

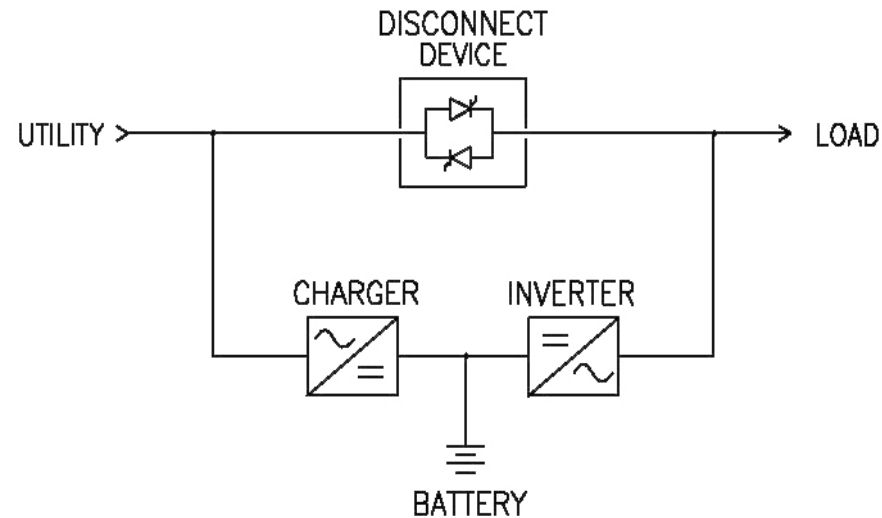
# UPS Theory & Operation

**M G E**

UPS SYSTEMS

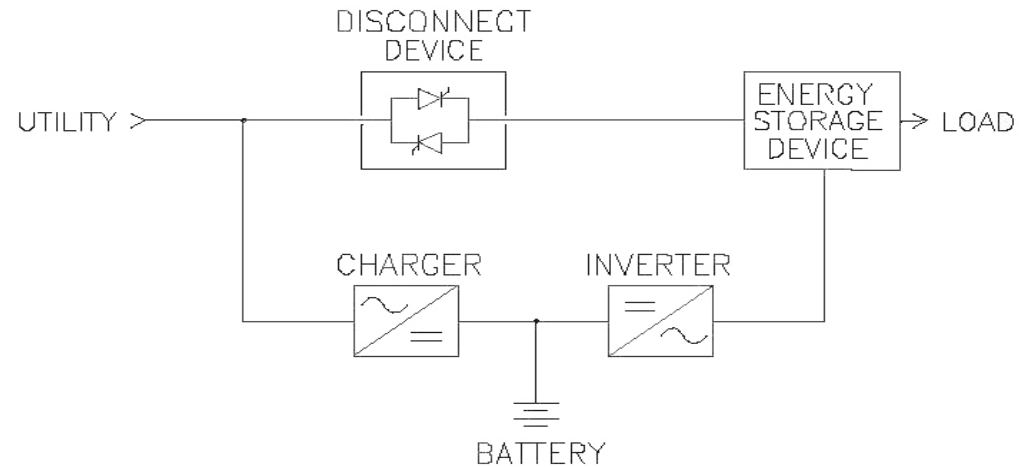
[www.mgeups.com](http://www.mgeups.com)

# STAND-BY LINE UPS



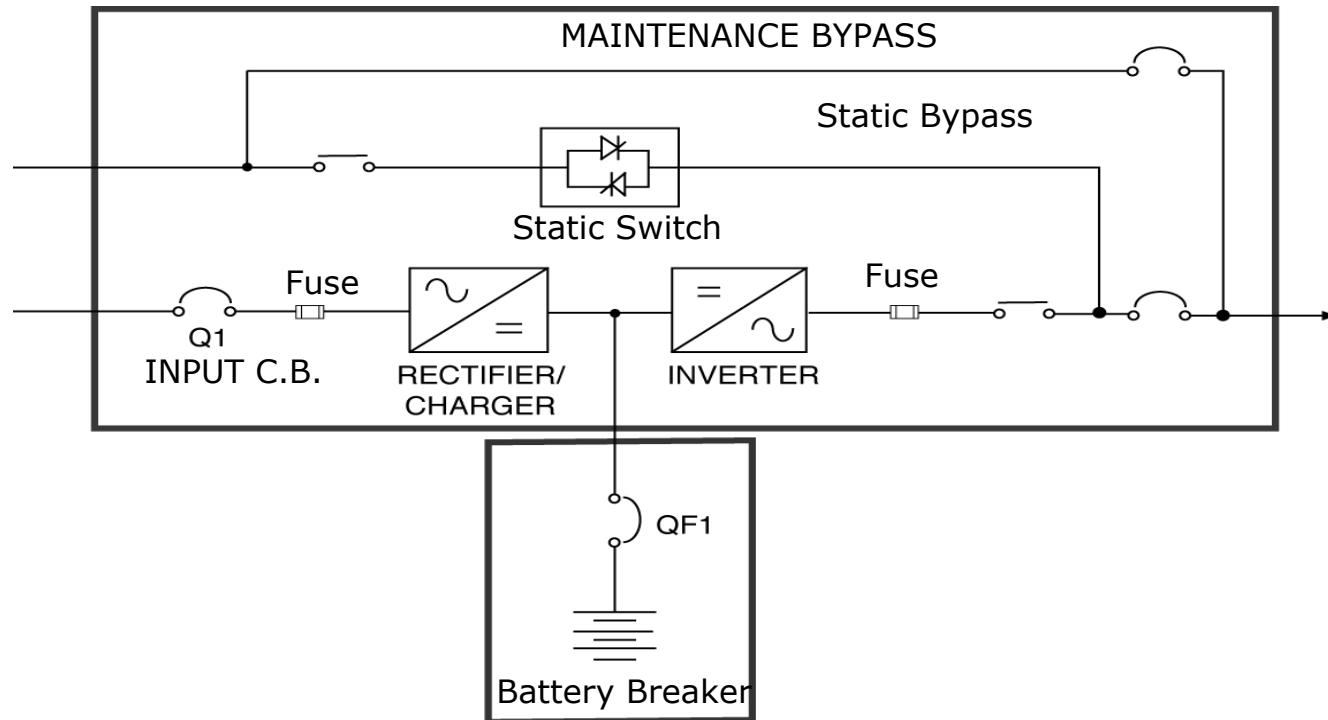
- ▶ Utility power is feeding the load
- ▶ Disconnect switch (solid state or electro-mechanical)
- ▶ Charger is on, keeping the battery under charge
- ▶ Inverter is off
- ▶ No voltage or frequency regulation
- ▶ 4 to 10 msec transfer time (with break on the output)

# LINE-INTERACTIVE UPS



- ▶ Utility power is feeding the load, through energy storage device
- ▶ Typical storage device: Ferroresonant or Motor Generator
- ▶ Disconnect switch (solid state or electro-mechanical)
- ▶ Charger is on, keeping the battery under charge
- ▶ Inverter is off
- ▶ Voltage regulation
- ▶ 4 to 10 msec transfer time (no break on the output)

# On-Line UPS

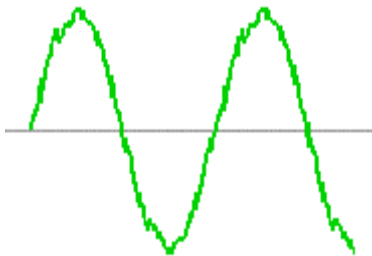


- ▶ Double Conversion  
(AC to DC, DC to AC)
- ▶ IGBT PWM Inverters
- ▶ 6 or 12 Pulse SCR Rectifier
- ▶ Continuous Rated Static Bypass
- ▶ Maintenance Bypass
- ▶ Input Harmonic Filter

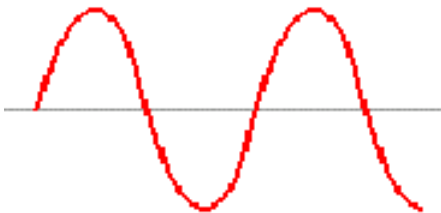
# Mitigating UPS Induced Harmonics



6 Pulse Rectifier

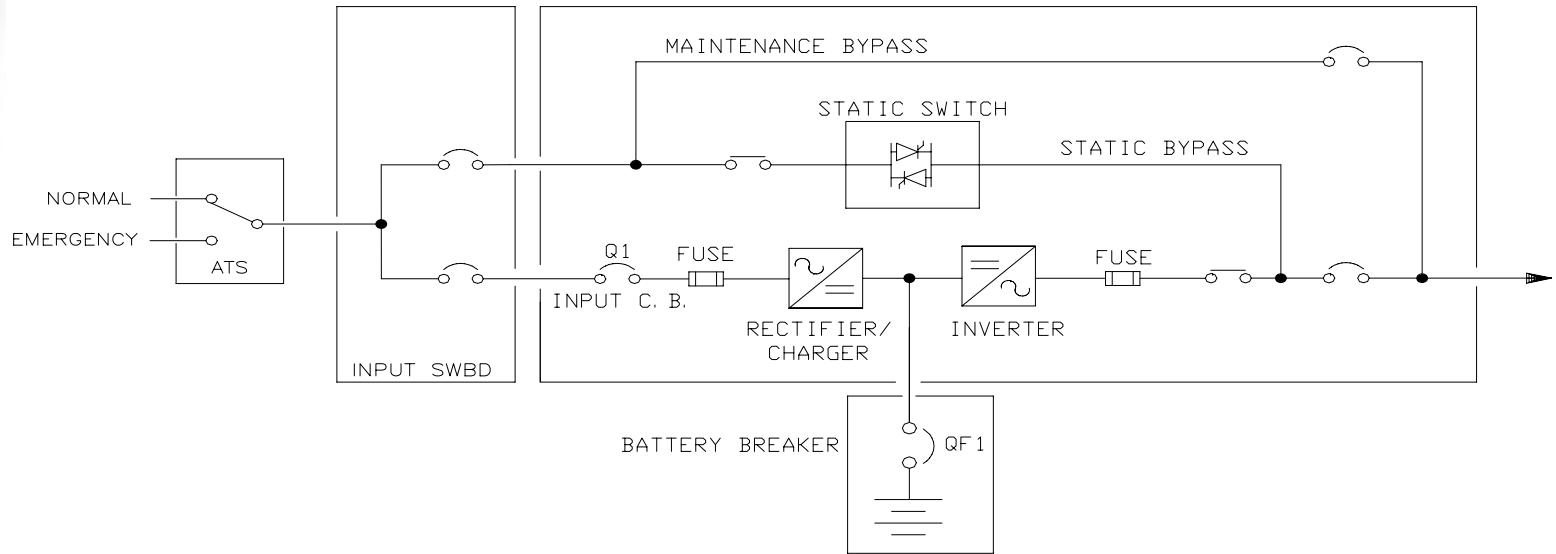


6 Pulse Rectifier  
w/ filter



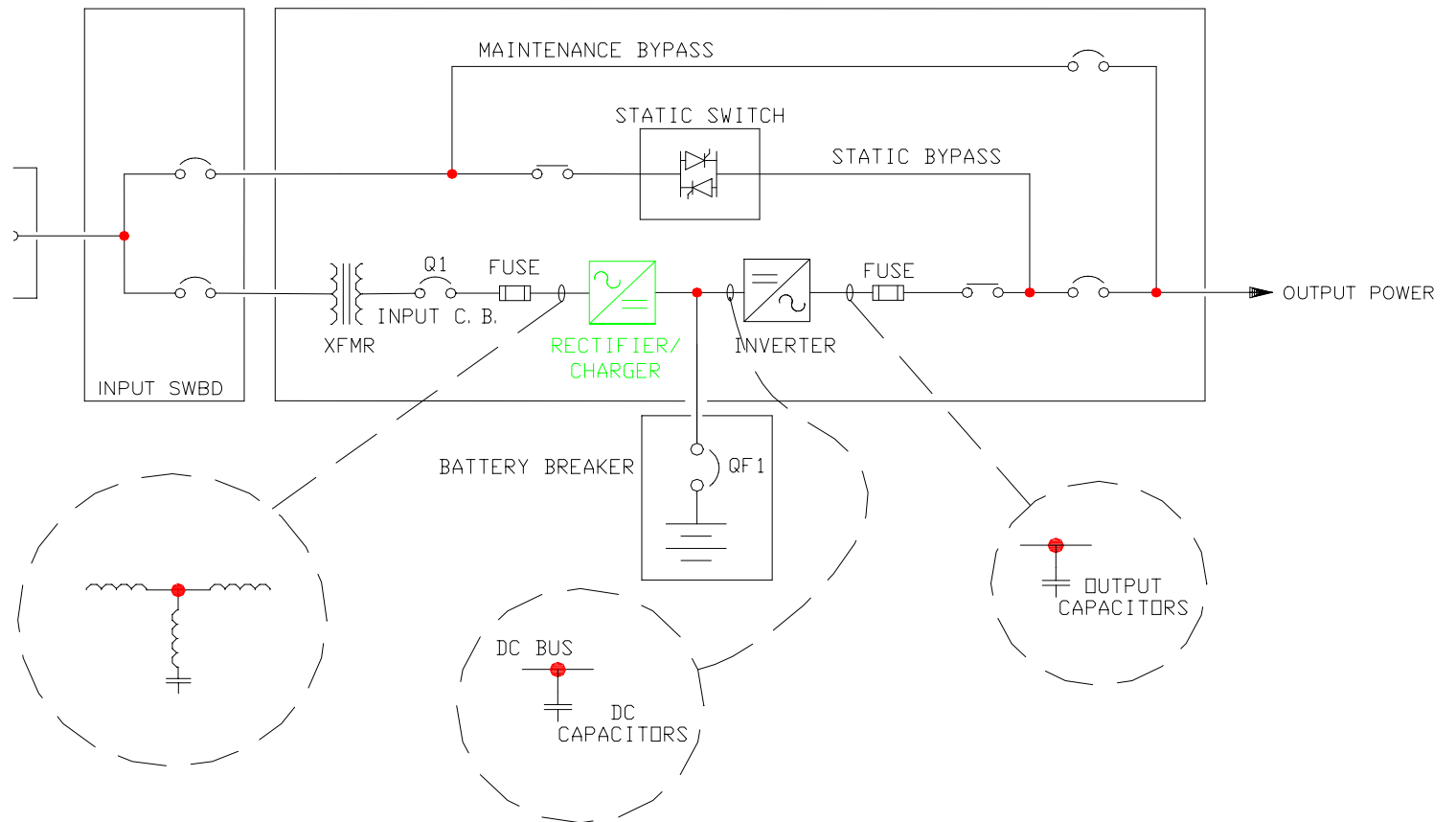
IGBT Rectifier

# On-Line Static UPS



- ▶ Double Conversion (AC to DC, DC to AC)
- ▶ IGBT PWM Inverters
- ▶ 6 or 12 Pulse SCR Rectifier
- ▶ Continuous Rated Static Bypass
- ▶ Maintenance Bypass
- ▶ Input Harmonic Filter

# UPS Rectifier



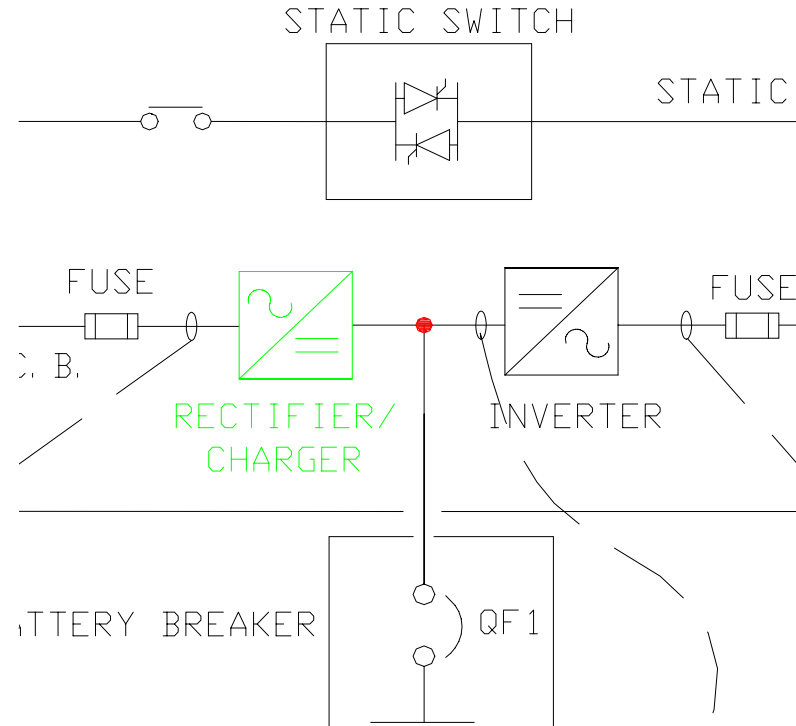
# Rectifier

## ▶ Operation

- > Converts AC/DC
- > Charges Battery

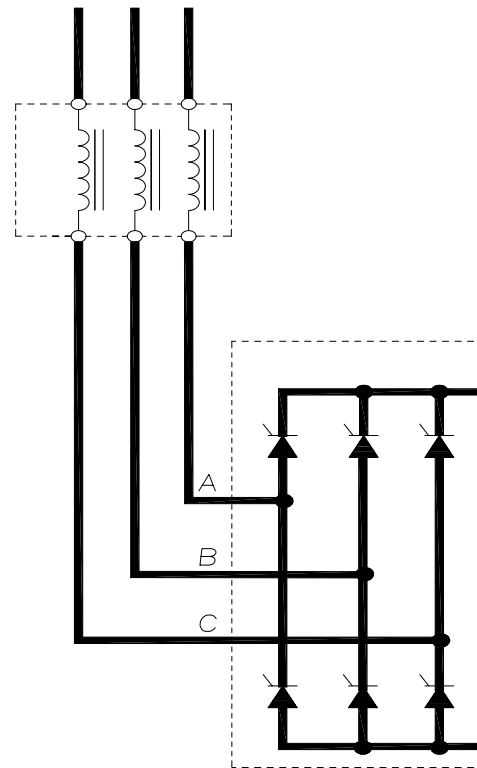
## ▶ Types

- > SCR
  - 6 pulse
  - 12 pulse
- > IGBT



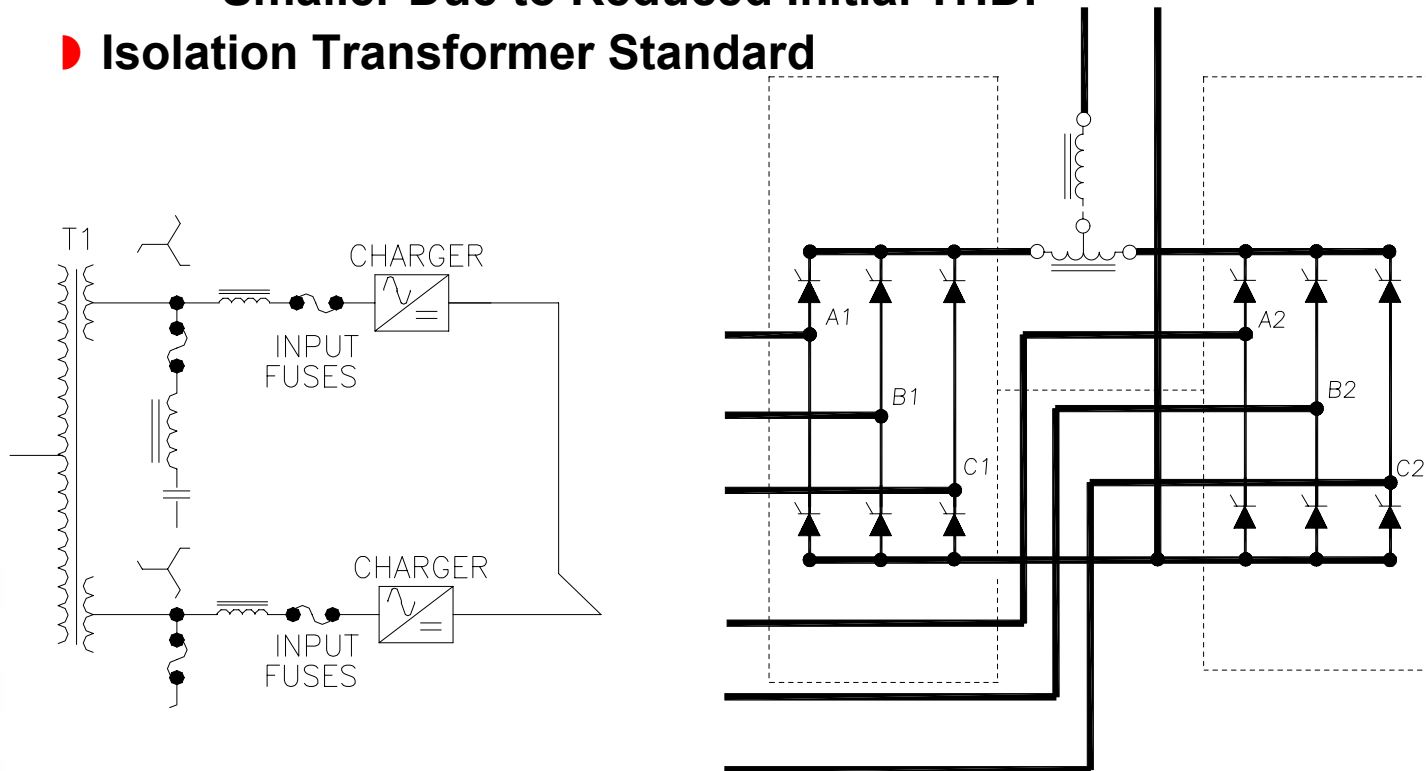
# Rectifier/Charger Design (6 Pulse Rectifier )

- ▶ 6 SCR's, Fully Controlled Rectification
- ▶ THDI is 27% - 30%, with no Filter
- ▶ Input Filter Reduces THDI to 5 - 7% (Improves PF to 0.95 Lagging)



# Rectifier/Charger Design (12 Pulse Rectifier)

- ▶ 2 x 6 SCR's, Fully Controlled Rectification
- ▶ THDI is 16%, with no Filter
- ▶ Input Filter Reduces THDI to 5%
  - > Filter Requirement (Capacitors) Substantially Smaller Due to Reduced Initial THDI
- ▶ Isolation Transformer Standard



# Rectifier/Charger Design

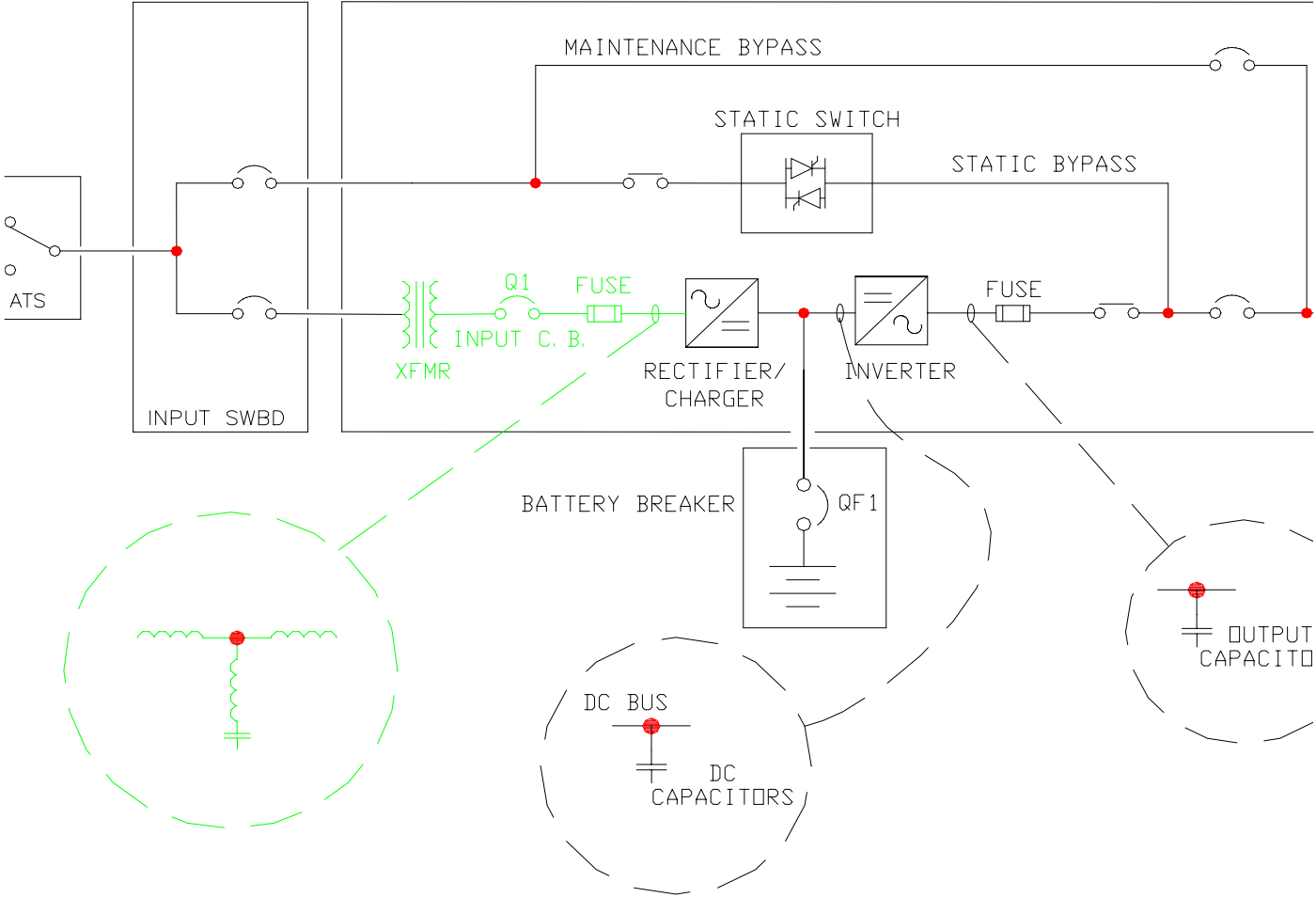
- **IGBT Front End**

- **Power Factor Corrected Input**
- **Sensitive Transistors Susceptible to Utility Surges (SCR's Tolerate to High Surges without Failure)**
- **Ideal at 208 V With Input Transformer, Questionable at 480 VAC**
- **Efficiency is also a Major Penalty – Operating Cost Typically Double**
- **Suitable for Small, not Very Large UPS**

- **SCR and IGBT Comparison**

	<b>SCR UPS w/Filters</b>	<b>IGBT Rectifier UPS</b>
<b>INPUT POWER FACTOR</b>	<b>Varies With Load</b>	<b>0.95 – 0.98 Lagging</b>
<b>THDI</b>	<b>5% - 10%</b>	<b>4% - 7%</b>
<b>Efficiency</b>	<b>94%</b>	<b>89%</b>

# UPS Input



# UPS Input Components

## ▶ Transformer

- > Provides voltage steps
- > Provides galvanic isolation
- > Required for 12-pulse rectifier

## ▶ Input Circuit Breaker

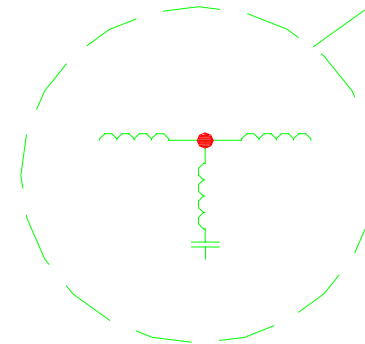
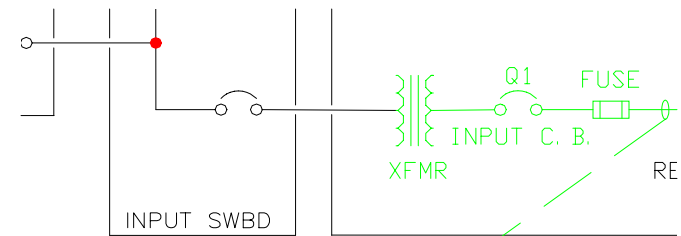
- > Disconnects UPS input
- > Provides Short Circuit Rating
- > Installed with Shunt Trip

## ▶ Input Fuses

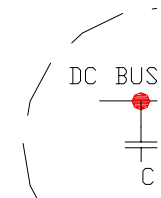
- > Protects Rectifier

## ▶ Input Filter

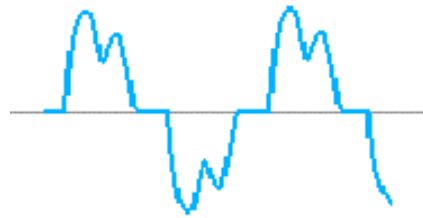
- > Reduces Reflected Harmonics
- > Improves Power Factor



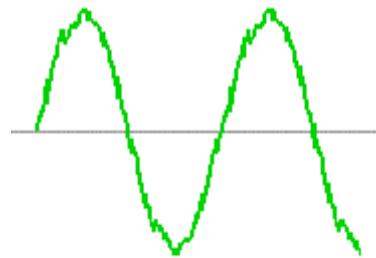
BATTERY BRI



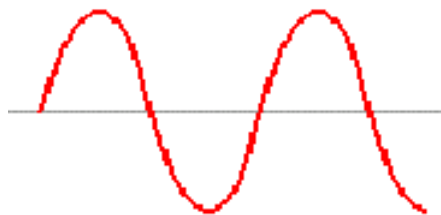
# UPS Induced Harmonics



**6 Pulse Rectifier**



**6 Pulse Rectifier  
w/ filter**

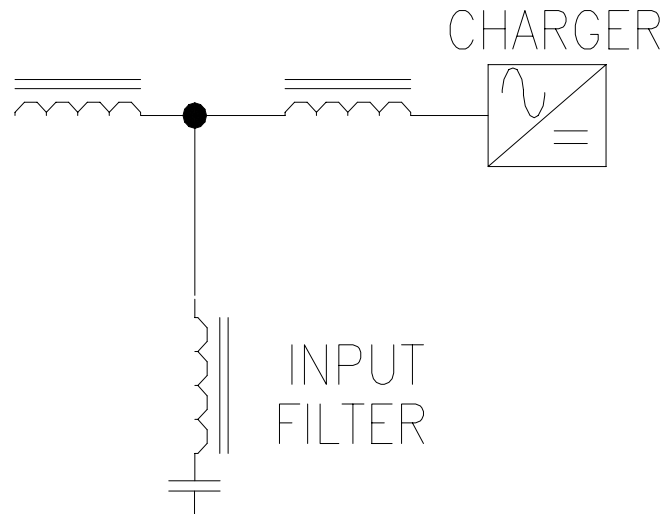


**IGBT Rectifier**

# UPS Input Filter Technology

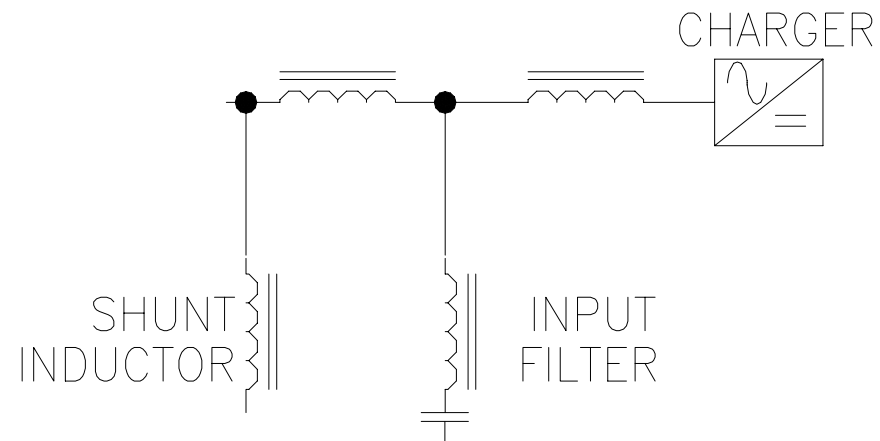
## (Trap Filter)

- ▶ Tuned to 5th or 7th Harmonics on 6 Pulse
- ▶ Tuned to 11th and 13th on 12 Pulse
- ▶ Reduced THDI to 5 - 7% @ 100% Load
- ▶ Constant KVAR as % Load changes
- ▶ Leading PF on Lightly Loaded UPS



# UPS Input Filter Technology (Shunt Inductor Filter)

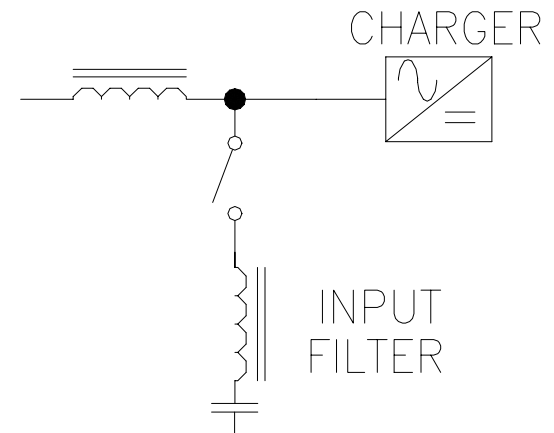
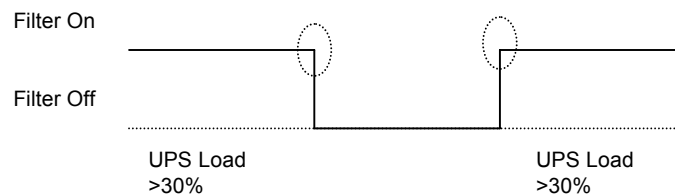
- ▶ **Compensates for Leading Power Factor**
- ▶ **No Further Reduction in THDI**
- ▶ **No Mechanical Component**
- ▶ **Lower PF at Full Load**



# UPS Input Filter Technology

(Load Variable Filter)

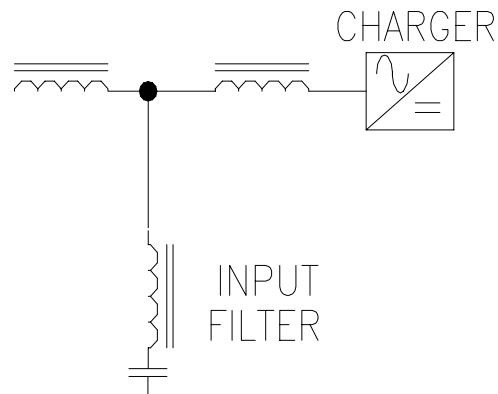
- ▶ Filter Disengaged at Light UPS Loads to (Via Mechanical Contactor)
- ▶ Filter Engaged as Load Increased
- ▶ Limits Source kVAR Load
- ▶ Potential Switching Surges



# UPS Input Filter Technology

(Low kVAR Filter)

- ▶ **Uses Inductors and Reduced Capacitance to Filter THDI**
- ▶ **Limits Input THDI to <7%, Maintaining Acceptable kVAR**
- ▶ **100% Passive / Solid State (no Contactors / Notching)**
- ▶ **Maintains Good Efficiency**



# Limiting UPS Induced Distortion (THDI)

- ▶ Rectifier Section Design:

- > SCR or IGBT?
- > 6 or 12 Pulse?

***THDI***

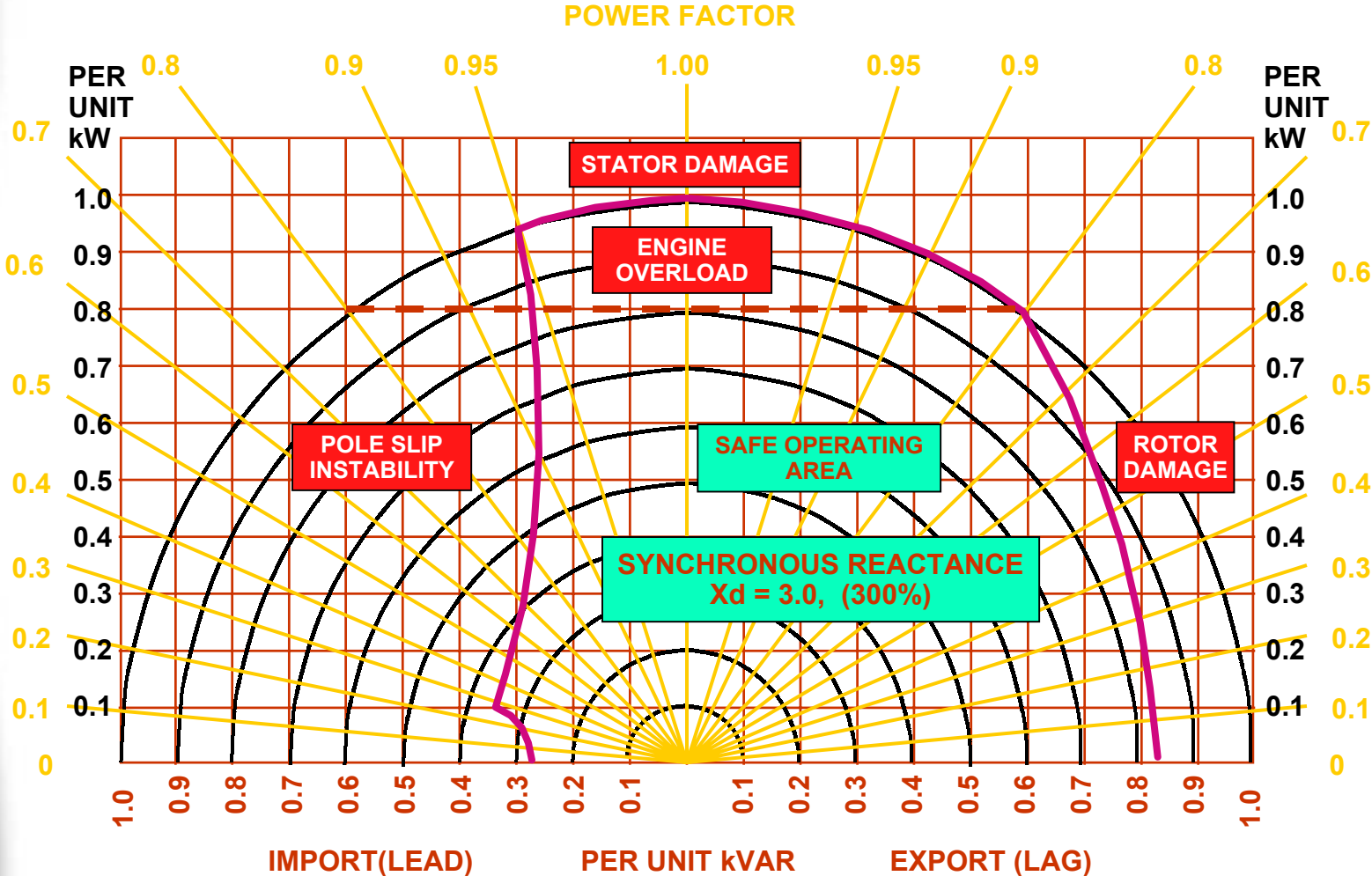
- ▶ Properly Designed and Applied Input Filtering:

- > Active, Passive or Switched?
- > Proportionate to UPS Load
- > Within Generator Reactive Capability

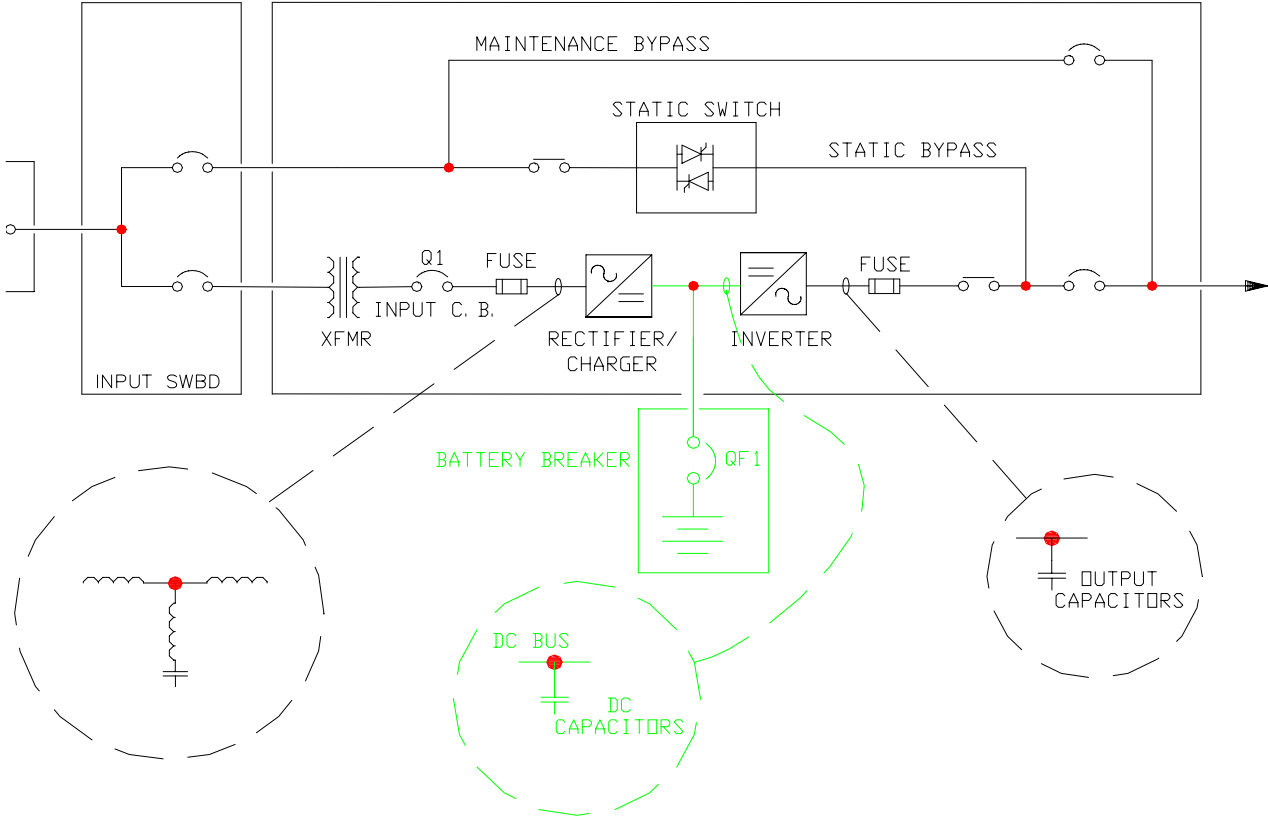


***kVARs***

# Alternator Reactive Capability



# UPS DC System



# DC System Components

## ▶ DC Bus

- > Product dependent voltage

## ▶ DC Capacitors

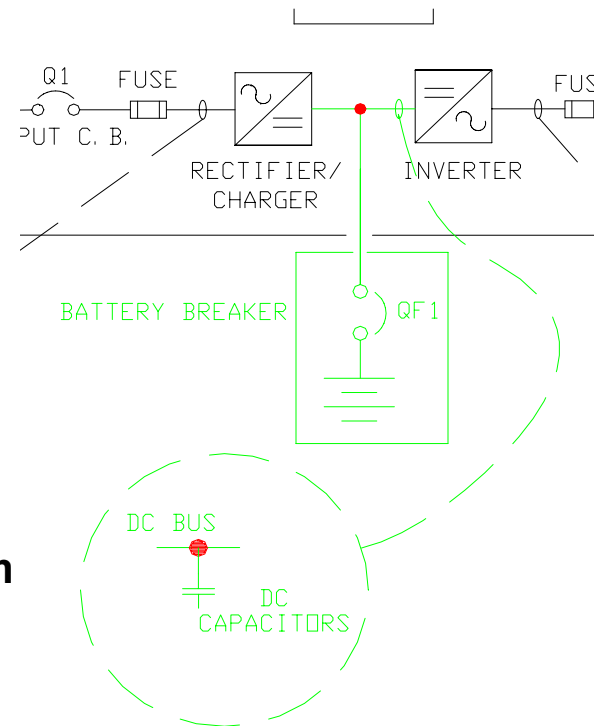
- > Mitigates AC ripple on the DC Bus

## ▶ Battery

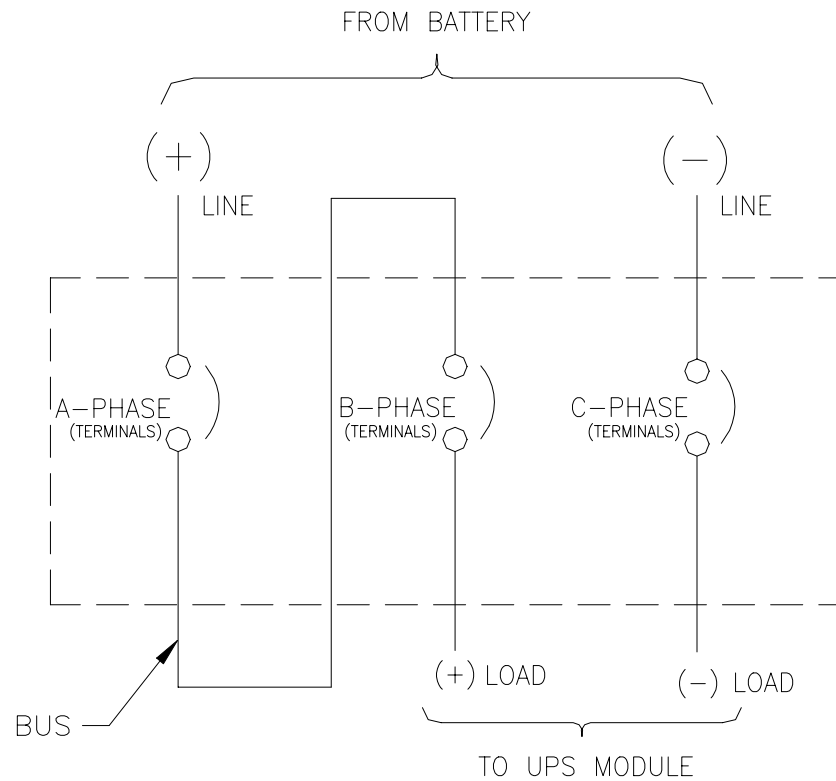
- > Wet cell
- > Sealed

## ▶ Battery Disconnect

- > Provides Isolation of battery from DC bus
- > Provides Automatic trip function via UVR or shunt trip
- > Wiring Configurations
  - end string
  - mid string

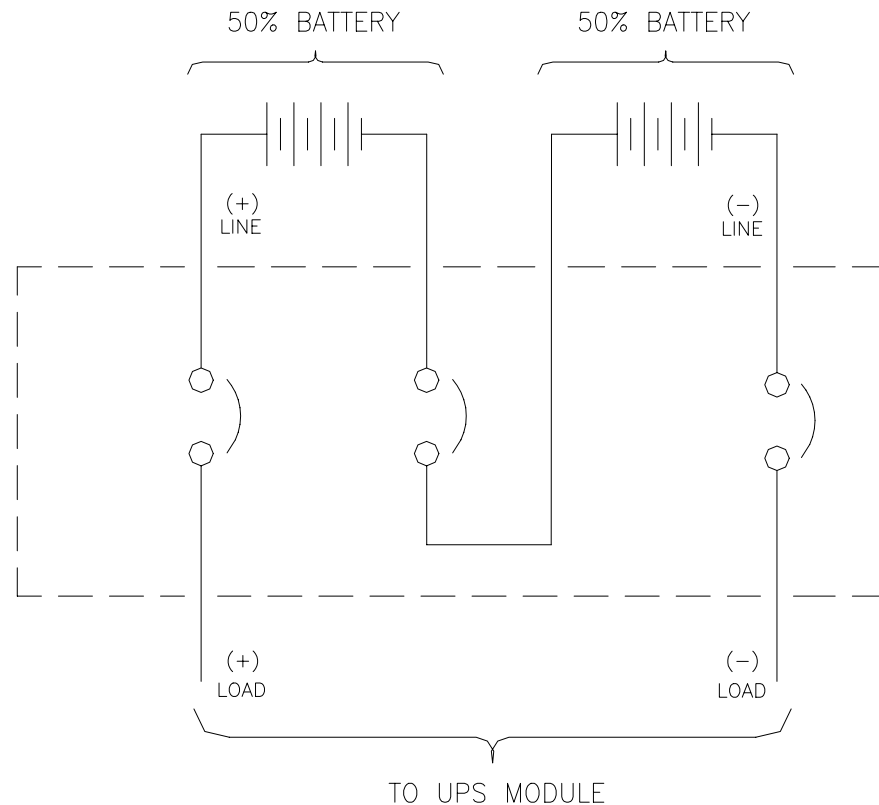


## End String Disconnect



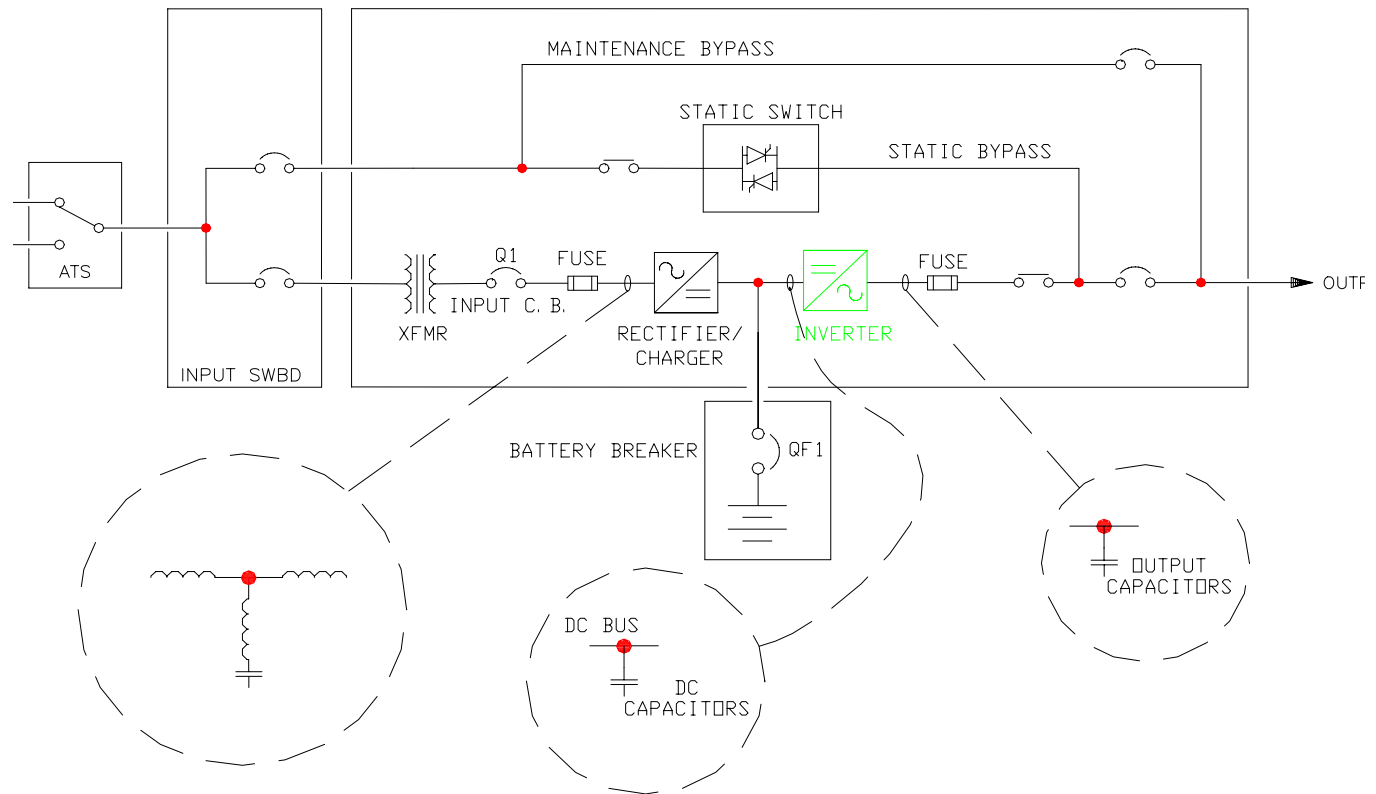
- Full pole to pole DC voltage
- Standard, unless specified otherwise
- Less expensive to install versus mid string
- Rack layout not necessarily important

## Mid String Disconnect



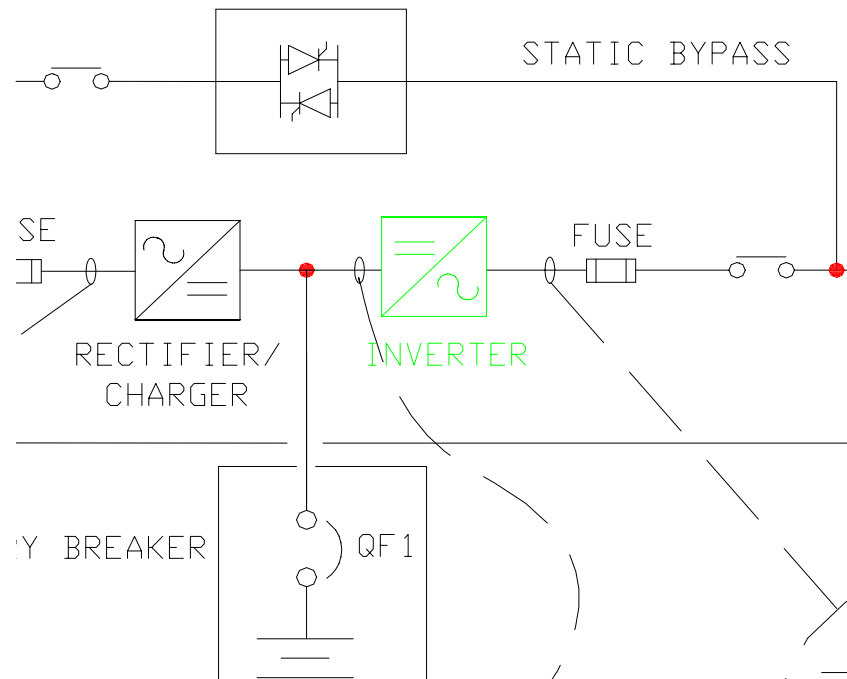
- Limits pole-to-pole voltage to less than 250VDC
- More expensive to install versus end string
- Rack layout considerations important

# UPS Inverter



# Inverter

- ▶ **Operation**
  - > **Converts DC/AC**
- ▶ **Types**
  - > **IGBT**
  - > **SCR**
- ▶ **Topologies**
  - > **Varies depending on manufacturer**



# Evolution & Paradigm Shift to IGBT and HF PWM

**Semiconductor types**



SCR

Bipolar



**Inverter Topologies**



6 Step

12 Step

LF PWM

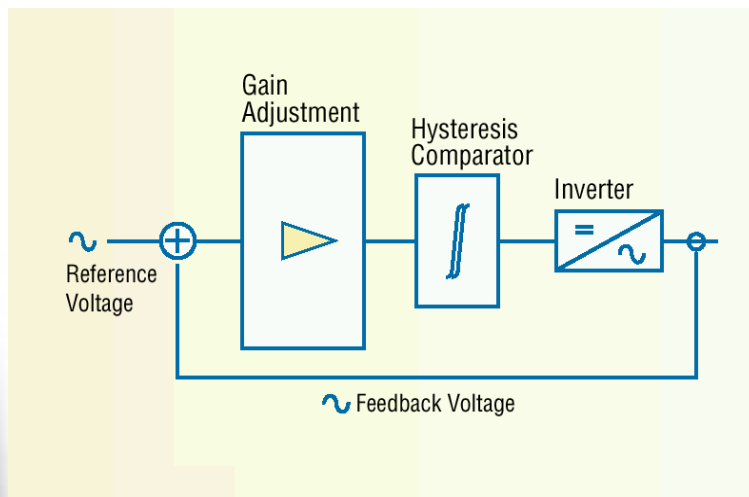
HF PWM



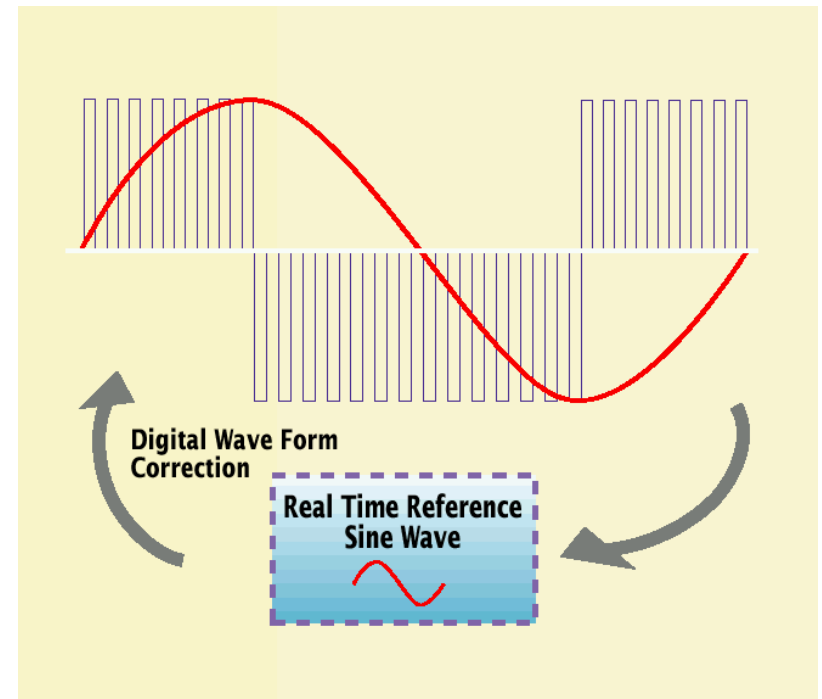
# Digital Power Quality Management System

*Creates a “perfect sine wave” (3.5% max THD) output under all conditions*

Eliminates harmonics and stabilizes voltage for “computer grade power”.

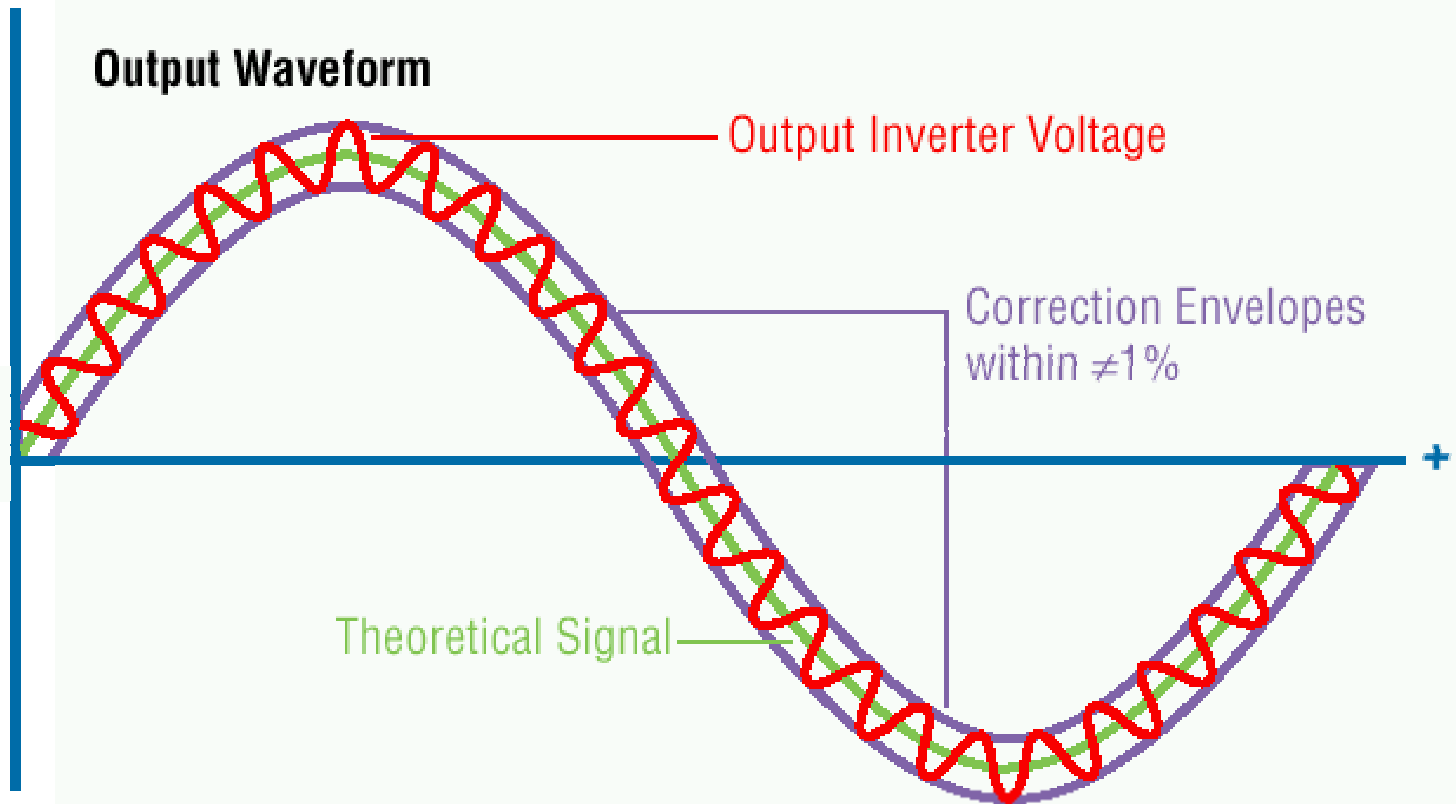


**Compares to “perfect” sine wave and correct**

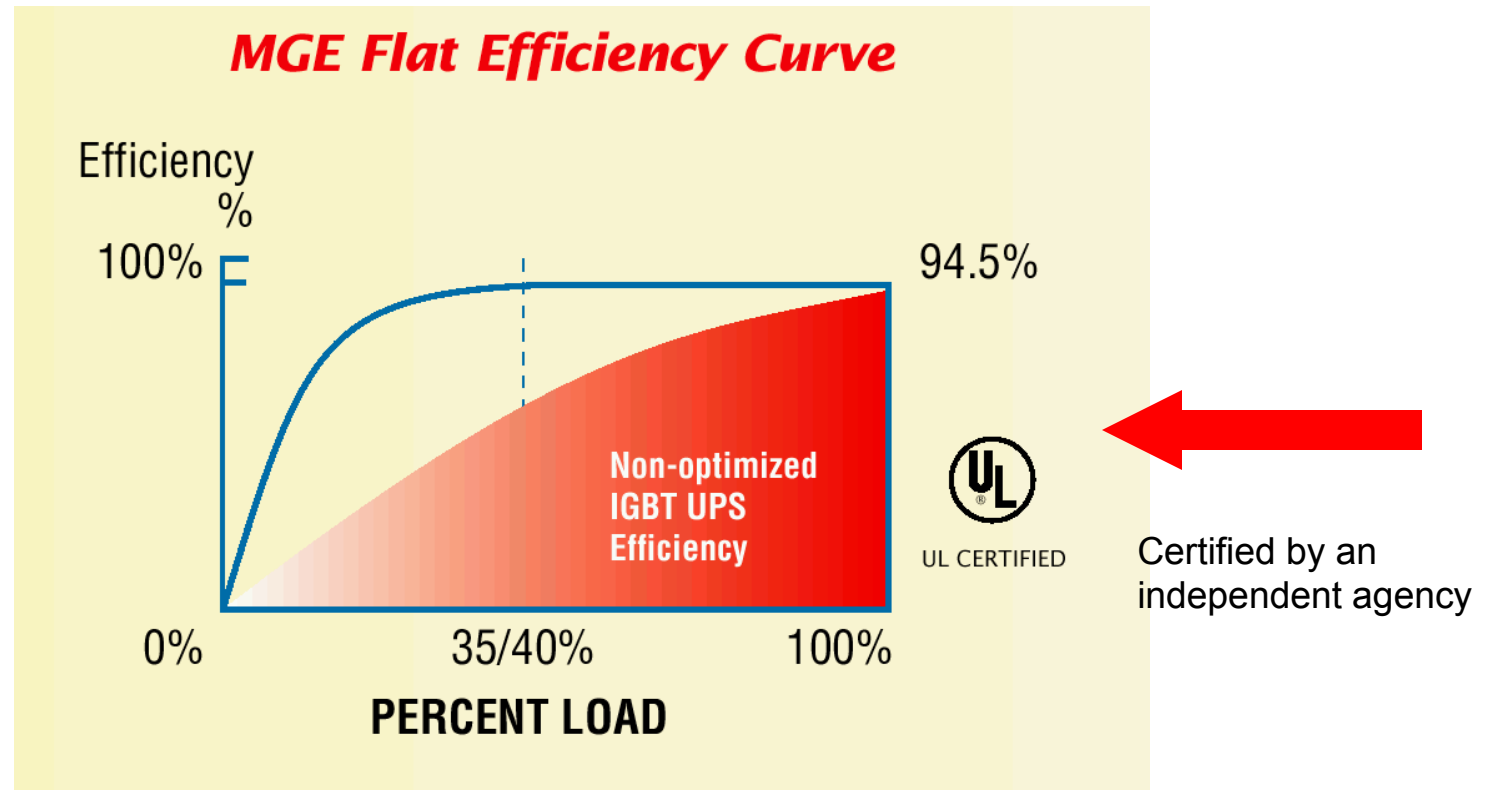


**Adjusts waveform to generate distortion free “perfect” output**

# Digital Power Quality Envelope



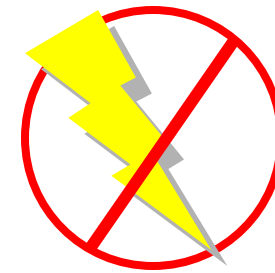
## High Efficiency even at lower loads means huge cost savings



Most manufacturers do not publish efficiencies under 50% where most UPSs operate  
MGE maintains high efficiency at lower loads resulting in substantial cost savings

# Output Performance

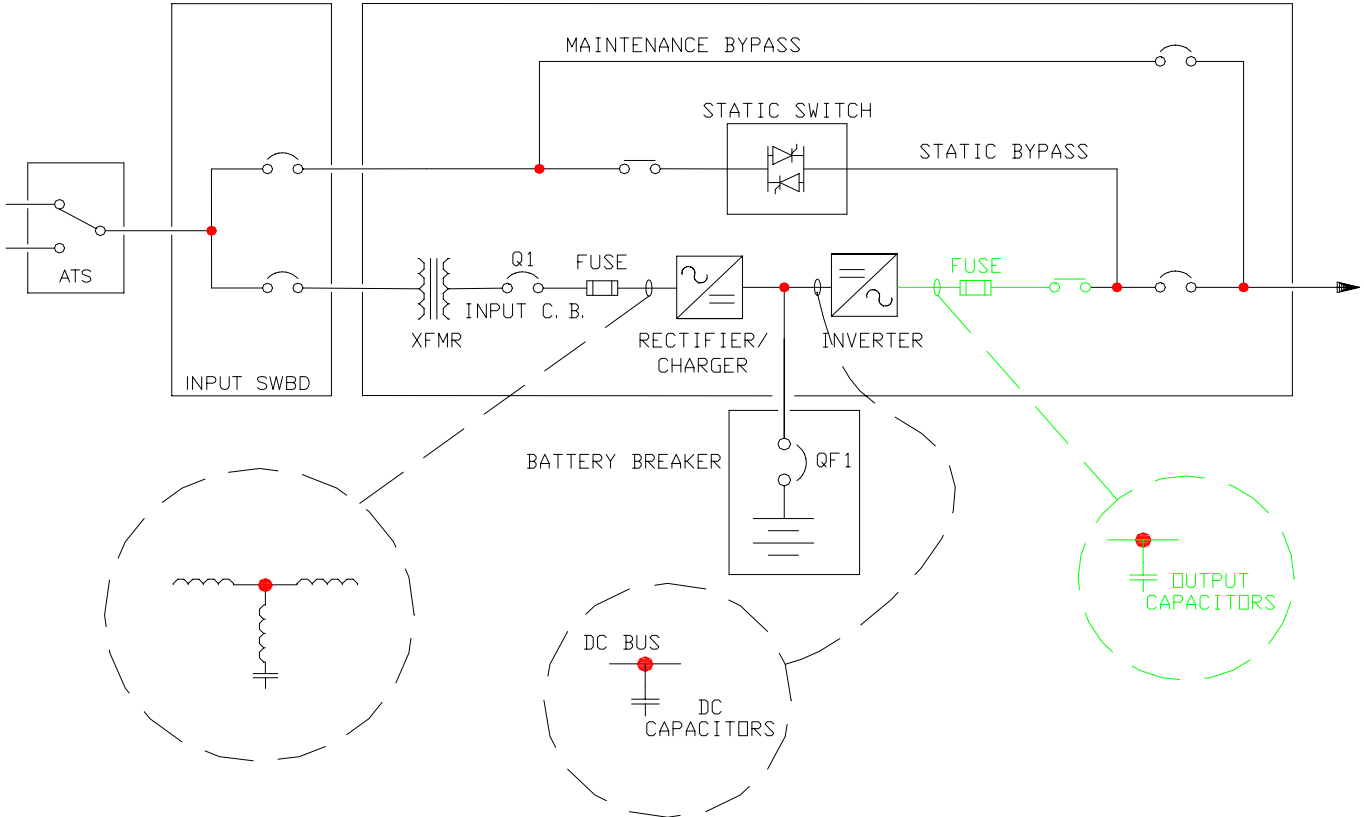
## *Fault Tolerant Circuitry*



- ▶ Dead short across the output bus will not damage the UPS
- ▶ Wiring changes on the critical bus are common today
- ▶ Other UPS will suffer fatally from output shorts

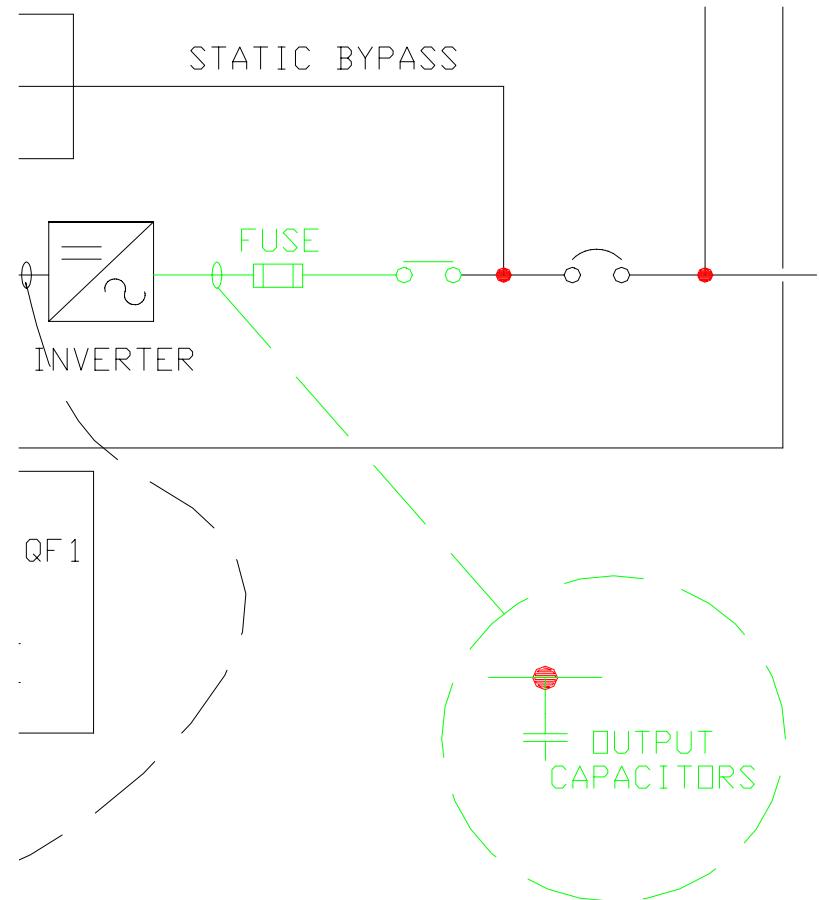


# UPS Output

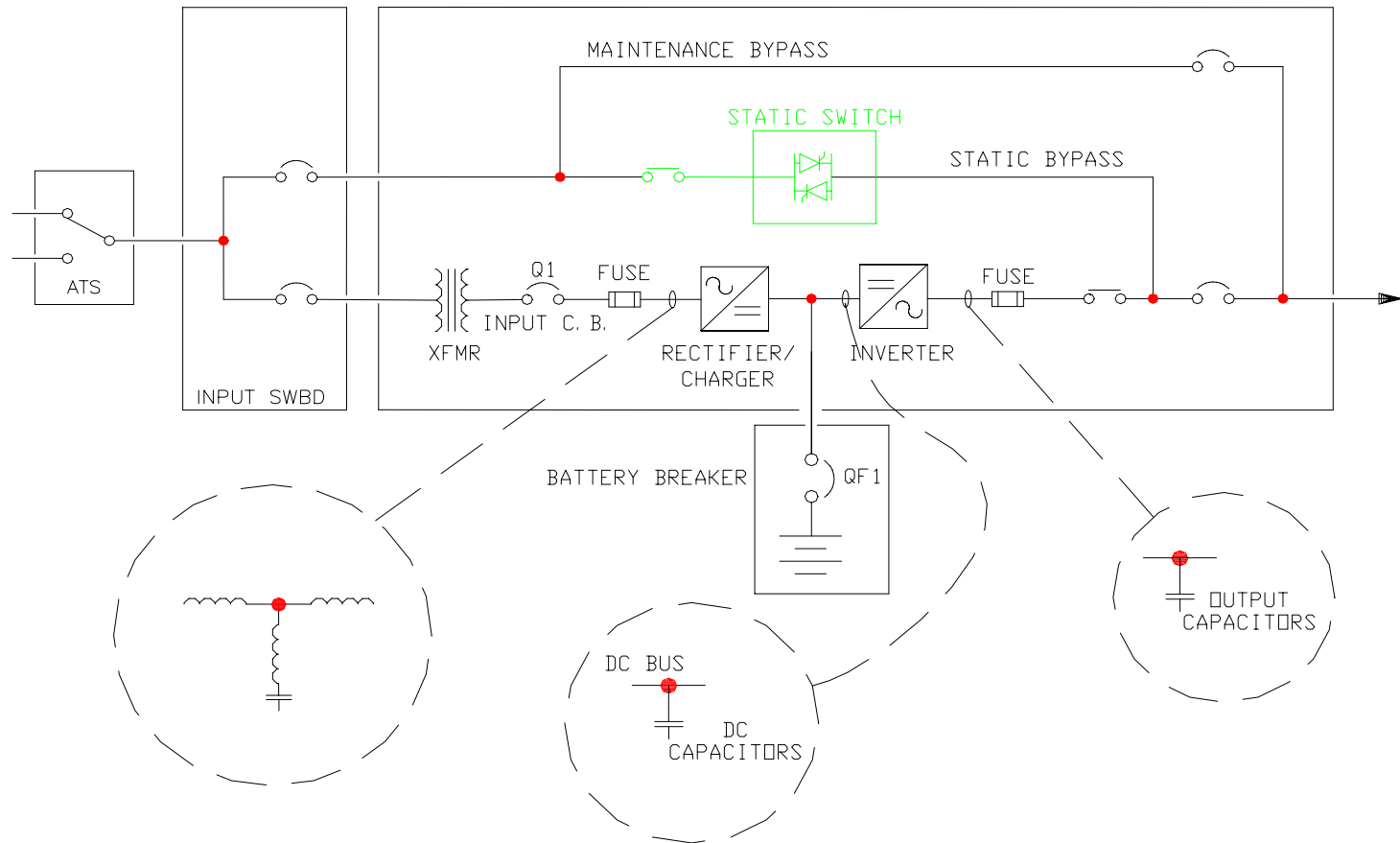


# UPS Output Components

- ▶ **Output Capacitors**
  - > Smooths output voltage waveform
  
- ▶ **Output Fuses**
  - > Fault protection
  
- ▶ **Output Disconnect**
  - > Isolates inverter from load
  - > Types
    - Contactor
    - Circuit Breaker
    - Static Switch



# Static Bypass



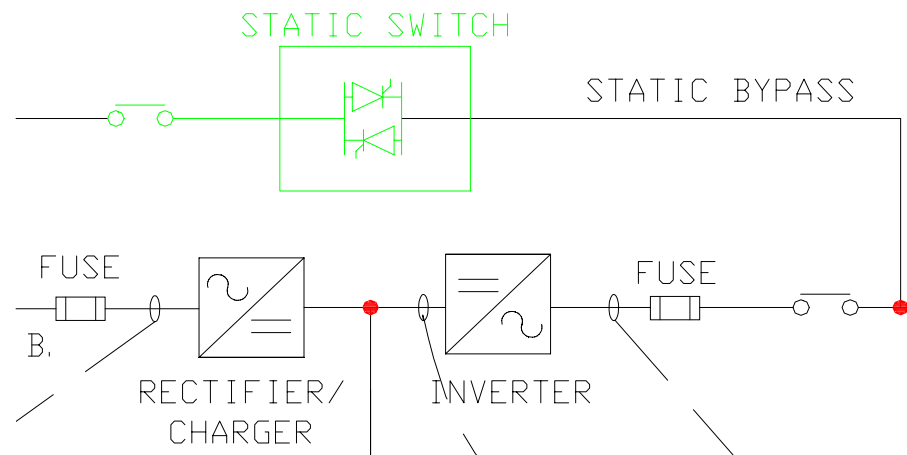
# Static Bypass Components

## ▶ Backfeed protective device

- > Required by UL

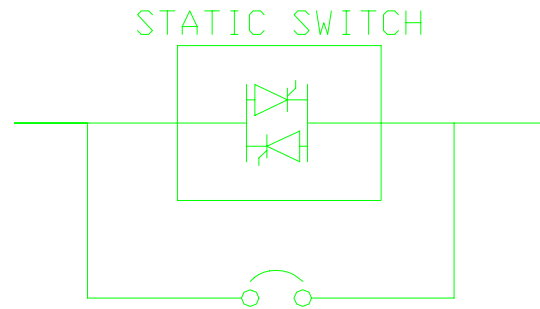
## ▶ Static Switch

- > provides “uninterrupted transfer” to utility from inverter in less than 1/4 cycle
- > provides voltage reference for inverter
- > Types
  - momentary
  - continuous



# Static Switch

## Momentary



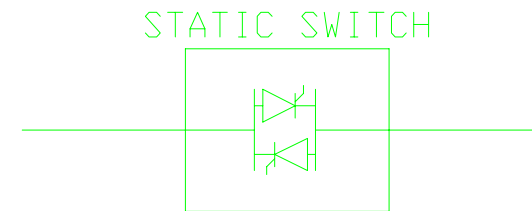
Advantages:

- Less expensive
- Smaller footprint

Disadvantages

- Less Reliability

## Continuous

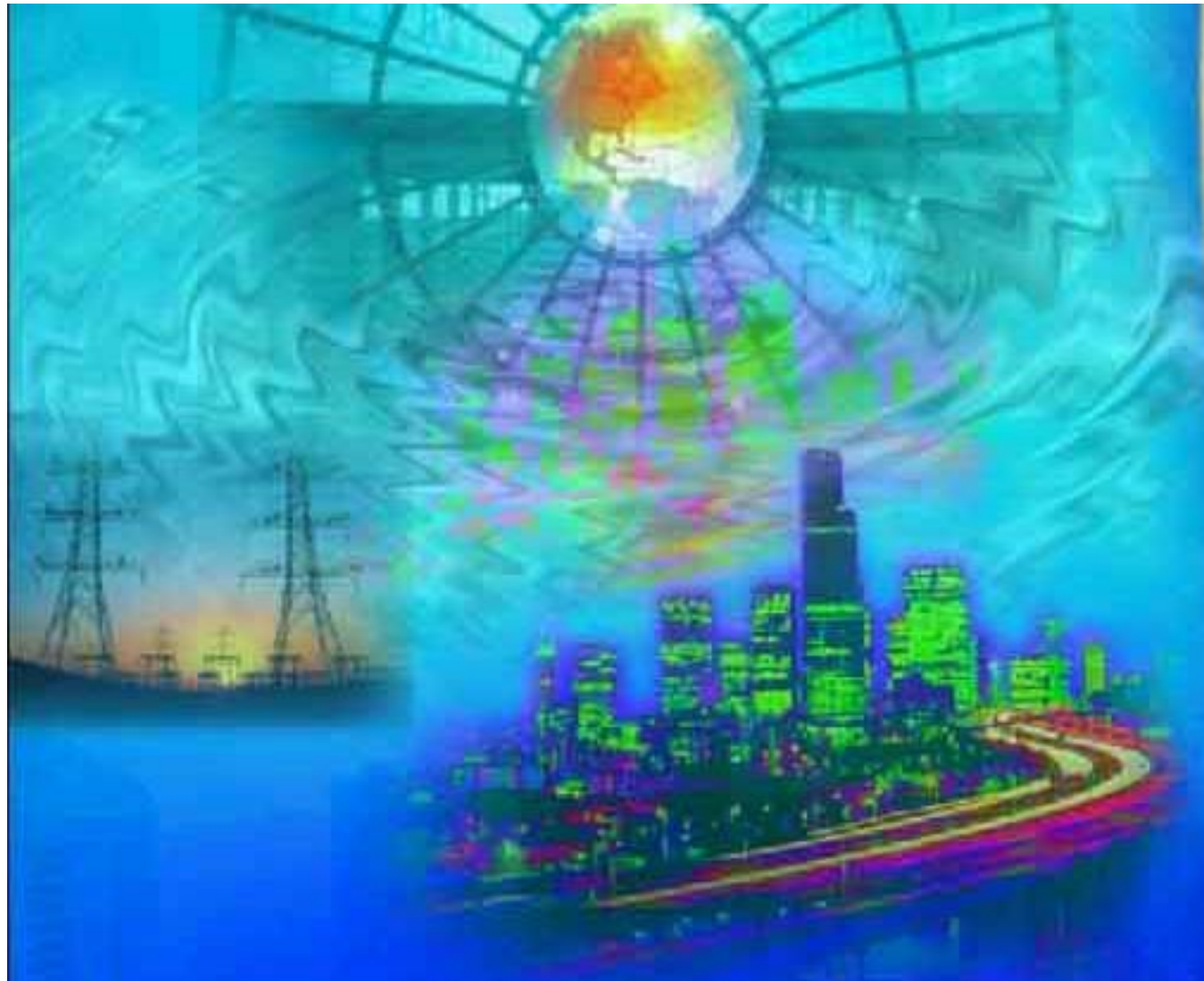


Advantages:

- Higher Reliability
- MGE Standard

Disadvantages

- More expensive
- Larger footprint



Power Systems Solutions

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[www.mgeups.com](http://www.mgeups.com)

# System Availability

“Zero Down Time” solutions

## Availability

The Availability of a UPS system is a function of the MTBF (Mean-Time-Between-Failure) and MTTR (Mean-Time-To-Repair). The MTTR of UPS Systems can range from 1/2 hour to 24 hours depending on the complexity and the self-diagnostic capability of the UPS system.

$$\text{Availability} = \text{MTBF} / (\text{MTBF} + \text{MTTR})$$

$$\text{Non-Availability} = 1 - \text{Availability}$$

<b>UPS System Configuration</b>	<b>Reliability MTBF in Hours</b>	<b>Availability</b>	<b>Non Availability</b>	<b>Mean Downtime in 5 years</b>
Single Module without Static Bypass	27,440 Hours	99.97813%	.0002187	9.58 Hrs
Single Module with Static Bypass	250,000 Hours	99.99760%	.0000240	1.05 Hrs
Shared Parallel-for-Capacity (2 Mod)	185,000 Hours	99.99567%	.0000433	1.90 Hrs
Conventional Parallel-for Capacity (2 Mod)	135,210 Hours	99.99408%	.0000591	2.59 Hrs
Shared Parallel-Redundant (2 Mod)	380,000 Hours	99.99789%	.0000210	0.92 Hrs
Conventional Parallel-Redundant (2 Mod)	345,000 Hours	99.99768%	.0000231	1.01 Hrs
Sync-Tie via Shared Paralleling (4 Mod)	190,000 Hours	99.99368%	.0000631	2.76 Hrs
Sync-Tie via Conventional Paralleling (4 Mod)	172,500 Hours	99.99304%	.0000695	3.05 Hrs
<b>Isolated Redundant/Distributed Redundant</b>	<b>498,000 Hours</b>	<b>99.99919%</b>	<b>.0000080</b>	<b>0.35 Hrs</b>

# Power Systems Design Factors

## ▶ Reliability

- how solid is the guarantee of 99.9999% uptime; reliability is a function of the quality of equipment and the configuration of the power system

## ▶ Availability

- will the system operate as required when needed (MTBF – MTTR)

## ▶ Maintainability

- can you service the system without interrupting / compromising power quality

## ▶ Expandability

- how easy will it be to add to the system

# Designing for Reliability

## *Reliability Factors*

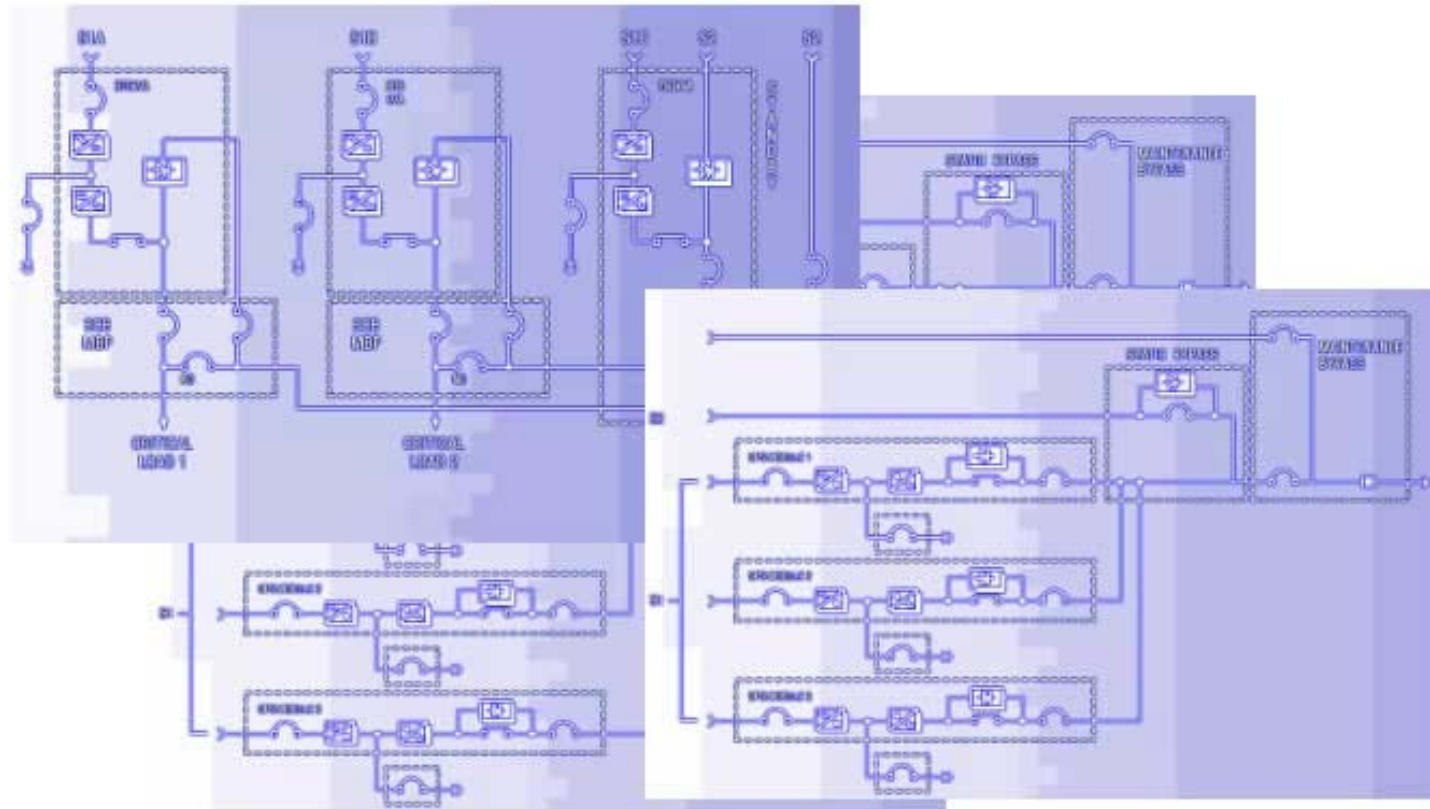
### FACTORS THAT **IMPROVE** UPS RELIABILITY

- ▶ Module redundancy
- ▶ Increased UPS bypass source reliability
- ▶ Individual battery systems
- ▶ Simplified operator interfaces and procedural safeguards
- ▶ IGBT PWM inverter technology
- ▶ Use of UL listed standard products

### FACTORS THAT **DECREASE** UPS RELIABILITY

- ▶ Complicated sync tie switchgear systems
- ▶ System controls for module paralleling
- ▶ Common battery systems
- ▶ System complexity
- ▶ Poor environmental conditions
- ▶ UPS topologies with narrow input voltage and frequency windows or topologies that switch states to remain on-line (line interactive).

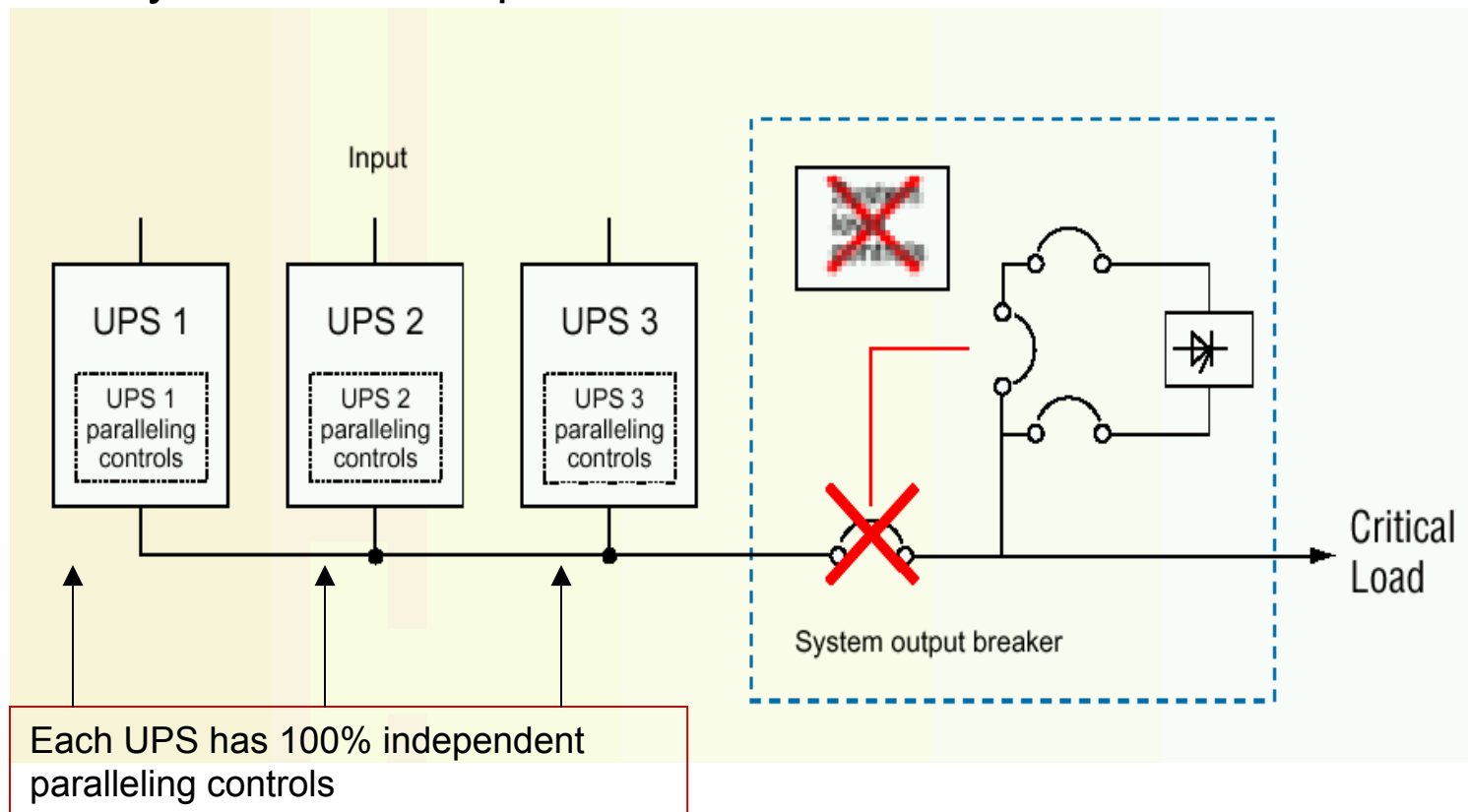
# UPS System Configurations



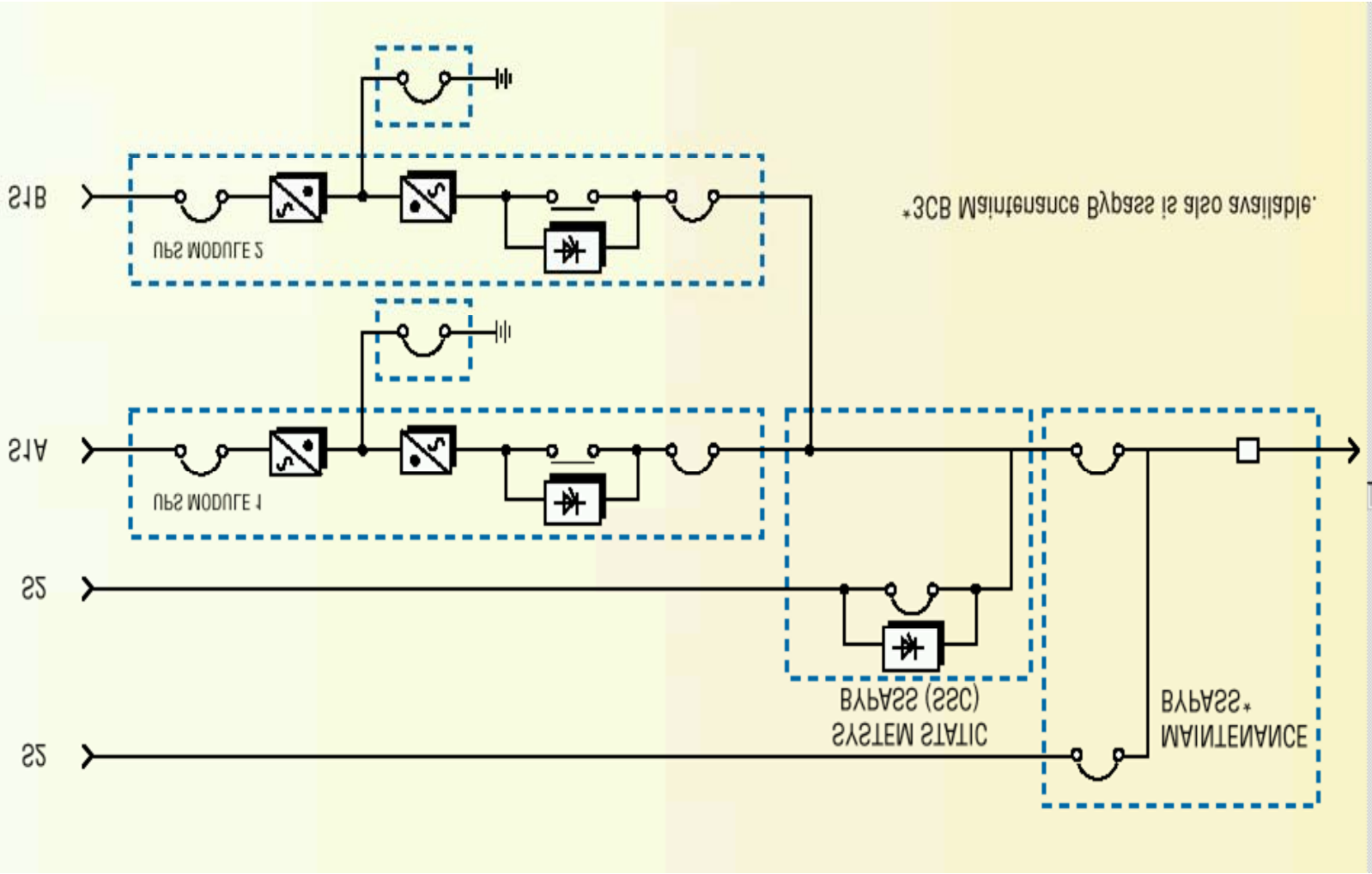
## MGE Shared Parallel Technology

*Limiting single points of failure to maximize reliability*

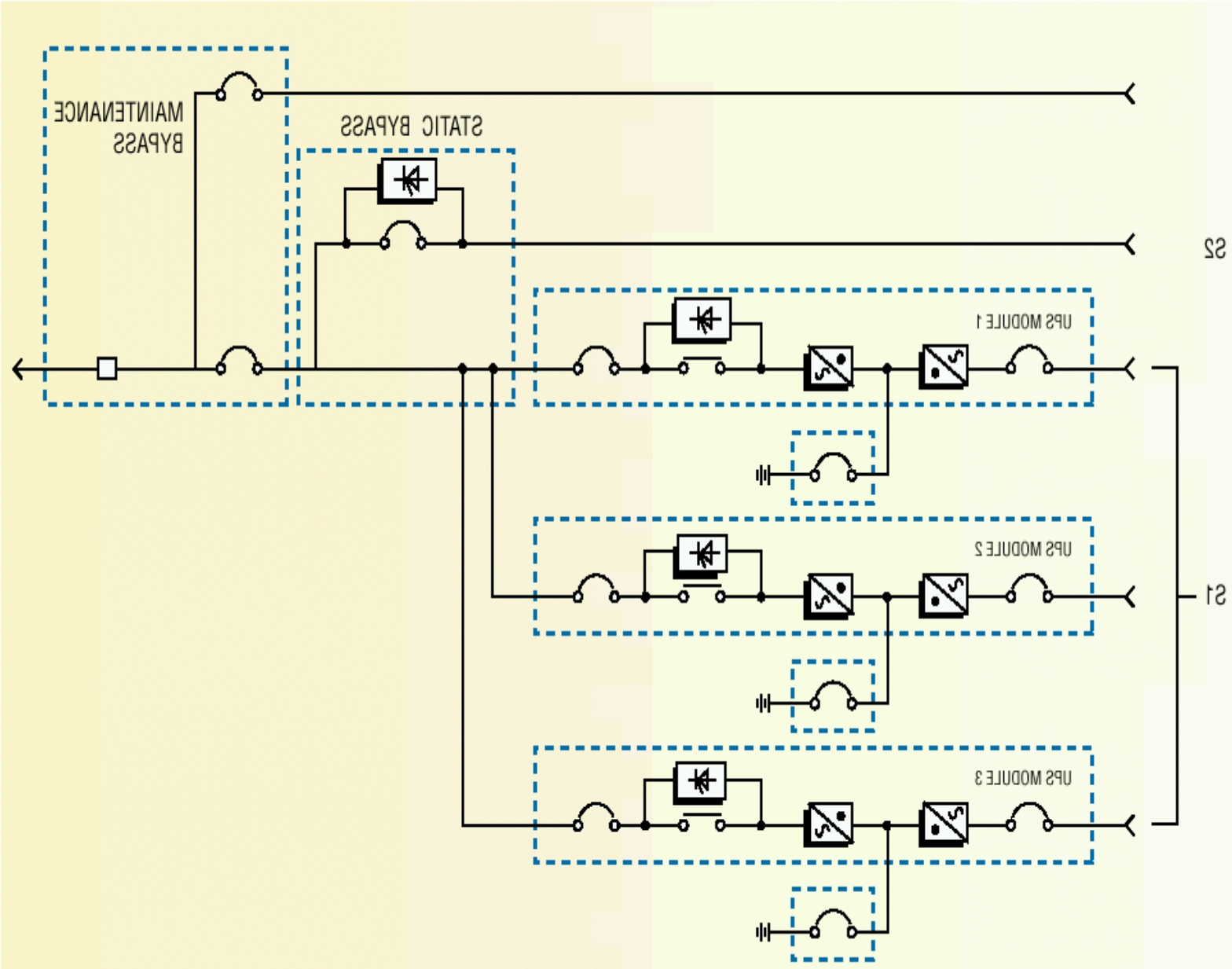
- ✓ No system level paralleling controls
- ✓ No system level output breaker



# Parallel for Capacity

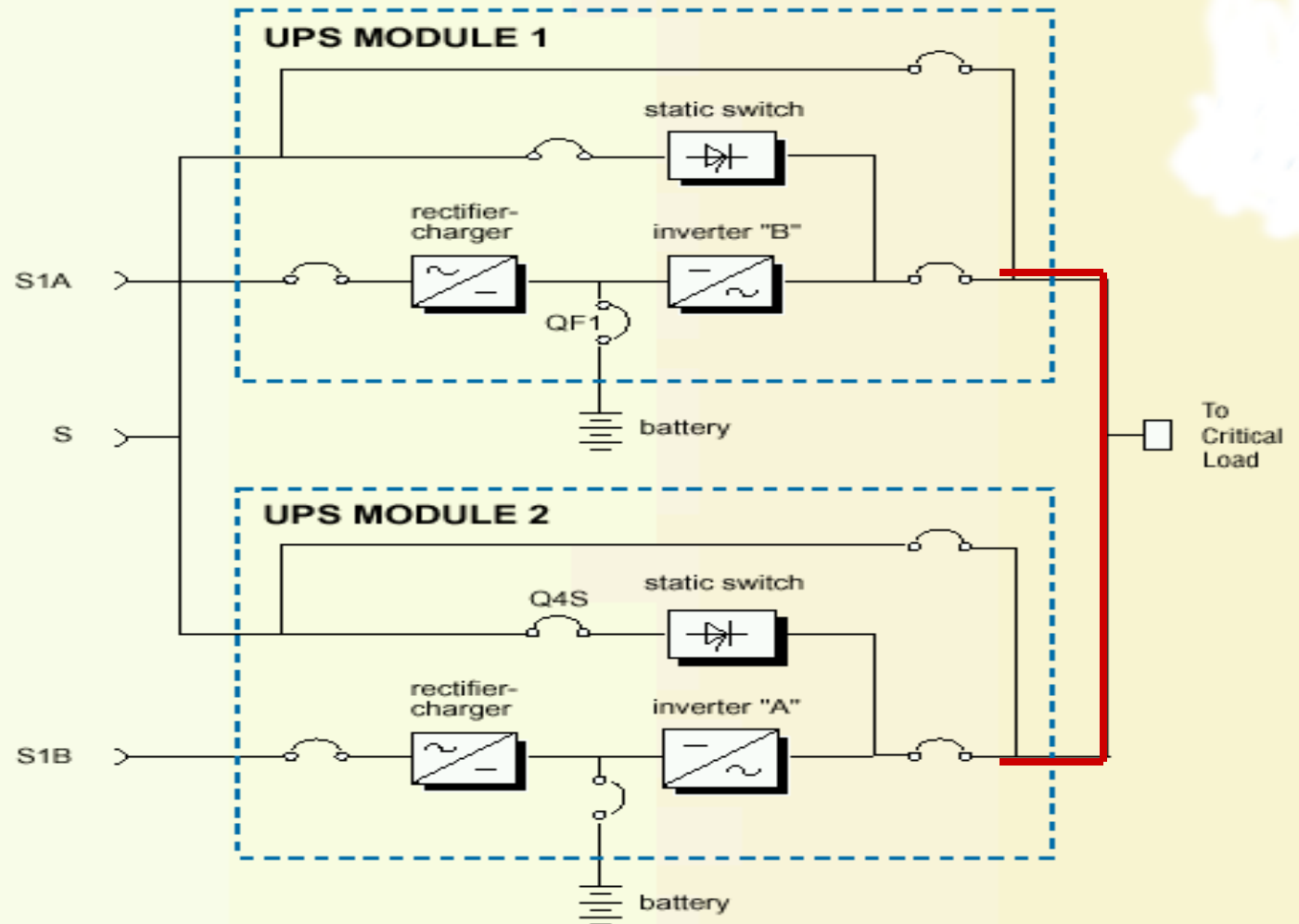


# Parallel for Redundancy



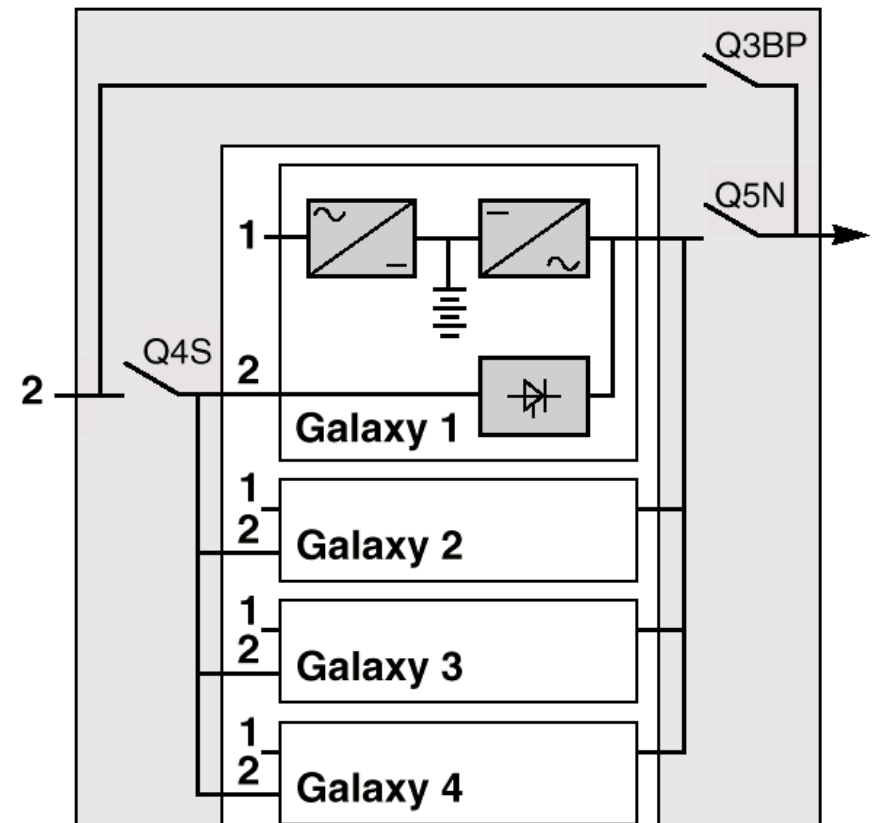
## Integrated Parallel

- ✓ Parallel for redundancy with no system static switch cabinet



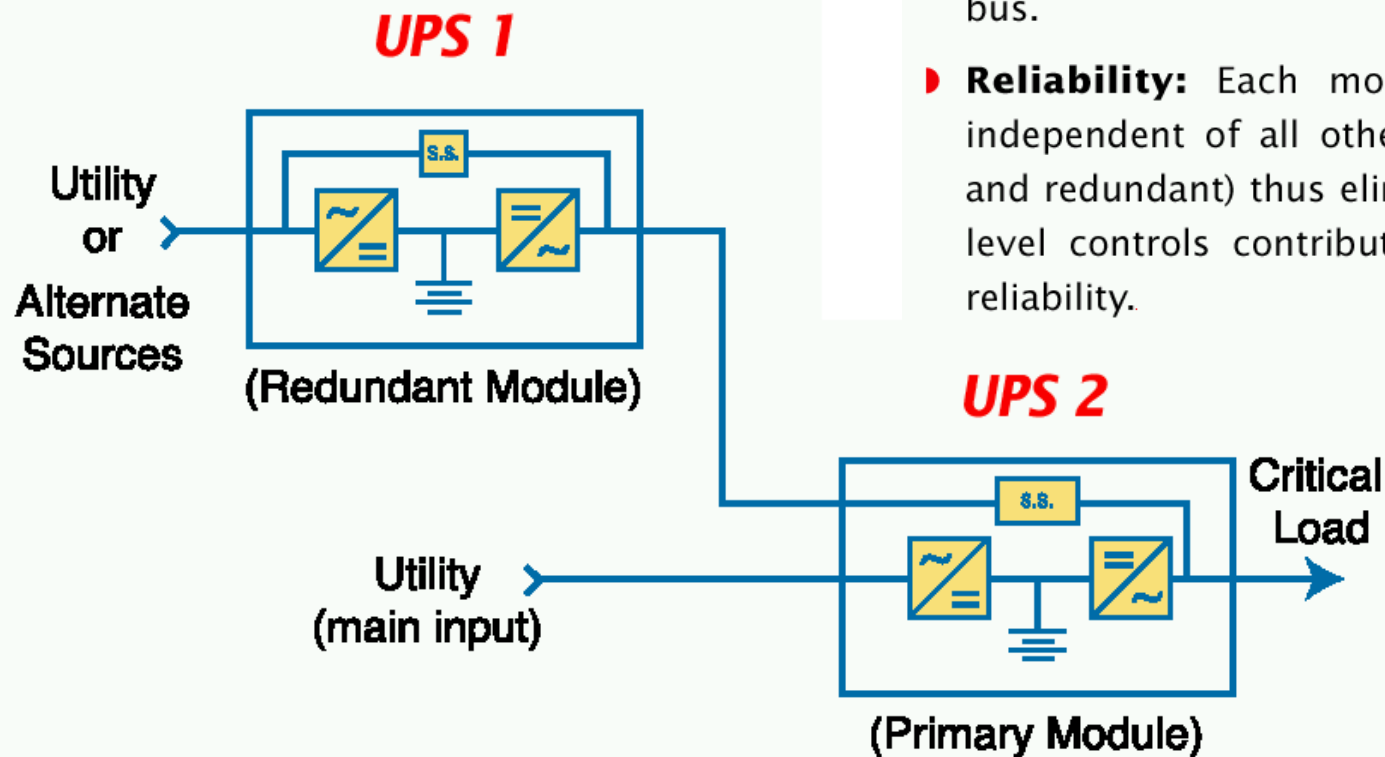
## Parallel for Capacity or Redundancy

- ▶ Up to four modules for parallel or capacity
- ▶ No SSC required!
- ▶ Expand on an as needed basis.



# Isolated Redundant

- ▶ **Availability:** Should the primary module go off-line, power is seamlessly transferred to the redundant system.
- ▶ **Maintainability:** The primary module and the redundant module are provided with a maintenance bypass allowing complete isolation for maintenance while maintaining conditioned UPS power to the critical load bus.
- ▶ **Reliability:** Each module's operation is independent of all other modules (primary and redundant) thus eliminating any system level controls contributing to unsurpassed reliability.

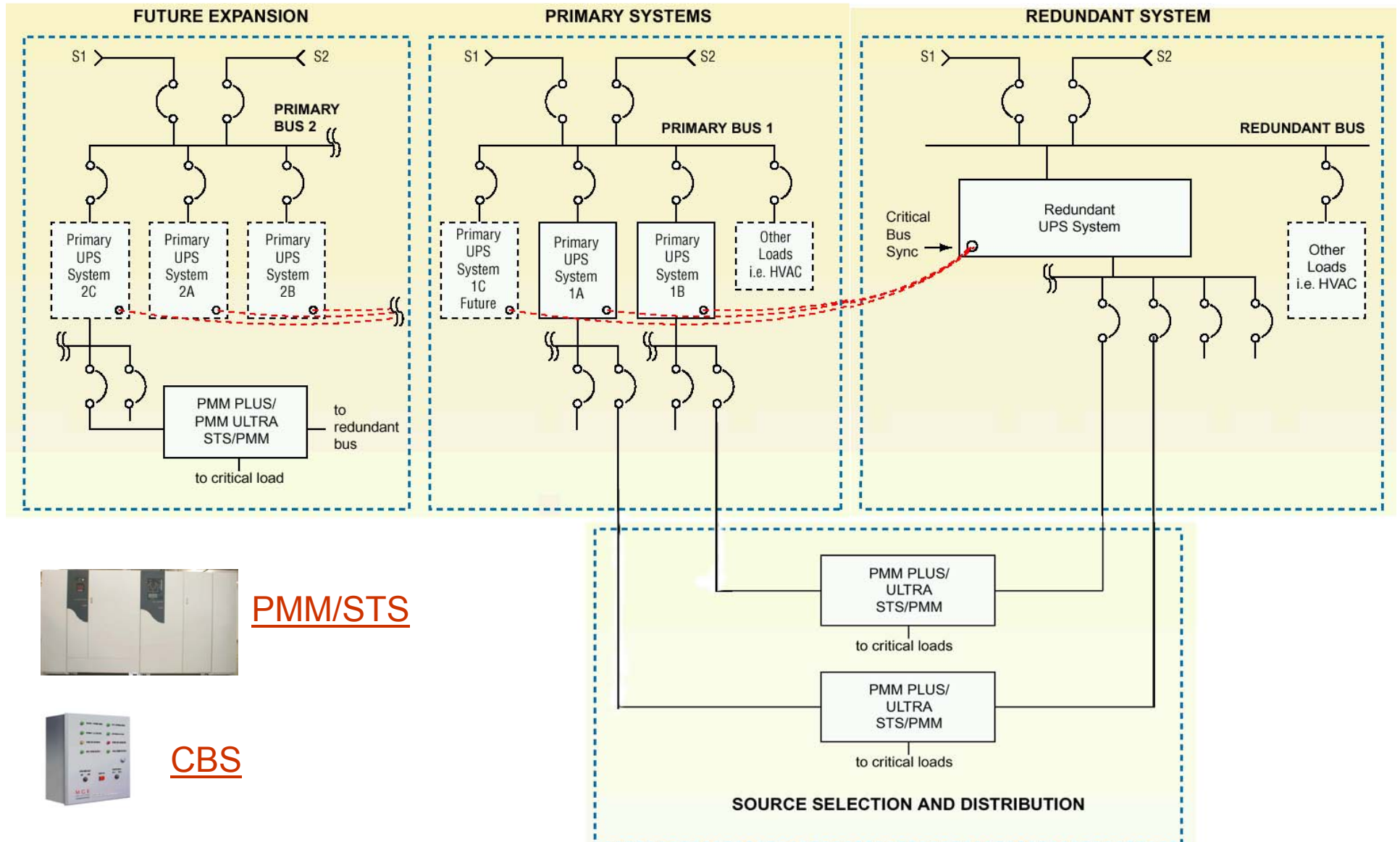


## Benefits of Isolated Redundant

### Unique advantages of isolated-redundant systems:

- ▶ Mix & match module kVA sizes
- ▶ Mix and match new & existing modules, technologies and manufacturers
- ▶ Modules can be in separate rooms
- ▶ Perform maintenance on each system without exposing the load to utility power
- ▶ Better protection against operator errors
- ▶ Smaller footprint
- ▶ No control circuitry interconnection between modules
- ▶ Smaller load bank requirements
- ▶ Sequential installation & start-up
- ▶ Higher operating efficiencies and reliability
- ▶ No single point of failure
- ▶ Multi level redundancy
- ▶ Lower system cost
- ▶ Maximum overall system reliability/lowest MTBF.

# Distributed Redundant

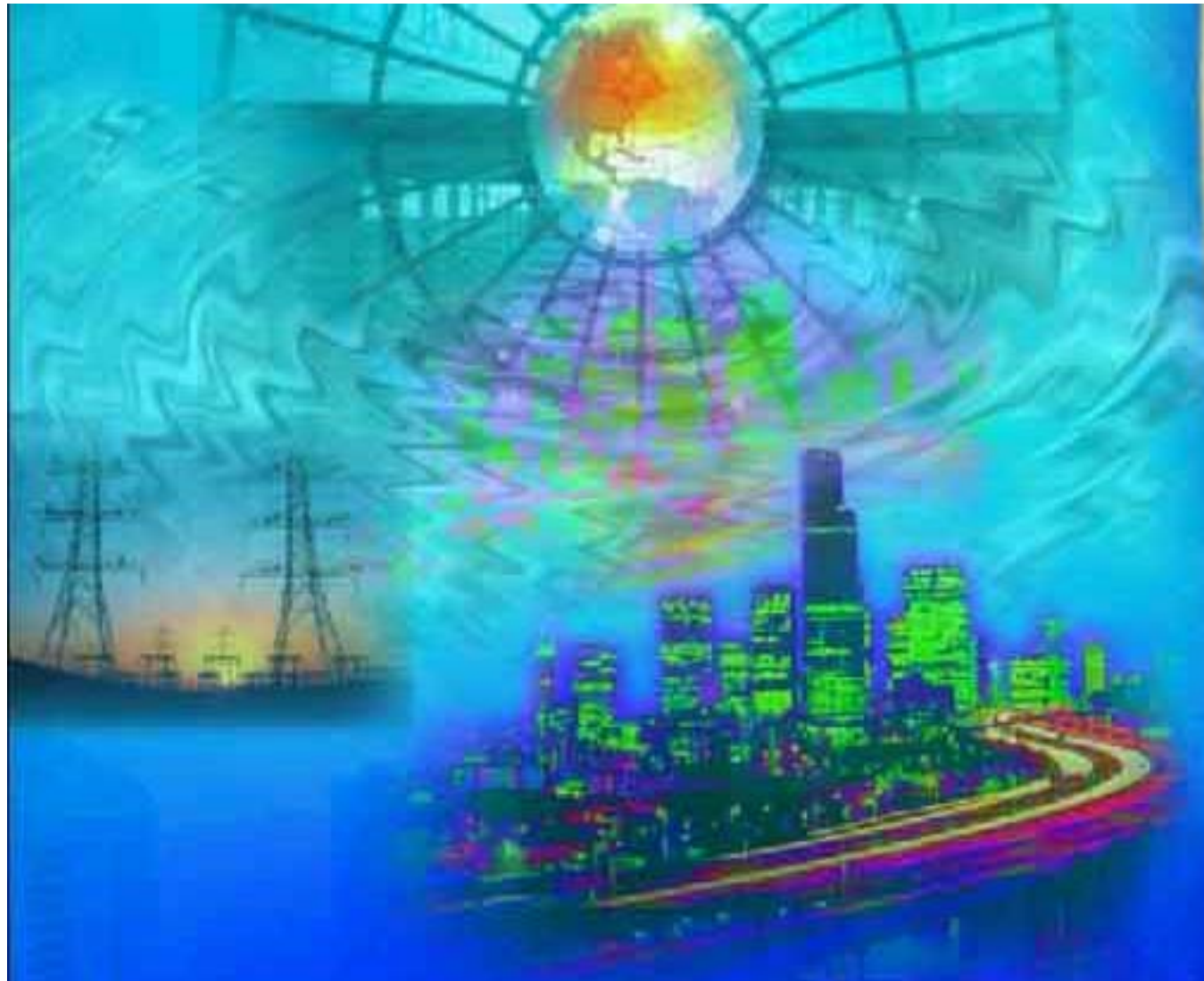


# Distributed Redundant Advantages

## Advantages of Distributed-Redundant Systems:

- ▶ **Availability:** Availability is accomplished by the static transfer switch (STS). Shutdown of the primary UPS or any deviation in power quality will cause an uninterrupted transfer to the redundant system.
- ▶ **Maintainability:** The availability of a distributed redundant system allows complete isolation of the primary bus for maintenance by seamlessly transferring the load via the static transfer switch (STS) to the redundant system.
- ▶ **Reliability:** Similar to an isolated redundant system, each module operates independently of all other modules (primary and redundant) eliminating any system level controls and optimizing reliability.
- ▶ **Expandability:** Primary busses can be added to expand the power demand without impacting the existing primary busses or the redundant bus since all are independent. This allows the system to expand on an as needed basis.

***EXPANDABILITY!***



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