National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

**Workshop on High Megawatt Electronics:**
**Technology Roadmap Workshop for Increased Power Electronic Grid Applications and Devices**
**May 24, 2012**

# Power Conversion System Architectures

## For Grid Tied Energy Storage

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DYNAPOWER COMPANY

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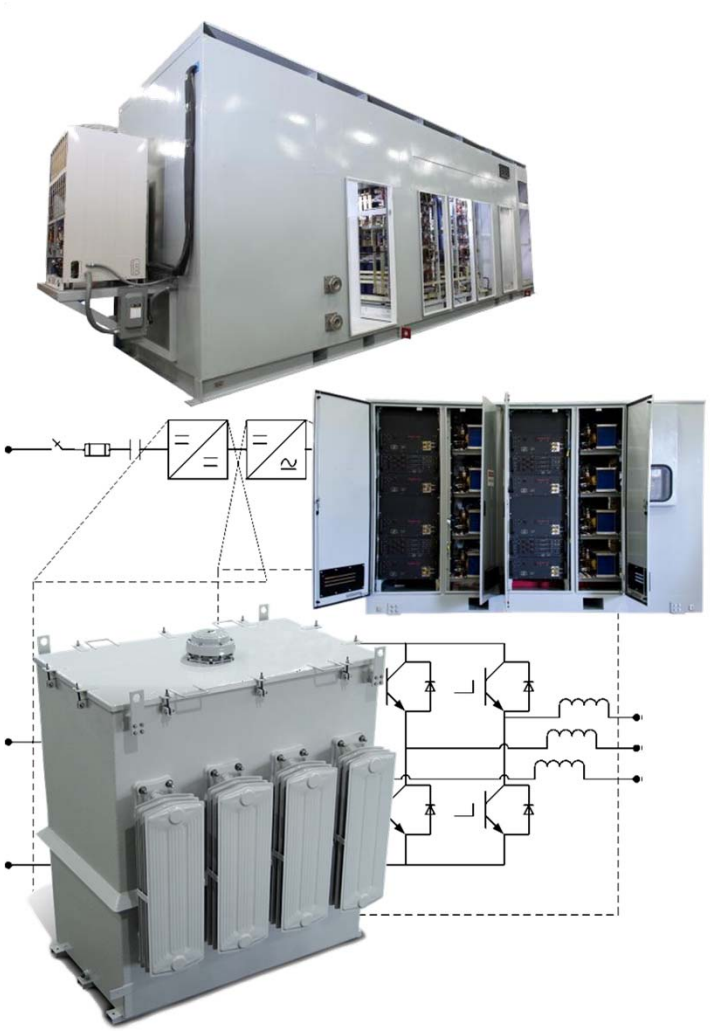
# Outline



1. Power Conversion System (PCS)
   - Overview and Purpose
2. Conversion Topologies
   - Single Stage three-legged IGBT based inverters
   - Multi-stage converters
   - Inverter Operation
   - Advanced Topologies
     - Multi-level inverters
     - Z-inverters
   - Multiple Module Topologies
3. Application Topics
   - Increasing Power Levels
     - Line Commutated Inverters
   - Islanding methods
   - Phase Configuration
   - Transformers for Energy Storage Systems (ESS)
- Output power compliance

# PCS Overview and Purpose

Grid Tied Energy Storage mediums are predominately direct current (DC) in nature. To effectively utilize the energy storage capacity on the present electric utility grid, the energy must be converted to a standard Alternating Current (AC) level and regulated through a converter.

Converter Purpose and Control:

- Bi-directional conversion from AC to DC and DC to AC.
- AC Grid to DC Storage isolation and protection
- Interconnection and control of multiple DC Sources
- Regulated, stable and controllable power flow

Control Modes

- AC current (P,Q) – Standard Grid Tied Operation
- AC Voltage (V,F) – Islanded Operation
- DC current ($I_{DC}$) – Grid Tied, Battery Charge/Formation
- DC Voltage ($V_{DC}$) – Grid Tied, Battery Conditioning

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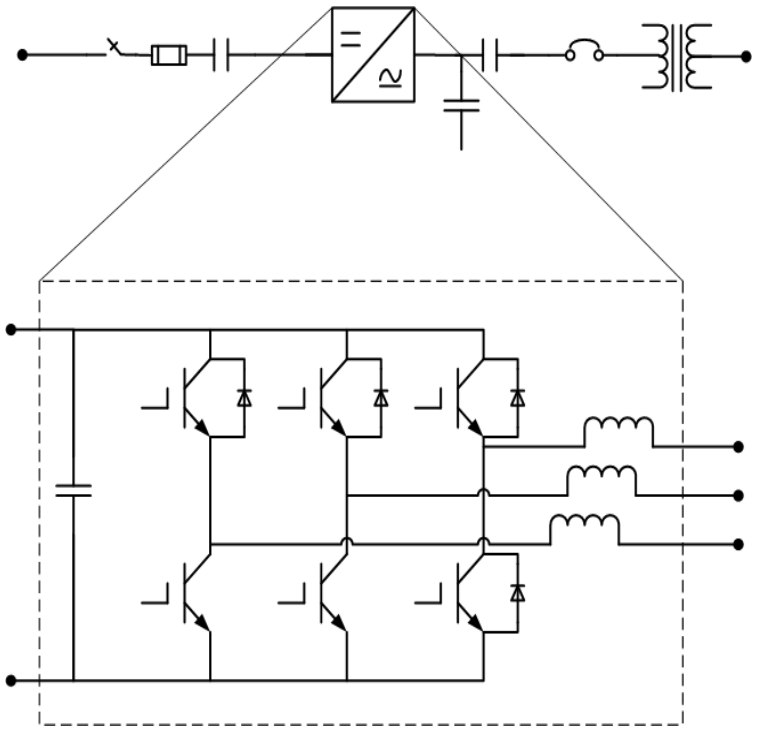
# Basic AC/DC Power Conversion Topologies

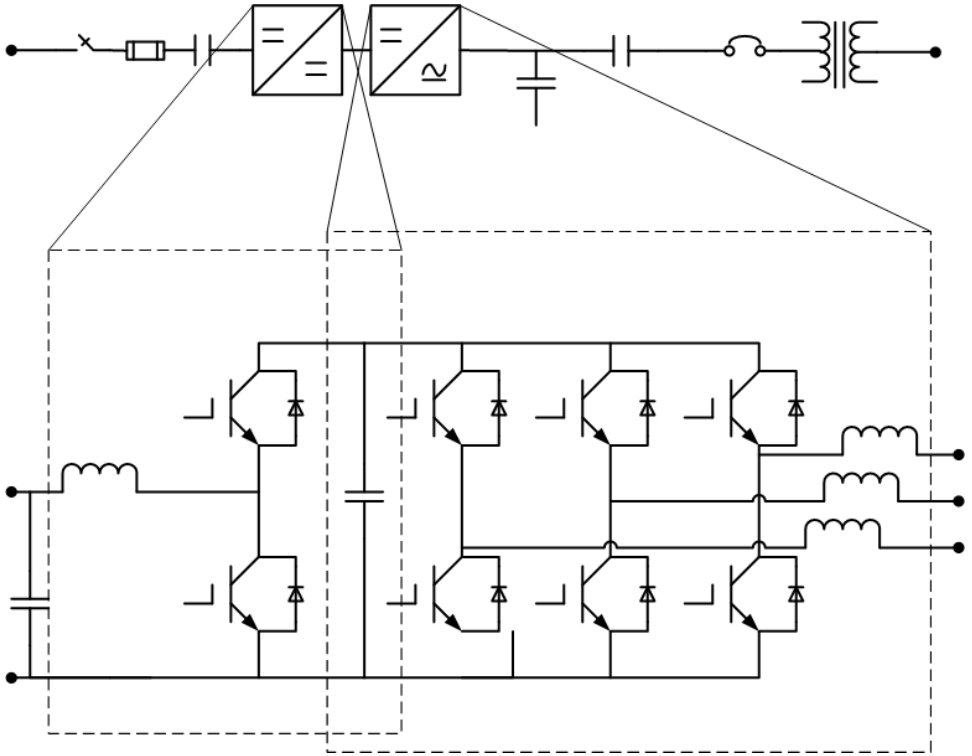
## Single Stage Converters

- Limited to DC Voltages > 1.5X $VAC_{RMS}$
- Maximum Efficiency



## Multi-Stage Converters

- Maximum DC Voltage Range
- Increased Losses
- Increased hardware Cost



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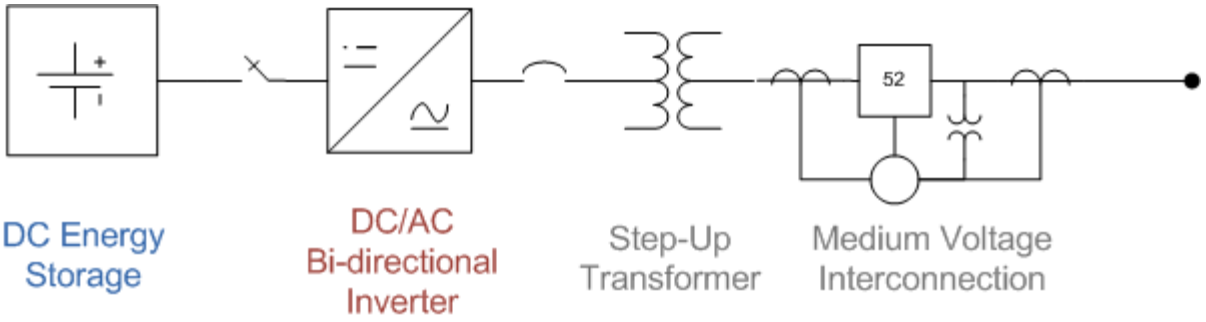
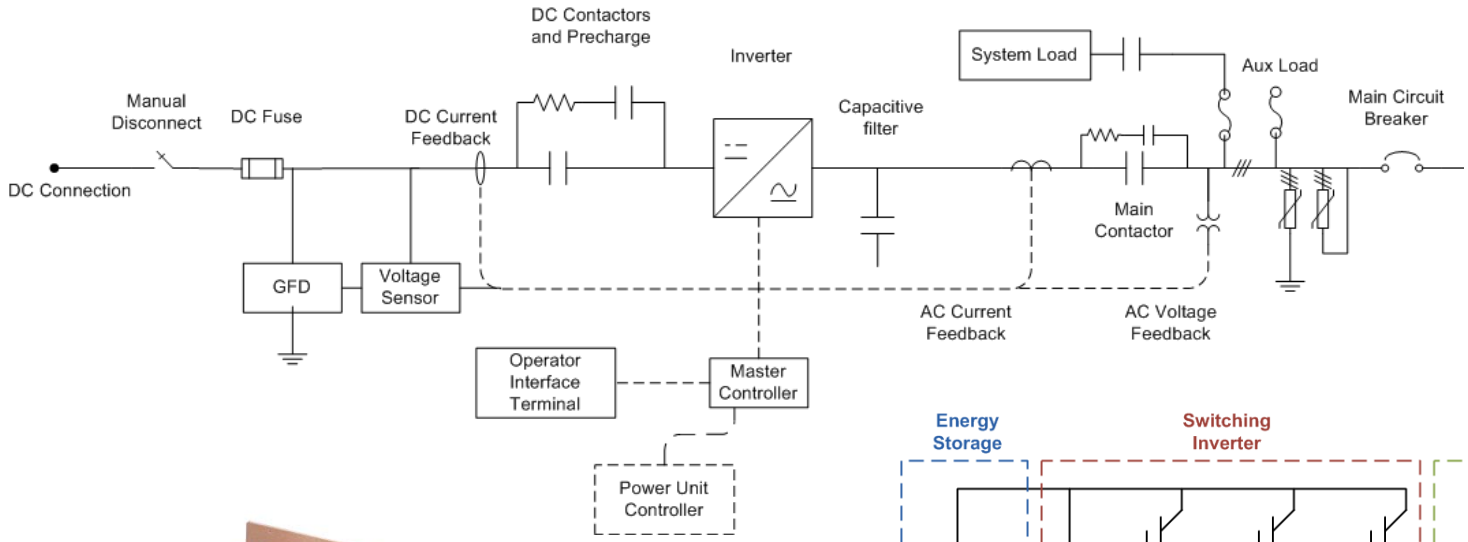
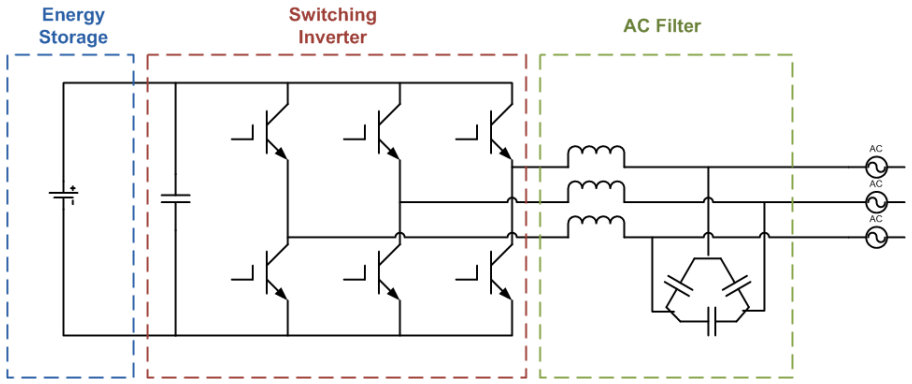
# Single Stage Inverter

## Primary Sub-Sections

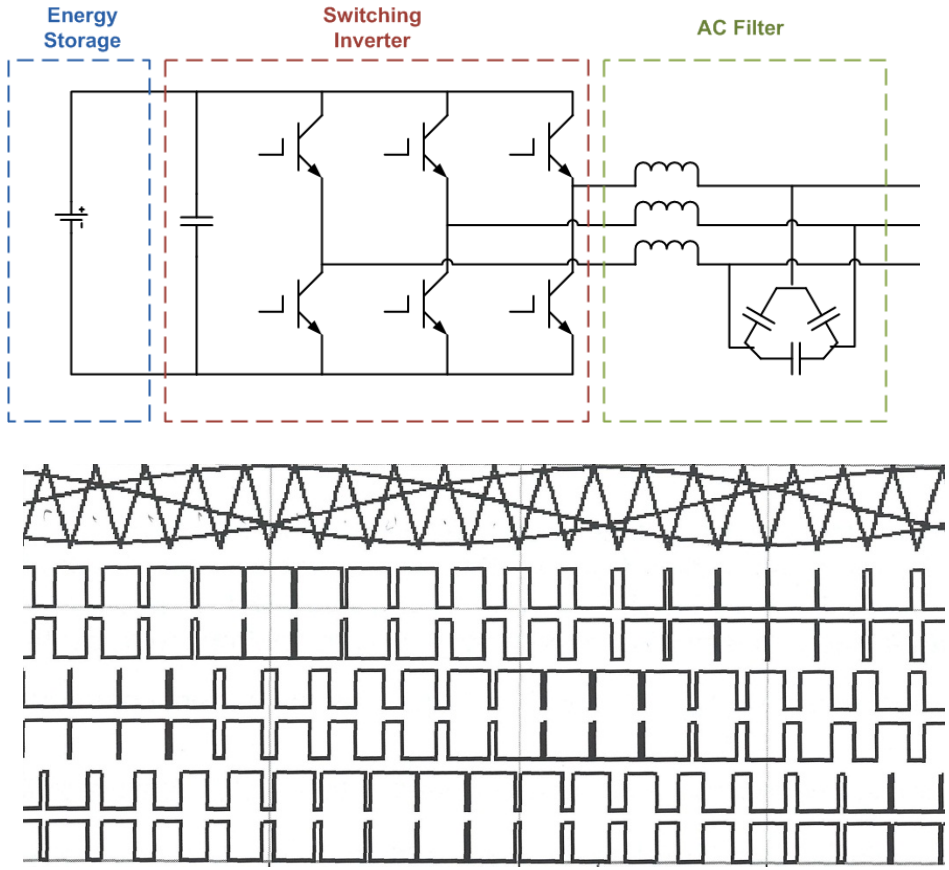



# Basic Inverter Operation

- Operation
  - Sinusoidal Pulse Width Modulation
  - Phase locked to Grid
  - Reference signal provided to compare with triangle waveform
  - Gates are triggered as output of controller
  - Modulation is provided to control power
  - Output is filtered to provide limited harmonics/switching noise



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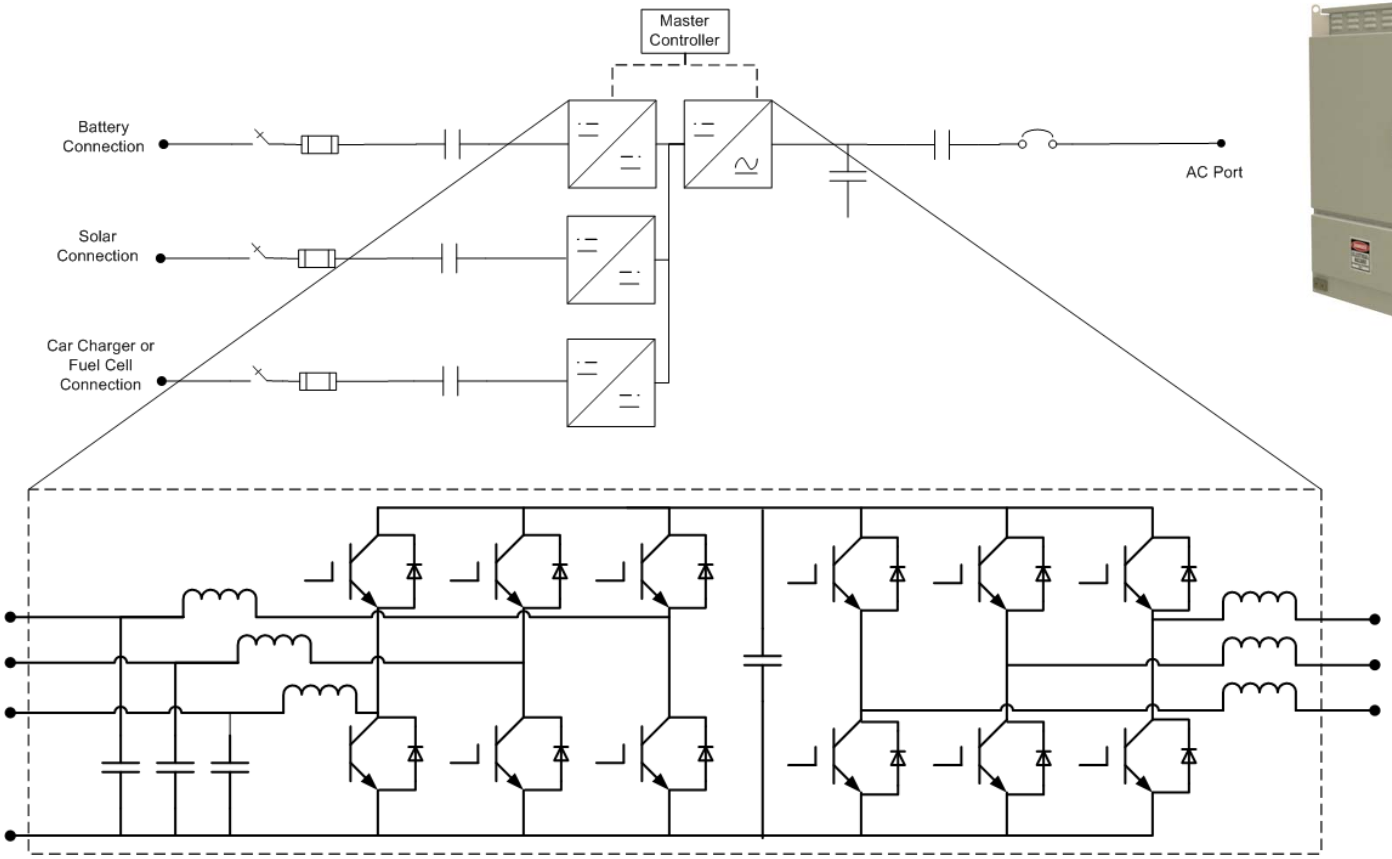
# Advanced AC/DC Power Conversion Topologies

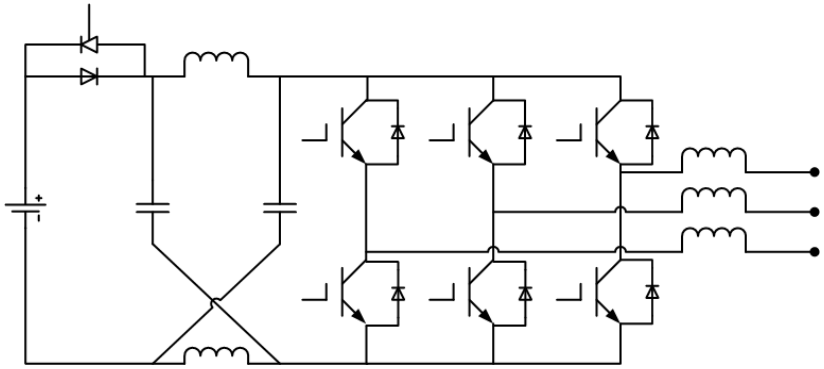
- Multi-Port, Multi-Stage Converter
  - Optimized for renewable integration with energy Storage

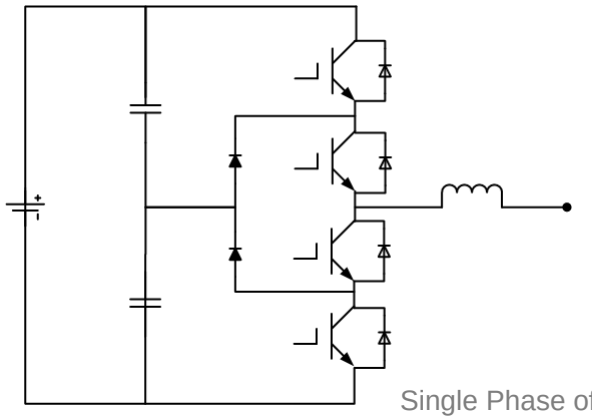



# Other Advanced Inverter Topologies

- Z-inverter
  - Accommodates reduced DC voltages (boost DC > AC)
  - Inherently protected by limiting DC current
- Multi-level inverters
  - Increased DC and AC voltages
  - Reduced Losses
  - Reduced Harmonics, smaller filters
  - Requires special $V_{iso}$ IGBTS

(Diode Clamped, Flying Capacitor and Cascade Multi-Level Cell)





Single Phase of
Diode Clamped
Three Level Inverter

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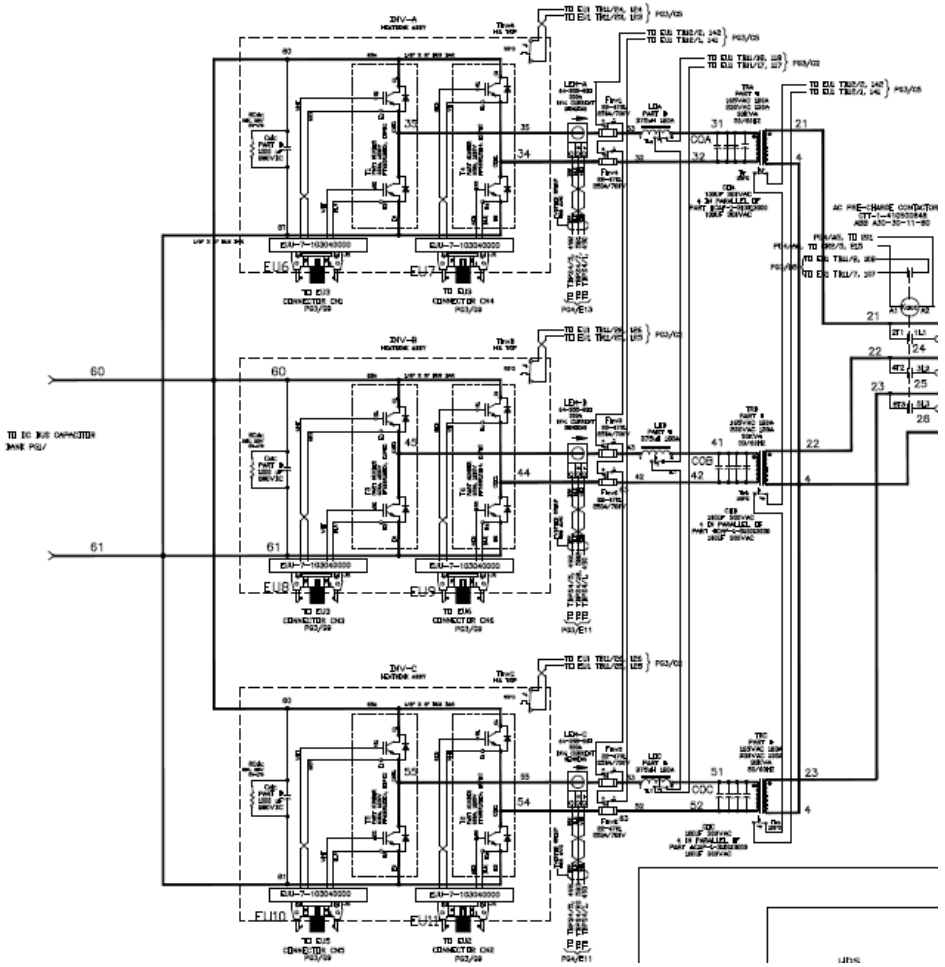
# Independent Phase Control Systems

- Independent Phase control
  - 240 VAC Split Phase
  - Three Phase systems
  - Grid Stabilization and Balancing
  - Single or independent Battery strings



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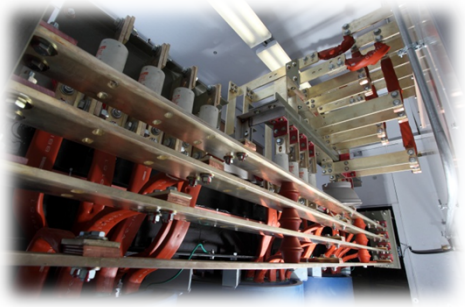
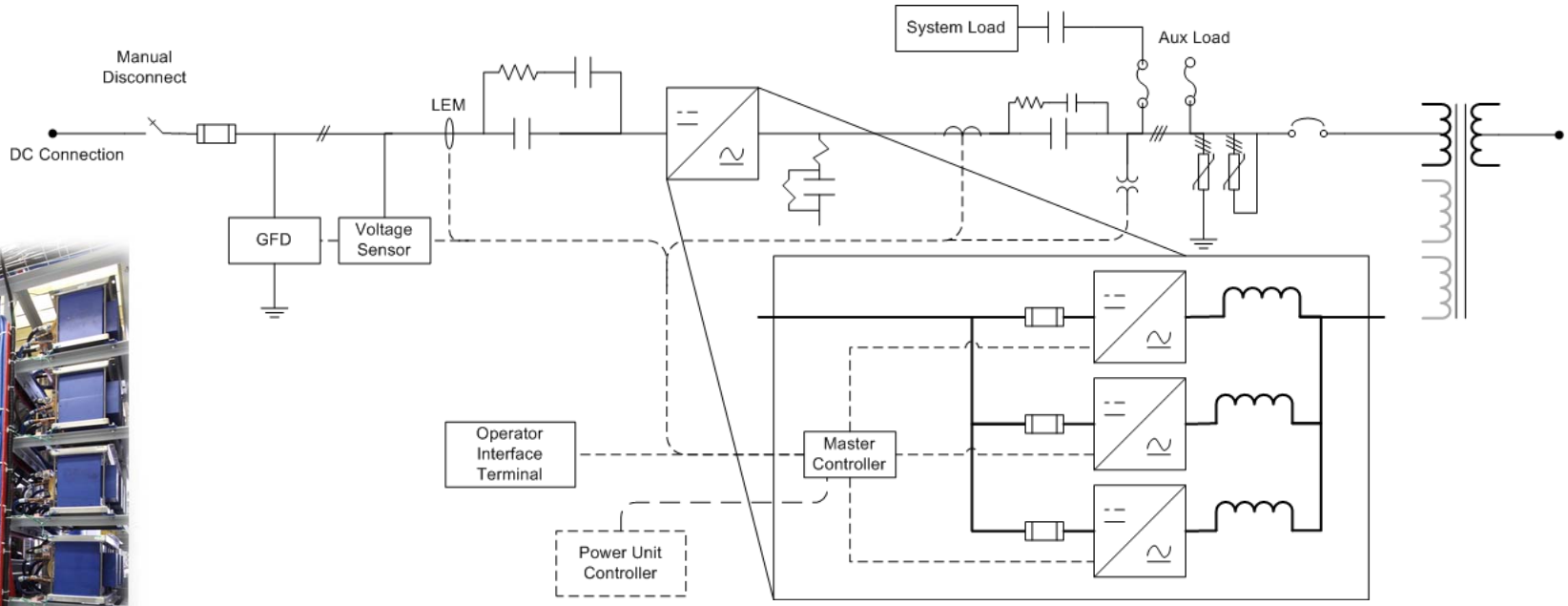
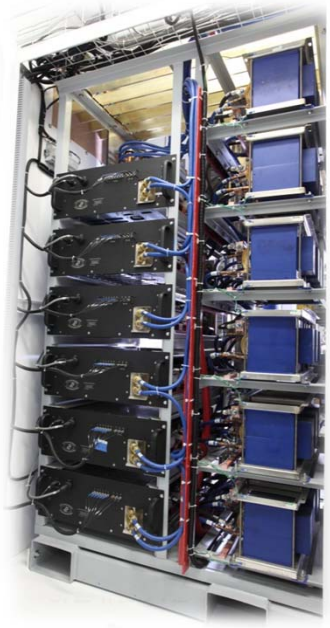
# Multiple Module Topology

- For Multi-MegaWatt Systems
- Redundant Parallel N+1 Configurations
- Synchronous and Interleaved Switching
- Independent Battery Strings





# Increasing Power Levels for ESS

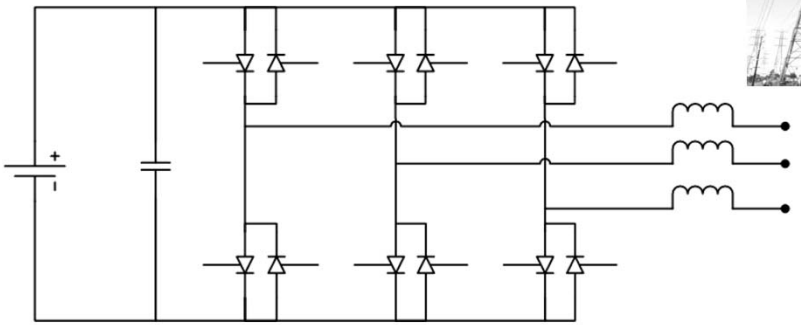
**Parallel, Multi-module IGBT based Inverter Systems**

- Sub-Cycle response
- True 4 quadrant operation
- Low harmonic levels

**Thyristor Based Line Commutated (Cycloconverter) Systems**

- Reduced cost per $/MW
- Limited power factor control
- Large AC Filters Required
- Increased Response Time
- Hybrid Systems

1.5MW Inverters installed at Xtreme Power BESS in Hawaii



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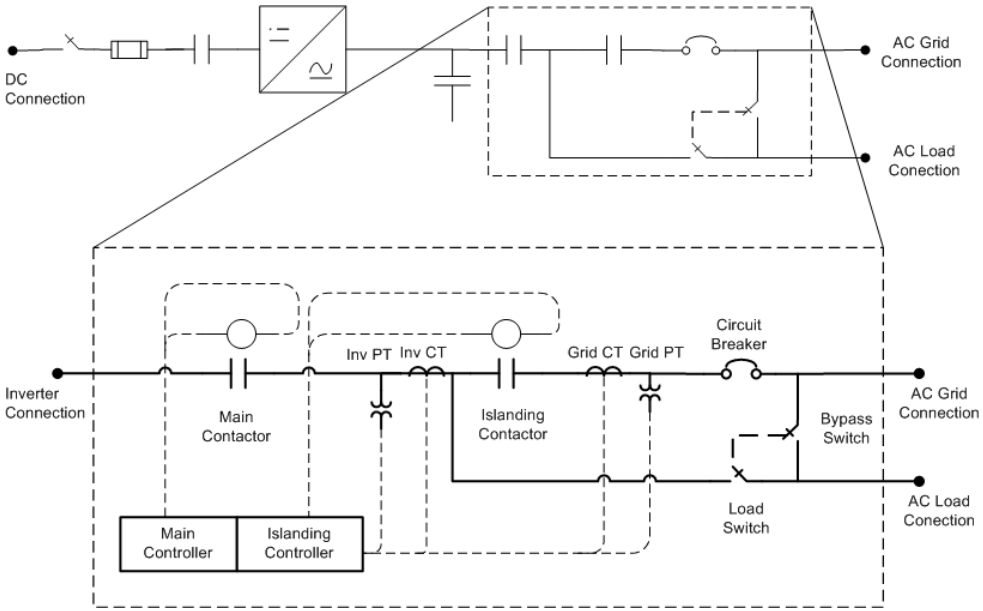
# ESS Islanding Methods

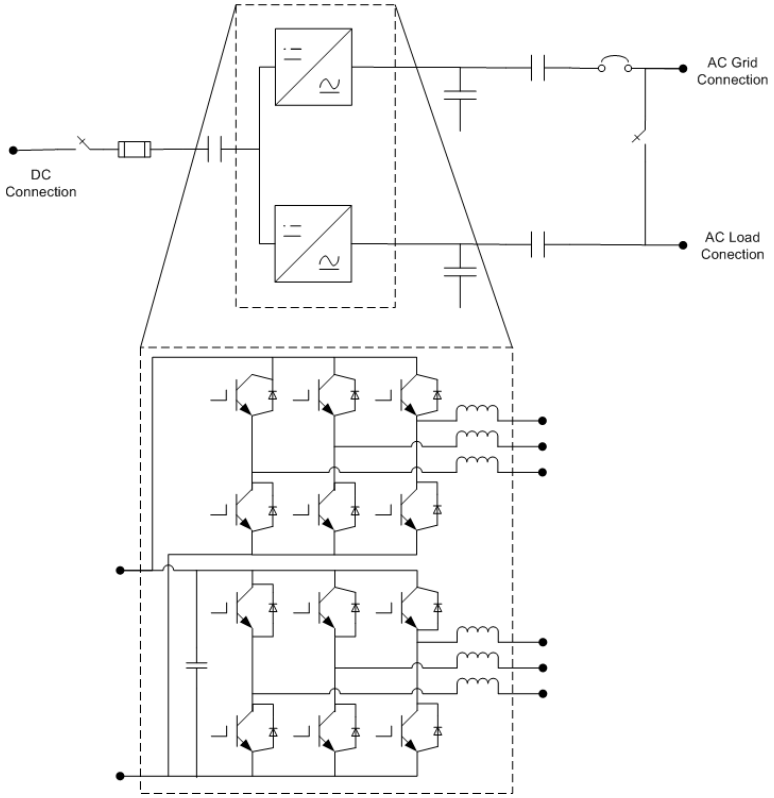
## Offline ESS with Dynamic Transfer (Islanding)

- Maximum Efficiency
- Minimum components
- Minimum Losses




## Online Double Conversion

- Limited to PCS Power to load
- 2X conversion losses
- Increased Complexity



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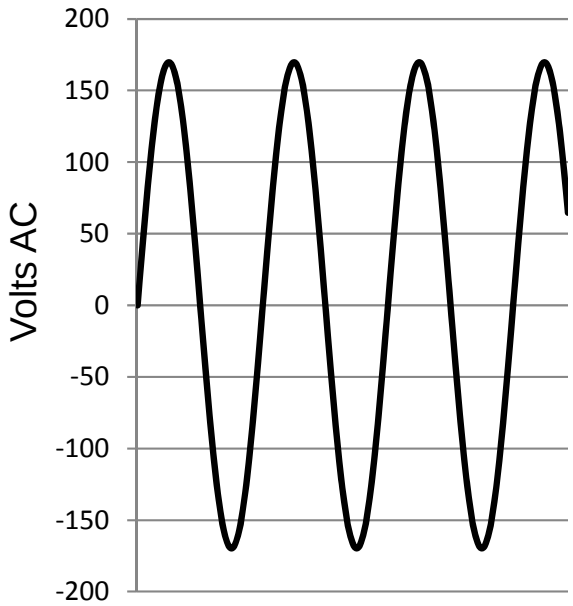
# Phase Configuration

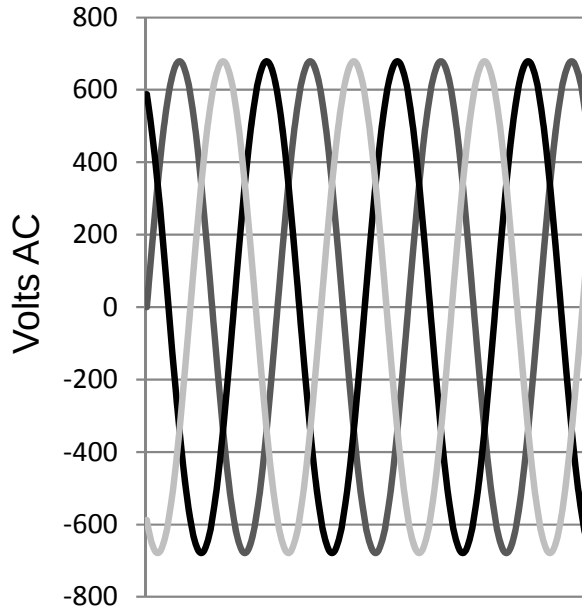
## Single Phase Systems

- Simple topology and control
- Low Power & Voltage
- High DC ripple voltage/current or increased filtering required
- Higher semiconductor current




## Three Phase Systems

- Simple integration to Utility Grid
- Medium to High Power
- Reduced DC Ripple voltage/current
- Lower semiconductor current



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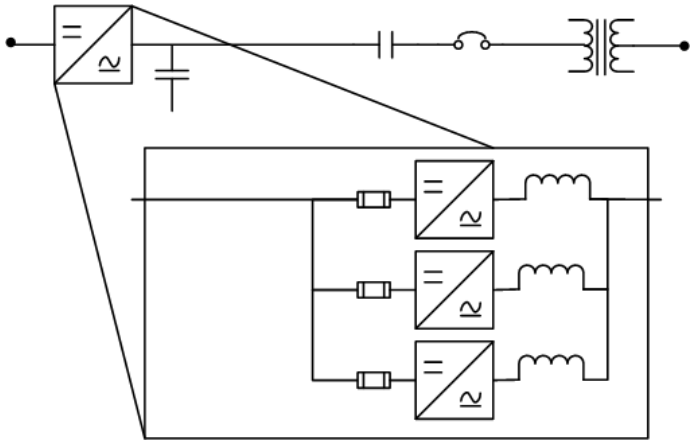
# Transformers for ESS

## Types of Transformers

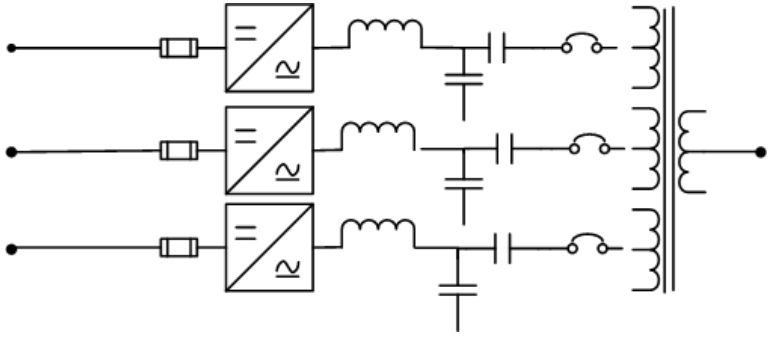
- Vacuum Pressure Impregnated (VPI)
- Oil Immersed
- Cast Coil

## Transformer Configurations

- Single winding



- Multiple LV Windings



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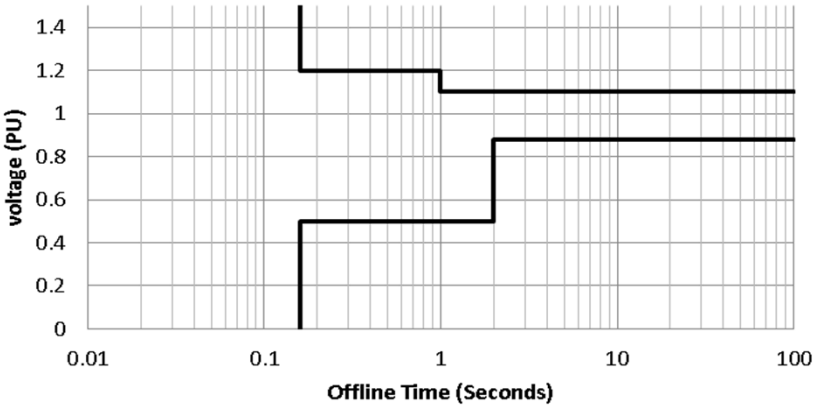
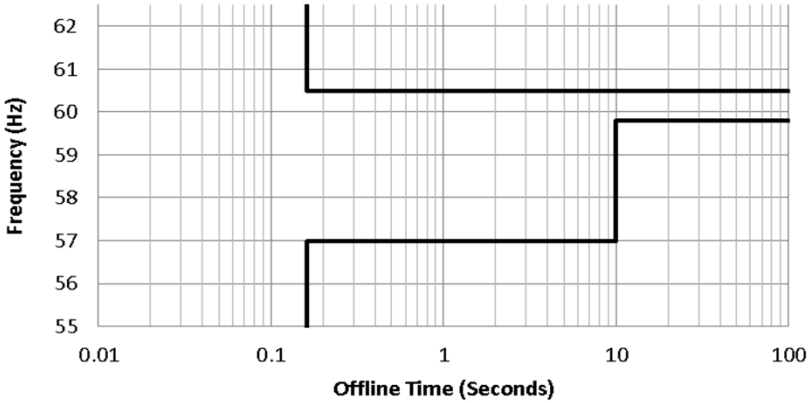
# Output Protection and Power Quality Assurance

## Voltage and Frequency Protection IEEE 1547




## Output Power Quality

Table 3—Maximum harmonic current distortion in percent of current (I)[a]

| Individual harmonic order h (odd harmonics)[b] | h < 11 | 11 ≤ h < 17 | 17 ≤ h < 23 | 23 ≤ h < 35 | 35 ≤ h | Total demand distortion (TDD) |
|---|---|---|---|---|---|---|
| Percent (%) | 4.0 | 2.0 | 1.5 | 0.6 | 0.3 | 5.0 |

[a] I = the greater of the Local EPS maximum load current integrated demand (15 or 30 minutes) without the DR unit, or the DR unit rated current capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).

[b] Even harmonics are limited to 25% of the odd harmonic limits above.

# Conclusions

- Power Conversion is an integral part of Energy Storage Systems
- Limit Conversion Stages to maximize efficiency and minimize complexity
- Integrate systems as soon as practicable to avoid grid interaction and maximize efficiency
- Modularized systems offer unique advantages in redundancy and expandability
- Advanced and hybrid topologies may offer the best solution for specific ESS Challenges

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