Energy Storage (ES) Supported

Photo-Voltaic (PV) Power Conditioning, including

Ancillary Services Provision and Isolated Grid Support

Presentation Contents

- **Commercial to Utility Scale PV Power Conditioning *today*:**
  - ✓ **PowerGate® Plus three-phase PV Inverters;**
  - ✓ **PV Plant Installations; and**
  - ✓ **PV View™ Plus, Remote Monitoring and Energy Management Systems.**

- **Utility Scale PV + ES Power Conditioning *tomorrow*:**
  - ✓ **PV + ES Inverter Power Train;**
  - ✓ **Ancillary Service Provision; and**
  - ✓ **Island Grid / MicroGrid Operation Capability.**

- **SatCon PV + ES Electrical Power Equipment Packages:**
  - ✓ **PV + ES Power Converter System; and**
  - ✓ **Project Management, Engineering, Manufacturing, Installation, Commissioning and After-Market Services.**

Commercial to Utility Scale PV Power Conditioning *today*

➢ PowerGate® Plus Photovoltaic Inverters (Gen II):

30kW ⟷ ***500kW***

- **First turn of the product line since its introduction, since 2004;**
- **Designed for Higher Efficiency, Shorter Lead Times, and the Next Level of Durability and Reliability; and**
- **100+ MW of PowerGate PV Inverters delivered 2007.**

Commercial to Utility Scale PV Power Conditioning *today*

➢ PowerGate® Plus Photovoltaic Inverters (Gen II):

Attribute	Highlights
Efficiency	✓ Continued leadership in efficiency.
Ease of Installation	✓ Improved ease of cabling.
Service	✓ Inverter Monitoring with Help Desk.
Technology	✓ State of the Art Digital Controls. ✓ Industrial grade equipment.
Reliability	✓ G90 galvanized steel enclosure. ✓ Printed circuit boards for- 40º C to plus 85º C range.
Economics	✓ Introduction of 250kW, 375kW(UL), 400kW(CE), and 1000kW(UL & CE) ratings. ✓ State of the art, Maximum Power Point Tracking (MPPT) algorithm for improved energy harvesting.

PV Plant Installations

225kW Ground Based Installation

PV Plant Installations

1.6MW Building Integrated PV (BIPV) Plant Installation at Google's corporate headquarters in Mountain View, CA equipped with PowerGate® PV Inverters

PV View™ Plus, Remote Monitoring and Energy Management

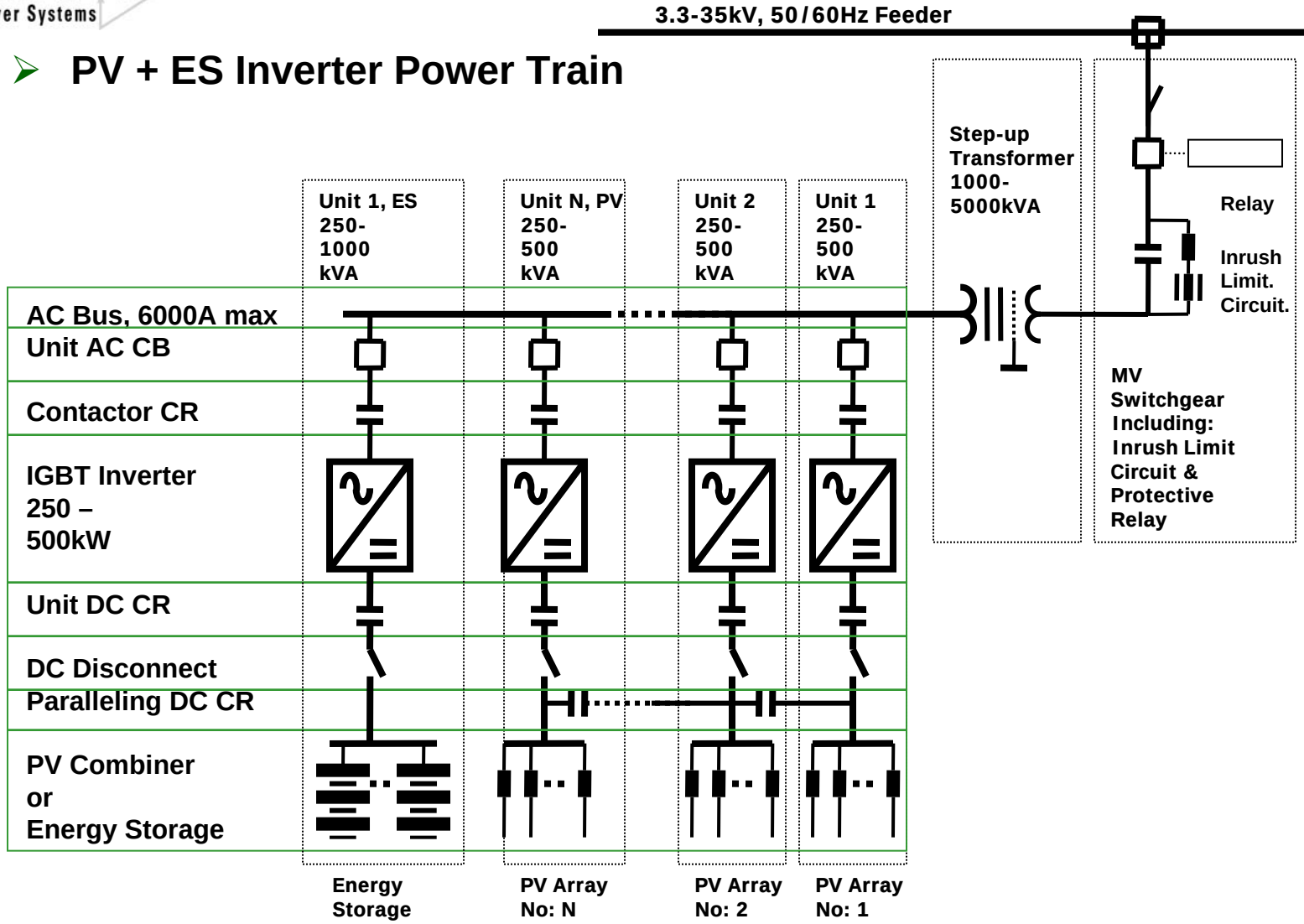
- **PV View™ Plus Remote Monitoring System:**
  - **Introduced in Late 2007:**
    - ✓ **Beta System operating in NJ since June of 2007.**

Home Page

Energy Reporting

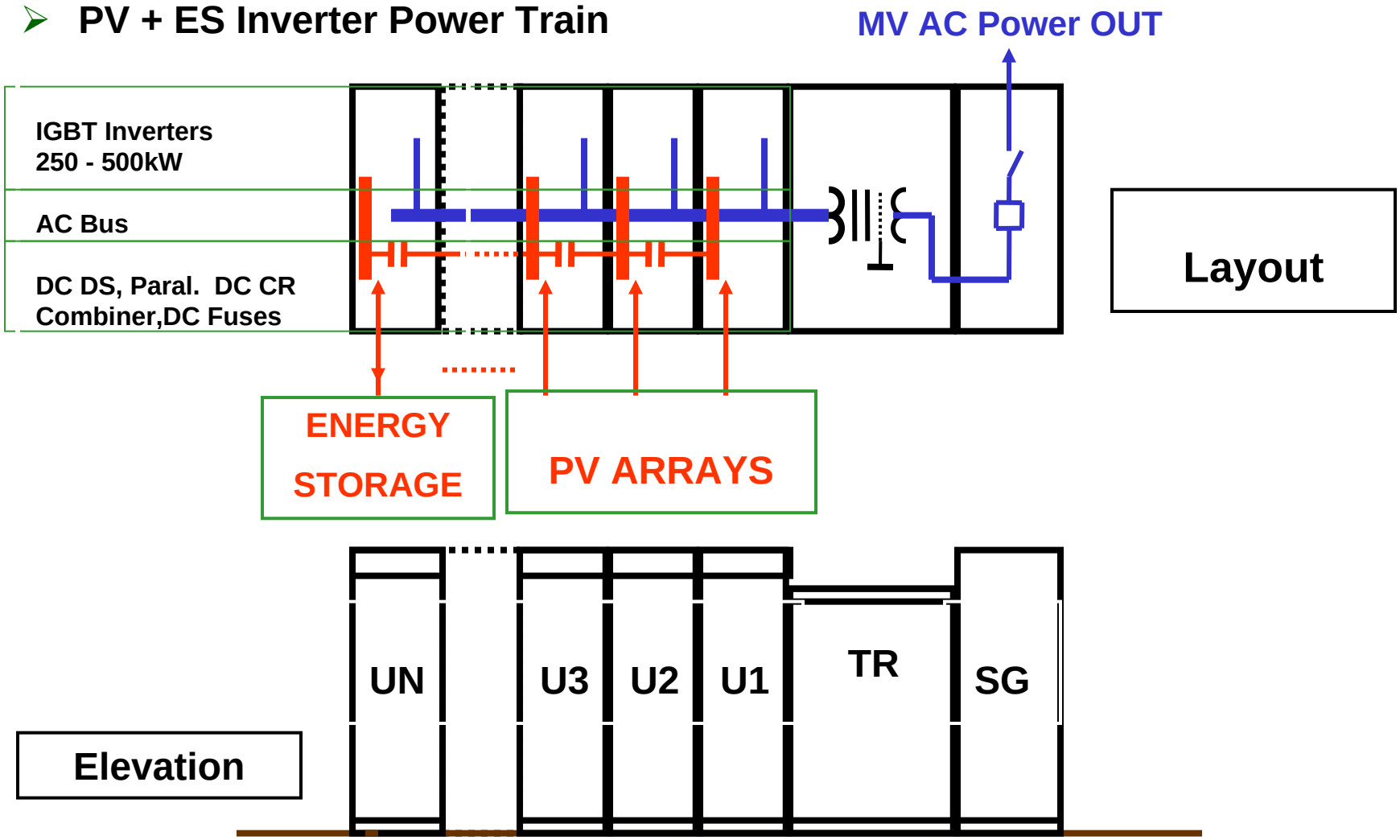
Utility Scale PV + ES Power Conditioning *tomorrow*

- **PV + ES Inverter Power Train**



Utility Scale PV + ES Power Conditioning *tomorrow*

- **PV + ES Inverter Power Train**



Utility Scale PV + ES Power Conditioning *tomorrow*

➢ PV + ES Inverter Power Train Application Versatility

Aside of PV power conditioning Inverter Units, when combined with energy storage device, can also be applied for:

1. **Voltage regulation via dynamic VAR injection/modulation (STATCOM role) including voltage sag compensation;**
2. **BIPV Customer demand peak shaving/utility load following;**
3. **Utility Ancillary Services such as:**
   - ⇨ **Frequency Keeping/Regulation;**
   - ⇨ **Instantaneous Reserve for frequency recovery after U/F events; and**
   - ⇨ **High-Inertia Generation to resist developing frequency deviations.**

✓ **Power Train (PT) Inverter Unit Redundancy/Improved Uptime:**

- ⇨ **Through addition of redundant Inverter Unit(s) in PT.**

Utility Scale PV + ES Power Conditioning *tomorrow*

➢ PV + ES Inverter Power Train Ancillary Service Provision

Item No:	Feature Description	ES Required	Impact on Inverter Size/Price
1	**Distributed Spinning Reserve (DSR) -** WATTs Generation on Demand	Yes, **15 - 30 minutes**	Inverter kVA Rating = **kW (PV)+ kW (DSR)**
2	**Distributed Frequency Regulation (DFR) -** WATTs Gener. and Absor. on Demand	Yes, **30-60 minutes**	Bi-direct. Inverter kVA Rating = **kW (PV) +/- kW (DFR)**
3	**Utility Load Following (ULF) -** Boosting the PV Generation Capacity Value	Yes, **2 - 4 hours**	Inverter kVA Rating = **kW (PV), + Boost Chopper**
4	**Frequency Stability Support (FSS) -** High Inertia Behavior of PV Generator	Yes, **30-60 seconds**	Inverter 10-sec kVA Rating = **kW (PV)+ 10-second kW (FSS)**
5	**Grid Faults / LV Ride Through (LVRT) -** An alternative to Anti-Islanding	Yes**, 1-10 seconds**	**No Impact** on Inverter Size, Minimum Impact on Inverter Price.
6	**Dynamic Voltage Support (DVS)** - Capacitive and Inductive VARs Generation	No	Inverter kVA Rating = **SR(kW (PV) **2 + kVAR (DVS)**2)**

Summary for Ancillary Services Capable DG

- **PV + ES Inverter based and Ancillary Service Capable DG Benefits**

  1. **Value of ancillary services can be significant and can represent *an incremental revenue stream* for DG owners;**
  2. **Low cost communication and monitoring or SCADA facilities would *extend aggregation opportunities* for DG to participate in the ancillary service market;**
  3. **Higher penetration of DG will *increase ISO options regarding T&D grid operation* and development decisions which can lead to:**
     - ⇨ ***Lower overall operating costs*; and**
     - ⇨ ***Enhance competition in ISO markets* for frequency control and spinning reserve as the demand for these services increase with intermittent renewable generation.**

Island Grid / MicroGrid Operation Capability

- **PV + ES Inverter Power Train for An Island Grid / MicroGrid Application**

Consider an *application case* of existing PV and Fuel Cell (FC) on-site generation equipment, owned by nearby critical facility, whose original purpose was to:

1. **Provide local facility load support through on-site generation; and**
2. **To sell excess green / clean power to utility grid customers.**

Can the existing grid-connected PV and FC on-site generation be retrofitted with ES to provide for critical facility load support during utility grid outages?

- ⇨ **Without any modifications to the existing grid-connected power electronics and controls?**
- ⇨ **Without any significant re-adjustments of facility load profile?**

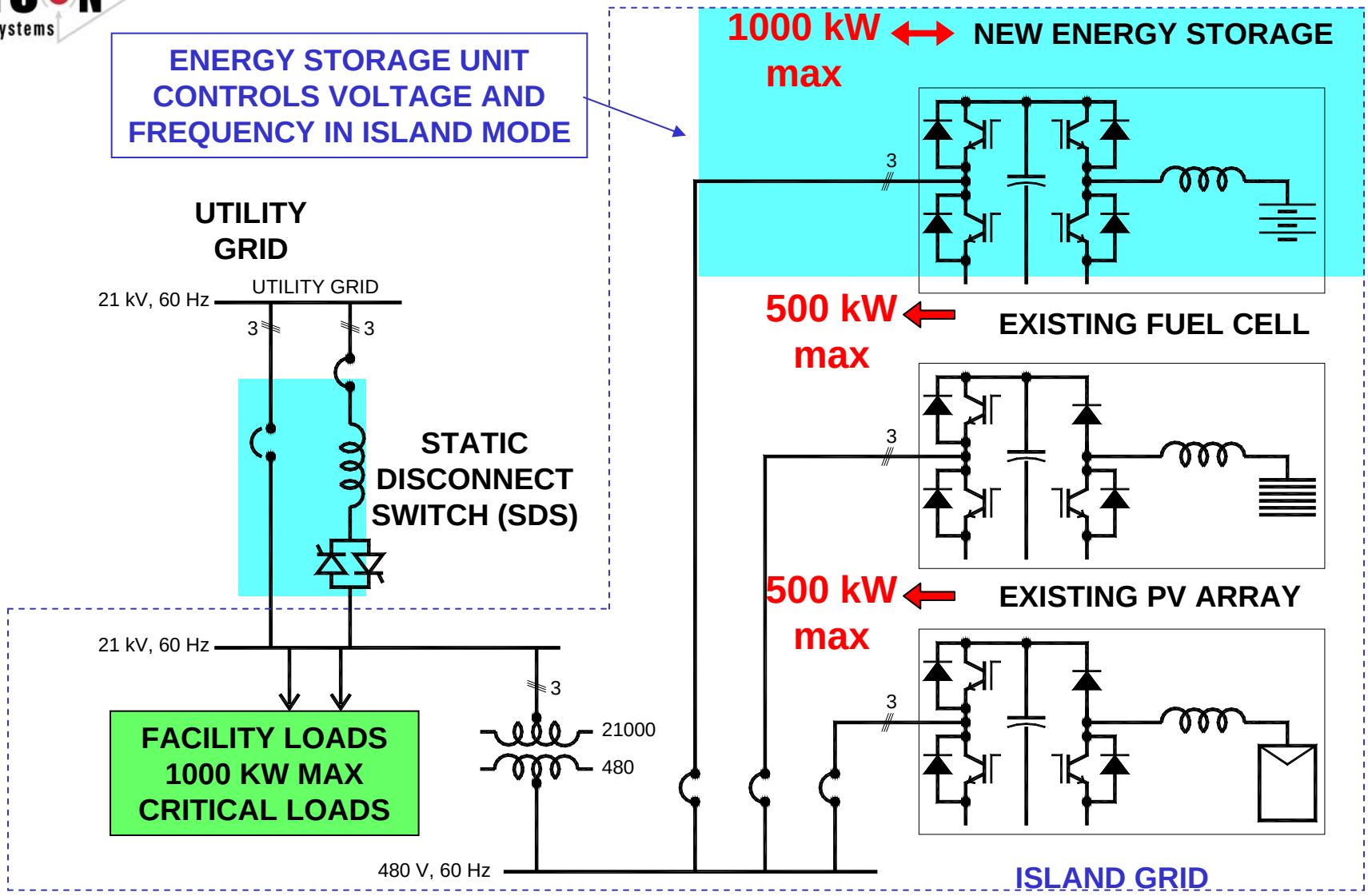
Island Grid / MicroGrid Operation Capability

The answers are positive to all questions!

Existing normally grid connected PV and FC generation can be made to support an islanded distribution portion of the utility grid or critical facility related micro-grid during utility grid outages by retrofitting the island grid with following additional equipment:

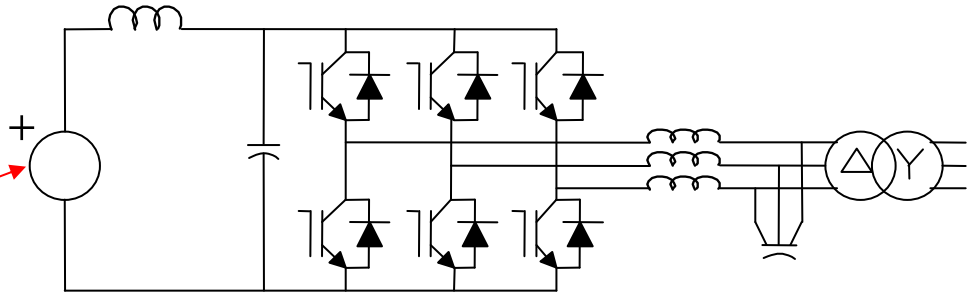
- ⇨ **A suitably rated AC-Connected Energy Storage System (ACCESS); and**
- ⇨ **A fast, Sub-cycle / Static Disconnect Switch (SDS).**

ACCESS and a SDS Enable Support of an Island Grid



ACCESS - Single Stage Power Conversion
From DC Energy Storage to AC Bus

Energy Storage Device Determines DC Voltage



DC Energy Storage | DC Filter | DC/AC Converter | AC Filter | Transformer

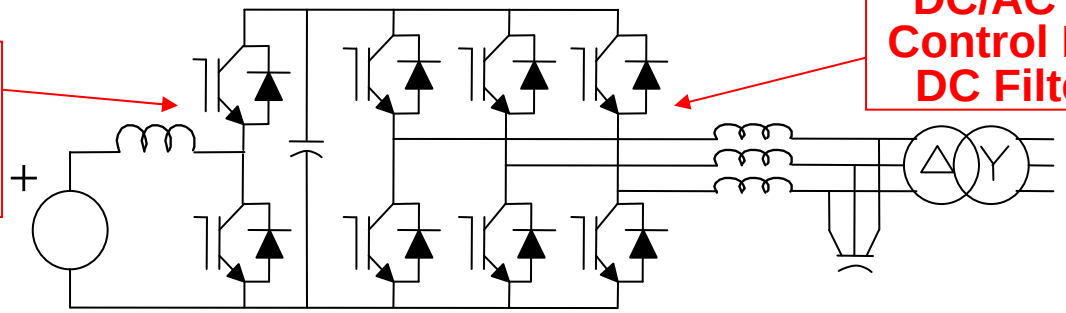
Converter Control Determines Current to/from Storage Device

SatCon Multi-Input, Single-Stage, 2.4 MW, 13.8 kV, custom-engineered and built power converter system (PCS) - 4 x 600 kW converters with external transformer (not shown).

Two-Stage ACCESS- From DC Energy Storage to AC Bus uses Optimum DC Filter Voltage

DC/DC Chopper Determines Current to/from Storage Device

DC/AC Converter Control Determines DC Filter Voltage



DC Energy storage | DC/DC Control | DC Filter | DC/AC Converter | AC Filter | Transformer

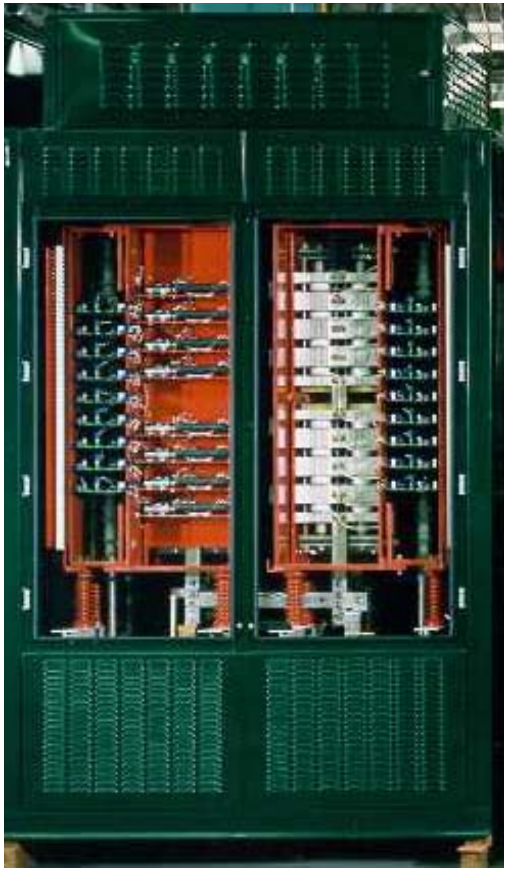
SatCon Multi-input, 2-stage,
1.5 MW, 480 VAC PCS
- 4 x 375 kW converters with internal transformers.

SDS Minimizes the Impact of Utility Grid Faults on Island Grid Voltage

Medium Voltage Sub-cycle Disconnect Switches (MV SDS)

- *Sub-cycle* voltage sag sense & disconnect times, half-cycle, or 10ms max,
- *Solid-state* (thyristor valve based) switching, up to 35kV system voltage and 25kA fault isolation rating,
- *Static*, wear & tear-free, including *switching parts*,
- Equipped with conventional *service isolation and bypass disconnects*.

SatCon MV Sub-cycle Disconnect Switch

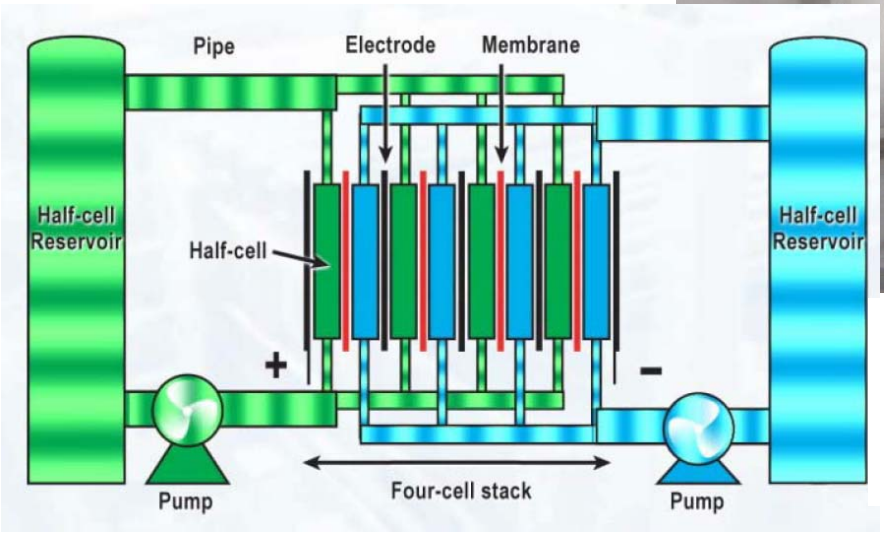


Energy Storage Device Options

- **Energy Storage options by length of required outage support:**

  - Long term (minutes/hours) storage
    - various battery technologies (cells have defined capacity)
    - flow batteries (storage capacity depends on electrolyte volume)
  - Short term (< 1 minute)
    - transitional power for brief grid outages or while fueled generation is started
    - flywheels
    - ultra-capacitor bank

Flow Battery - Output KVA depends on Power Converter, Stored Energy Depends on Electrolyte Volume



SatCon Power Converter System (375 kVA/250 kW) + VRB Flow Battery (2 MWh) - PacifiCorp, Castle Valley, Utah

Diesel Generator with Flywheel Energy Storage Provides No-Break Power for an Island Grid

Diesel (normally at rest) provides continuous power (through clutch) when needed

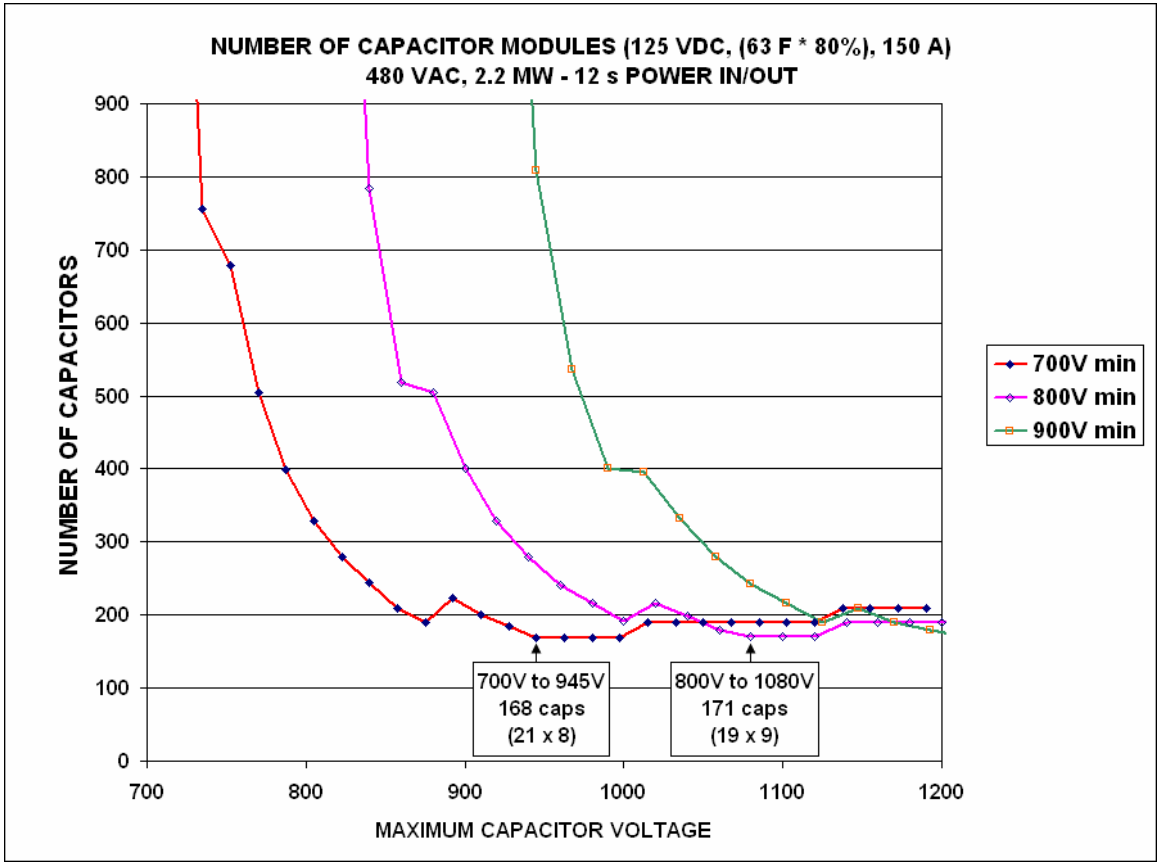
Low-speed flywheel provides full output for 12 seconds during engine startup

SatCon flywheel generator with coupled diesel engine regulates voltage/frequency while supplying 2.2 MVA output to an AC Grid

SatCon Rotary UPS Installation for NIST, CO

Ultra-Capacitors are a Static Alternative for Transitional Power while Fueled Generation is Started

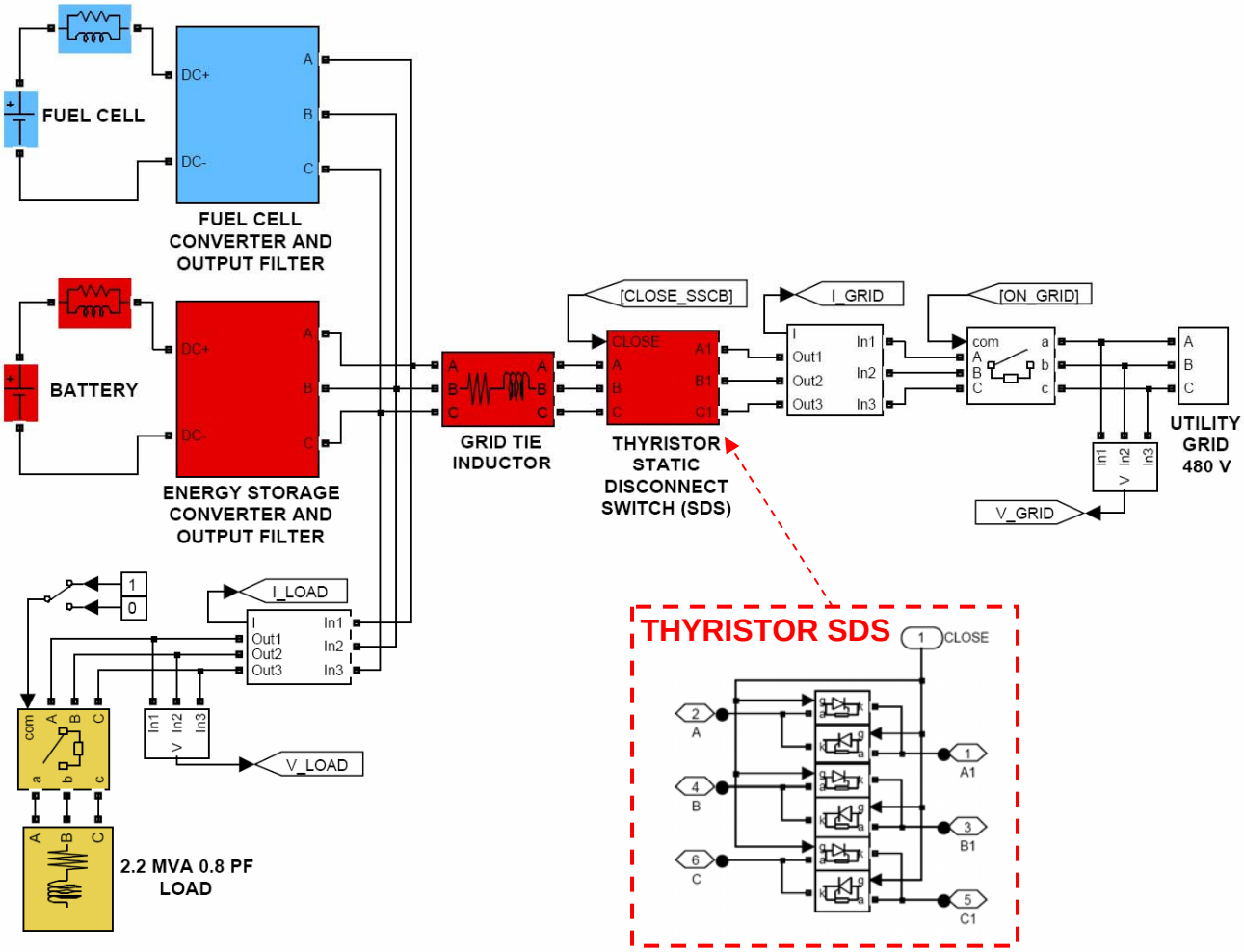
Capacitor + DC/AC Converter can replace Flywheel Generator



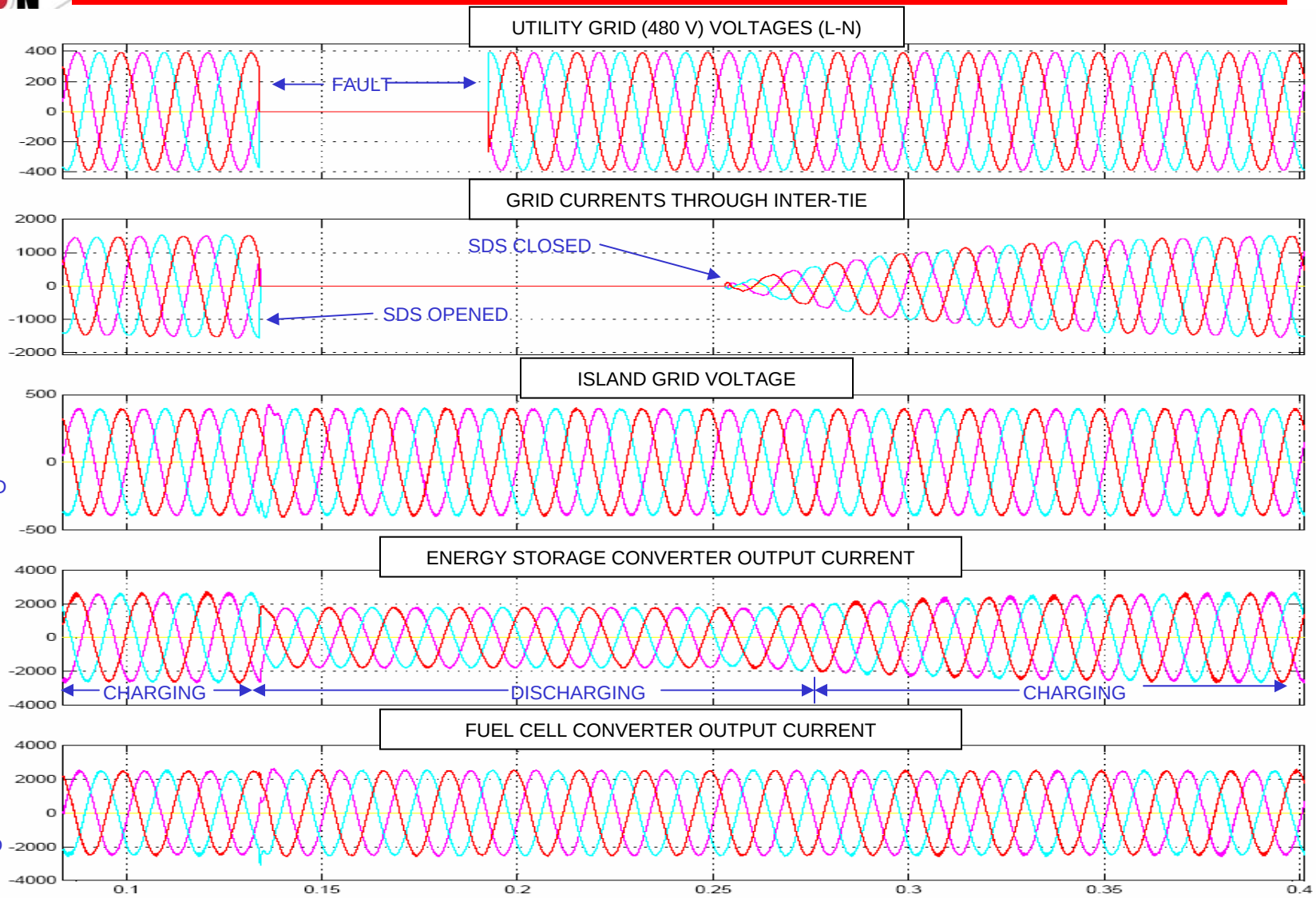
MAXWELL TECHNOLOGIES
BMOD0063 P125
MODULE
63 F, 125 V
150 A CONTINUOUS
SERIES CONNECTION TO 1500 V
20 YEAR LIFE ACHIEVABLE

Number of modules for specified power and useable energy depends on working DC voltage range selected

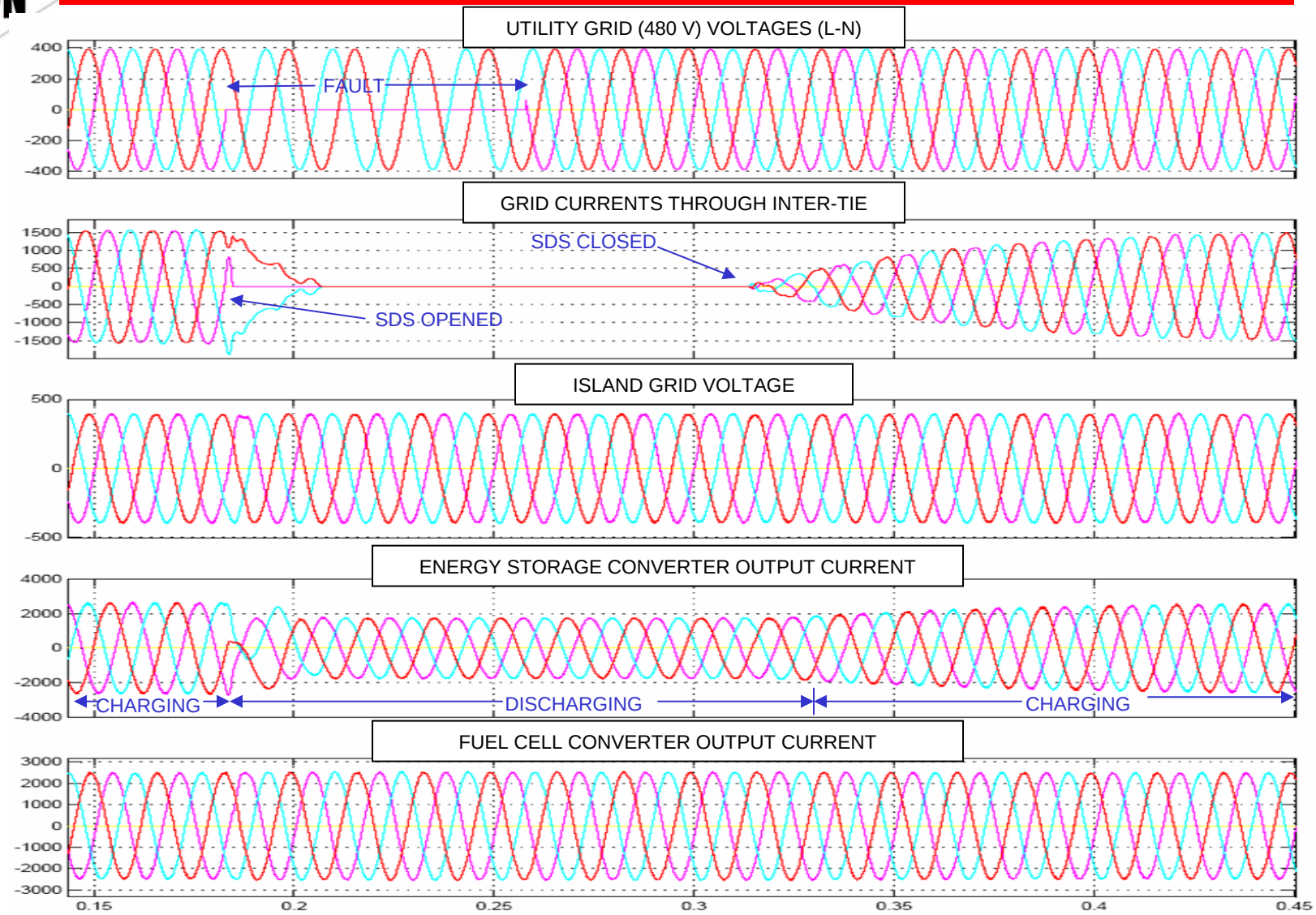
Simulink Model of Island- Micro-Grid with SDS, Fuel Cell, ACCESS for 2.2 MVA Critical Facility Load



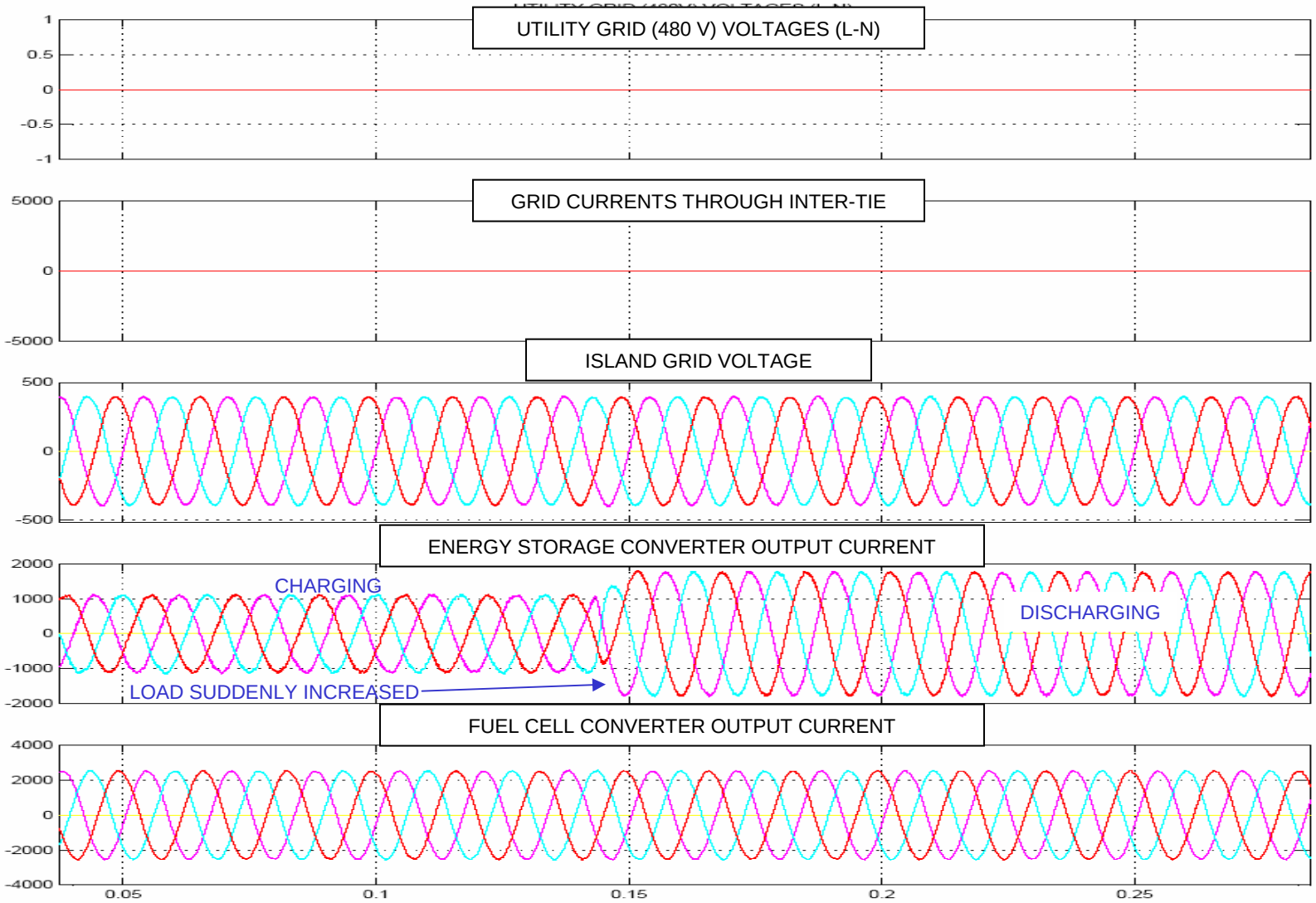
Simulated 3-Phase Fault on Utility Grid
2.2 MVA, 0.8 P.F. Constant Load on Island Grid



Simulated Single-Phase Fault on Utility Grid
2.2 MVA, 0.8 P.F. Constant Load on Island Grid



Simulated Operation in Island Mode - Load Suddenly Increased (1.1 to 2.2 MVA, 0.8 P.F.)



SatCon's Turnkey Project Delivery Capability

- **<u>Scope of Equipment Supply</u> (Major Power System Components), to provide for Island- or Micro-Grid island operation in <u>retrofit</u> applications, includes:**

    1. **Bi-directional Power Conditioning System (B-PCS);**
    2. **Short-term or Long-term Energy Storage Device (S-ESD or L-ESD);**
    3. **Medium Voltage Sub-cycle Disconnect Switch (MV SDS).**

SatCon's Turnkey Project Delivery Capability

- **Scope of Equipment Supply (Major Power System Components) to provide for Private- Micro- Grid Island enable operation in new, "green-field" applications, includes:**

1. **Bi-directional Power Converter System (B-PCS) combined with Unidirectional Power Converter System (U-PCS) for Clean-Energy Source (Fuel Cell, PV Array or Wind Turbine) utility grid interface ;**
2. **Short-term or Long-term Energy Storage Device (S-ESD or L-ESD);**
3. **Low Voltage or Medium Voltage Sub-cycle Disconnect Switch (LV-SDS or MV-SDS).**

SatCon's Turnkey Project Delivery Capability

- **SatCon – Project Management, Engineering, Manufacturing, Installation, Commissioning and After-Market capabilities provide for:**
  1. **Island- Micro-Grid Power System *Design Engineering*;**
  2. ***Project Management* and Electrical & Controls *Equipment Manufacturing*;**
  3. **Through an ES Partner: Energy Storage Device *Engineering and Manufacturing*;**
  5. **Through an Electrical Contractor: the performance of *Civil Works and Equipment Installation*;**
  6. **SatCon and ES Partner: to perform Power System *Commissioning and After-Market Services* (Warranty, PM or Extended Warranty contracted Services);**
  7. **SatCon and ES Partner, to perform *Project Performance Reporting*.**

Summary for Isolated Grid

- **Addition of AC-Connected Energy Storage System (ACCESS) equipment to an existing alternative energy generation equipment installation increases the DG installation value by:**
  - **enabling existing generation *to support critical*, local facility *load during utility outages*; and**
  - **allowing more *cost-effective energy efficiency management* when the utility grid is available.**

- **Addition of a fast Static Disconnect Switch (SDS) equipment *allows separation from a faulted utility grid* without significant deviation of the micro-grid AC bus voltage, *enables the facility load ride-through/operation continuity*.**

SatCon Power Systems

Thank you for your attention.

Contact:

✓ **(905) 639-4692**

✓ **Janos.Rajda@SatCon.com**