Session 4a

Enjeti

High-Megawatt Converter Technology Workshop for Coal-Gas Based Fuel Cell Power Plants

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Introduction

- Fuel cells have been recognized as one of the most promising clean energy sources for power generation.
- High temperature fuel cells such as solid oxide fuel cell (SOFC) and molten carbonate fuel cell (MCFC) have been shown to be over 60% efficient at 500kW rating and above.
- Since the voltage produced by each cell is around 0.6 V DC many cells need to be stacked in series

Dimensions	
Height	27.5'
Width	49.4'
Length	59.6'

Features	Benefits
2000 kW net	Clean energy
480 VAC, 50 or 60 Hz	Efficient
By-product heat availability	Easily sited
Modular and scalable	Quiet Operation
Internal fuel reforming	High-quality power
Few moving parts	
Small package	
Fuel-flexible	

Emissions	
NOx	< 0.3 ppmv
SOx	<0.01 ppmv
CO	<10 ppmv
VOC	<10 ppmv

Available Heat	
Exhaust Temperature	≈650° F
Exhaust Flowrate	27,200 lbs/hr
Exhaust Heat Available	≈2.8 mm Btu/hr.

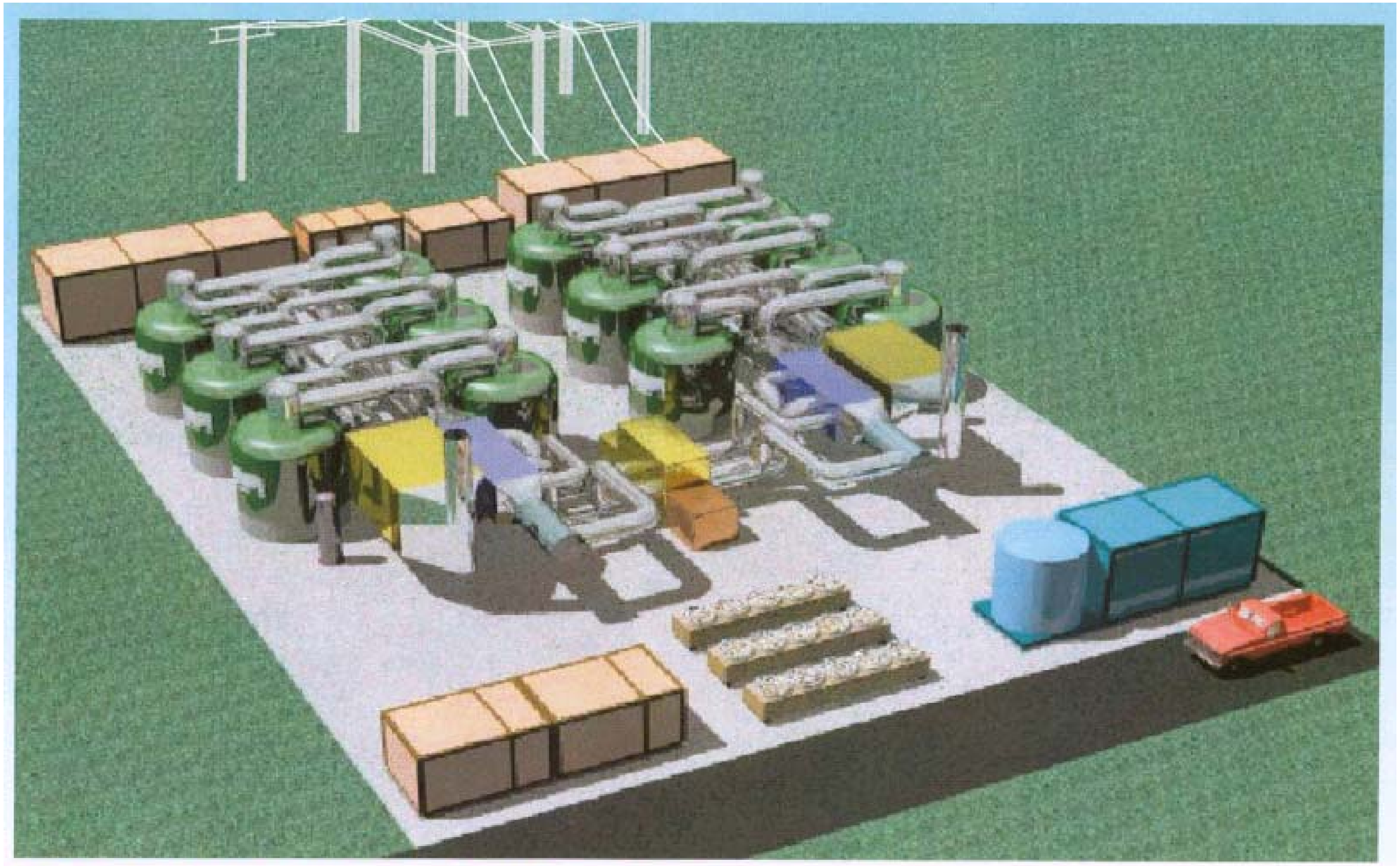
DFC 3000, 2MW Fuel Cell Plant
Fuel Cell Energy Inc.

A 250kW PSOFC / MTG System

Figure 1. The SWPC 220 kW PSOFC/MTG

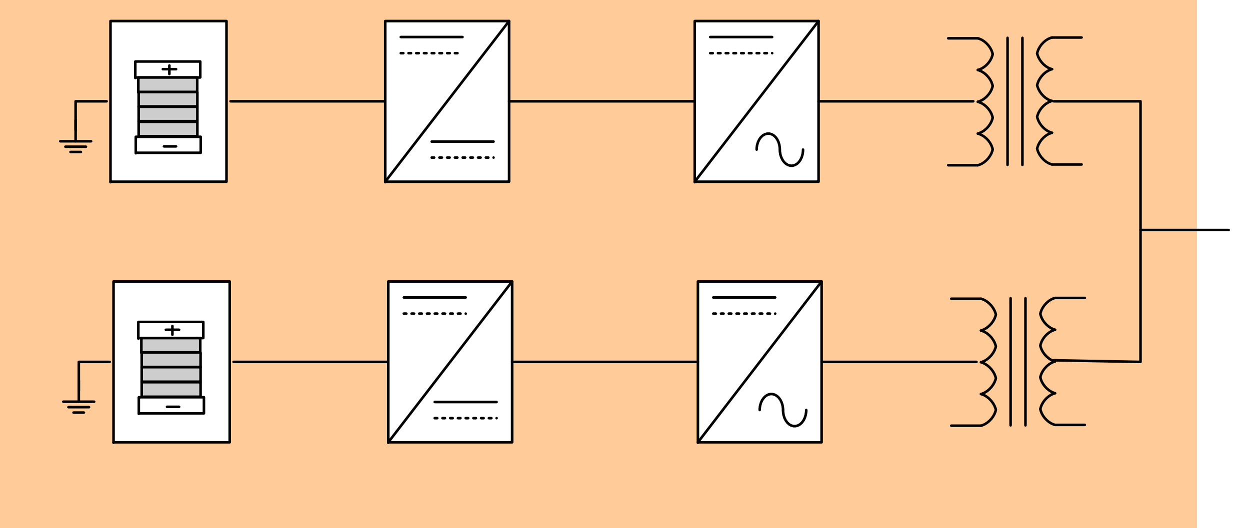
A Direct Fuel Cell Turbine Hybrid

by: Fuel Cell Energy Inc.

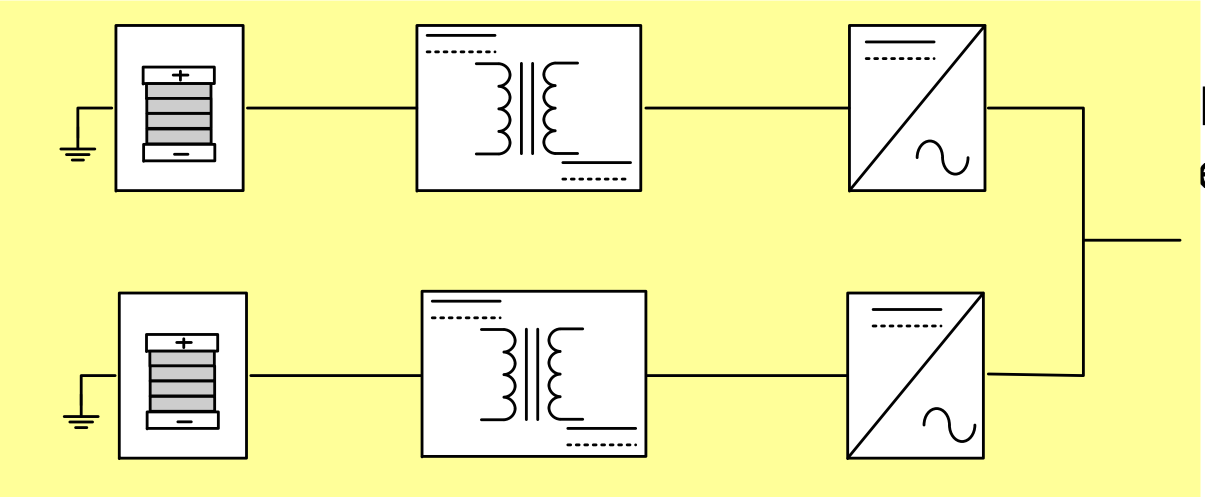


20 MW HIGH EFFICIENCY DFC®/TURBINE HYBRID POWER PLANT

Multi Stack Fuel Cell Systems & Associated Power Electronics



With 50/60 Hz Isolation Transformer



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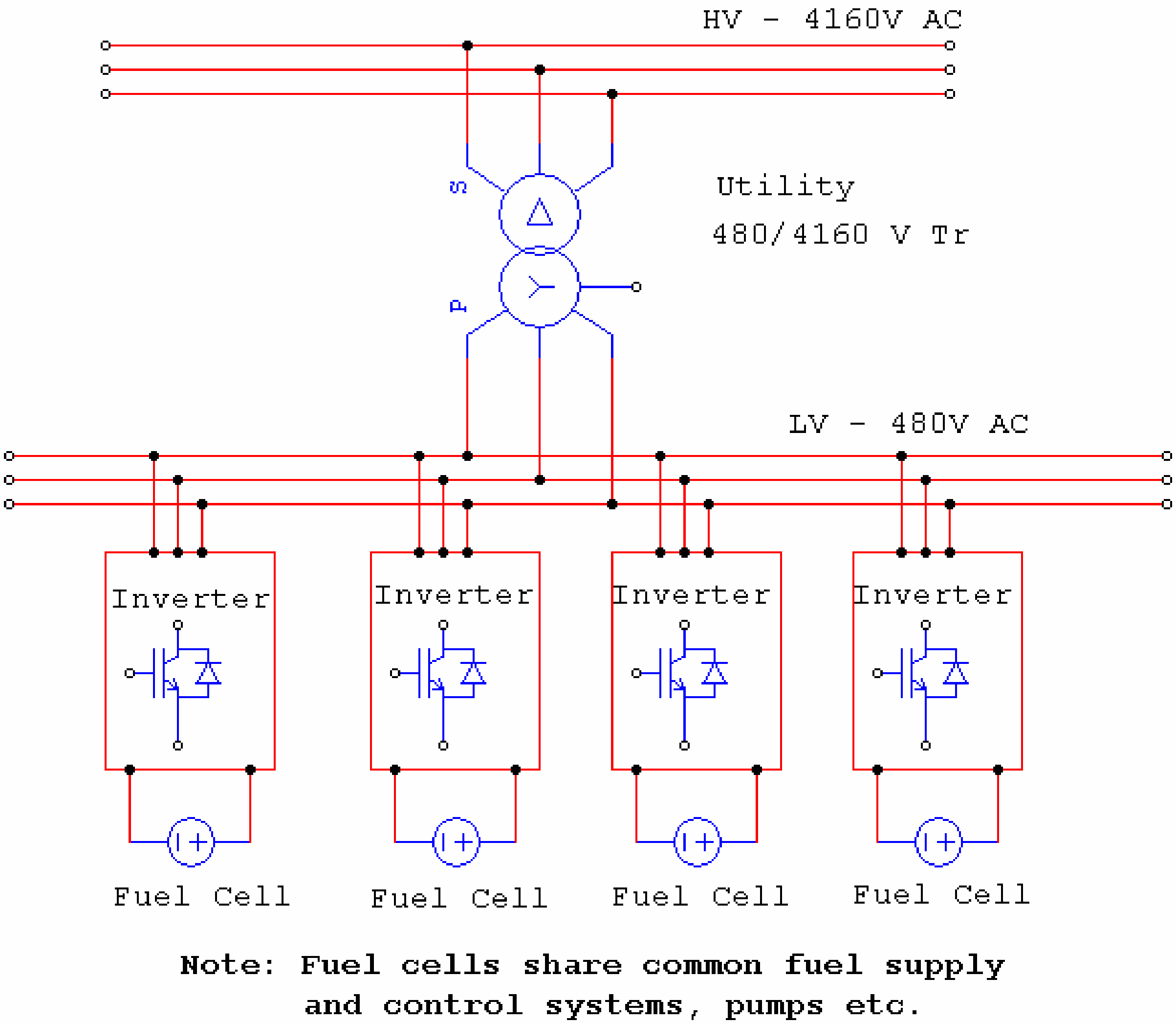
Without 50/60 Hz Isolation Transformer

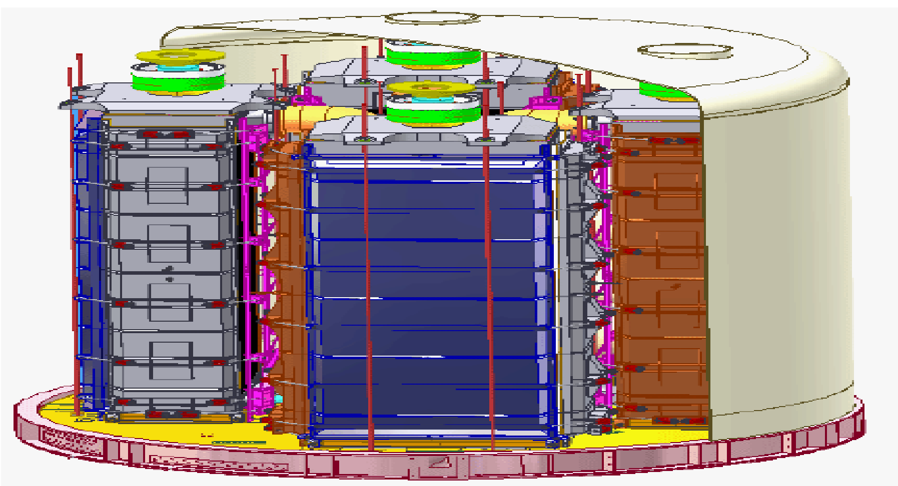
Standard Power Conversion Topology # 1

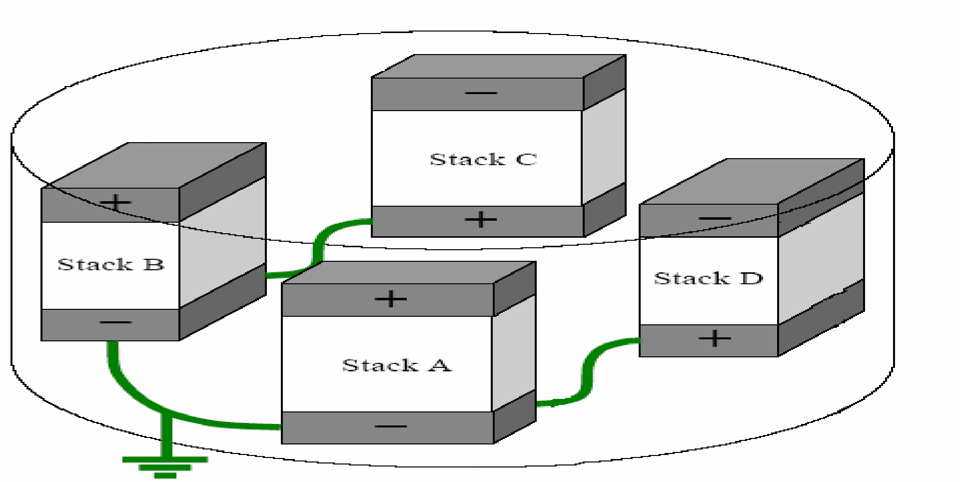


- **Each Fuel Cell & its Inverter is rated for say 300kW**
- **Inverters employ 1200V Si or SiC devices**
- **Modular system**
- **Fuel Cells can share a common fuel supply, heat exchangers etc.**
- **Failure in power electronics and/or a fuel cell only disables one unit**

Fuel Stack Voltage Limitation

- Since each cell produces only 0.6V, there is a maximum number of cells that one can stack before thermal/water management issues can be safely managed. In addition, electrostatic potential to ground within the fuel cell stack needs to be limited for safe operation
- Considering the above factors the maximum voltage that a fuel cell stack can safely produce is around 350V





Commercially Available Medium Voltage Power Converters for Utility Applications

Applications of medium voltage converters

- **Medium voltage converters are mainly used in the industry for**

  - **Voltage disruption compensation**
    - **Dynamic Voltage Restorer – ABB**
    - **MegaDySC - Soft Switching Technologies**

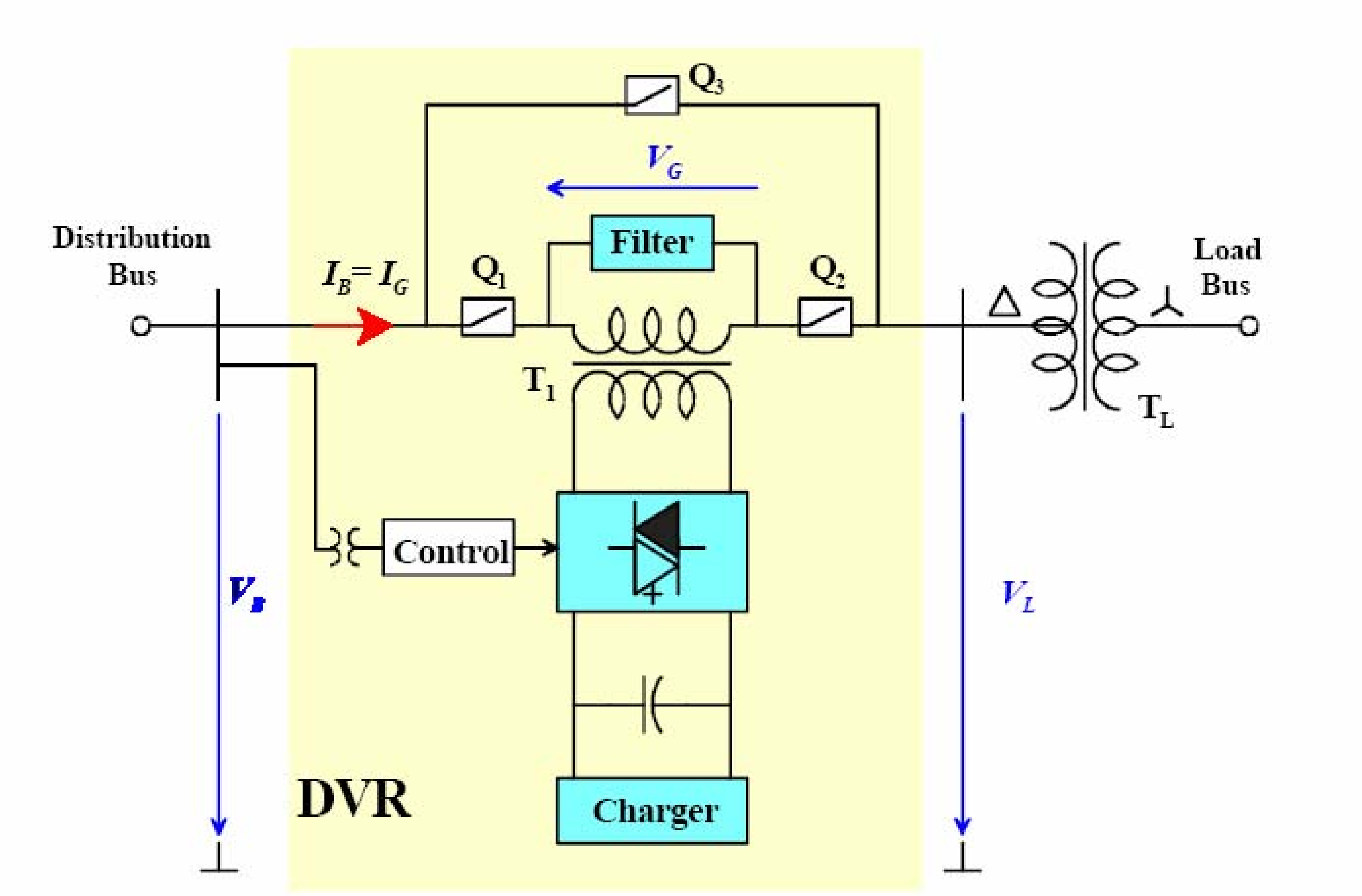
  - **Medium voltage ASD's**
    - **NPC Drives (IGCT's) - ABB**
    - **Series Connected 1-phase Inverters – GE Robicon - Toshiba**

Power Conversion for High Power Hybrid Fuel Cell / Turbine System

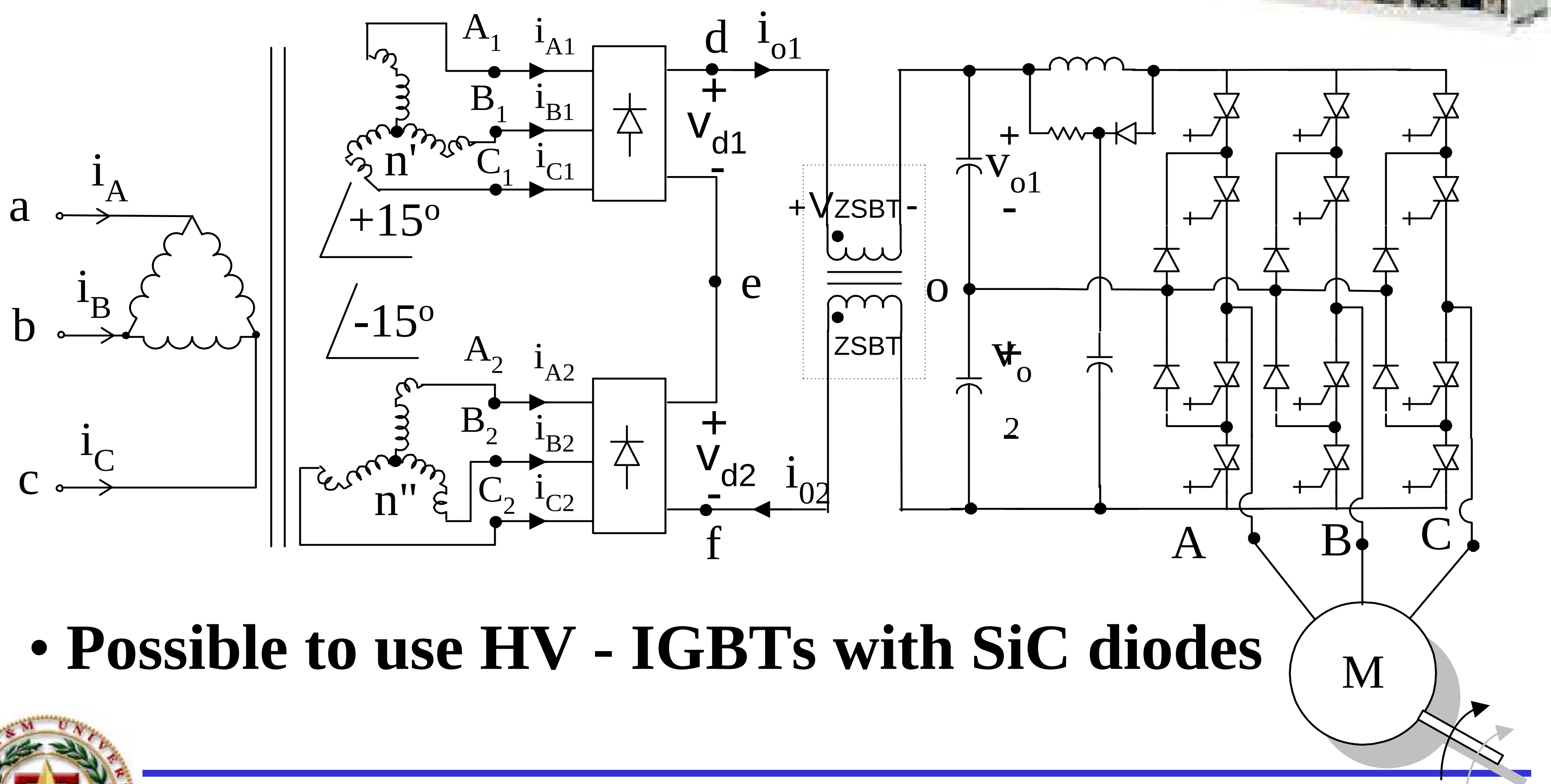
IGCT – Integrated gate commutated thyristor (ABB)

The ACS 1000 is the first drive to use a new power semiconductor switching device called IGCT (Integrated Gate Commutated Thyristor). This advanced, high-power semiconductor approaches the "ideal switch" for medium-voltage applications. IGCT brings together a versatile new power handling device, the GCT, (Gate Commutated Thyristor) and the device control circuitry in an integrated package.

Medium voltage DVR - ABB

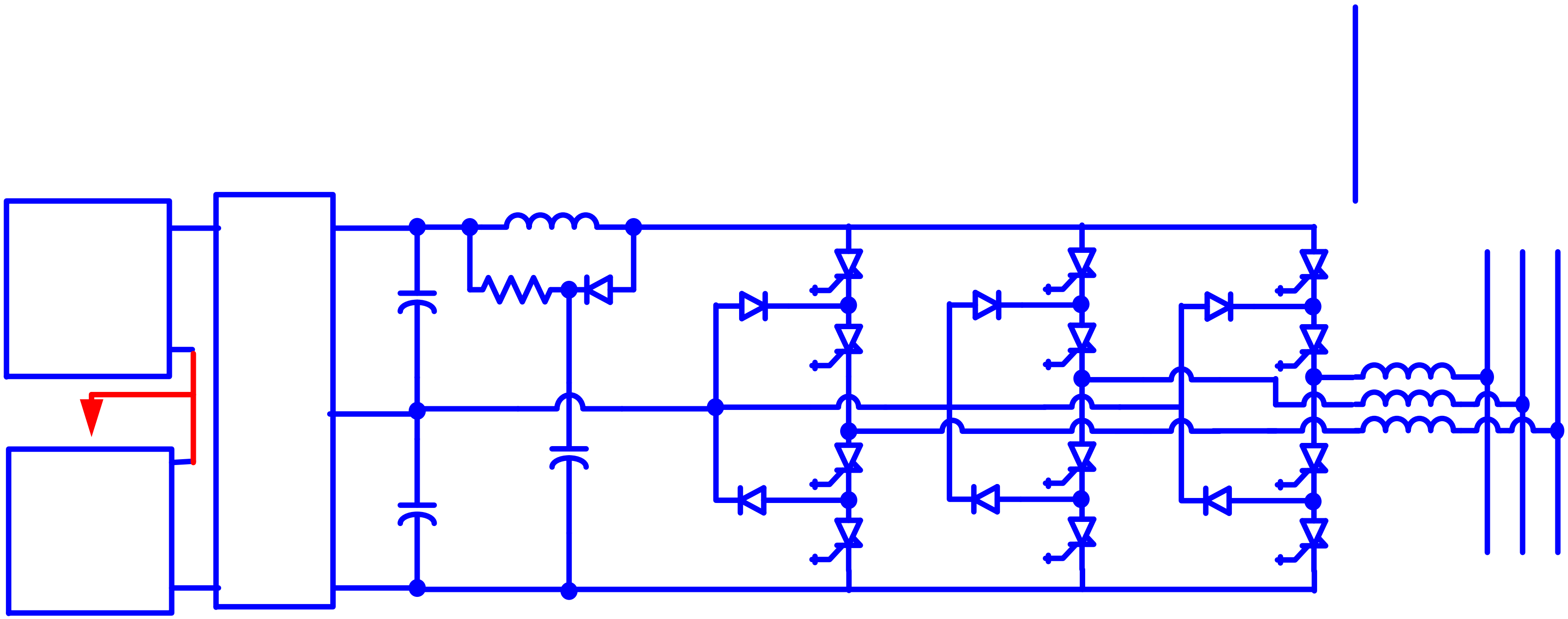


Medium Voltage Adjustable Speed AC Motor Drive – ABB: ACS 1000, Silcovert – ASI-Robicon Vout: 4kV; Po = 12 MW



- **Possible to use HV - IGBTs with SiC diodes**

Power Conversion Topology # 1
For Utility Interface of Fuel Cell Systems

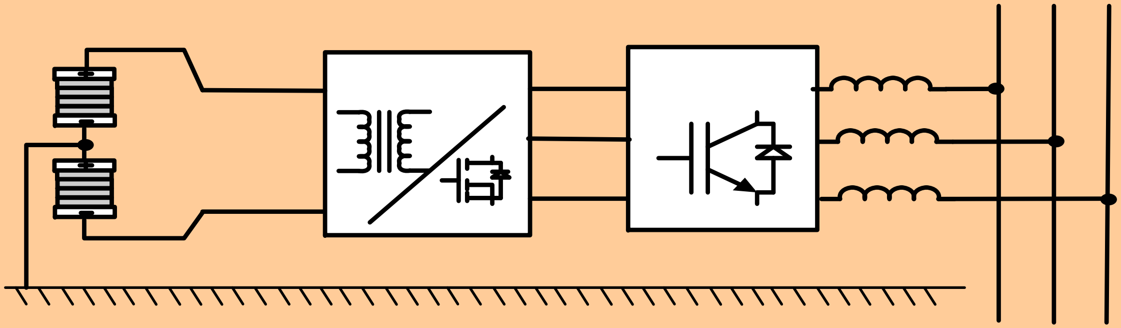


- **IGCT / IGBT devices are available in higher voltage and current ratings**
- **3 level PWM output voltage is high quality & suitable for 4160V, 60Hz utility interface**
- **Each fuel cell stack voltage does not exceed 350V (dc)**

750V dc

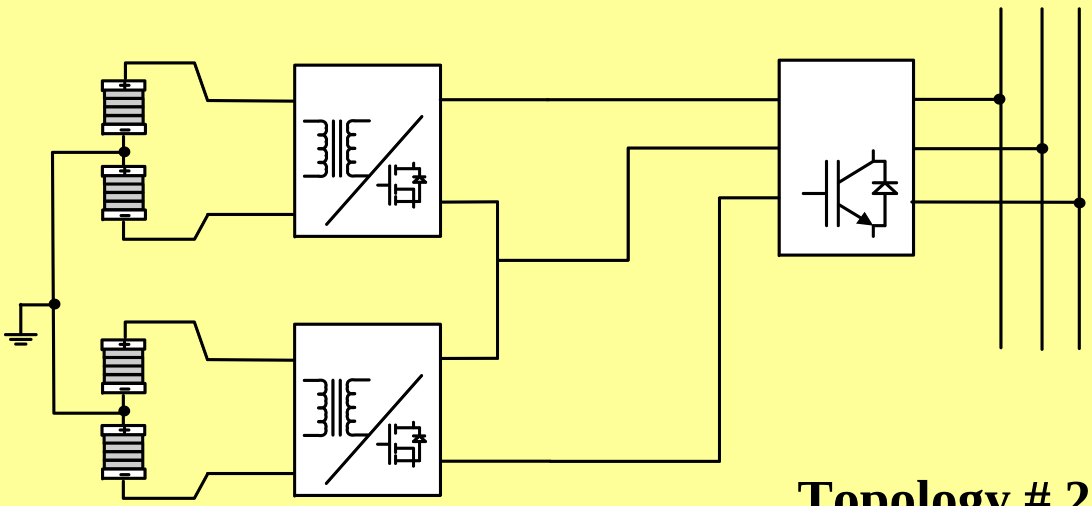
3500V dc

Multi Stack Fuel Cell Systems & Associated Power Electronics



Topology # 1

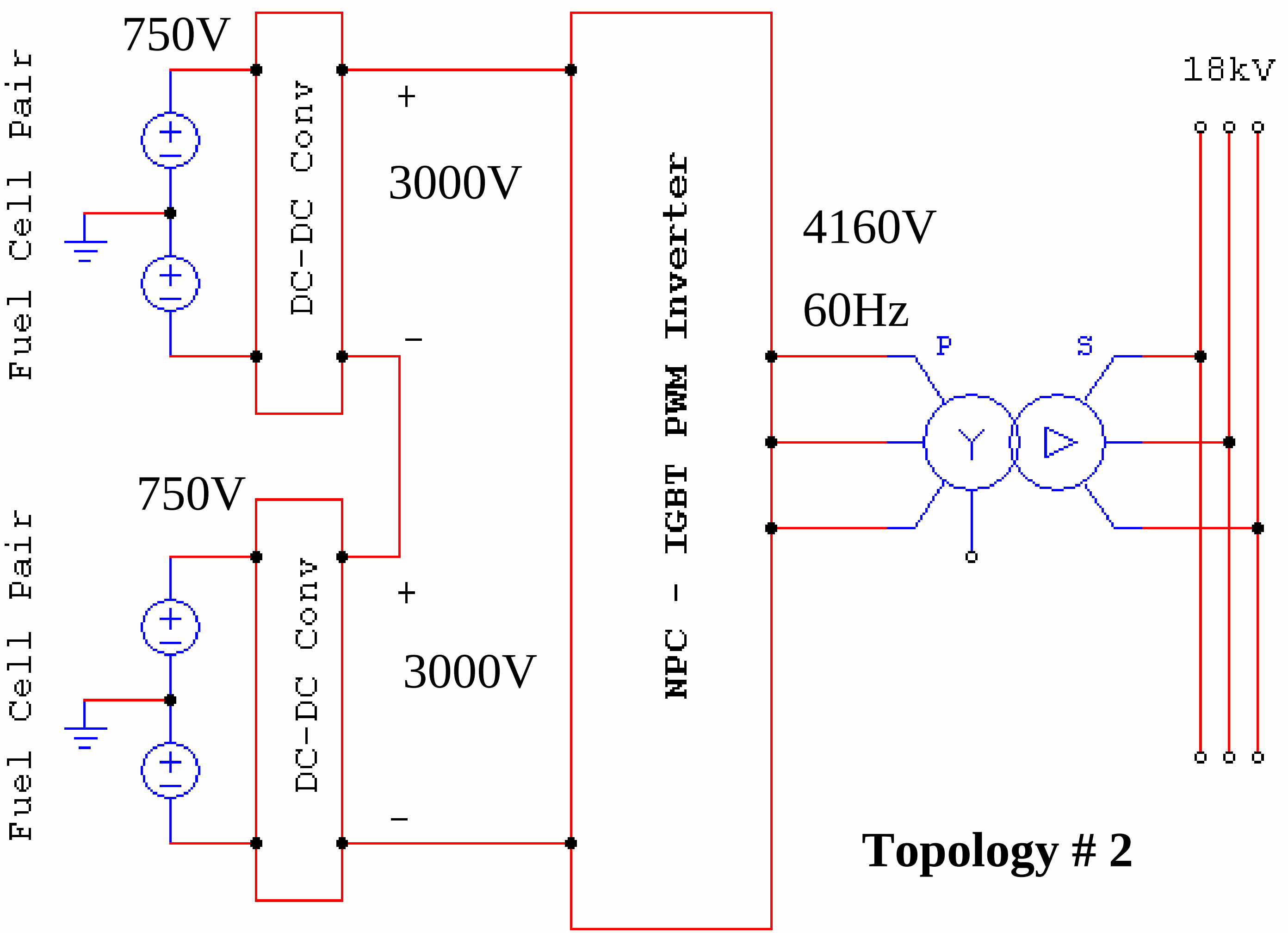
- Two stack fuel cell systems with a high frequency DC-DC converter and DC-AC Inverter
- One dc-dc converter one Inverter for one pair of fuel cell stack: IGBT or IGCT Inverter



Topology # 2

- Four stack fuel cell systems with two cascaded high frequency DC-DC converter and one DC-AC Inverter is employed
- Each fuel cell stack is subjected to a maximum voltage of 350V
- Topology offers control flexibility of fuel cell stack pairs. Control of dc-dc converters is possible to allow each pair of fuel cell stacks to supply different output power

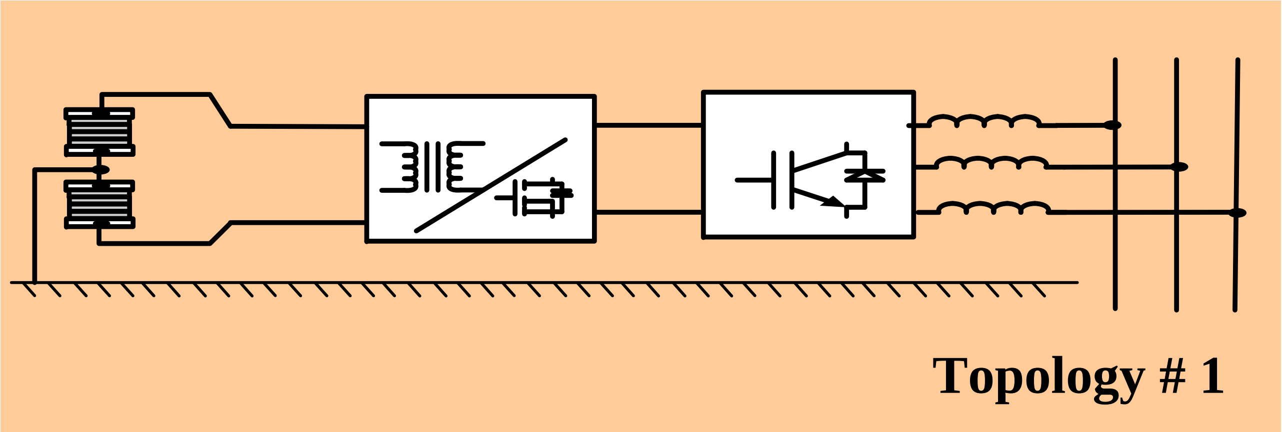
Multi Stack Fuel Cell Systems & Associated Power Electronics

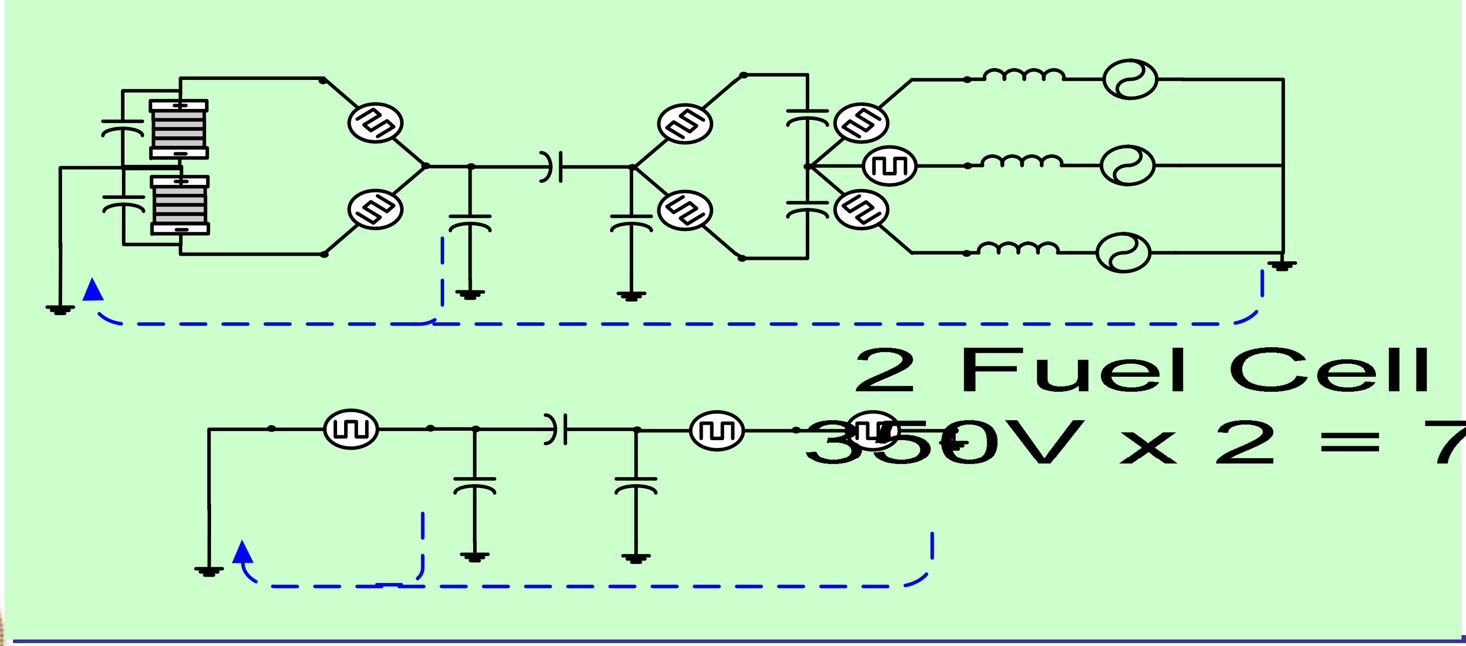


Topology # 2

Additional Considerations: Common mode currents

- **The transformer in the DC-DC converter is modeled by lumped capacitances from primary and secondary to ground, and a capacitance from secondary to primary**

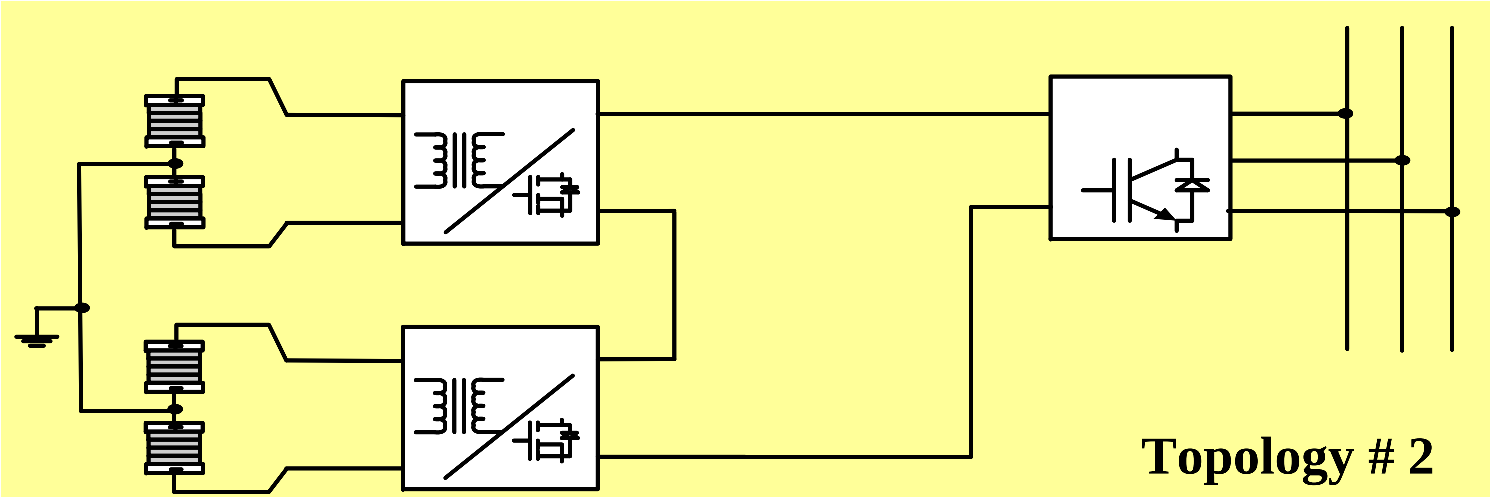


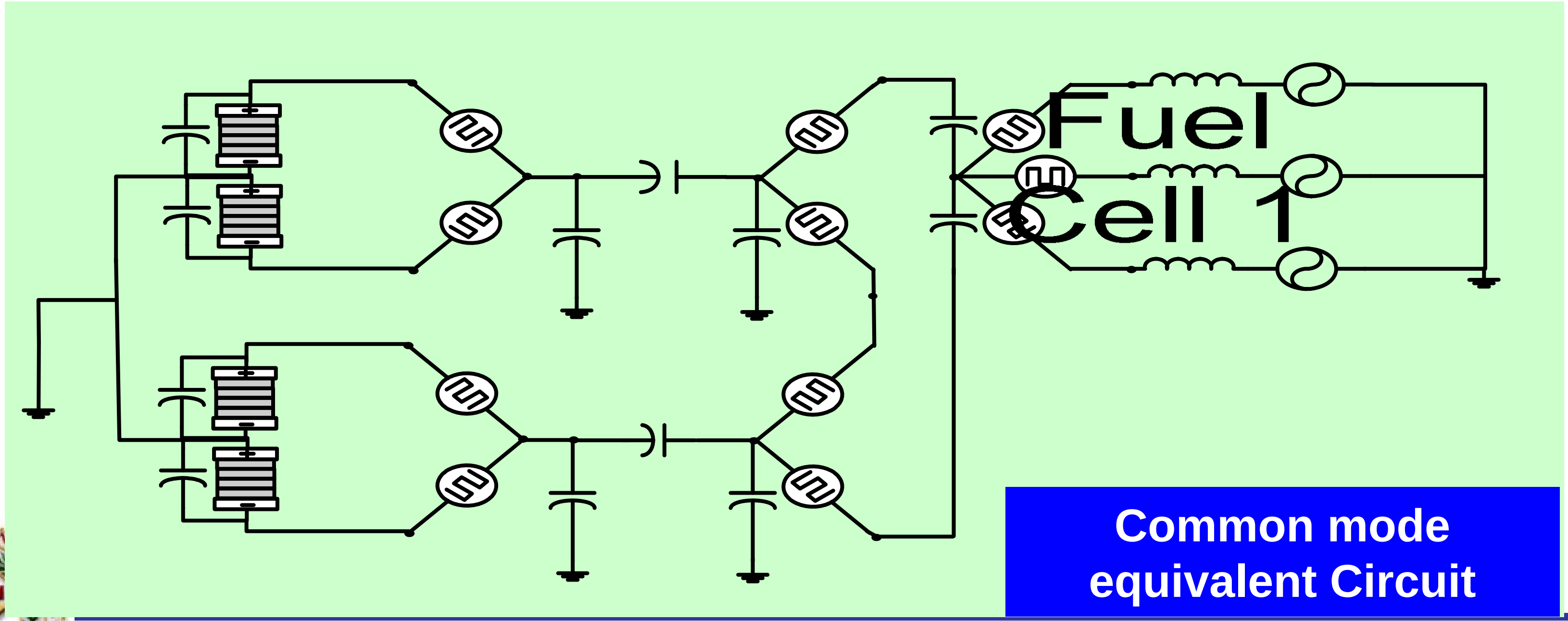


2 Fuel Cell stack

350V x 2 = 750V

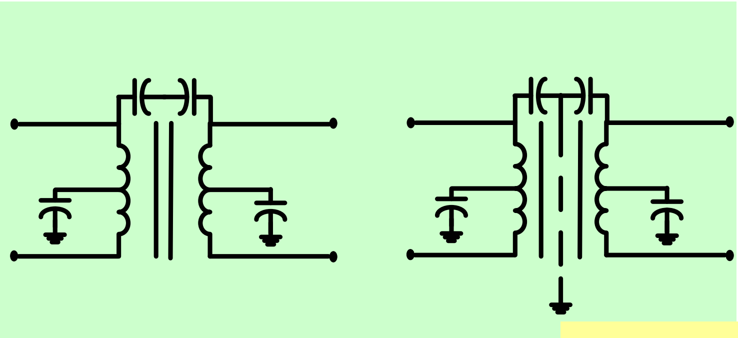
Additional Considerations: Common mode currents



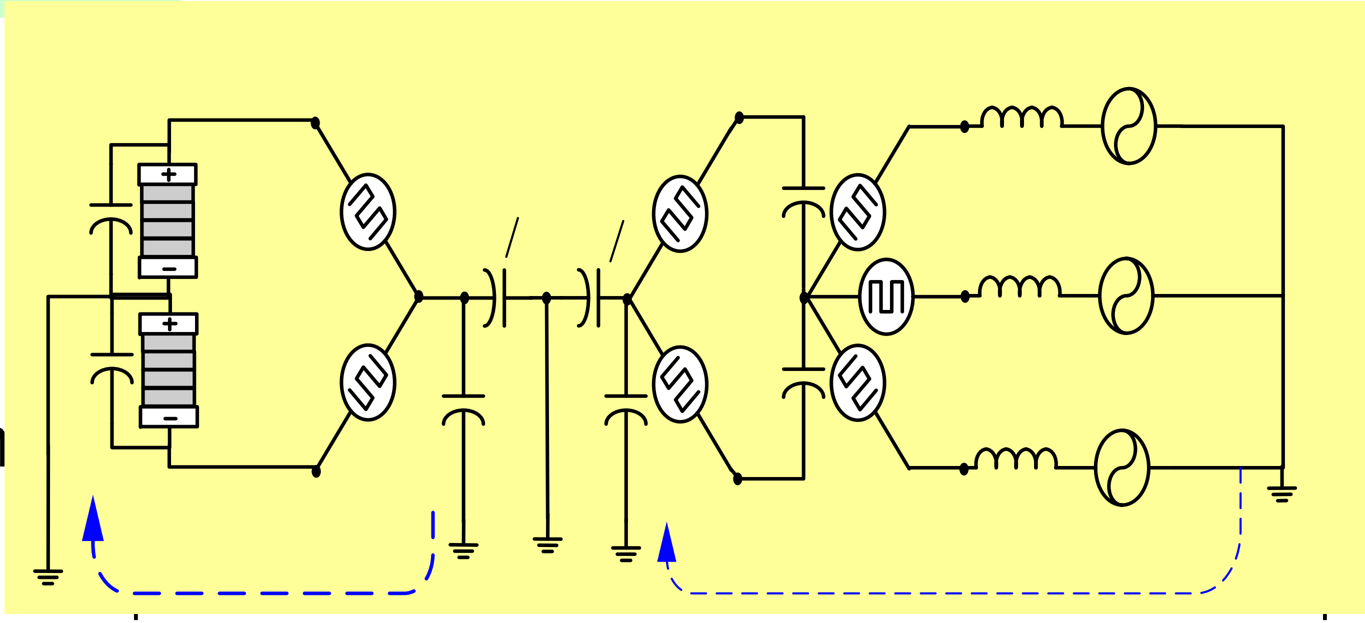


Multi stack DC-DC converter and inverter analysis

- **A shielded transformer is proposed to isolate the interaction between the DC-DC converter & Inverter stages**



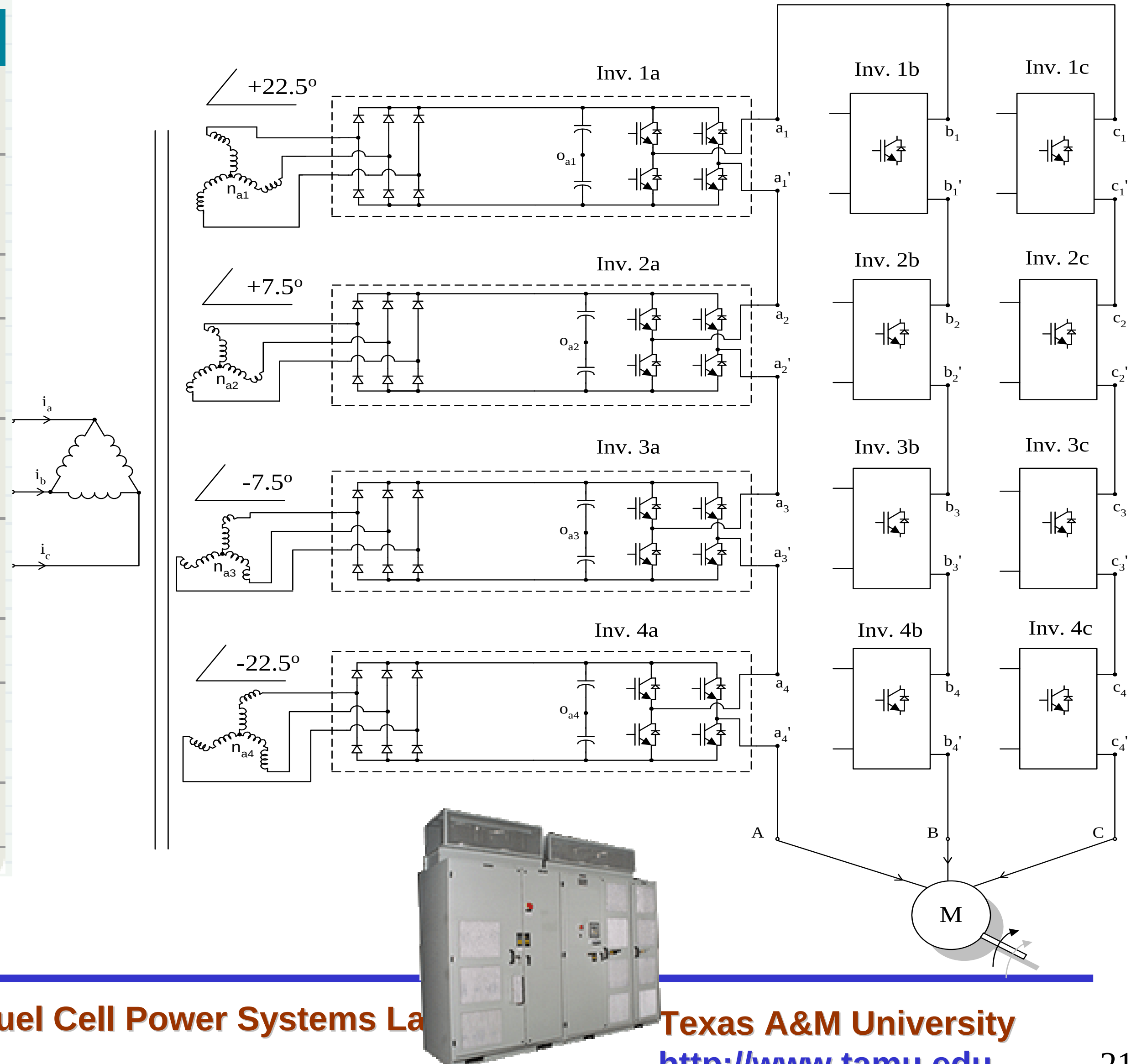
Conven



- **To further reduce Icm a common mode filter needs to be installed at the output of the DC-DC Converter**

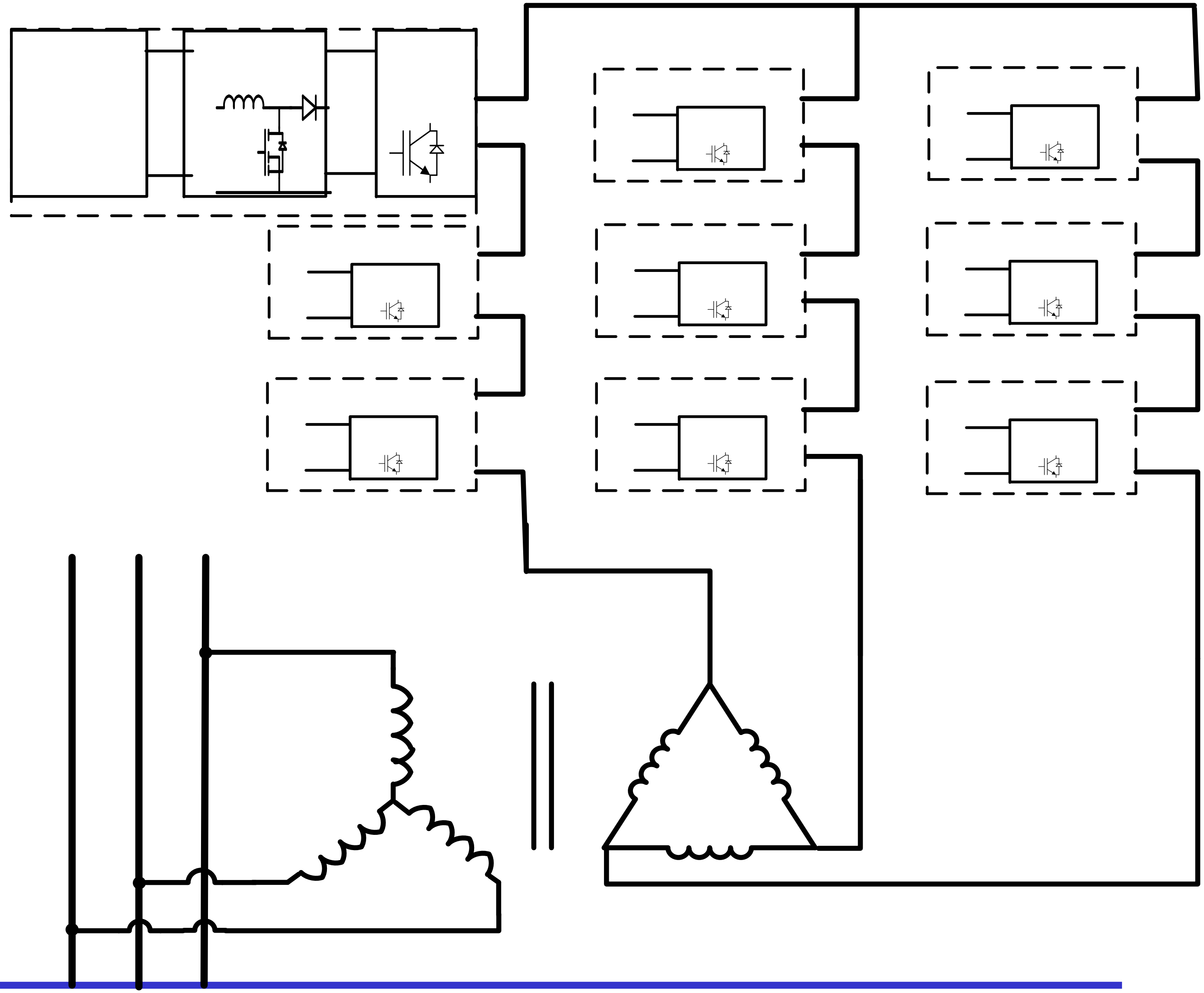
Medium Voltage Adjustable Speed AC Motor Drive: ASI-Robicon – Perfect Harmony

SPECIFICATIONS	
Power Range:	300 kW - 75 MW
Output Voltage:	2300 - 13800 VAC
Motor Voltage:	2.3 - 13.8 kV
Motor Power Range:	300 kW - 32 MW 225 - 43000 HP
Continuous Power Range:	290 kVA - 35 MVA
Rated Output Current:	70 - 1400 A
Topology:	Multi-level PWM
Power Device:	Voltage Source IGBT
Output Frequency:	0 - 330 Hz



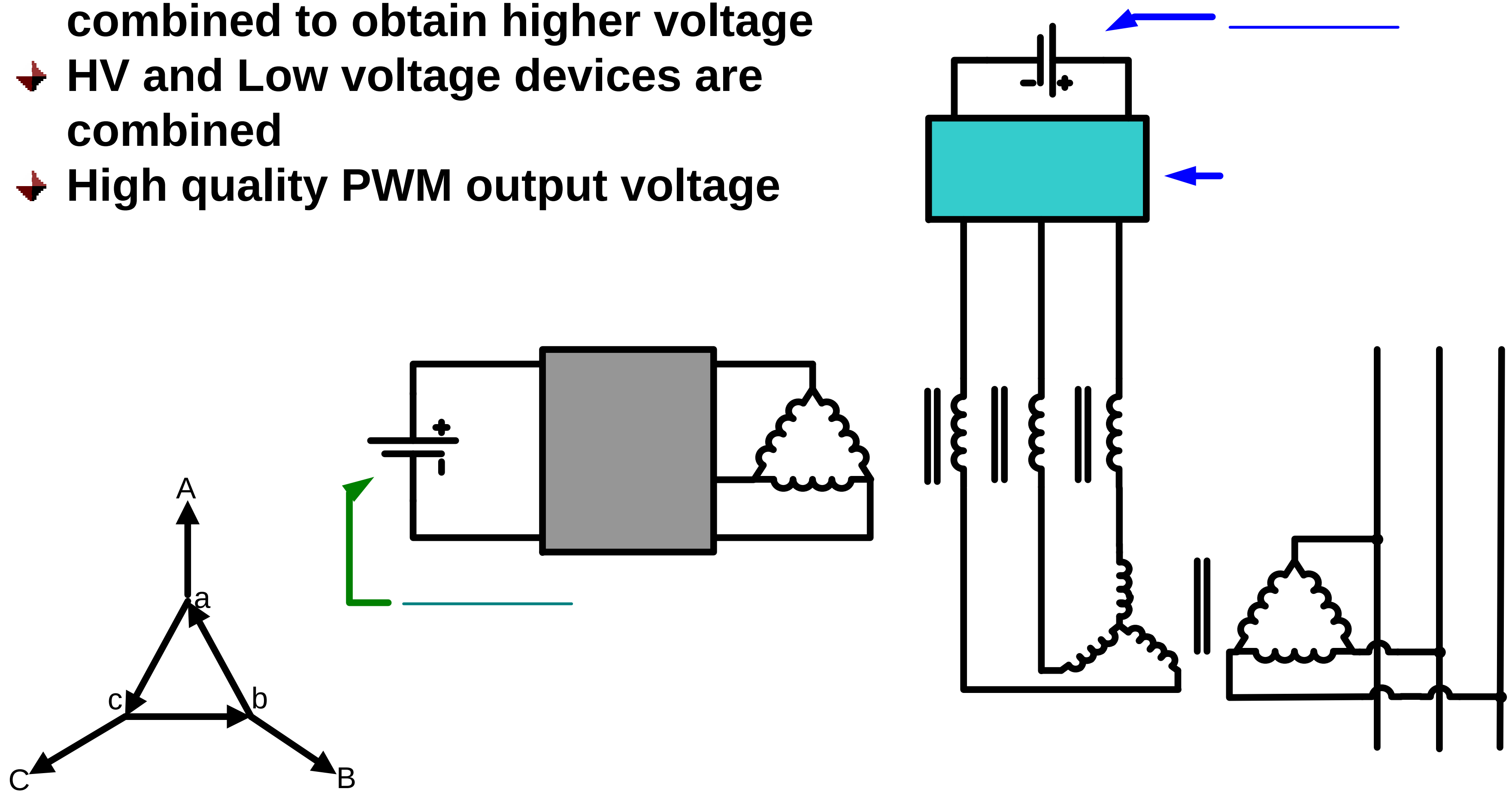
Power Conversion Topology # 3

- Modular 1-phase converters can be connected in cascade to realize higher output voltage
- Advantage: Lower voltage power electronics
- Disadvantage: Common mode elevation of different fuel cell stacks may be unacceptable



Power Conversion Topology # 4

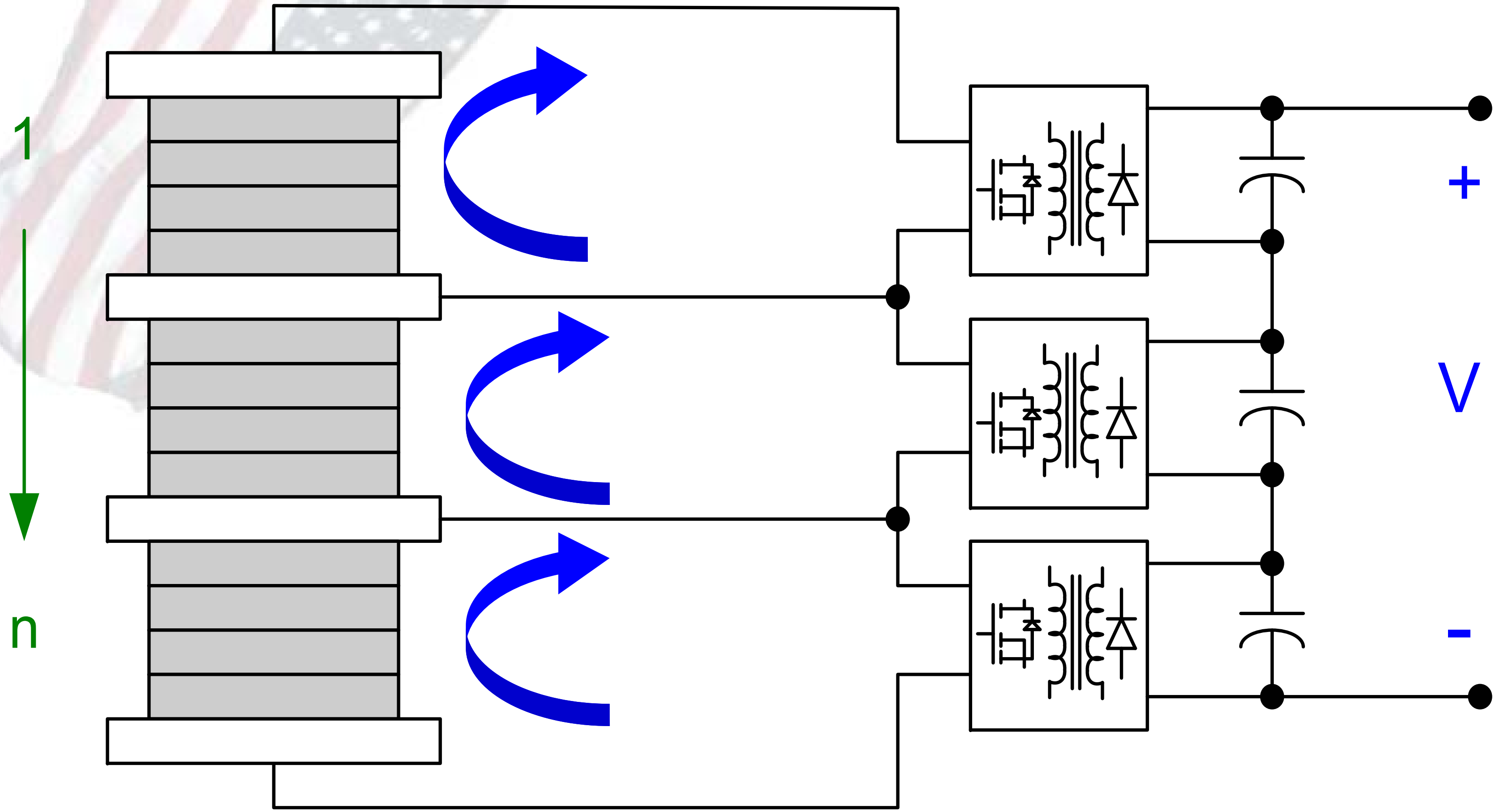
- Several 3-phase converters can be combined to obtain higher voltage
- HV and Low voltage devices are combined
- High quality PWM output voltage



Comparison of Power Conversion Topologies

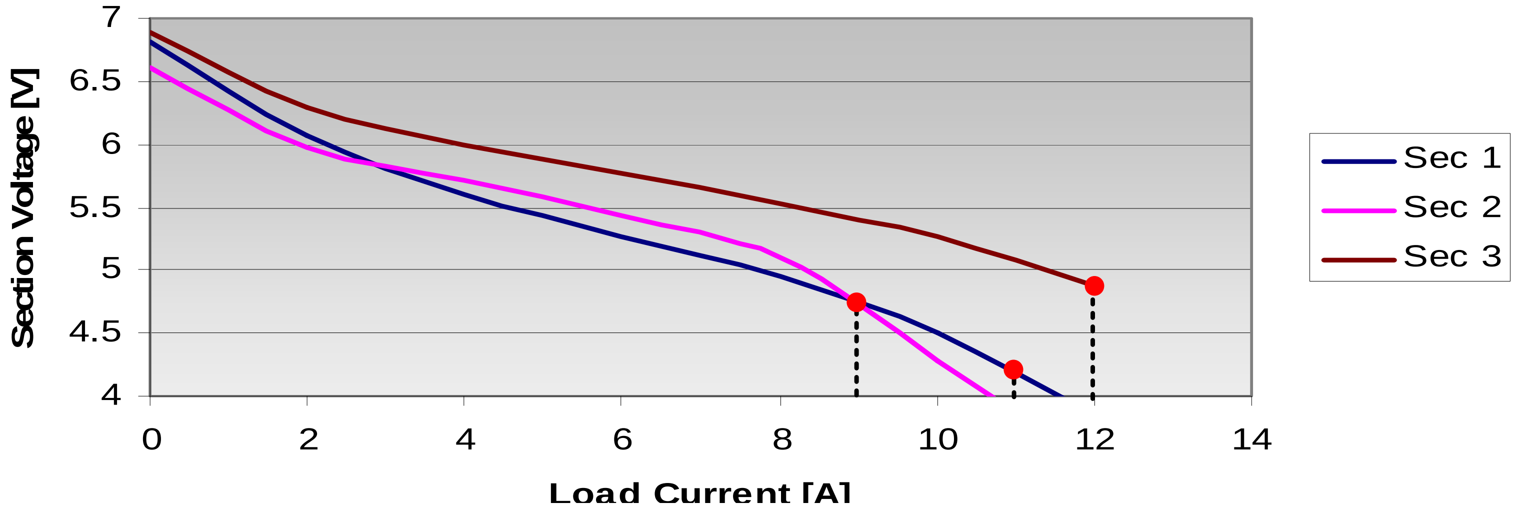
Topology # 1	2 fuel cell stacks (350V) series connected & center point grounded, one dc-dc converter followed by a 3-level inverter to produce 2300V 3-phase ac
Topology # 2	4 fuel cell stacks (350V) series connected in pairs and center point grounded, two dc-dc converters with outputs connected in series, followed by a 3-level inverter to produce 4160V 3-phase ac
Topology # 3	Each fuel cell stack (350V) connected to a dc-dc converter with isolation, followed by a 1-phase LV inverter. Several such modules are connected in cascade to form one MV ac system
Topology # 4	Fuel cell stacks followed by dc-dc converter & 3-phase inverters. Several of these modules are combined together via 3-phase transformers to realize a multilevel inverter system for medium voltage.

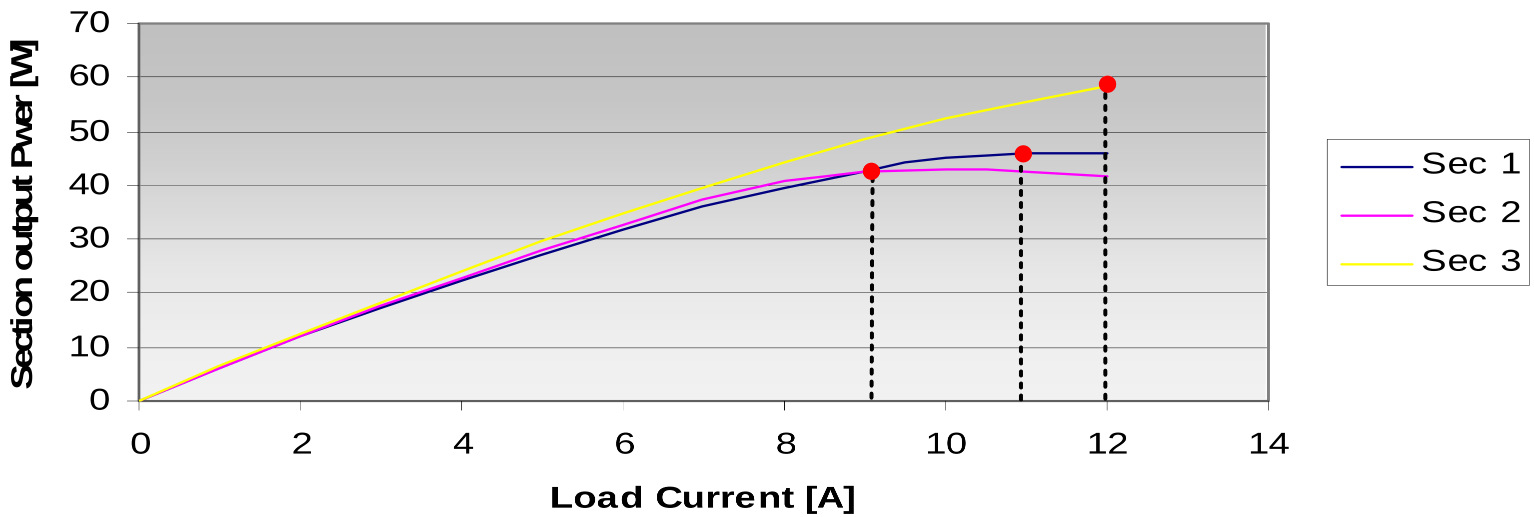
Modular Fuel Cell Stacks & Modular Power Electronic Converters



The power generated by the different section in the modular fuel cell stack can be independently controlled. Sections containing better performing cells can produce more power. The current drawn from sections containing under-performing cells can be limited in order to minimize internal losses & enhance reliability.

Modular Fuel Cell Stack & Modular Power Electronic Converters – 15% More Power





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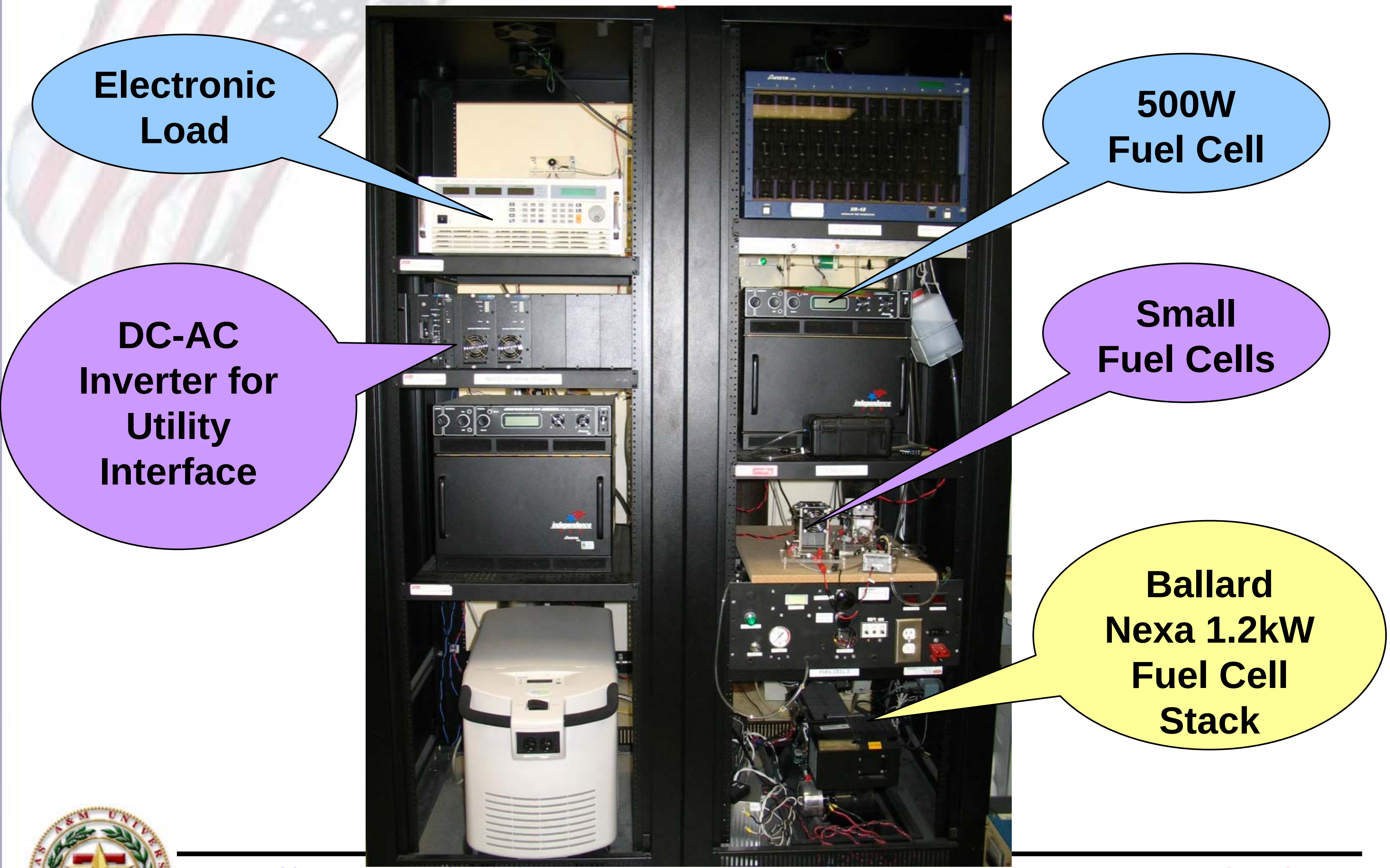
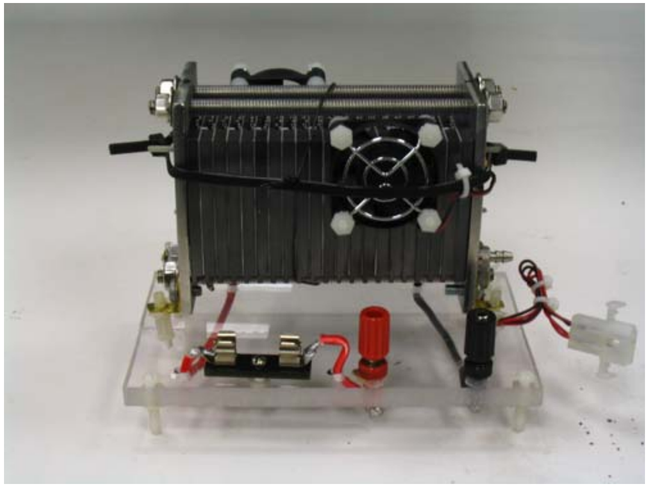
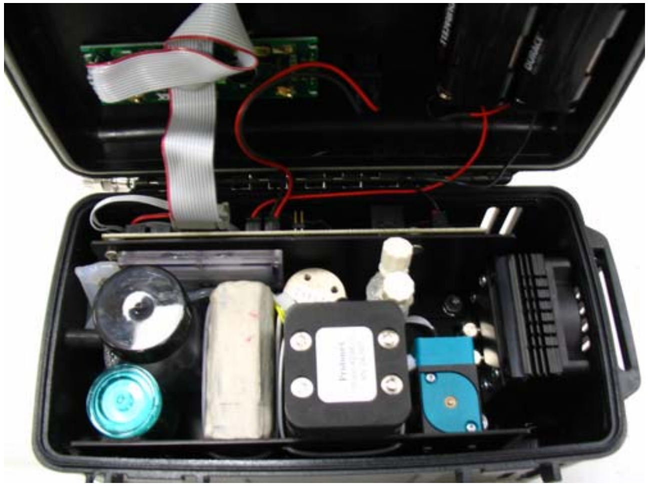


Small Fuel Cells: 20W to 50W Systems





Questions ?