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DOE High-Megawatt Power Converter Technology R&D Roadmap Workshop

Tom Gordon April 8, 2008 NIST Gaithersburg, MD

DOE Integrated Coal Gasification Fuel Cell System with CO_2 Isolation

A Multi-Year, Multi-Phase Cost Shared Program

- **Coal Syngas fueled, 100 MWe class fuel cell central station**
- **Efficiency > 50%, (based on HHV but excluding CO_2 Sequestration)**
- **90% CO_2 Sequestration Potential**
- **$400/kWe (power island)**
- **Integrated Gasification Fuel Cell Cycle …IGFC Cycle**

DOE Integrated Coal Gasification Fuel Cell System with CO_2 Isolation

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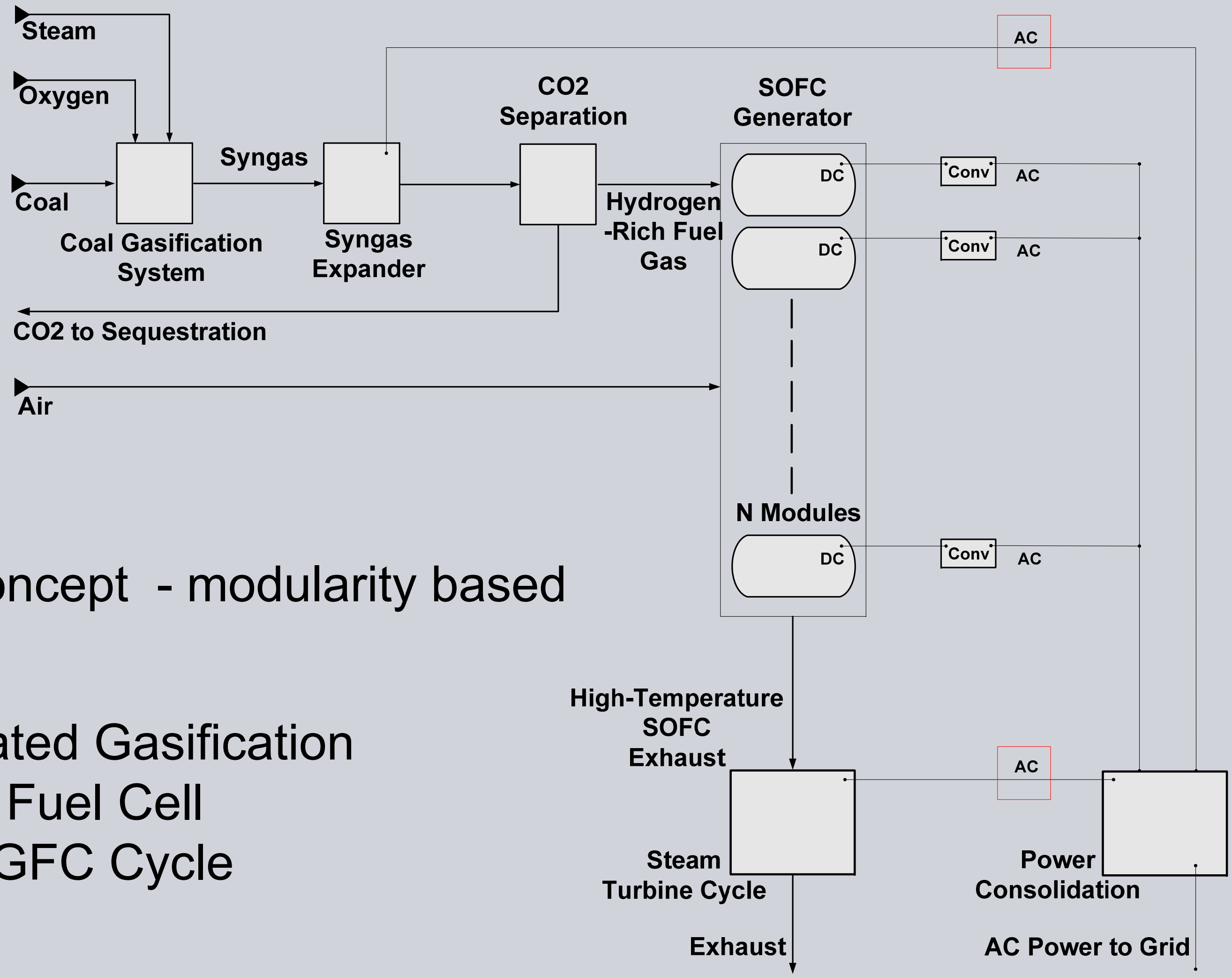

Evolving concept - modularity based

Integrated Gasification
Fuel Cell
IGFC Cycle

Direction –How To Realize High Power System

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- High power ratings will be accomplished with Multiple Modules of Fuel Cell Power Blocks.   Limitations include:

- Specific power (kWe/m^3) ratings –transportation issues
- Avoidance of flow and thermal asymmetries
- Maximize current loading of the actual fuel cells –multiple modules foster this goal
- Fuel cell stack dielectric system limitations

Direction –Characteristics of Basic Fuel Cell Module

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- **Fuel cells are a soft voltage source –poor terminal voltage regulation under load**
- **Present SOFC's terminal voltage drop under fully loaded conditions may approach a ratio of nearly 2:1 vs. the maximum Vdc open circuit for the fuel cell**
- **SOFC modules for the IGFC system are expected to be in the range of 1000 Vdc open circuit and the 1000 ampere class**
- **Terminal voltage regulation improvements are anticipated but nevertheless this issue still must be accounted for … along with transient excursions too**

Direction –Requirements for PCS Topology

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- PCS topology must aggregate power from many fuel cell modules
- Topology must support individual current loading of the fuel cell modules … (or minimum groups)
- Topology should permit individual modules and electronics to be taken off line while the system continues to run … (or minimum groups)
- The fuel cell modules would not be at tightly uniform DC voltages
- The PCS also must integrate AC power from generators used to recover exhaust heat energy
- An example system is presented in the next slide

System to Consolidate Fuel Cell Power

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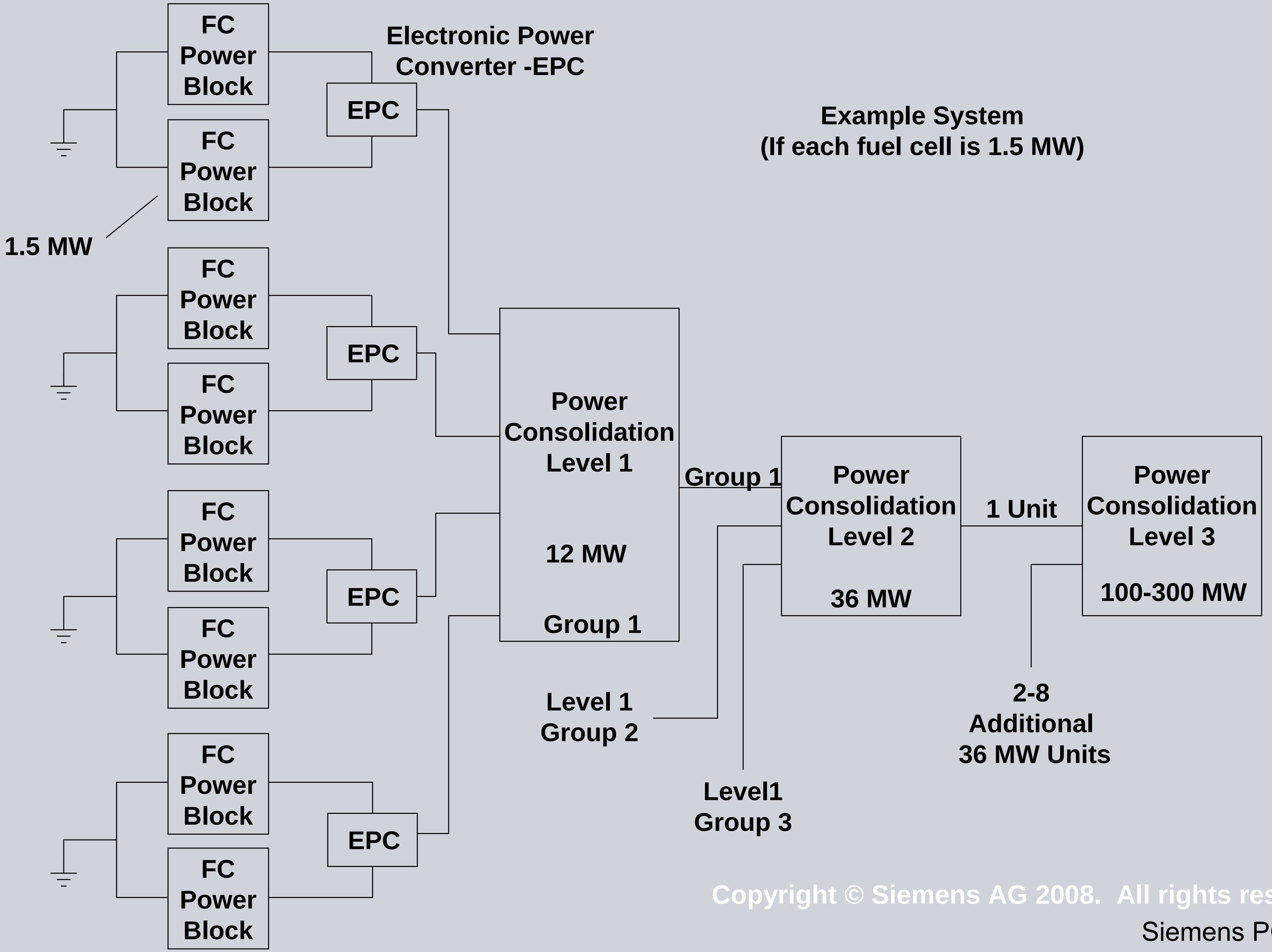

Elements Needed / Power Consolidation Essential

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- High power/ modular/ cost efficient/ loading control circuit building block (EPC-electronic power converter)
- Modular EPC for 0.7 to 2 MW fuel cell module
- Performance optimized and cost efficient power consolidation methods
- Power consolidation can be either DC based (capacitors) or AC based (transformers)
- Optimal inverter aggregation methods
- Practical and efficient transformer combinatory techniques

Elements Needed / Power Consolidation Essential

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Perspective of what is needed for larger converter systems

Efficient consolidation methods are needed to aggregate the power from many small approximately 1 MW fuel cell units

Viewpoint: It is important that methods to aggregate and combine the power must be identified, compared and evaluated. The inverter per se is not the challenge.

A viable IGFC system at the 100-300 MW level will require virtually hundreds of small converter power groups to be efficiently strung together and consolidated to create one large plant

Power & Voltage Level Check

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- from an EPRI study:

15 kV $_{L\text{-}L}$ class circuit _peak load 4-6 MVA

25 kV $_{L\text{-}L}$ class circuit _peak load 7-10 MVA

35 kV $_{L\text{-}L}$ class circuit _peak load 10-16 MVA

- Check Power Capability:

115 kV L-L @500A = 100 MVA

Power & Voltage Level Check

- Previous slide demonstrates high voltage systems are needed to deliver the power level of interest
- The same logic would apply to the converter system if enough power can be consolidated to supply higher level types of power converters
- Conclusion: Examination of PWM inverter systems is very appropriate. But possible use of higher power multi-pulse stepped square wave inverters also should be considered.
- Stepped square wave inverters are GTO based line frequency switching utility grade inverters …100-500+ MVA class. Applications SVC, FACTS, HVDC

Modularity and Power Consolidation

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- Both bottom up (load control) and top down (aggregate power rating & delivery) perspectives are needed for selection of a low cost high megawatt PCS topology and system design
- The load control building block at the fuel cell module level must be highly cost optimized since it will repeat many times
- Power consolidation strategies need to support the necessary modularity
- Converter $/kW targets include and must be assessed on the complete network … the complete consolidation network must be evaluated. And the complete consolidation network design plan must influence how the fuel cells are individually loaded.

Power Consolidation Example 1
DC Choppers

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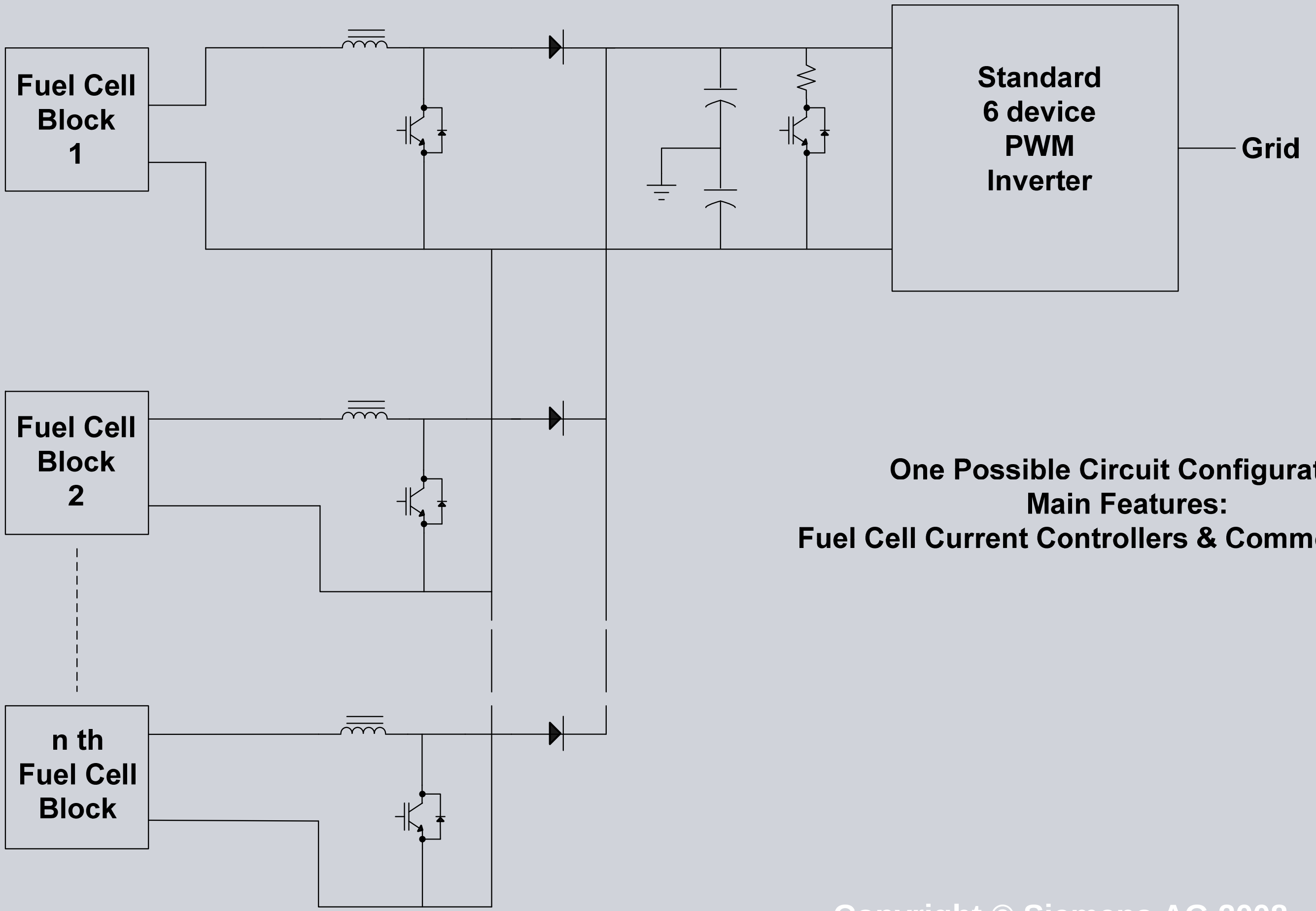
Array of DC to DC Chopper Converters



One Possible Circuit Configuration
Main Features:
Fuel Cell Current Controllers & Common DC Link

Power Consolidation Example 2
DC to DC Converters

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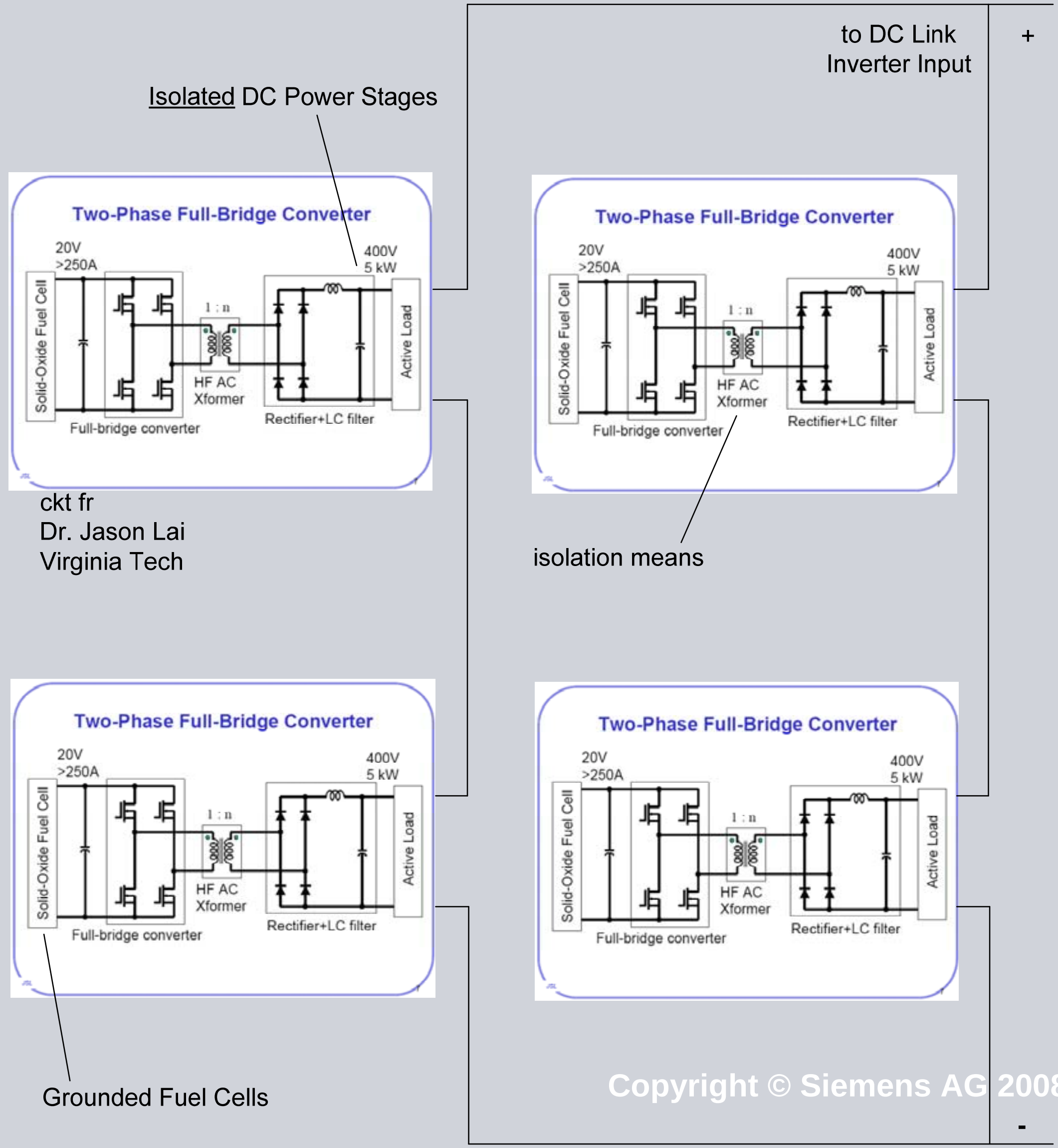
Array of DC to DC Isolated Converters

2 x 2 shown
n x p capable



Consolidation Concept & System Power Buildup

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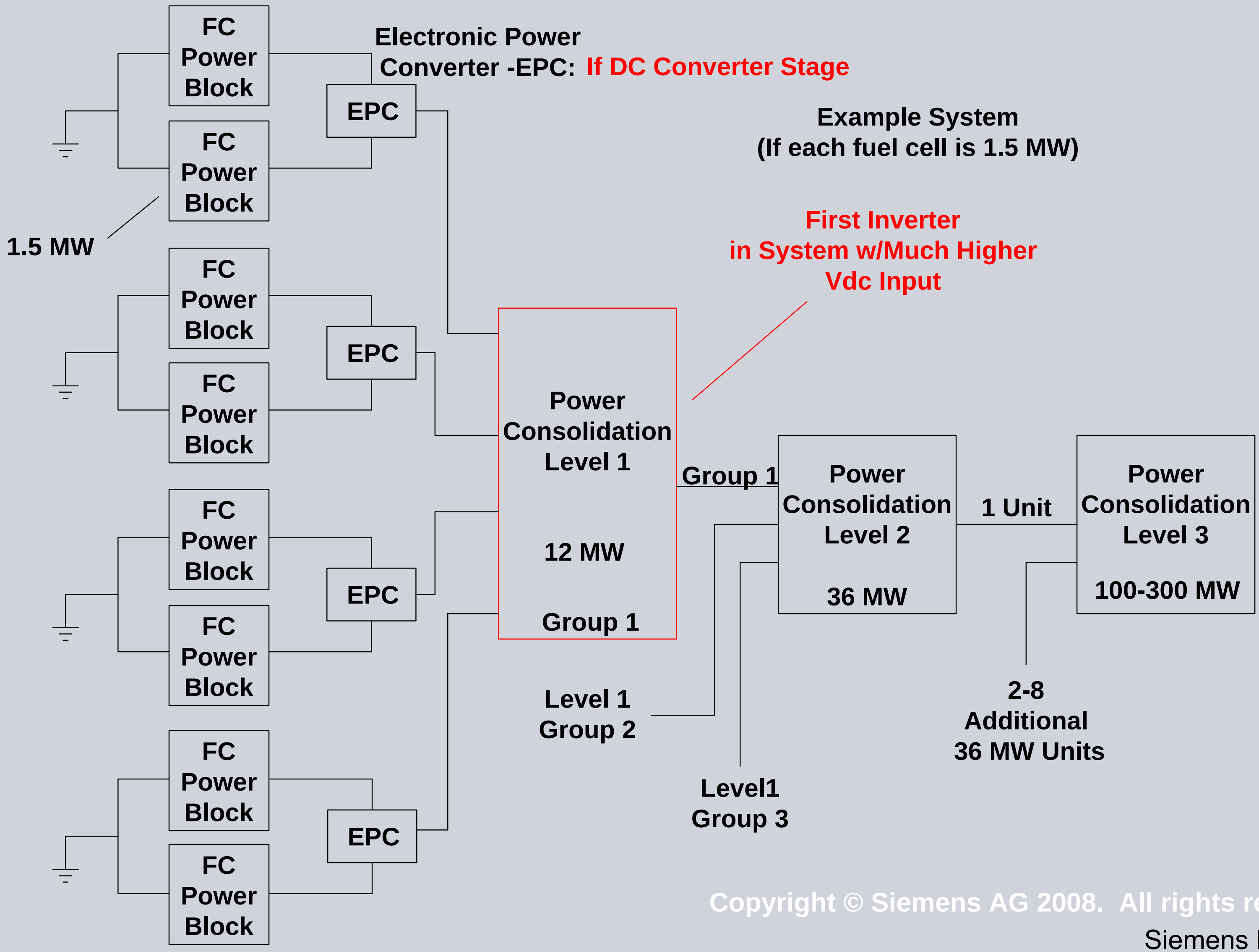

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Alternative Strategy to Aggregate Power

The previous slides suggest the modular EPC (electronic power converter) to load the fuel cell has a high kVA rating equal to the level of the fuel cell power block … 0.5 to 2.0 MW

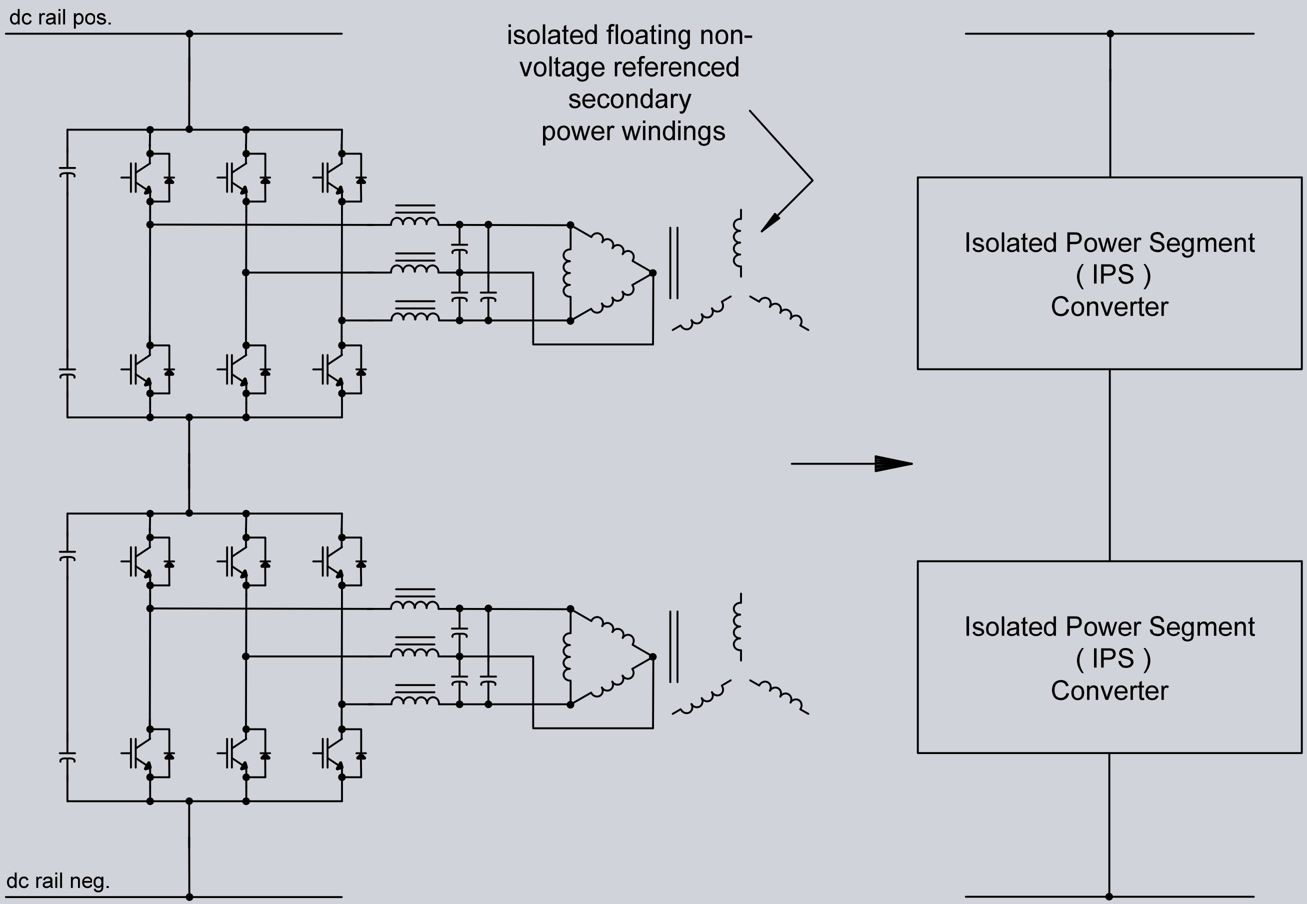
Next 2 slides take a different tack for the EPC loading device

Power Consolidation Example 3

Premise: several low-voltage drives are less expensive than one medium-voltage drive of equal total rating

cascaded multi-cell multi-level design

from a concept by
D.A. Derek
Mesta Electronics



Power Consolidation Example 3

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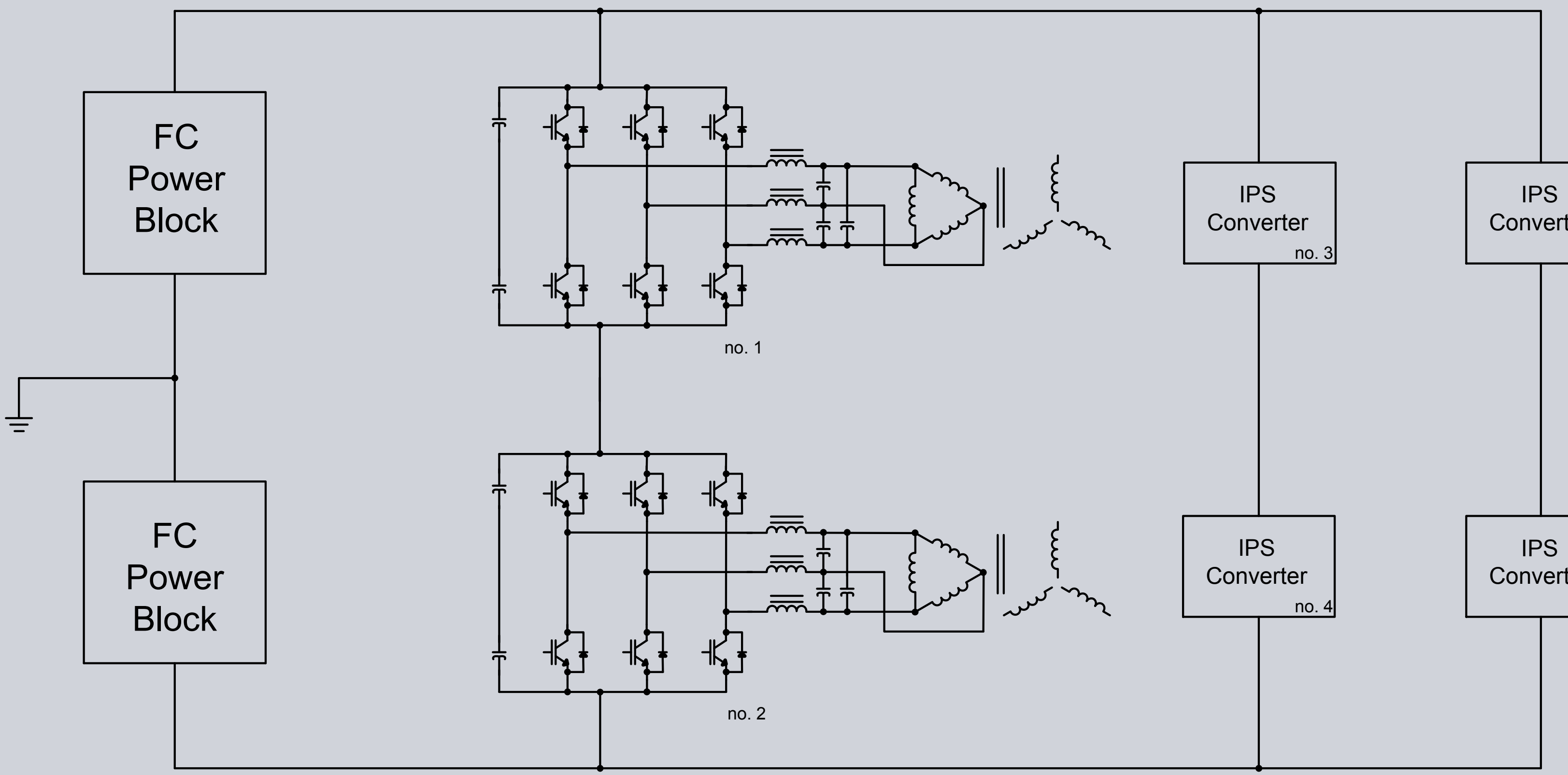
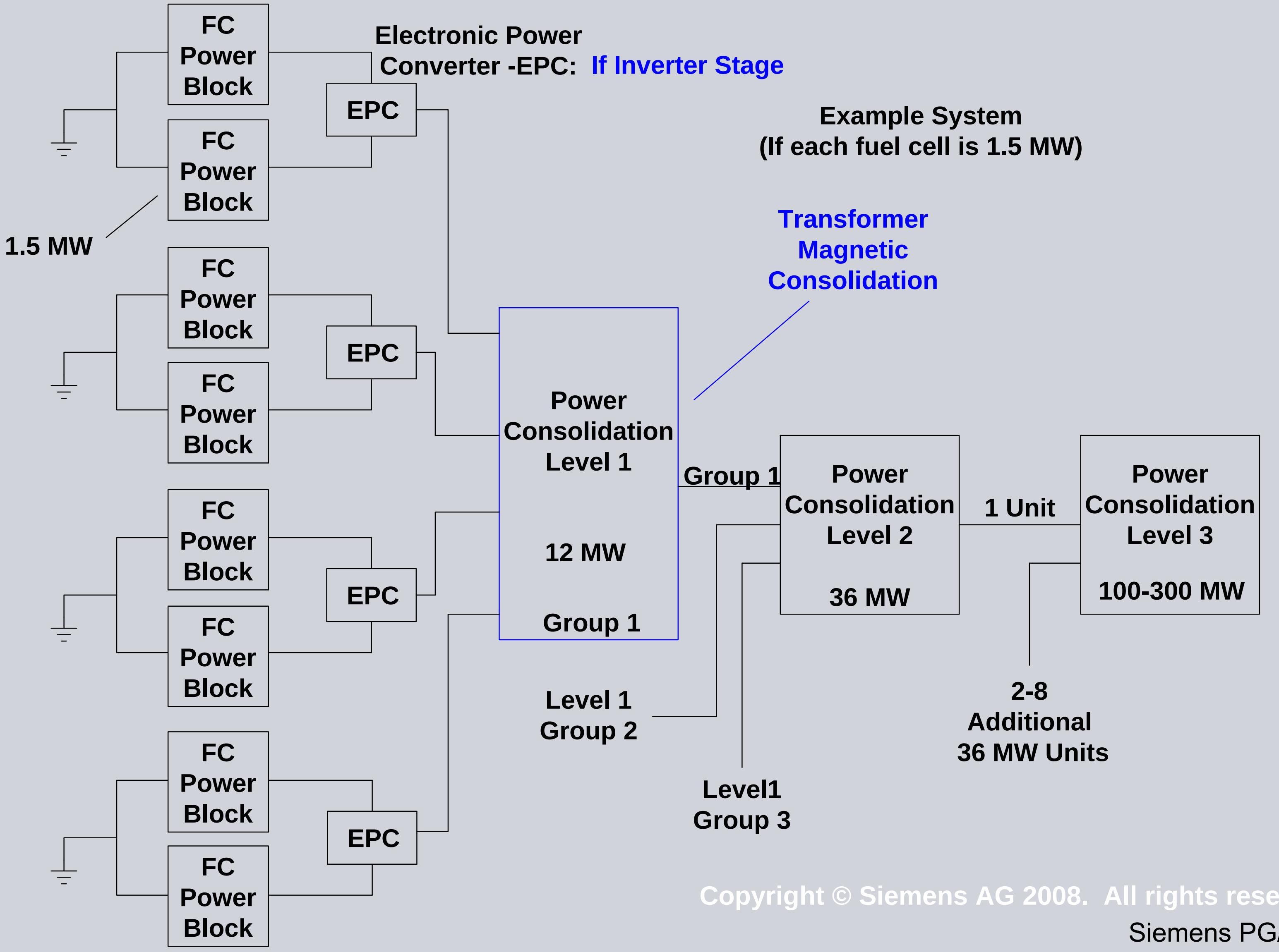


Array of DC to AC Isolated Converters

2 x 3 shown
n x p capable

Secondary phase wndgs. in series for ac voltage
Parallel IPS converter legs for dc current

Consolidation Concept & System Power Buildup



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Conclusions:

A design plan for a power circuit network (100-300 MW) is vital. The network must easily aggregate small power blocks and consolidate them into larger electrical sources.

Key to all this working well is a set of effective methods to appropriately combine the electrical power drawn from all the relatively small units and then present it to the grid as one generation source.