“State of the Art” of Standby Power Systems

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IEEE, SCV IAS & PES

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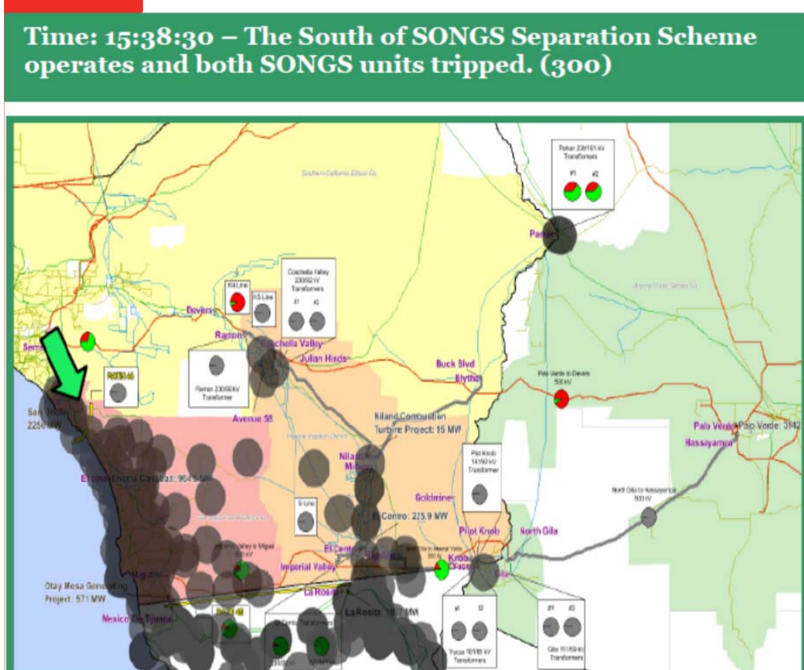
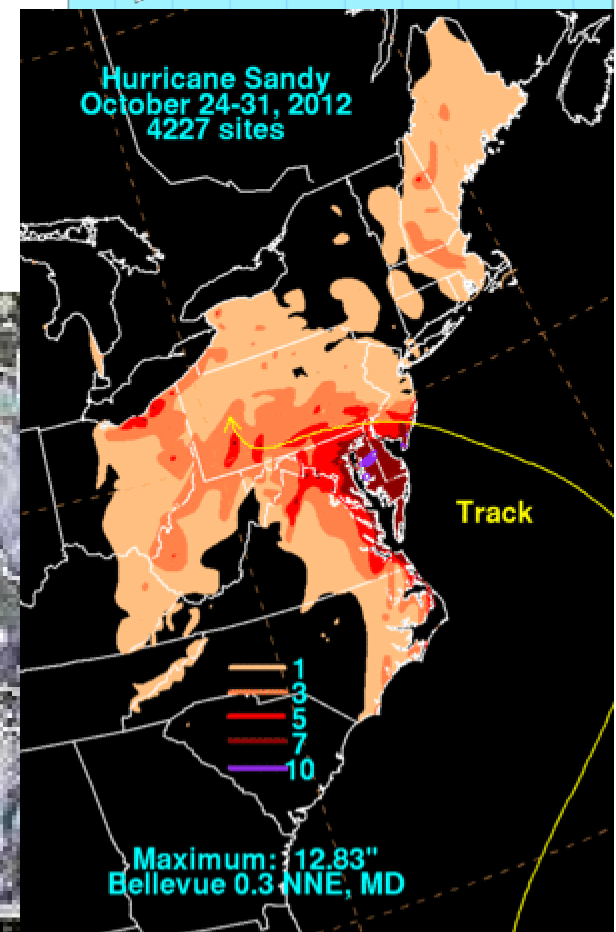
Agenda

- Current Trends on Critical Power Systems
- Emergency Power System Architectures
  - Common Topologies
  - Data Center Variations
  - Uptime Institute Tier Ratings
- Exhaust Emission Trends

Observing Standby Systems in Recent Real World Events – Lessons Learned

- Hurricane Katrina (Aug 2005)
- Fukushima Power Plant (Mar 2011)
- SoCal regional outage (Sept 2011)
- Hurricane Sandy (Oct 2012)





Applicable Standards

- NEC/CEC 700 Emergency Systems
- NEC/CEC 701 Legally Required Standby Systems
- NEC/CEC 702 Optional Standby Systems
- NEC/CEC 708 Critical Operation Power Systems
- IEEE 493 Guide to Reliability in Commercial & Industrial Power Systems (Gold Book)
- IEEE P3006.7 Practice for Determining Reliability of "7x24" Continuous Power Systems (Bob Schuerger)
- NFPA 99 – Healthcare
- NFPA 110 – Emergency Power Systems

NEC Article 708 - Critical Operation Power Systems (2008)

- Holistic approach to EPS
- Mainly meant for infrastructure facilities
- Risk assessment (natural & human caused)
- Above 100 year flood plane
- Means of connecting portable generator
- Backup gen when performing maintenance on generator
- Testing under actual load
- Annual fuel quality test
- Physical security and restricted access (indoor preferred)
- 72 hour run time
- Fire rated feeders

Other Developments

- Data Centers
  - 50-100 MW Requirements not uncommon
  - Reliability, Availability Requirements getting more acute
  - Genset continuous ratings required for Tier 3,4 certifications
- Hospitals
  - Seismic testing
- Increasing size & complexity (campus environments)
  - Critical (10 sec) Loads increasing beyond size of one gen
- Monitoring and DCIM
- Exhaust Emission Levels lower

Diesel Engine Developments

- Internal designs of engines have been advancing
- Emissions are much lower (EPA Tiers are driving)
- Durability is increasing
- Materials and technique
- Power Density is going up
- Fuel consumption coming down
- Ultra low sulfur fuel becoming common
- High speed computing necessary for emission control

Cummins Power Generation

Agenda

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Common Topologies

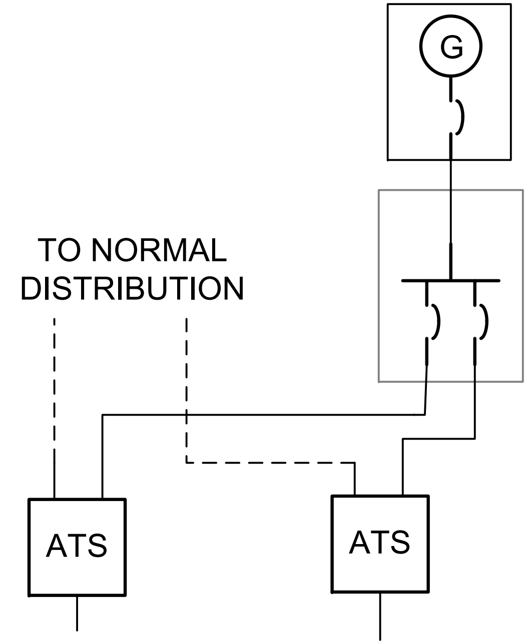
- Isolated Bus
- Isolated Bus with Gen main
- Common Bus
- Transfer Pair
- Main Tie Main
- Multiple Transfer Pair

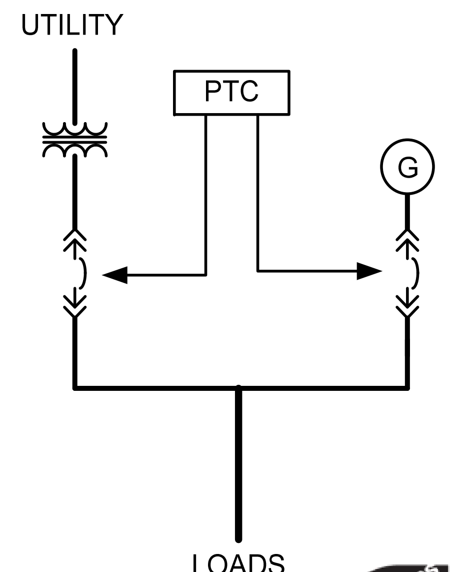
Critical Power System Designs

- Huge variety of designs
  - Simple Systems - Single genset and transfer switches
    - Bypass/Isolation and closed transition options
  - Paralleling with ATS
  - Paralleling with Power Transfer, Bus Ties
  - Other variations (Swing generators)
- Systems becoming very large (>100MW in many sites)
  - 1GW in the future?
- High speed diesel gensets still most common choice: lowest cost/kW, fast starting, local fuel supply, stable, easy to service
- Tendency for Redundant and Modular Systems

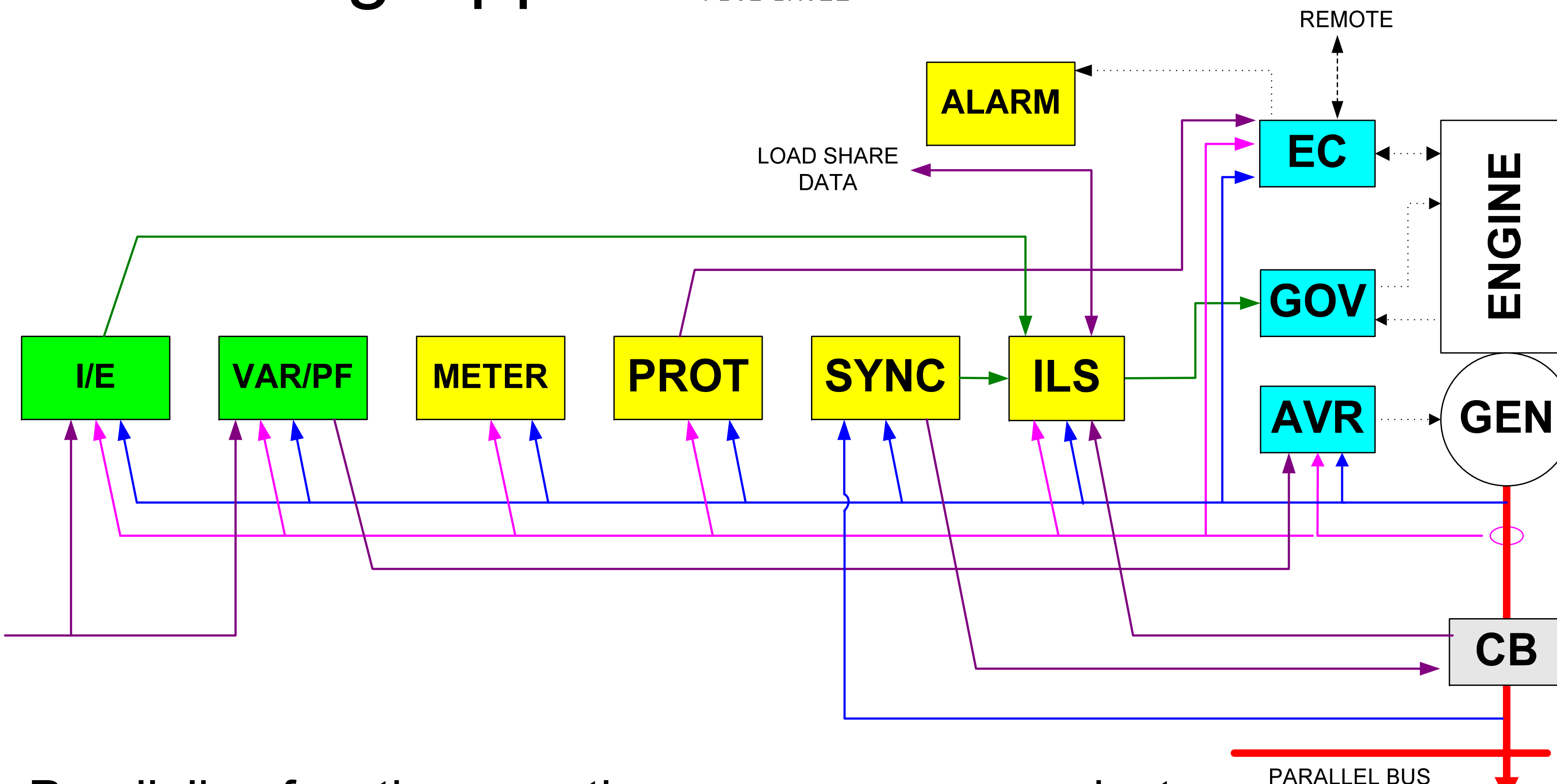
Simplest Designs

- Genset with one or more ATS
  - Best for smaller projects, open transition
  - Can be multiplied for larger projects
- Genset operating power transfer breaker pair
  - Best for larger generators, switching near service
  - Lowest cost, smallest footprint
  - Can synchronize and ramp loads between live sources
  - Breakers can trip, so need to deal with that logically
  - Can be multiplied for any size project
- When used in multiples, each genset/transfer equipment has single points of failure, but only part of system fails



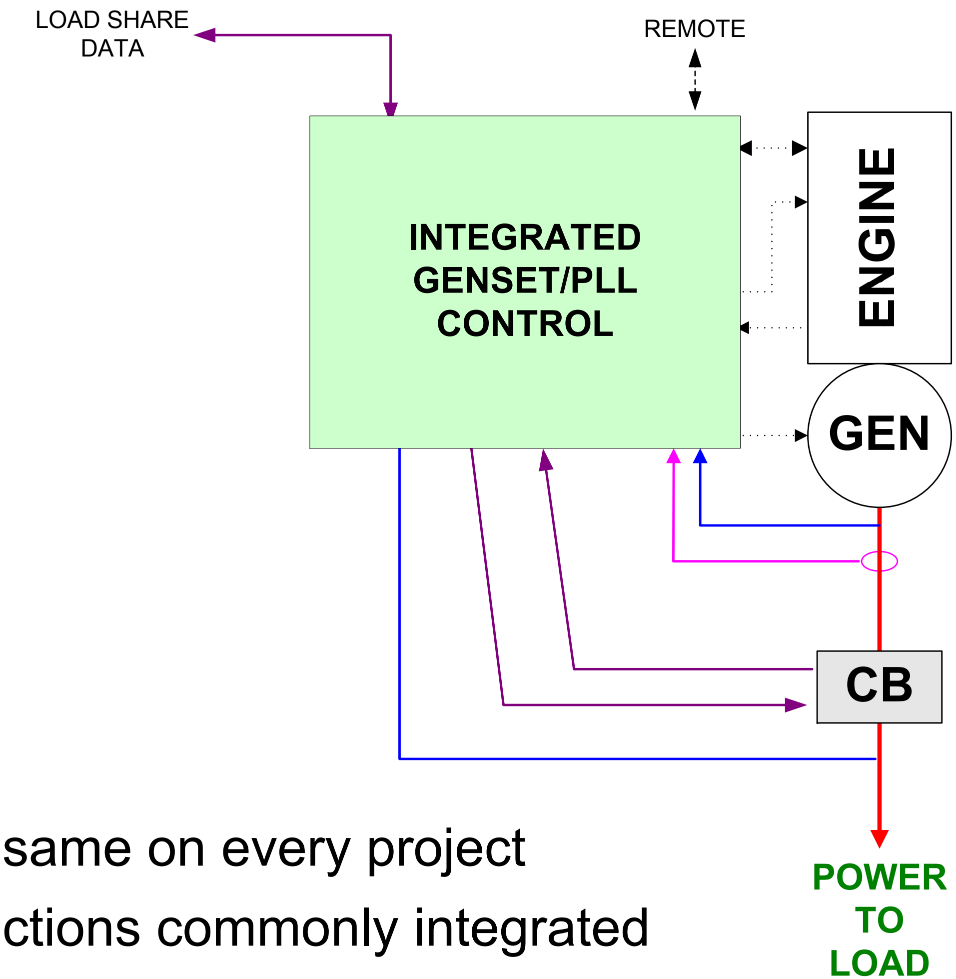


Paralleling Applications



- Paralleling functions are the same on every project
- Generator set paralleling functions commonly integrated
  - No/very limited switchgear space for separate control equipment
  - Dedicated purpose controllers with firmware rather than PLC-based or component functions

Paralleling Applications



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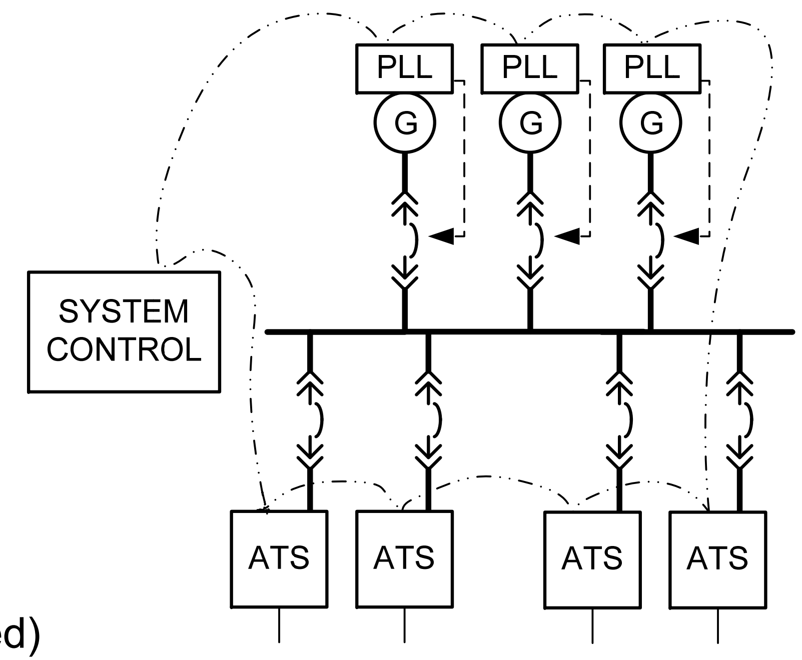
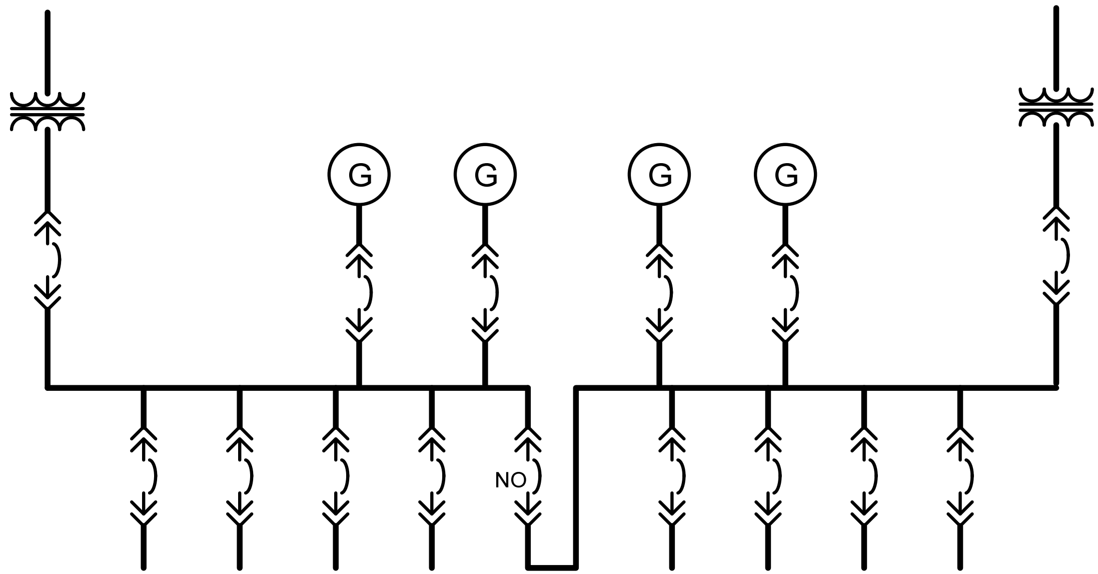
Parallel Applications

- Paralleling Systems Utilize Major Control Blocks with Common Functions
  - Parallel Controllers (PLL)
    - Start/Stop/Protect Genset
    - Black Start Control
    - Synchronize
    - Load Share
    - Bus Protection
  - Transfer Controllers (ATS)
    - Source Availability
    - Transfer Logic
  - System Control
    - System monitoring
    - Load Management (load add/shed)
    - Capacity Management (load demand)
- Distributed Logic Strategy
- Design Control
  - "One Throat to Choke"



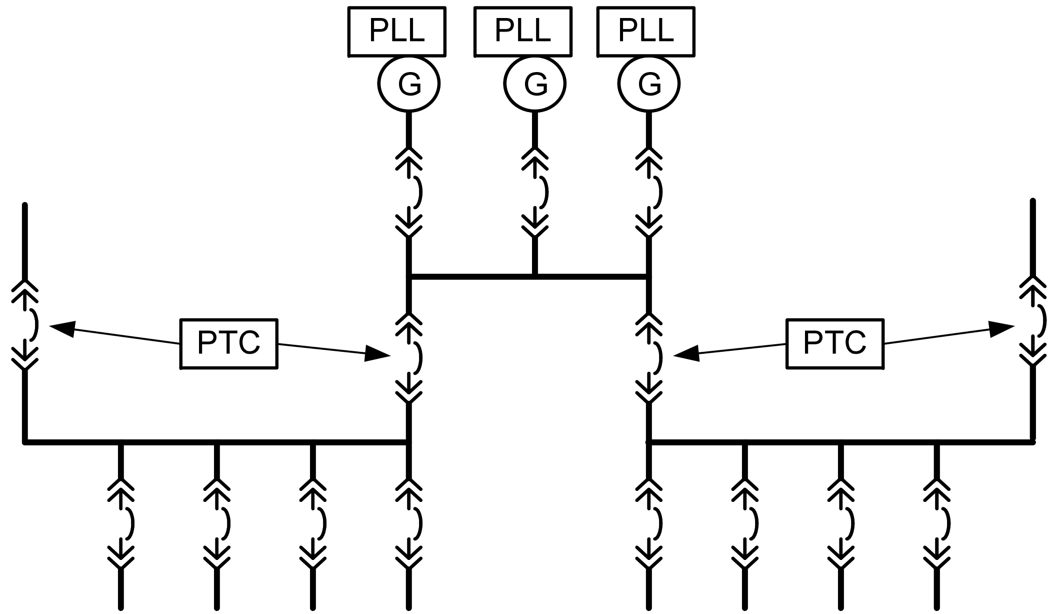
Power Generation

More Complex Designs



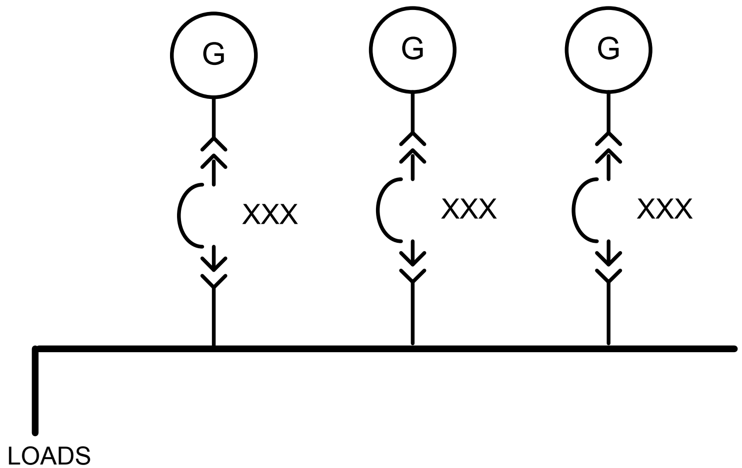
- “Main-tie-Main” Configuration
- Service issues due to gensets on common bus with utility
- Logic Variations due to automated tie can be problematic

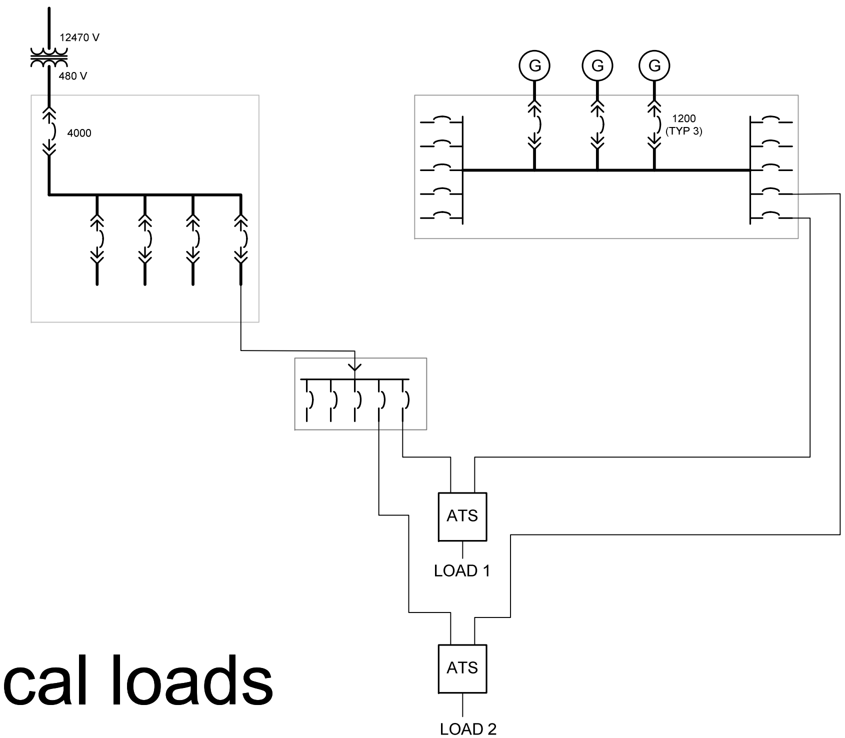
More Complex Designs



- A combination of core paralleling and power transfer control blocks
- May have many generators and many transfer pairs
- Usually includes a central monitoring system for entire package

Isolated Bus



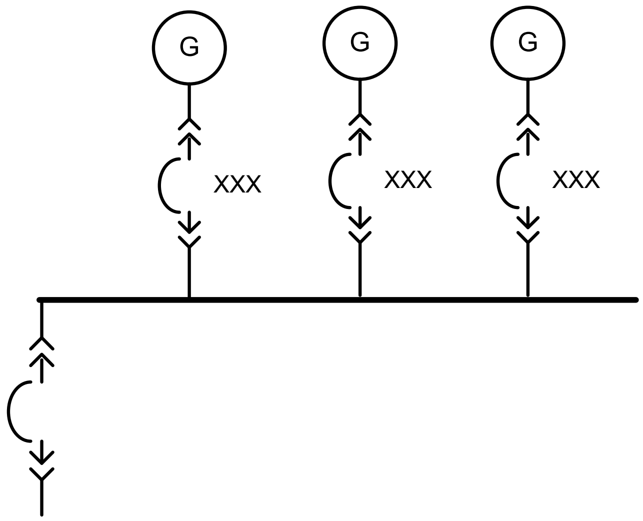


Most reliable service to critical loads

- Simplest, most common topology
- No connection with utility
- Power Interruptions on re-transfer
- Each gen must be large enough to carry emergency loads
  - Need to be on line in 10 seconds (per NEC)
- Load control required to make sure that sufficient capacity is on line before connecting loads

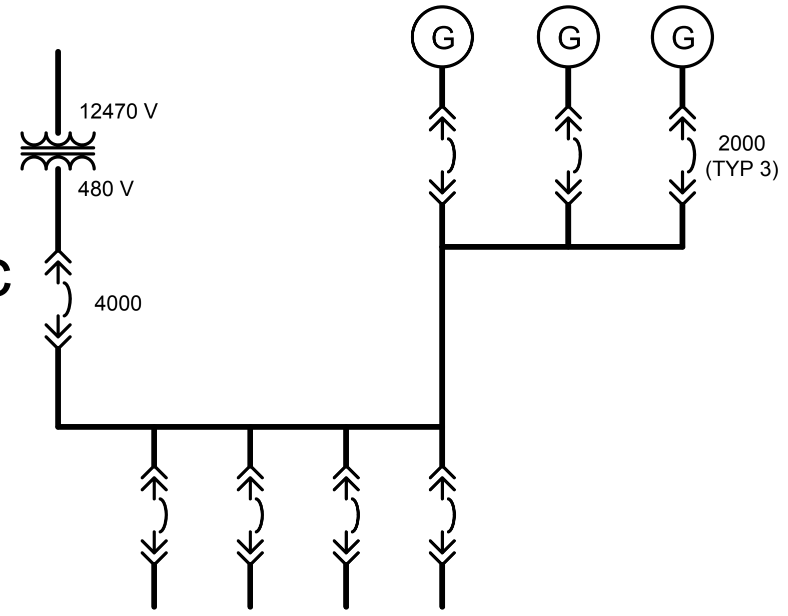
Isolated Bus with Gen Main

- Allows configuration for minimum generator sets online before connecting critical load.
- Common topology for prime power



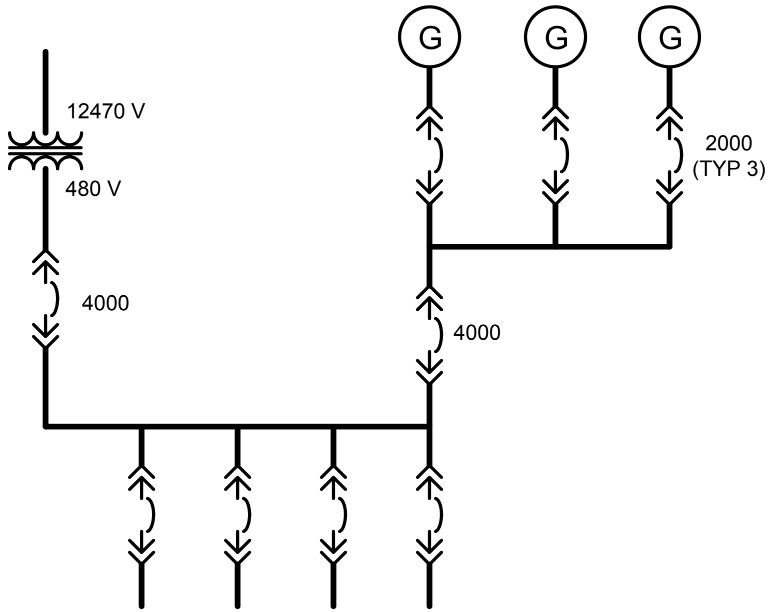
Common Bus

- Low cost
- Can do open & ramping closed transition transfer
- Can't guarantee 100msec max parallel time
- Service Problem: paralleling problems require interruption in service to loads
  - Loads can not be isolated from gen bus

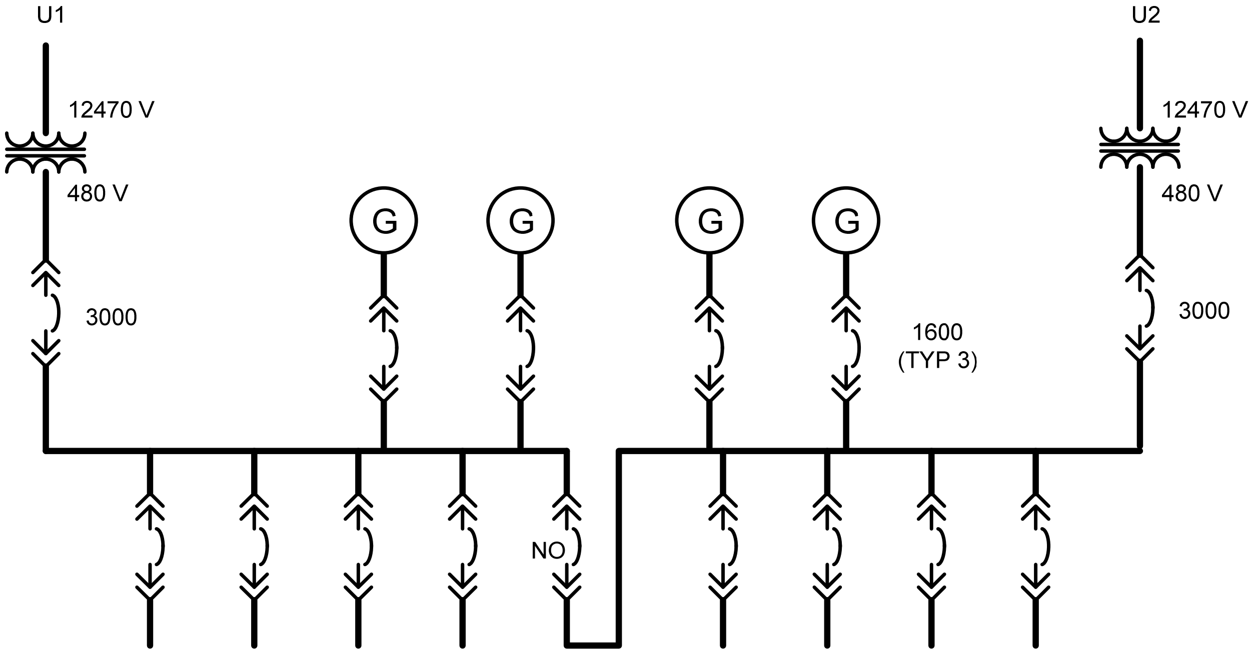


Transfer Pair

- Allows for bumpless retransfer and test with load functions
- Good for maintenance as generator source can be isolated from loads and tested

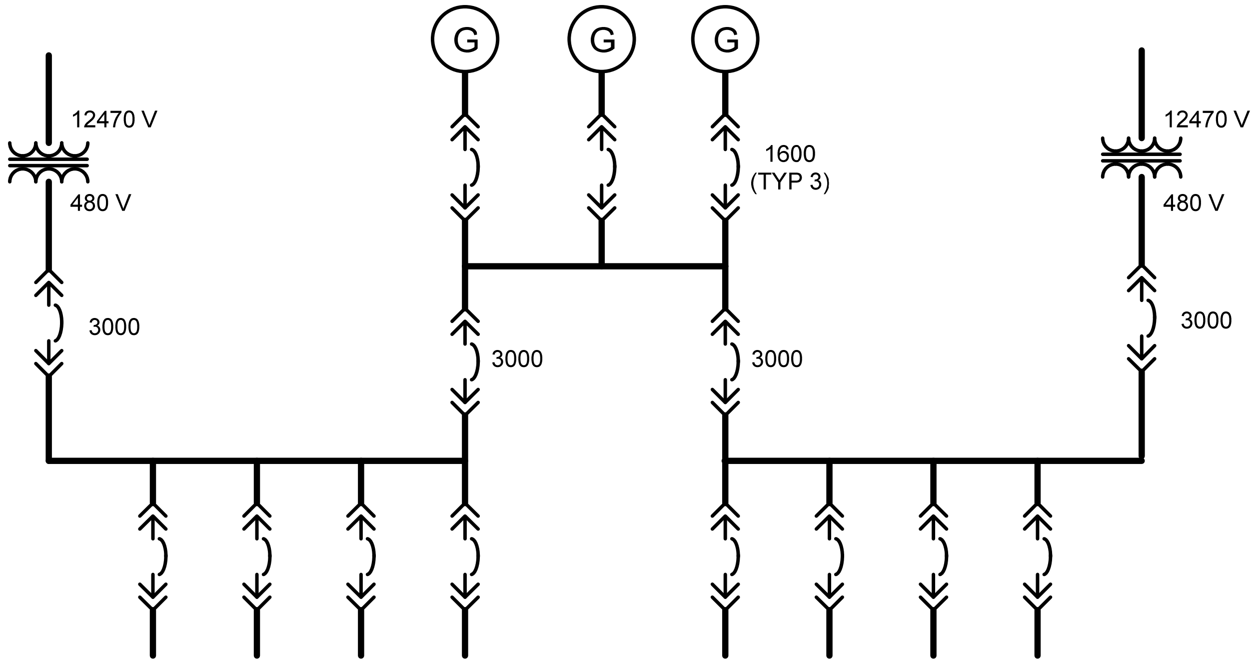


Main Tie Main



- Tie is normally open
- Similar to two Common Bus designs
    - Similar serviceability issues

Multiple Transfer Pair

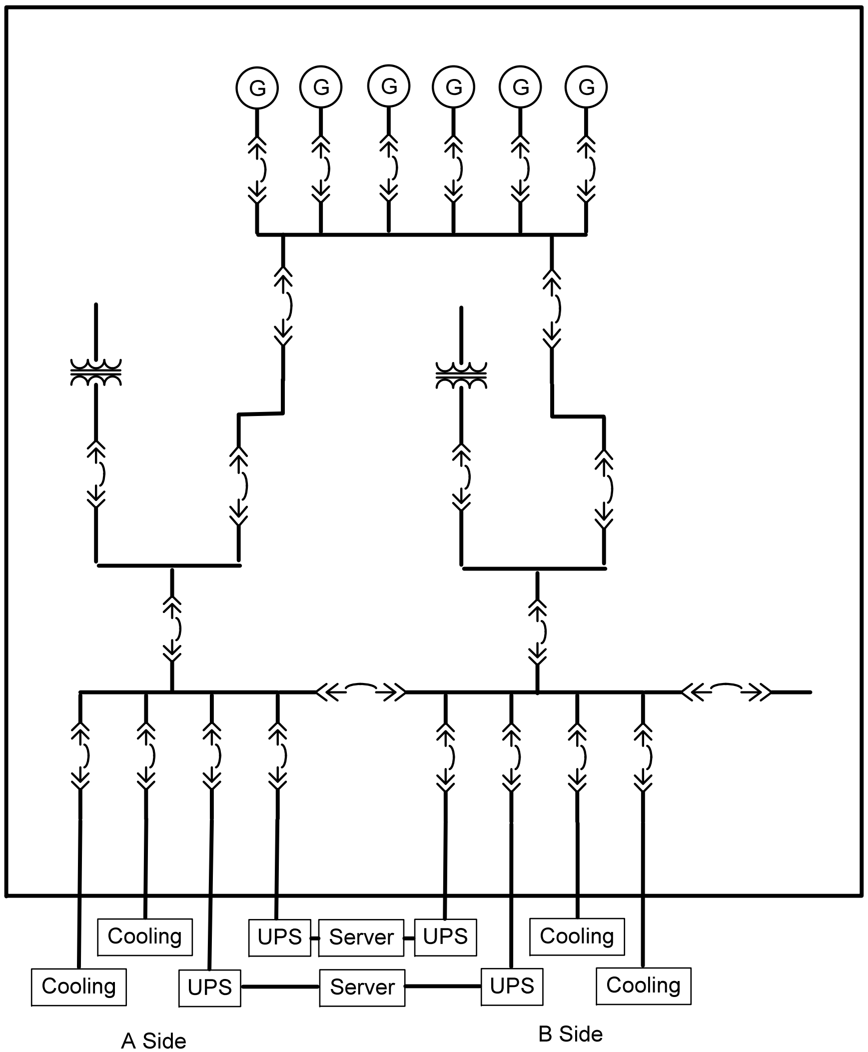


- Has better serviceability than Main-Tie-Main
- System operates like two transfer pairs
- Gens can parallel with either utility but not both
  - On closed transition transfer gens sync with one utility at a time

Agenda

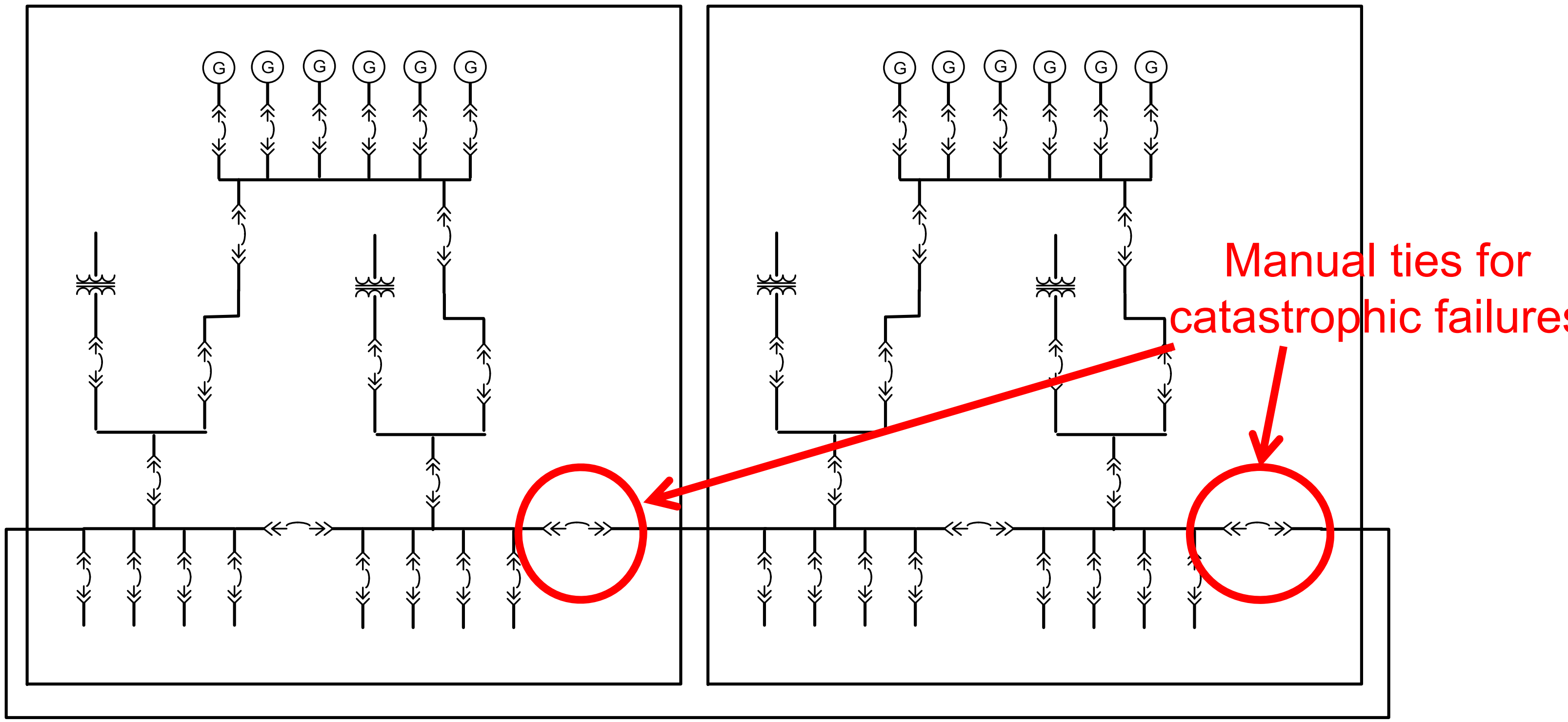
- Common Topologies
- Data Center Variations
- Uptime Institute Tier Ratings

Modular Data Center



- Modular concept allows for redundancy and scalability
  - Redundant power capacity
  - Redundant distribution paths
  - Redundant data storage
  - Redundant cooling

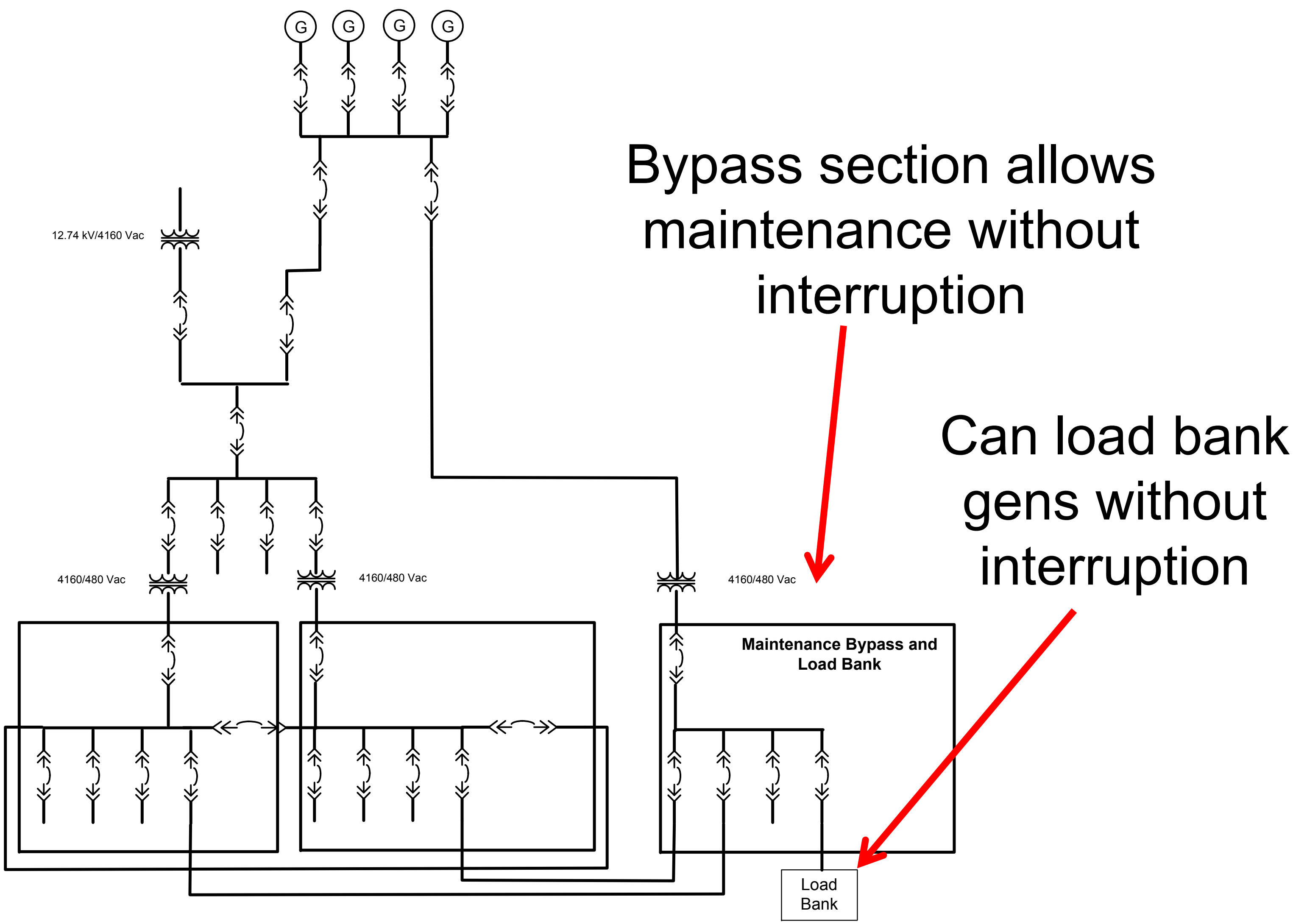
Modular Data Center - Scalability



Example

- Three modules on site, installed in 2008, 2010, 2012
  - Long term plan is to add a fourth module
- Each module is sized for 25 MW
  - Running at about ½ capacity

Modular Data Center with Maintenance Bypass



Tier Level Ratings

- The tier rating system has long been the industry standard for benchmarking data center reliability.
- Four tiers, each building on requirement to the one below. (ex. Tier II requires all of Tier I capability, plus the added requirements)
- Power Generation and distribution is one of 16 subsystems evaluated
- No fractional tier ratings
- Tiers do not specify certain equipment, but rather a level of redundancy and security to maximize run time.
- To be an enterprise class data center, UPS and Gensets are required equipment.
- Significant costs associated with tier rating higher

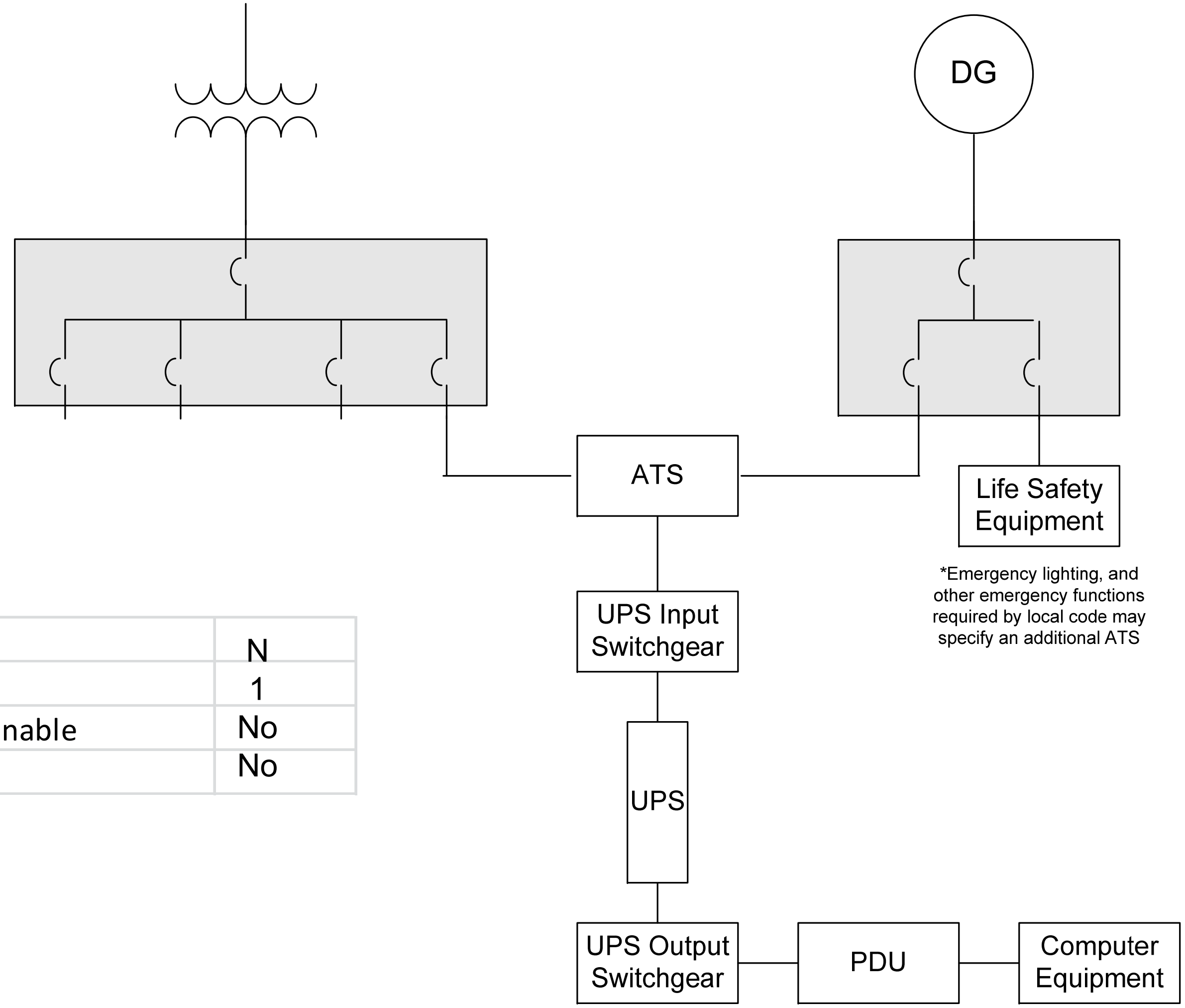
Uptime Institute Tier Ratings

	Tier 1	Tier 2	Tier 3	Tier 4
Description	Basic	Redundant Capacity	Concurrently Maintainable	Fault Tolerant
Capacity	N	N+1	N+1	2N (N after any failure)
Distribution Paths	1	1	1 Active, 1 Alternate	2 Simultaneouly Active
Concurrently Maintainable	No	No	Yes	Yes
Fault Tolerant	No	No	No	Yes
Typical Topology	Standby Genset	Isolated Bus	Dual transfer Pair	Dual Transfer Pair

Down Time Statistics

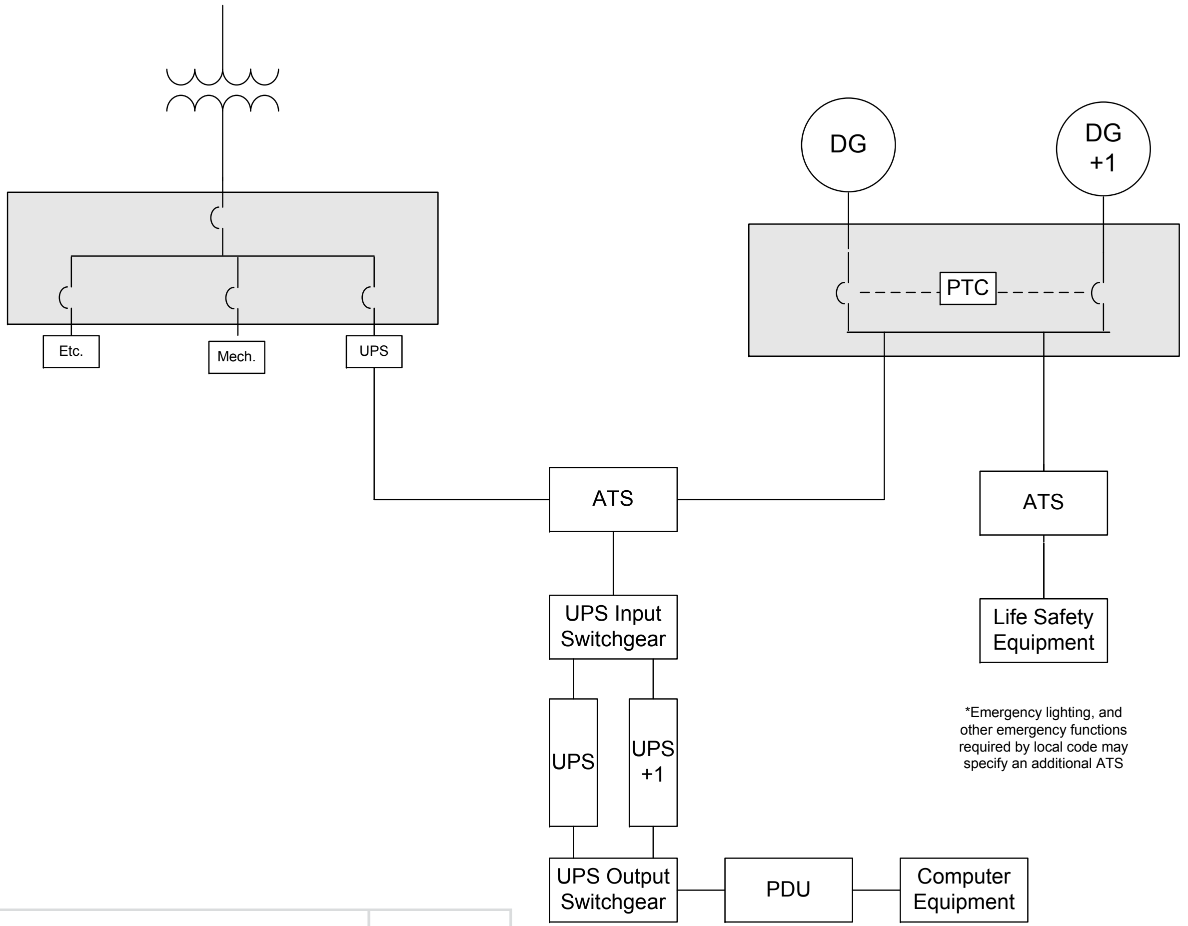
	Tier I	Tier II	Tier III	Tier IV
Avg. Downtime/Failure	4 Hrs	4 Hrs	4 Hrs	4 Hrs
Avg. Failures	1.2 per year	1 per year	1 every 2.5 years	1 every 5 years
Avg. Down Time/Year (planned and unplanned)	28.8 Hrs	22.0 Hrs	1.6 Hrs	.8 Hrs
Availability	99.67%	99.75%	99.98%	99.99%

Tier I - Basic



Capacity	N
Distribution Paths	1
Concurrently Maintainable	No
Fault Tolerant	No

Tier II – Redundant Capacity



Capacity	N+1
Distribution Paths	1
Concurrently Maintainable	No
Fault Tolerant	No

Tier III: Concurrent Availability

- Adds redundancy to network distribution paths as well as capacity established in tier II systems.
- Every distribution component can be removed or replaced during a planned event without loss of service.
  - Allows for a more aggressive maintenance program
  - Enables site to be upgraded as technology, capacity and infrastructure requirements change
- An unplanned event can still lead to disruption.

Tier III and Tier IV Generators

- “Disruptions to the utility power are not considered a failure but an operational condition for which the site must be prepared”
- “A Tier III or Tier IV engine-generator system, along with its power paths and other supporting elements shall meet … performance confirmation tests while they are carrying the site on engine-generator power”
- “Engine-generators for Tier III and Tier IV sites shall not have a limitation on consecutive hours of operation when loaded to ‘N’ demand.”
- No limitation on run time implies that a Continuous or Prime rated set would be required

Tier III/IV Generators

- Engine-generator systems are considered the primary power source for the data center.

1. Generator system must be large enough to power the entire data center.
2. **No limitation** on the run time of the generators.

(The manufacturers' certification of capacity at an unlimited duration will be used to determine compliance with Tier requirements)

New Data Center Continuous Ratings

- Data Center Continuous (DCC) Ratings have been defined to clarify compliance with Tier III and Tier IV requirements
- Data Center Continuous (DCC) Rating is defined as

  The maximum power which the generator is capable of delivering continuously to a constant or varying electrical load for unlimited hours in a data center application where a reliable utility is present

- Ratings available from 1135 kW to 3350 kW

Diesel Generator set QSK60 series engine

1600 kW - 2000 kW 60 Hz

Data Center Continuous

EPA Emissions

Description

Cummins Power Generation commercial generator sets are fully integrated power generation systems providing optimum performance, reliability and versatility for stationary standby and prime power applications.

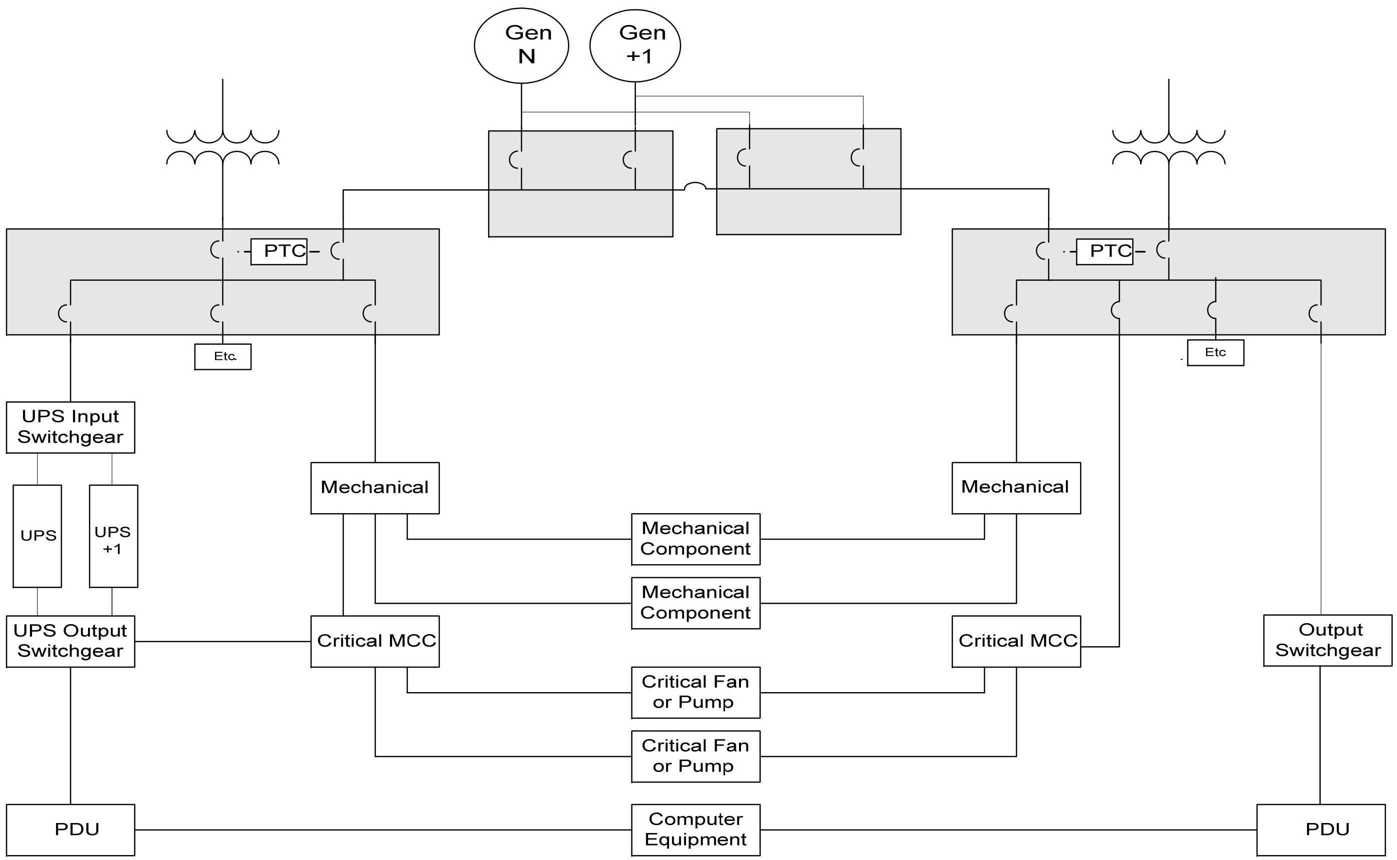
Features

Data Center Continuous (DCC) - Applicable for supplying power continuously to a constant or varying electrical load for unlimited hours in a data center application.

Uptime Compliant - Meets the requirement of a Tier III and IV data center site by being rated to run for unlimited hours of operation when loaded to 'N' demand for the engine generator set.

Power Generation

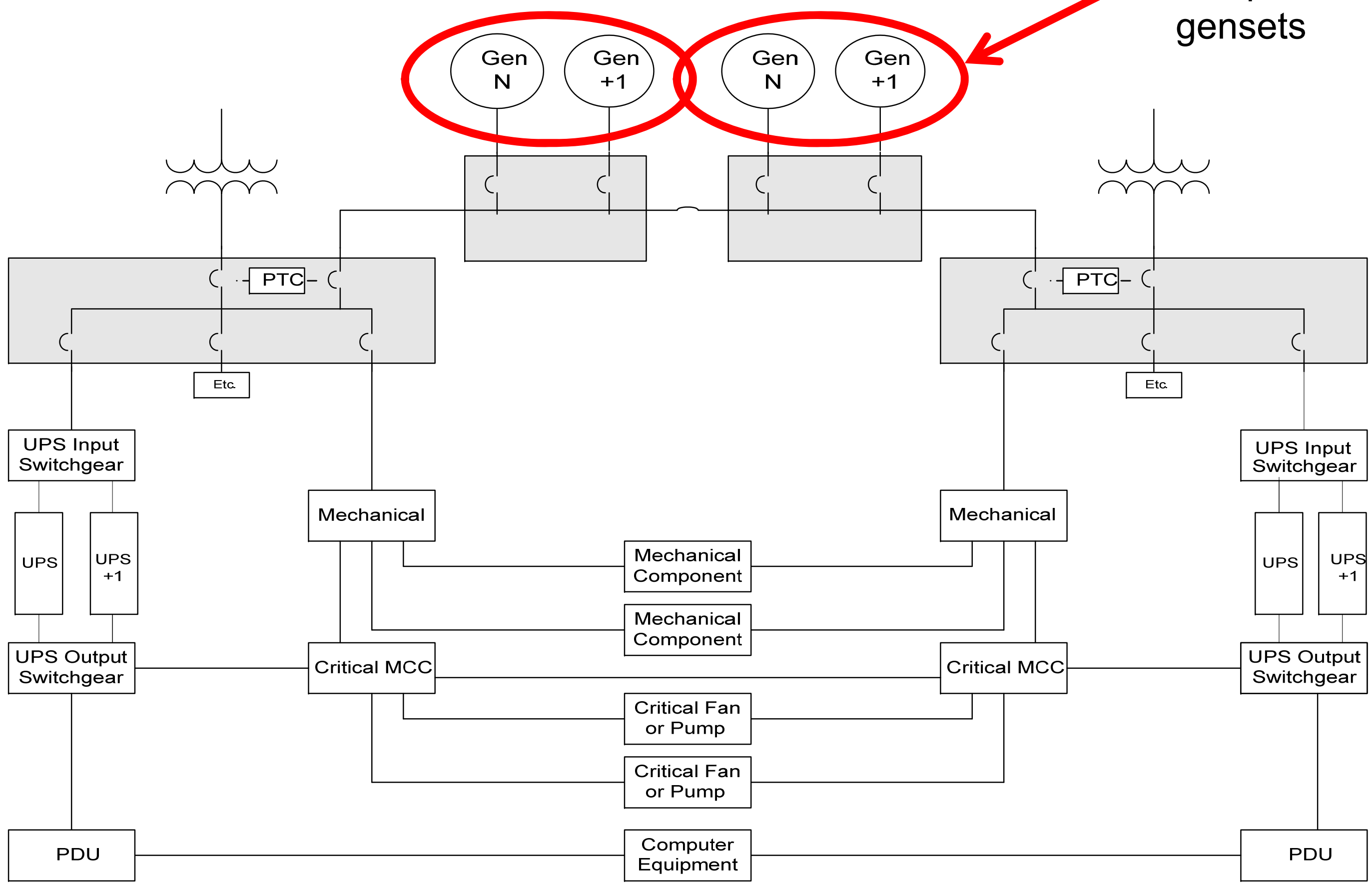
Tier III - Concurrently Maintainable



Capacity	N+1
Distribution Paths	1 Active, 1 Alternate
Concurrently Maintainable	Yes
Fault Tolerant	No

Tier IV – Fault Tolerant

Tier 4 requires compartmentalized gensets



Capacity	2N (N after any failure)
Distribution Paths	2 Simultaneously Active
Concurrently Maintainable	Yes
Fault Tolerant	Yes

Tier Rating Summary – Power Distribution

- Tier I - Basic
  - Backup gen and UPS
- Tier II – Redundant Capacity
  - Redundant generators
- Tier III – Concurrently Maintainable
  - Maintenance path
  - No interruption required for maintenance anywhere in the distribution system
- Tier IV – Fault Tolerant
  - No interruption for any single failure

Architecture Conclusions

- Using standard system topologies makes the system more reliable and serviceable
- Consider ease of maintenance and future expansion when designing system topology
- The Uptime Institute Tier Rating system serves as a good framework for evaluating redundancy, maintainability and scalability in a system design

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CI NSPS Stationary Emissions (Stationary Power Gen Engines)

U.S. EPA NOx / HC² / CO / PM (g/kW-hr)

Engine Power (NOx+NMHC) / CO / PM (g/kW-hr) [Conversion: (g/kW-hr) x 0.7457 = g/bhp-hr]

(HP)	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
(0 - 24)	(7.5) / 6.6 / 0.40									
(25 - 48)	(7.5) / 5.5 / 0.30					(4.7) / 5.0 / 0.03 (7.5) / 5.5 / 0.30 Emergency				
(49 - 74)	(4.7) / 5.0 / 0.40				(4.7) / 5.0 / 0.03 (4.7) / 5.0 / 0.40 Emergency					
(75 - 99)	(4.7) / 5.0 / 0.40				3.4/0.19/5.0/0.02 (4.7) / 5.0 / 0.40 Emergency			0.40 / 0.19 / 5.0 / 0.02		
(100 - 173)	(4.0) / 5.0 / 0.30				3.4/0.19/5.0/0.02 (4.0) / 5.0 / 0.30 Emergency			0.40 / 0.19 / 5.0 / 0.02		
(174 - 751)	(4.0) / 3.5 / 0.20			2.0 / 0.19 / 3.5 / 0.02 (4.0) / 3.5 / 0.20 Emergency			0.40 / 0.19 / 3.5 / 0.02			
(752 - 1207)	(6.4) / 3.5 / 0.20			3.5 / 0.40 / 3.5 / 0.10 (6.4) / 3.5 / 0.20 Emergency				0.67/ 0.19/ 3.5/ 0.03		
(1208 - 3000)	(6.4) / 3.5 / 0.20			0.67 / 0.40 / 3.5 / 0.10 (6.4) / 3.5 / 0.20 Emergency				0.67/ 0.19/ 3.5/ 0.03		
(>3000)	9.2 / 1.3 / 11.4 / 0.54			0.67 / 0.40 / 3.5 / 0.10 (6.4) / 3.5 / 0.20 Emergency				0.67/ 0.19/ 3.5/ 0.03		

Notes: Tier 1 | Tier 2 | Tier 3 | Tier 4 Interim | Tier 4 Final

2008 technology is still OK for emergency engines (per EPA)

Local districts and cities can and do add further restrictions

SCAQMD requires T4 PM levels for "sensitive receptors" and K-12 schools

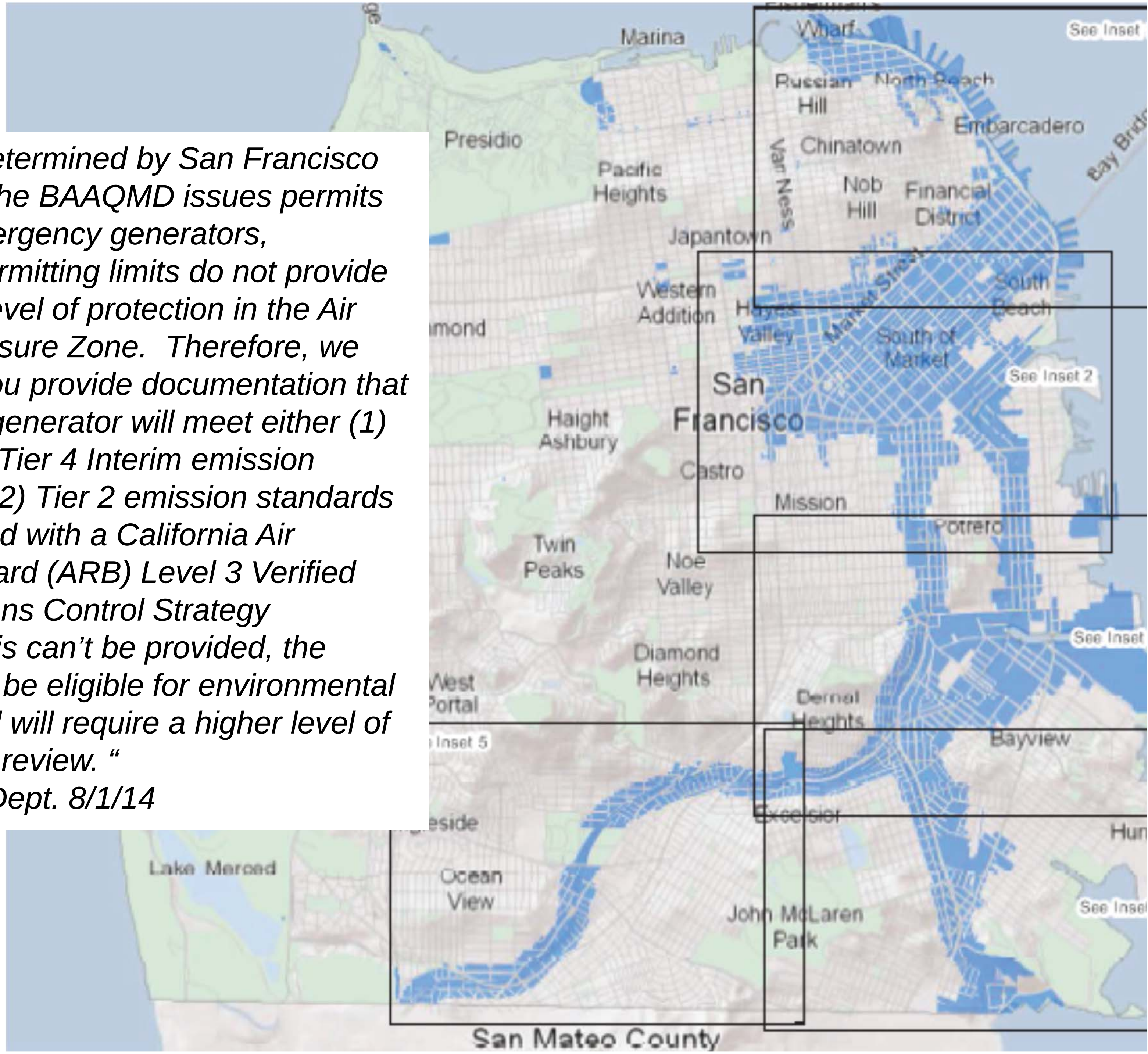
Requirements if project in California (except SCAQMD)

- Health Risk Assessment performed on all projects
- Won’t know if aftertreatment is required until process is complete
- About 10% of applications are requiring a Diesel Particulate Filter
- Get permit applications in early!
- Cummins Pacific personnel will help with all of the forms and communications with the District (equipment submittal usually contains these docs)

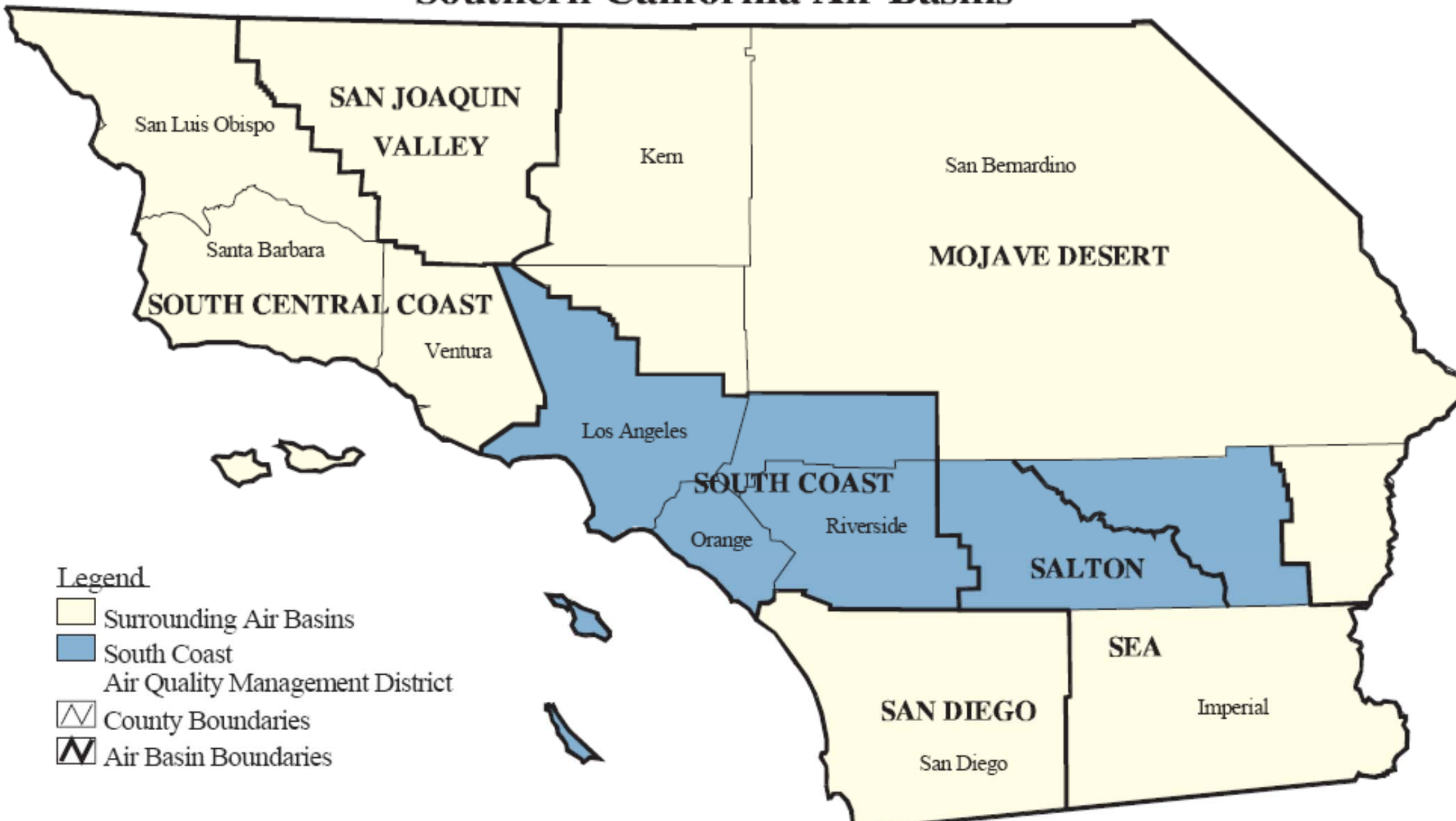
Power Generation

"It has been determined by San Francisco that although the BAAQMD issues permits to operate emergency generators, BAAQMD's permitting limits do not provide an adequate level of protection in the Air Pollutant Exposure Zone. Therefore, we request that you provide documentation that the proposed generator will meet either (1) Tier 4 Final or Tier 4 Interim emission standards, or (2) Tier 2 emission standards and is equipped with a California Air Resources Board (ARB) Level 3 Verified Diesel Emissions Control Strategy (VDECS). If this can't be provided, the project will not be eligible for environmental exemption and will require a higher level of environmental review. "

-SF Planning Dept. 8/1/14



Southern California Air Basins



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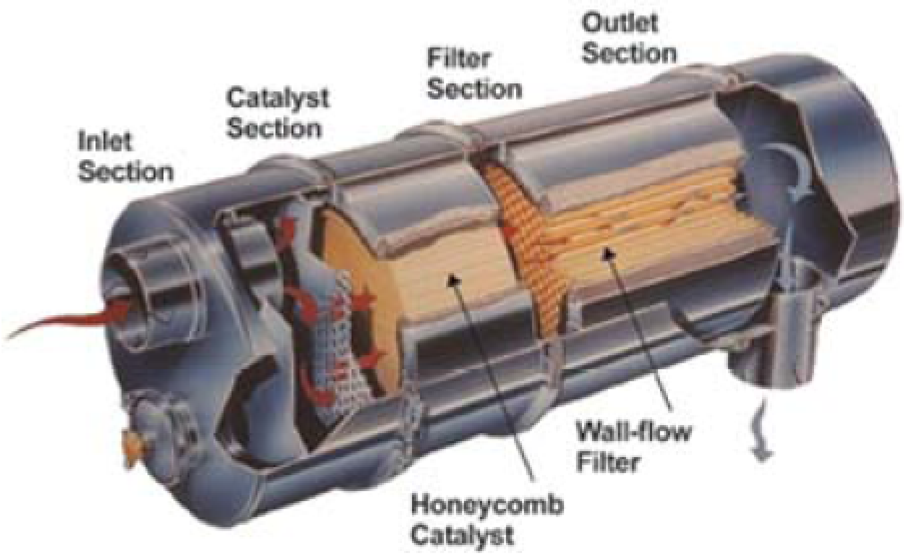
SCAQMD Rule 1470

- This rule requires a Diesel Exhaust Particulate Filters (DPF) on engines within 328 feet (100 meters) of schools (common to all districts)
- This rule requires a Tier 4 PM levels on engines within 164 feet (50 meters) of "sensitive receptors"
- Sensitive Receptor Definition (paragraph b.70):

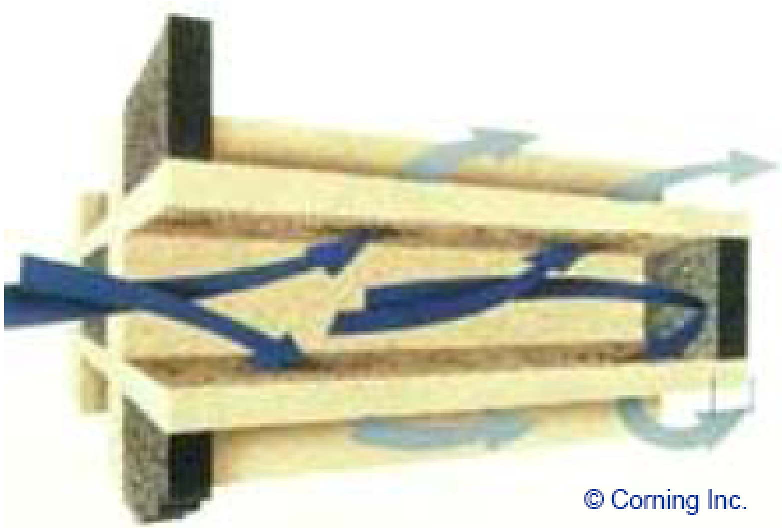
SENSITIVE RECEPTOR means any residence including private homes, condominiums, apartments, and living quarters, schools as defined under paragraph (b)(57), preschools, daycare centers and health facilities such as hospitals or retirement and nursing homes. A sensitive receptor includes long term care hospitals, hospices, prisons, and dormitories or similar live-in housing.

Diesel Particulate Filters needed for low PM emissions
- Wall-flow monolith filters as primary choice of industry

- Honeycomb substrate with checkerboard plugging
- PM trapped on/inside walls
- Periodic regeneration of combustible fraction of the PM



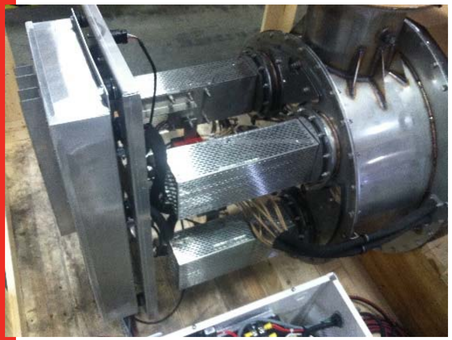
Source: Diesel Technology Forum website

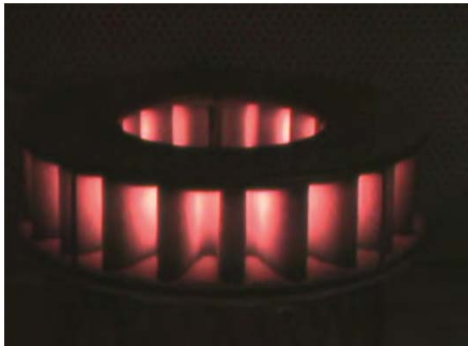


CORNING

Internally Active DPF – Has internal heaters (usually fed from Genset mounted breaker)

- DPF control individually isolates the metallic filters from service
- Sends genset current though these filters to “cook” them and remove soot





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Applying PM Filters to Emergency Standby Engines

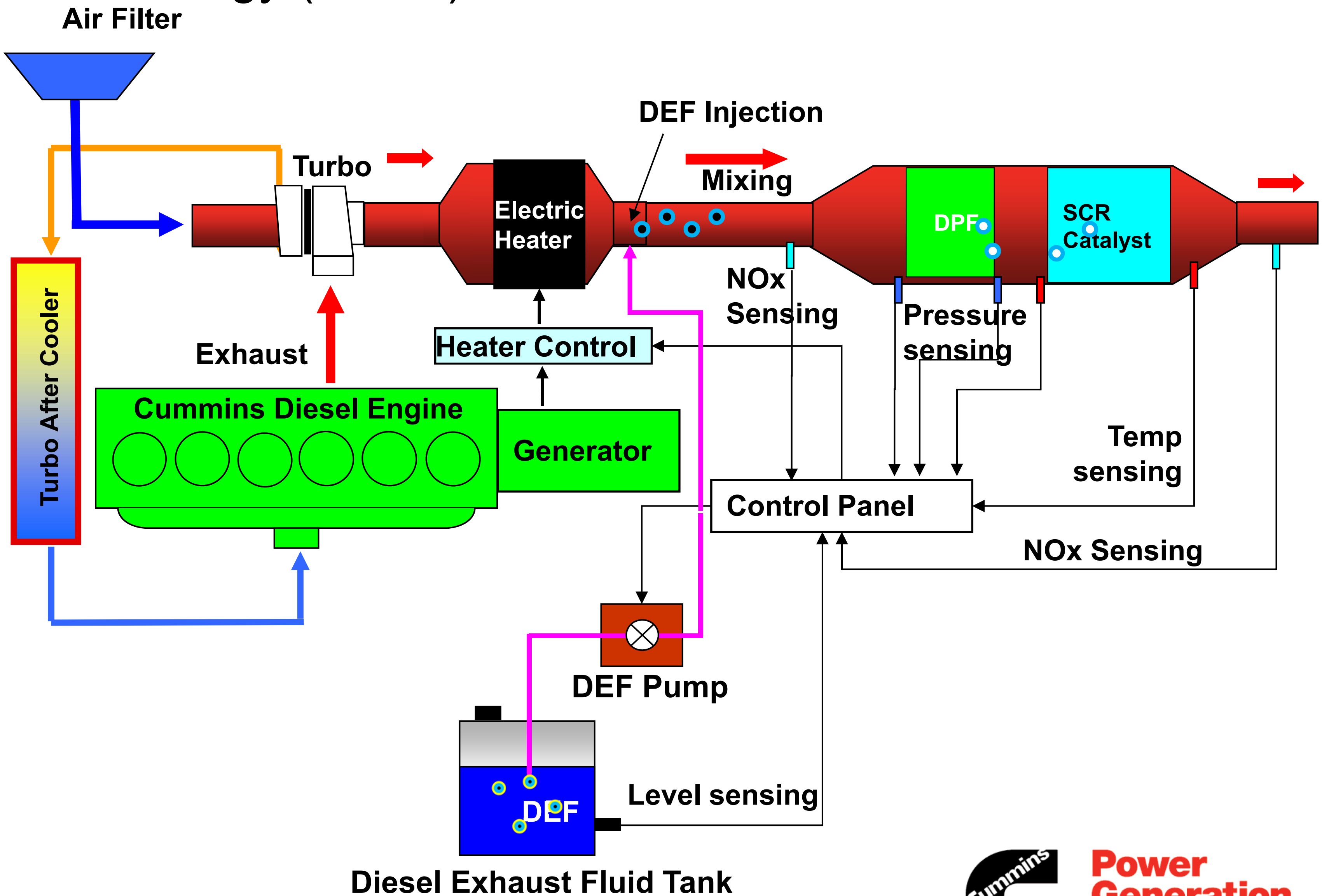
– PM Filter Issues

- Light loading
- Low temperatures
- Filter clogging
- Consequential Engine issues

– Recommendations

- Add exhaust heater/load bank and control to regulate temperatures and assure full load is available to building when needed
- Fully annunciate DPF condition to operators and people on duty (add part load alarms)
- Allow sealed bypass for life safety applications
  - Inspection/consequences for broken seal

Tier 4 Final Schematic - Best Available Control Technology (BACT)



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Tier 4 Final Technology Video

https://www.youtube.com/watch?v=lll3tXSo3Q0

https://www.youtube.com/watch?v=lll3tXSo3Q0

For more information…

http:\\powersuite.cummins.com

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