

An aerial photograph of a city grid, likely New Haven, Connecticut, with a semi-transparent blue overlay. The image shows a dense network of streets and building footprints. The text is centered over the middle of the image.

Microgrid Reliability Upgrades and Commissioning Best Practices at Yale University

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Introduction

- Yale University Microgrids
 - 2 Sites – Main Campus (Central Power Plant) and Medical School/Hospital (Sterling Power Plant)
 - Each 15 MW with heat recovery and grid interconnection
 - Primary Select Campus Distribution Circuits fed at 15 kV
 - Sterling Plant converted to cogeneration in 2010
 - Central Plant repowered in 2016

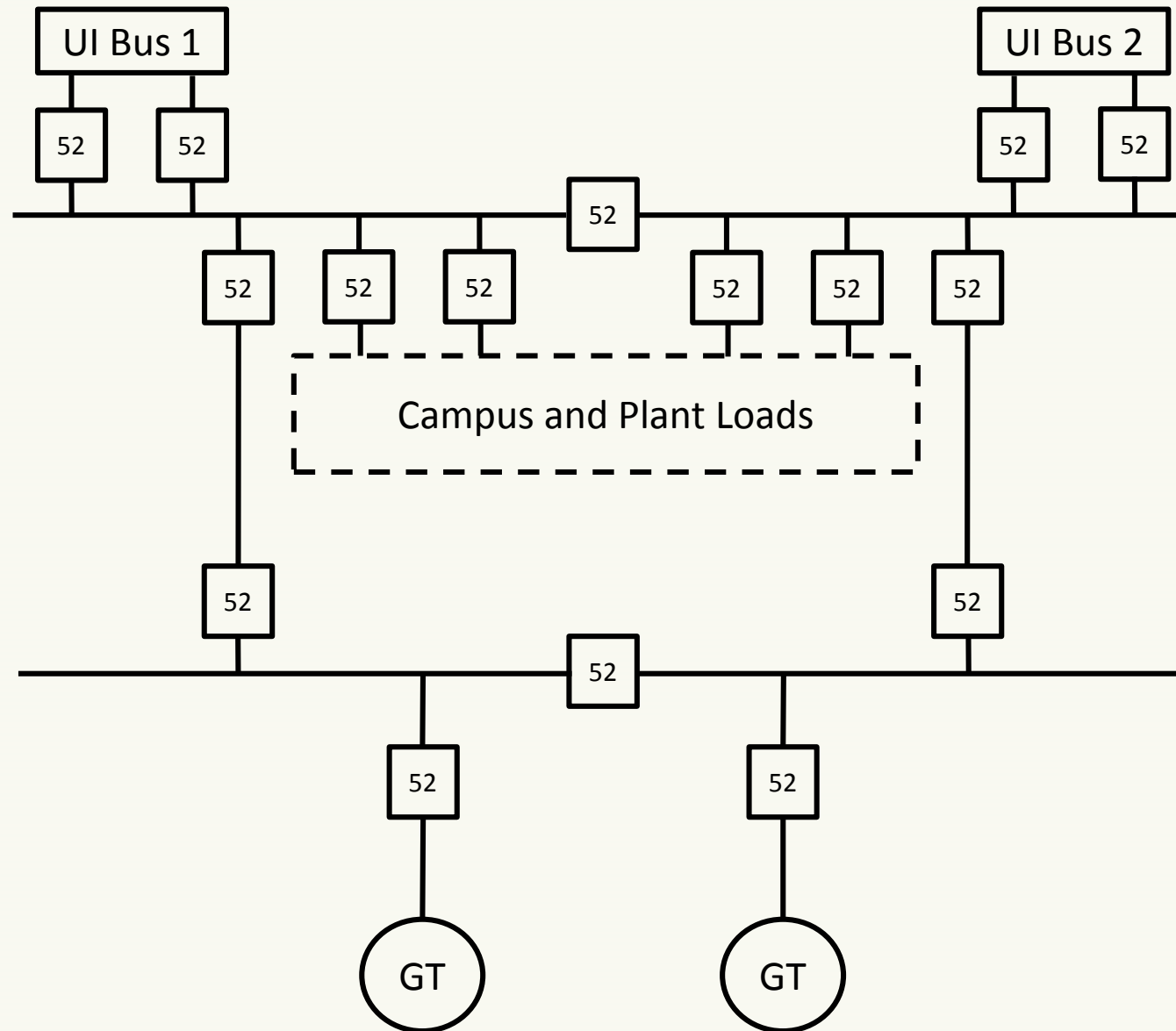
Background

- Intent is to share some of the things we missed or got wrong – not to blame anyone!
- Most of our relays are solid state by ABB, with some GE and Schweitzer, and a limited number of electromechanical for differential protection and load shed
- ABB REA Arc Flash protection scheme
- Most of the switchgear is Eaton Cutler-Hammer

Sterling Power Plant Cogeneration Project

- Existing boiler/chiller plant serving Yale School of Medicine and portions of Yale-New Haven Hospital
- Cogeneration conversion installed in 2010
 - 2 x 7.5 MW gas turbines with heat recovery boilers
 - New cogeneration collector switchgear
 - Extensive rework of existing utility switchgear
 - New utility feeder added and high/low load scheme implemented
 - Black start and island capable
 - Frequency-based load shed for plant circuits

Sterling Power Plant Simplified 1-Line



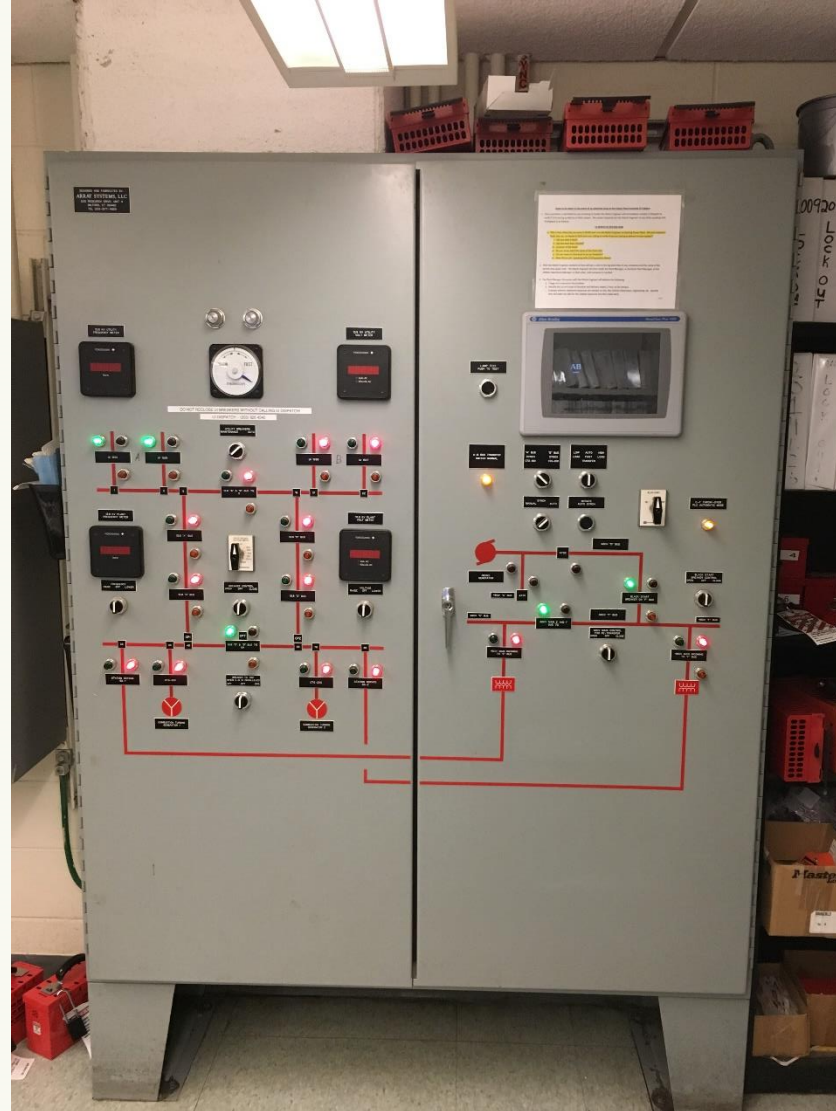
Variable Bus/Feeder Configuration

- Campus load not evenly balanced between busses
- Limits ability to run GT at full load
- Solution:
 - “High Load” configuration – 4 Utility Feeders closed, Bus Ties Open
 - “Low Load” configuration – 2 Utility Feeders closed, Main Bus Tie Closed
- Challenge: What happens when two feeders trip?

Solution: Fast Bus Transfer Scheme

- Implemented via contact logic
- Enabled and supervised by Synch Panel PLC and local Synch Check
- High Load Sequence:
 - UI feeder trip (not Arc, Bus Diff, Bus O/C)
 - UI Breakers proven open
 - Tie breaker closes
- Low Load Sequence:
 - UI feeder trip (not Arc, Bus Diff, Bus O/C)
 - UI Breakers proven open
 - Other two UI breakers close

SPP Synchronizing Panel



Construction and Commissioning Issues

- Details regarding desired relay functionality and integration to plant control system were not included in the bid documents
- Commissioning requirements were not clearly delineated in project documents
- As a result contractor commissioning plans were inadequate and missed multiple construction issues on the first pass
- Inadequate integration of P&C to the plant control system resulted in major headaches later on

Operating Issues

- IEEE Anti-Islanding settings made the campus much more sensitive to faults on the utility distribution system than expected
- Local utility preference for low forward power (32U) over reverse power (32R) protection resulted in much higher than anticipated power import
- Despite having 4 utility feeders and two turbines the campus lost power on multiple occasions

Lessons Learned – Design/Construction

- Make sure you (as the owner) understand:
 - What your switchgear P&C is and is not capable of
 - What is required to enable this capability
 - How this can be integrated to your plant control system
- Ultimately the system will do what you tell it – you just need to know what “it” is!
 - Consider engaging a specialty consultant and/or OEM applications engineer
 - Determine how best to convey this to your construction team

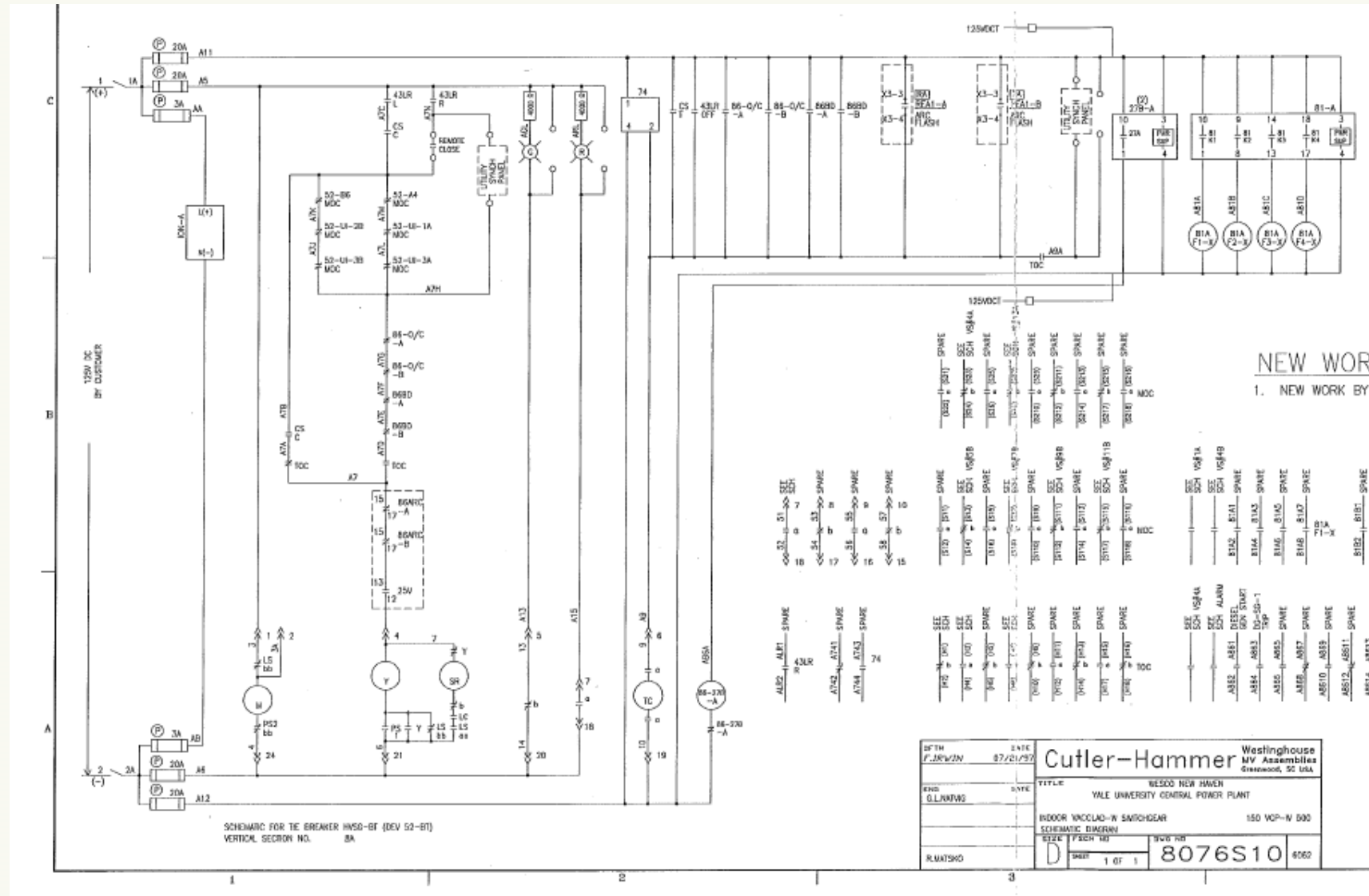
Lessons Learned - Commissioning

- There are many ways to commission switchgear
- Without specific direction, you may just get a functional check of the relay outputs
- This approach can miss a number of key items:
 - Validation of key inputs that are not “settings” per se – such as PT and CT ratios
 - CT polarity
 - Relay I/O Mapping
 - Interface to plant control system – both physical and operational

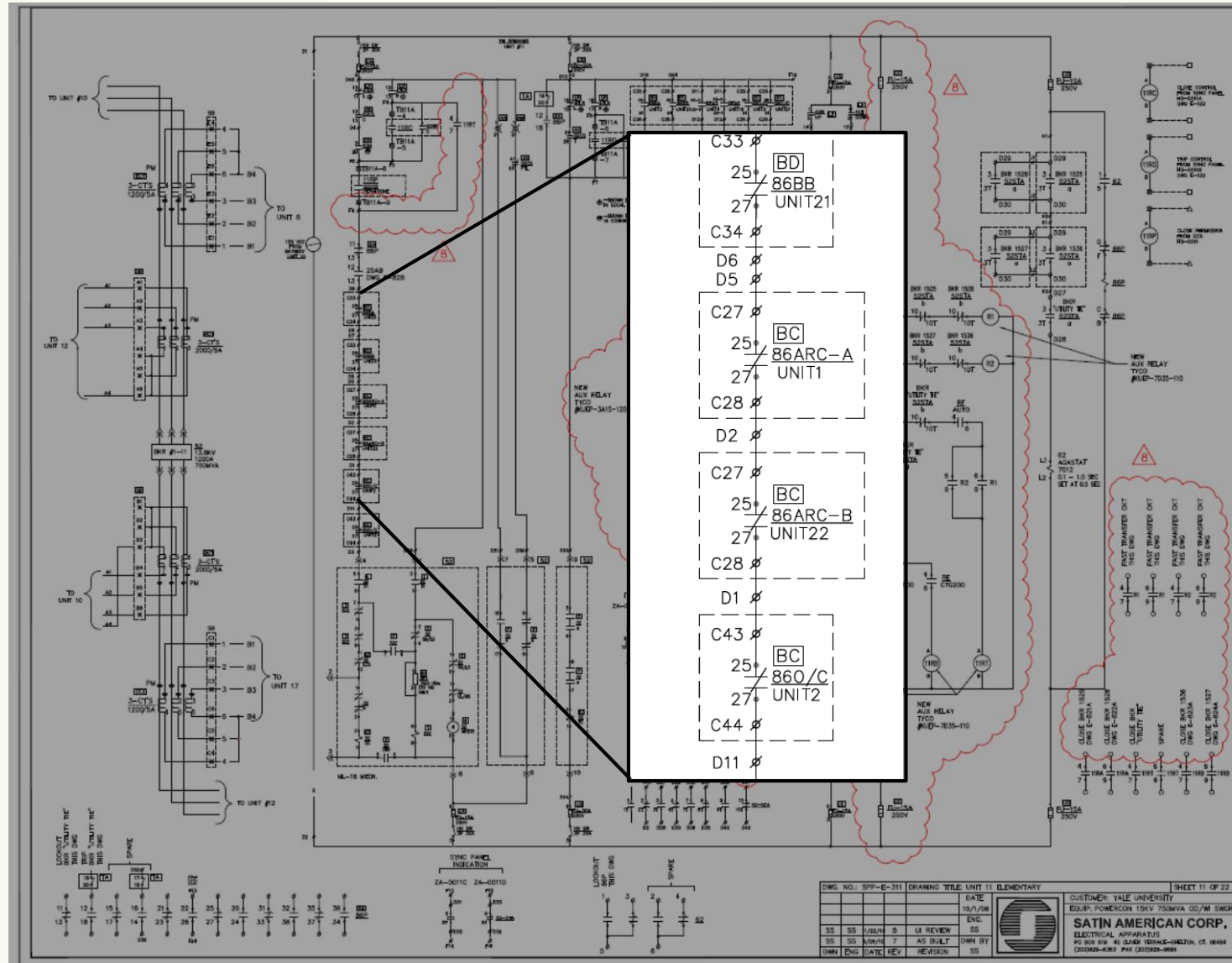
Lessons Learned - Operating

- Multiple utility feeds don't necessarily provide the redundancy you thought
- Cogeneration will make your facility more sensitive to utility distribution faults beyond the circuits feeding your campus
- Even the best design, construction and commissioning process may not contemplate all the ways your system can fail!
- Be prepared to re-evaluate your system if/when the bad thing happens

Best Practice – Schematic Drawings



Best Practice – show complete wiring path



Best Practice – Control System Integration

Query at 09/23/10 01:02:21 SOE Event Mode Report Page 1

Timestamp	Quality	Type	ID	Resource	Reference	Message
09/22/10 21:05:59.701	P	SOE	SOE_ALM	0107	XA-0022A	SPP BKR #22 UI-2 86
09/22/10 21:05:59.819	P	SOE	SOE_ALM	0107	XA-0021A	SPP BKR #21 UI-3B 86
09/22/10 21:05:59.819	P	SOE	SOE_ALM	0107	XA-0022B	SPP B SIDE ARC FLASH
09/22/10 21:05:59.842	P	SOE	SOE_ALM	0107	XA-0021D	SPP B SIDE OPN POWER
09/22/10 21:05:59.875	P	SOE	SOE_RTN	0107	XA-0021D	SPP B SIDE OPN POWER Recover
09/22/10 21:08:42.495		SOE	SOE_ALM	0202	XY1664	GT2 NORMAL STOP
09/22/10 21:08:42.549		SOE	SOE_ALM	0203	XSCP2TRP	COGEN 13.8KV SWGR CP2 TR
09/22/10 21:08:42.578		SOE	SOE_RTN	0203	XSCP2TRP	COGEN 13.8KV SWGR CP2 TR Recov
09/22/10 21:08:43.615		SOE	SOE_ALM	0201	XY1661	GT1 FAST STOP
09/22/10 21:08:43.715		SOE	SOE_RTN	0201	XY1606	H1 LO SCAN AIR PRES TRP Recover
09/22/10 21:08:43.833		SOE	SOE_ALM	0203	XS0815	GC1 TRIP SOE POINT
09/22/10 21:08:43.853		SOE	SOE_ALM	0203	XS0816	GC2 TRIP SOE POINT
09/22/10 21:08:43.868		SOE	SOE_ALM	0203	XS0604	IAS DRYER/FLTR SYS FLT
09/22/10 21:08:43.903		SOE	SOE_ALM	0202	LYLL0520	H2 WC RLYS IN LO CUTOUT
09/22/10 21:08:43.903		SOE	SOE_ALM	0201	LYLL0420	H1 WC RLYS IN LO CUTOUT
09/22/10 21:08:43.919		SOE	SOE_ALM	0202	XY1617	H2 BURNER TRIP
09/22/10 21:08:43.931		SOE	SOE_RTN	0202	XY1616	H2 LO SCAN AIR PRES TRP Recover
09/22/10 21:08:43.974		SOE	SOE_ALM	0202	XY1663	GT2 FAST STOP
09/22/10 21:08:44.000		SOE	SOE_ALM	0201	XY1662	GT1 NORMAL STOP
09/22/10 21:08:44.264	P	SOE	SOE_ALM	0107	XS1232	FOP-300 VFD COM ALM
09/22/10 21:08:44.298	P	SOE	SOE_ALM	0107	XA-0004B	SPP A SIDE 127A UV TRIP
09/22/10 21:08:45.848		SOE	SOE_ALM	0203	PSL0773	AMM HDR PRESS LO
09/22/10 21:08:49.159		SOE	SOE_ALM	0203	XS1007	BFPM-002 COM ALM
09/22/10 21:08:49.163		SOE	SOE_ALM	0203	XS1008	BFPM-003 COM ALM
09/22/10 21:08:49.959		SOE	SOE_ALM	0201	PDSL0410	H1 HRSG SYS PRES DROP LO
09/22/10 21:08:50.433		SOE	SOE_ALM	0201	XY1606	H1 LO SCAN AIR PRES TRP
09/22/10 21:08:50.452		SOE	SOE_ALM	0202	XY1616	H2 LO SCAN AIR PRES TRP
09/22/10 21:08:51.789		SOE	SOE_ALM	0202	PDSL0510	H2 HRSG SYS PRES DROP LO

-What protective element tripped the breaker?
-There was no Arc Flash event!!
-What do you suppose "OPN POWER" means?

Best Practice – Integrated Commissioning

- Challenge as much of the protection circuit as possible
- Validate external outputs – e.g. control system annunciation/SOE
- Be prepared to add to your test script on the fly

A. Phase A

- a. Initiate a "Phase A" 87 Bus Differential by injecting current into the Breaker #1A (1903) phase A CT ~~AT RELAY~~

Current Setting	3.2A
A-Phase KAB Indicates pick-up	Check <input checked="" type="checkbox"/>
86BD-A relay activated	Check <input checked="" type="checkbox"/>
86BD-A2 relay activated	Check <input checked="" type="checkbox"/>
SOE point in DCS	Check <input checked="" type="checkbox"/>
DCS Graphics Display	Check <input checked="" type="checkbox"/>

Indicate Breaker trip on chart below. — BLOCK CLOSE BYPASSED WHILE

10544-3 S61 ON OFF ON OFF ON OFF OFF ON

LET 1 CRT
 OFF OFF → SET AR12 FROM
 ENCOAM 3/3/16

1903 LOR TO DCS

86A	86B	86C	86D	86E	86F	86H	86O/L-A	86ARC-A
OK	OK	OK	OK	OK	OK	OK	OK	OK

1903	TCM	CCM	IRF	1911	TCM	CCM	IRF	7B	TCM	CCM	IRF
	OK	OK			OK	OK			OK	OK	OK

1903 LOR BLOCK CLOSE IN CONN. POS.

86A	86B	86C	86D	86E	86F	86H	86O/L-A	86ARC-A	86BD-A/A2
OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

1911 LOR BLOCK CLOSE IN CONN. POS.

86O/L-A	86ARC-A	86BD-A/A2
OK	OK	OK

HUTR-1 LOR BLOCK CLOSE IN CONN. POS. (25V JUMPER REQUIRED)

86O/L-A	86ARC-A	86A	86B	86C	86D	86BD-A/A2
OK	OK	OK	OK	OK	OK	OK

Feeder #1A (1903) Functional Testing, Rev. 3, 2/19/16

Other Things We've Learned (most the hard way)

- If you don't want to test against your campus load, determine how you will provide the load needed – early on!
- Transfer Trip and Line Differential schemes may be worth the money
- Test switches are worth every penny
- Make sure your OEM controllers are on the same clock as your plant controls
- Some electromechanical relays are more sensitive to vibration than you might think
- You may have short frequency excursions when you island your facility

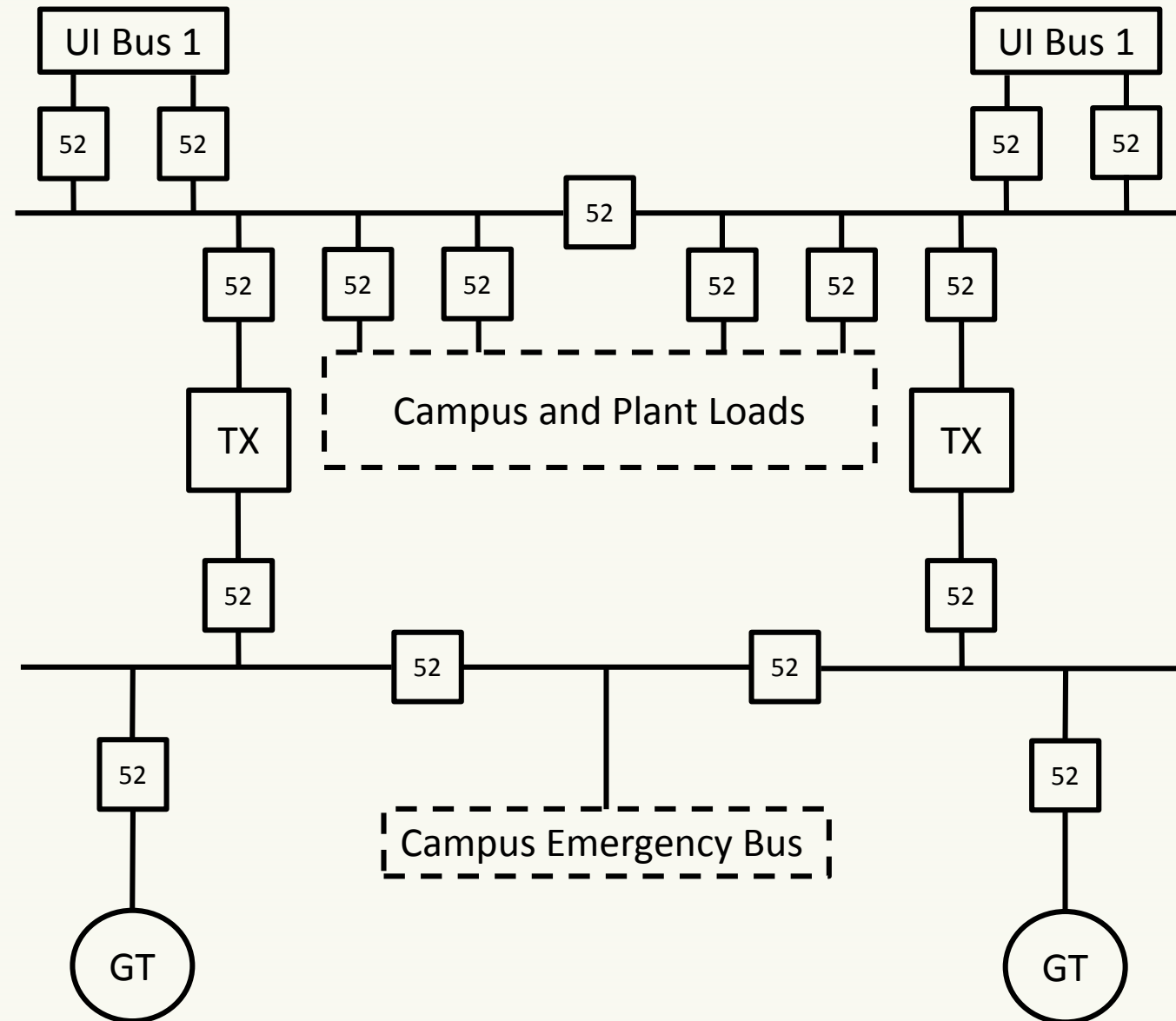
Bonus Footage



Yale Central Power Plant

- Converted to cogeneration mid-1990's
- Repowered in 2018:
 - 2 x 7.5 MW gas turbines with heat recovery boilers
 - Relays and P&C upgraded
 - Black start and island capable
 - Frequency-based load shed for campus circuits
- Most of the SPP Lessons Learned implemented successfully on the Repowering

Central Power Plant Simplified 1-Line



Campus Load Shed

- Uses electromechanical frequency-based load shed relays
- Installed with original cogen – hardwired scheme:
 - Residential/Academic buildings shed first
 - Low Density Science/Academic next
 - High Performance Science last
- All made sense until October 29, 2012

Hurricane Sandy

- Prior to repowering of Central Power Plant so islanding not an option
- State of Connecticut travel ban
- Yale University closed to non-essential personnel
- Students told to shelter in their dormitories
- One Problem: In the event of a loss of utility, these buildings would be the first to lose power!

Solution: Selectable Load Shed

- Load shed relay outputs rewired to local PLC-based controller
- Load shed lockout relays installed for each campus breaker
- Controller outputs to each LOR
- DCS Supervision of controller allows outputs to be reconfigured to different load shed levels as needed
- PLC refresh adds small amount of time; however, experience has been that the system works very well

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Questions?

Yale OFFICE OF FACILITIES