Microgrid Resiliency at Yale University

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Resiliency of Campus Microgrids

A modern campus microgrid is incredibly complex, with many integrated components – generation, switchgear, protection and control, automation and SCADA, power distribution and building substations.

This complex physical infrastructure must be operated reliably and efficiently against a complex backdrop of campus operations, unpredictable weather, aging electrical grids, shifting academic priorities and constrained operating budgets.

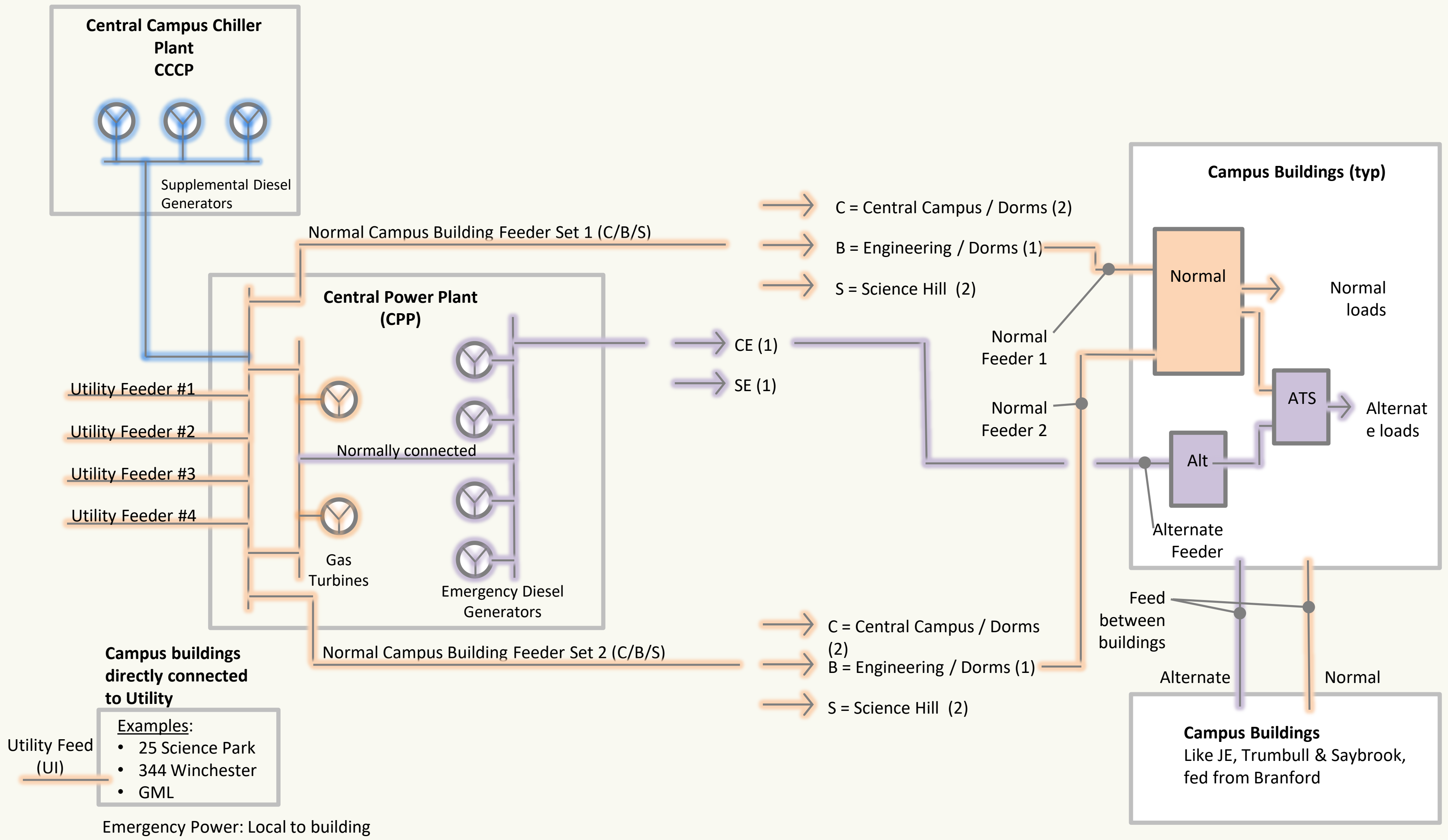
Microgrid Resiliency Strategies

- Develop an operating philosophy for your system
- On new projects, build in reliability from the start
- Make your system as flexible as possible
- Take extra time and money to fully commission everything
- Use automation so "when the bad thing happens" stable operation is maintained

Yale University Microgrids

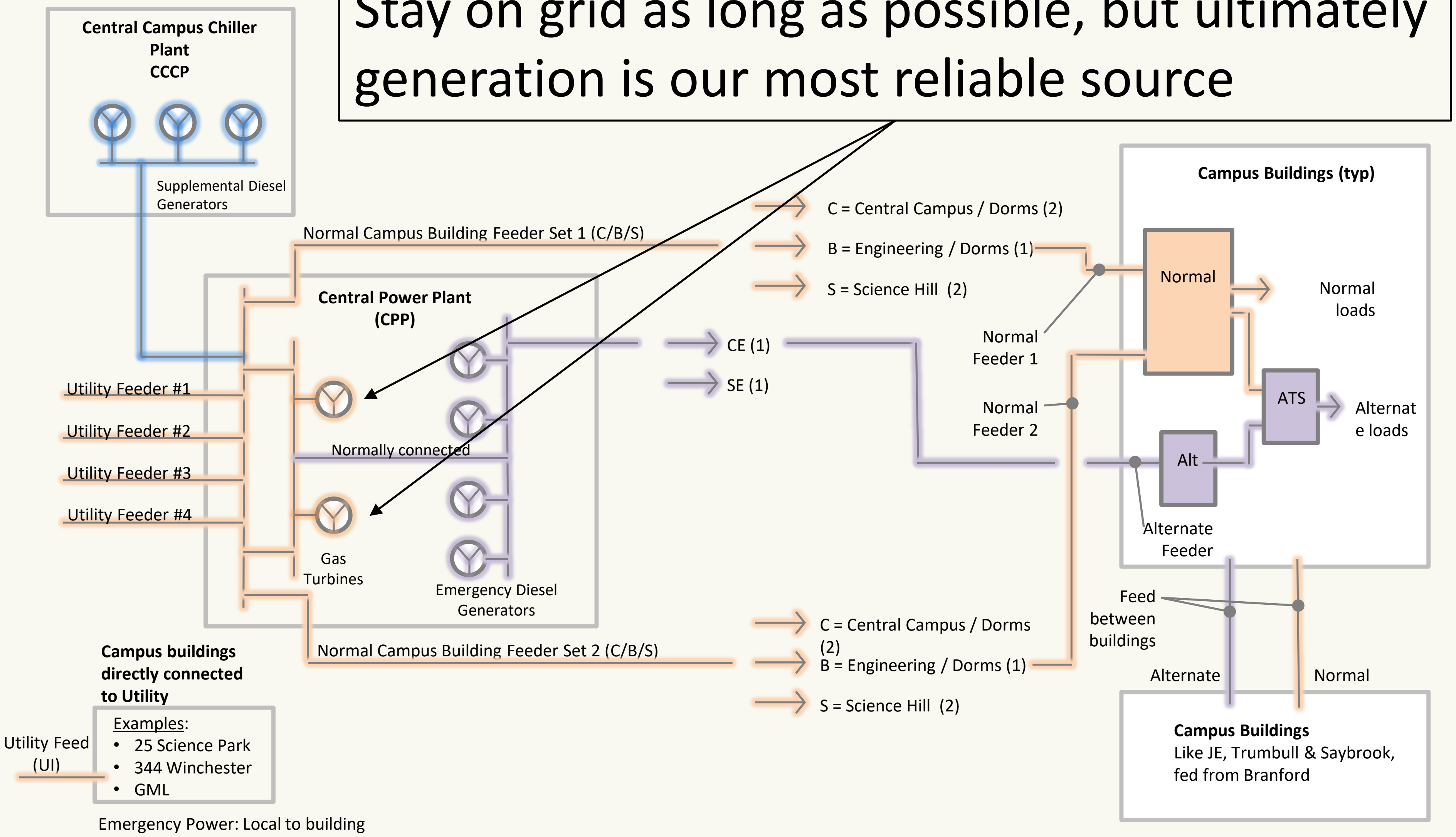
- 2 Sites – Main Campus (Central Power Plant) and Medical School/Hospital (Sterling Power Plant)
- Each 15 MW with heat recovery and grid interconnection
- Primary Select Campus Distribution Circuits fed at 15 kV
- Sterling Plant converted to cogeneration in 2010
- Central Plant original cogeneration in 1997, repowered in 2016

Yale Central Power Plant Microgrid



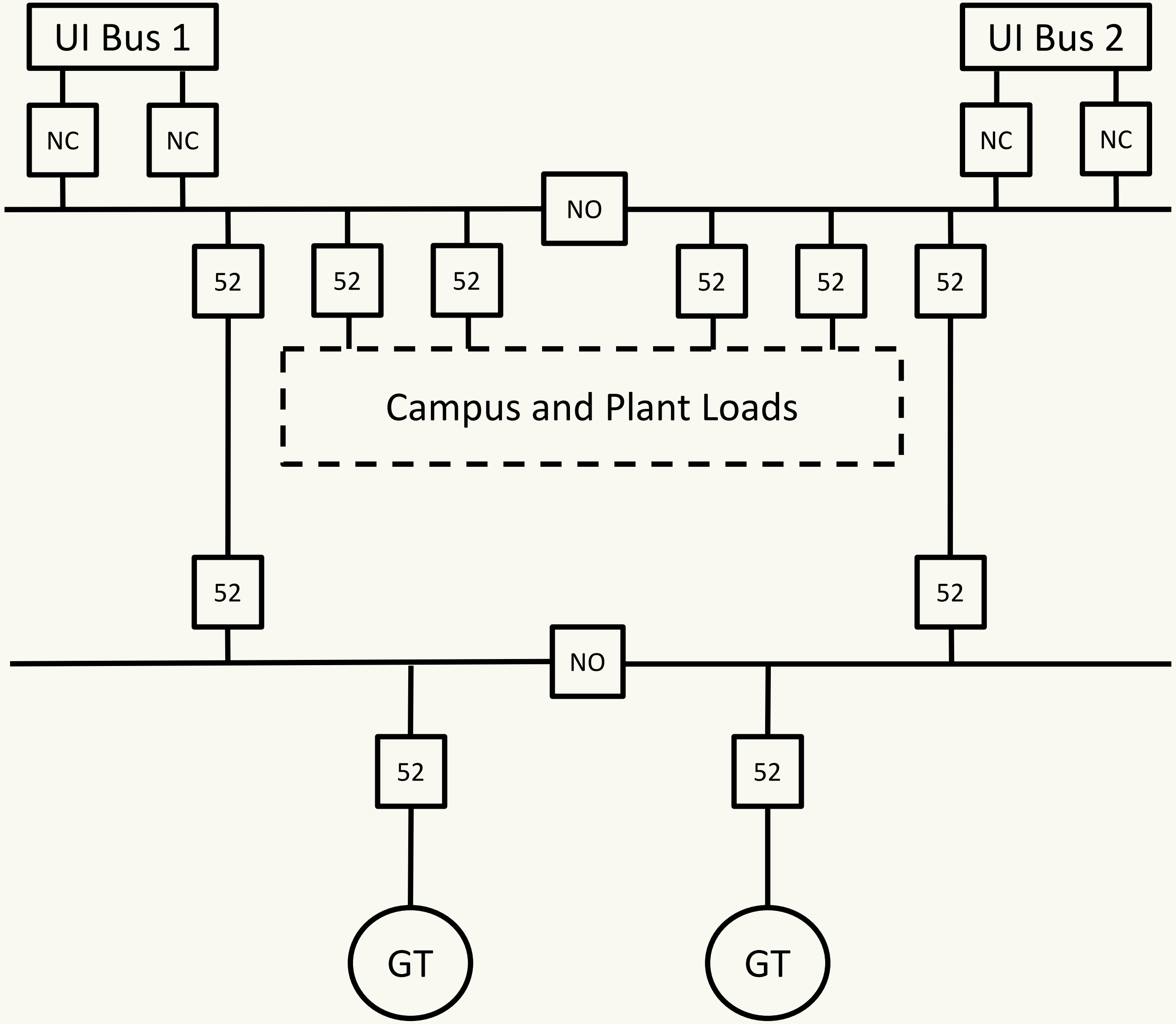
Operating Philosophy

Stay on grid as long as possible, but ultimately generation is our most reliable source



Fast Bus Transfer – Stay on Grid

- Implemented via contact logic
- Enabled and supervised by Synch Panel PLC and local Synch Check
- Sequence:
    - 2 UI feeders trip (not Arc, Bus Diff, Bus O/C)
    - UI Breakers proven open
    - Main Tie breaker closes
    - GT Tie breaker stays open



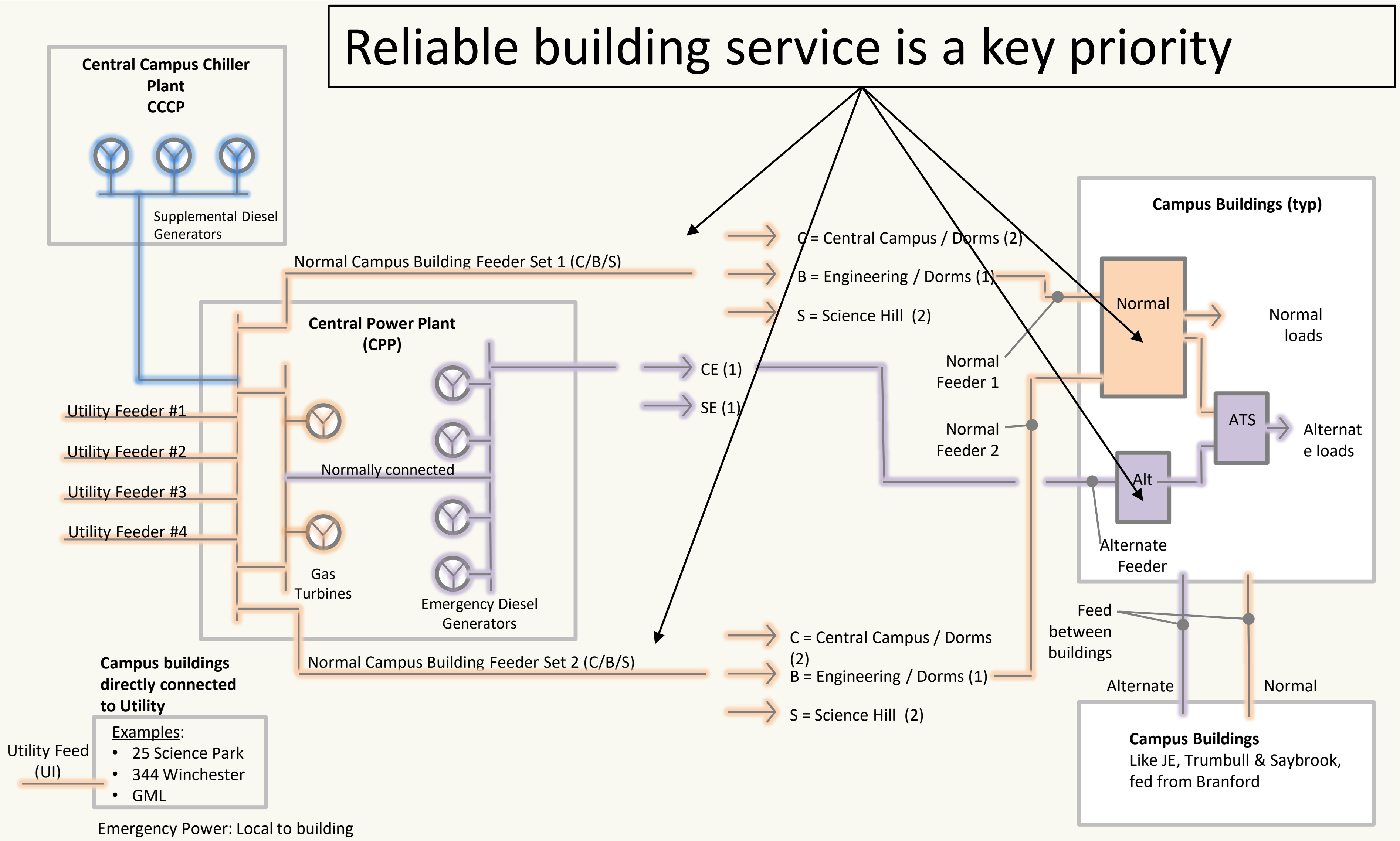
Campus Load Shed – Keep Generation Running

- Uses electromechanical frequency-based load shed relays
- First installed with original cogen – hardwired scheme:
  - Residential/Academic buildings shed first
  - Low Density Science/Academic next
  - High Performance Science last
- Made sense until October 29, 2012 – Hurricane Sandy:
  - Load too high to Island
  - 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!

Selectable Load Shed – Flexible Solution

- 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

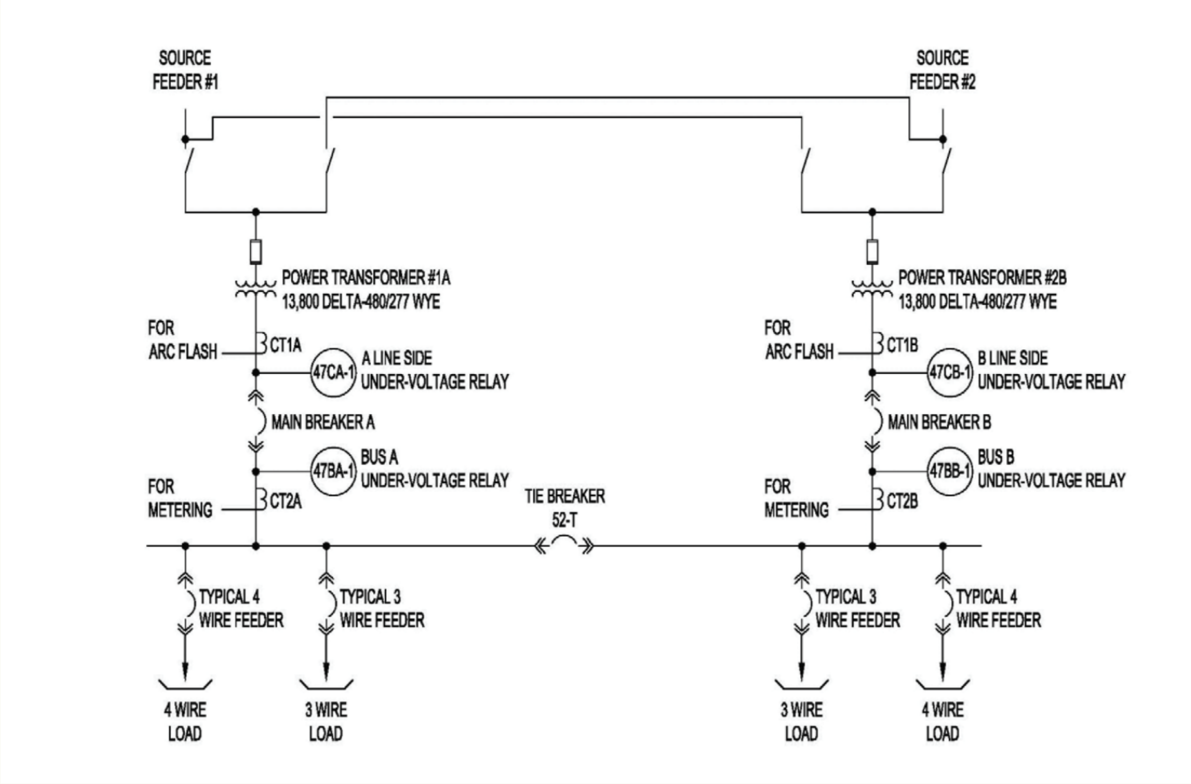
Operating Philosophy



Standardized Double-Ended Substation Design

Double-Ended Substation with Auto-Throwover:

- Automatic system supervised by PLC
- Bus Undervoltage trips main and closes tie
- Inhibited on overcurrent, ground fault or arc detection
- Automatic retransfer after 10 seconds



Commissioning Best Practices

“Commissioning is a process that begins in design, continues through construction, and concludes with functional testing.”

Cx Best Practices: Design

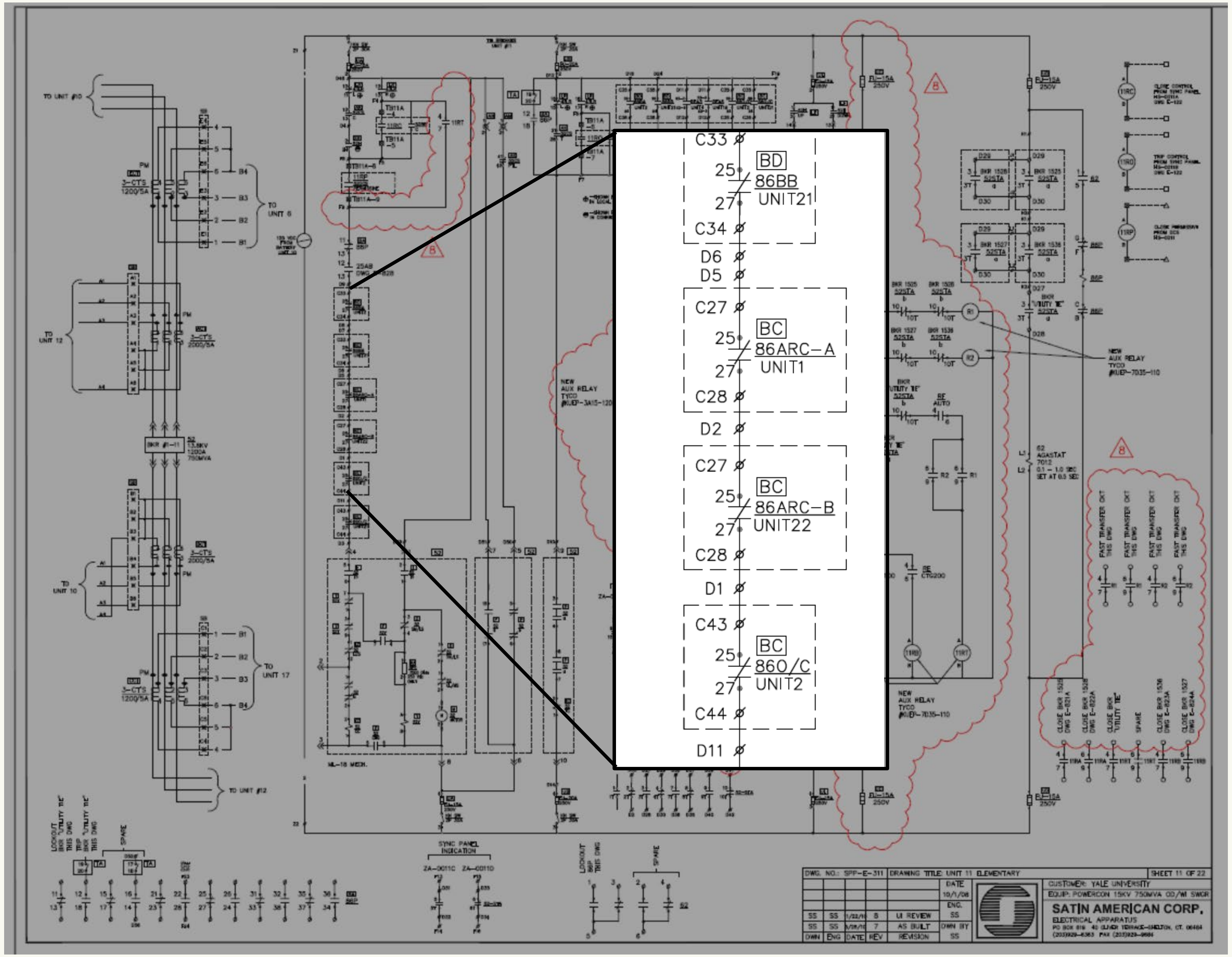
- Make sure you (as the owner) understand:
  - What your electrical system is and is not capable of – especially the Protection and Control
  - What is required to enable this capability?
  - How will we test it to make sure?
- Design Considerations:
  - Have we included break points in the system, such at test switches?
  - Where will the load come from to test? How will it be connected to our system?
  - Do the project documents describe the full control philosophy? Do they include enough documentation to troubleshoot?

Cx Best Practices: Construction

Construction QA is vital to functional testing going well:

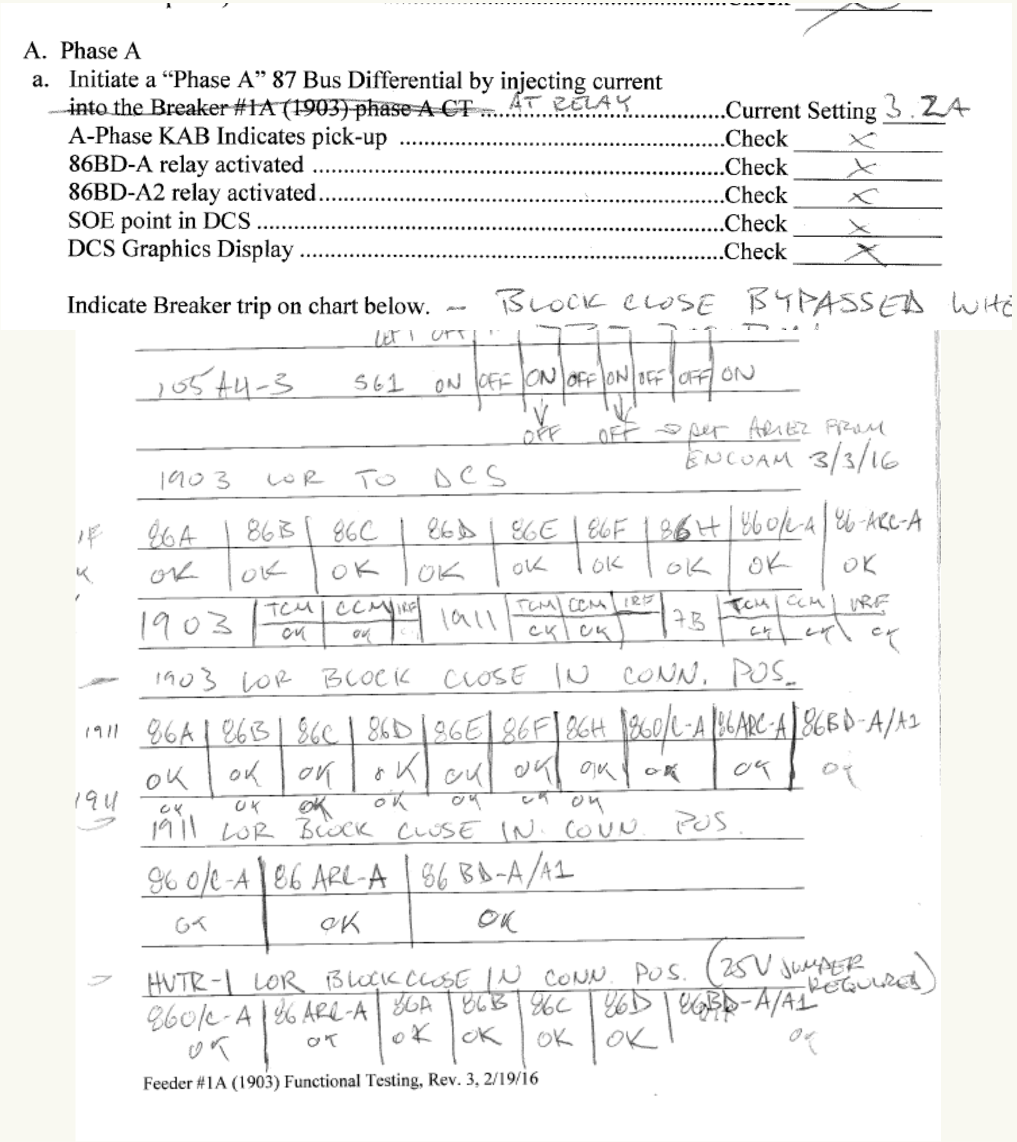
- Validation of key inputs that are not “settings” per se – such as PT and CT ratios
- CT polarity
- Documentation of control wiring between pieces of equipment (e.g., generator differential CT wiring to generator breaker relays)
- Relay I/O Mapping
- Interface to plant control system

Example: Show complete wiring path on Schematic



Cx Best Practice: Integrated Functional Testing

- 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

105A4-3 561 ON OFF ON OFF ON OFF OFF ON

1903 LOR TO DCS

86A	86B	86C	86D	86E	86F	86H	860/C-A	86-ARC-A
OK	OK	OK	OK	OK	OK	OK	OK	OK

1903 LOR BLOCK CLOSE IN CONN. POS.

86A	86B	86C	86D	86E	86F	86H	860/C-A	86ARC-A	86BD-A/A1
OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

1911 LOR BLOCK CLOSE IN CONN. POS.

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

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

860/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

Questions?

Thank You!

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