UPS Technology

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Agenda

- UPS History
- Current Designs
- Current Market Drivers
- Technology Trends
- Application Trends

A Brief History of Uninterruptible Power Supplies

First UPS Systems

~1950s Double conversion MG set

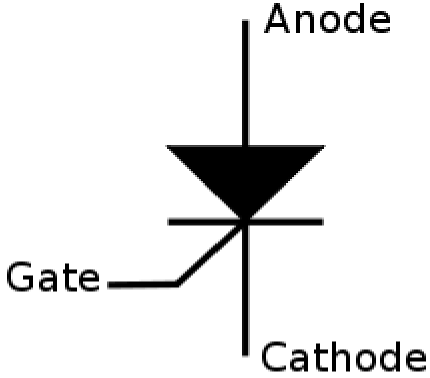
- Motor (DC or Synchronous AC)
- Flywheel
- Generator

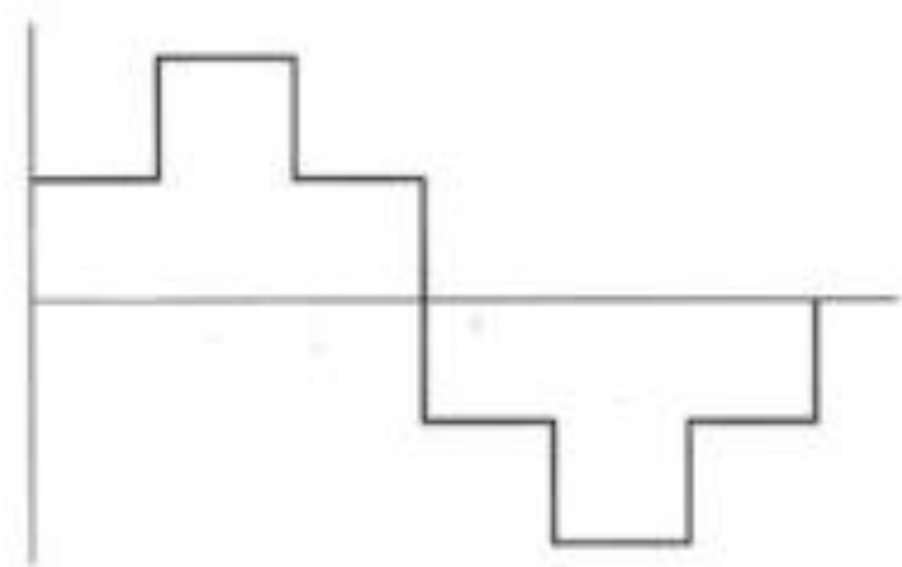
Electrical Energy converted to Mechanical Energy then back to Electrical Energy

- Inefficient
- Reliable
- Simple
- Limited Ride through times
- Still available today (process industry, frequency converters)

First Static UPS Systems

~1960s Static UPS
- SCR based
- Six Step SCR Inverters
- Isolation Transformers





- Low Switching frequency
- Wave form filtering
- Transformers

First Commercial Three Phase Static UPS

ALL STATIC UNINTERRUPTIBLE POWER SYSTEMS

THIS BULLETIN COVERS

- Complete UPS (Uninterruptible Power Systems) including batteries and battery charger.
- Standard static inverter specifications and optional features.
- Application information.

WHERE TO USE

For military, industrial, utility and other applications including:

- data processing computers
- process control computers
- electronic process instrumentation
- critical communication complexes
- critical process machinery
- emergency lighting
- microwave and crypto equipment
- frequency conversion

FEATURES

- Precise uninterruptible power.
- Super-reliable--field proven with 30,000 KVA of inverters operating today. Conservative design and best quality components.
- Low maintenance--no moving parts, no aging.
- Easy installation--modular design--no special

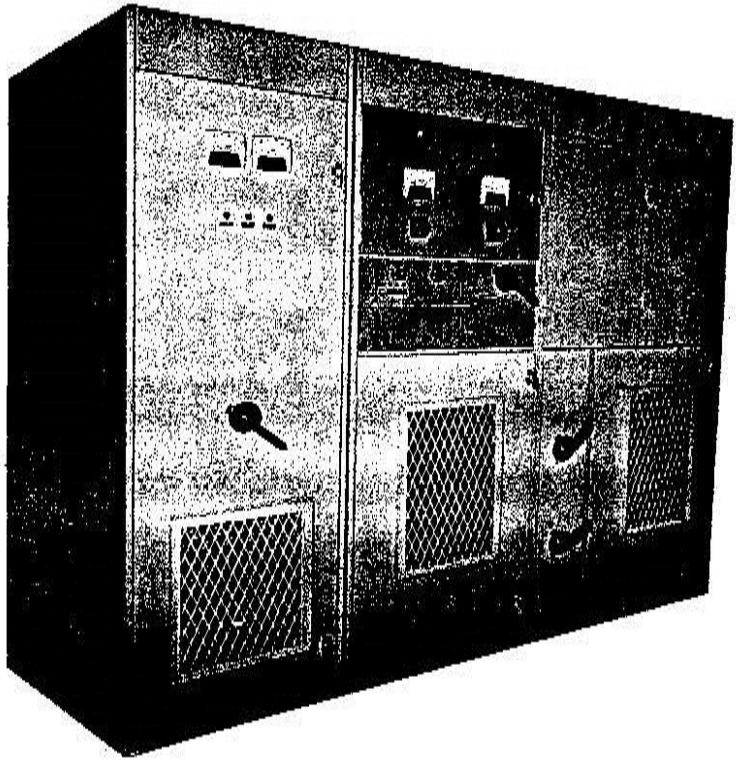
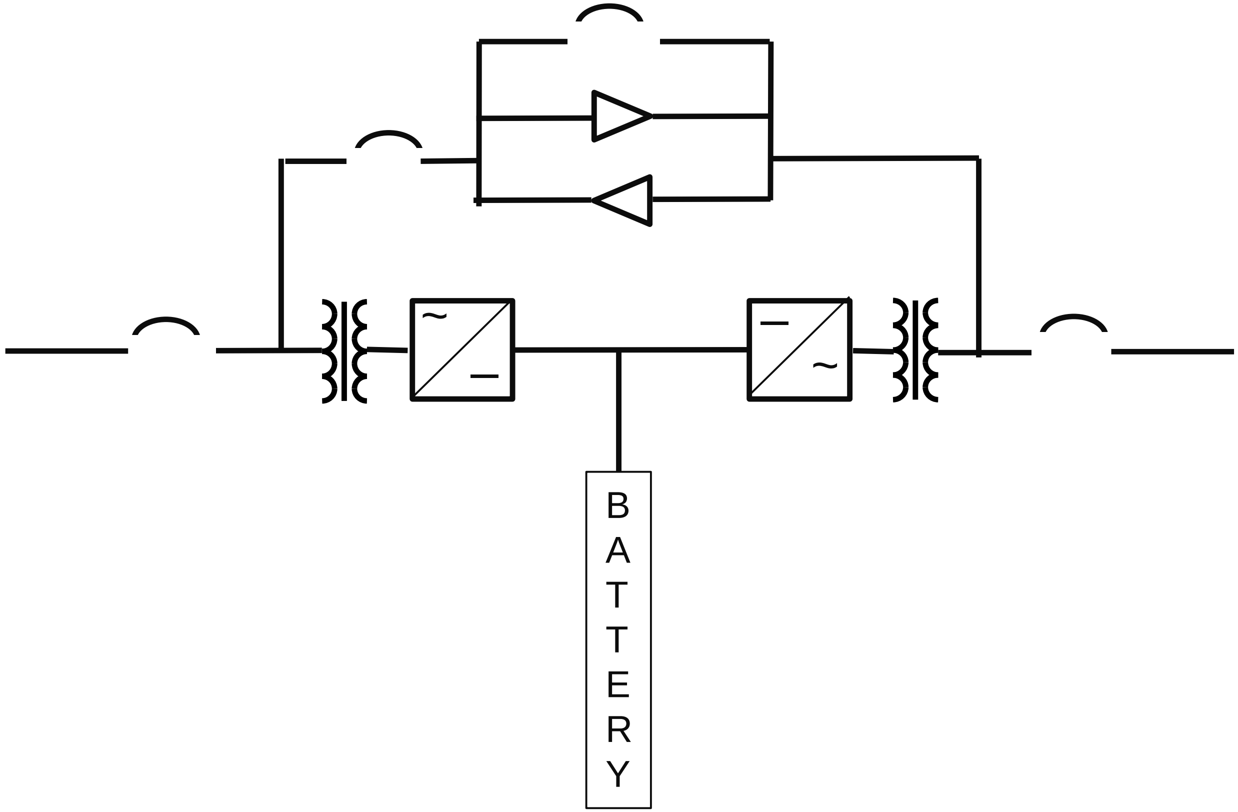


Figure 1. Typical Rectifier and Inverter Line-up, 185 KVA Output

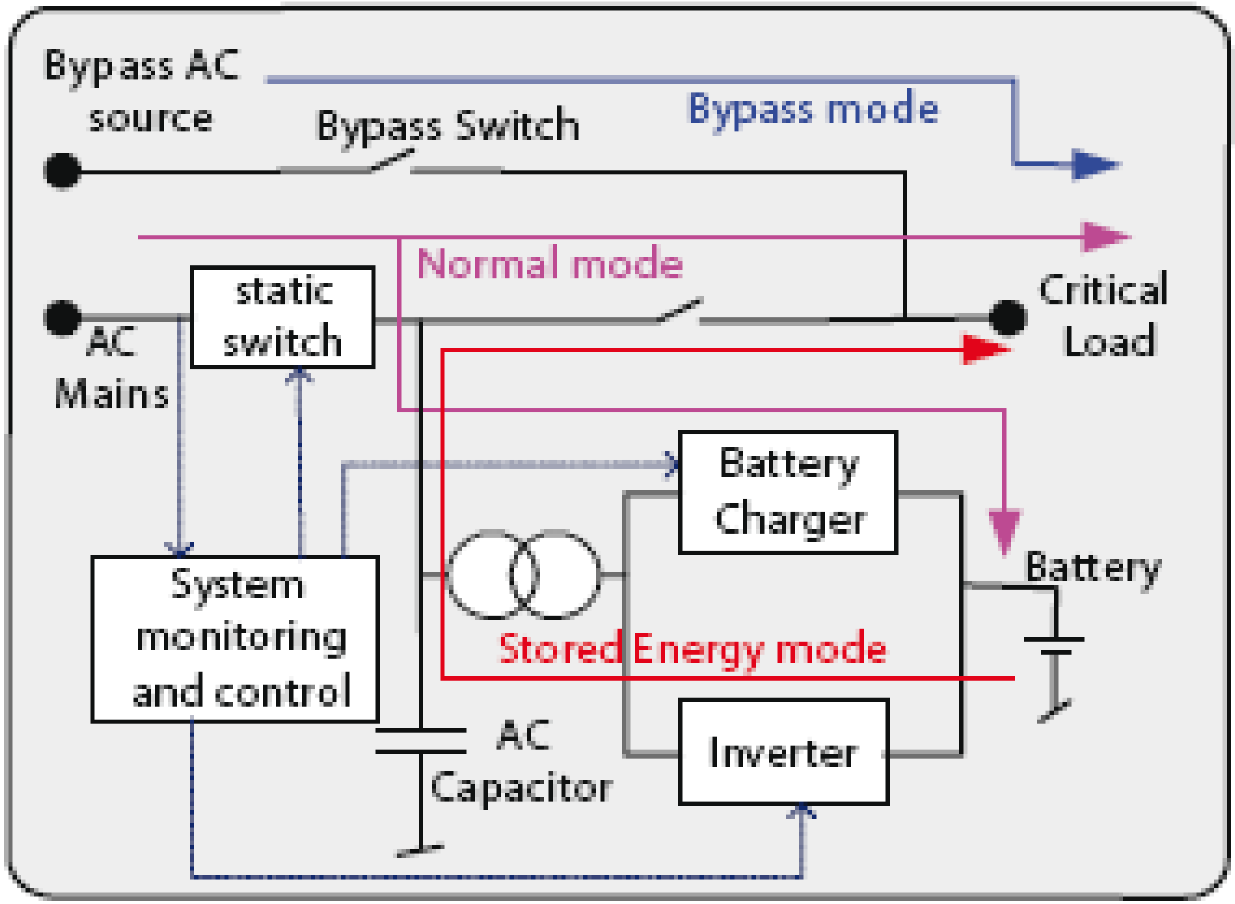
Traditional North American UPS System



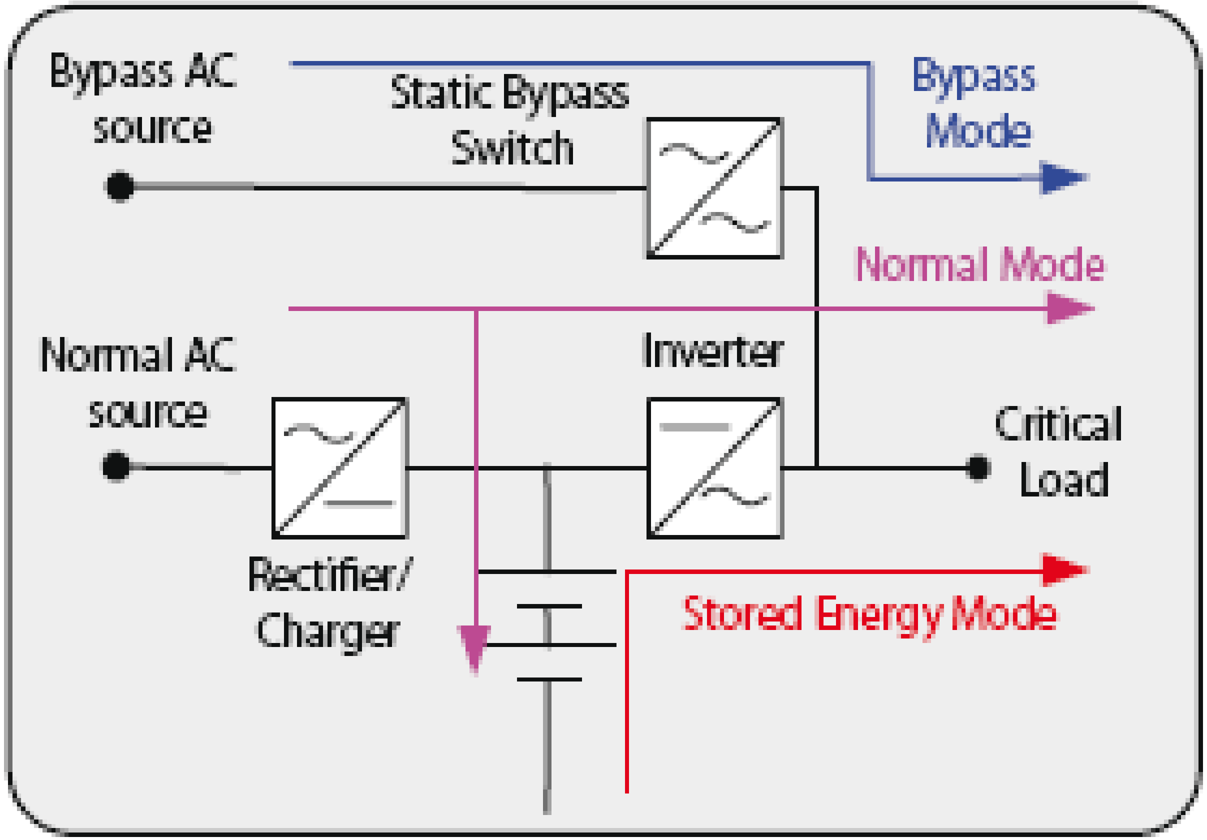
Transformer based with circuit breakers

Current Designs

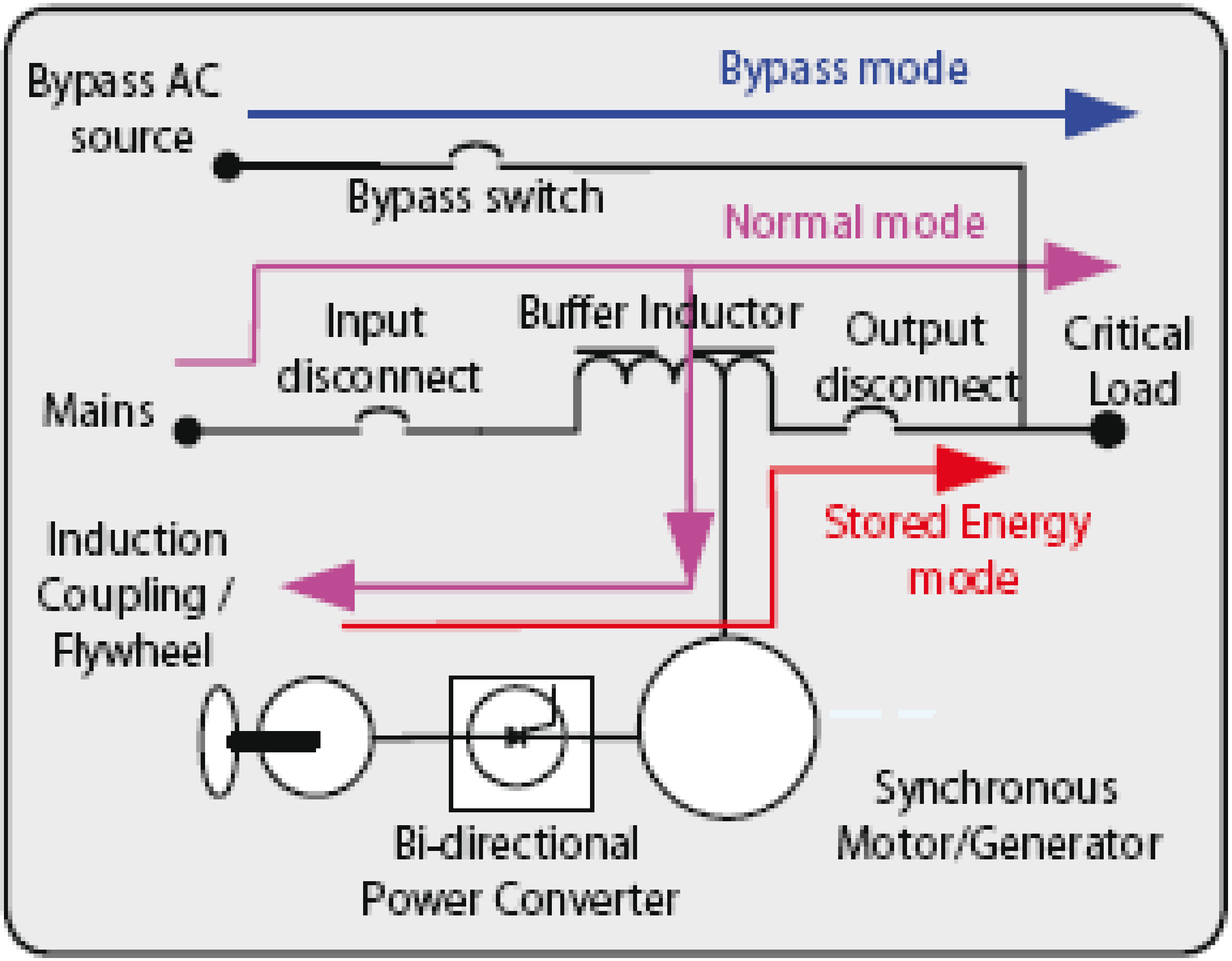
Line Interactive



Double Conversion

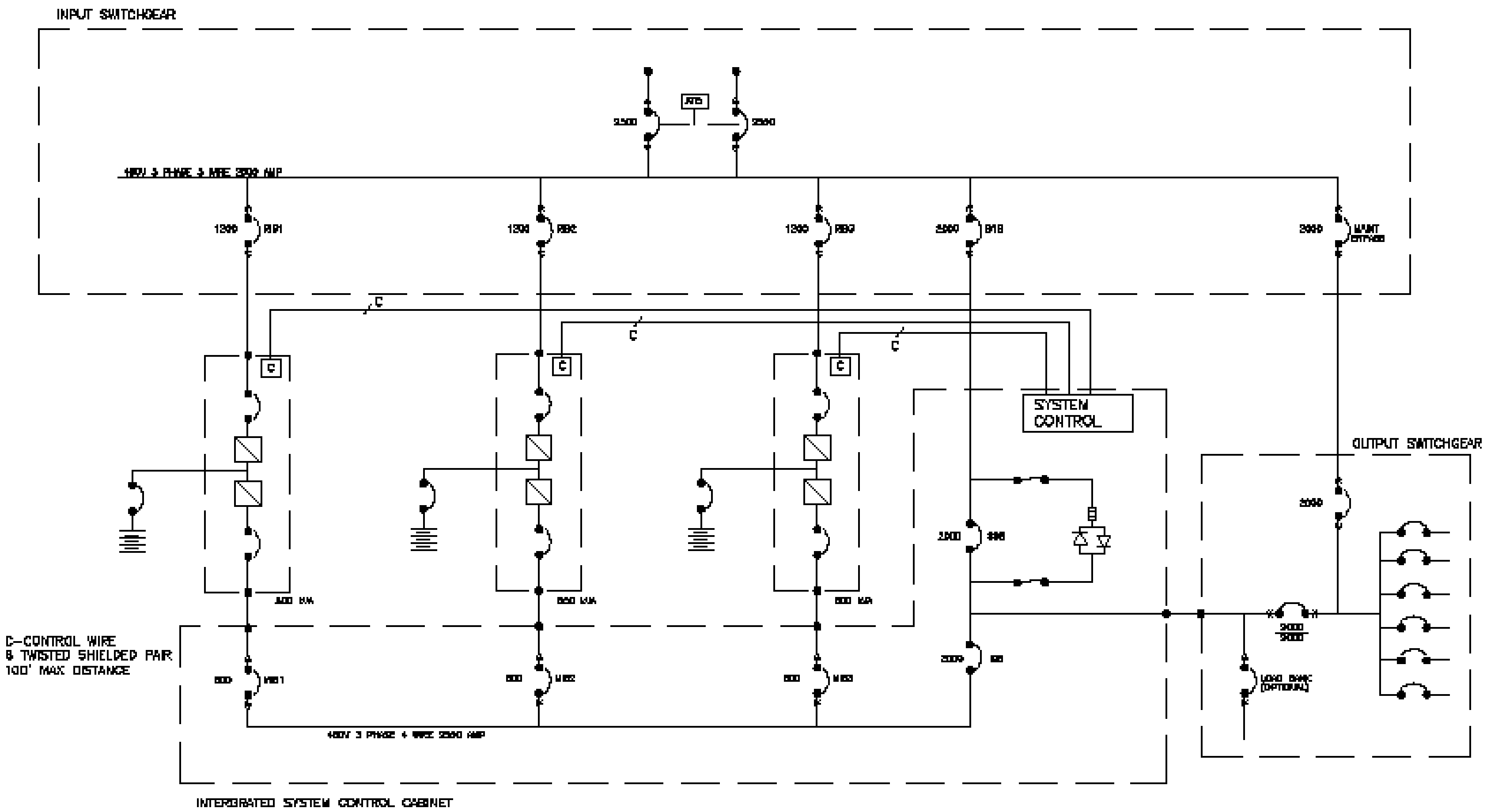


Rotary



Bypass AC source
Bypass mode
Bypass switch
Normal mode
Input disconnect
Buffer Inductor
Output disconnect
Critical Load
Mains
Induction Coupling / Flywheel
Stored Energy mode
Bi-directional Power Converter
Synchronous Motor/Generator

Parallel UPS with Central Bypass



Nobody likes change

"Change is like heaven. Everybody wants to go there, but nobody wants to die."

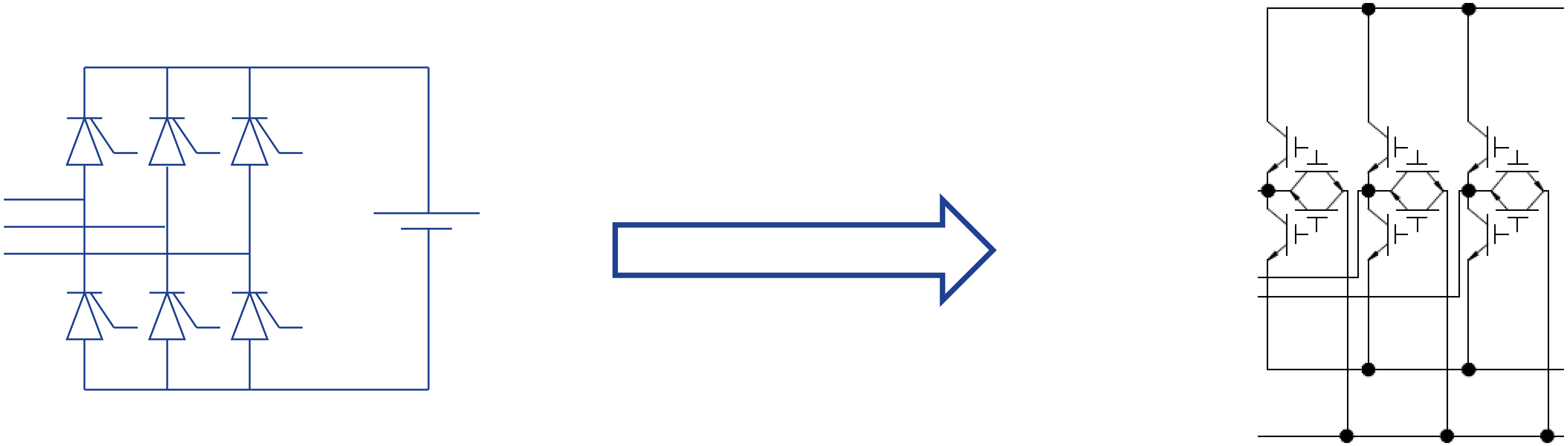
Carly Fiorina
Former Chairman and CEO
Hewlett Packard

Current Market Drivers

Technology Advances

- Controls – Analog to digital
- Switching – Breakers to Contactors

- Power Electronics – SCR to IGBT



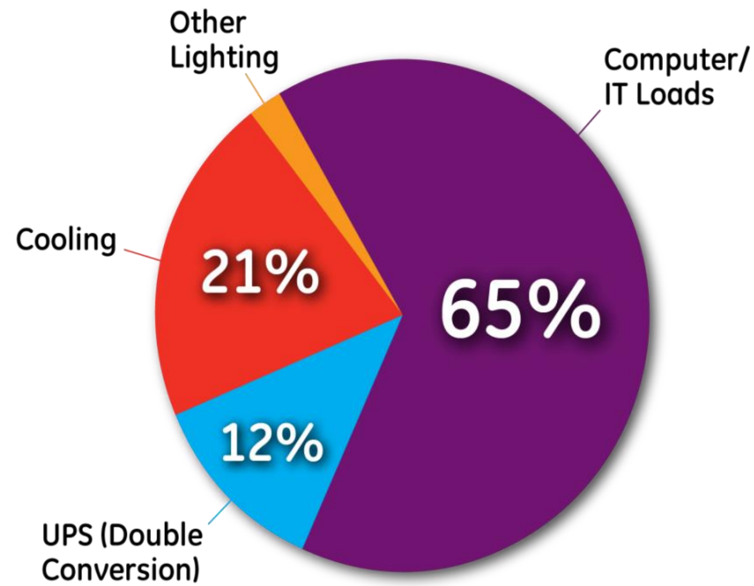
Data Center Efficiency

"No one will remember how much you saved on the utility bill if you drop the load"

-unknown
(it might have been me)

Reliability is still the number one design criteria, but efficiency is starting to move up the list. Efforts by The Green Grid, Green Data Center, and EPA are putting a spotlight on data center efficiency. EPA has expanded the Energy Star program to included Data Centers, Servers, Storage, and **UPS modules**.

Data Center Energy Efficiency



$$\text{PUE} = \frac{\text{Total Facility}}{\text{IT Equipment}}$$

$$= \frac{\text{IT+Cooling+UPS+Other}}{\text{Computer/IT}}$$

$$= \frac{1}{0.65}$$

$$= 1.53$$

Data Center Energy Efficiency Regulations?

PUE being adopted as a standard globally

Example:

- Amsterdam requires a PUE of 1.3 or less on new data centers
- Currently operational datacenters are required to have a PUE of 1.4 or less, within 5 years.

Amsterdam Regulation – Program to reduce carbon emissions by 40% by 2025 compared to 1990 levels. In 2008 datacenters accounted for 6% of total CO_2 emissions of the city.

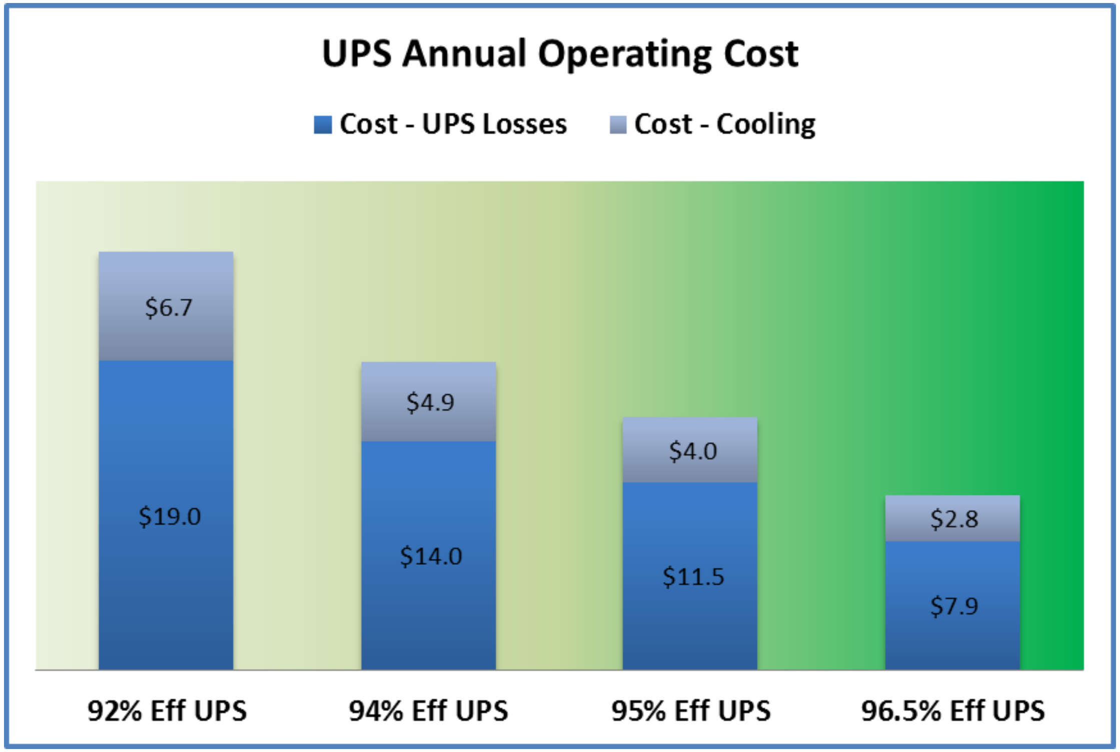
Data Center UPS Operating Costs

High efficiency up to 96.5%

- ✓Considerable life cycle cost savings
- ✓Reduction in UPS operating cost
- ✓Reduction in cooling cost

Assumptions:

- ✓Power cost = $ 0.10 /kw-hr
- ✓Operating hours/year = 8760
- ✓Cooling factor = 0.35
- ✓Configuration = 500 kW UPS @ 50% load



96.5% efficent UPS annual savings Compared to

92% efficiency UPS > $ 14,980

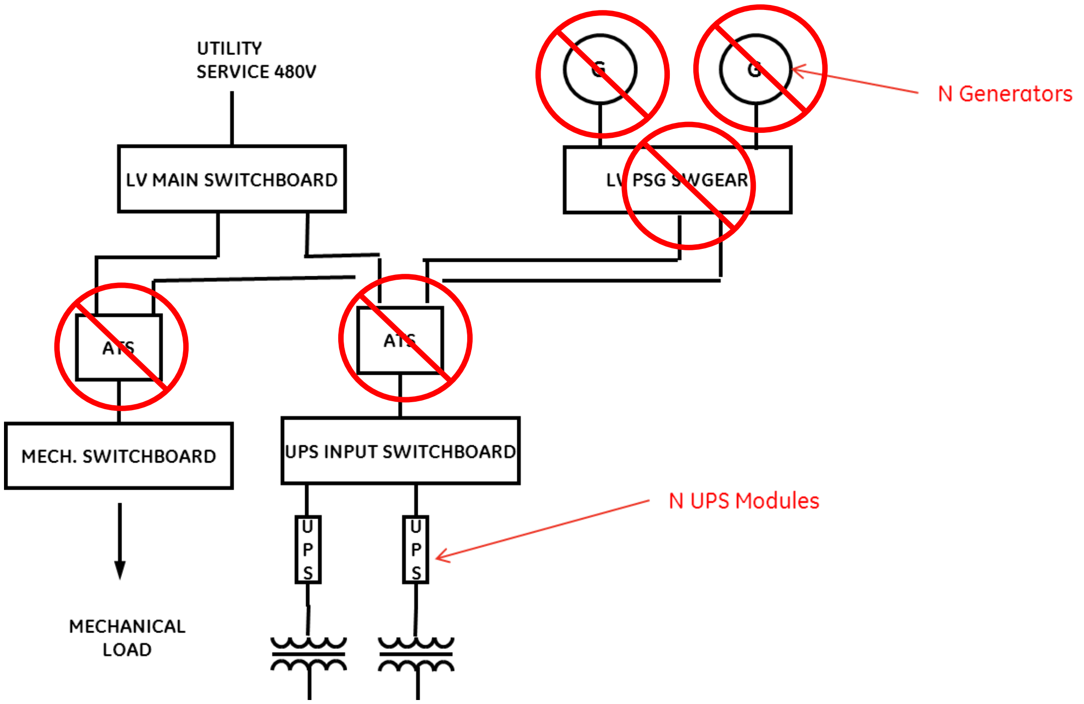
94% efficiency UPS > $ 8,140

95% efficiency UPS > $ 4,830

Data Center Mission

Cloud Computing

- Redundancy in the software in lieu of physical infrastructure
- Smaller “Zones of Reliability”
- Less infrastructure? – No generators – limited UPS



Data Center Mission

HPC Computing

- N+N UPS on Storage
- N UPS or No UPS on Processing

Internet or Social Media

- UPS at the rack or row
- Energy Storage integral to Power Supply

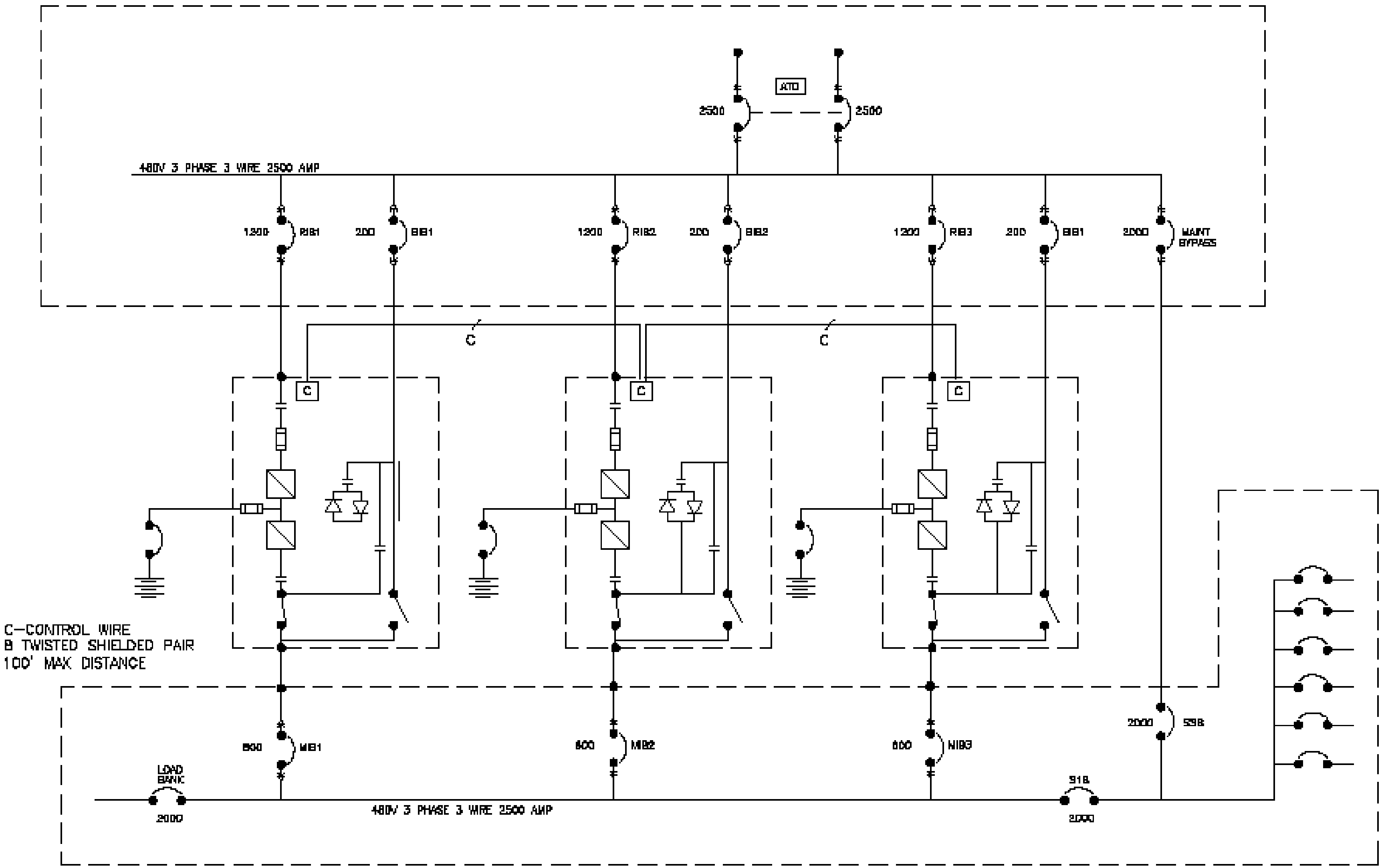
Data Center Economics – Obsoleting Designs

Customers vote for product designs via **Purchase Orders**

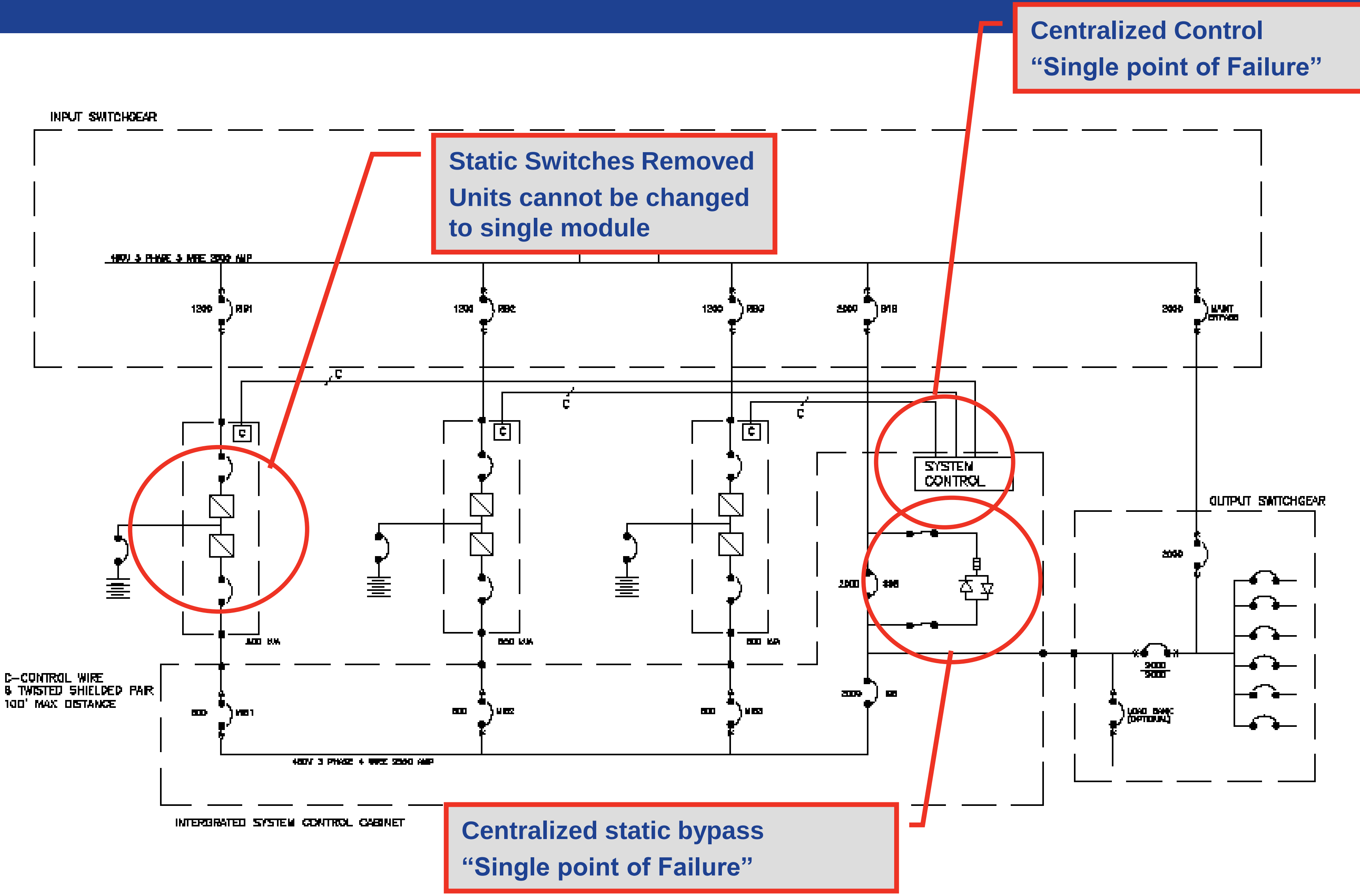
- Features that customers are not willing to pay for will go away
- Examples:
  - Centralized Bypass
    - Higher cost than distributed bypass
    - Larger footprint
  - Transformer Based UPS
    - Higher cost (not necessarily price)
    - Larger footprint
    - Lower efficiency

Technology Trends

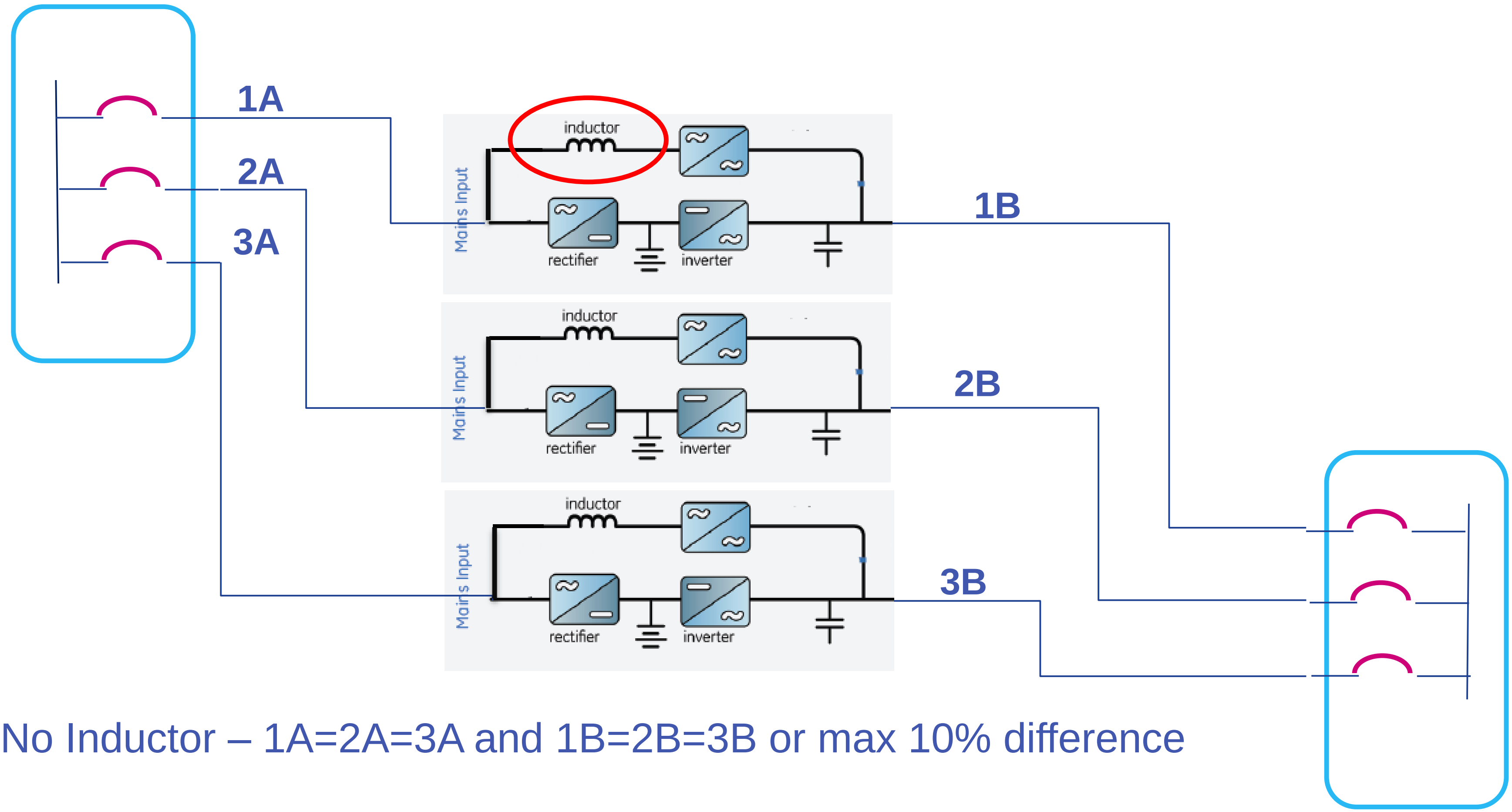
Distributed Bypass



Centralized Bypass



Distributed Bypass – Cable Lengths



No Inductor – 1A=2A=3A and 1B=2B=3B or max 10% difference

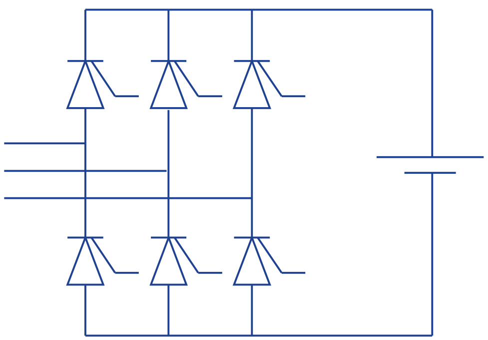
With inductor = allows variation up to 20-25% (depends on UPS rating & cable section

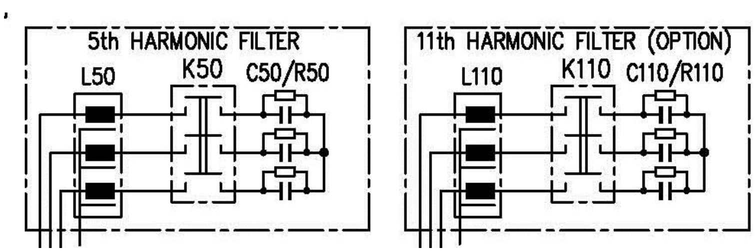
SCR Rectifiers

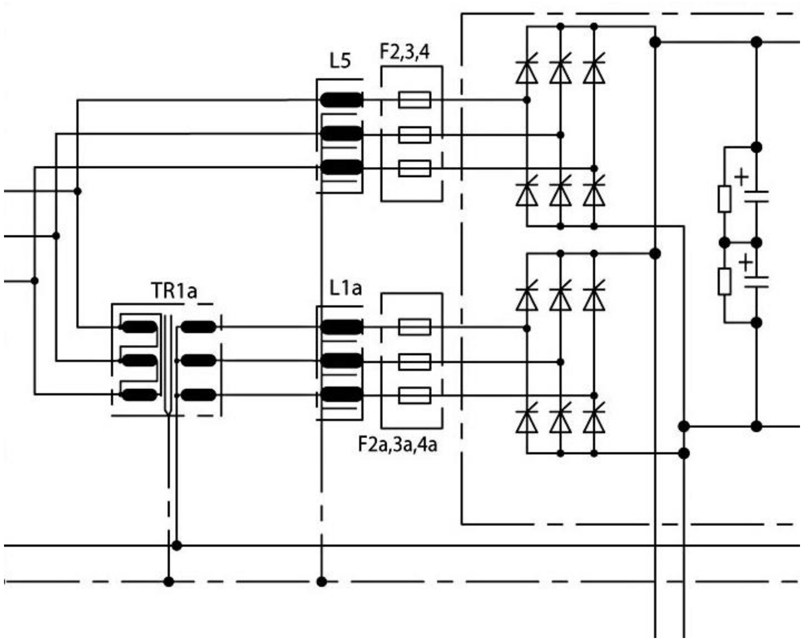
6 Pulse & 12 Pulse

SCR Rectifiers

- Harmonic issues
- Capacitive Filters
- Low switching frequency
- Low input power factor



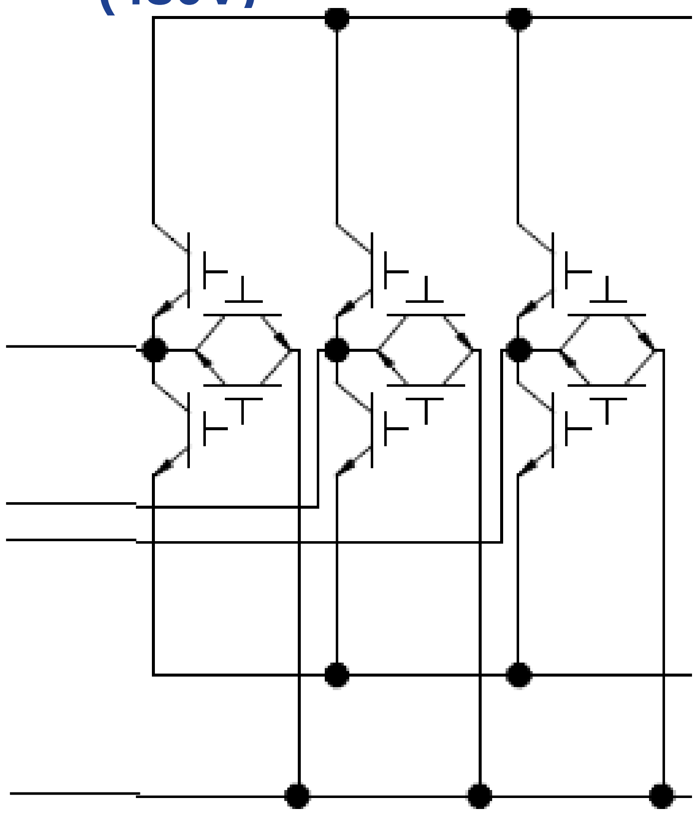




3-Level IGBT Topology

Reduced switching and filter losses improves efficiency

250kW Power Module (480V)



3-Level IGBT Inverter and Rectifier

Three level technology with an Advanced Neutral Point Clamped topology implemented with true Reverse Blocking IGBT.

Reduced switching and filter losses compared to std. two level technology

Transformer-less UPS

Transformer based UPS

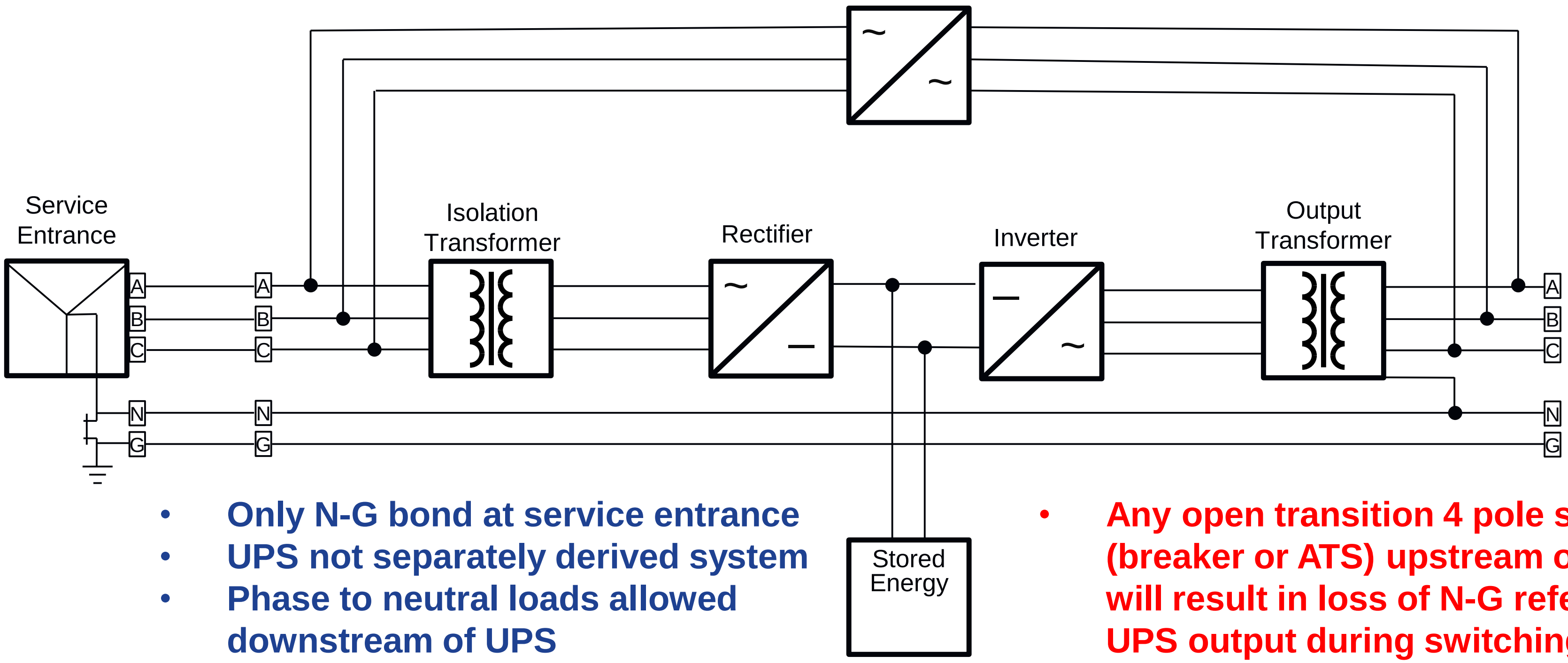
- Galvanic isolation (+)
- Large Footprint (-)
- Poor Efficiency <92% (-)
- Higher Mfg Cost (-)

Transformer-less UPS

- High Efficiency(+)
- Low Harmonics (+)
- High Input PF (+)
- Bus Optimization (+)
- Small Footprint (+)
- Less Weight (+)
- Battery Monitoring (?)
- Three Wire Input (?)
- Lower Mfg Cost (+)

Transformer Based /UPS

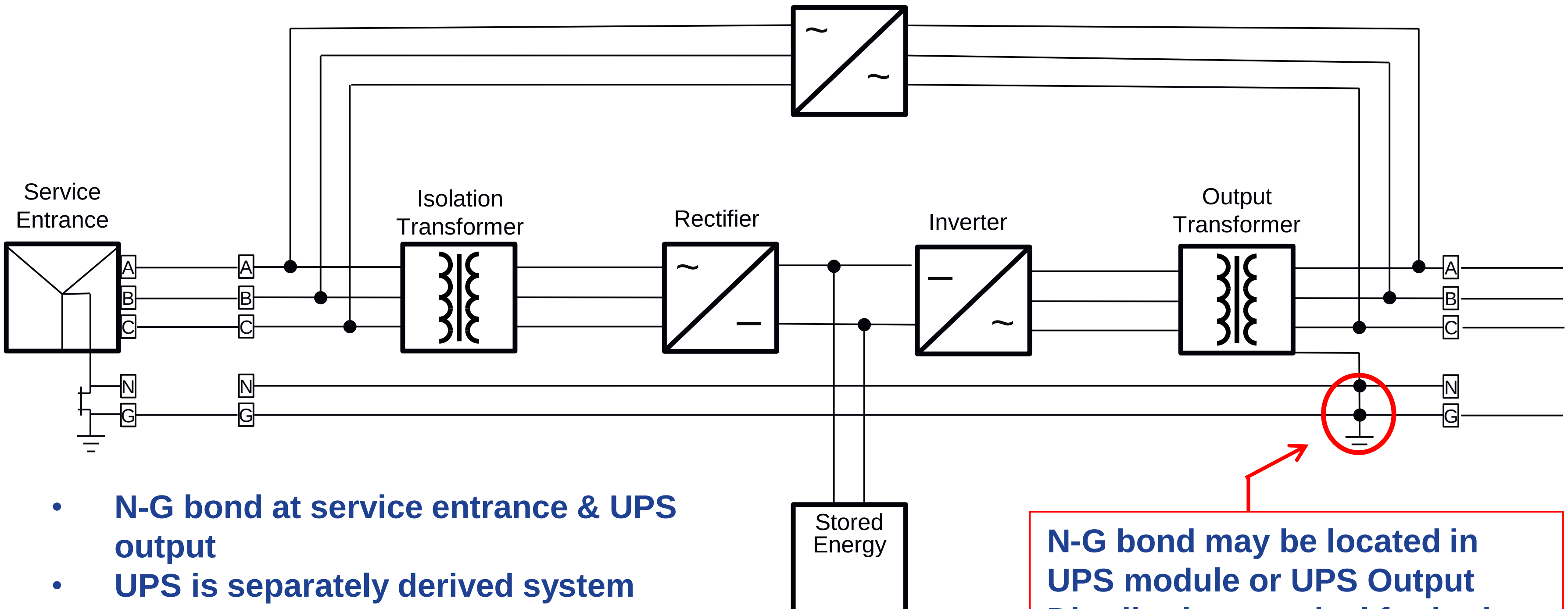
4 wire input



- **Only N-G bond at service entrance**
- **UPS not separately derived system**
- **Phase to neutral loads allowed downstream of UPS**

- **Any open transition 4 pole switching (breaker or ATS) upstream of UPS will result in loss of N-G reference at UPS output during switching. (see appendix for more details)**

Transformer Based /UPS
3 wire input

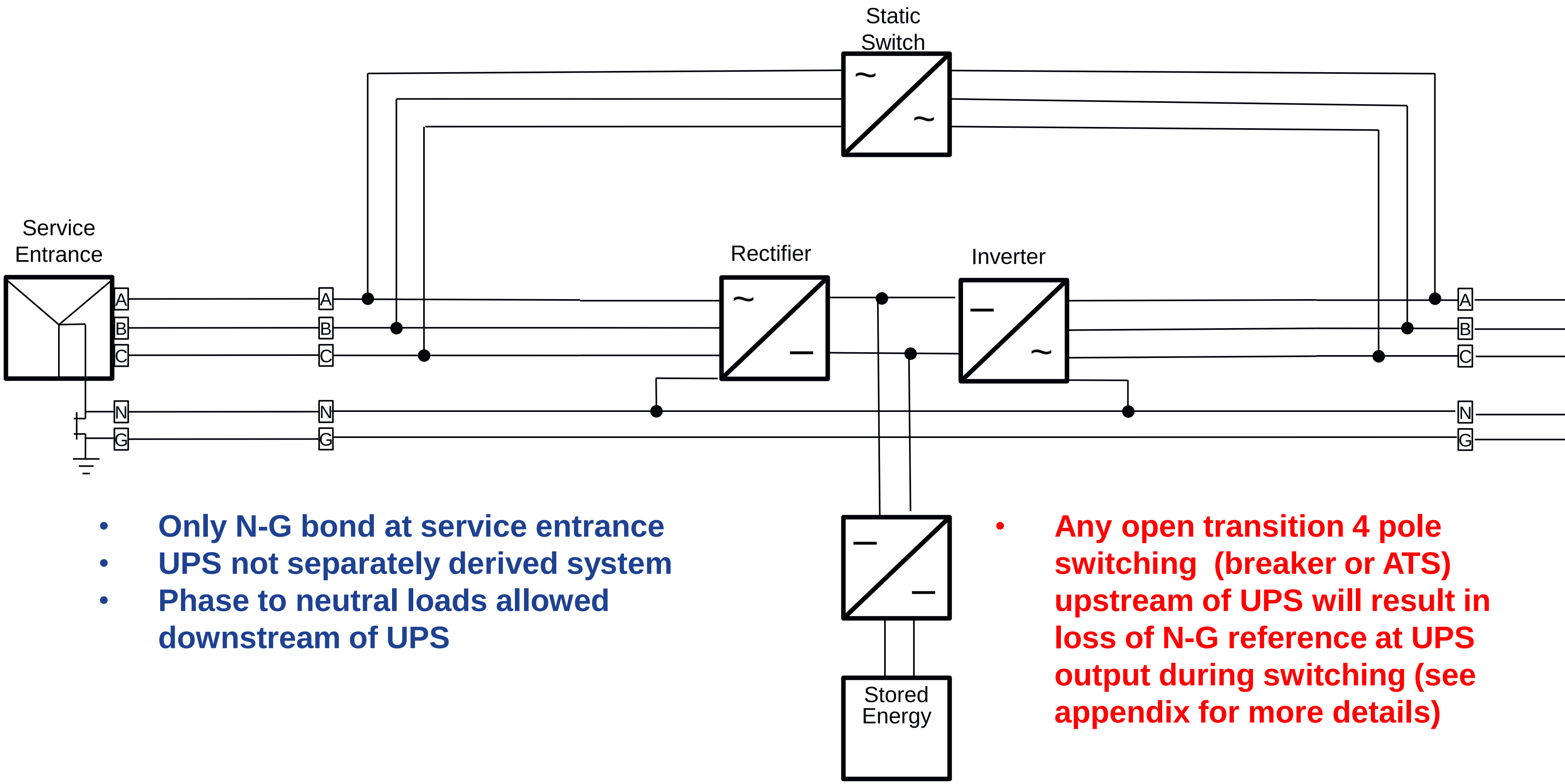


- N-G bond at service entrance & UPS output
- UPS is separately derived system
- Phase to neutral loads not allowed downstream of UPS

N-G bond may be located in UPS module or UPS Output Distribution – typical for both transformer based and transformer-less UPS modules

Transformer-less UPS

4 wire input (Modules with 4 Wire Inverter Output)



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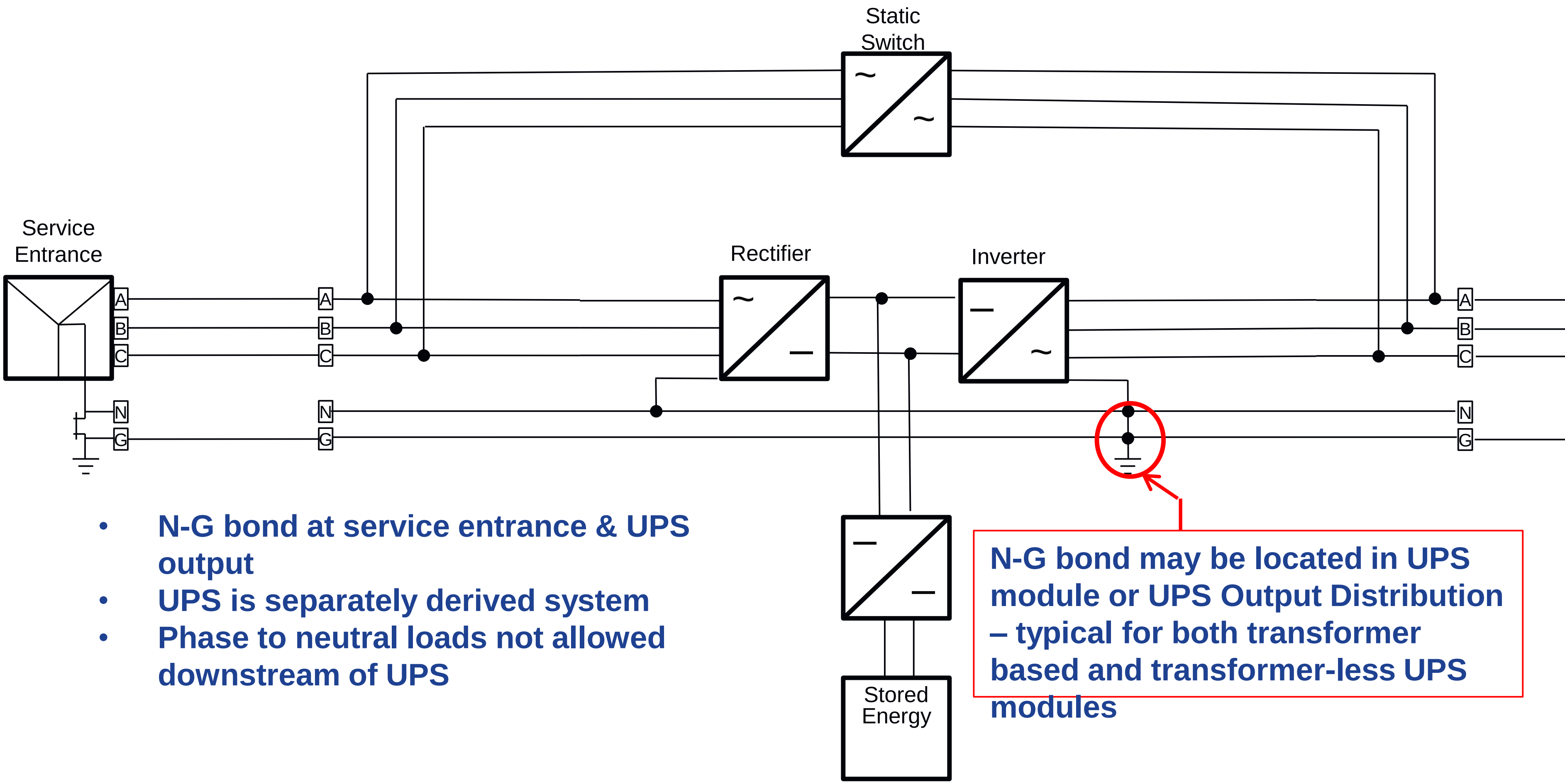
Grounding and application identical to transformer based UPS

Transformer-less UPS

3 wire input (Modules with 4 Wire Inverter Output)



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Transformer-less UPS

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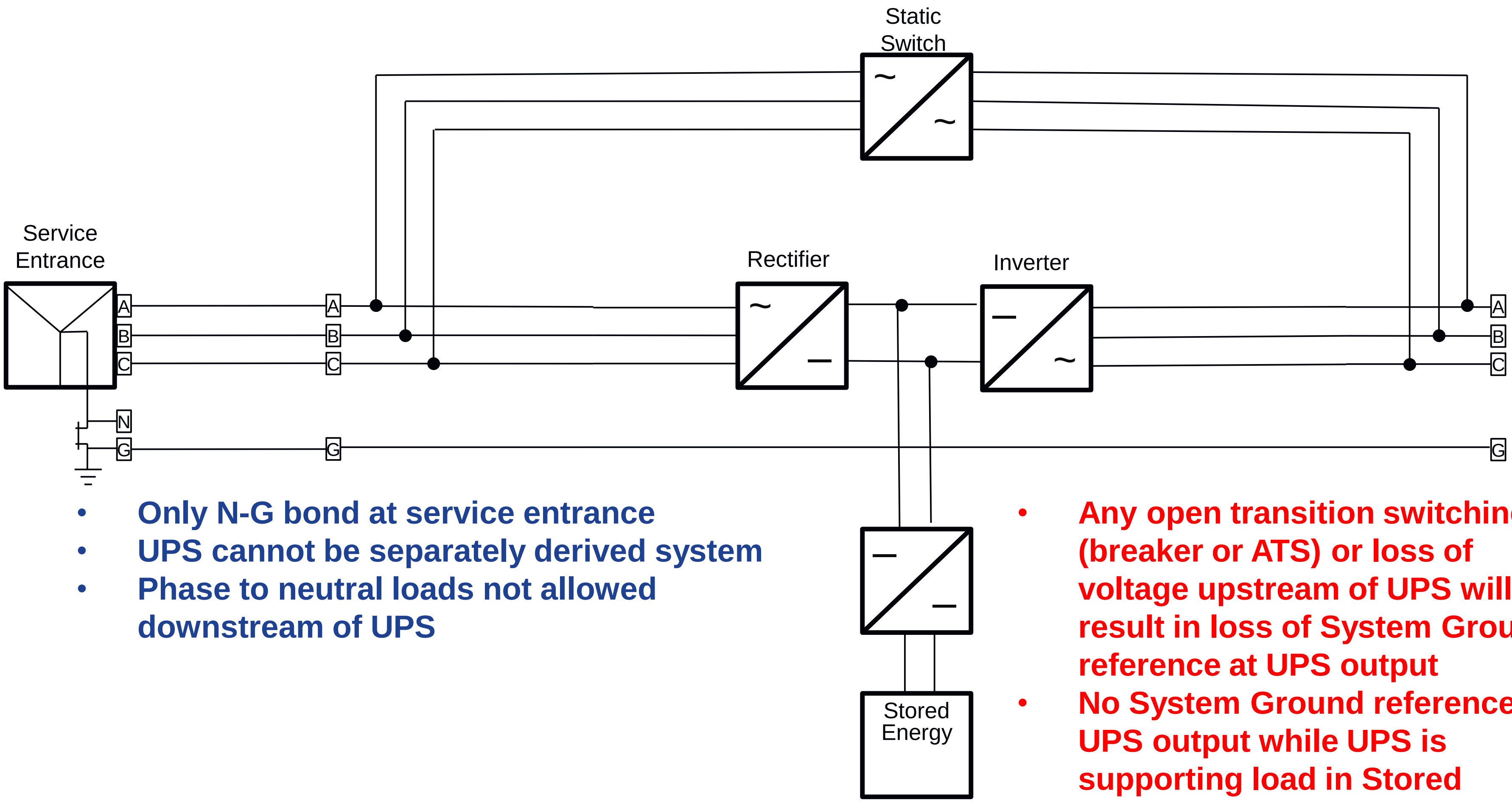


- **Only N-G bond at service entrance**
- **UPS cannot be separately derived system**
- **Phase to neutral loads not allowed downstream of UPS**

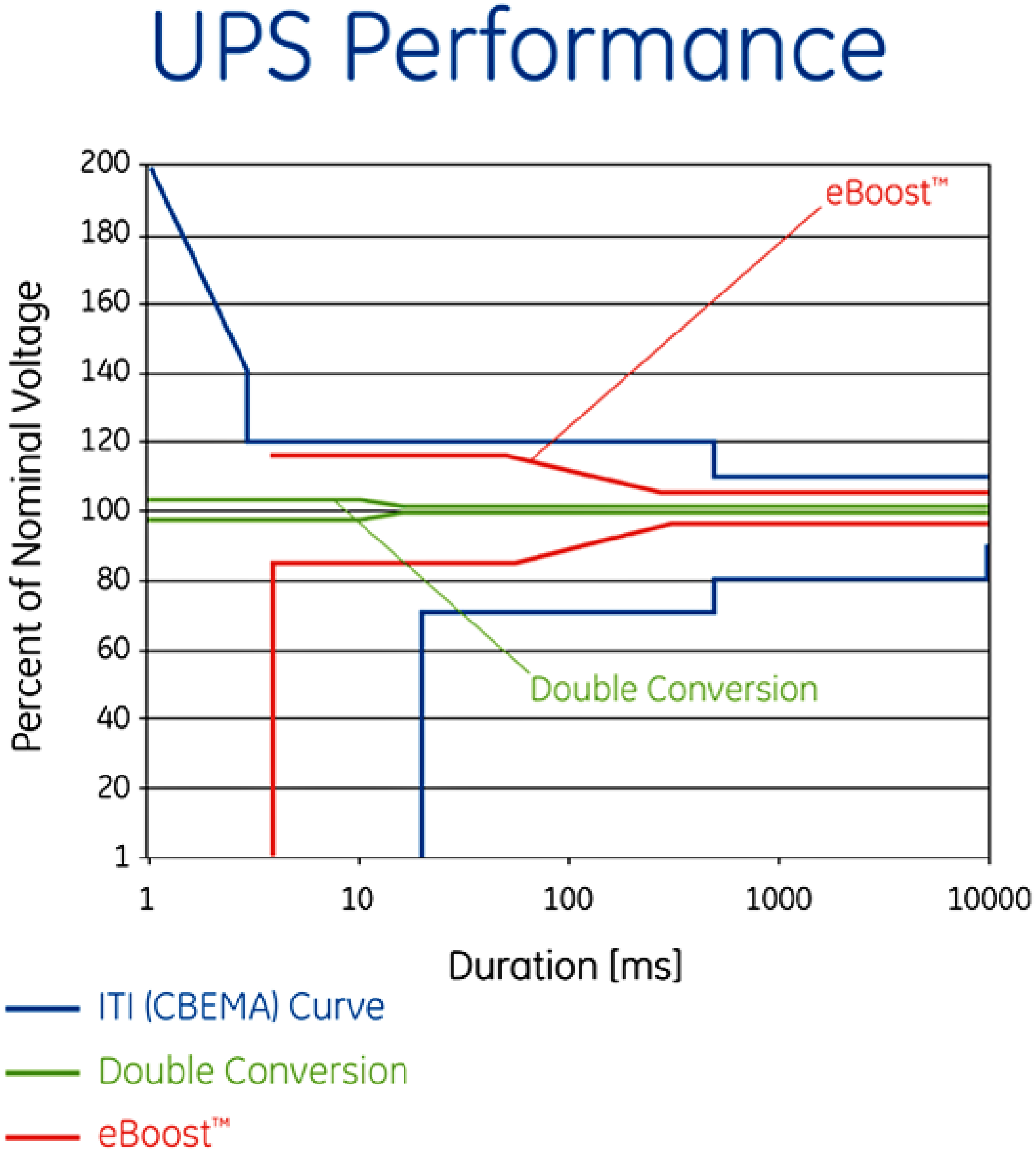
- **Any open transition switching (breaker or ATS) or loss of voltage upstream of UPS will result in loss of System Ground reference at UPS output**
- **No System Ground reference at UPS output while UPS is supporting load in Stored Energy mode of operation**

Significant Grounding and Application Issues

Eco-mode

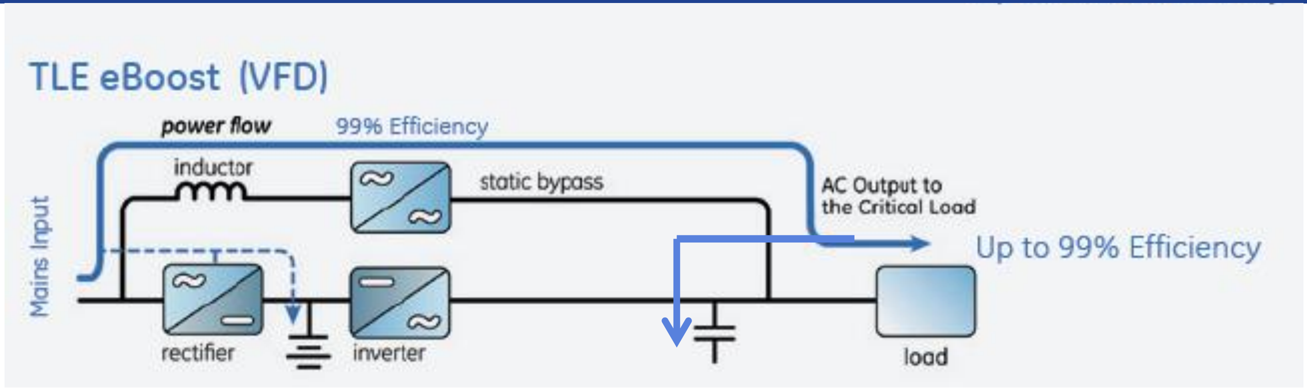
Double conversion mode provides the best protection, more protection than is required by the IT equipment, but at the highest operating cost

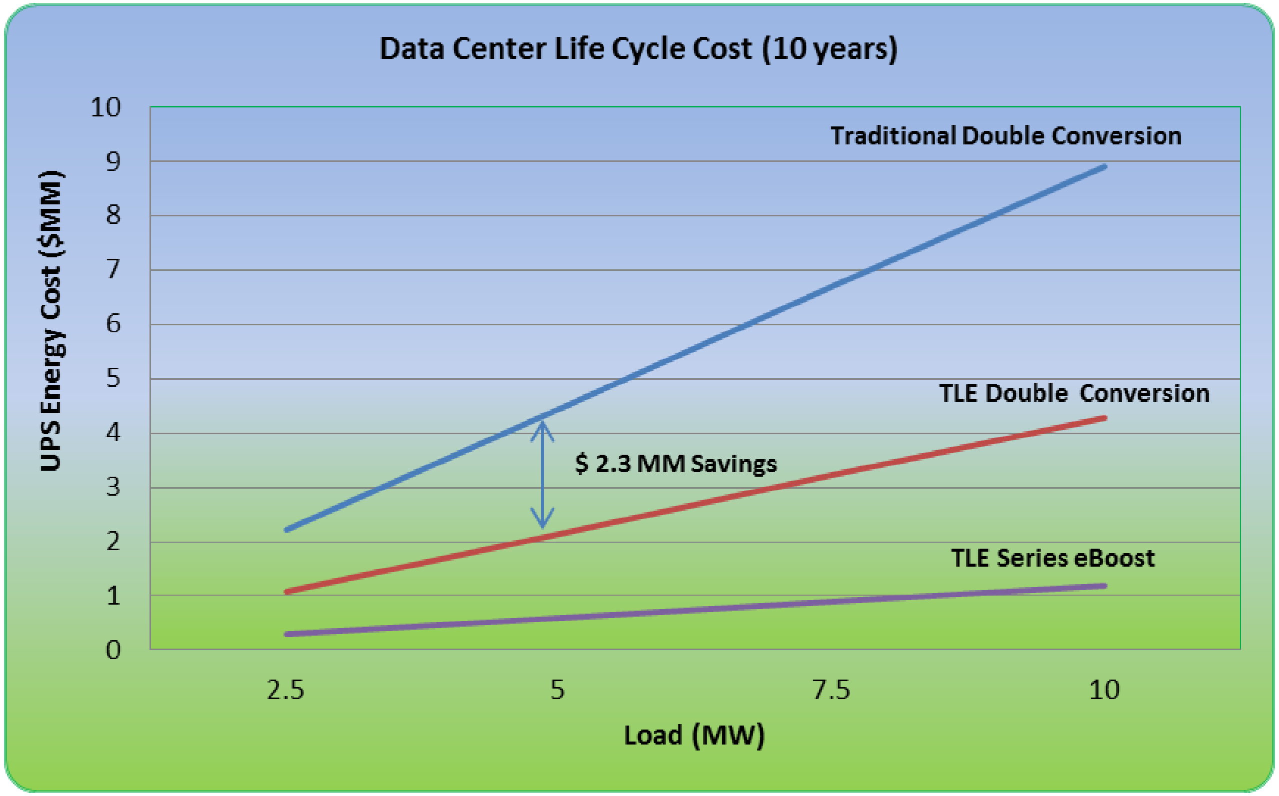
Adoption is increasing, especially in N+N configurations where one side is VFI and the other is ecomode



Ecomode Operation & Impact

Inductor and output filter capacitors provide filtering in eBoost





The Green Grid Data Center Maturity Model

Power

			Level 0 Minimal/No Progress	Level 1 Part Best Practice	Level 2 Best Practice	Level 3	Level 4	Level 5 Visionary - 5 Years Away
1.2	Architecture		• Low efficiency power infrastructure and inefficient UPS use • Greater redundancy than required • Numerous isolation transformers	• Eco Mode UPS if applicable to business type • Fewer and higher efficiency transformers (NEMA TP1 or equivalent) • Verify the product's efficiency curve is highest for the load range used vs. highest overall	• Consolidate transformers (use fewer series isolation transformers, consider autotransformers) • Select power (and backup) technologies based on TCO, Materials & Sustainability	• Eco Mode UPS that works for all business types • Scalable power infrastructure • Use products with flat, high efficiency at all loads • Review and capture waste heat (for example, to augment generator block heaters)	• Move to higher IT load voltage, either AC or DC	

Modular

What are the benefits

- Scalable
  - Delay CAPEX cost
- Internal Redundancy
  - Higher Reliability ?
- Hot swappable
  - Low Power 208V
  - High Power 480V
  - Arc Flash
  - Human Error
- Lower MTTR

What is Modular?

Where do these features make sense?

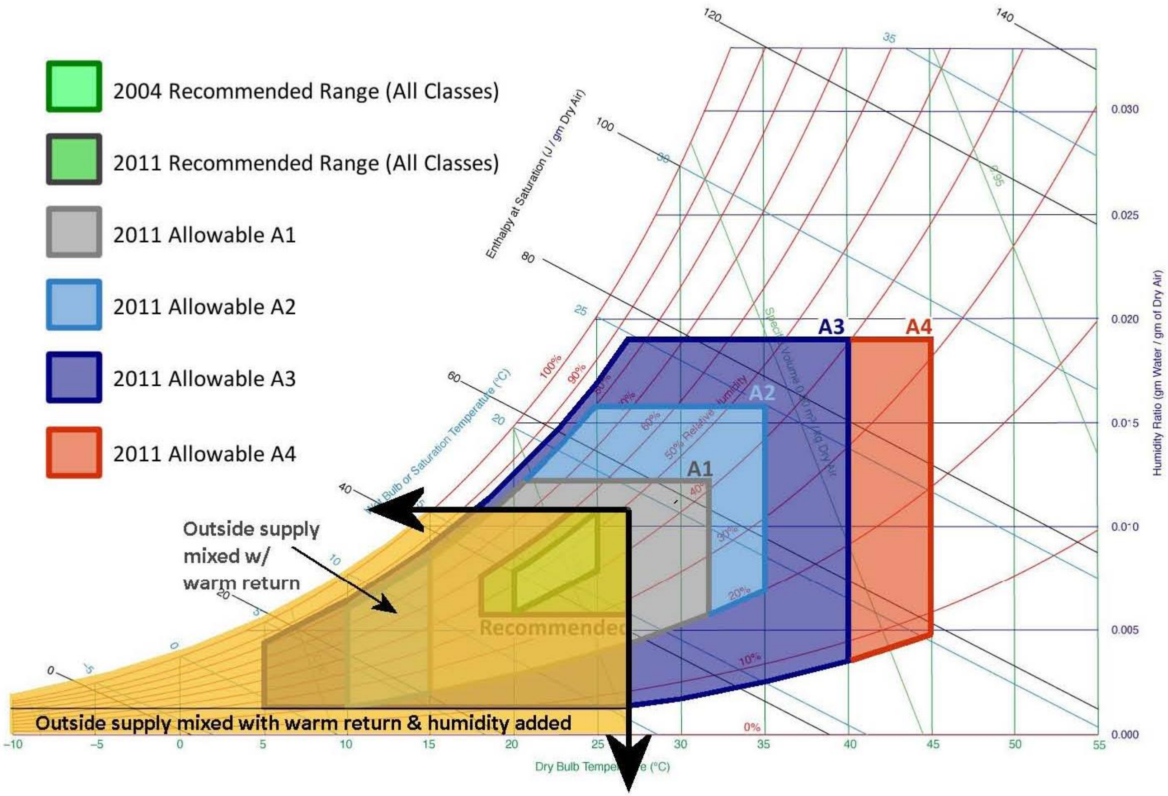
Monolithic ⟷ Modular

	0	1	2	3	4	5	6
Common breakers	X	X	X	X	X	X	X
Common Battery	X	X	X	X	X	X	X
Common Contactors	X	X	X	X	n/a	n/a	n/a
Power Block Construction		X	X	X	X	X	X
Bolted Power Blocks		X	X	X	X	n/a	n/a
Field upgrade			X	X	X	X	X
Distributed Batteries				X	X	X	X
Cold Swap - no FSE?							
Contactors per PB					X	X	X
N+1 Block Failover					X	X	X
Plug-in Power Blocks						X	X
Hot swappable Blocks							X
Redundant Static Switches							X
Redundant Controls Per PB							X

↓ Increased Cost

Application Trends

Elevated Temperatures



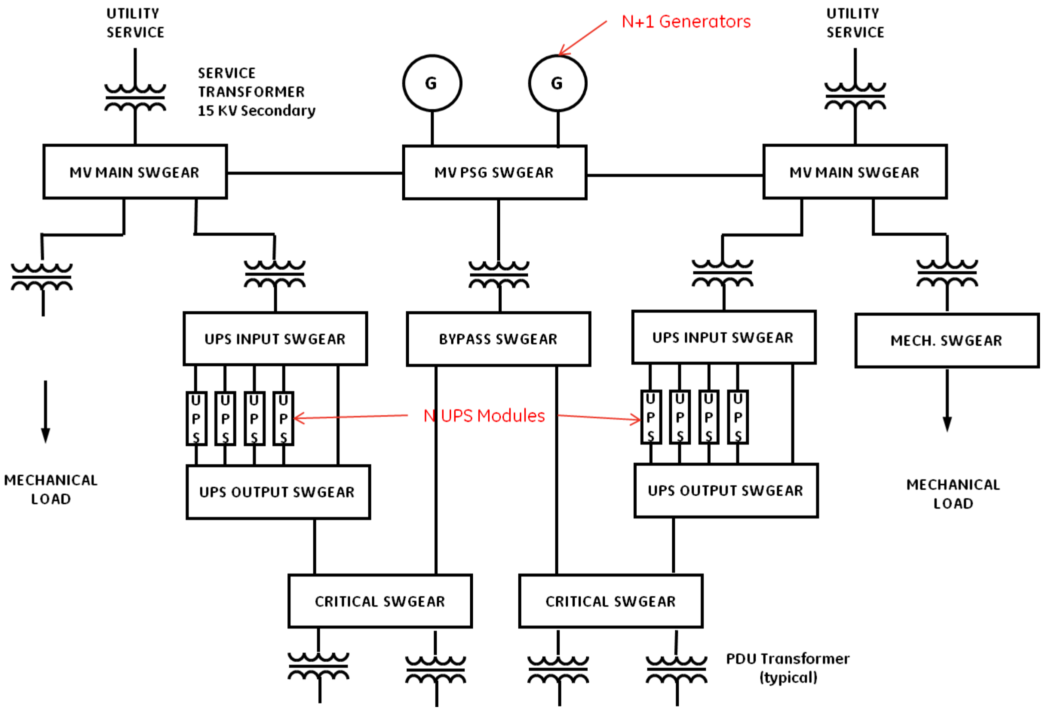
- UPS rated 104^0 F
- Batteries rated 68-77^0 F
- Air Conditioned Battery Cabinets ?

Energy Storage

1. Flywheel Energy Storage
2. Lithium Batteries
3. Sodium Batteries
4. Super Capacitors
5. Pure Lead Batteries

Alternative Topologies

- Reduce CAPEX costs
- Reduce stranded assets
- Improve efficiency
- Improve capability to handle “Dynamic Loads”?
- Pressure on Data Centers to be “Competitive”

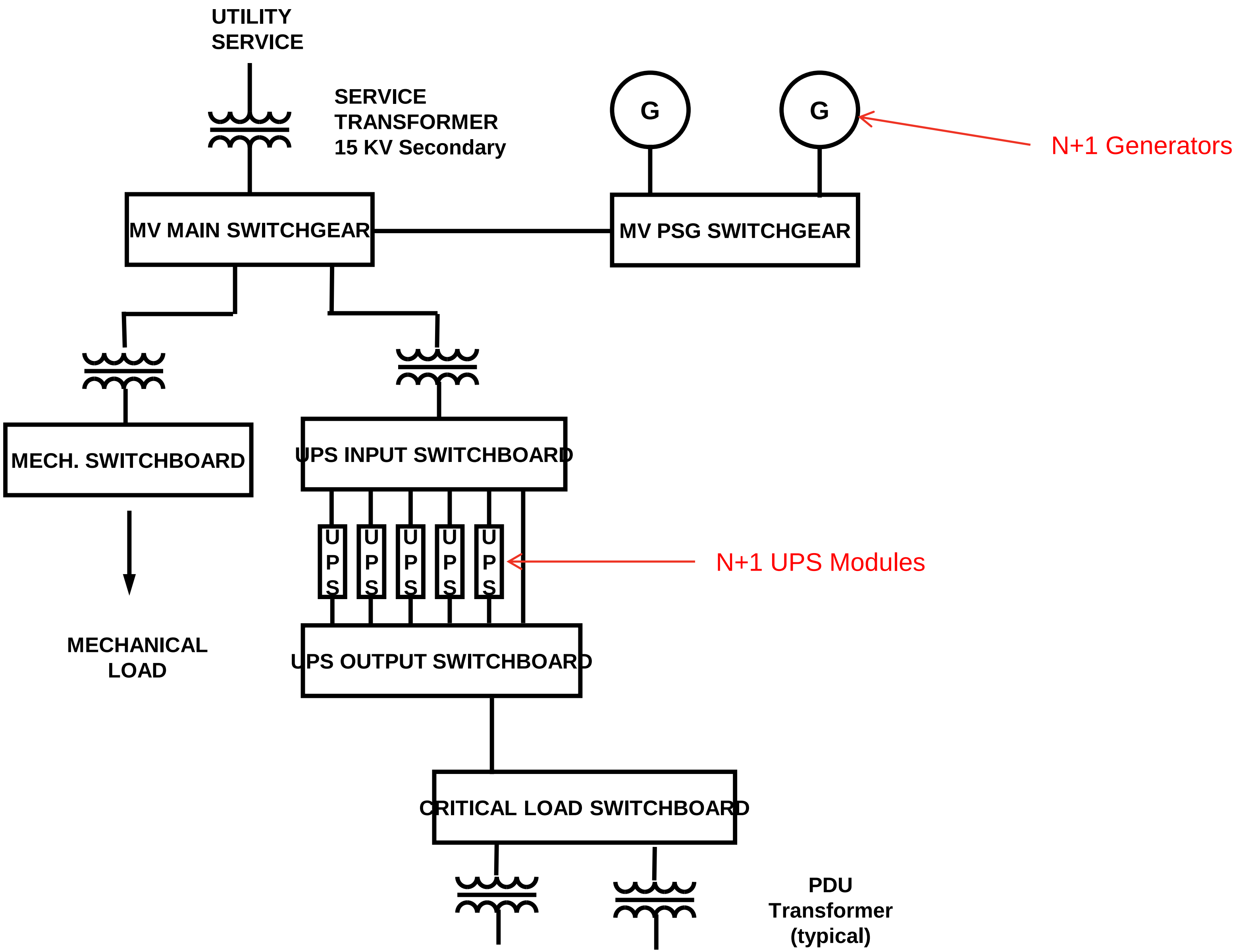


Changes in Reliability Metrics?

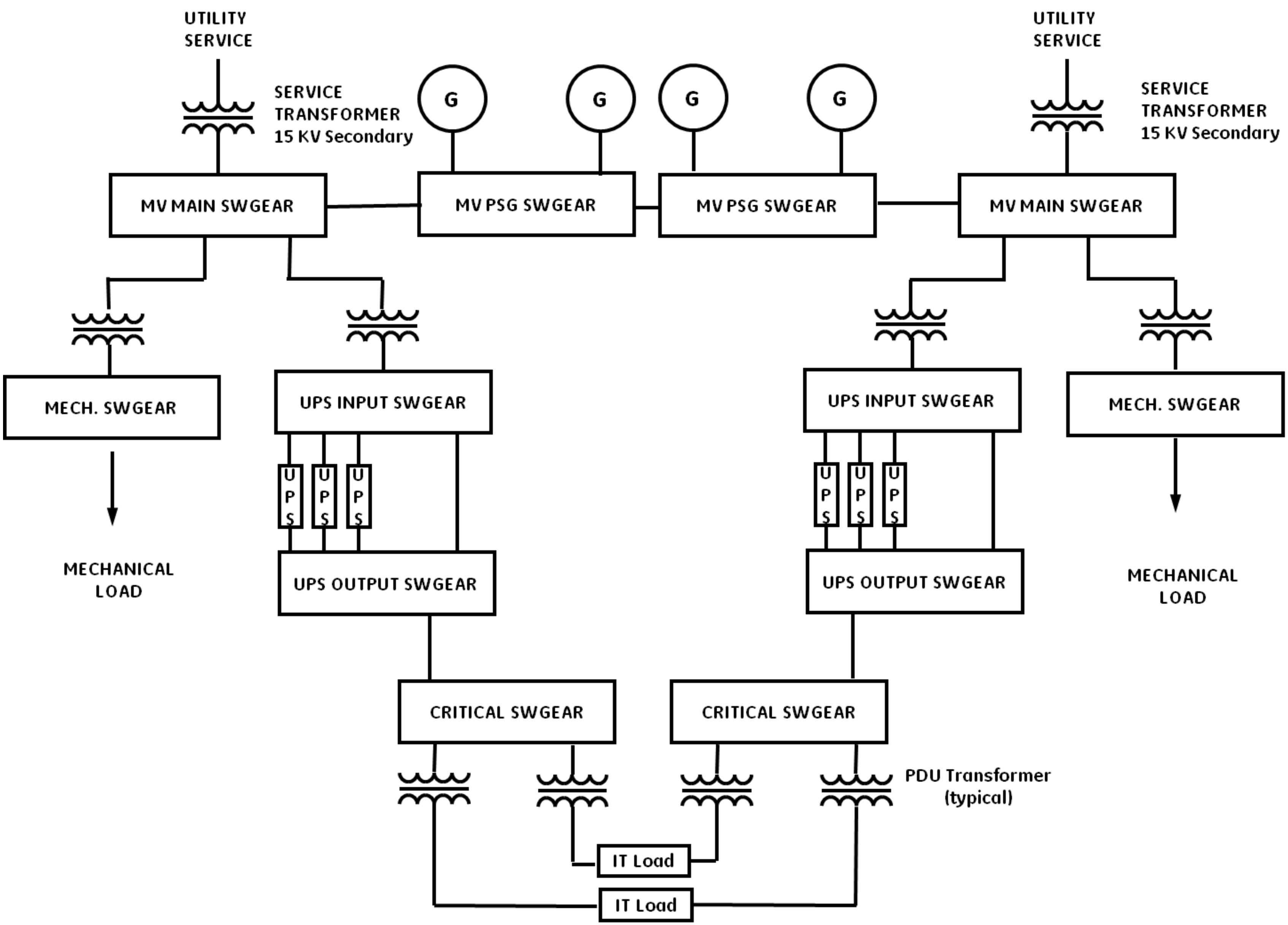
Data Center Tier *	Tier I	Tier II	Tier III	Tier IV
System Component Redundancy	N	N+1	N+1 or S+S	Minimum of N+1
Distribution Paths	1	1	1 Normal 1 alternate	2 Active
Concurrently Maintainable	No	No	Yes	Yes
Fault Tolerant	No	No	No	Yes
Staffing	None	1 Shift	1+ Shifts	24 x Forever
Single Points of Failure	Many + human error	Many + human error	Some + human error	None + fire + EPO
Annual IT Downtime	28.8 hours	22.0 hours	1.6 hours	0.8 hours
Site Availability	99.67%	99.75%	99.98%	99.99%

- Uptime Tier System
  - De-facto Metric
  - Relates Topology Characteristics to Reliability
  - Simple
- IEEE P3006.7 Recommended Practice for Determining the Reliability of "7 x 24" Continuous Power Systems in Industrial and Commercial Facilities
- M Technology introducing a new approach at 7X24 June 2015 conference

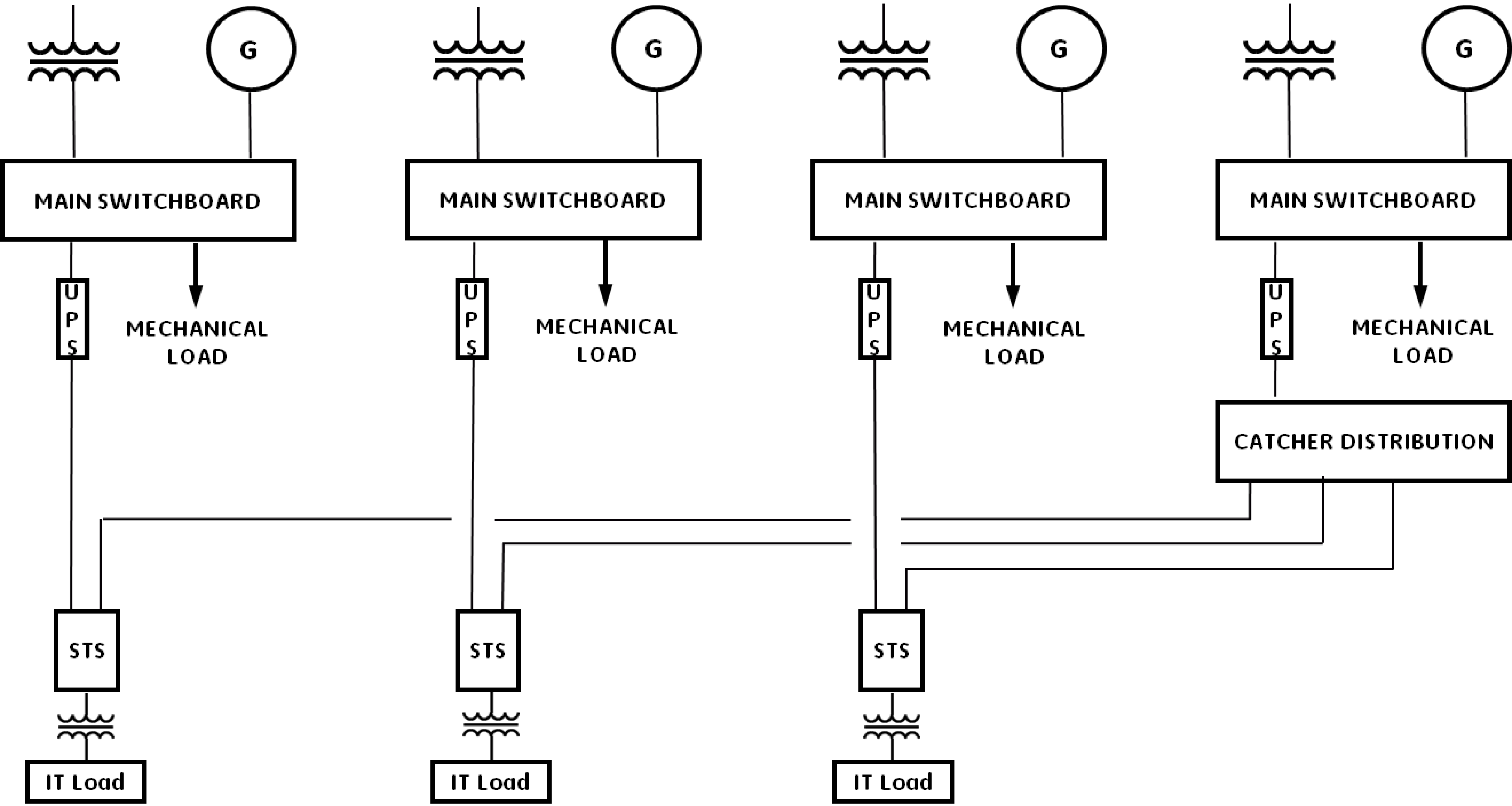
Traditional Topologies – N+1



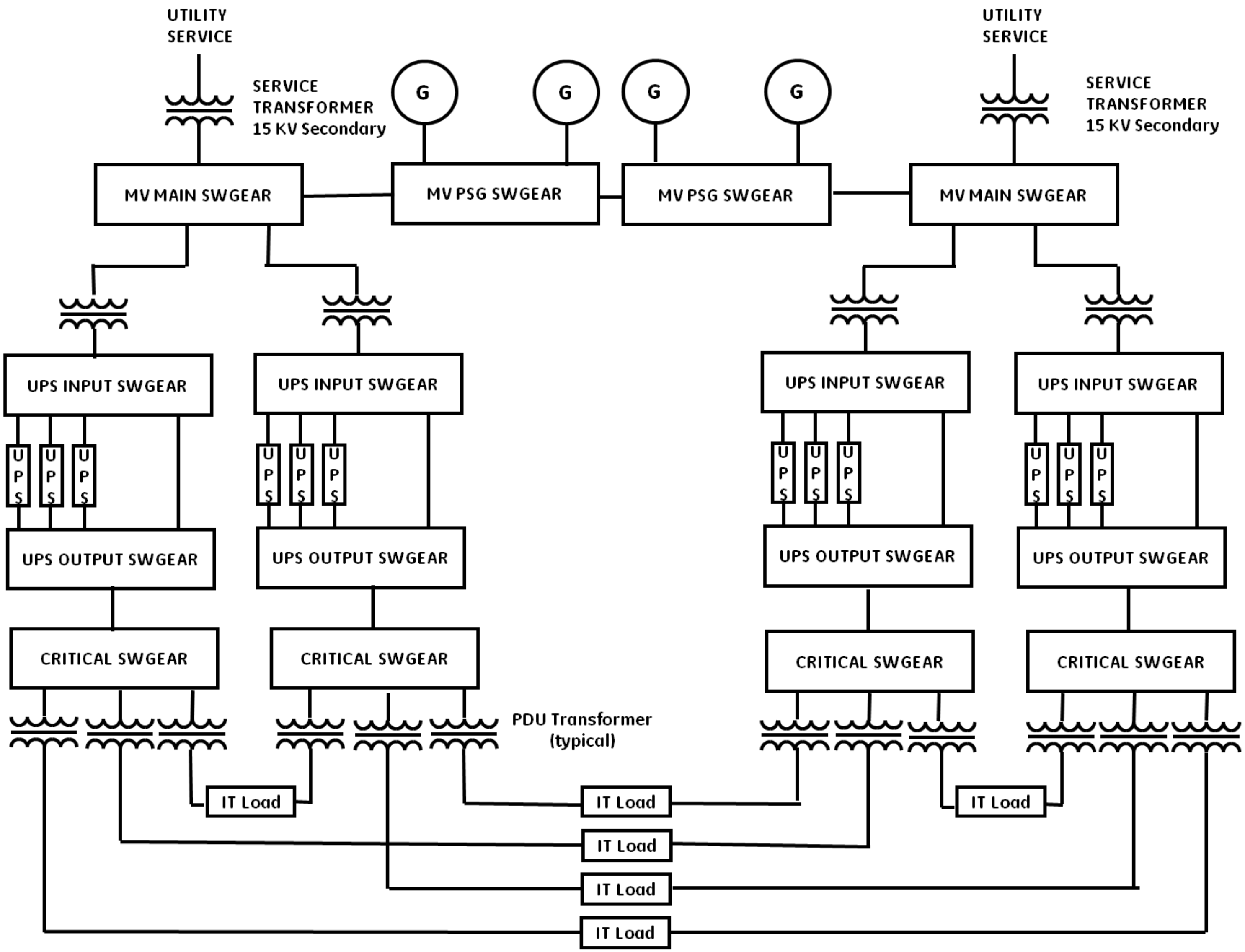
Traditional Topologies – N+N



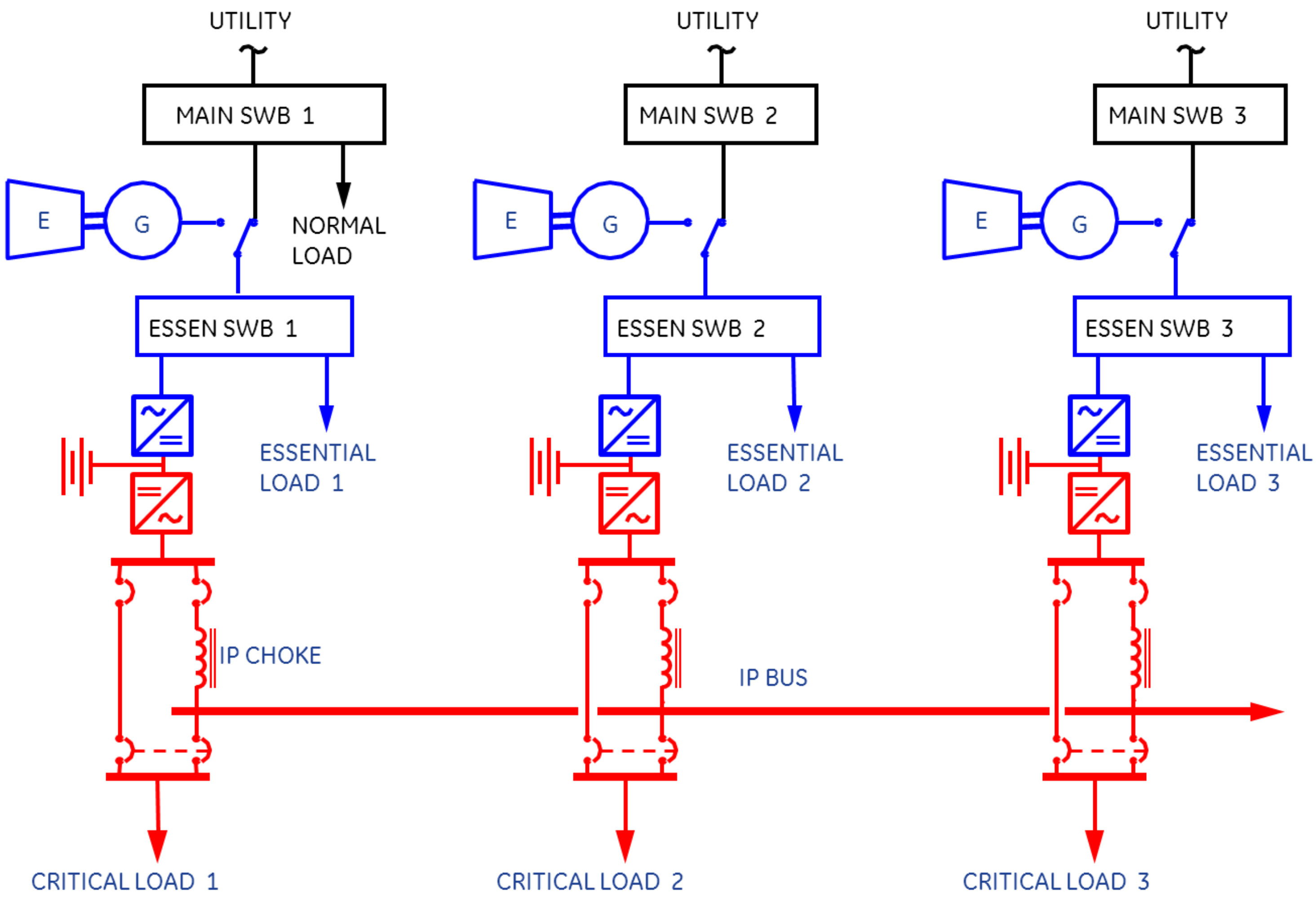
Alternative Topologies – Catcher Systems



Traditional Topologies – 4N/3



Alternative Topologies – Isolated Parallel



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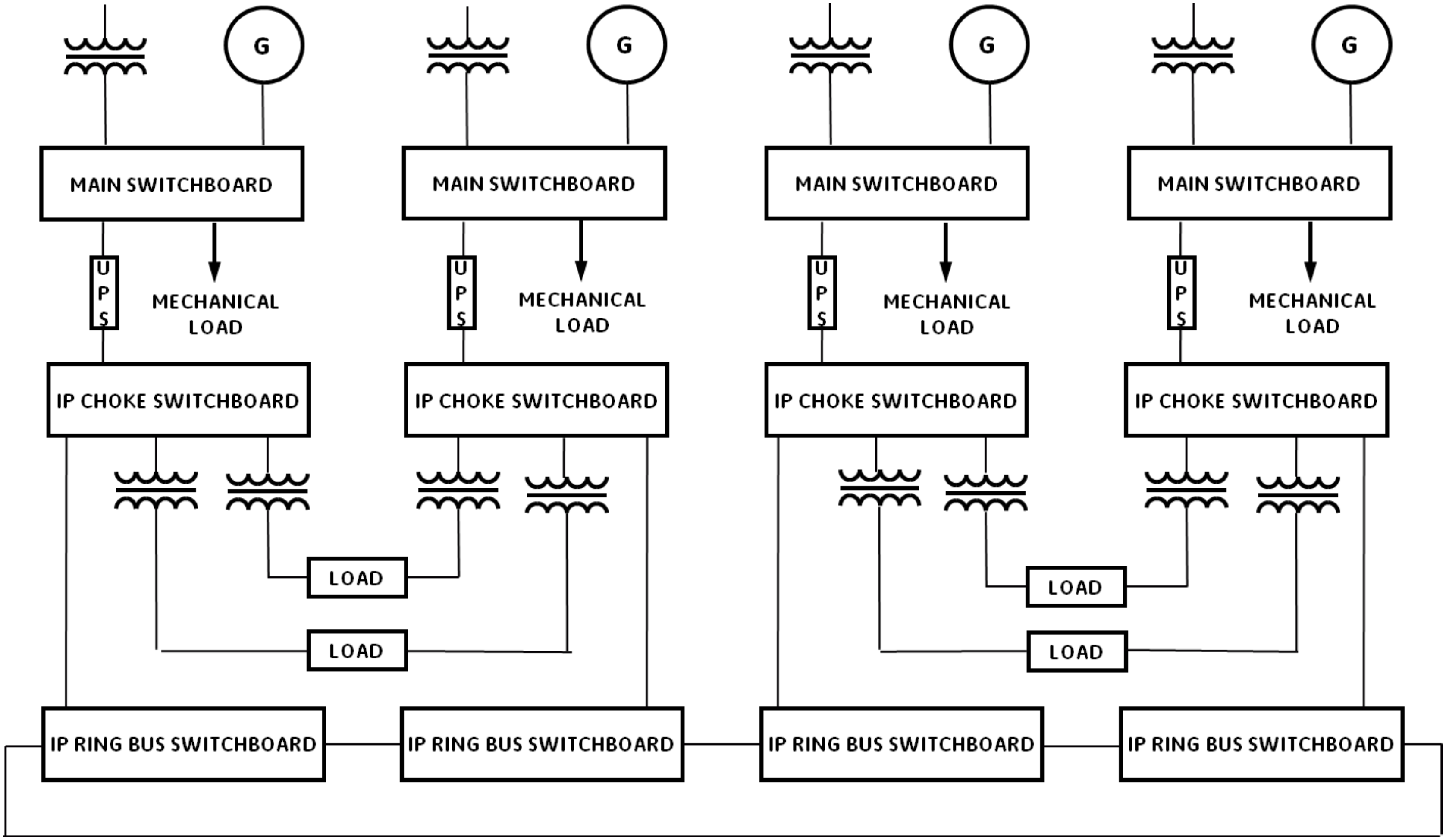
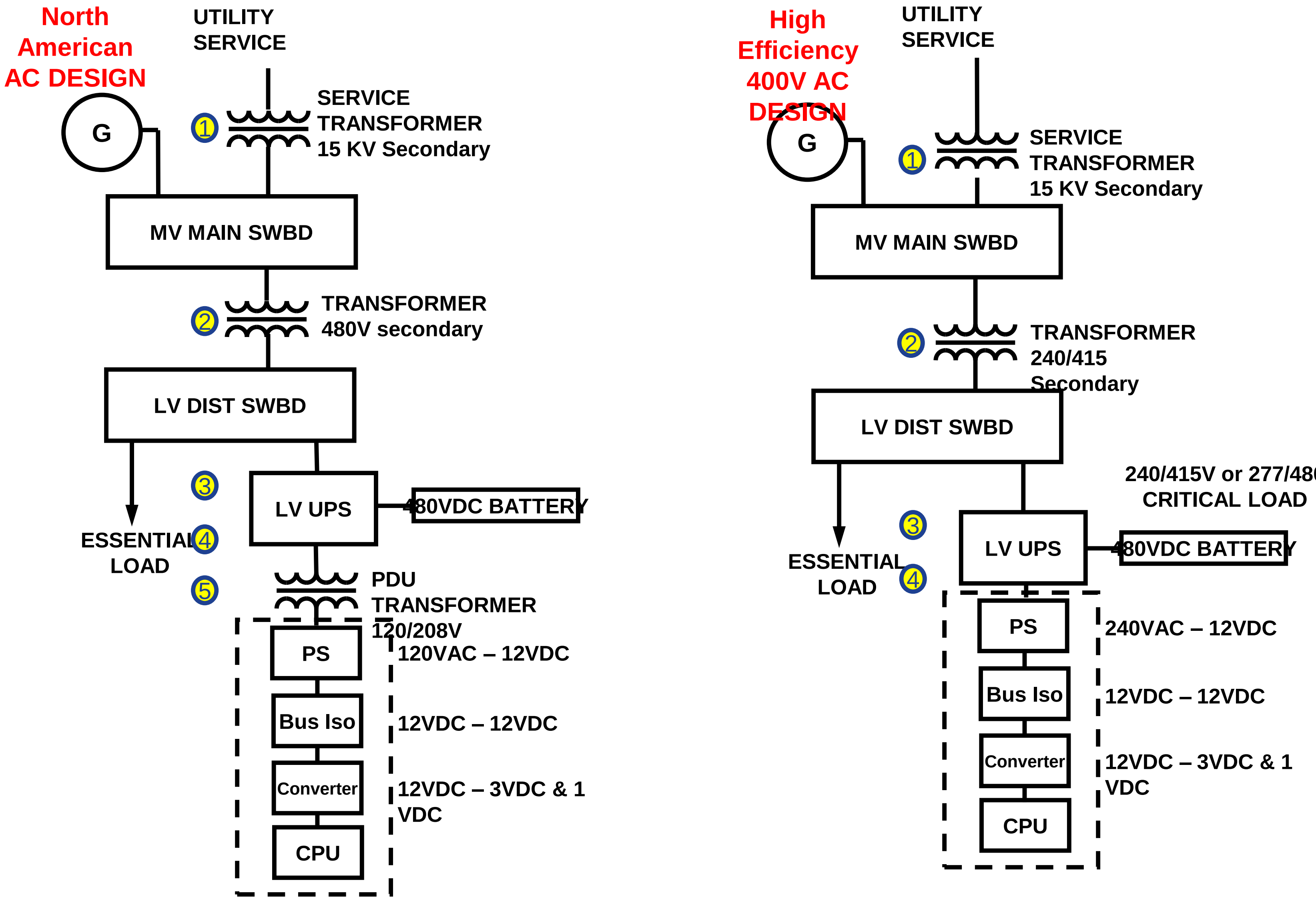


480V & 400V Power Chain



Power Transformation

400V

Advantages:

1. Improves server power supply efficiency (from 90% to 92%)
2. Eliminated PDU losses
3. EPA includes multi-mode operation in the Energy Star for UPS standard

Potential Design Issues:

1) Higher Short Circuit currents – Higher Arc Flash
2) Selective Coordination
3) Neutral requirements – 4W design and possible Ground Fault Issues

400V Ground Fault Issues

National Electric Code requires ground fault protection

Data Centers have redundant circuit paths to improve reliability

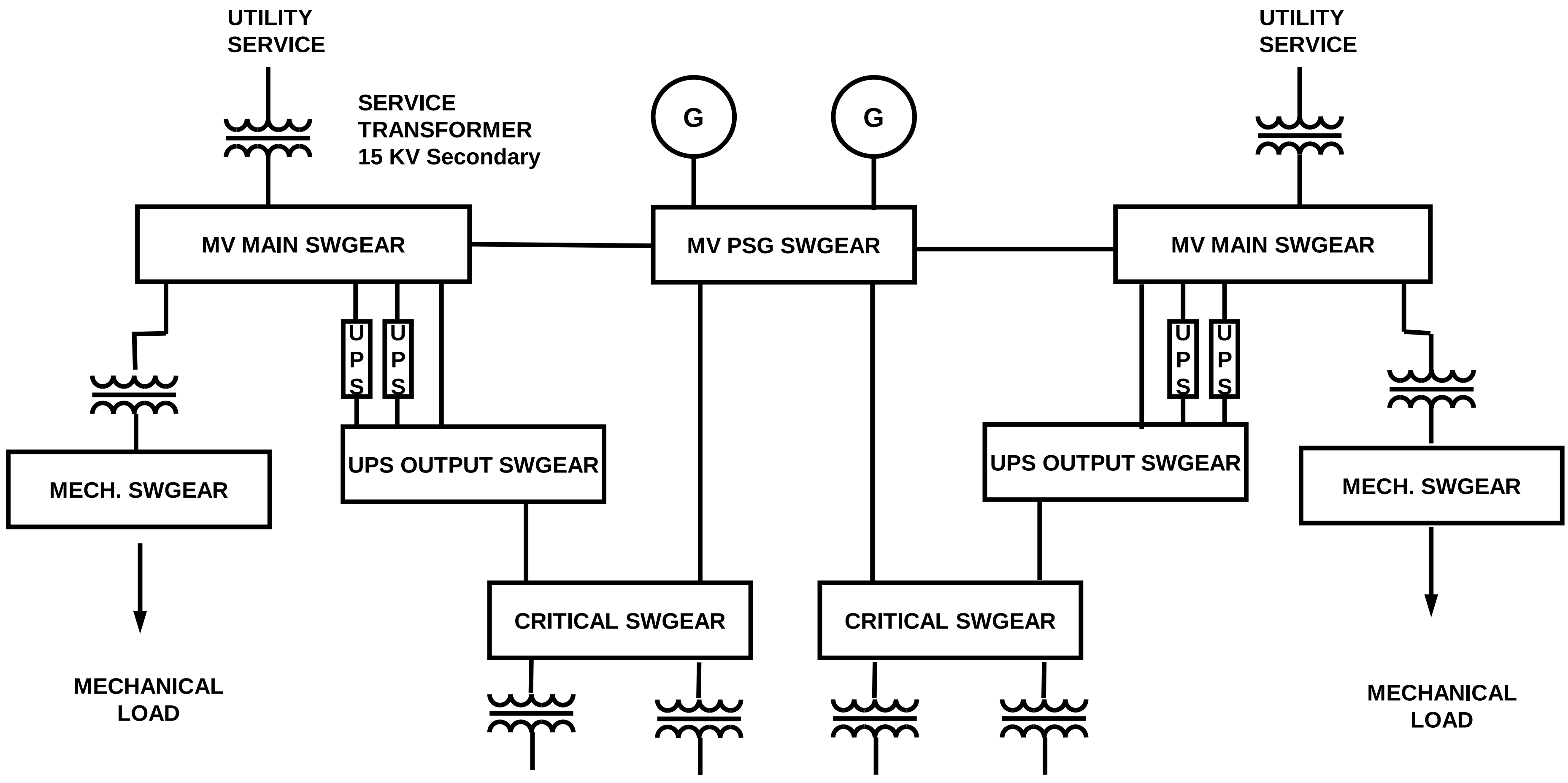
Redundant neutral paths comprise traditional ground fault protection.

Most data centers are 3 wire to avoid these issues

Only solutions are:

1) Modified differential ground fault protection
2) Four pole breakers to break neutral path – Four pole breakers simplify the process, but does not eliminate the issue (closed transition transfers are still an issue)

MV UPS

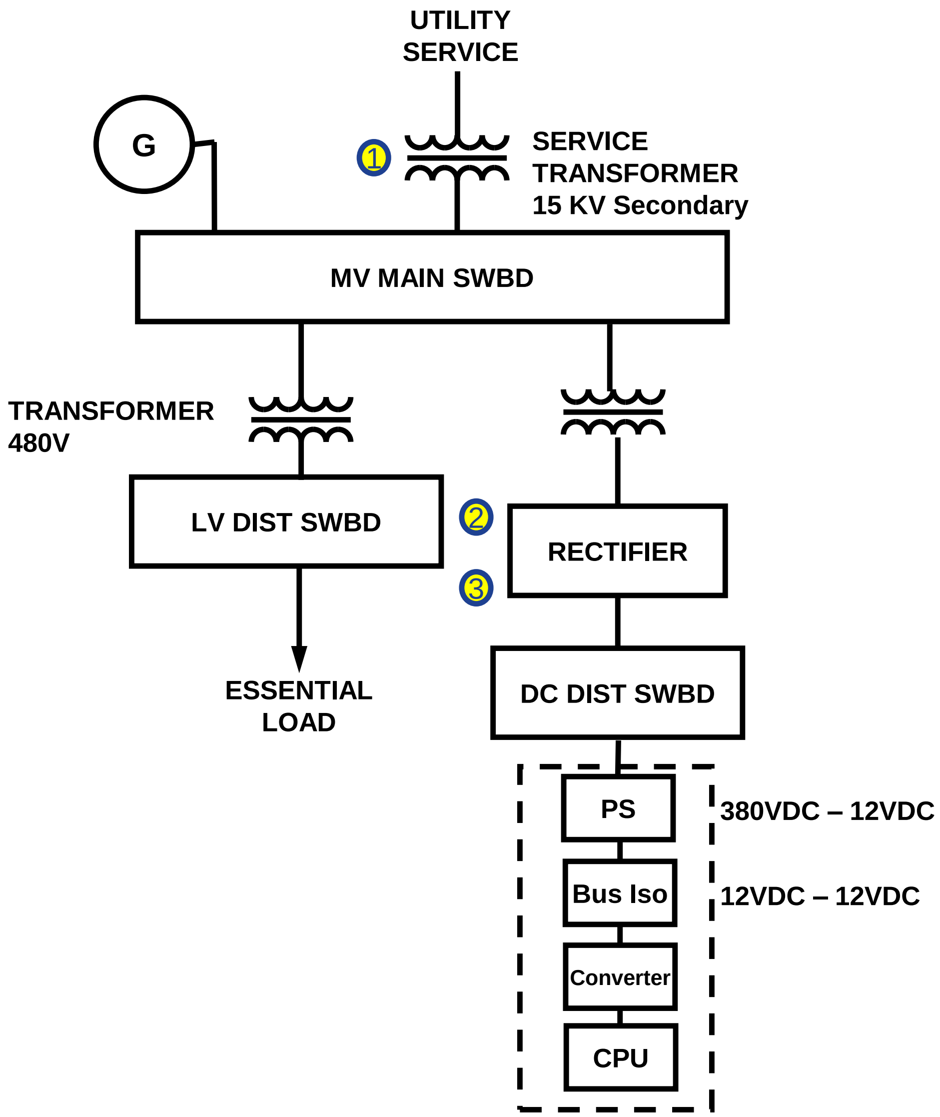

UTILITY SERVICE
SERVICE TRANSFORMER 15 KV Secondary
G
G
UTILITY SERVICE
MV MAIN SWGEAR
MV PSG SWGEAR
MV MAIN SWGEAR
UPS
UPS
UPS
UPS
MECH. SWGEAR
UPS OUTPUT SWGEAR
UPS OUTPUT SWGEAR
MECH. SWGEAR
CRITICAL SWGEAR
CRITICAL SWGEAR
MECHANICAL LOAD
MECHANICAL LOAD

Lower Cost driving MV designs

- Less Copper Less PVC conduit
- Less Labor
- Shorter construction cycle
- Equipment costs about the same.
- Overall, total cost is lower (estimate 10-15% on installed cost)

Possible Future Trends

DC UPS


UTILITY
SERVICE
G
1
SERVICE
TRANSFORMER
15 KV Secondary
MV MAIN SWBD
TRANSFORMER
480V
LV DIST SWBD
2
3
RECTIFIER
ESSENTIAL
LOAD
DC DIST SWBD
PS
380VDC – 12VDC
Bus Iso
12VDC – 12VDC
Converter
CPU

High Performance Semi-conductors

Silicon-carbide IGBT

- Extremely efficient
- Currently very expensive

What premium for 99% efficiency in VFI (double conversion) mode

Questions?