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

High MW Power Conditioning Systems Workshop

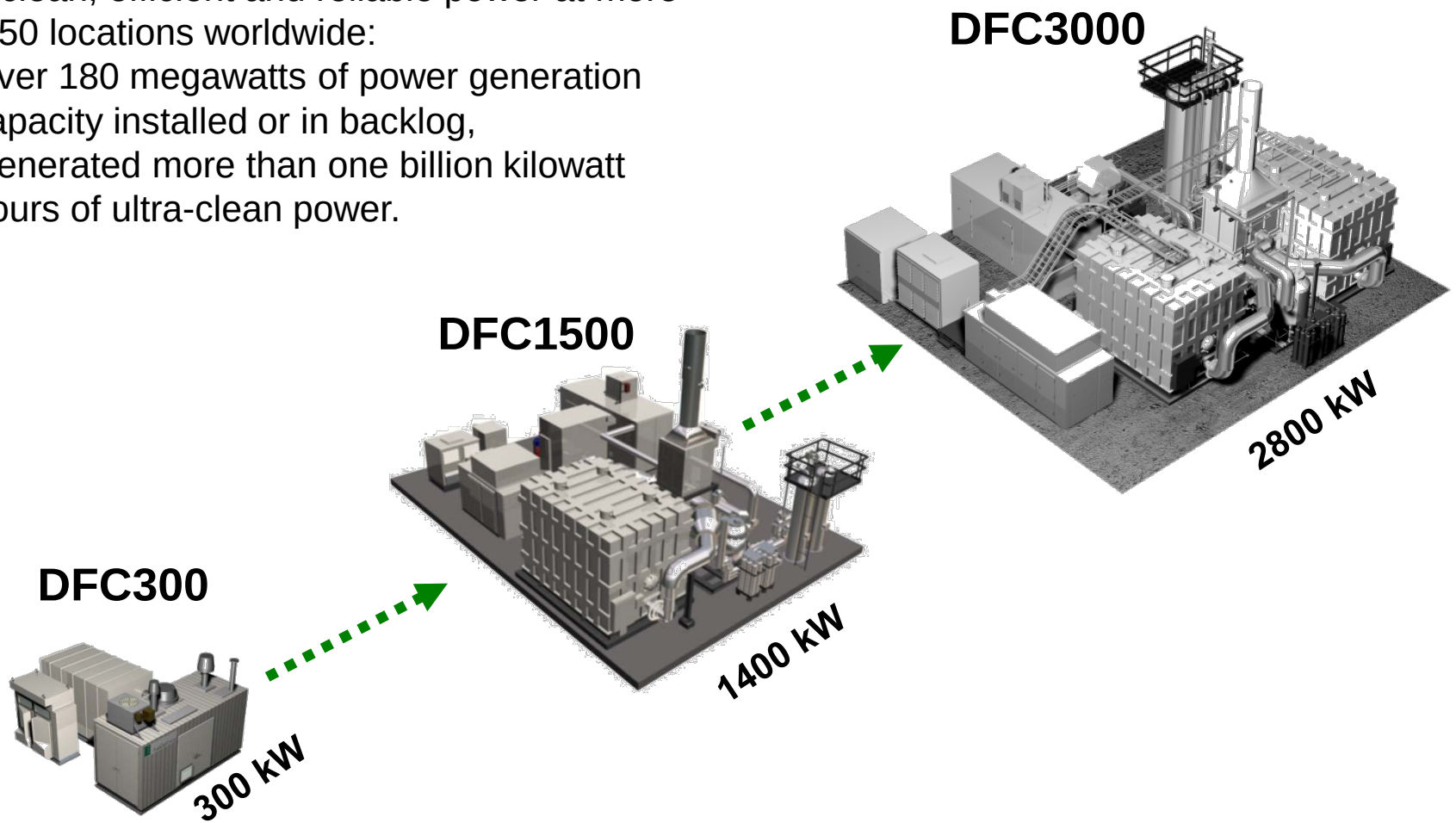
- Fuel Cell Applications for Power Electronics
- Prospects for Increased Penetration

G. Berntsen, 5/24/12

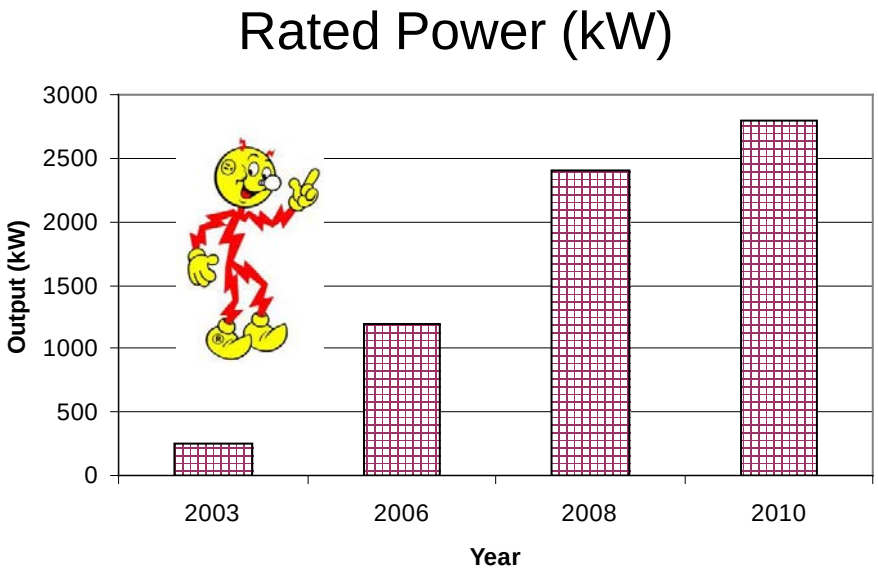
DFC Models

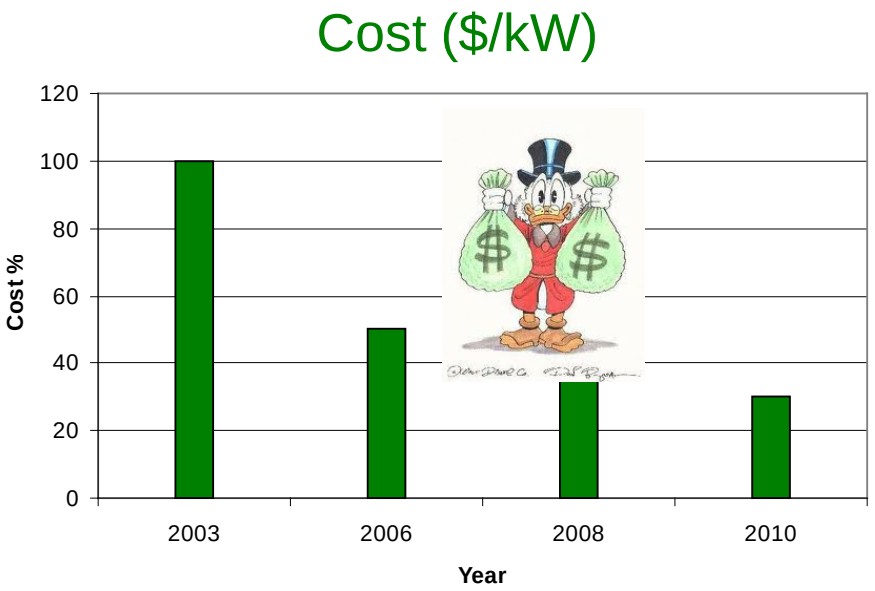
Direct FuelCell® power plants are generating ultra-clean, efficient and reliable power at more than 50 locations worldwide:

- Over 180 megawatts of power generation capacity installed or in backlog,
- Generated more than one billion kilowatt hours of ultra-clean power.



Scale-Up and Cost Reduction



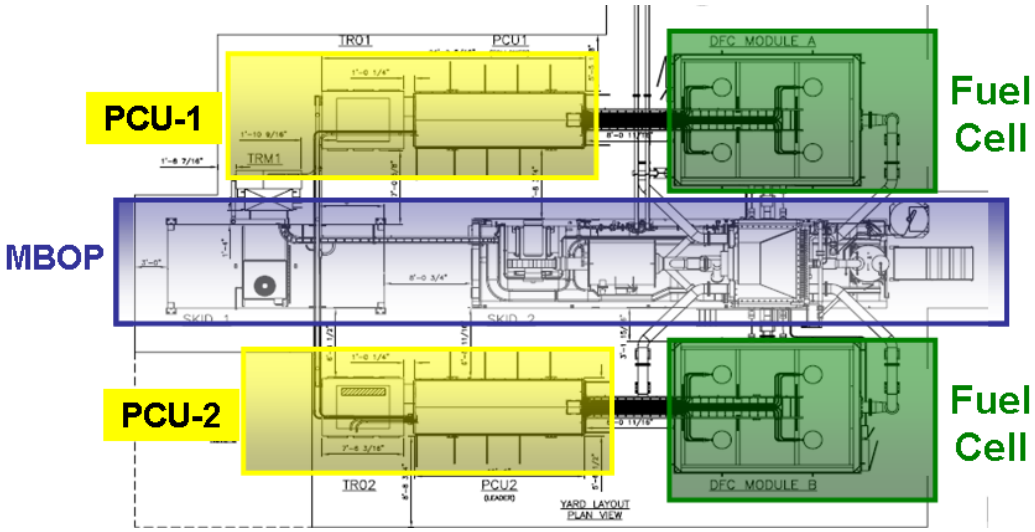


70% $/kW cost reduction achieved through:

- Value Engineering
- Power Up-Rate, Economy of Scale

Gross Margin Positive Sales

3.0 MW Plant



- (2) 1500kW Power Trains
  - Common PCU, Module = Volume Savings
- Economy of Scale Achieved Thru:
  - Common Mechanical Balance-of-Plant (MBOP)
  - Transactional Costs, Service

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Scale-Up Limitations

Fuel Cell Module Size

- Road Transport Constraints

1.4 MWnet module

>100,000 lbs.

Max. Height

Max. Width

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Multi-MW Sites (4 x DFC3000)

10.4 MW
Yulchon, S.Korea

11.2 MW
Daegu, S.Korea

22.9kV Express Feeder Connection to Sub-Station

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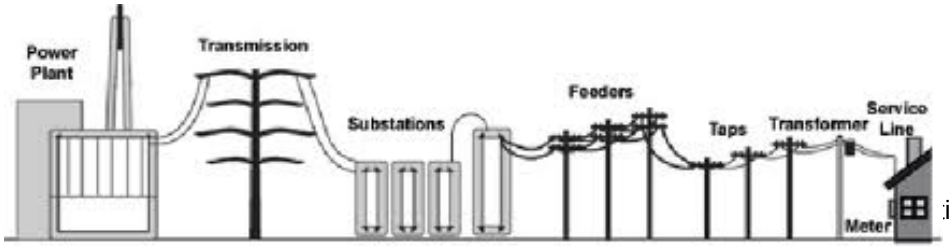
Scale-Up Limitations

Distribution System Limitations

- Feeder Capacity (7-12MVA)
  - Express Feeders needed > 1.5/3.0 MW
- Sub-Station Minimum Load
  - Voltage Regulation Limitations
  - Protection Scheme Limitations
- Smart Grid Technologies May Reduce Technical Constraints
  - Jurisdictional, Statutory Constraints.

Transmission System Interconnection

- Requires much larger plant size (50MW) to be cost effective.



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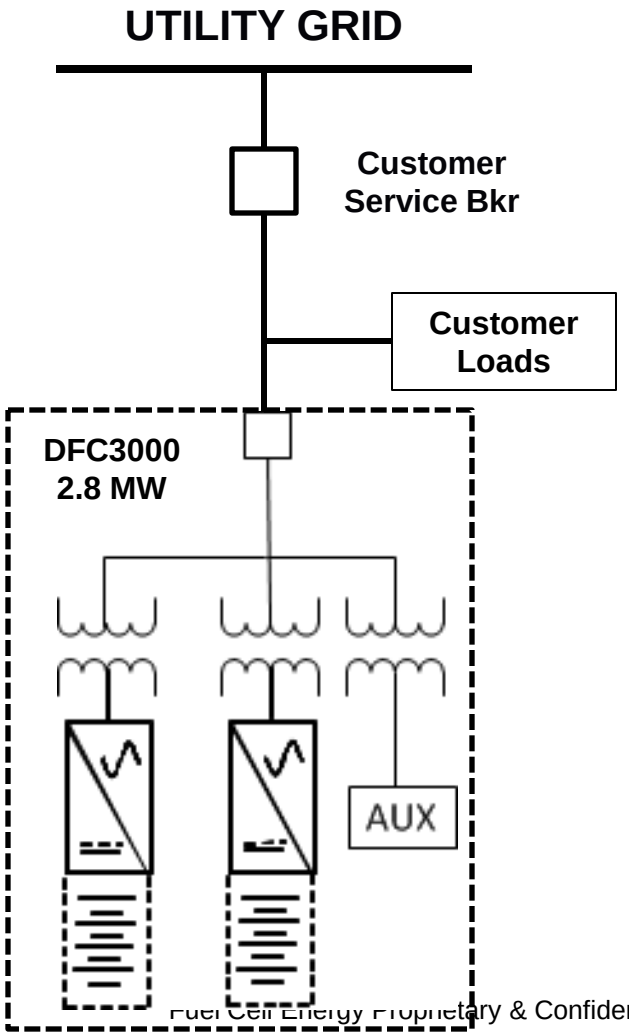
DFC Capabilities

Grid Connected Mode
Normal Operation

- Baseload, Full Power Production
- >90% Capacity Factor
- Current Control Mode
- Match & Follow Grid Voltage
- UL-1741 Anti-Islanding Detection
  - Abnormal Volt. & Freq.
  - Active anti-islanding algorithm



DFC Capabilities

Stand-Alone Mode

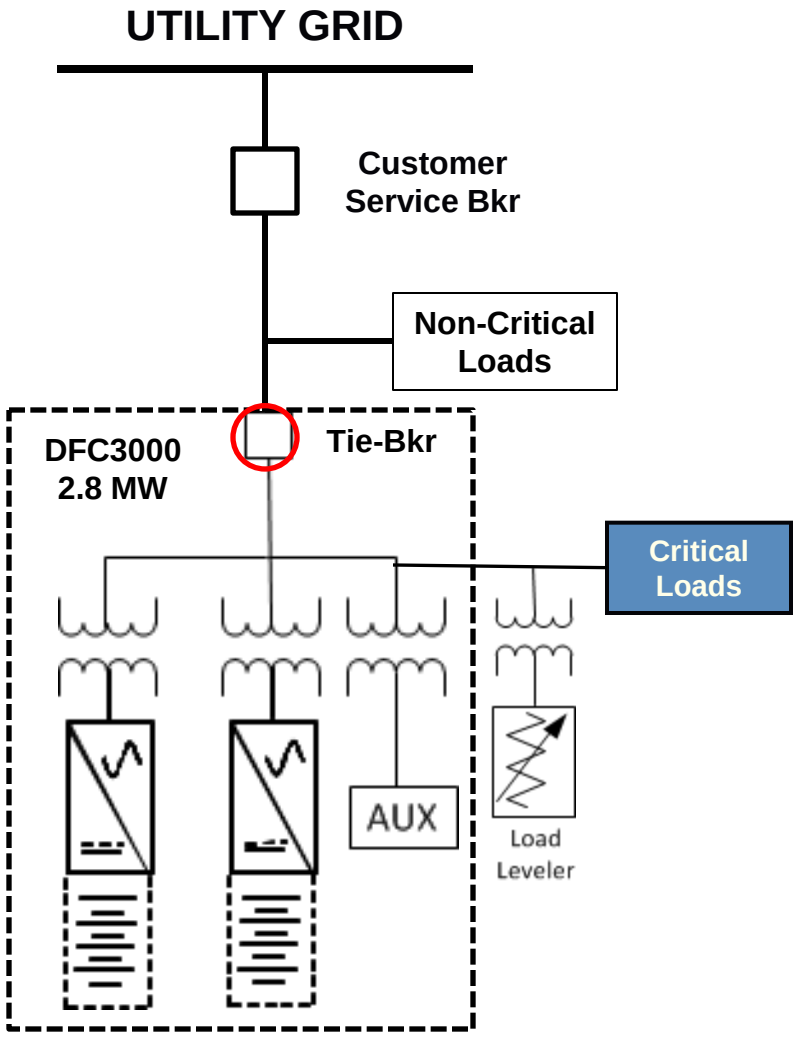
Grid Outage

Upon detection of abnormal Volt./Freq.

- Tie Breaker Opens
- Switch to Voltage Control Mode
- Voltage to Critical loads recovered <4 cycles
- Load Leveler Starts to maintain constant fuel cell load for varying loads.
  - PLC controlled resistive load bank

Challenge: Failed transitions

- e.g. Instantaneous Over-current trip instead of transition on under-voltage.
- Plan to address in LVRT development.



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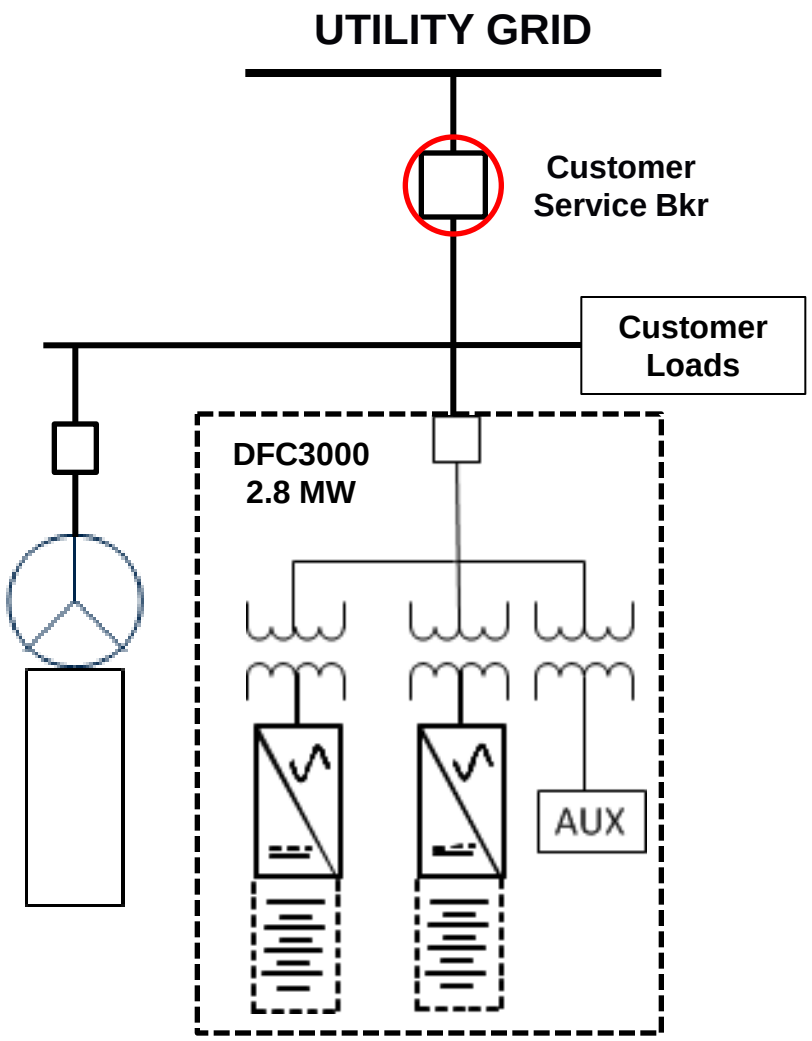
DFC Capabilities

Micro-Grid Base Load Mode

Typical Sequence of Operation:

- t0: Grid Outage
- t1: DFC transitions to Stand-Alone Mode, Facility goes dark
- t2: Genset(s) starts, Service Breaker Opens, Sends micro-grid signal to DFC
- t3: Genset connects to bus at rated voltage and frequency.
- t4: DFC syncs with genset and connects to bus with wider V&F relay settings and active anti-islanding disabled.
- t5: DFC ramps to rated power in 5 minutes.



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Micro Grid Experience

FCE is actively implementing micro-grid mode at several sites.

- Parallel operation with other generators when utility service unavailable
- Customer facilities, behind-the-meter applications
- Interruptible and Seamless Applications

Recent Micro grid Implementations:

Central CT State University
- Gensets & 1.4MW fuel cell

San Jose Water Treatment Plant
- Gensets & 1.4MW fuel cell

Santa Rita County Jail
- DOE Smart Grid Demonstration
- Facility Static Switch Disconnect
- 1MW early generation Fuel Cell
- Gensets,1mw solar,
- 2MW energy storage

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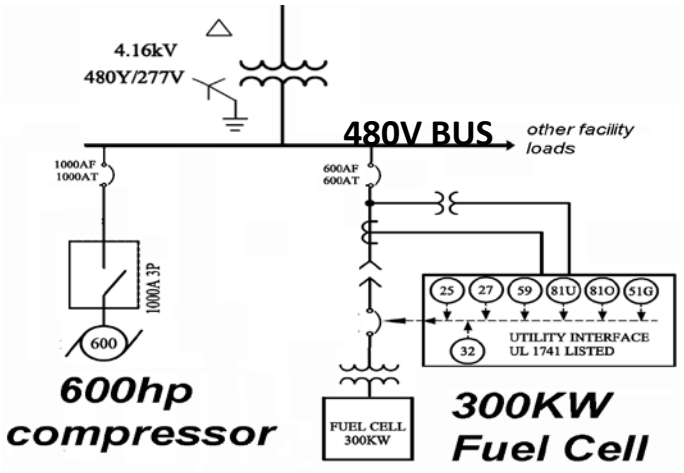
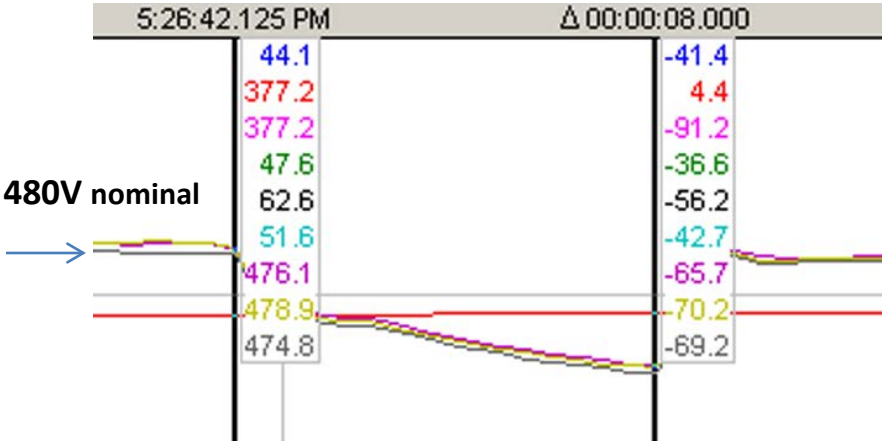
Reactive Power Support

All plants capable of generating rated output from (-) 0.9 to (+)0.9 pf





Case Study:

- *A 600hp compressor's start-up pulled bus voltage down below 88% for almost 8 seconds.*
- *The voltage sag was below UL-1741 / IEEE1547 limits requiring the fuel cell to disconnect.*

Solution:

- *The controls that start the motor now also provide a signal to the fuel cell to add 130KVAR.*
- *The leading reactive power offsets the compressor start-up and voltage sag is now much less, enabling the fuel cell to stay connected.*

In Development

Low Voltage Ride-Through

- Germany is a New Area of Business Development
- LVRT required for fuel cells connected to the Medium Voltage Network (i.e. Distribution System)

Challenges:

- Technical Approach
- German Certification Agency
- Testing Facility

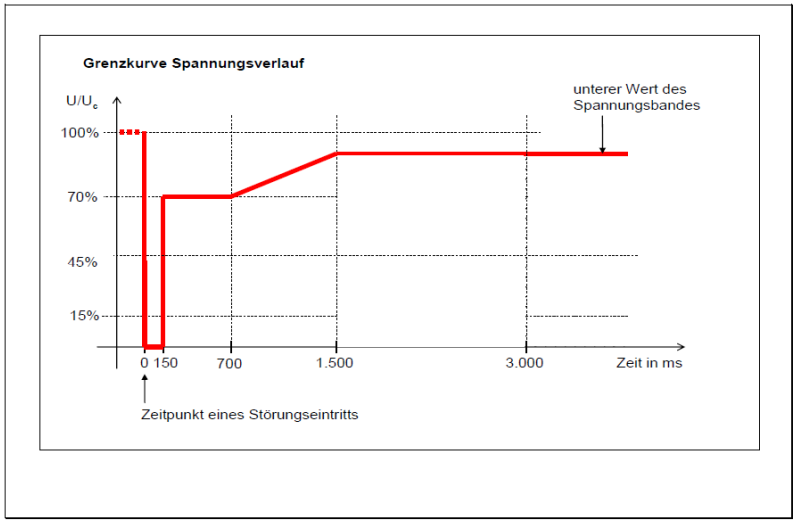


Figure 2.5.1.2-1: Borderline of the voltage profile at the network connection point of a type-1 generating plant

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Favorable Trends

Recent Legislation in Connecticut and California enables utilities to procure Distributed Generation

- Ensures optimal siting for enhancing Distribution System
  - Power Quality
  - Reliability
  - Load Constraints
- Reduces project uncertainty regarding Electric System upgrade feasibility and costs.

60MW Projects in process in S. Korea with Utility

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QUESTIONS?