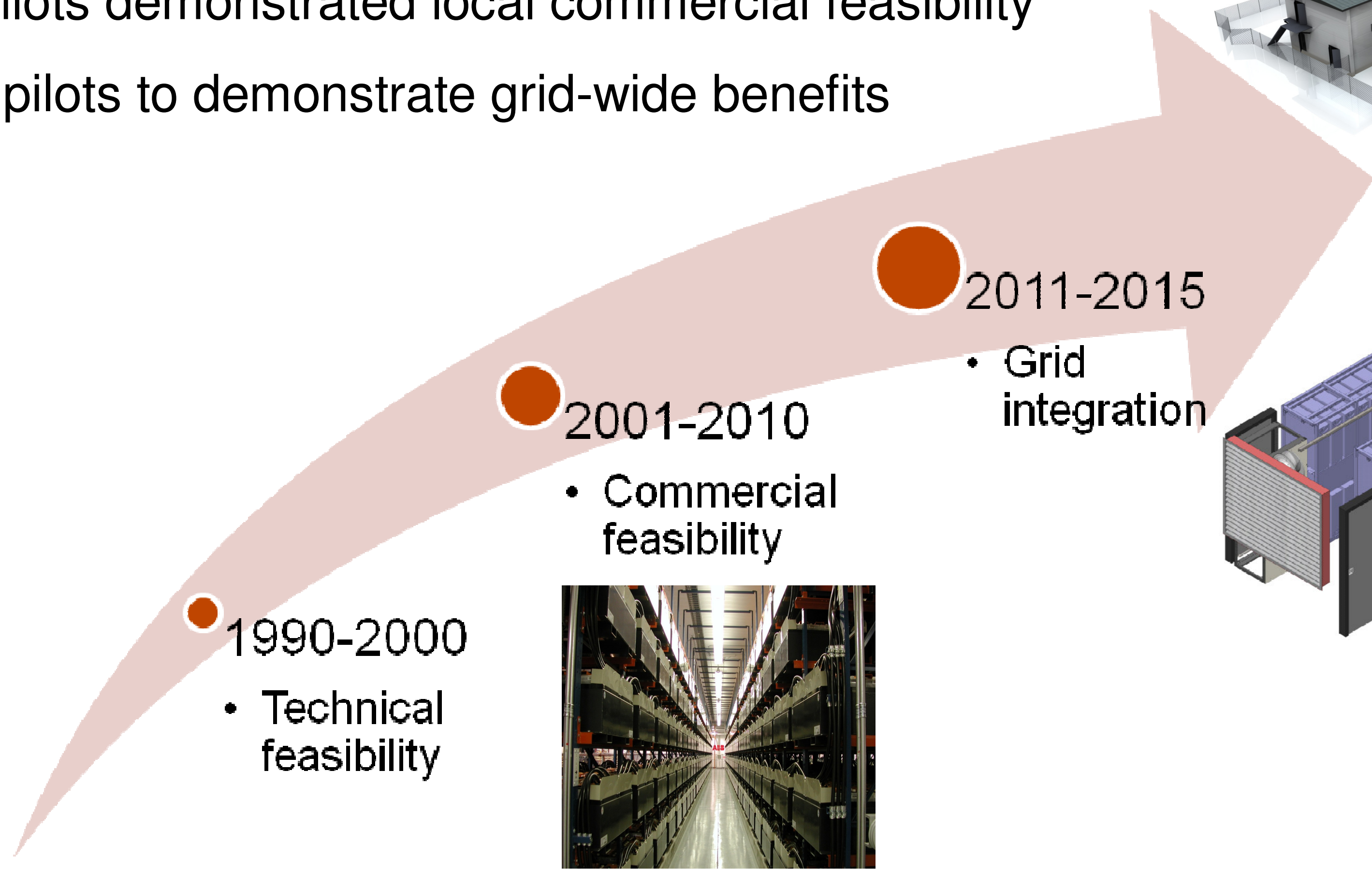
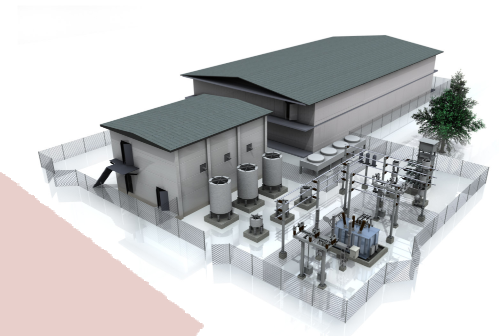
Power Electronics - February 8, 2012 - IEEE PES meeting in Chicago

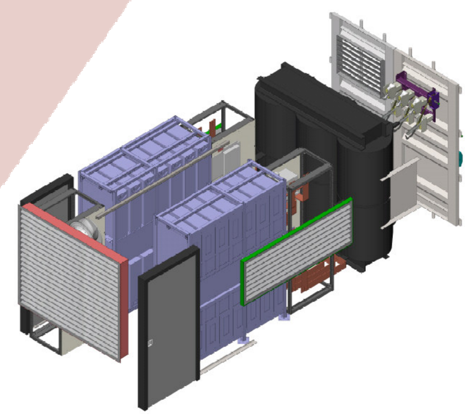
BESS Overview - Components, Drivers, Applications

Energy Storage Systems
Becoming part of the Smart Grid

- Pilot projects
  - Early pilots demonstrated technical feasibility
  - Later pilots demonstrated local commercial feasibility
  - Future pilots to demonstrate grid-wide benefits







ABB

Energy Storage Value Chain
Where to apply and which applications?

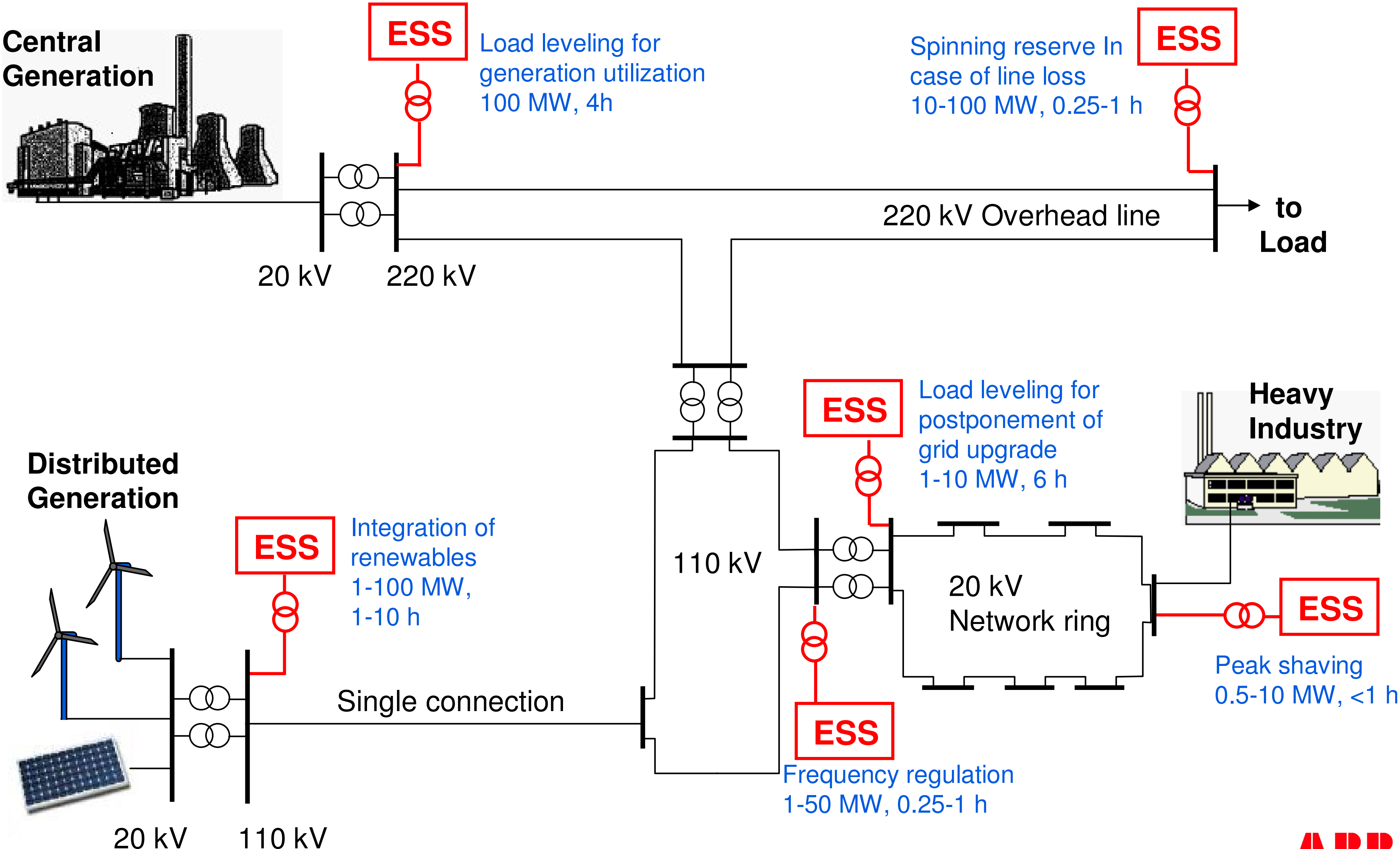
Generation
- Renewables capacity firming
- Capacity Firming and ramping
- Energy & Power applications

Transmission
- Ancillary services
- Frequency regulation
- High power applications

Distribution
- Load management
- Peak shaving
- Energy and Power applications

Residential
- Time shifting
- Energy applications

PCS100 ESS
ESS applications



Storage Applications - Power vs Energy

Electricity Storage Spectrum in Utility Grids

Power Quality Applications:
"increase of power grid reliability"

Energy Management Applications:
"production can be decoupled from demand"

seconds or less

- Flicker compensation
- Voltage sag correction
- Reactive power control

minutes

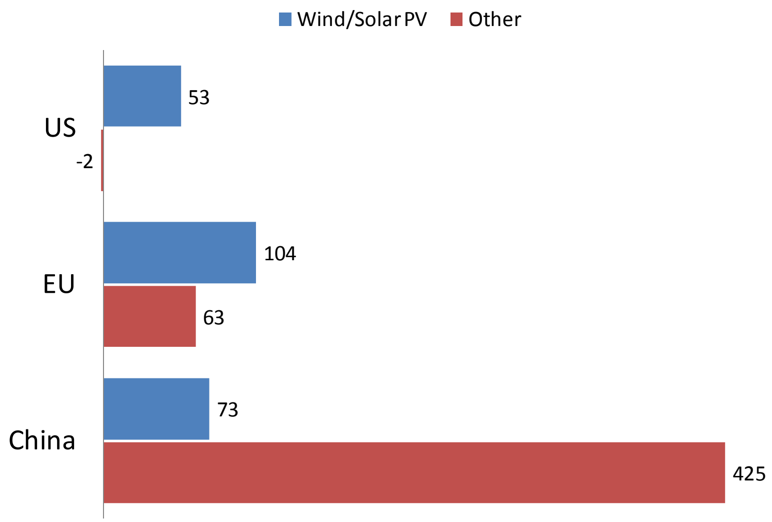
- Spinning reserve (for voltage and frequency regulation)
- Uninterruptible power supply
- Blackstart

hours

- Load leveling
- Peak shaving
- Energy trading
- Integration of renewables
- Island operation

Volatile generation creates global need for storage
Impact on varies by region and by locality

Change in generation capacity (GW); 2008 to 2015



Need for new storage capacity / technologies

- >80% of new volatile generation will be in US, EU or China
- Proportion of volatile generation will no longer be matched by pumped hydro storage (PHS)
- Local instabilities (e.g. islands) within regions will first create need for distributed energy storage
- Need for additional bulk storage will follow

	US	EU	China
Total generation capacity (GW); **2015** [2008]	**1100** [1050]	**1000** [850]	**1300** [800]
Proportion of Wind / Solar PV; **2015** [2008]	**7%** [2%]	**18%** [9%]	**7%** [2%]
Proportion of Pumped Hydro Storage (PHS); **2015** [2008]	**2%** [2%]	**5%** [6%]	**2%** [3%]
2010 Smart Grid stimulus funding (BUS$)	**7.1** [0.2 for Storage]	**1.8**	**7.3**

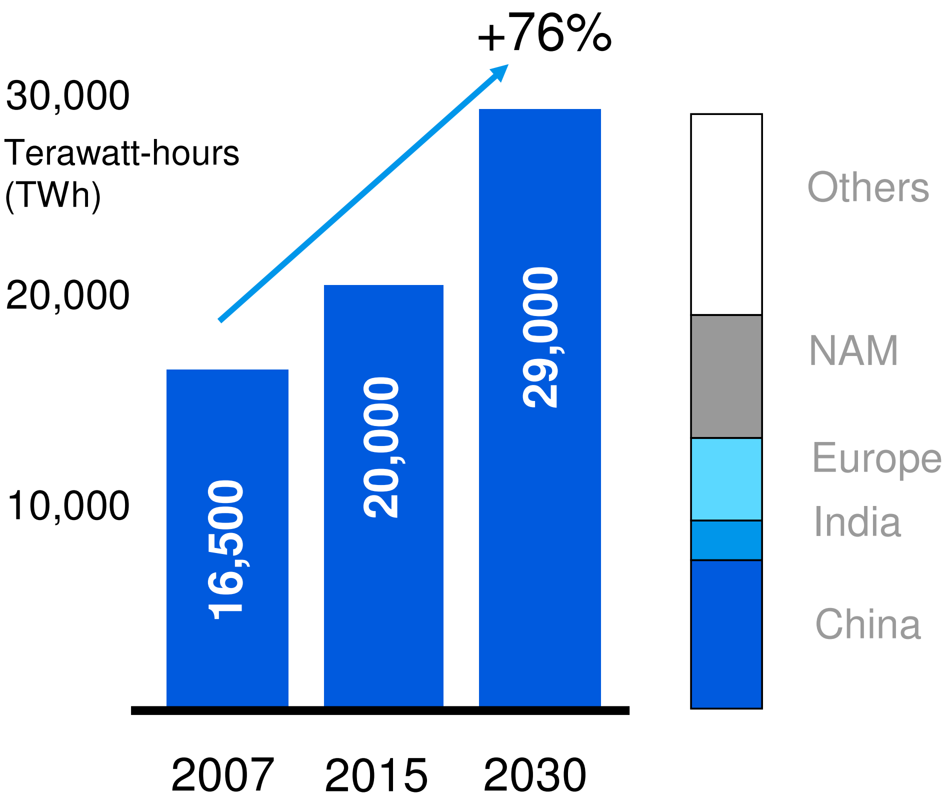
© ABB Group
February 8, 2012 | Slide 6

Source: IEA World Energy Outlook 2010; Zpryme SmartGrid Insights; SBI Storage Report; ABB analysis

Tackling society's challenges on path to low-carbon era means helping utilities do more using less

Forecast rise in electricity consumption by 2030

Source: IEA, World Energy Outlook 2009



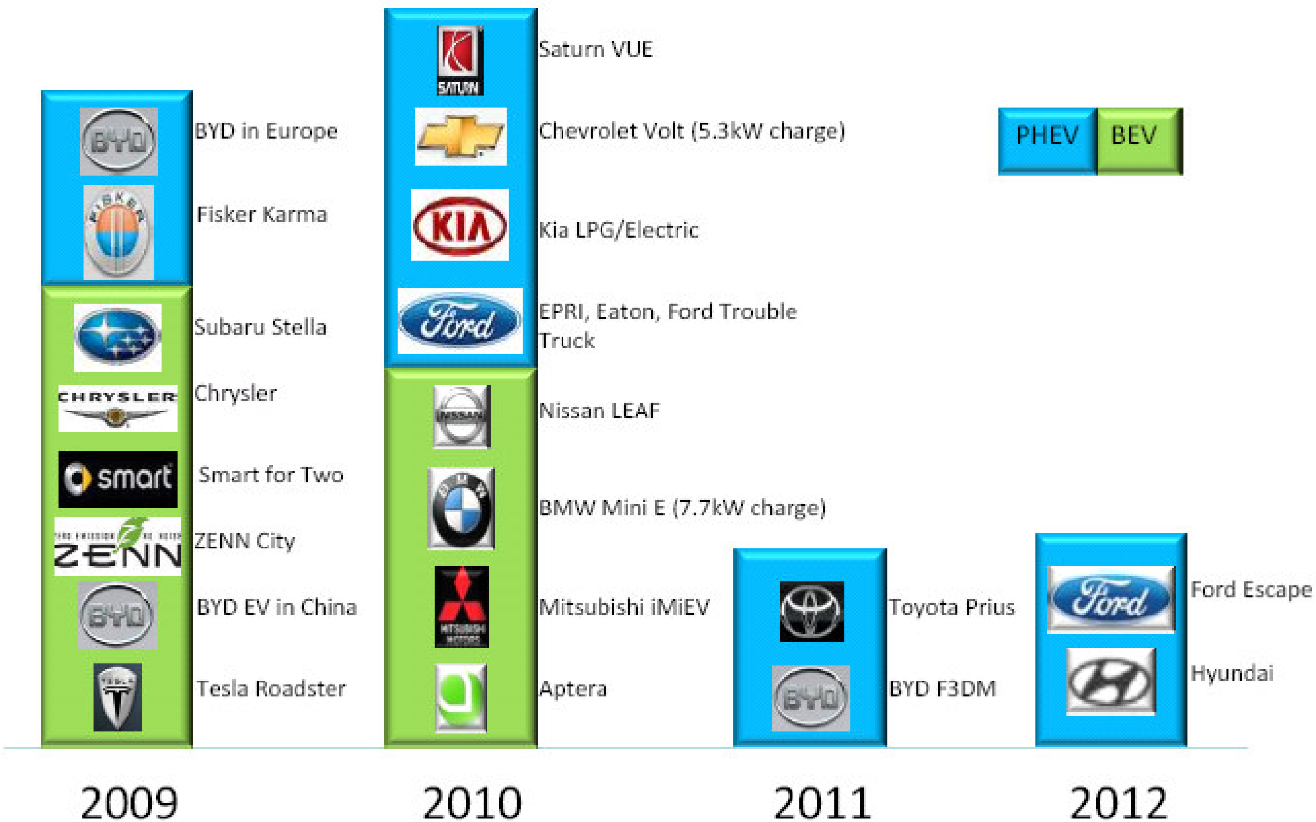
Power and automation solutions are needed for:

- Meeting rising demand for electricity
- Increasing energy efficiency and reducing CO_2 emissions
- Improving productivity to raise competitiveness of businesses and utilities

Meeting the rise in demand will mean adding a 1 GW power plant and all related infrastructure every week for the next 20 years

ABB

Energy Storage Drivers – Rollout of EVs

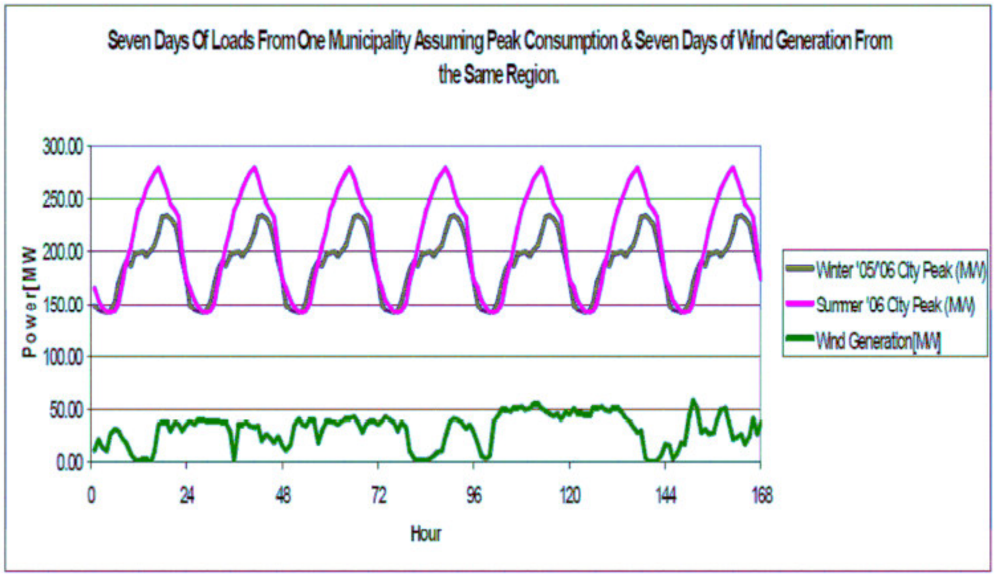


- EV charging will stress out the distribution system
- EV roll out will increase batteries volume and reduce cost

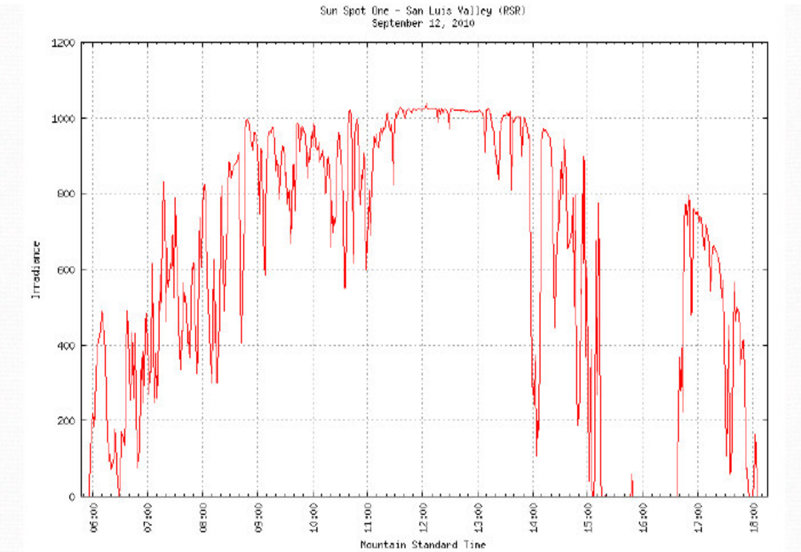
Energy Storage Drivers – Goverment incentives

- **AB 2514 -** California Assembly had just passes the bill AB 2514 that set a deadline by 2012 to set objectives for the utilities to invest in energy storage projects (all technologies).
- **Storage act (1091 – pending) –** the storage act will amend tax code to create incentives for energy storage deployment:
- **SGIP** (Self generation Incentive program), provides financial incentives (usd 2/watt) for installation of storage (behind the meter) combined with wind turbines and fuel cells.
- **EISA 2007 –** Requires Council to develop a 5 year plan (by dec 2009) for storage as a tool to manage variability and capacity concerns. Directs DOE to conduct a cost sharing R&D
- **ACELA (1462) –** Peak demand reduction and load shifting goals with tools like demand response technologies (smart grid technology, dynamic pricing, distributed generation, energy storage)

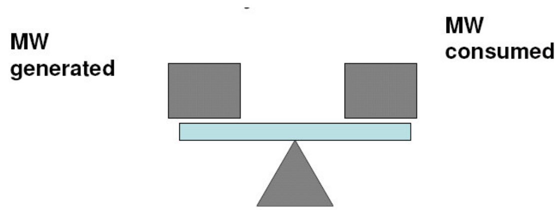
Energy Storage Drivers – Renewables Penetration Capacity Variability



San Luis Valley Solar Data (09/12/2010) Bad Day [1]

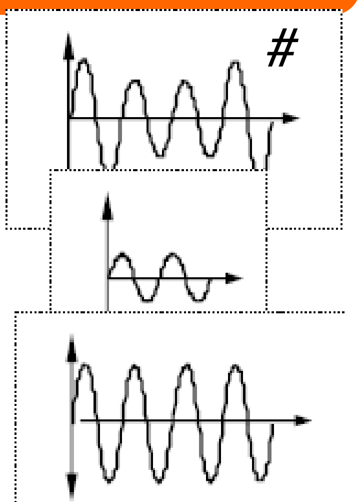


- US government targets of 20 % (renewable generation) by 2020
- Variability generates stress on the fossil generation assets and **jeopardize system stability**
- **Generation > Demand + reserve**



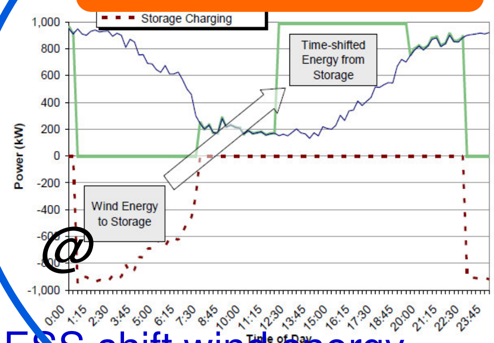
Wide applications of Energy Storage System (ESS)

Power Quality Improvement



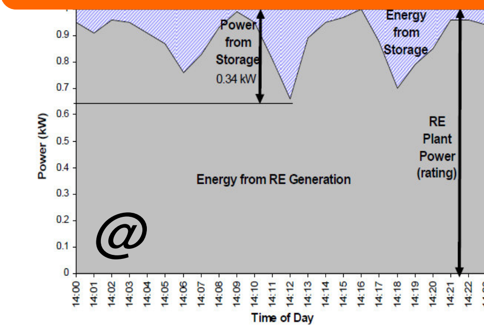
ESS supply minimize the voltage sags

Load shifting



ESS shift wind energy from night to peak hour

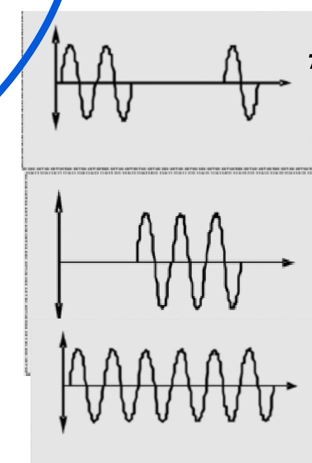
Peak power shaving



ESS supply the power during peak output

Source: SANDIA

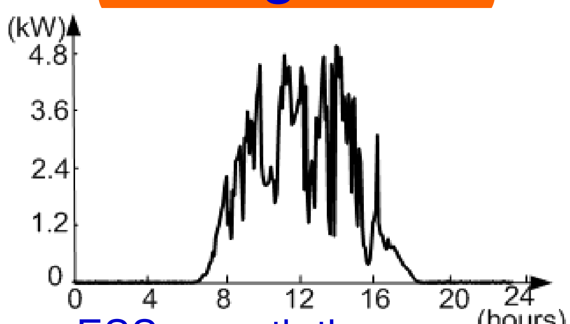
Uninterrupted Power Supply



ESS supply power when source fails

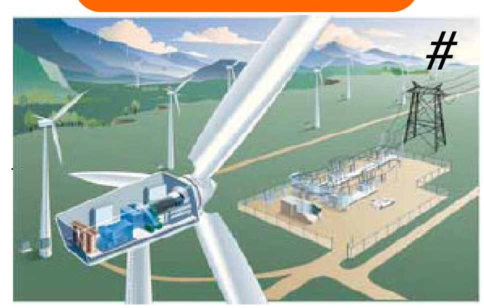
Energy Storage System (ESS)

Intermittency Mitigation



ESS smooth the power output from PV

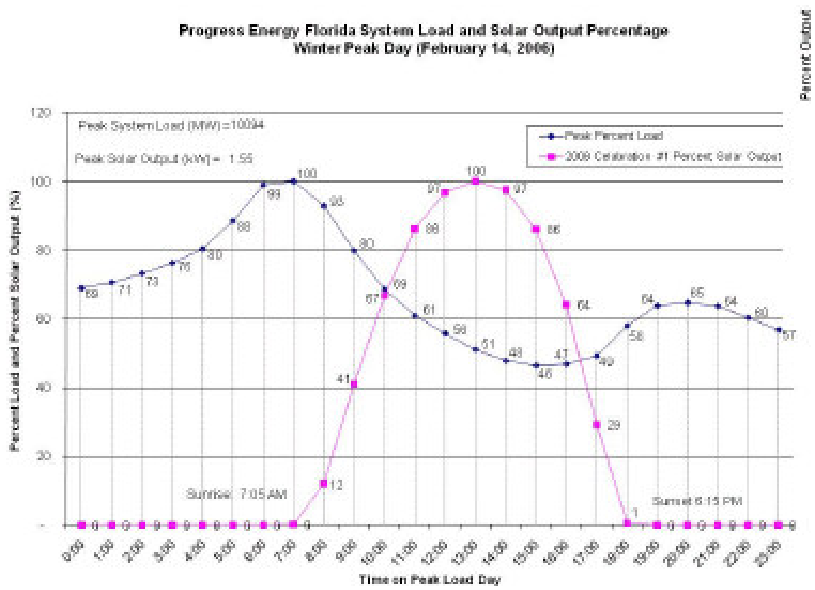
Frequency regulation

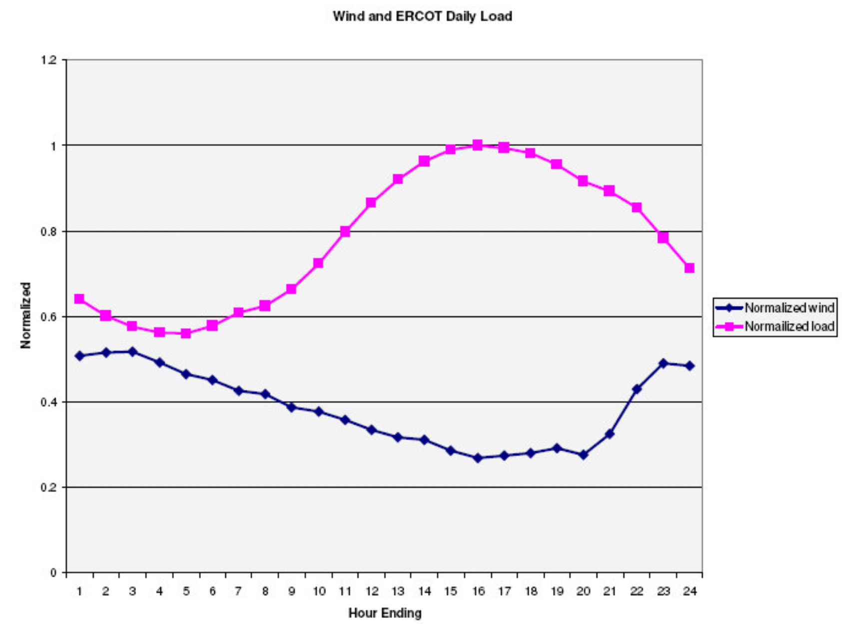


ESS regulate frequency when wind is connected to grid

@Source: SANDIA
 # Source: ABB

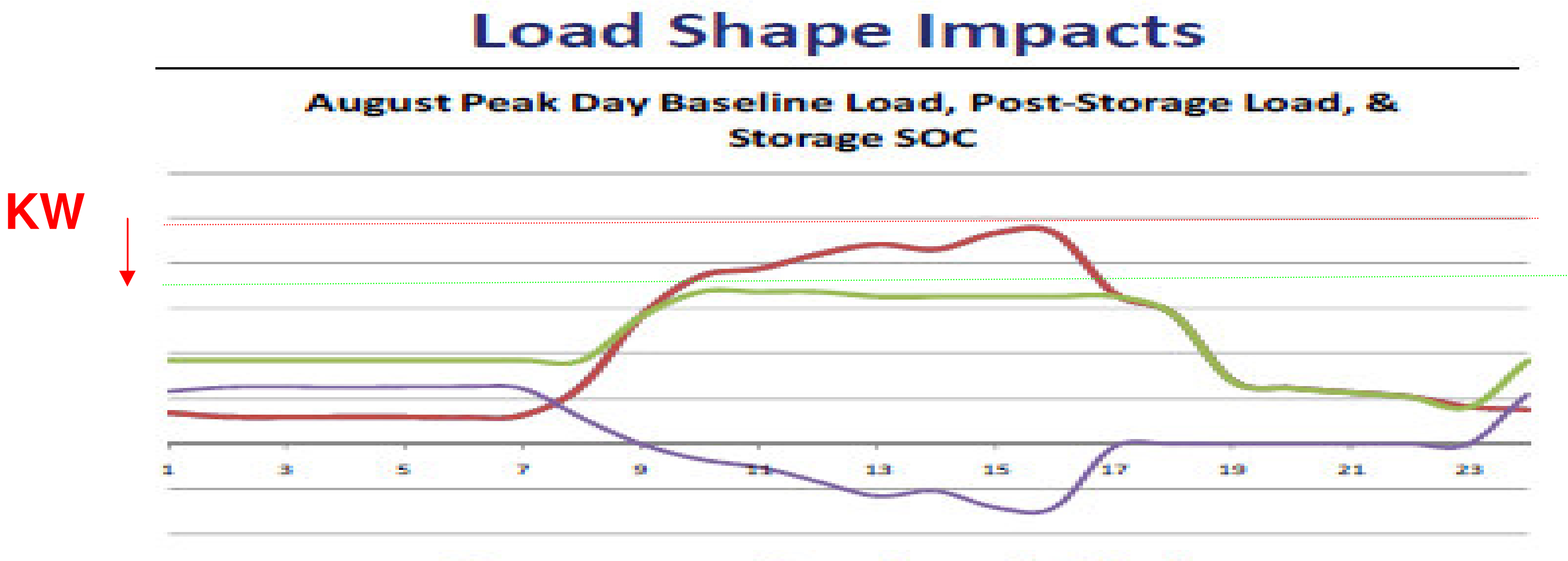
Energy Storage Drivers – Renewables penetration – Wind /solar Generation's capacity peak





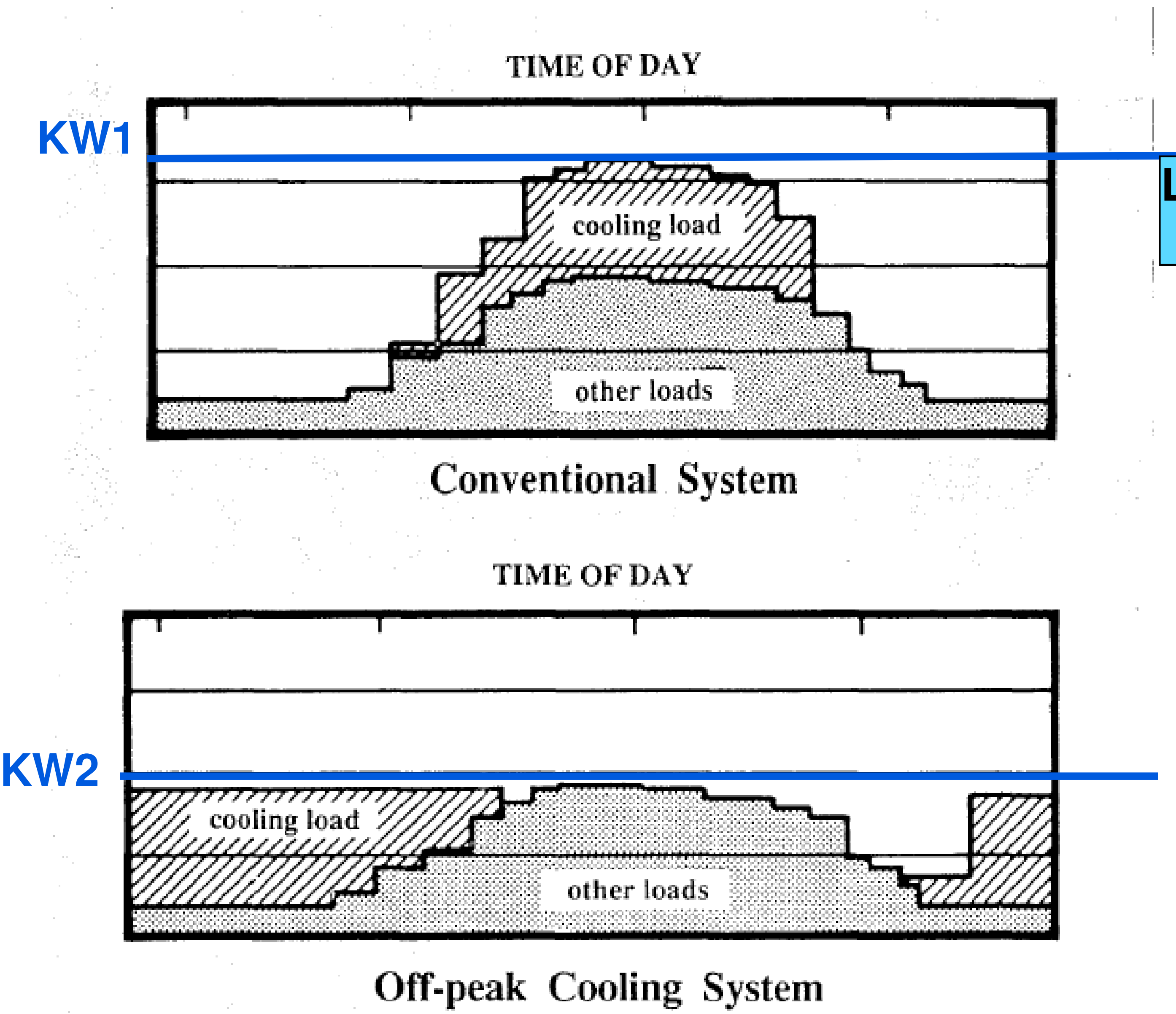
- US government targets of 20 % (renewable generation) by 2020
- Wind and solar generation peaks are not aligned with demand peak

Applications - Load Shifting / Peak Shaving Benefits



- **Load Shifting.-** defined as the practice of altering the pattern of energy use so that on-peak energy use is shifted to off-peak periods. – **energy arbitrage – cost savings**
- **Peak Shaving.-** Peak shaving uses store energy to eliminate the peaks in the energy consumption pattern. – **load factor increase, reduction of power charges, increased return on investment of utility assets, cost savings due to reduction in peak generation**
- Time shift benefit ($) = ($/kwh$_{peak}$*Sthr-$/kwh$_{off}$*Sthr/eff)*Power
- Peak shaving benefit ($) = Power (kw) * Power fee ($/kw)
- $/kwh$_{peak}$: onpeak energy price ($/kwh)
- $/kwh$_{off}$: off peak energy price ($/kwh)
- Sthr: hours of storage (hr)
- Eff: efficiency system (%)

Energy Storage Drivers – Demand management

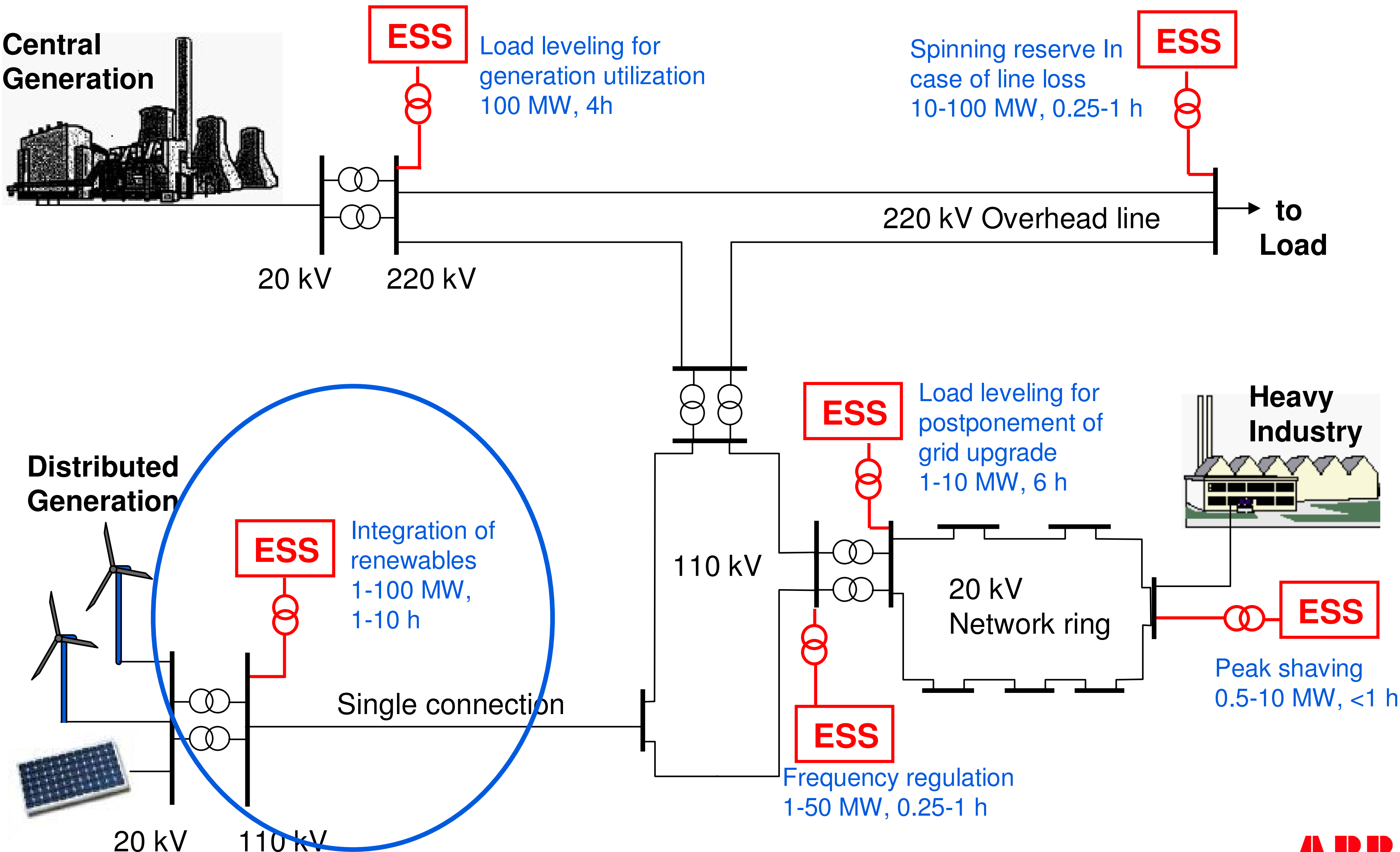


KW2 << KW1

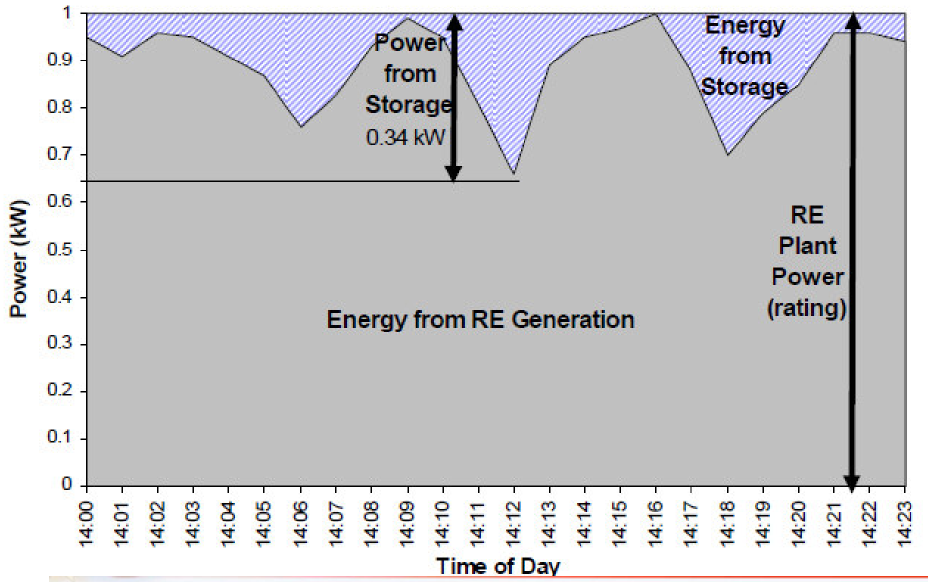
Load Factor= Avg KW/ Max KW

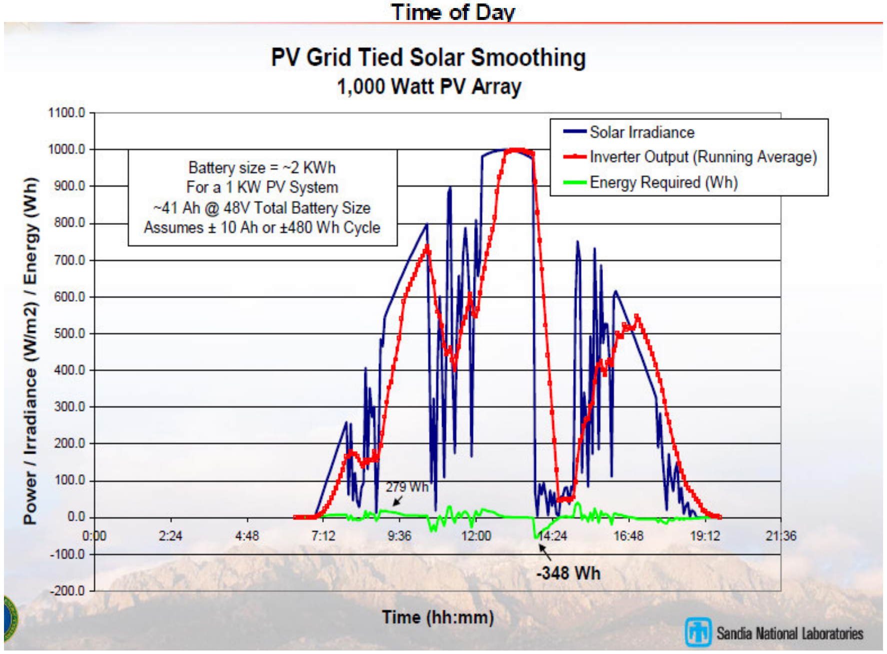
- Generation, Distribution and Transmission assets need to be sized for peak demand
- Peak shaving allows to increase the Load factor of the assets, **increasing the return on the investments**

PCS100 ESS
ESS applications



Renewables Capacity Firming
Wind and solar generation intermittency

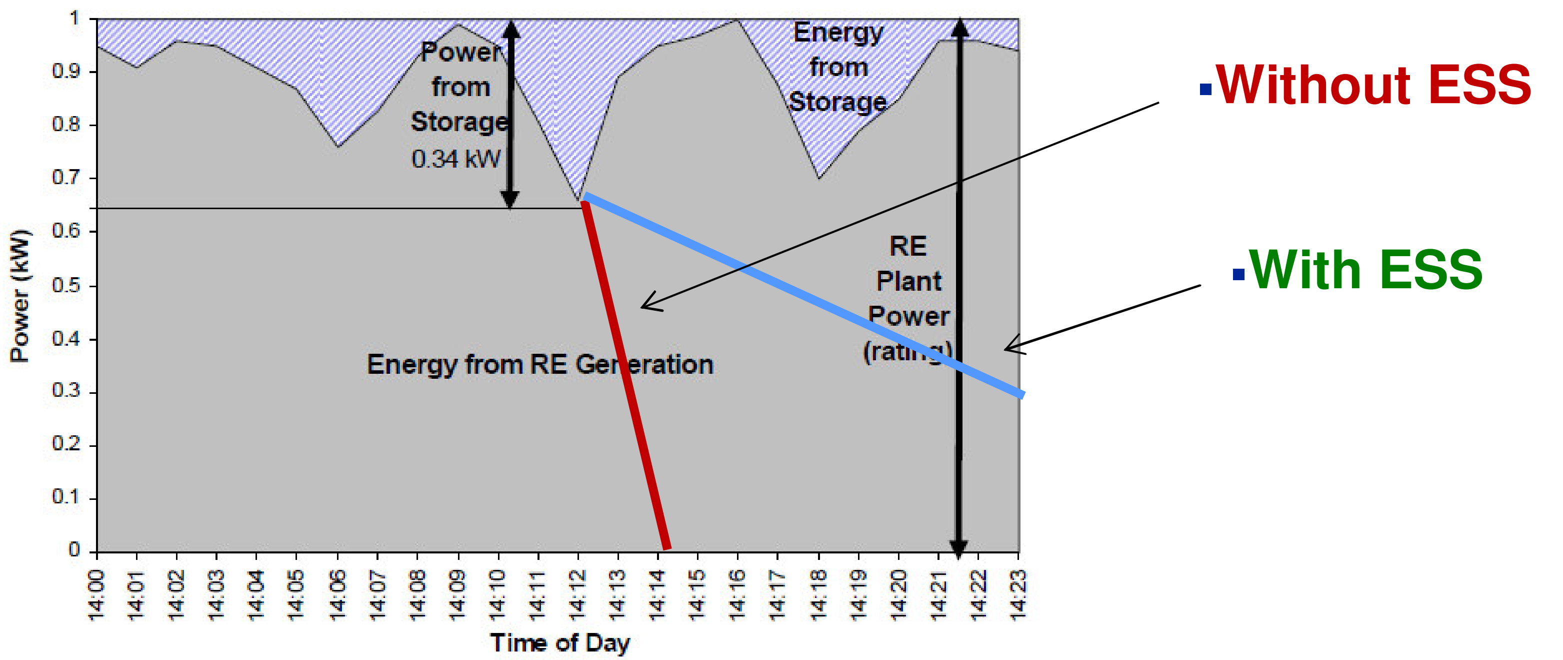




- Short duration intermittency from variations in wind speed and/or shading of the sun occur through the day
- Objective is to use BESS to "fill in" so that the combined output from the renewable generation plus storage is close to constant
- Maintain higher forecasted levels of generation => higher revenue
- Increased amount of CO_2 free generation to allow renewable integration

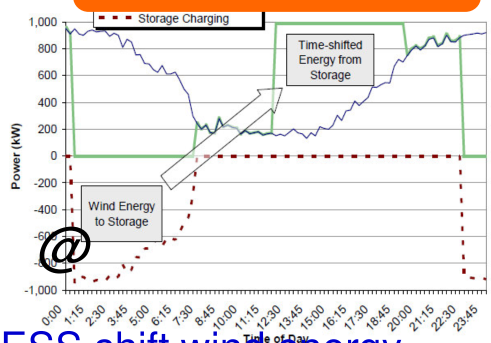
Ramping
Need for dispatchable generation

- Sudden changes in wind – heavy wind conditions could lead to that an entire wind park is disconnected to the grid, which could have severe impact on the power system
- Need for dispatchable power sources whose output can change rapidly => ESS to play a role
- Use ESS to bridge the time needed to start up other generation



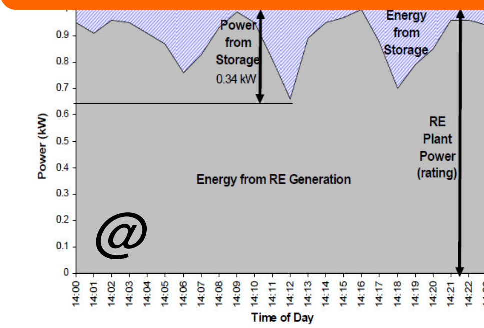
Wide applications of Energy Storage System (ESS)

Load shifting



ESS shift wind energy from night to peak hour

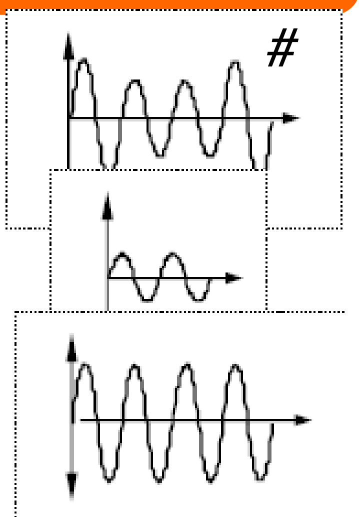
Peak power shaving



ESS supply the power during peak output

Source: SANDIA

Power Quality Improvement

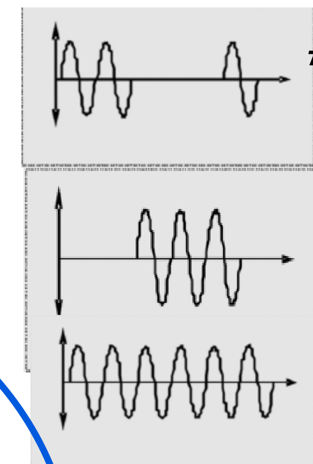


ESS supply minimize the voltage sags

@Source: SANDIA
 # Source: ABB

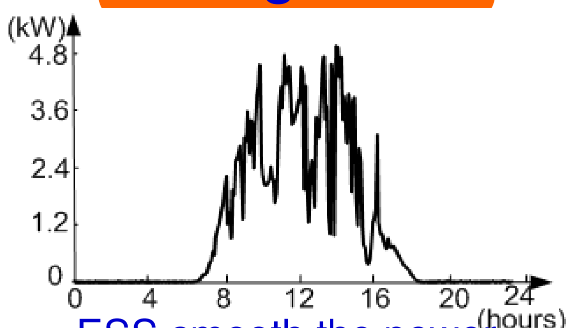
Energy Storage System (ESS)

Uninterrupted Power Supply



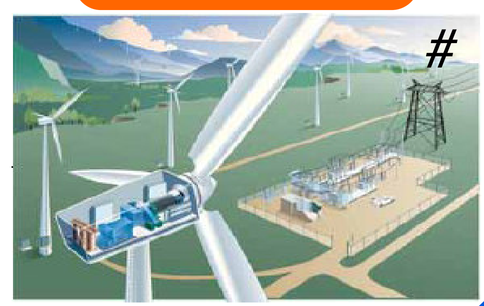
ESS supply power when source fails

Intermittency Mitigation



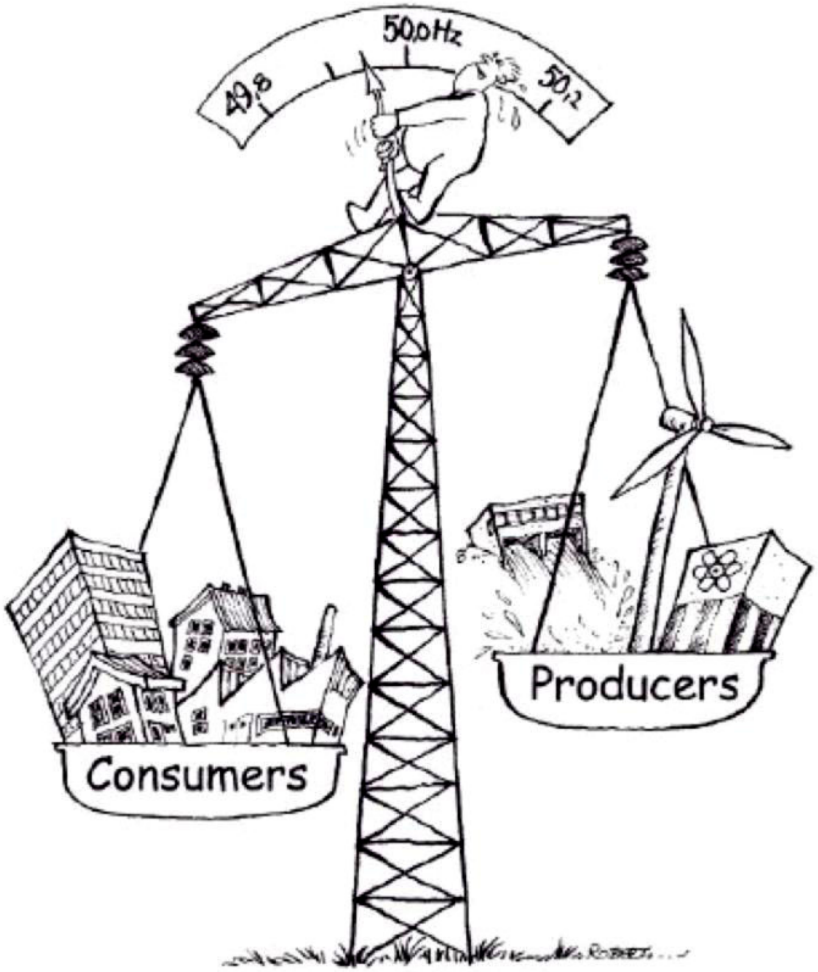
ESS smooth the power output from PV

Frequency regulation



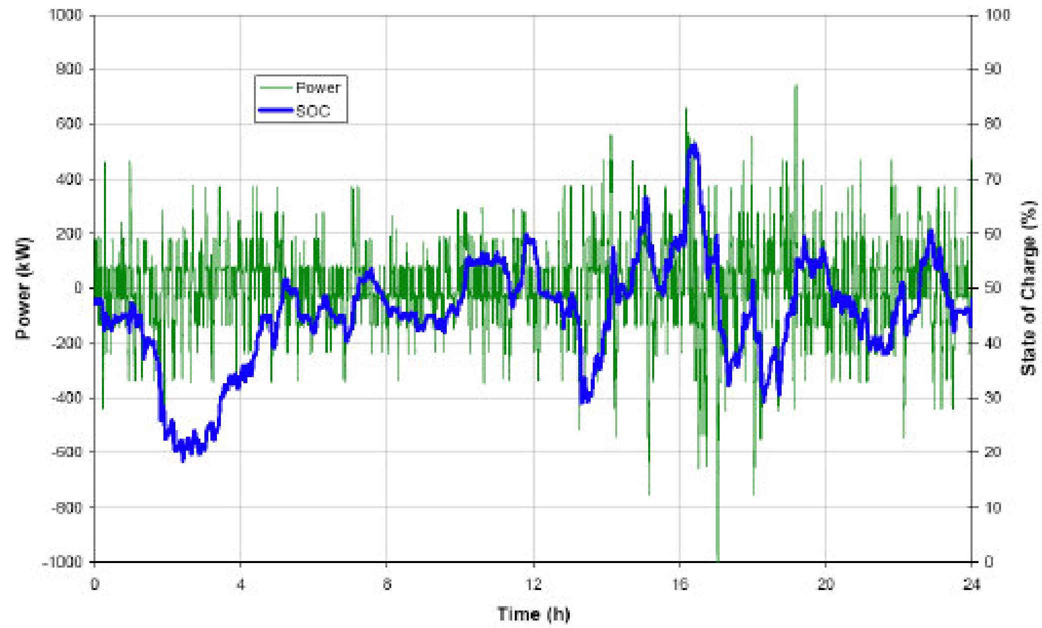
ESS regulate frequency when wind is connected to grid

Primary Frequency Regulation



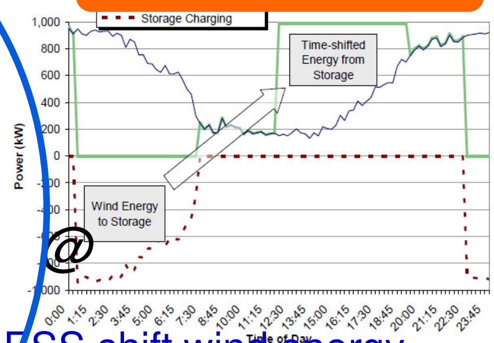
© Svenska Kraftnät 2001

- Frequency control (50 or 60 Hz)
- Fast reserve for emergencies



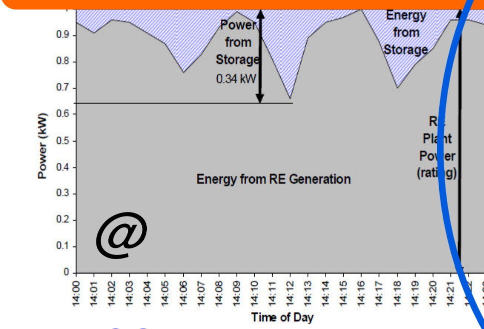
Wide applications of Energy Storage System (ESS)

Load shifting



ESS shift wind energy from night to peak hour

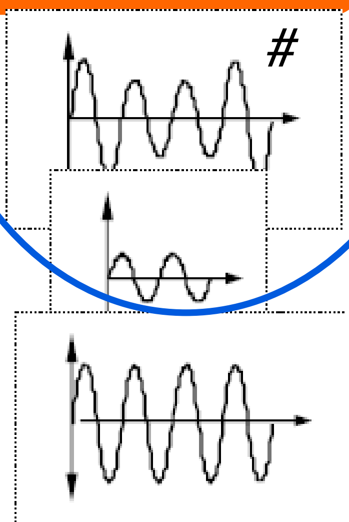
Peak power shaving



ESS supply the power during peak output

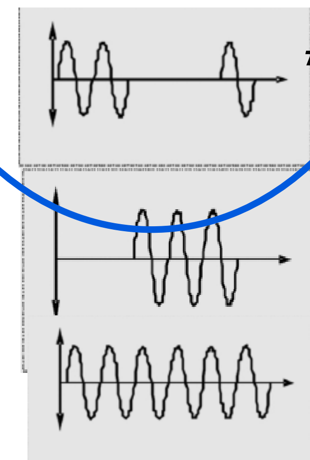
Source: SANDIA

Power Quality Improvement



ESS supply minimize the voltage sags

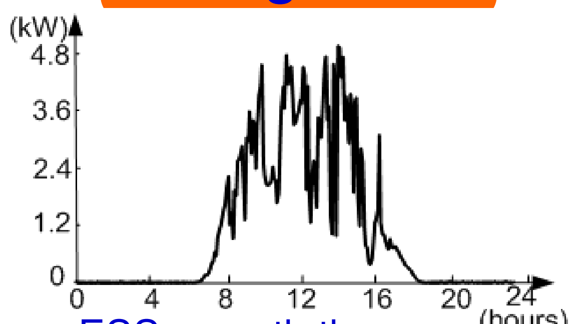
Uninterrupted Power Supply



ESS supply power when source fails

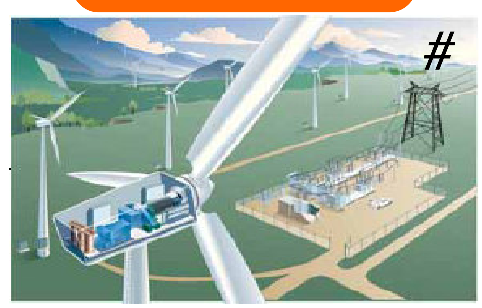
Energy Storage System (ESS)

Intermittency Mitigation



ESS smooth the power output from PV

Frequency regulation



ESS regulate frequency when wind is connected to grid

@Source: SANDIA
 # Source: ABB

ABB

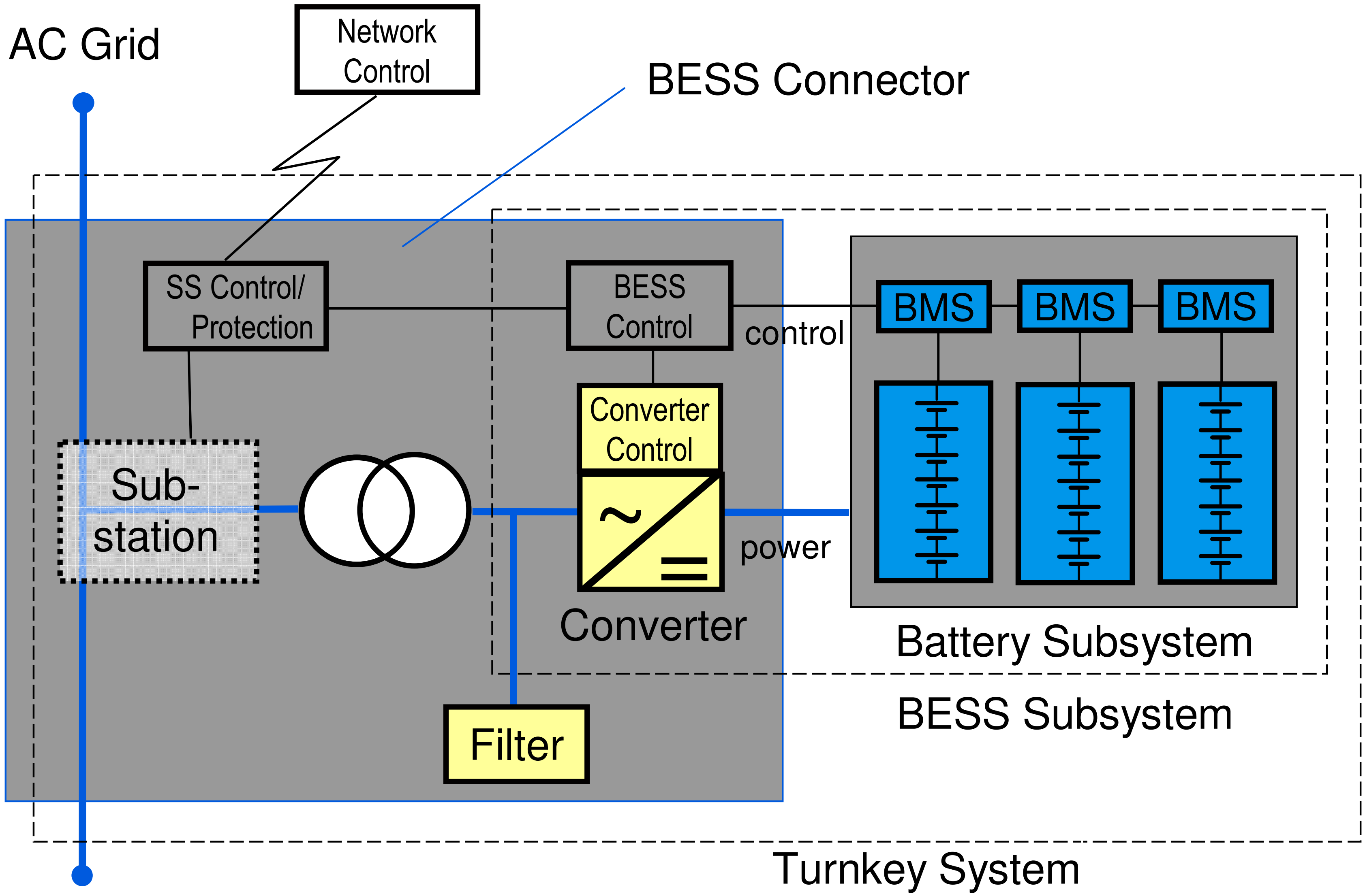
Additional Applications

Power Quality.-

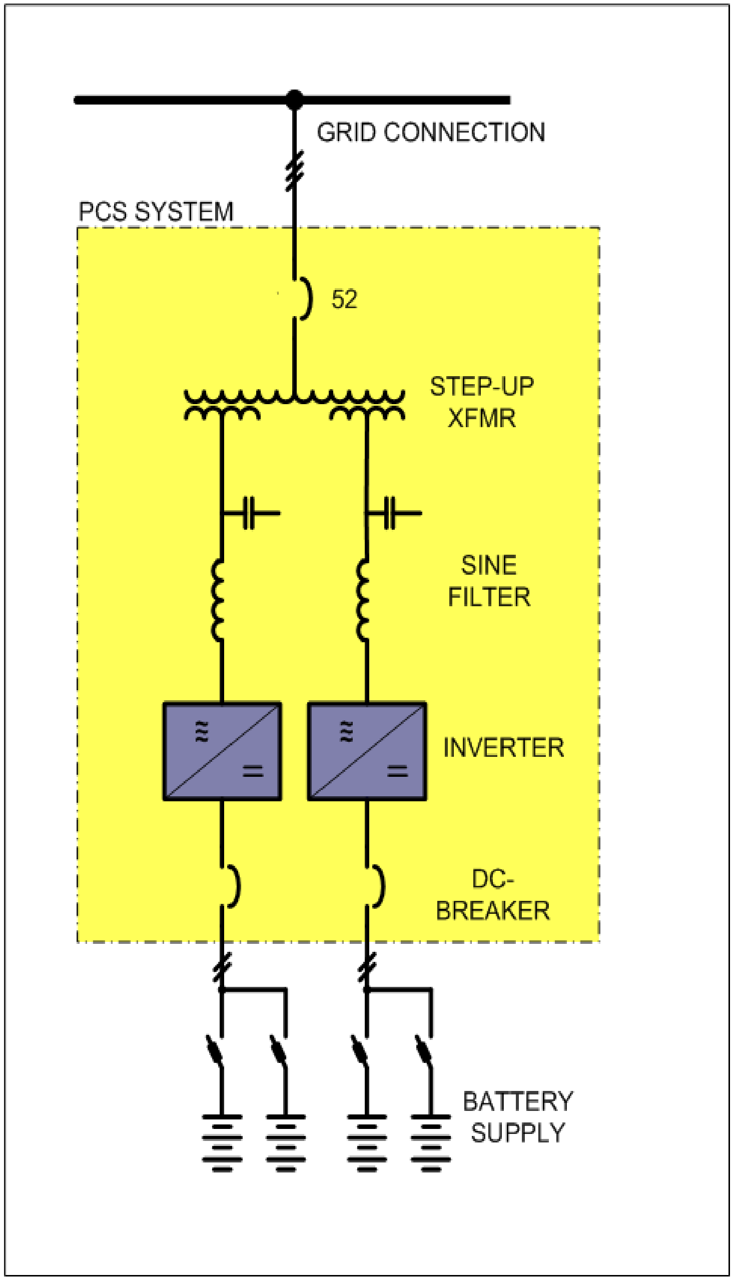
- Power quality applications involve using ESS to protect loads downstream against short-duration events that affect the quality of power delivered to the load.

- **Voltage Support** / Energy storage with reactive power capability can provide voltage support and respond quickly to voltage control signals.

Battery Energy Storage Components



BESS Design Components

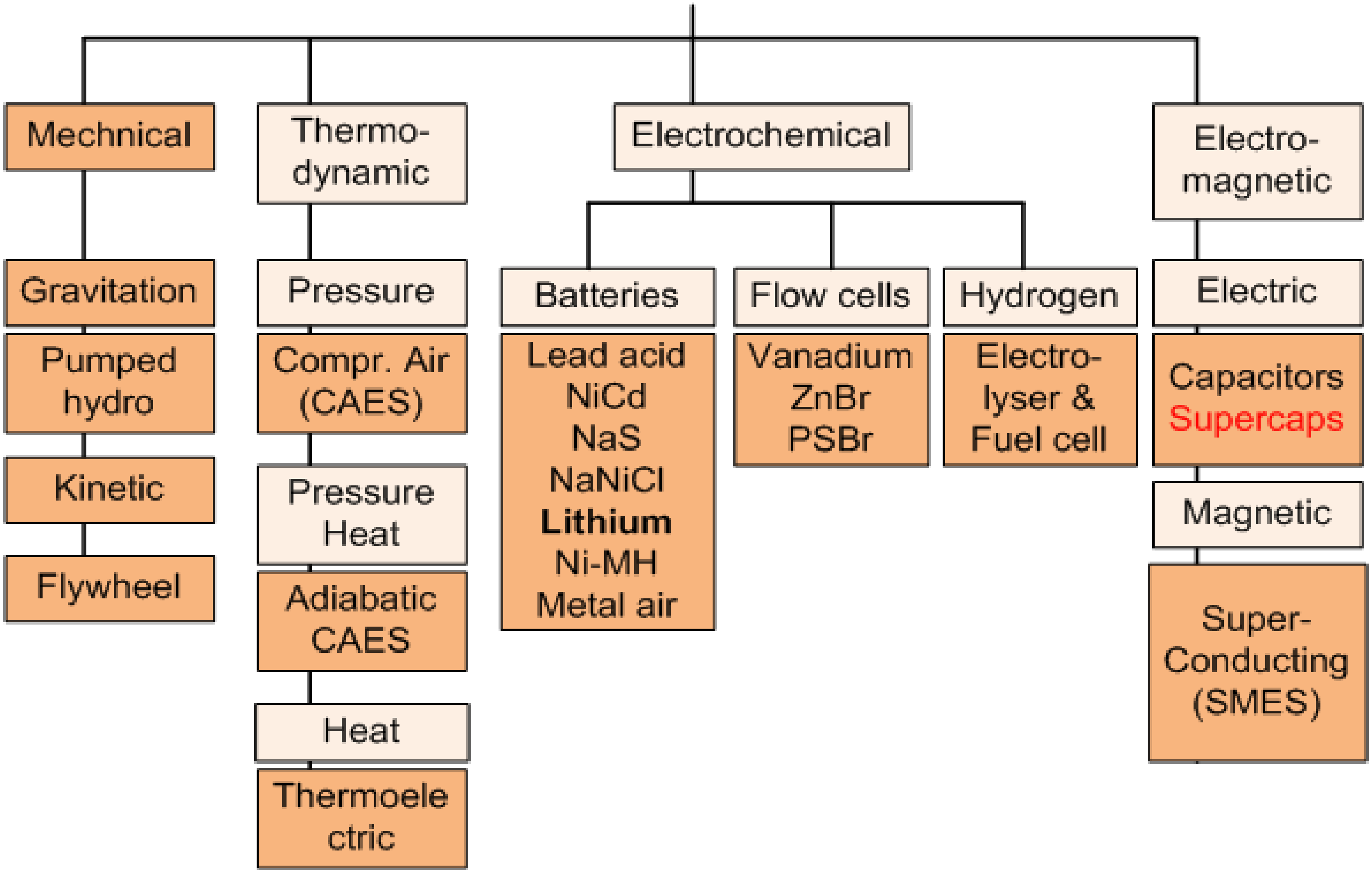


- **AC Grid Voltage**
- **Battery DC Voltage & Application**
  - **Battery Type**
- **PCS SYSTEM**

BESS Layout

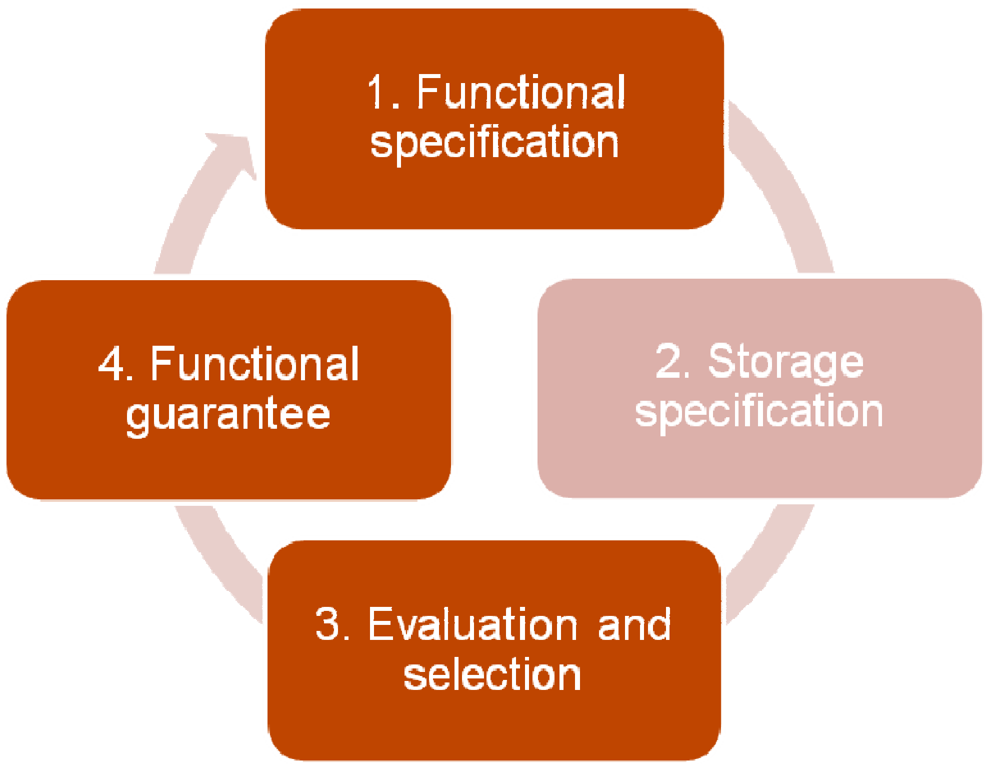
1MW / 6.5MWHr

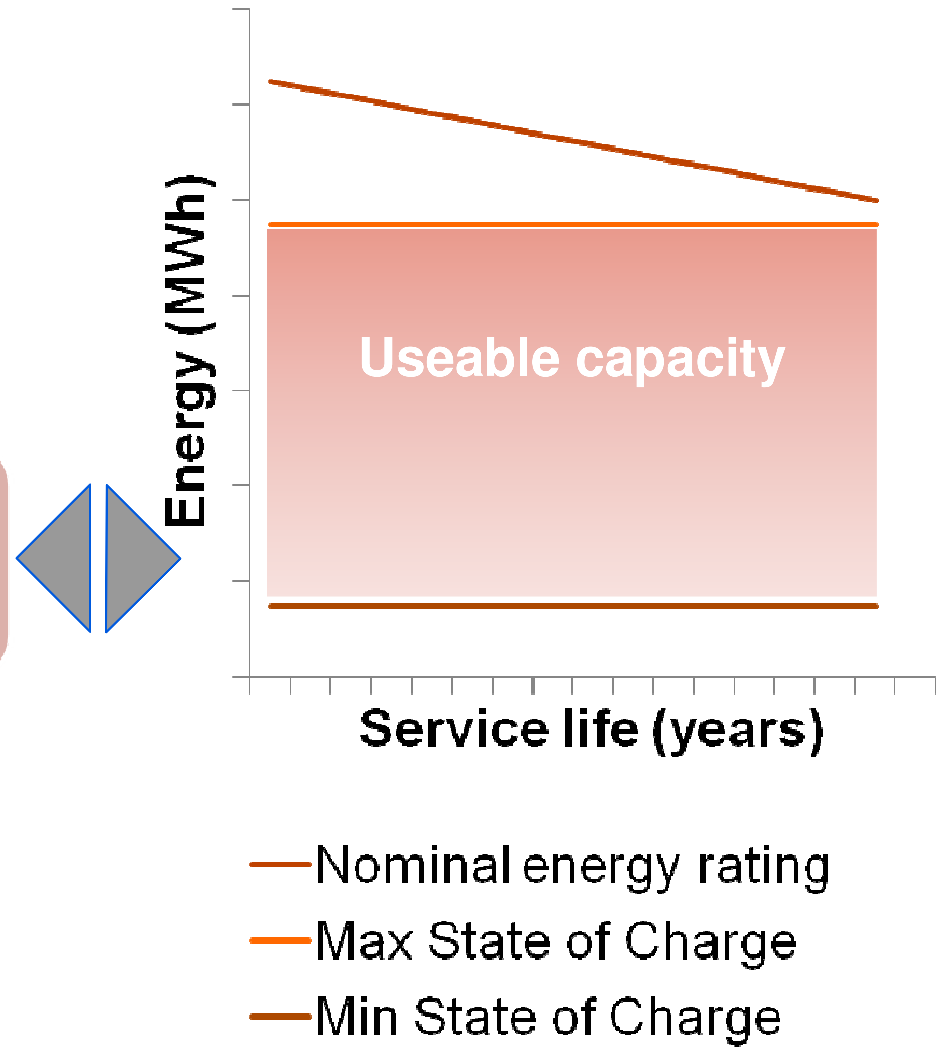
Various types of energy storage



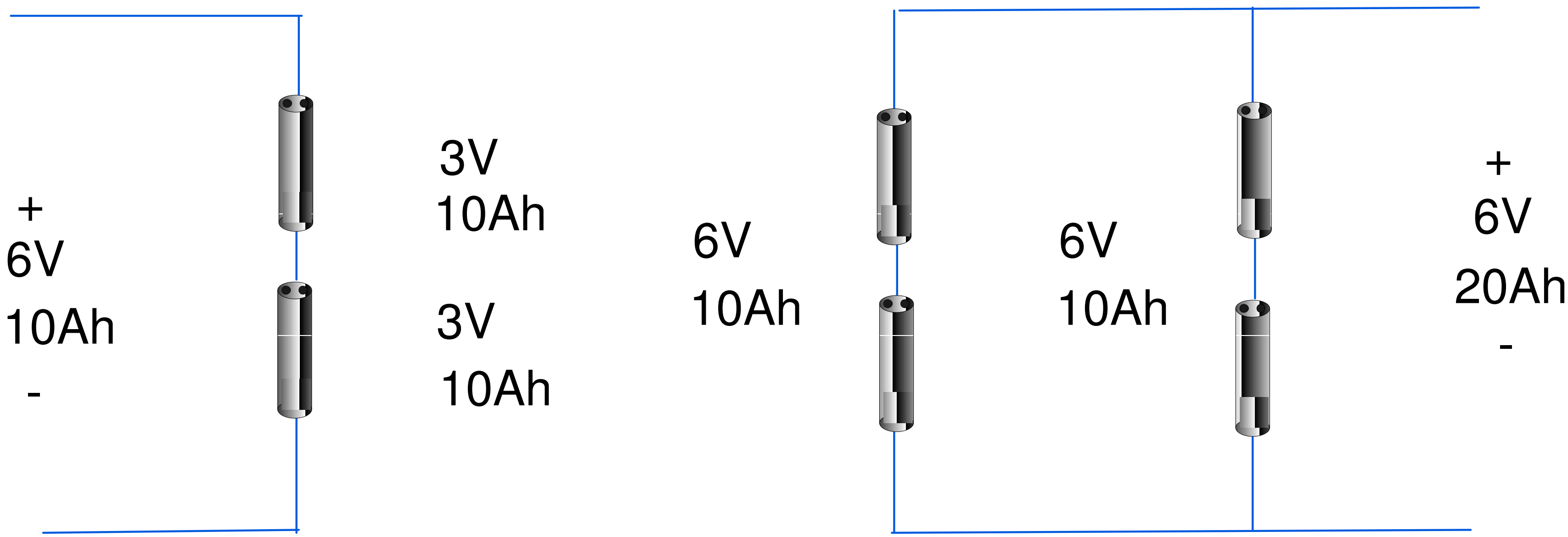
* Holger Hannemann, "*Innovative Solutions for grid stabilization and support*" , ABB Power Electronics Napier, 30 March 2010

How to select the 'right' storage technology
Define what it must do, not what it must be



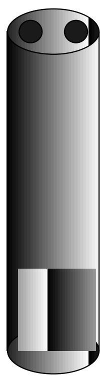


Battery Power Module Construction



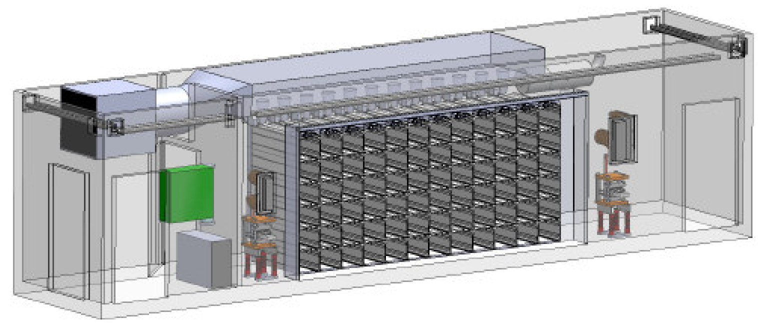
ABB

Hierarchy of the battery solution - <1200Vdc



Cell

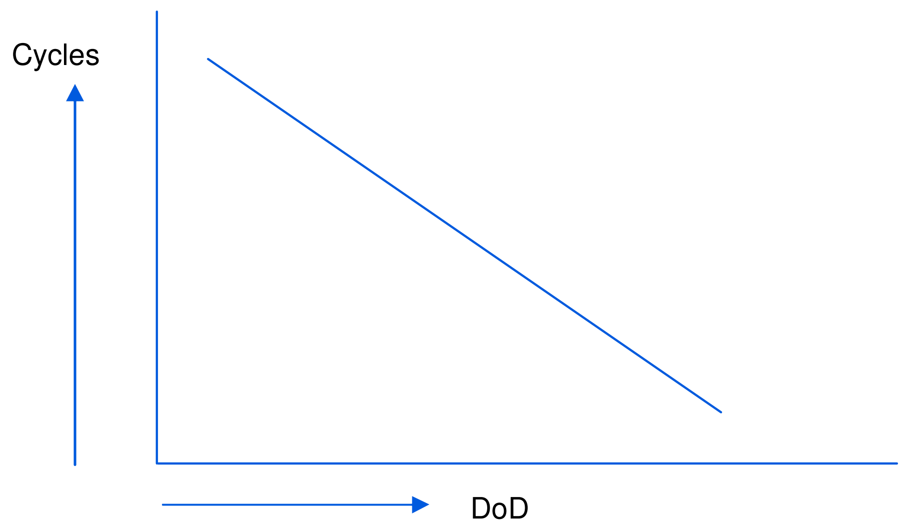
Modules



Battery
Container

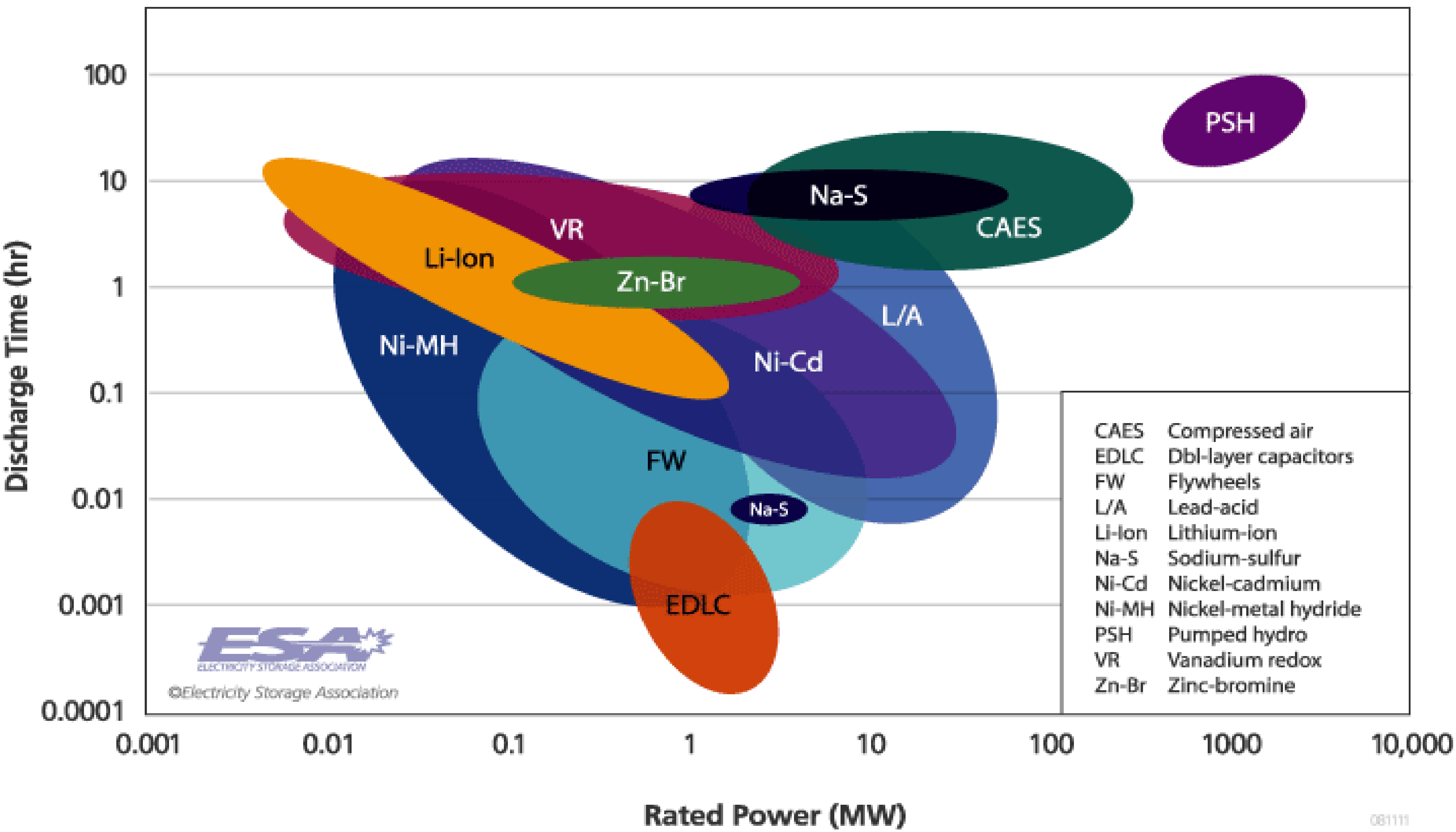
Battery System Definitions

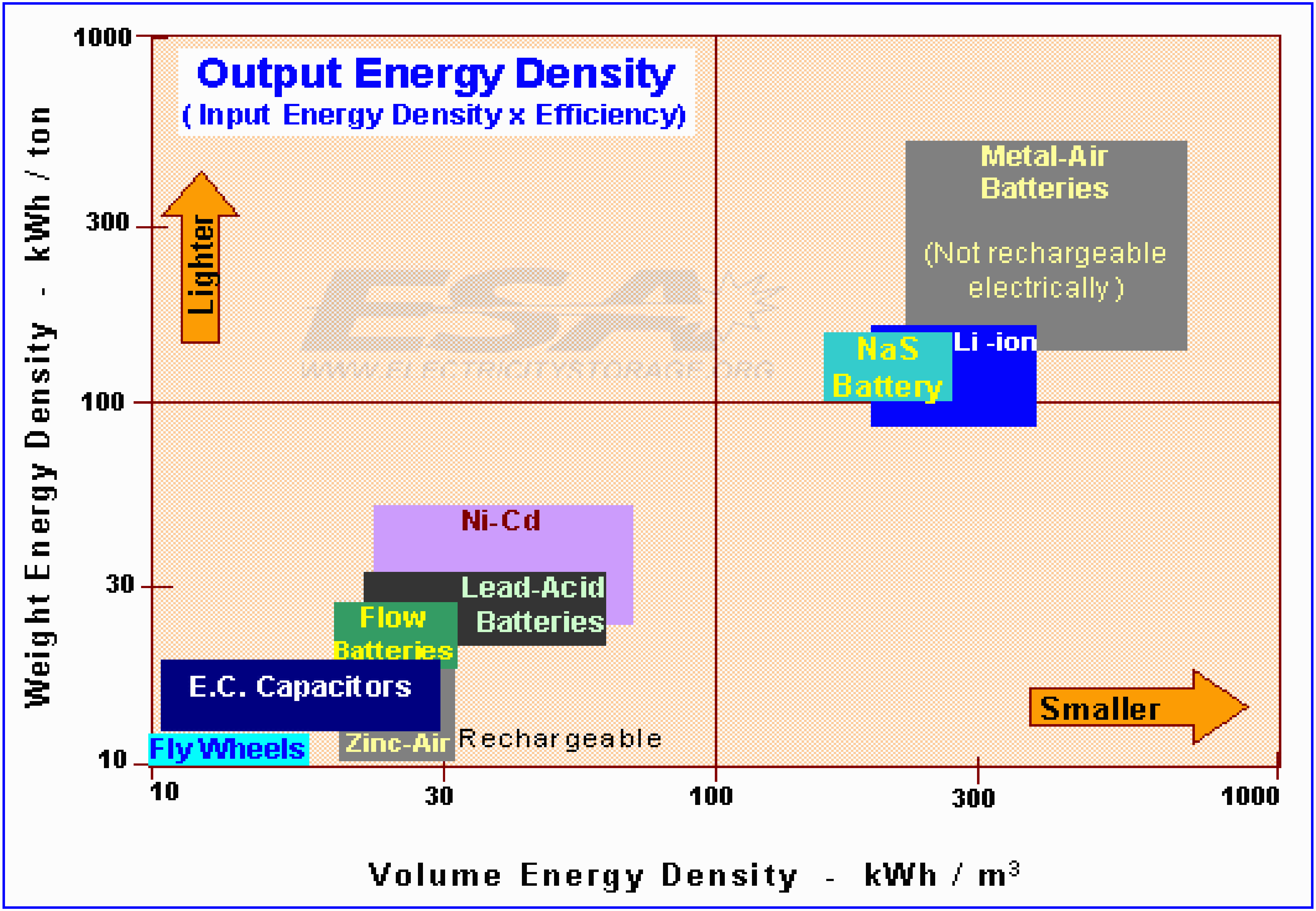
- C-rate - Discharge or Charge rate. Capacity of cell (or battery) divided by 1 hour.
  - 1MWh battery will deliver 1MW for 1 hour (1C)
  - 1MWh battery will deliver 2MW for 30 min (2C)
  - 1MWh battery will deliver 500kW for 2 hours (C/2)
- Efficiency
  - Defined through charge/discharge cycle
- Depth of Discharge (DoD) and Cycle Life



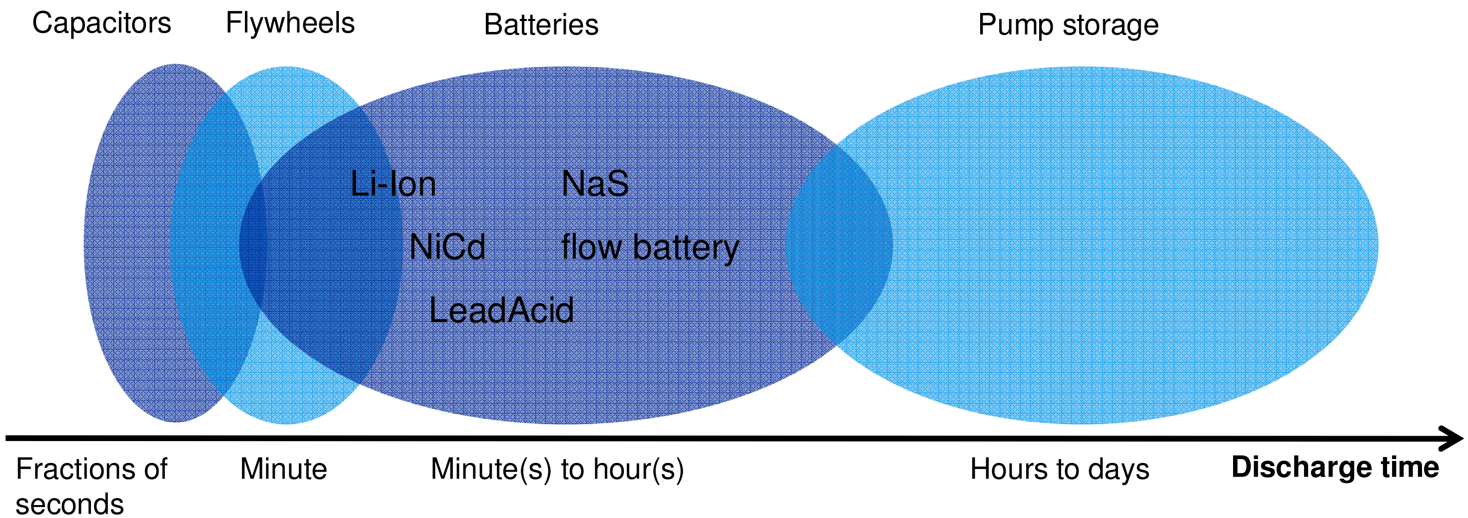
System Ratings

Installed systems as of November 2008




Output Energy Density
(Input Energy Density x Efficiency)
Weight Energy Density - kWh / ton
Volume Energy Density - kWh / m^3
1000
300
100
30
10
10
30
100
300
1000
Lighter
Smaller
Metal-Air Batteries
(Not rechargeable electrically)
NaS Battery
Li -ion
Ni-Cd
Lead-Acid Batteries
Flow Batteries
E.C. Capacitors
Fly Wheels
Zinc-Air
Rechargeable

PCS100 ESS
Discharge times



Power Electronics based Energy Storage Systems core range:

- Supercaps: 5 to 15 seconds ~500,000 cycles
- Flywheels: 1-30 min no cycle limitation
- Batteries: NiCd 30-120 min ~2500 cycles @ 80% depth of discharge
  Li-Ion: 15-60 min ~3,000-6,000 @ 80% DoD
  flow: 3-6 hours expected 10,000 cycles @ 80% DoD
  NaS: 6-8 hours ~ 4500 @ 80% DoD

BESS – ABB PCS Design Capabilities

Packaging

- Indoor or Outdoor
- Transformer internal/external to PCS container

Environmental Conditions

- Temperature
- Altitude
- Wind, dust, harshest environments

AC Grid and DC Battery voltages

Control and Operations

- BESS function, Statcom
- BMS interface
- EMS/SCADA interface
- Remote Diagnostics

Operation and Maintenance Support

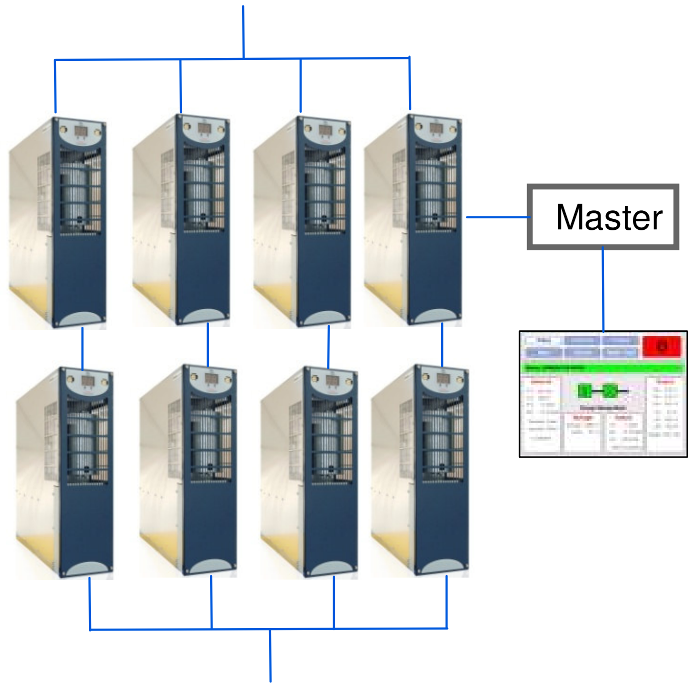
PCS100 Inverter module

Power Conditioning System Package for BESS

PCS100 Platform
The Concept

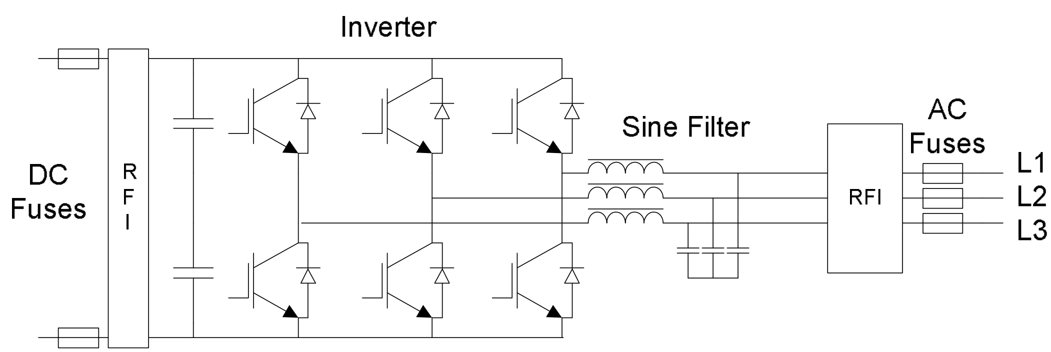
- Traditional high power converters are constructed as a single unit
- Topology is not as flexible
- Service is complex

- The PCS100 converter platform is a modular structure
- Flexible sizing of converters by adding power modules
- Service is simple
- Highly reliable with redundancy



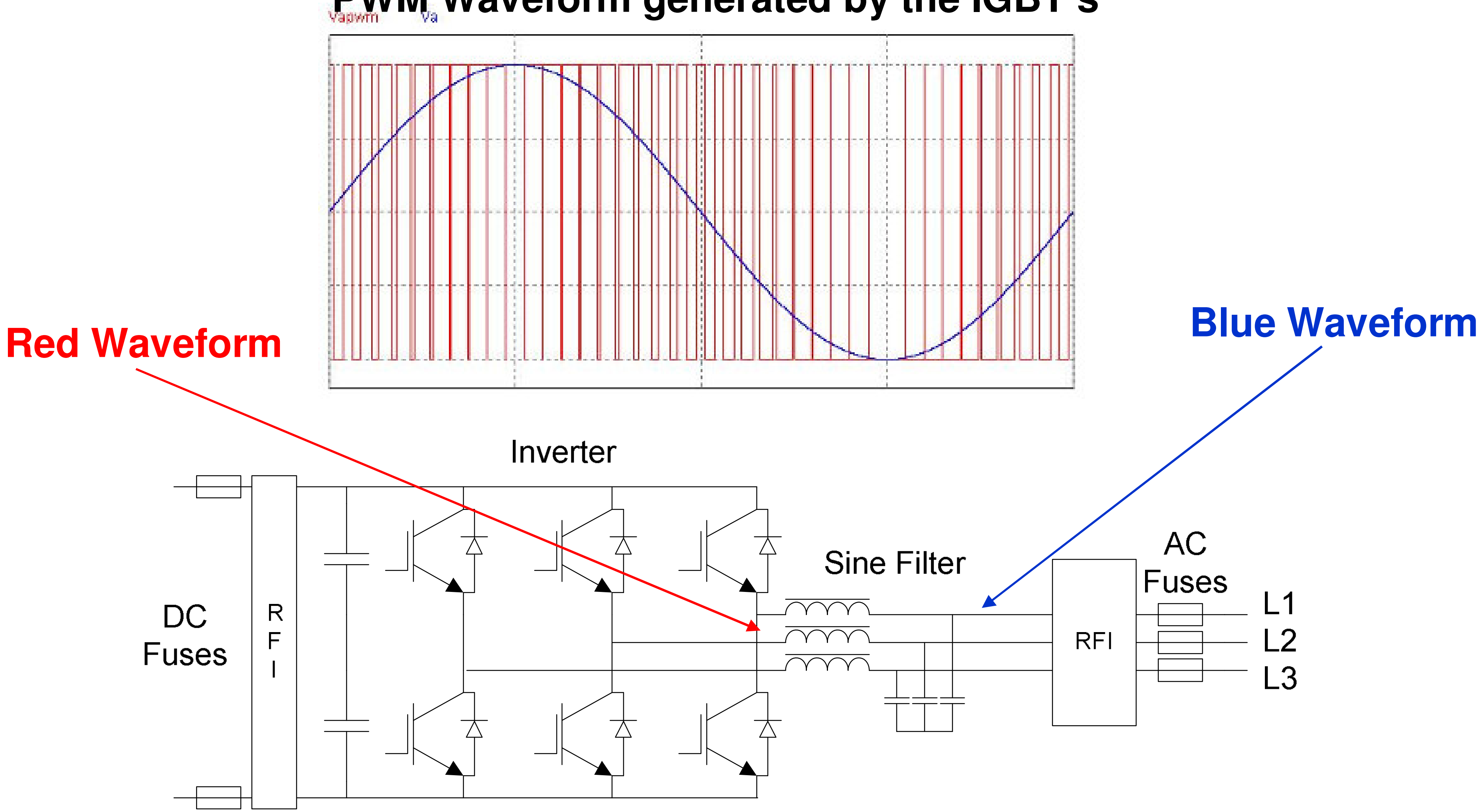
Inverter Technology

- IGBT Technology
- DC Voltage Range
- Forced Air, HVAC or Liquid Cooled
- Module kVA rating
- LCL Filter integrated or external
- Sized for temperature, altitude, overload and kVA ratings.



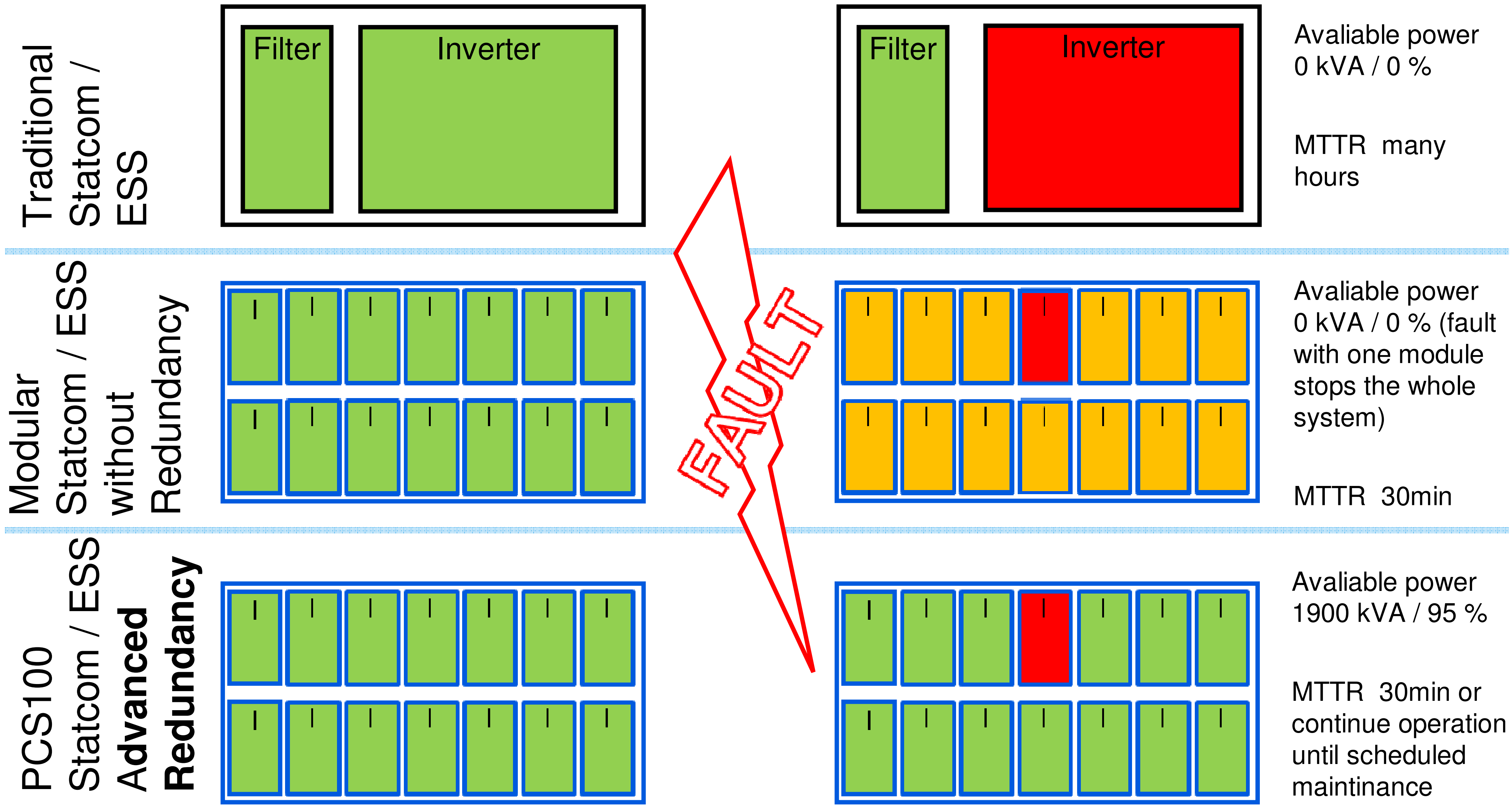
Inverter Waveforms
Sinusoidal PWM Modulation

PWM Waveform generated by the IGBT's



PCS100 Statcom & ESS
Advanced redundancy feature

(Power rating: 2 MVA)



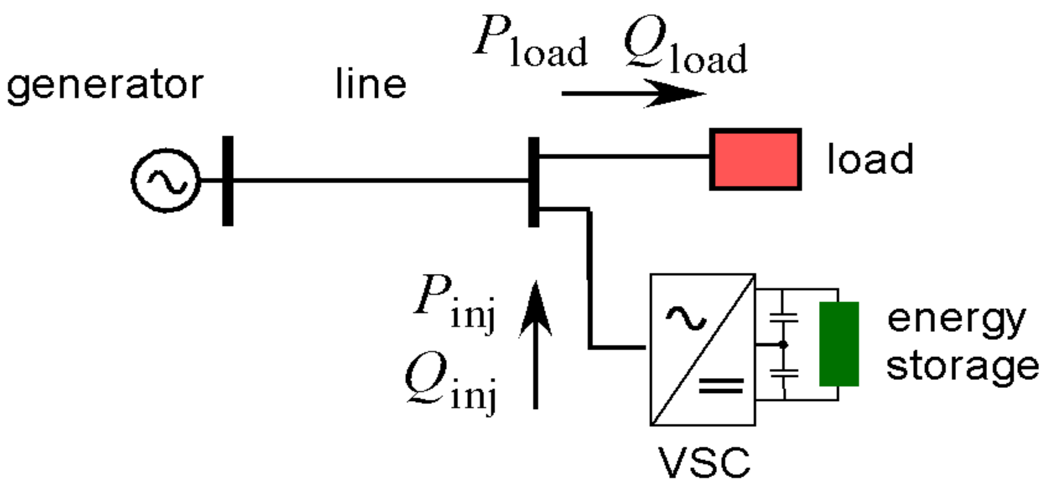
BESS – PCS Containerized Solution

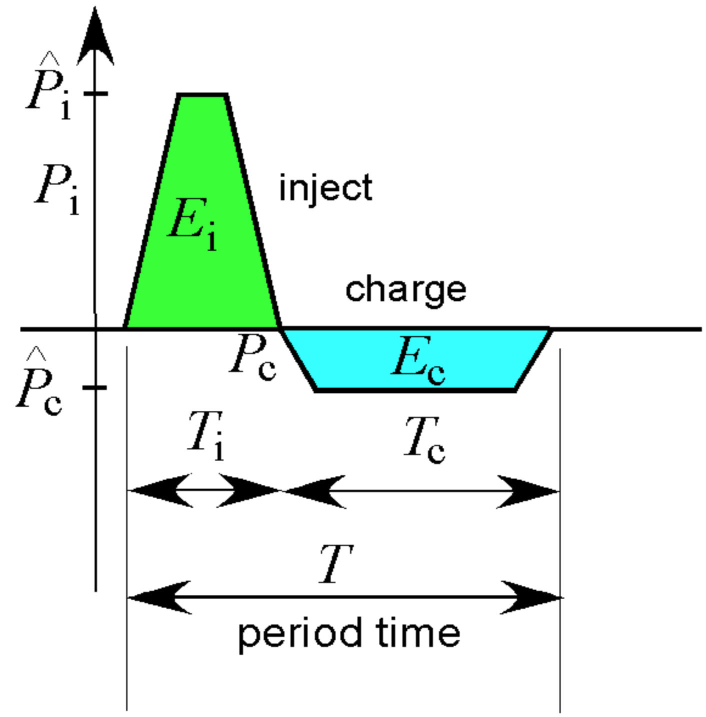
- Fully Containerized solutions for ratings up to 4MW.
- Transformer contained for <2.5MW units and <20kV.
    - External transformer for ratings above that.
- Testing for complete PCS prior to shipment to site.
- Mobile solution
- Minimize install & commissioning time
- Reduce transportation costs
- Non-walk-in enclosure for added safety.

2MW Containerized PCS

PCS Designs - Indoor and Outdoor

ABB FACTS: Dynamic Energy Storage

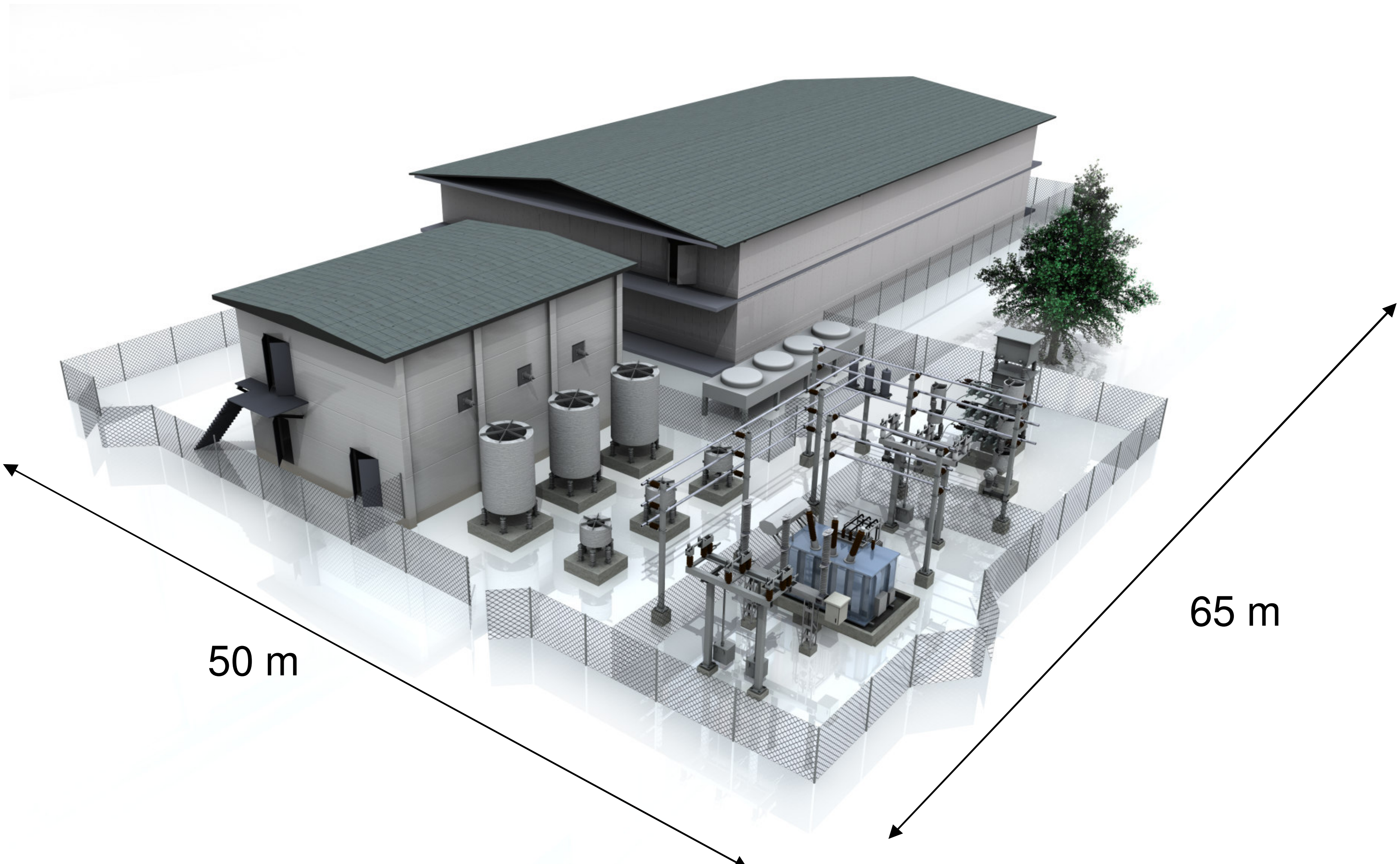




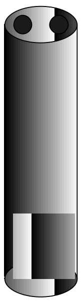
- Energy storage connected on DC-side of converter (SVC Light)
- Size depends on power level and duration
- Charge energy equal to load energy
- Focus on “dynamic”, manages:
  - High number charge and discharge cycles
  - High Power at medium duration
- Chosen high performance battery as energy storage

Energy Storage Platform #2
DynaPeaQ / SVC Light with Energy Storage

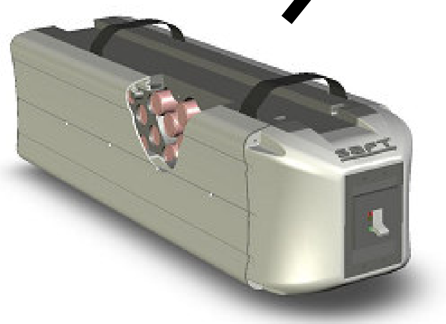
Typical layout for 20 MW during 15 min +/-30 MVAr continuously



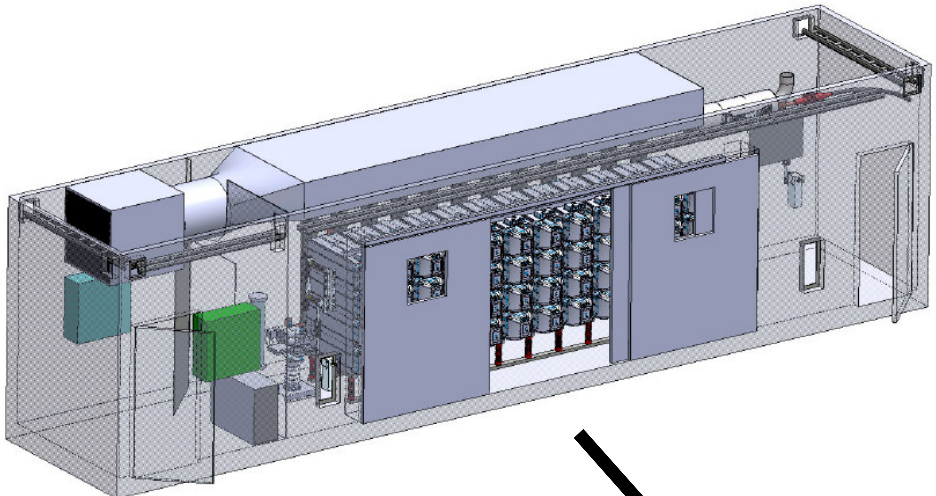
Energy Storage Platforms >1200V DC
Hierarchy of the battery solution for both Platforms



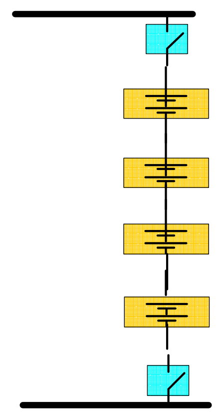
Cell
(3-4 V)



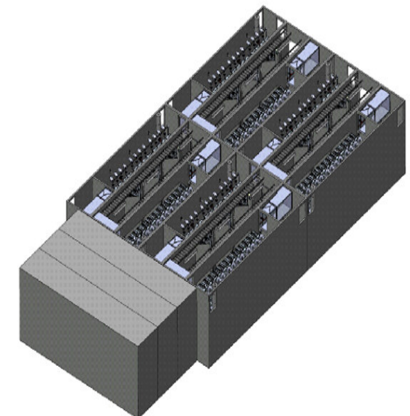
Module
(12-220 V)

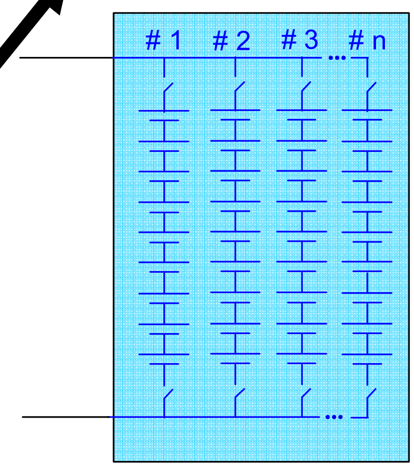


Room
(0.5-3 kV)



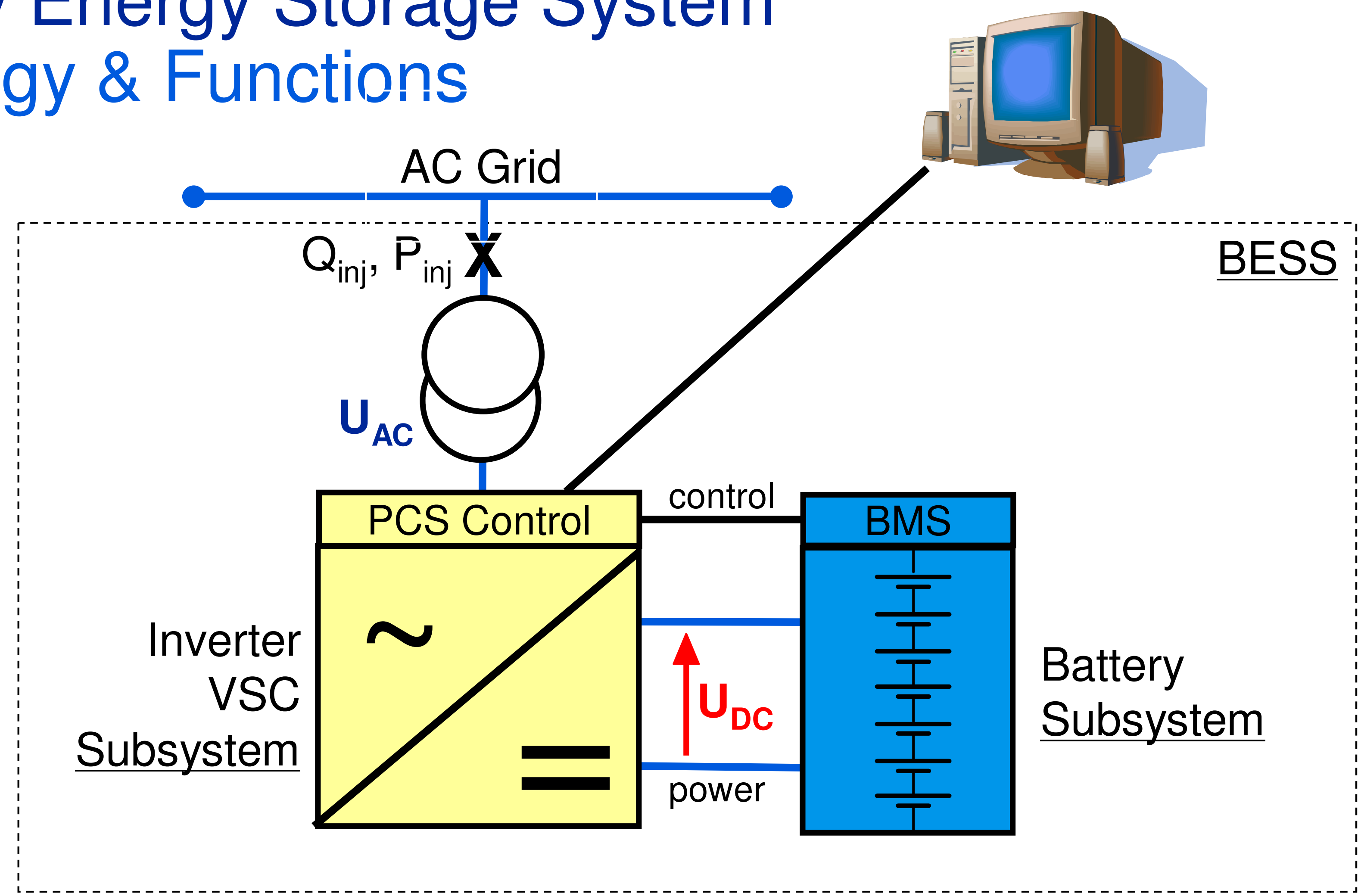
String
(1kV up to +/- 40 kV)





Storage

Battery Energy Storage System
Topology & Functions

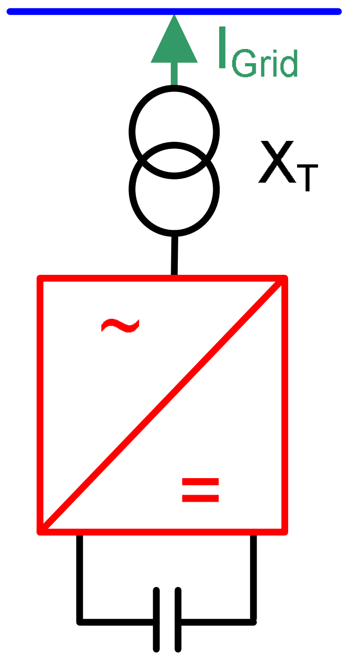


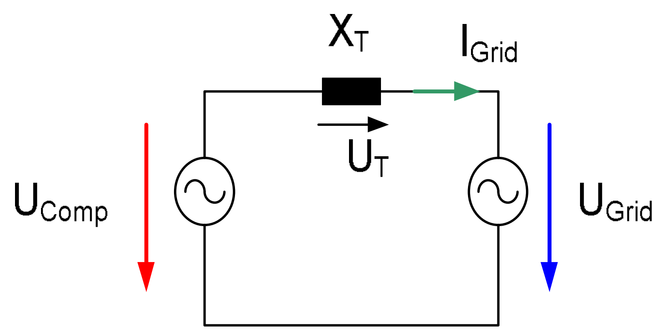
Functions:

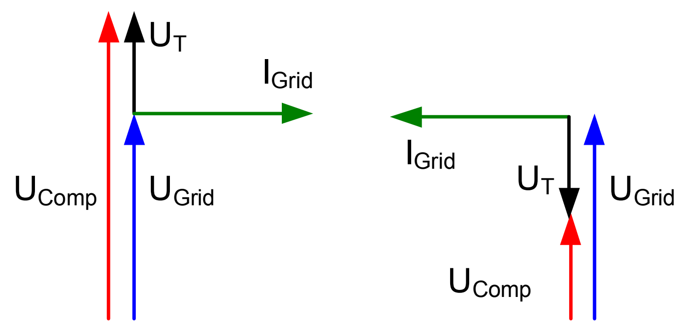
1. Voltage Control Operation: Reactive Power Q_{inj}
2. Frequency Control Operation: Real Power P_{inj}
3. Load Leveling / Peak Shaving Operation: Active Power
4. Black Start / Stand-alone Capability: Voltage and Frequency

Grid Connect Interfaces
STATCOM: The concept

- Voltage source with variable voltage amplitude
- Transformer acts as inductance
- Shunt connected to the distribution (or transmission) grid



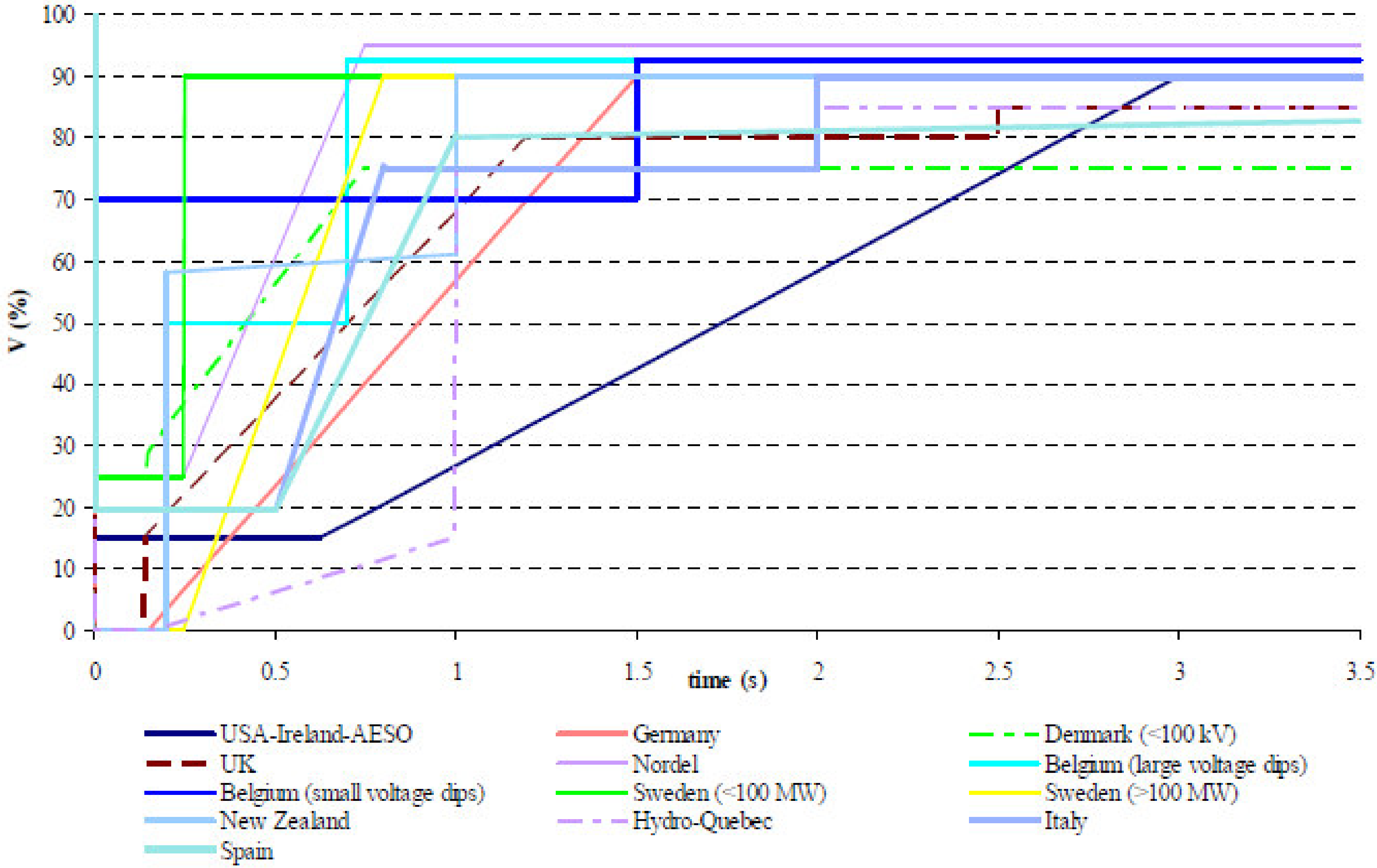




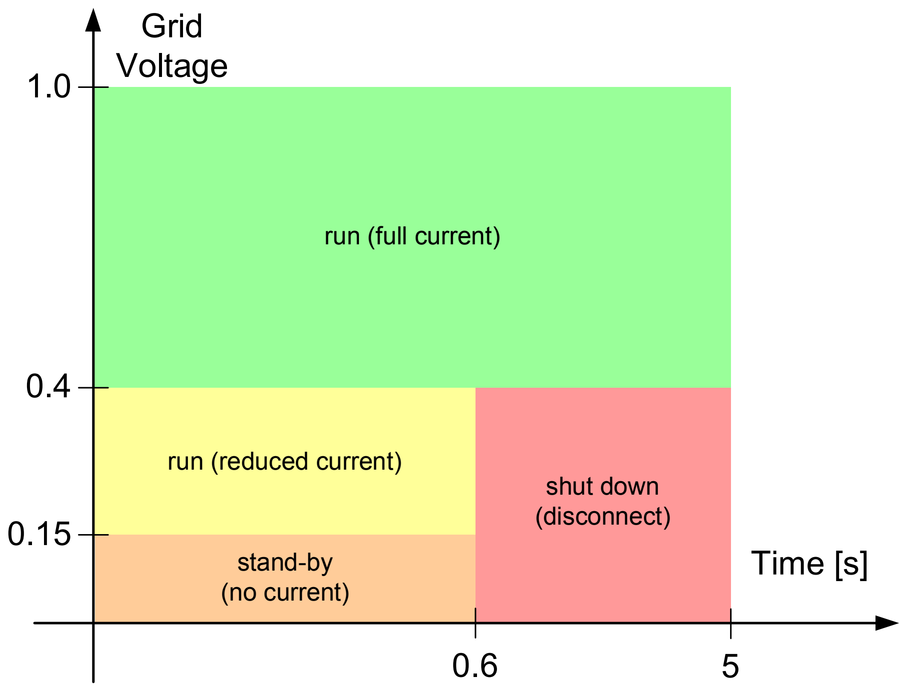
"capacitive"
over-excited

"inductive"
under-excited

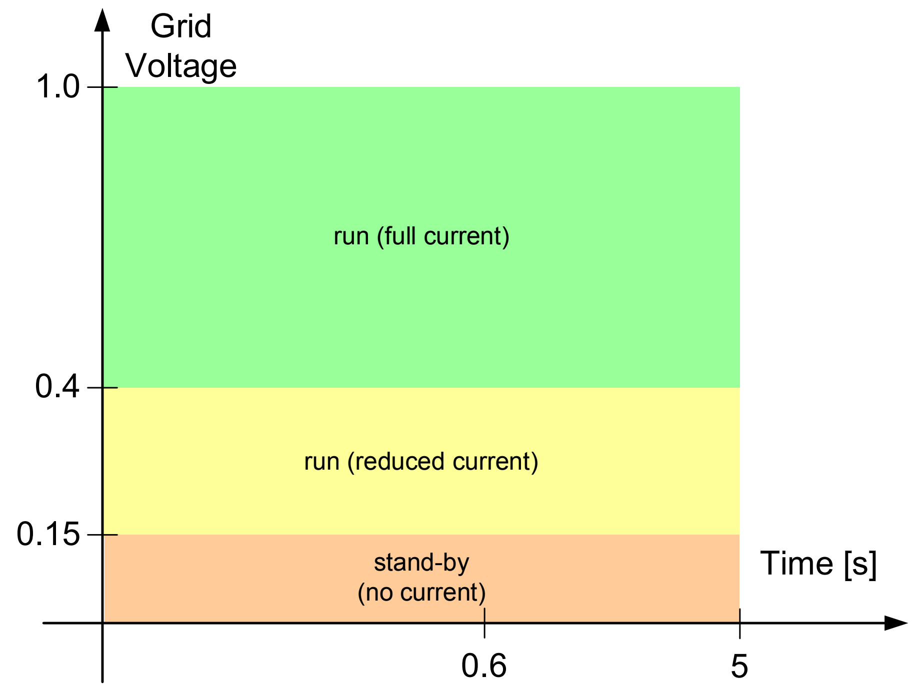
Low Voltage Ride Through – Grid Codes



PCS100-ESS Low Voltage Ride Through capability

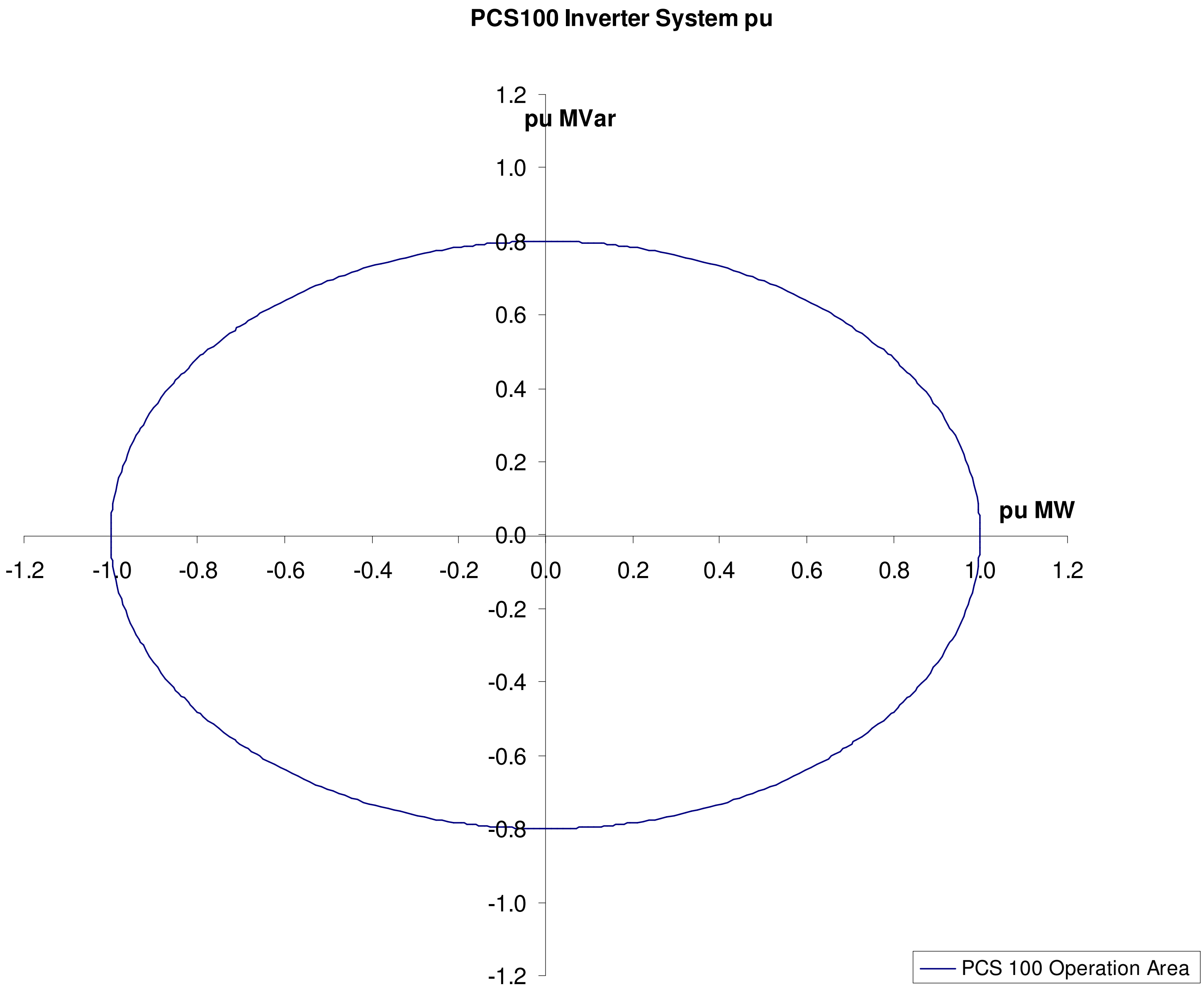


No UPS



With UPS

PCS100-ESS Operating Range



Grid Connect Interfaces
ESS inverter control modes

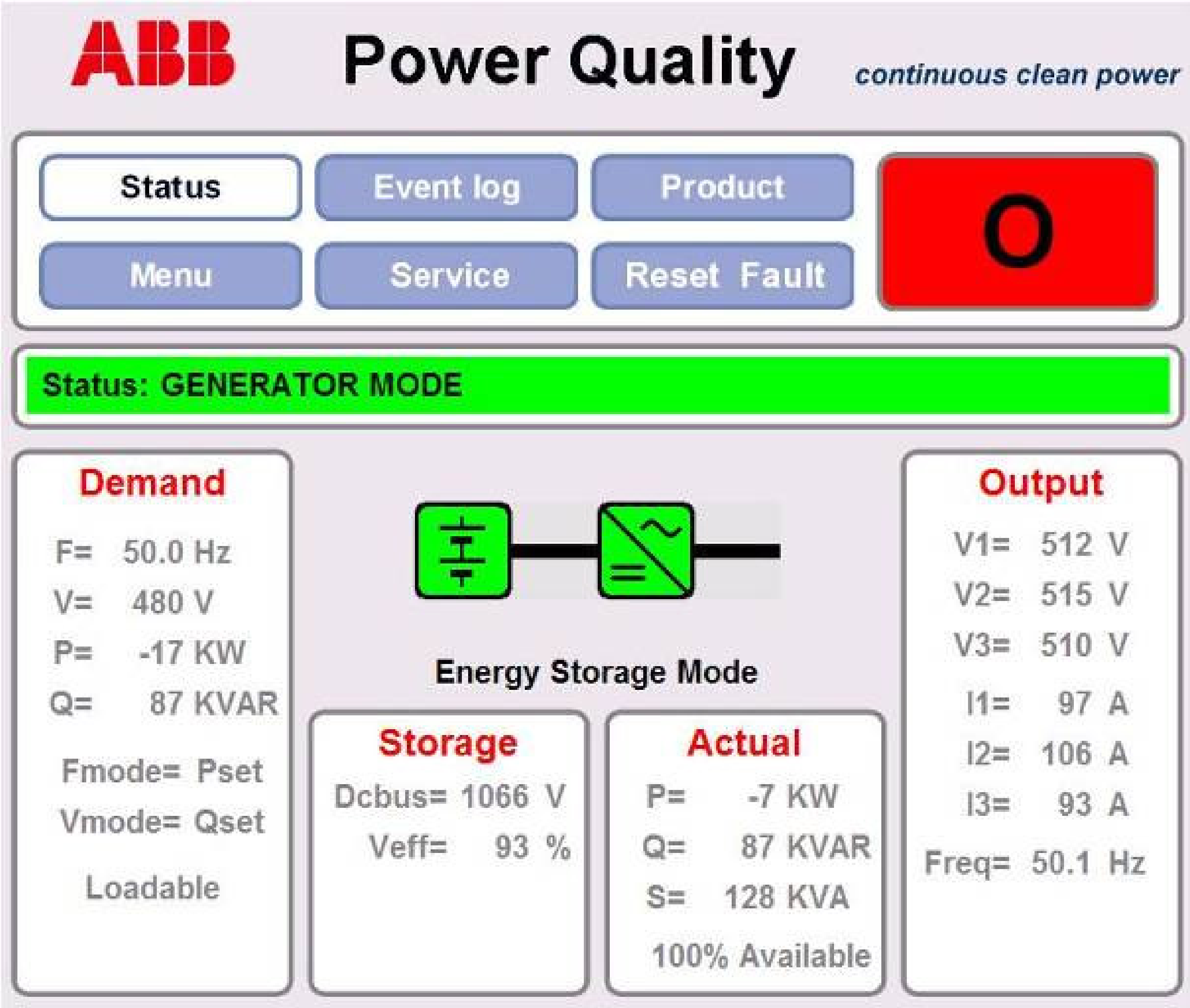
- **Generator Emulator Voltage Source Control**
  A unique feature of the PCS100 is its ability to provide power to the grid in the same manner as a regulator generator. This has many benefits for the grid;
  - Ability to source negative sequence current to correct grid unbalance
  - Stabilization of small grids through ‘synthetic’ inertia
- **High Speed Current Source Control**
  The PCS100 can also control power flow by controlling the current from the inverter. Direct current control provides a faster response to a power command.
  - Sinusoidal current regardless of grid voltage distortion
  - Minimizes DC ripple current
  - Fast response

Operating Modes

- Dynamic Power
- Voltage & Frequency Regulation
- Island

- Dynamic Power

PCS100 Graphic Display Module (GDM)
Interfaces



GDM

- Touch PC
- Easy access to information
- Visual representation of the system
- Event log, date and time stamped
- Fault log, date and time stamped
- Factory tags and location data
- Ethernet (SCADA)
- USB (service)

PCS100 Graphic Display Module (GDM)
Interfaces

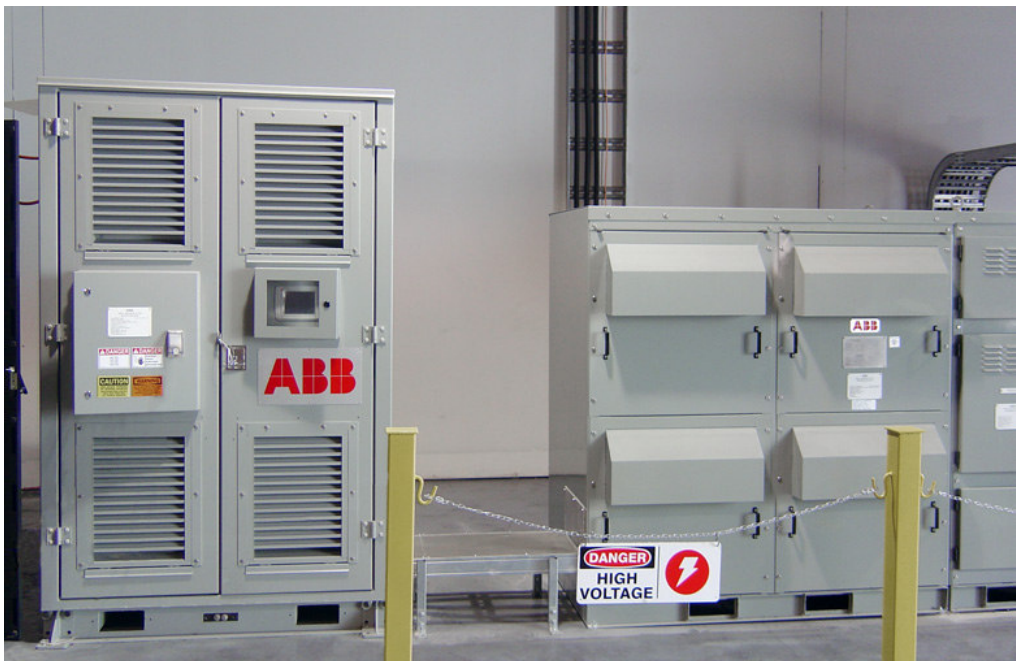
#	Date	Time	Event	Origin	Code	Description
1	2010-04-29	16:22:48.94	Warning	System	67	VCAN Warning
2	2010-04-29	16:17:57.65	Info	System	165	Run
3	2010-04-29	16:17:57.65	Info	System	159	Sync'd, output enabled
4	2010-04-29	16:17:57.65	Info	System	158	Sync'd, No Output
5	2010-04-29	16:17:56.36	Info	System	156	Syncing Phase, No Output
6	2010-04-29	16:17:55.43	Info	System	155	Syncing Volt/Freq, No Output
7	2010-04-29	16:17:55.23	Info	System	154	Wait Sync Good, No Output
8	2010-04-29	16:17:55.01	Start Local	System	0	
9	2010-04-29	16:17:47.57	Stop Local	System	0	
10	2010-04-29	16:17:47.35	Reset Local	System	0	

Factory and Site Acceptance Testing

ABB in-house test capability to test systems up to a primary voltage of 26 kV and power up to 4 MVA.

- **Functional testing**
- **Full power testing**
- **Heat Run testing**

ABB New Berlin FAT



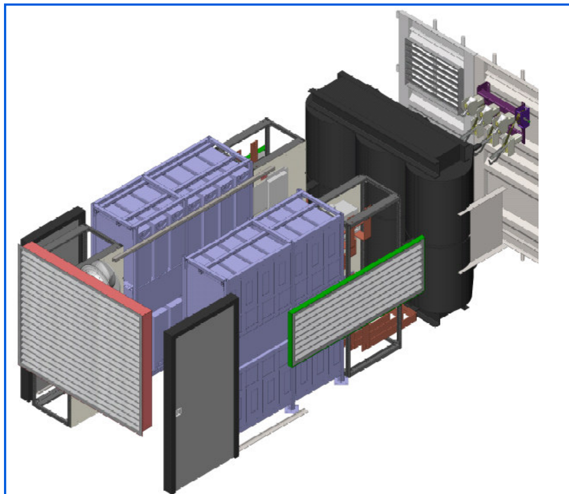
BESS/PCS FAT

Delivering a distributed energy storage system
Resources needed

Power System modeling

Research & development

Quality & OpEx



Power Electronics

Modular Systems

FACTS

Substations

Supply management

Sustainability

Service

Conclusions

- Energy Storage Systems
  - …are approaching maturity
  - …are one more tool for the Power System engineer
  - …must integrate seamlessly into the grid

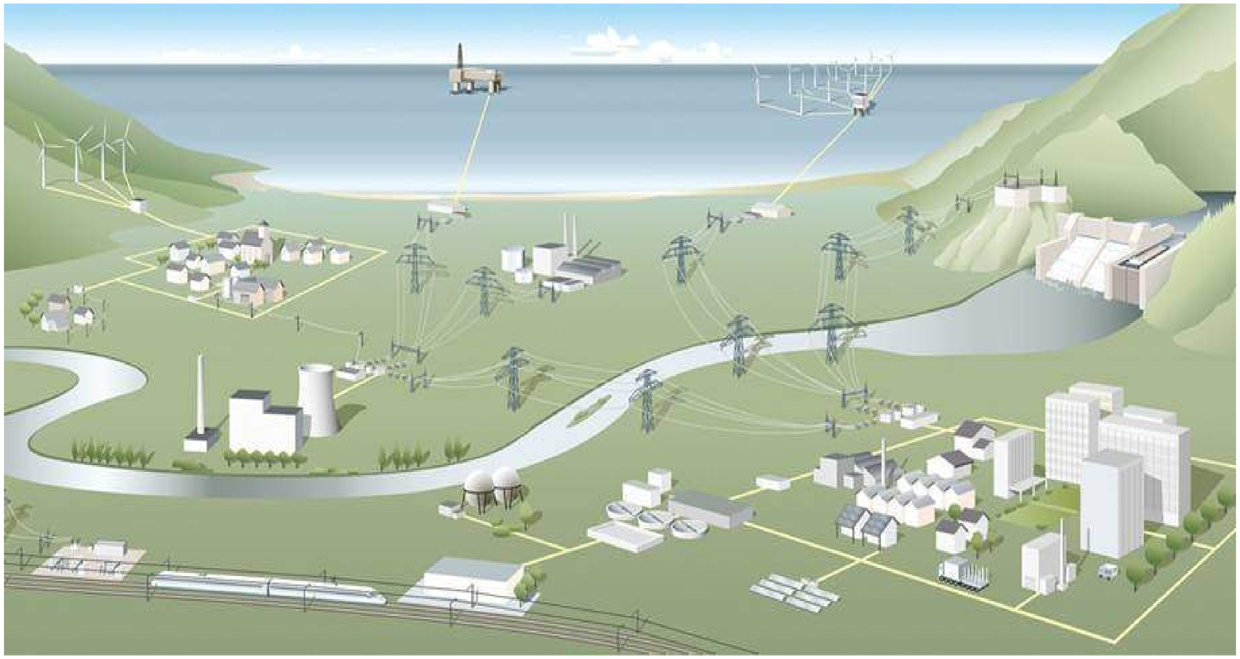


ABB Power Electronics

ABB contacts:

- Pat Hayes - Sales Account Manager – Energy Storage Systems
    - Office - 262-785-3426
    - Cell - 262-408-3217
    - E-mail - pat.hayes@us.abb.com
- Paul Koester - Sales & Marketing Manager - Power Electronics
- Gary Morris – Proposal Manager
- Joe Fox – Application Engineer

Power and productivity
for a better world™