Microgrid Reliability Upgrades and Commissioning Best Practices at Yale University

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Yale OFFICE OF FACILITIES

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

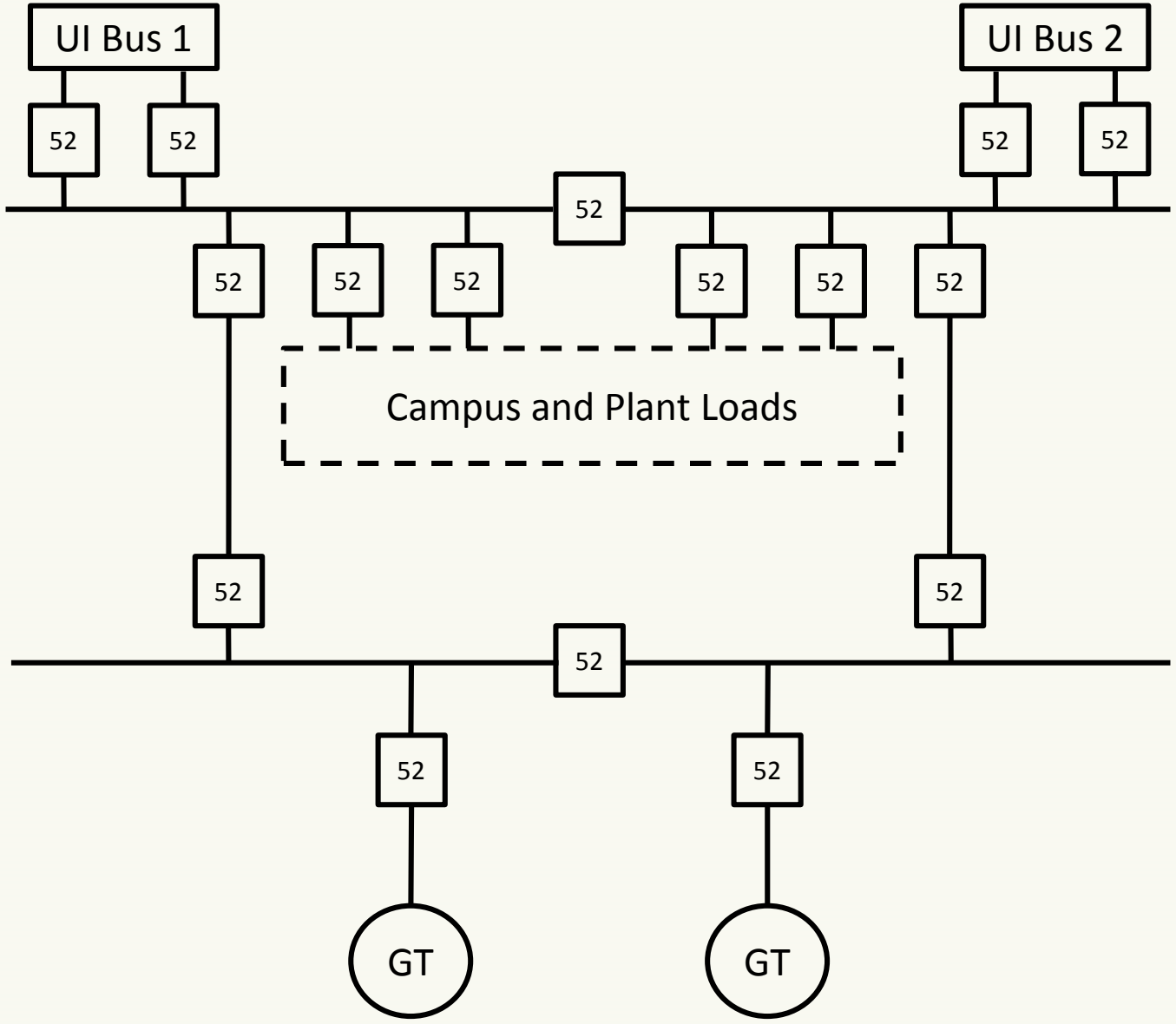
Background

- 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



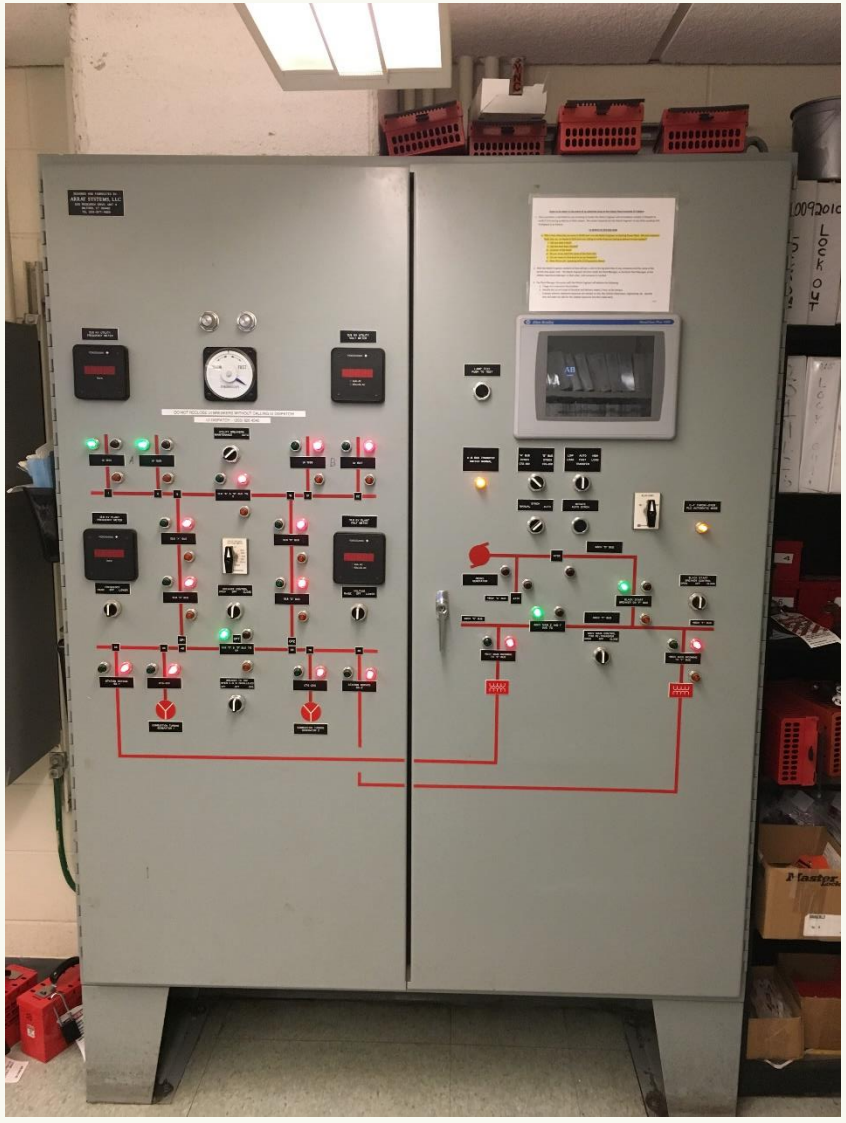
Variable Bus/Feeder Configuration

- 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

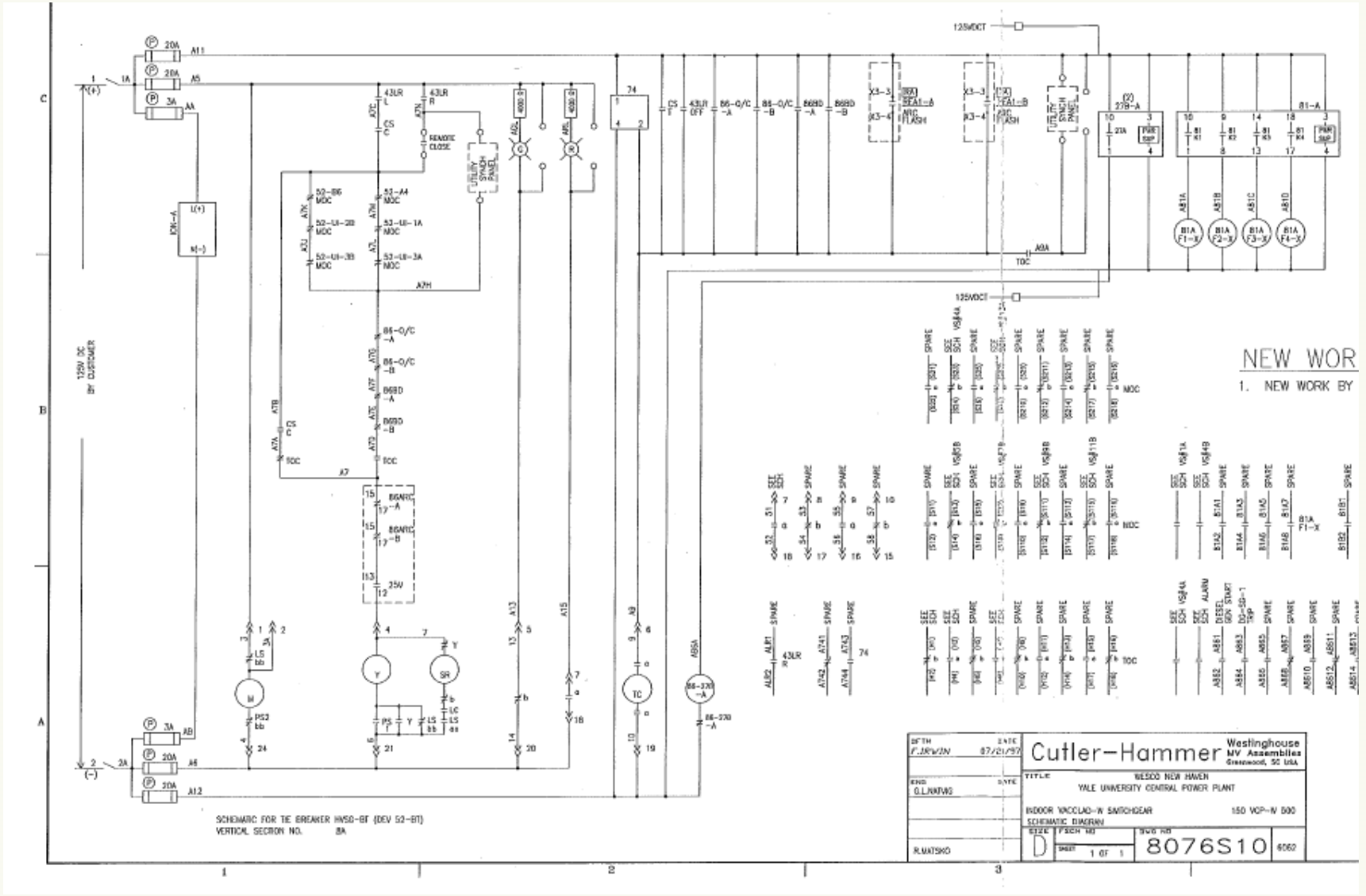
Lessons Learned - Commissioning

- 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

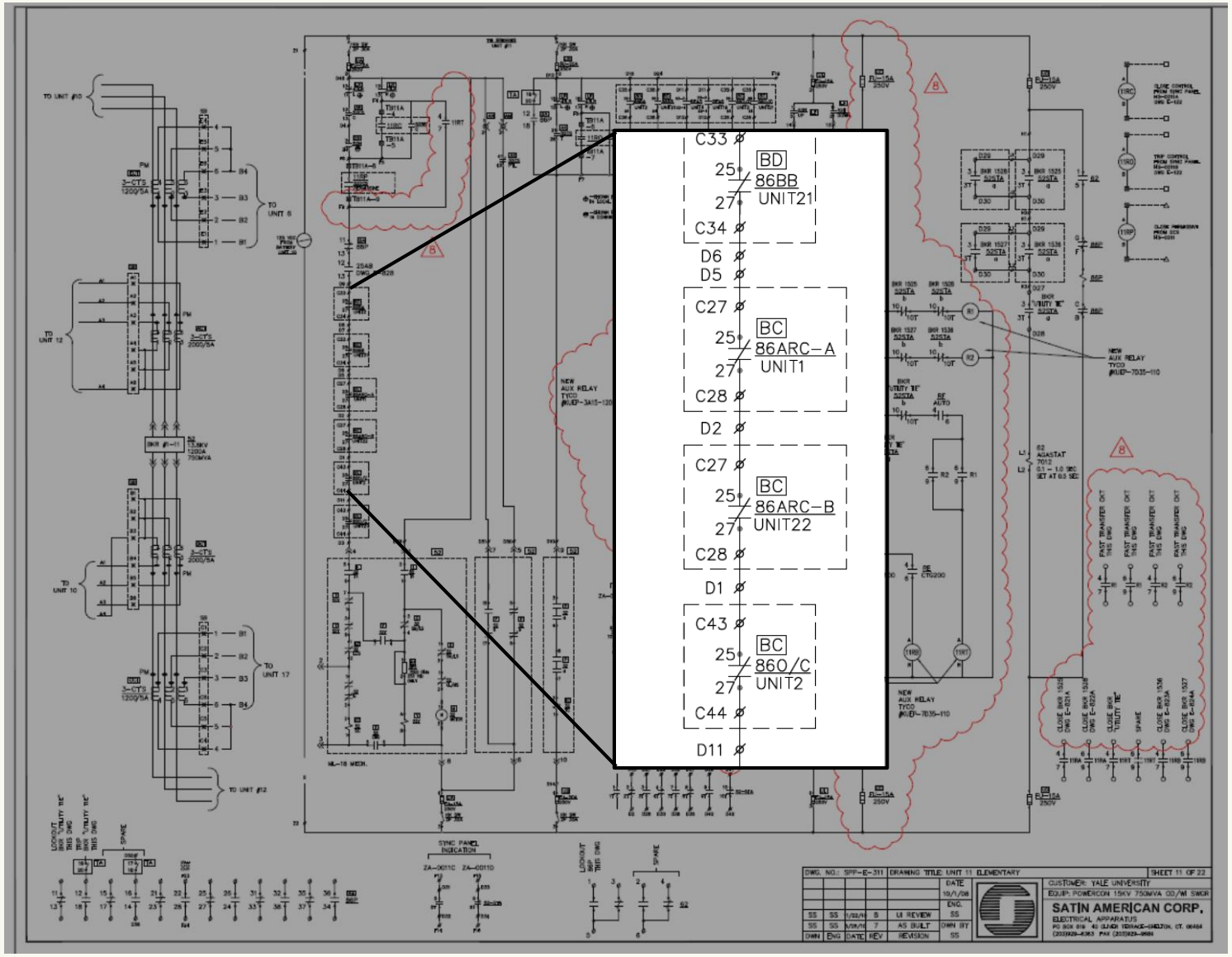
Lessons Learned - Operating

- 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

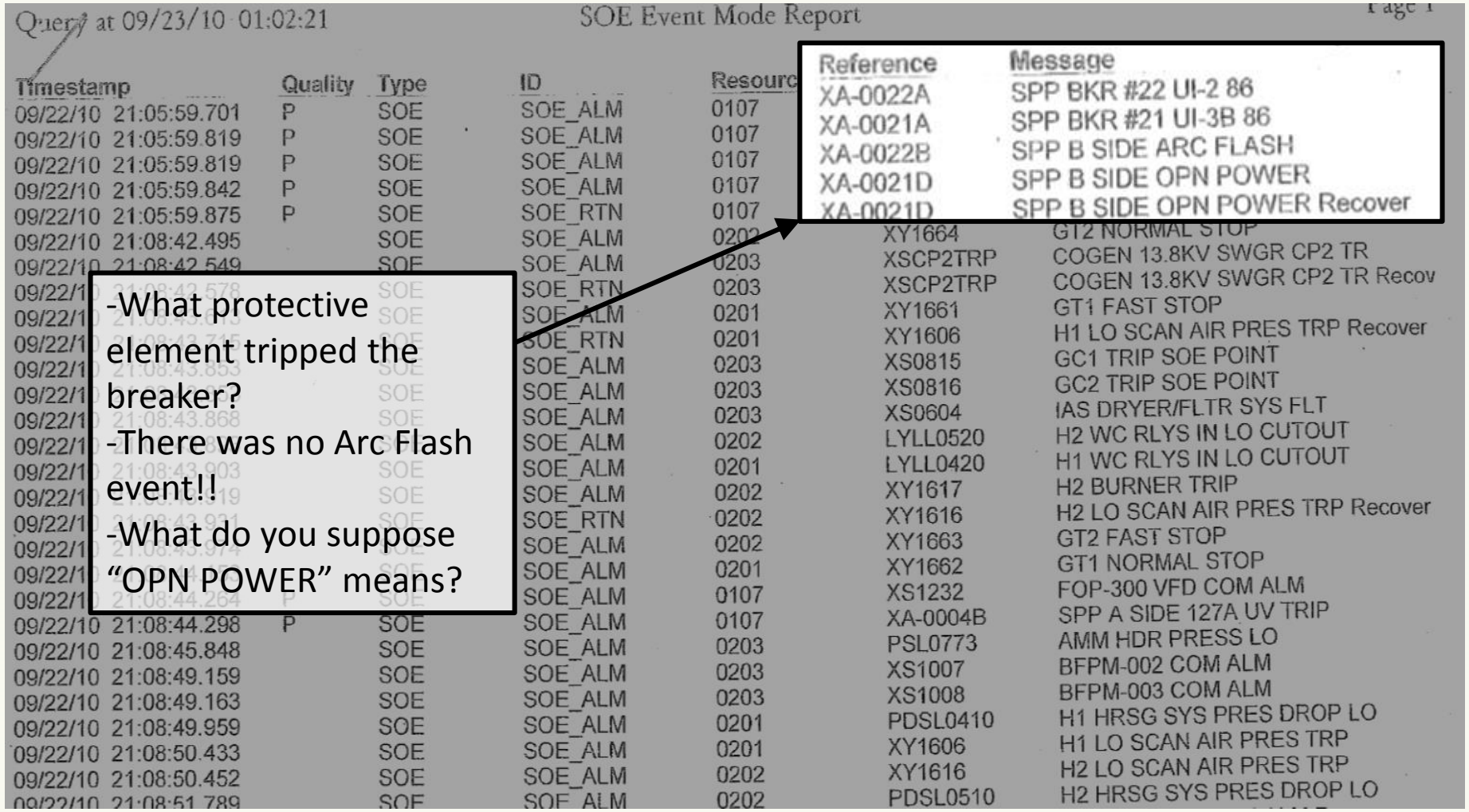
Best Practice – Schematic Drawings



Best Practice – show complete wiring path

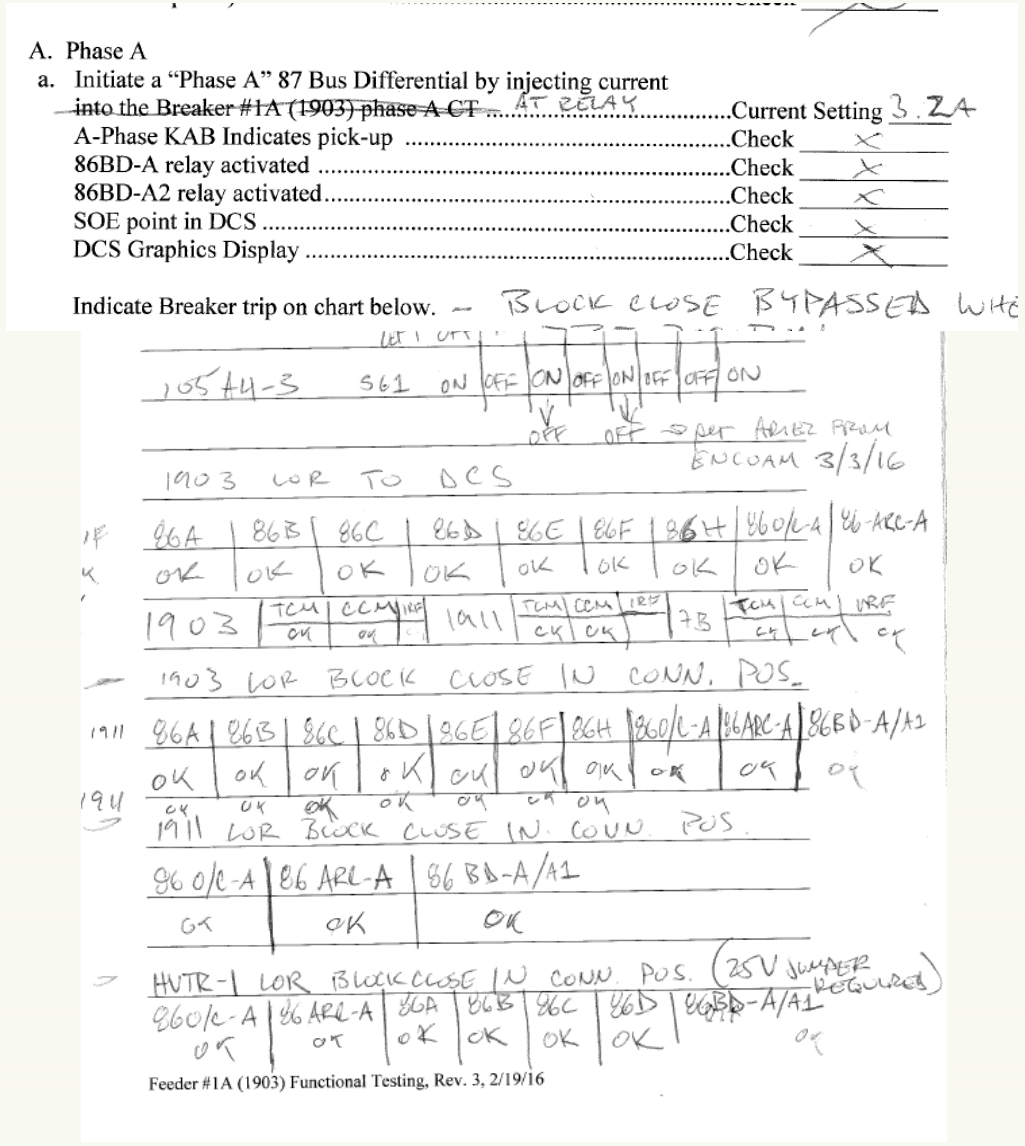


Best Practice – Control System Integration



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 X

86BD-A relay activated ..... Check X

86BD-A2 relay activated ..... Check X

SOE point in DCS ..... Check X

DCS Graphics Display ..... Check X

Indicate Breaker trip on chart below. – BLOCK CLOSE BYPASSED WHE

105 H4-3	S61	ON	OFF	ON	OFF	ON	OFF	OFF	ON

OFF OFF ⇒ RET ADMIN FROM ENCOAM 3/3/16

1903 LOR TO DCS

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

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

1903 LOR BLOCK CLOSE IN CONN. POS.

	86A	86B	86C	86D	86E	86F	86H	86O/C-A	86ARC-A	86BD-A/A1
1911	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

OK OK OK OK OK OK OK

1911 LOR BLOCK CLOSE IN CONN POS.

86 O/C-A	86 ARC-A	86 BD-A/A1
OK	OK	OK

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

86O/C-A	86 ARC-A	86A	86B	86C	86D	86BD-A/A1
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)

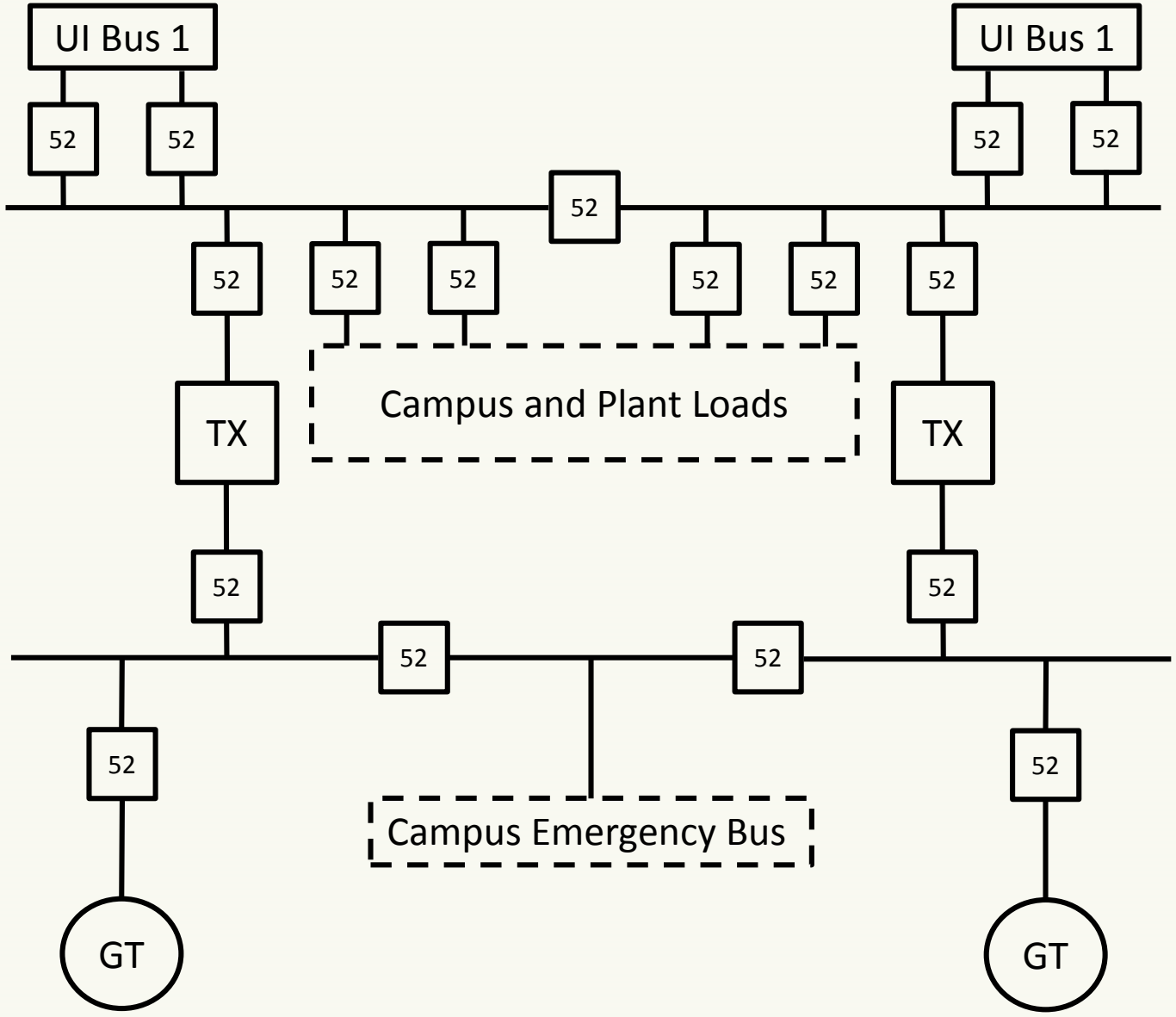
- If you don't want to test against your campus load, determine how you will provide the load needed – early on!
- Transfer Trip and Line Differential schemes may be worth the money
- Test switches are worth every penny
- Make sure your OEM controllers are on the same clock as your plant controls
- Some 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

Questions?