	5.23	On	On	Off	Off	Off	Off

ISO Sharing Permissive	Generators Running in Parallel
Disabled	Yes

VOLTAGE CONTROL SYSTEM

	CONTROL / SETPOINTS					STATUS										ALARMS		
Description	MVAR Enable Control	MVAR Control Mode	MVAR Base Setpoint	MVAR Lower Regulation Limit	MW Upper Regulation Limit	Bus Connection	Generator Islanded	Generator Mode	Breaker Status	Voltage	Present Q	Requested Setpoint	RCS Mode	Under RCS Control	Control In Progress	Min/Max Capacity	Following Error	Exciter Not Responding
CTG-200	Enabled	Regulation	0.00	-15.00	25.00	GAC+GBD	No	Volt	Closed	13.77	10.02	10.16	On	On	Off	Off	Off	Off
CTG-300	Enabled	Regulation	0.00	-15.00	25.00	GAC+GBD	No	Volt	Closed	13.77	10.35	10.46	On	On	Off	Off	Off	Off

Autosynchronization HMI Example



Frequency OK to Initiate	Healthy
Voltage OK to Initiate	Healthy
Sync Initiated	No
Sync In Progress	No
Close Fail(Target Reset Required)	Healthy
Lockout (Target Reset Required)	Healthy
Sync Aborted (Target Reset Required)	Healthy
Running Bus Voltage	13974.30
Incoming Bus Voltage	13810.20
Running Bus Frequency	60.00
Incoming Bus Frequency	60.00
Slip	0.00
Slip OK to Close	No
Angle Difference	-0.39
Voltage Difference	164.09
Countdown Timer	300.00

Load Restoration HMI Example

	Description		Status								
#	Breaker Number(s)	Description	Breaker Status	Load Bus Connection	86 LO	43 L/R	15 min Average (MW)	Restore MW Estimate	Restore/ Closed/ Inhibit		
1	13C1	13.8 kV Feeder	Closed	Bus 13C	No	Remote	2.75	3	Restore		
2	13C2	13.8 kV Feeder	Closed	Bus 13C	No	Remote	2.75	3	Restore		
3	13C3	13.8 kV Feeder	Closed	Bus 13C	No	Remote	2.75	3	Restore		
4	13C4	13.8 kV Feeder	Closed	Bus 13C	No	Remote	2.75	3	Restore		
5	13C5	13.8 kV Feeder	Closed	Bus 13C		Remote	2.86	3	Restore		
6	13C6	13.8 kV Feeder	Closed	Bus 13C	No	Remote	2.23	3	Restore		
7	13D2	13.8 kV Feeder	Open	None	No	Remote	0.0	3	Restore		
8	13D3	13.8 kV Feeder	Closed	Bus 13D	No	Local	4.57	4	Inhibit		
9	13D4	13.8 kV Feeder	Closed	Bus 13D	No	Remote	3.97	4	Closed		
10	13D5	13.8 kV Feeder	Closed	Bus 13D	No	Remote	4.68	4	Restore		
11	13D6	13.8 kV Feeder	Closed	Bus 13D	No	Remote	2.98	4	Restore		
12	13D7	13.8 kV Feeder	Closed	Bus 13D	No	Remote	5.55	4	Restore		
13	13GTA	13.8 kV Incomer	Open	None	No	Local	0.0	4	Inhibit		
14	13GTB	13.8 kV Incomer	Alarm	None	No	Remote	0.0	4	Inhibit		
15	N16A-7	4.16kV Chiller	Closed	Bus 13GAC	No	_	0.15	2.5	Restore		
16	N16A-8	4.16kV Chiller	Closed	Bus 13GBD	No	_	2.34	2.5	Restore		
17	N16-9	4.16kV Chiller	Closed	Bus 13GAC	No	_	2.55	2.5	Restore		
18	N16-10	4.16kV Chiller	Closed	Bus 13GBD	No	_	2.45	2.5	Restore		
19	N16-11	4.16kV Chiller	Closed	Bus 13GAC	No	_	0.17	2.5	Restore		
20	N16-12	4.16kV Chiller	Closed	Bus 13GBD	No	_	0.17	2.5	Restore		
21	13GAC7	Future Load	Open	Bus 13GAC	No	Remote	4.57	0	Restore		
22	13GBD7	Future Load	Open	Bus 13GBD	No	Remote	3.97	0	Restore		
23	13GAC1	Bus Tie	Closed	Bus 13GAC	No	Remote	5.55	7	Restore		
24	13GBD1	Bus Tie	Closed	Bus 13GBD	No	Remote	4.57	7	Restore		
25	13GAC9	Bus Tie	Closed	Bus 13GAC	No	Remote	3.97	7	Restore		
26	13GBD9	Bus Tie	Closed	Bus 13GBD	No	Remote	8.68	7	Restore		

LOAD RESTORATION START	LOAD RESTORATION STOP
RESET SHED FAIL ALARM	
Frequency Dead Band (Hz)	0.05
Voltage Dead Band (kV)	0.5
Wait Time (minute)	5
Total Cal Ava Capacity (MW)	0.00
UV 13GAC4/13GBD4	Yes
Circuit Breakers in Remote	No
Automatic LR Stopped	Inactive
Automatic LR Completed	Inactive
Automatic LR in Progress	Active
Initiate Black start	
Yes	No

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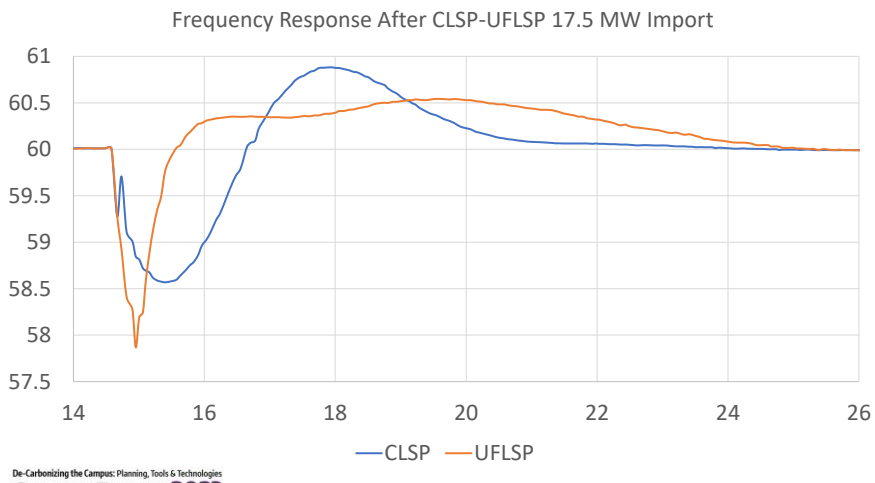
Commissioning CLSP vs. UFLSP



CLSP	UFLSP
CTG 8.56 MW	CTG 9.3 MW
Import 17.5 MW	Import 17.6 MW
IRM 5 MW	UF Level Level 1 ROCOF 5
RTS 12.5 MW	RTS 22.12 MW
STS 13.17 MW	STS 22.13 MW
Minimum Frequency 58.58 Hz	Minimum Frequency 57.86 Hz

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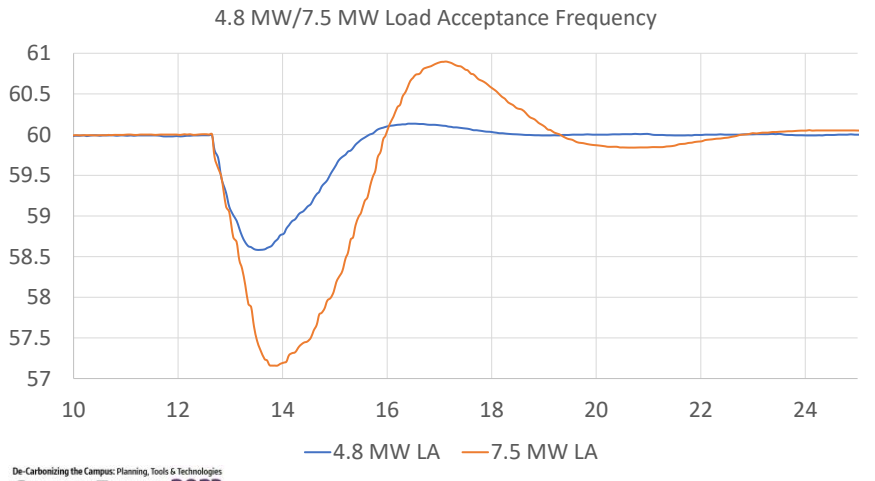
Commissioning Load Restoration



4.8 MW	7.5 MW
Settling Time ~12 seconds	Settling Time ~12 seconds
Minimum Frequency 58.58 Hz	Minimum Frequency 57.16 Hz
Maximum Frequency 60.1 Hz	Maximum Frequency 60.9 Hz

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Microgrid Electrical Modifications

- Have power availability and reliability during island mode operation and grid power outages to protect campus functions
- Add and upgrade existing 15 kV microgrid electrical switchgear and paralleling capabilities and increase redundant bus configuration
- Double the campus loops in microgrid
- Create a smart microgrid controller system for CHP load control and sharing, paralleling, frequency control, island mode operation, and load-shedding mode

Lessons Learned

Key elements

- Complete permitting prior to construction start
- Early engineering cycle – FEED study
- Consistent, collaborative, and technical team
- Collect specific generator response
- Significant team participation in FATs
- Complete separation of power islands

Extensive site testing with load banks

- No campus load interruptions
- Facilitated load-shedding scheme testing
- Gas turbine load sharing response tested
- Starting without utility power and with temporary, replacement roll-up generator

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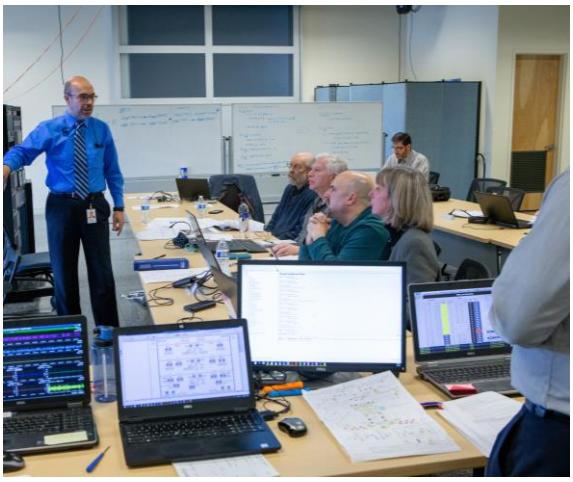
Factory Acceptance Test



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Thank You!
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VANDERWEIL POWER GROUP
Wayne Schweidenback, PE
SEL SCHWEITZER ENGINEERING LABORATORIES
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