

**Session 2a**  
**Gordon**

# **DOE High-Megawatt Converter Technology Workshop**

Tom Gordon, January 24, 2007

# DOE Integrated Coal Gasification Fuel Cell System with CO<sub>2</sub> Isolation

**SIEMENS**

## 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<sub>2</sub> Sequestration)
- 90% CO<sub>2</sub> Sequestration Potential
- \$400/kWe (power island)



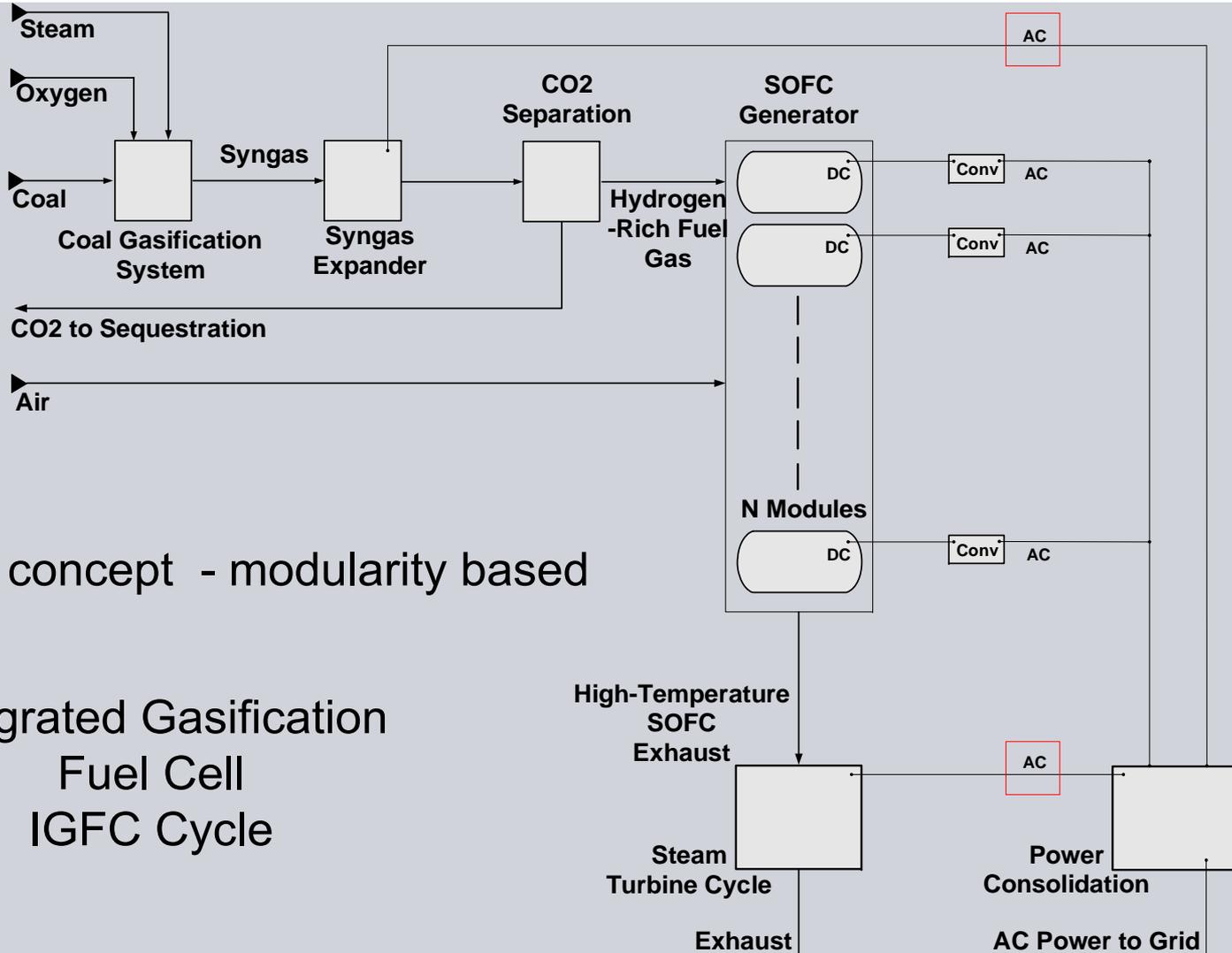
# DOE Integrated Coal Gasification Fuel Cell System with CO<sub>2</sub> Isolation

**SIEMENS**

Early concept - modularity based



# DOE Integrated Coal Gasification Fuel Cell System with CO<sub>2</sub> Isolation



Evolving concept - modularity based

Integrated Gasification  
Fuel Cell  
IGFC Cycle

- **High power ratings will be accomplished with Multiple Modules of Fuel Cell Power Blocks** Limitations include:
- **Specific power (kWe/m<sup>3</sup>) 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**

- **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

- **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**



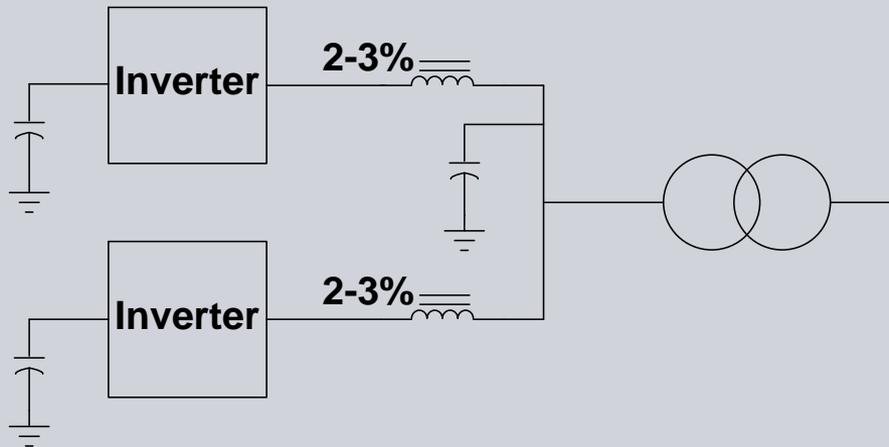
## Elements Needed

- **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**

# Some Issues Involved with Power Consolidation

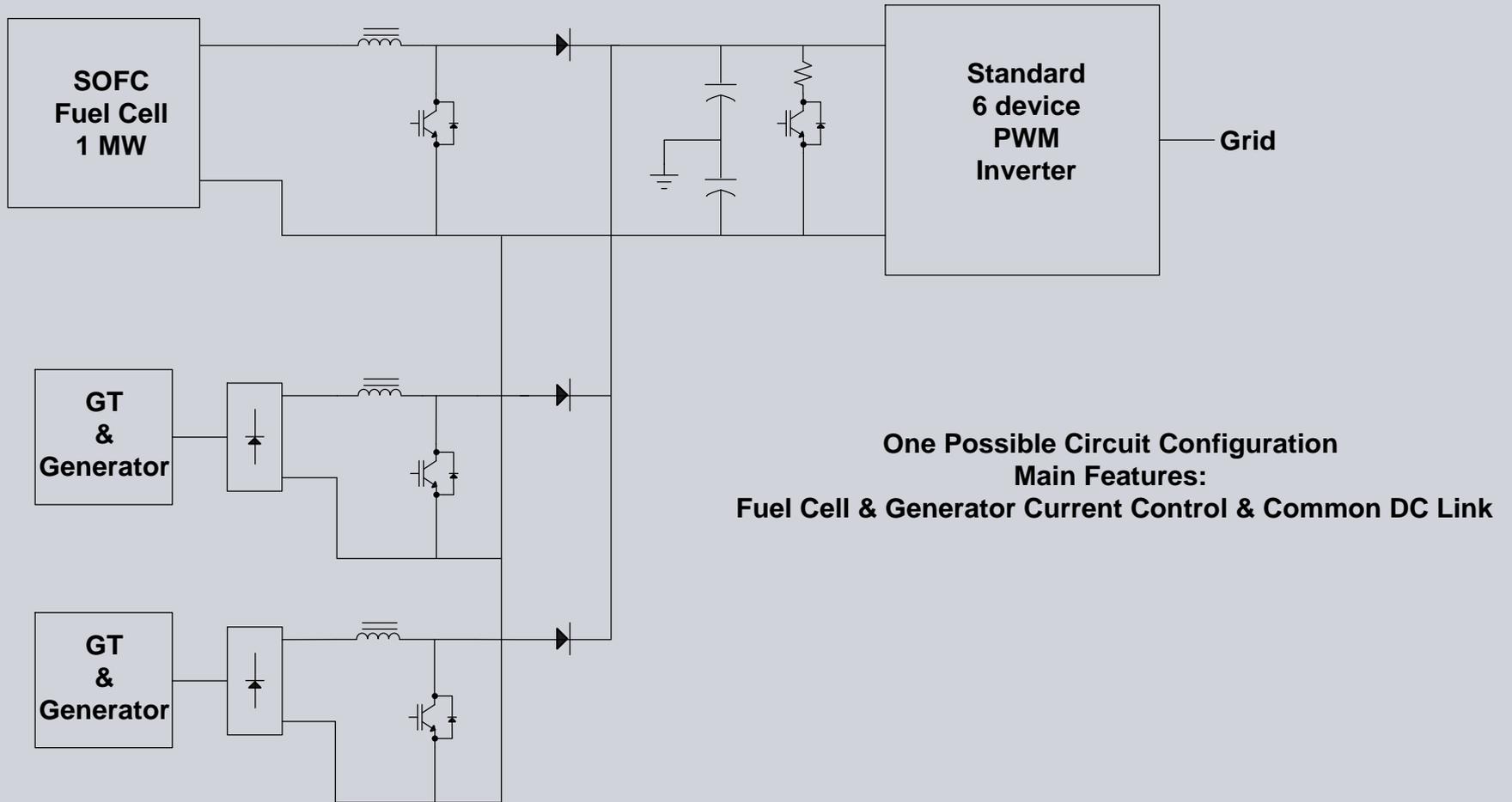
## Issues Involved When Connecting Multiple Inverters from Separate DC Links

If interconnection impedance  $\sim 5\%$  then a 1% voltage error between any two inverters will give  $V/Z = 0.01/0.05$  p.u.  
= 20% current flow

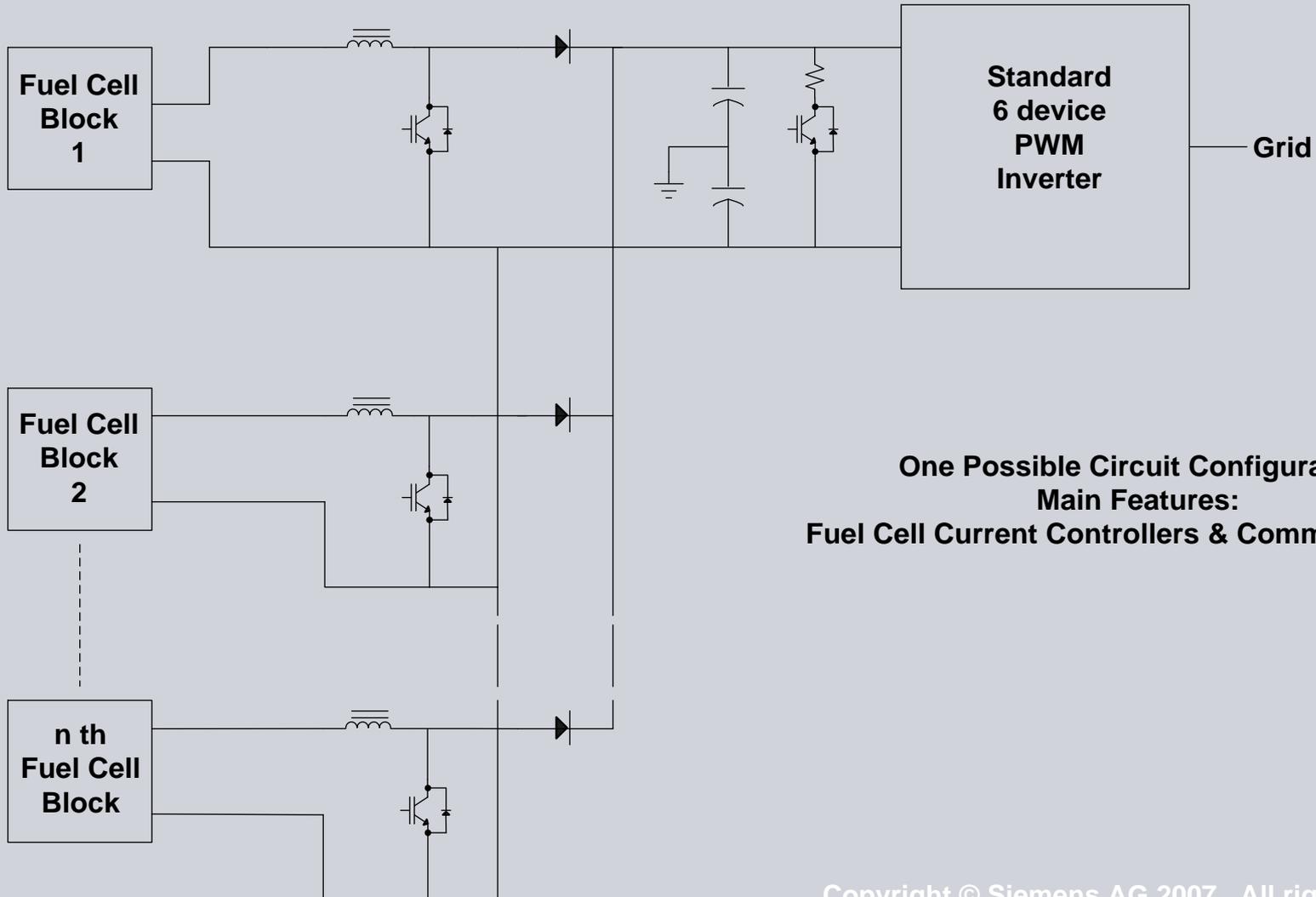


This corresponds to a 1% mismatch on the DC link or, a 0.6 degree phase reference error between the two inverter controllers

# Alternative Concept for Power Consolidation

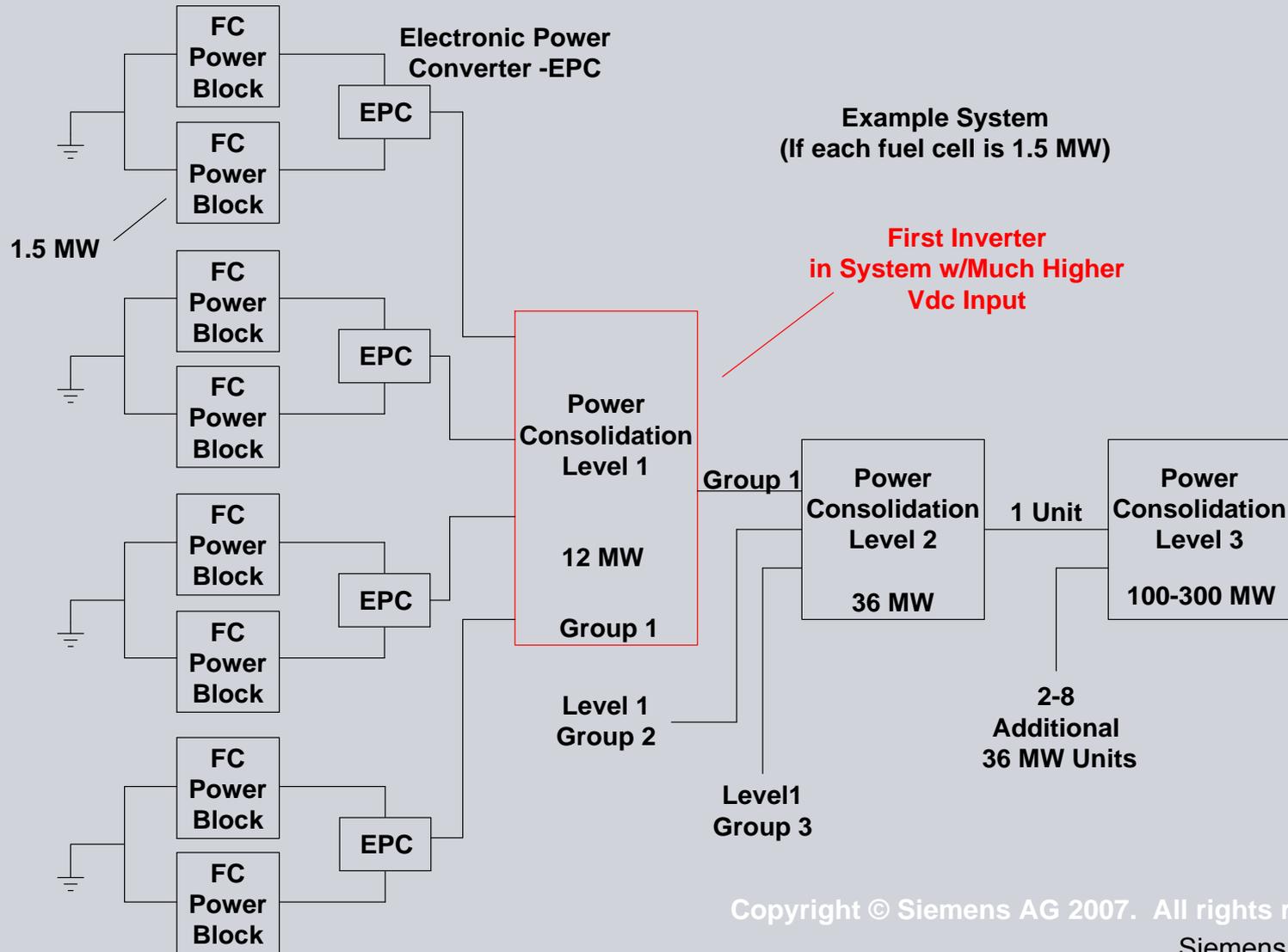


# Concept Extended to Multiple Fuel Cells



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

# Consolidation Possibility based on Previous Concept



## Power Consolidation - Review

- **Previous concept not necessarily preferred ... it's an alternative with interesting advantages**
- **A disadvantage might be circuit protection at the lower stages since it would appear to be an all DC design (excepting a high frequency chopper transformer design approach to raise Vdc)**
- **With very limited samples we have seen chopper costs at about 1/8 total PCS costs when fully incorporated ... higher if standalone**
- **The final target power level also drives design choices as the next slides address**

## Voltage & Power Sensitivity Check

- from an EPRI study:

**15 kV<sub>L-L</sub> class circuit \_peak load 4-6 MVA**

**25 kV<sub>L-L</sub> class circuit \_peak load 7-10 MVA**

**35 kV<sub>L-L</sub> class circuit \_peak load 10-16 MVA**

- Check Power Capability:

**115 kV L-L @500A = 100 MVA**

# Voltage & Power Sensitivity Check and Other Possible Approaches

- **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 potential use of higher power multi-pulse stepped square wave inverters also should be considered**

# Voltage & Power Sensitivity Check and Other Possible Approaches

- **Multi-pulse stepped square wave inverter systems switch at line frequency not kHz frequency and use GTO (gate turn off thyristor) switches not IGBT switches**
- **GTOs have much higher power handling capability ... cost advantages may exist by this approach**
- **Utility grade inverters use these devices and this method**
- **Applications include Static VAR Compensators (SVC), Flexible AC Transmission Systems (FACTS) and are built in the 100 – 500 MVA class**

# Modularity and Power Consolidation Review

- **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**

# **Modularity and Power Consolidation Review & Summary**



- **A complete system circuit design with the component means and the network for power consolidation is required to answer the \$/kW question for the high megawatt converter**
- **Once a complete system circuit design is made costing can be done and performance and cost tradeoffs for various elements can be evaluated**

# **Modularity and Power Consolidation Review & Summary**



- **One possible approach: conduct design exercises to determine a number of different circuits and system arrangements which can deliver the 100-300 megawatts to the grid**

# Modularity and Power Consolidation Review & Summary



- **From this initial study select three or four different approaches for much closer scrutiny**
- **Evaluate these on performance, availability, reliability, durability, redundancy strategies, cooling, fault tolerance, etc. ... both at the modular level and at the 300 MW grid level ... and which meet the various requirements for a modular design**
- **Gather costs (both existing & projected components) for the systems which meet the requirements and offer a durable and reliable design solution and then determine the \$/kW question for the electrical conversion system**