SESSION 2018
TUTORIAL

Impact of Battery Energy Storage Systems (BESS) on Distribution Networks

Based on WGC6.30 Report

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SC C6

30 November 2018

For power system expertise

TABLE OF CONTENTS

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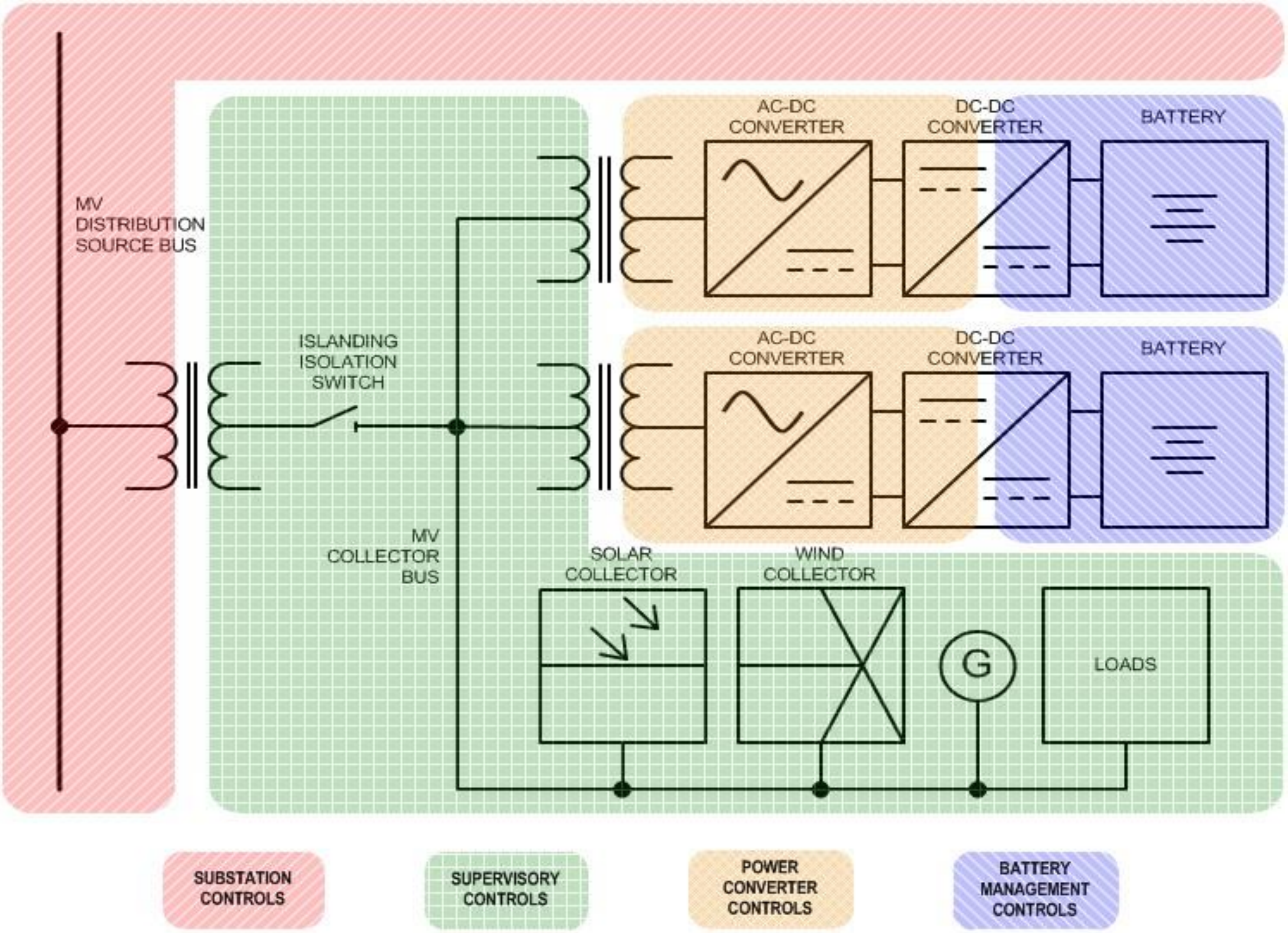
Acknowledgement: this tutorial is based on the CIGRE Technical Brochure TB 721
"The Impact of Battery Energy Storage Systems on Distribution Networks" of Study Committee C6,
convenor Nikos Hatziargyriou, Greece

SECTION 1 TUTORIAL

BATTERY ENERGY STORAGE SYSTEMS (BESS) GENERAL CONSIDERATIONS

BESS generic architecture and controls



Source: CIGRE WG C6-30 brochure

Basic model of the storage element

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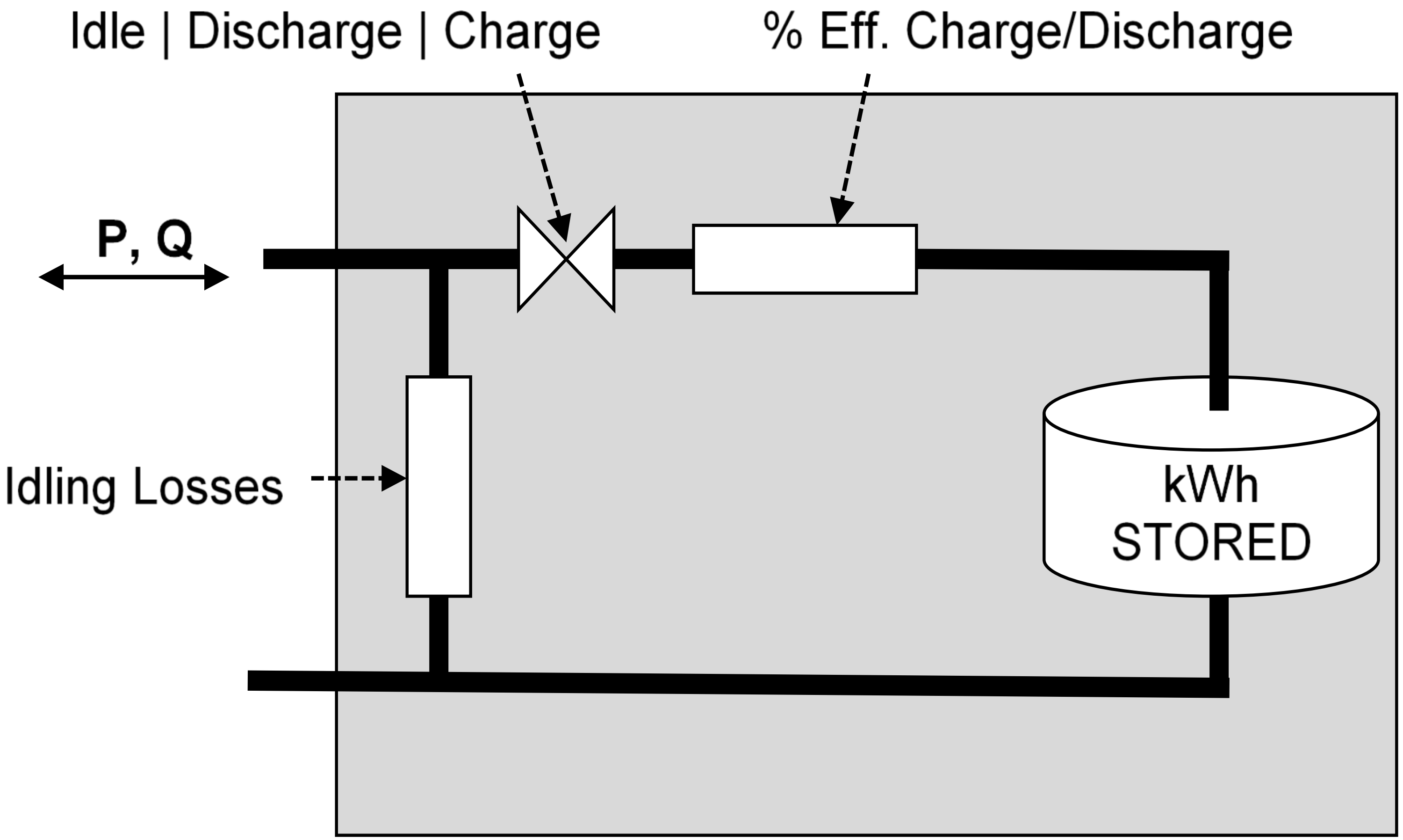

Other Key Properties
% Reserve
kWhRated
kWhStored
%Stored
kWRated
etc.

Source: EPRI

Energy storage – power and energy

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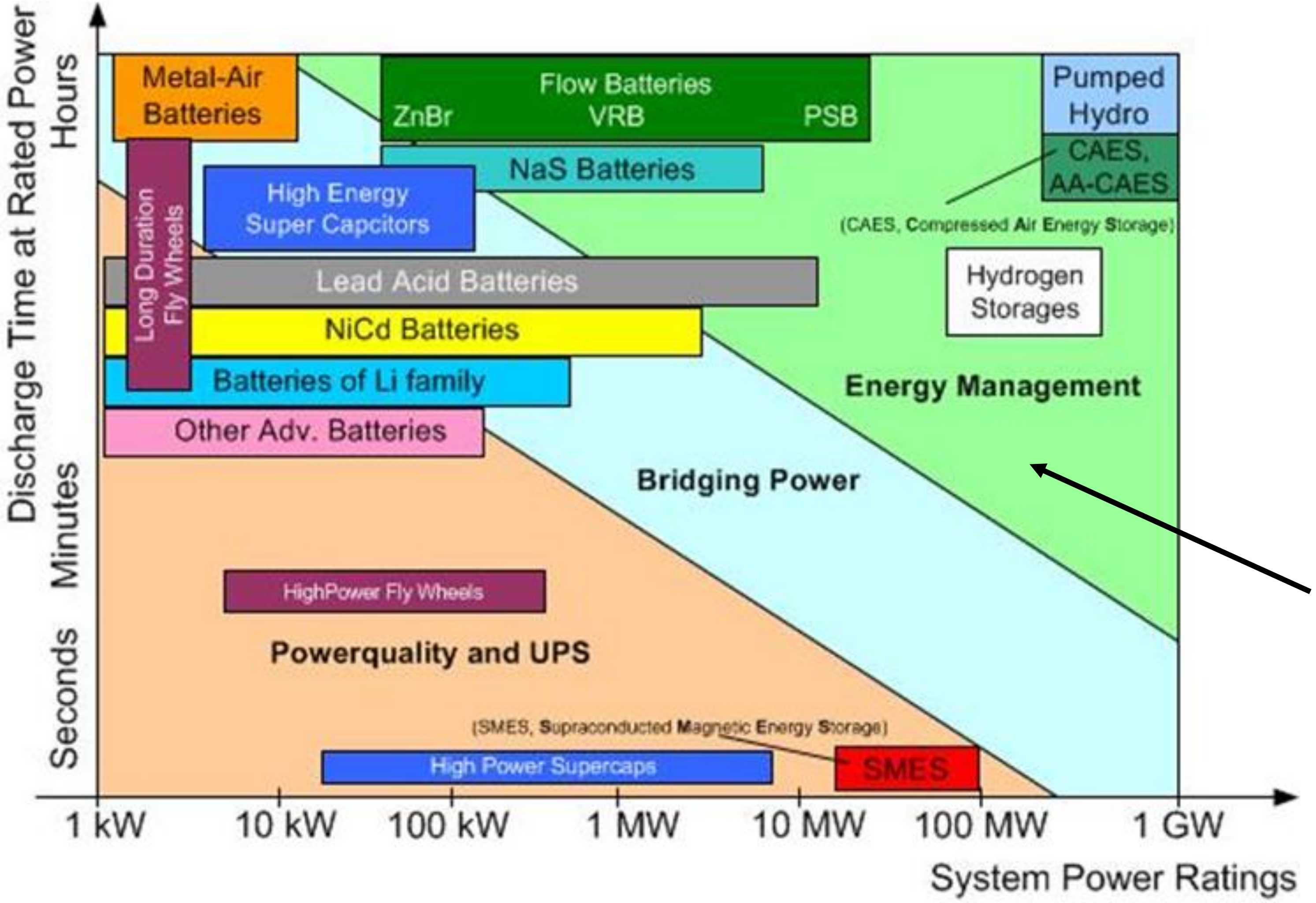
Operation duration (Time)



*Energy = P * t*

Power, W

Source: EPRI, December 2010

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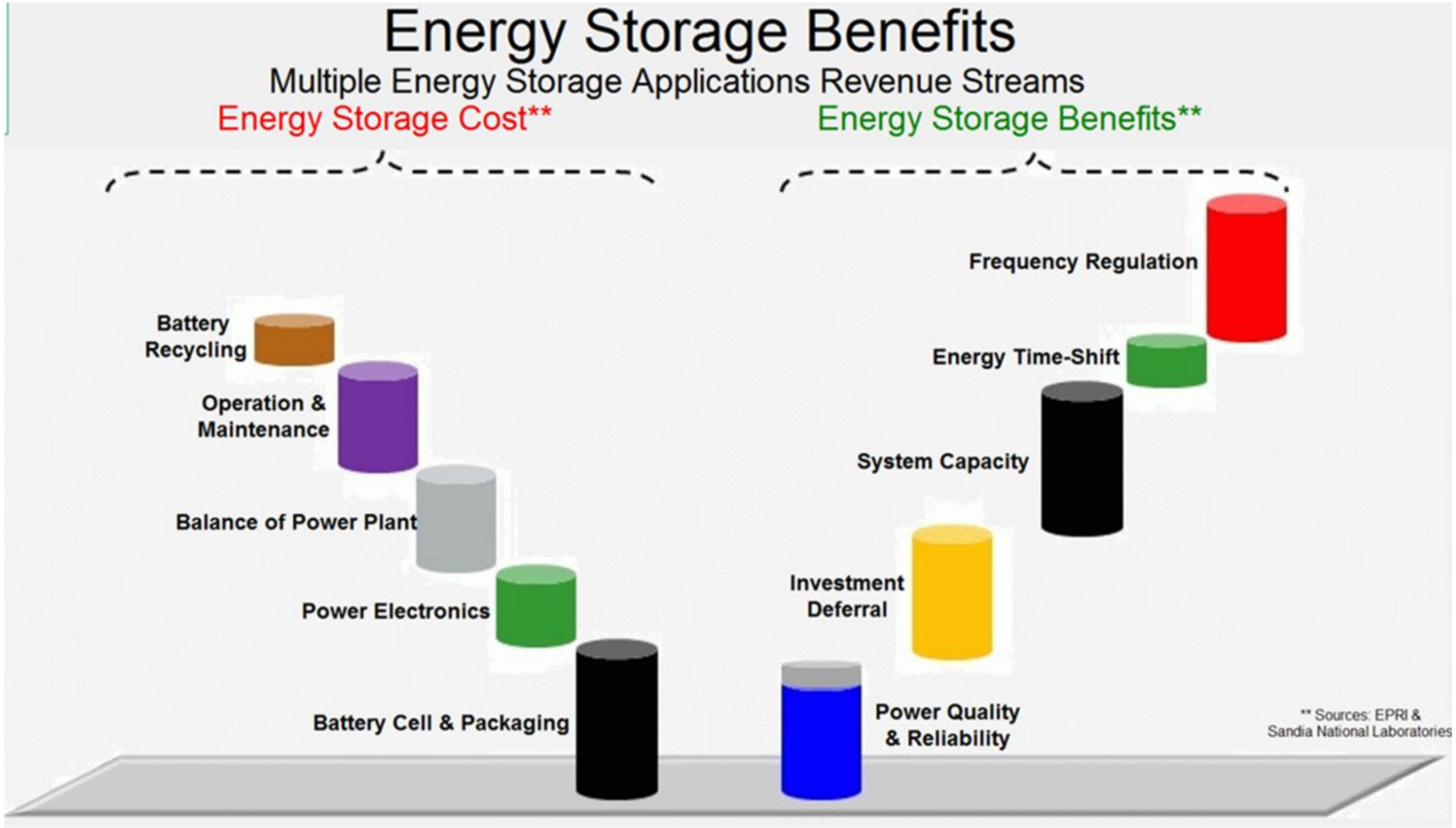
BESS IMPACTS AND BENEFITS ON ELECTRIC GRIDS

Energy storage systems – features



Source: CIGRE WG C6-30 brochure

Energy storage – grid benefits

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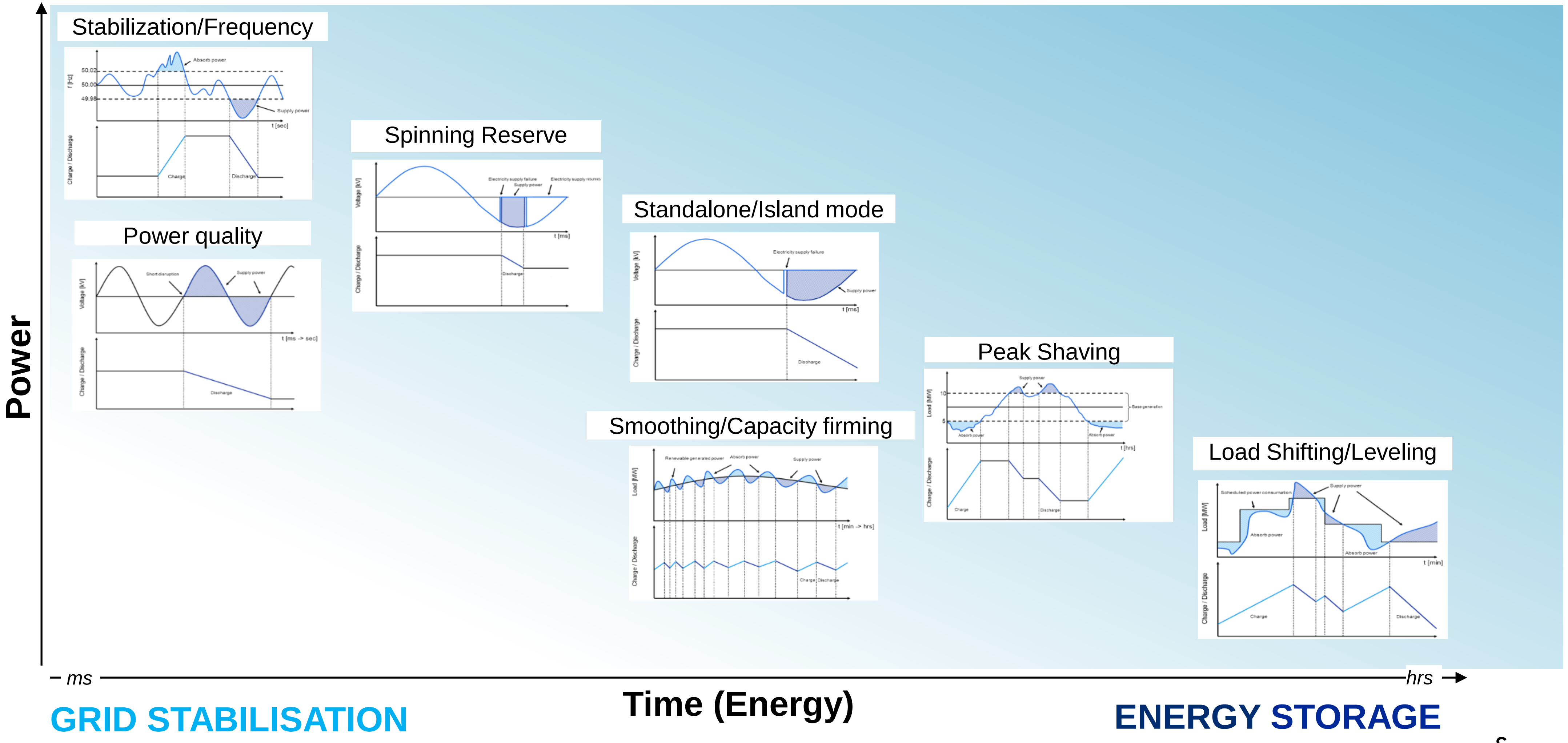

Source: ABB

BESS – balancing renewable resources

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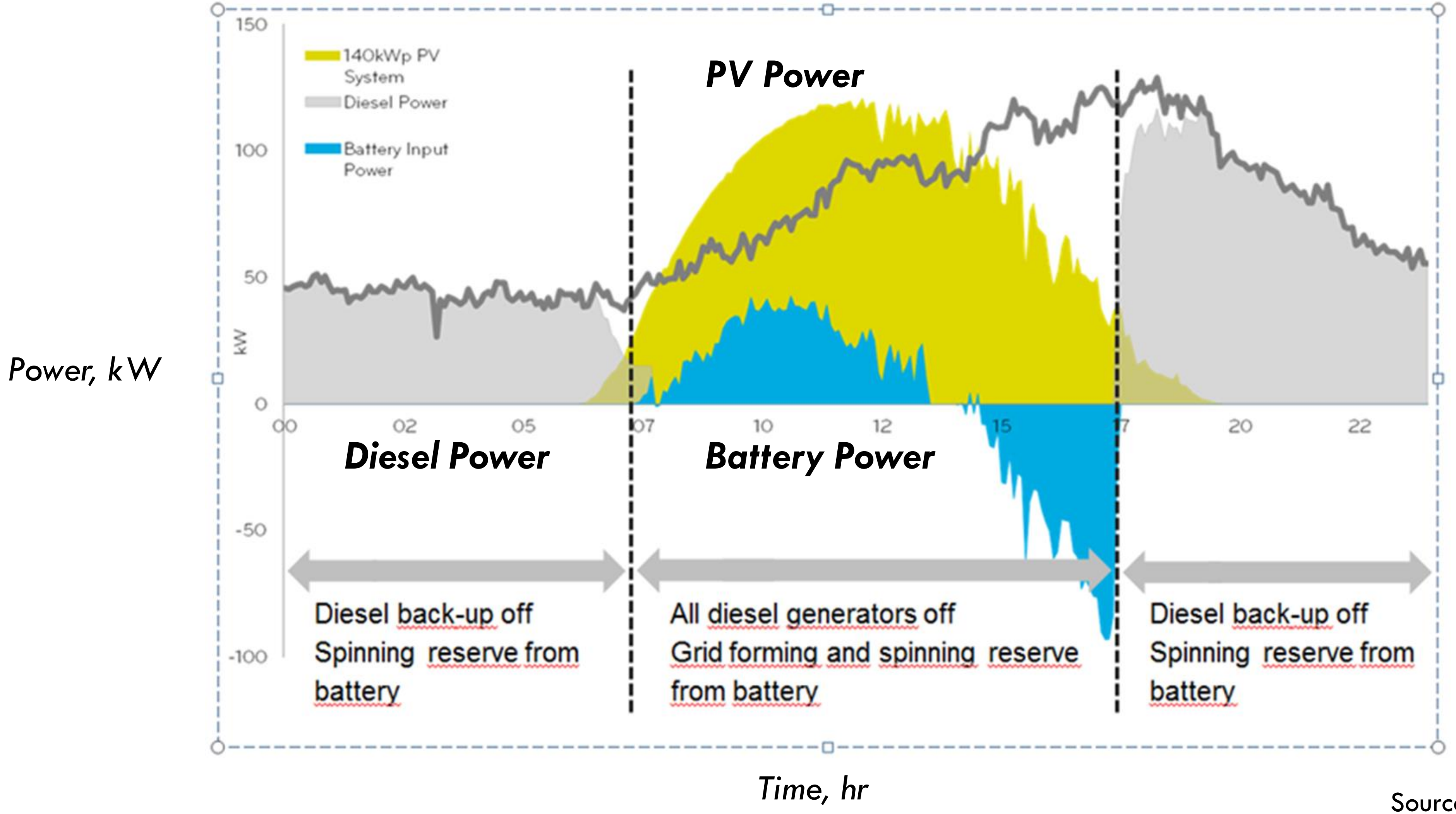
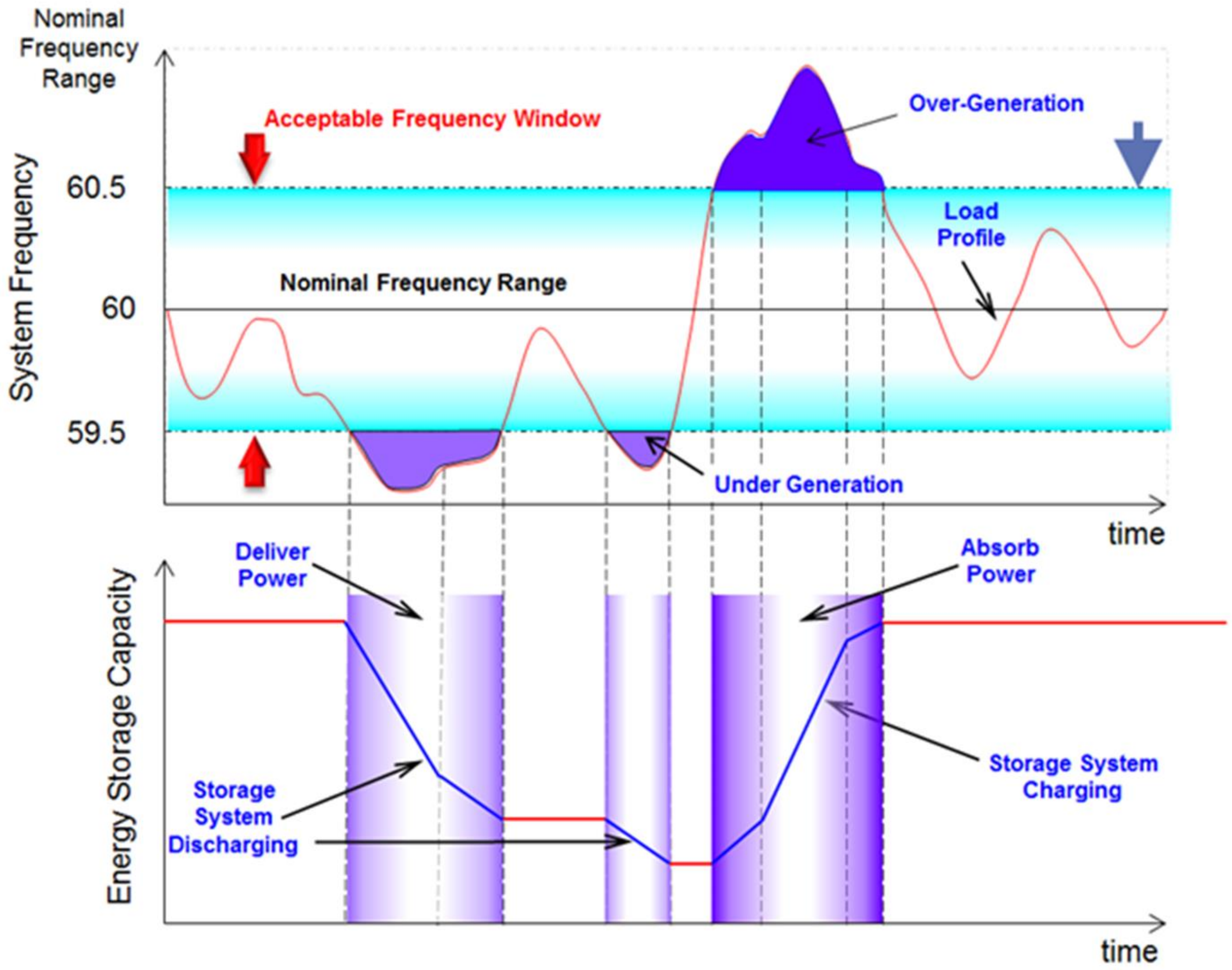


Source: CIGRE WG C6-30 brochure

BESS – frequency regulation

Frequency Hz

Battery current



Source: CIGRE WG C6-30 brochure

Load shifting – feedler load reduction

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BESS AS A POWER SOURCE FEATURES AND OPERATION

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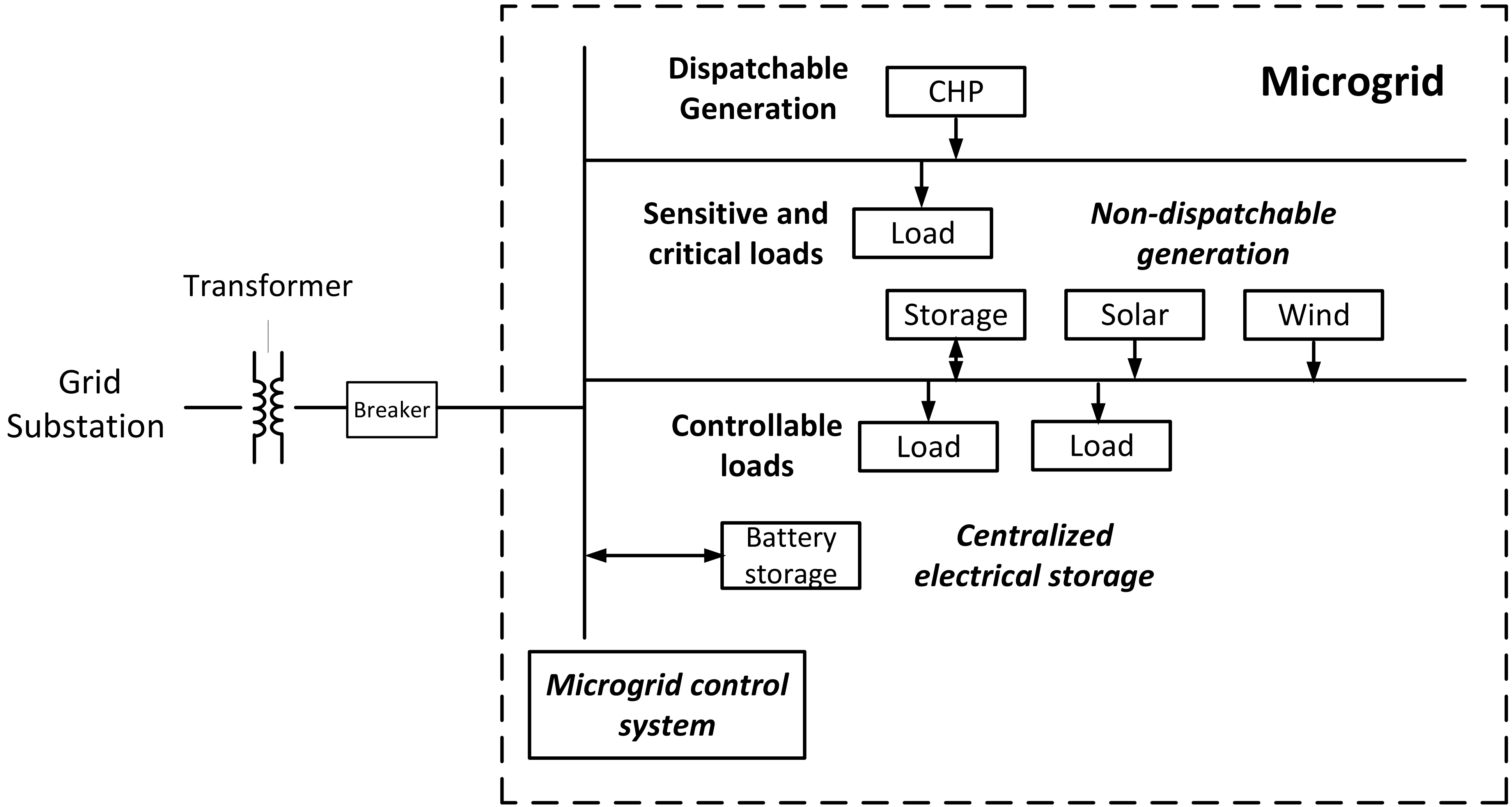
BESS integration – role in microgrid



BESS impact on congestion

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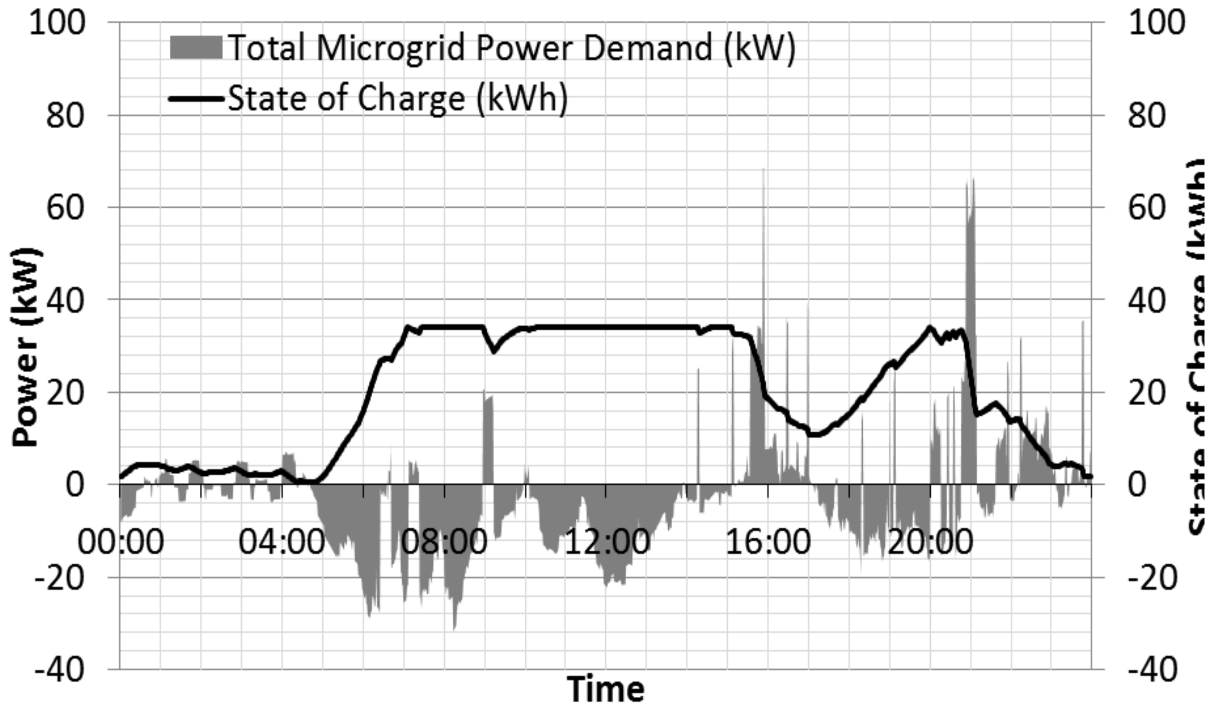
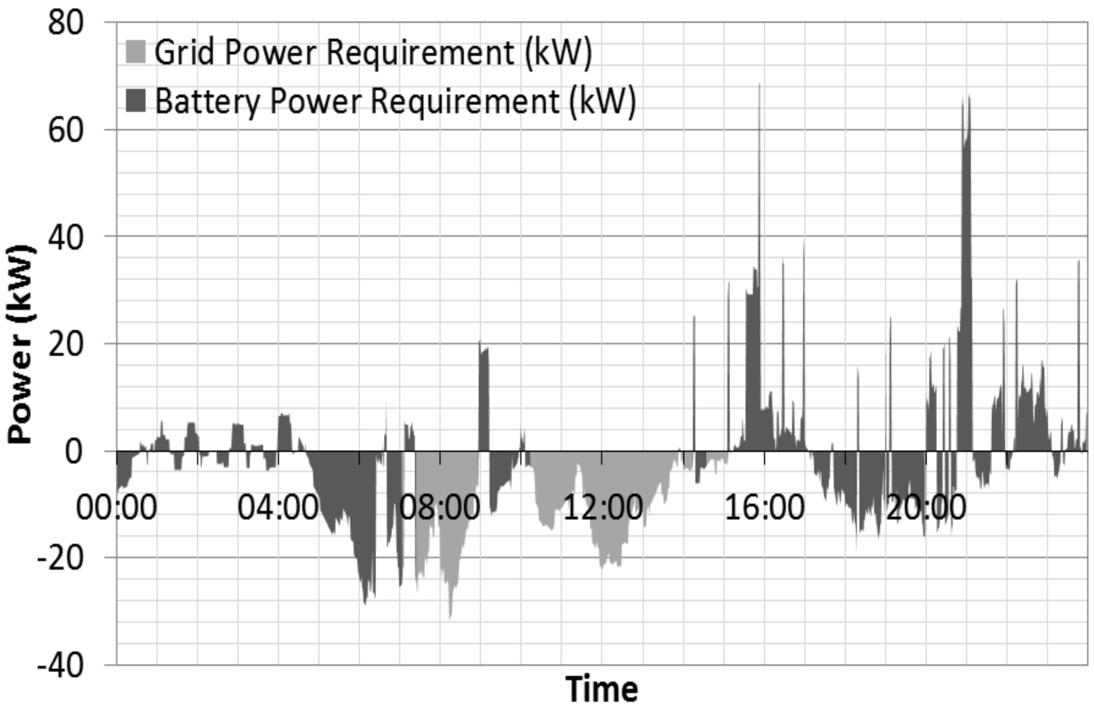
Local Balancing





Source: CIGRE WG C6-30 brochure

DER configuration and grid interface

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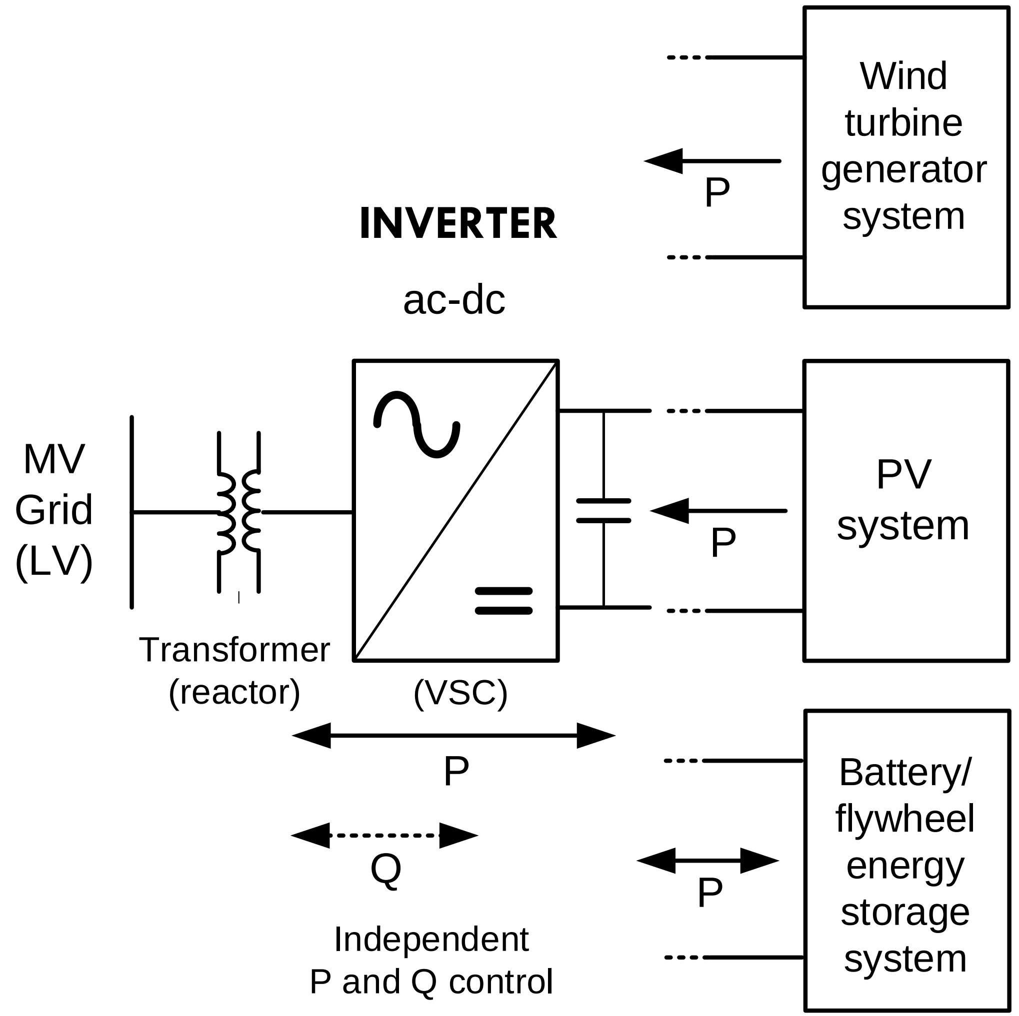

Inverters

- Have grid supportive capabilities – Q injection, P injection
- Control capability – P and Q outputs can be independently controlled
- Can be equipped with supplementary control functions/loops, to help support the grid including
  - Peak power P limitation/curtailment at the point of connection
  - Reactive power Q regulation as a function of bus voltage
  - P regulation as a function of bus voltage
  - P regulation as a function of system frequency

Common functions for DER inverters

- Connect/disconnect function – adaptive settings (grid-connected and islanded)
- Maximum generation limit – peak power limiting
- Battery storage functions
  - Charge/discharge management – coordinated management
  - Price-based charge/discharge function
- Fixed power factor function – Intelligent Volt-Var function
- Volt-Watt function – fixed and dynamic settings
- Frequency-Watt function
- Low/high voltage ride-through – Low/high frequency ride-through
- Dynamic reactive power/current support
- Real power smoothing
- Load and generation following

Source: EPRI report

DER inverter – intelligent function

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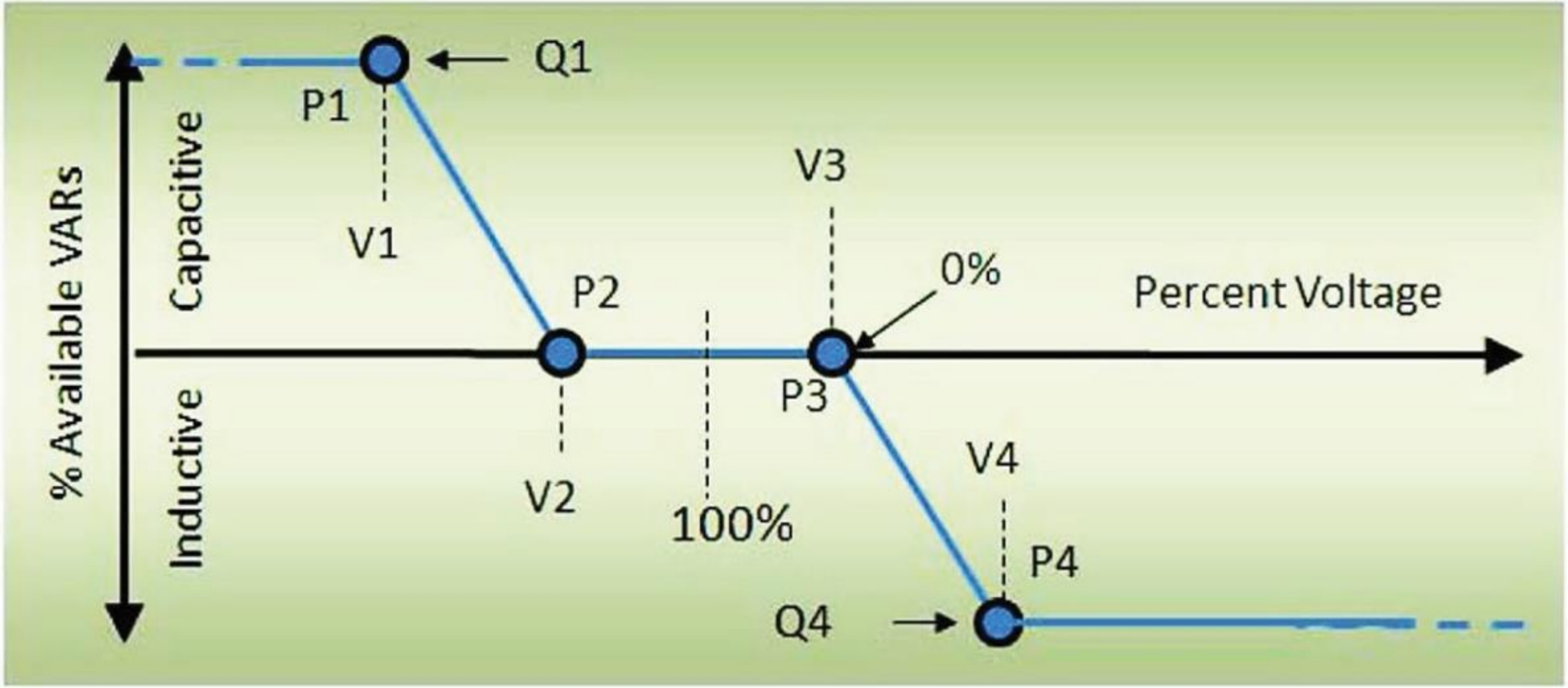
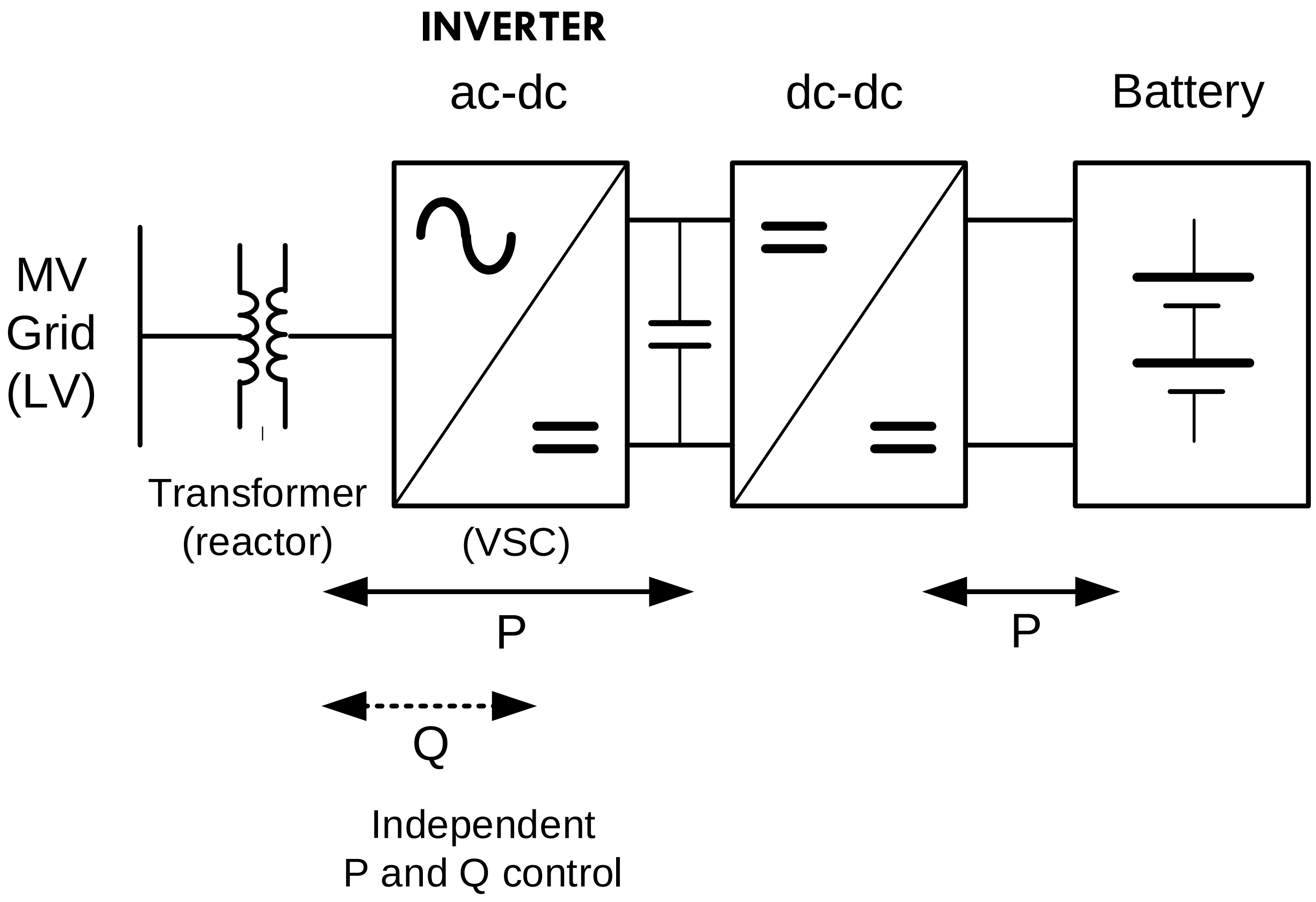


Volt-Var function – settings

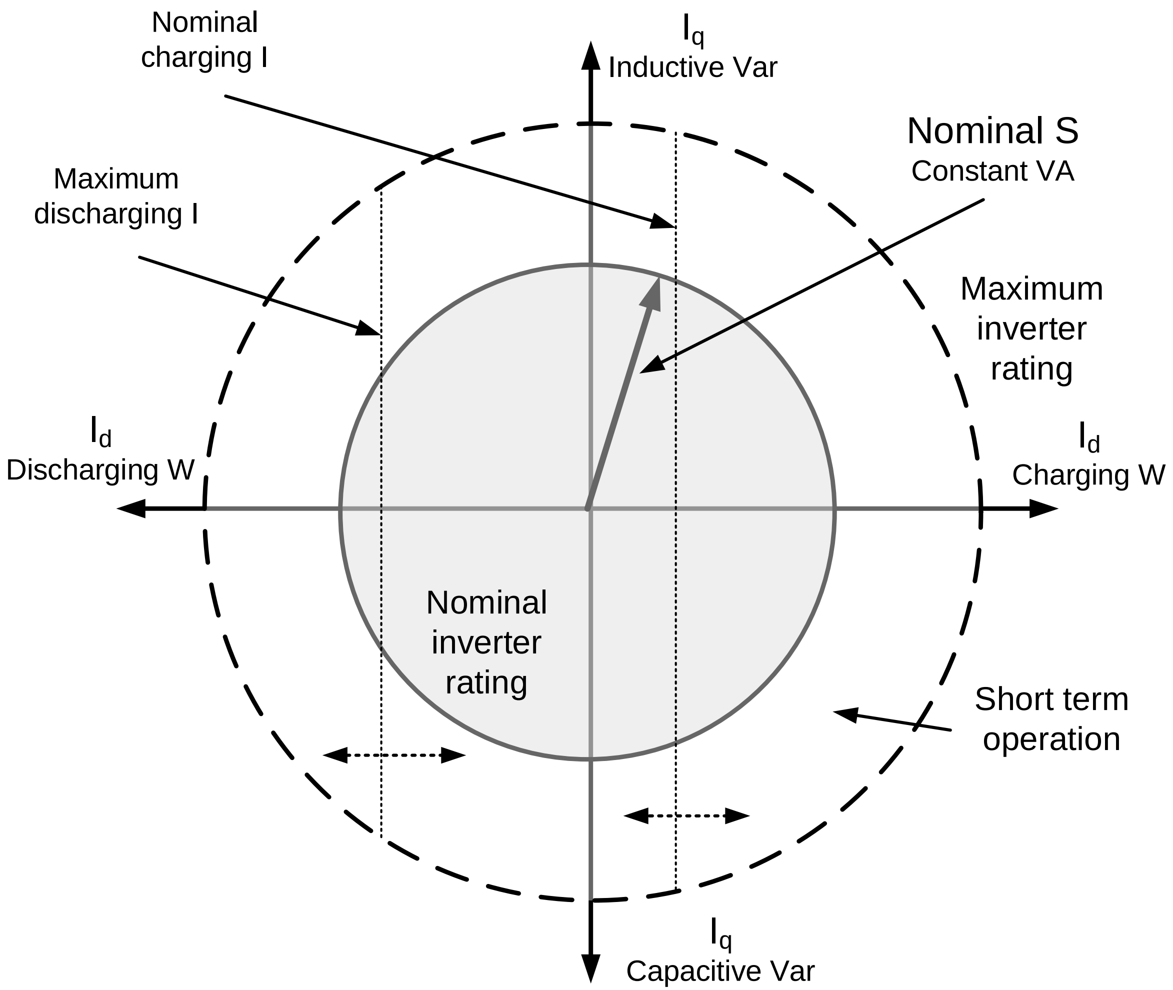
Source: EPRI report

BESS interface and structure – functions



- The BESS uses the same basic ac side structure as other power electronic interfaced DER
- Supplementary DER control functions can be implemented
- Differences with DER generators
  - The ability to act as both load and generator, depending on the real power P reference and the state of charge
  - It can act as a reference bus in islanded operation, setting frequency f and bus voltage V
  - It can be used to smooth out power variations produced by the operation of renewable energy resources based generators and loads

BESS operating regions and modes



- Inverter interfaced BESS operating modes – 4-Q
  - Real power (P) injection or absorption
  - Reactive power (Q), leading or lagging
  - Combination of P and Q
- Basic relations
  - $P = V \times I_d$
  - $Q = V \times I_q$
  - $S = V \times I$
- Operating constraints – kVA vs KWh
  - Inverter rated in current (kVA rating)
  - BESS real power capability = energy stored (kWh)
  - Limitations: charge/discharge rate

BESS – a virtual synchronous generator

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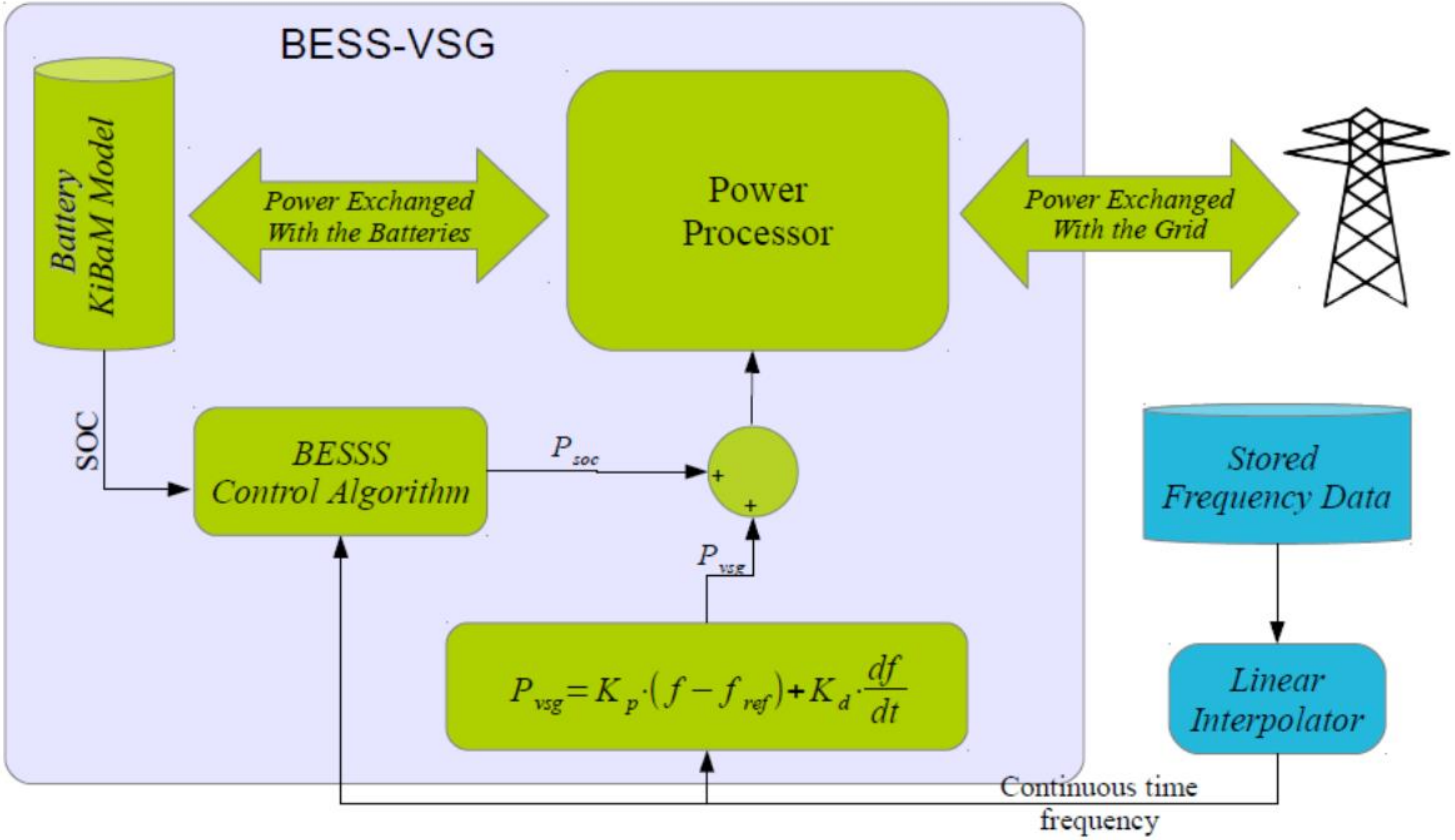

Source: CIGRE WG C6-30 brochure

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GRID CODES AND STANDARDS

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BESS grid codes and standards

- DER standards and grid codes applicable to BESS
- Ability of the DER to regulate the voltage at the bus to which it is connected
- Provision for reactive power in support of the grid voltage
- Possibility of real power curtailment – non-receptive grid
- Low/high voltage ride-through requirement
- Low/high frequency ride-through requirement
- Power system stabilization functions – damping power system oscillations
- Reference grid codes and standards: IEEE Std 1547, CEI 021, ENTSO-E, CENELEC, utility grid codes

Grid codes – V and f requirements

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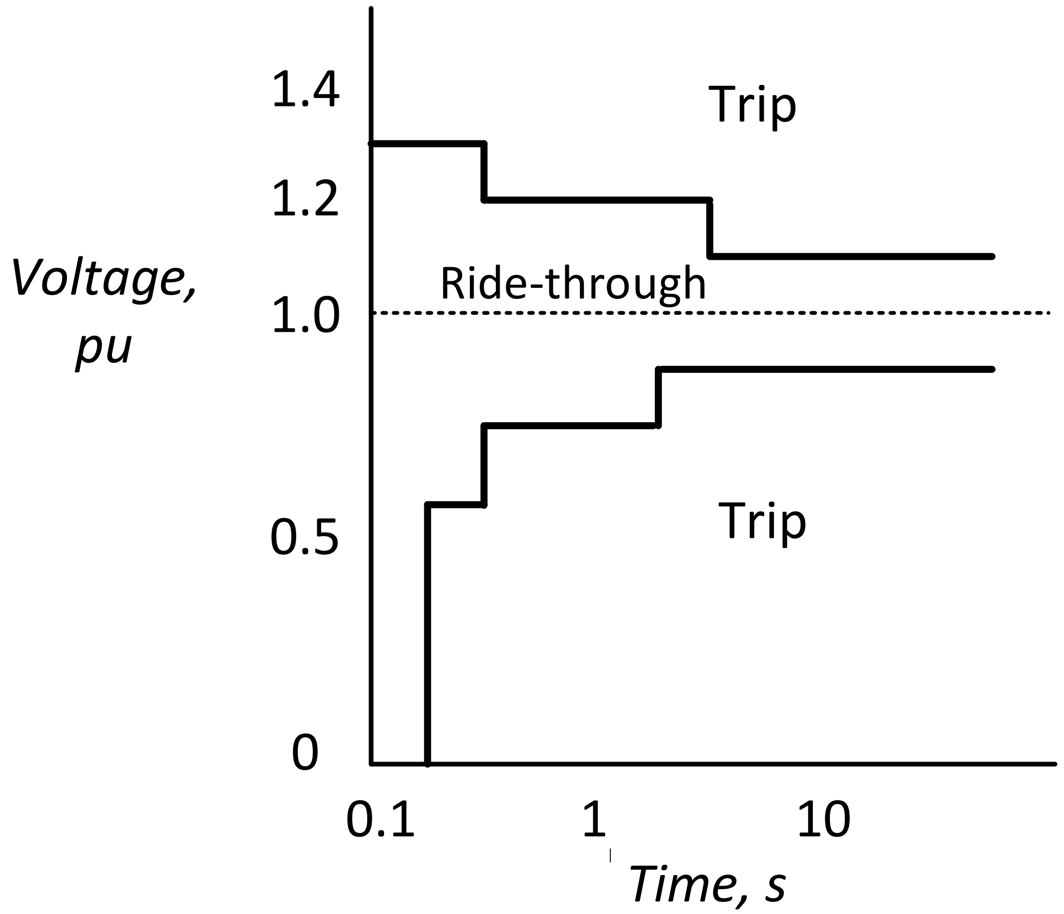

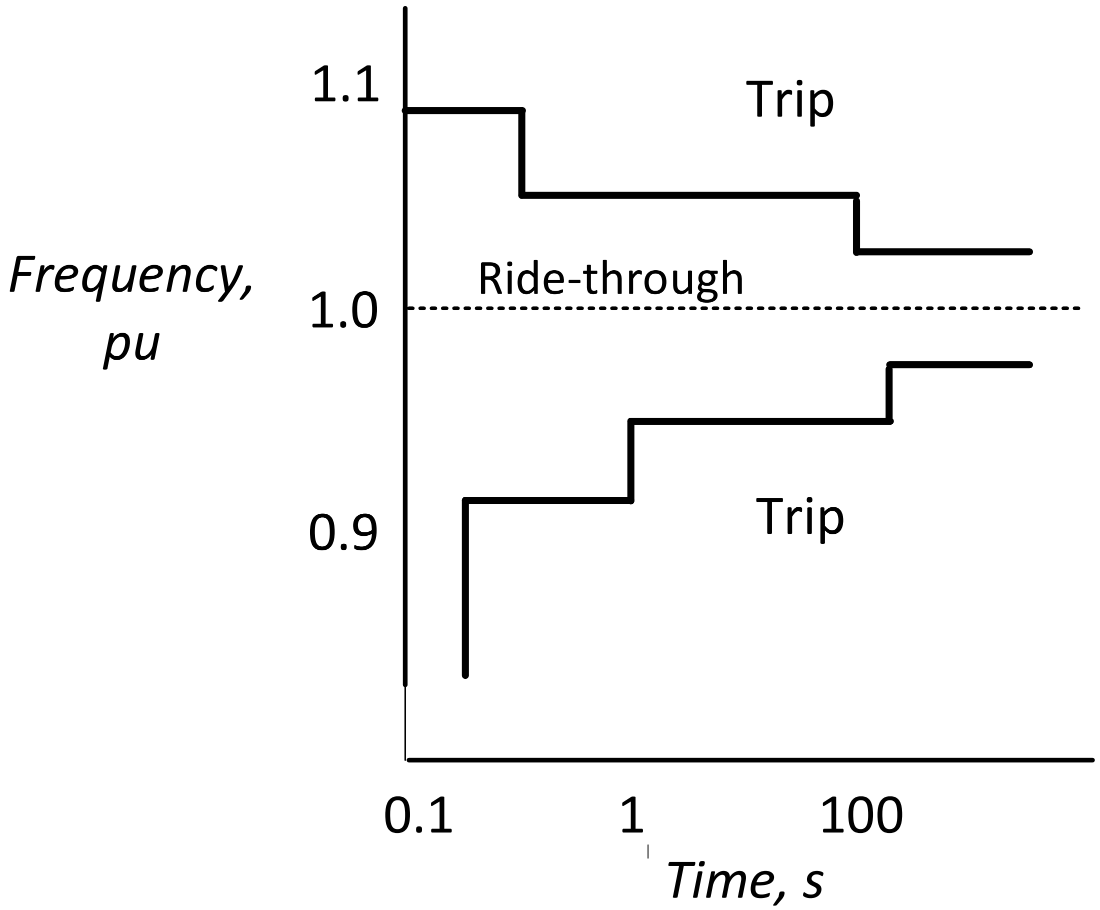

Source: Adapted from IEEE Std 1547

BESS standards and guidelines

- IEEE Standard 2030 series
  - IEEE Standard 2030TM – Guide for smart grid functional performance, Smart Grid Interoperability Reference Model
  - IEEE Std 2030.3TM – IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications
  - IEEE Std 2030.2™ – IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure
- USA energy storage system safety, standards and codes
  - Guide to Safety in Utility Integration of Energy Storage Systems
  - DER standards – IEEE Std 1547TM – Interconnecting DR with Electric Power Systems
- IEC 61850 standard and related developments
  - IEC 61859 – Communications for power system automation, collection of international standards describing devices in an electrical substation and information exchanges between these devices
  - IEC 61850-7-420, object models for ES-DER through IEC TC57 WG17

BESS integration considerations

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- Grid integration and interconnection requirements
  - Utility interconnection agreement
  - Interfacing with the Distribution Management System (DMS) – DSO control
  - Connection to primary/secondary substations or distribution feeders
  - Connection to grid nodes and customers (building load management)
- Grid integration studies
  - System studies – impact on the grid, harmonics and power quality
  - Protection studies – short circuit contributions (inverter limited)
- Combining different energy storage technologies – alternative designs
  - Purpose: cover a wider range of operating conditions (dynamic and steady state) and energy requirements, as needed
  - Example: combining a flywheel energy storage system (ESS), short term power, with a battery ESS, medium term power

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INTERNATIONAL EXPERIENCES
INSTALLATIONS

BESS Installations

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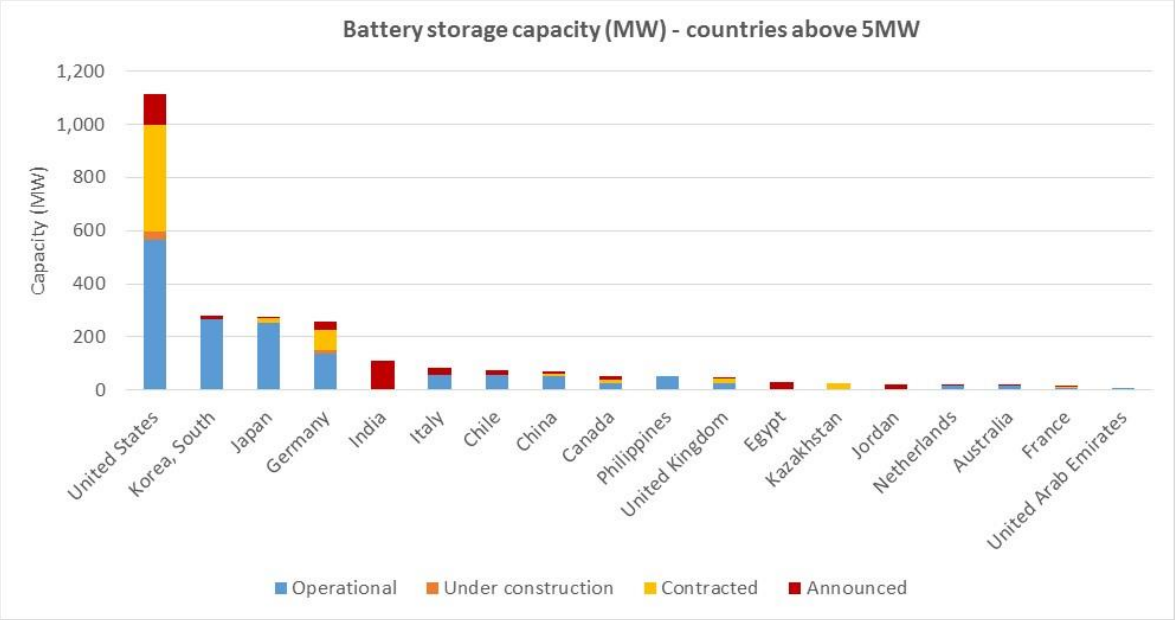
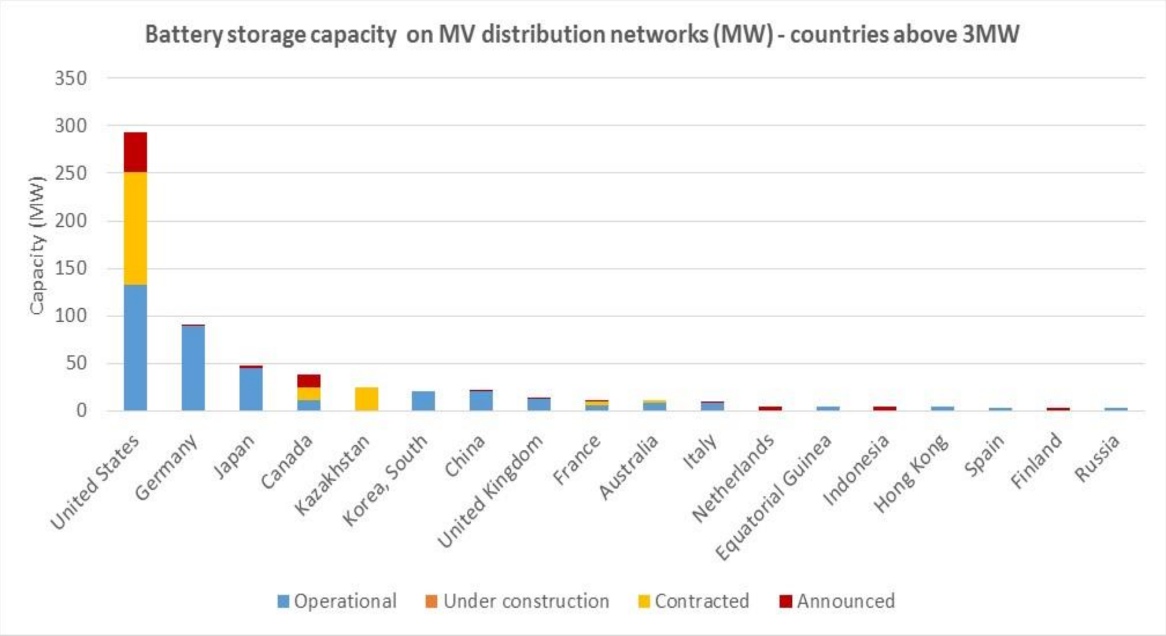
Analysis of DOE Global Energy Storage Database with 1,575 storage projects registered (171GW of operational capacity) by July 2016

Battery installations above 6MW, at renewable and conventional power plants/stations and off-grid installations excluded.





Source: CIGRE WG C6-30 brochure

Capacity by size of installation

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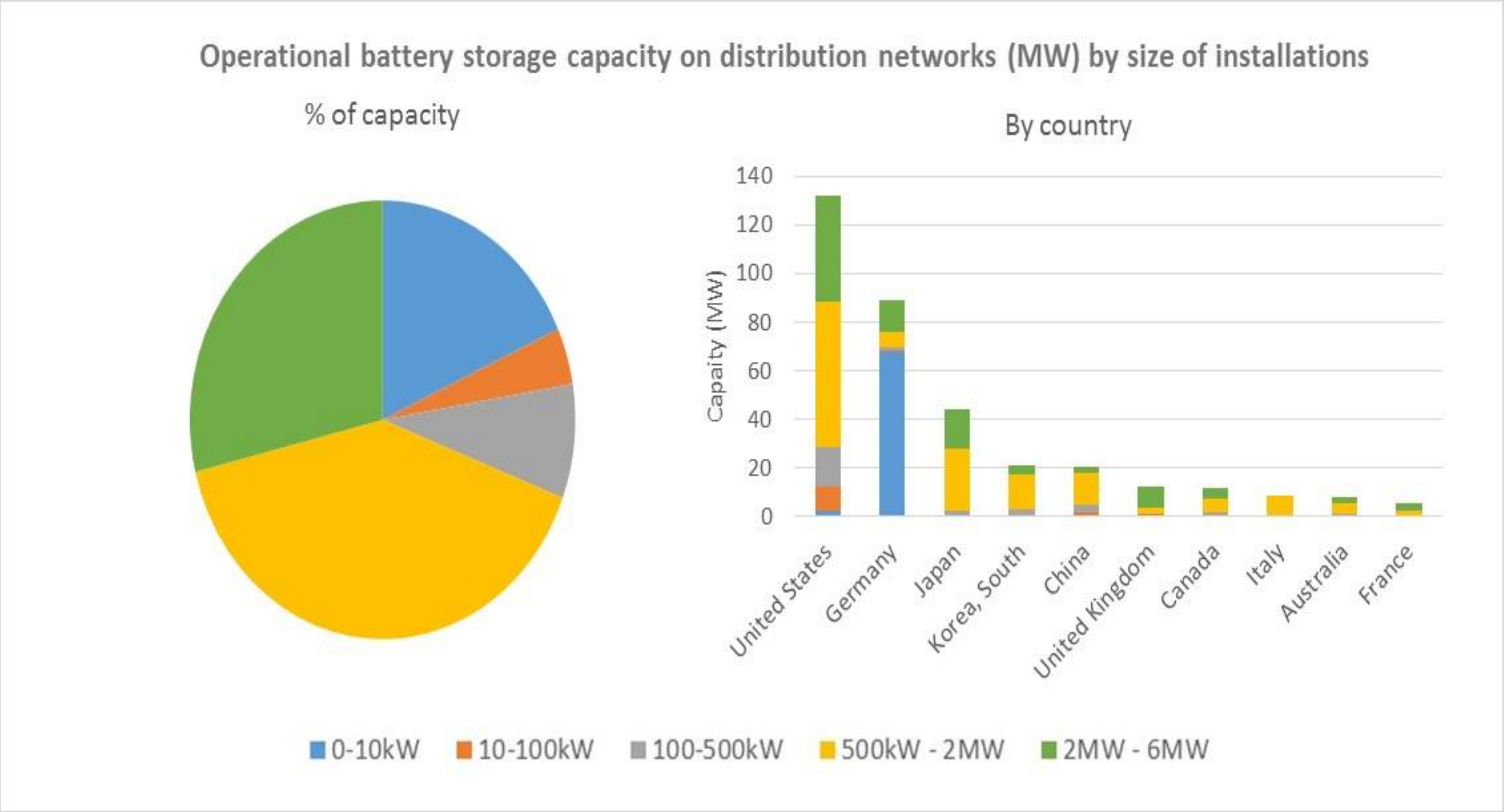

Source: CIGRE WG C6-30 brochure

BESS Technologies

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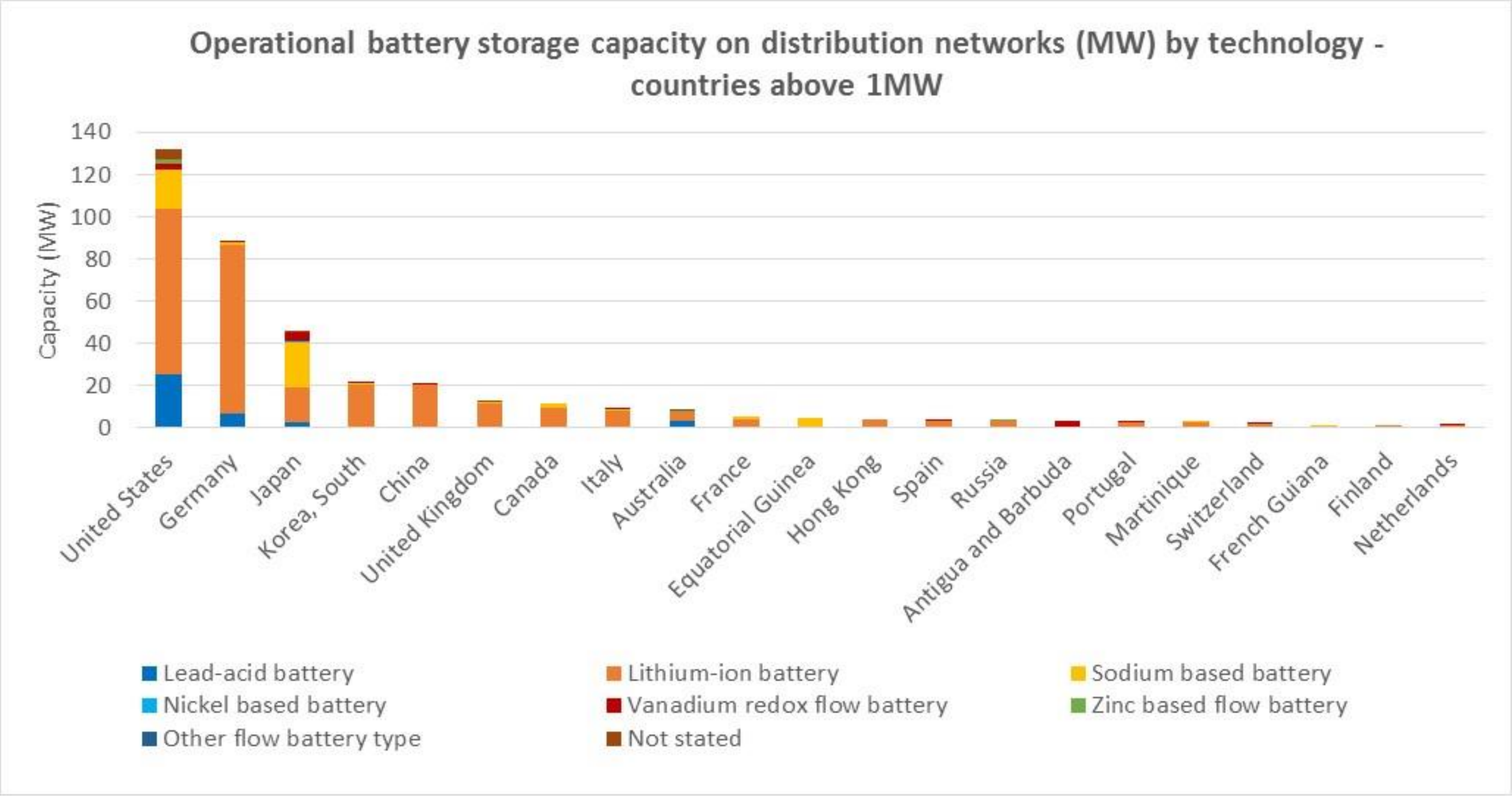

Lithium-ion batteries (~70%)

Source: CIGRE WG C6-30 brochure

Demonstration projects – use cases

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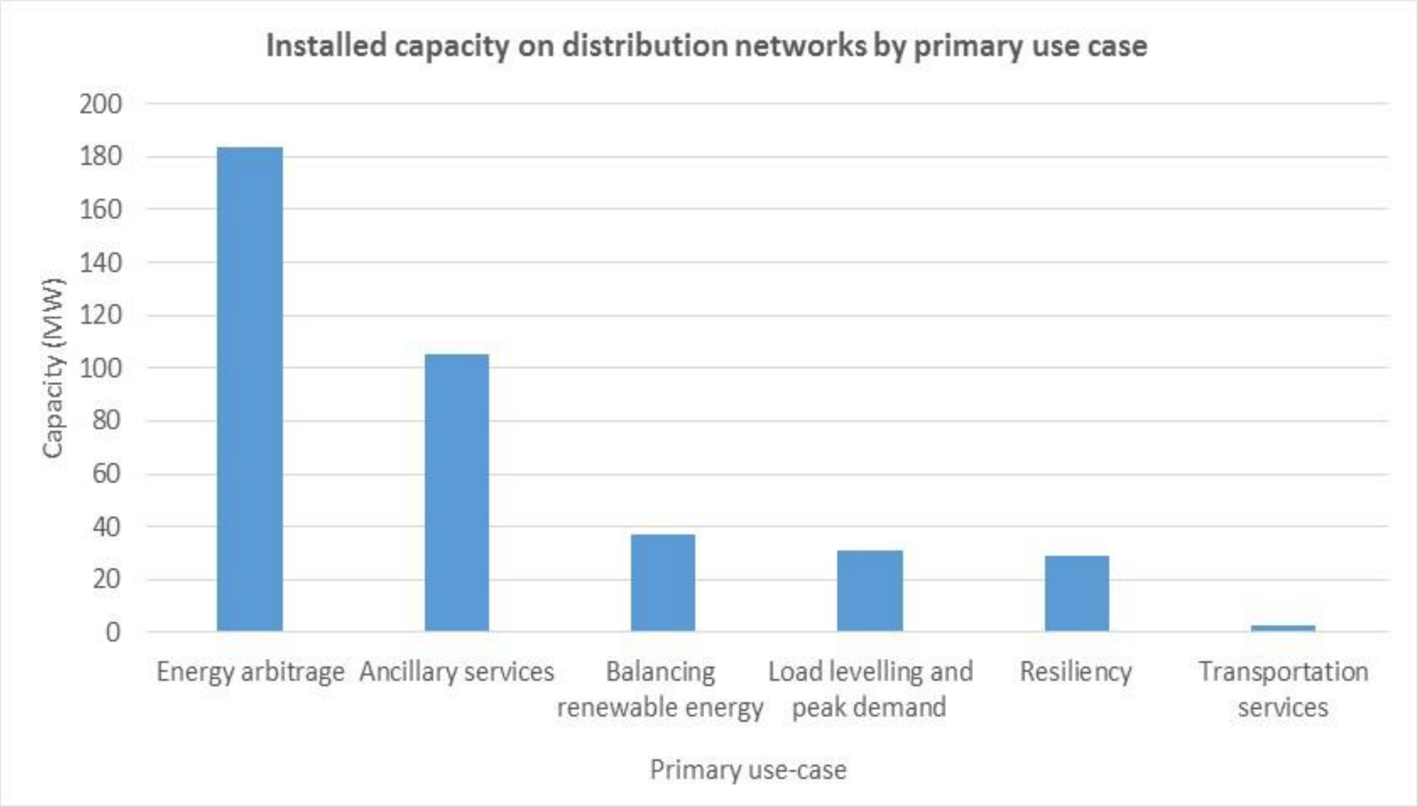
Analysis of DOE Global Energy Storage Database with 1,575 storage projects registered (171GW of operational capacity) by July 2016



Source: CIGRE WG C6-30 brochure

Energy arbitrage: 'Electric Bill Management', 'Electric Bill Management with Renewables', 'Electric Energy Time Shift'.

Ancillary services: 'Frequency Regulation', 'Load Following (Tertiary Balancing)', 'Electric Supply Reserve Capacity – Spinning', 'Electric Supply Reserve Capacity – Non-spinning', 'Voltage Support', 'Black start', 'Ramping', 'Transmission support'

Balancing renewable energy: 'Renewables Capacity Firming', 'Renewables Energy Time Shift', 'Onsite Renewable Generation Shifting'

Load levelling and peak demand: *'Demand response, 'Distribution upgrade due to solar', 'Distribution upgrade due to wind', 'Transmission upgrades due to solar', 'Transmission upgrades due to wind', 'Transportable Transmission / Distribution Upgrade Deferral'*, 'Stationary Transmission / Distribution Upgrade Deferral', 'Transmission Congestion Relief', 'Electric Supply Capacity', *'On-Site Power'*

Resiliency: *'Resiliency'*, 'Grid-Connected Commercial (Reliability & Quality)', 'Grid-Connected Residential (Reliability)', *'Microgrid capability'*

Demonstration projects – use cases

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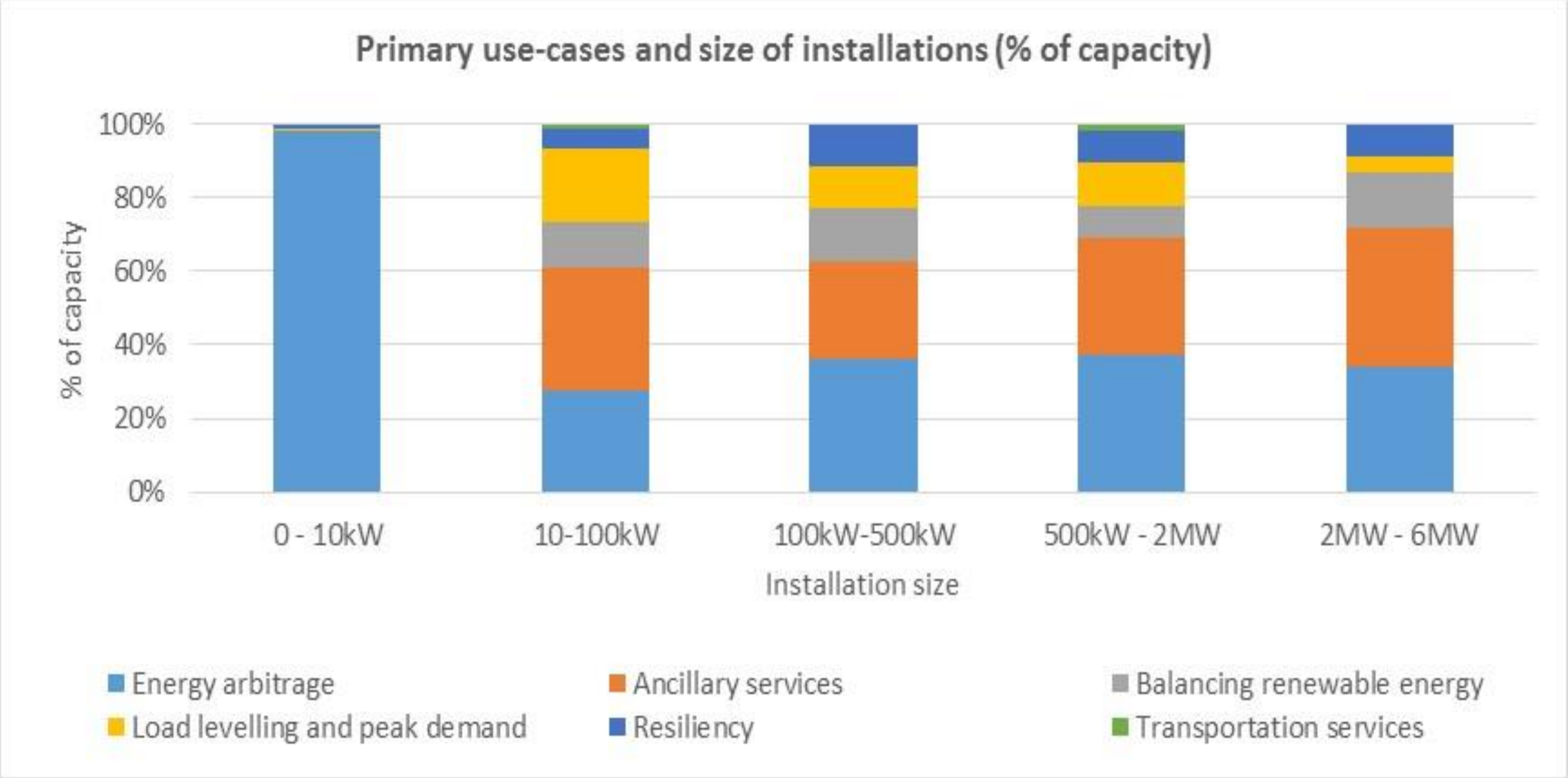
Analysis of DOE Global Energy Storage Database with 1,575 storage projects registered (171GW of operational capacity) by July 2016

Primary use-cases depending on size of installation



Source: CIGRE WG C6-30 brochure

Demonstration projects – ownership

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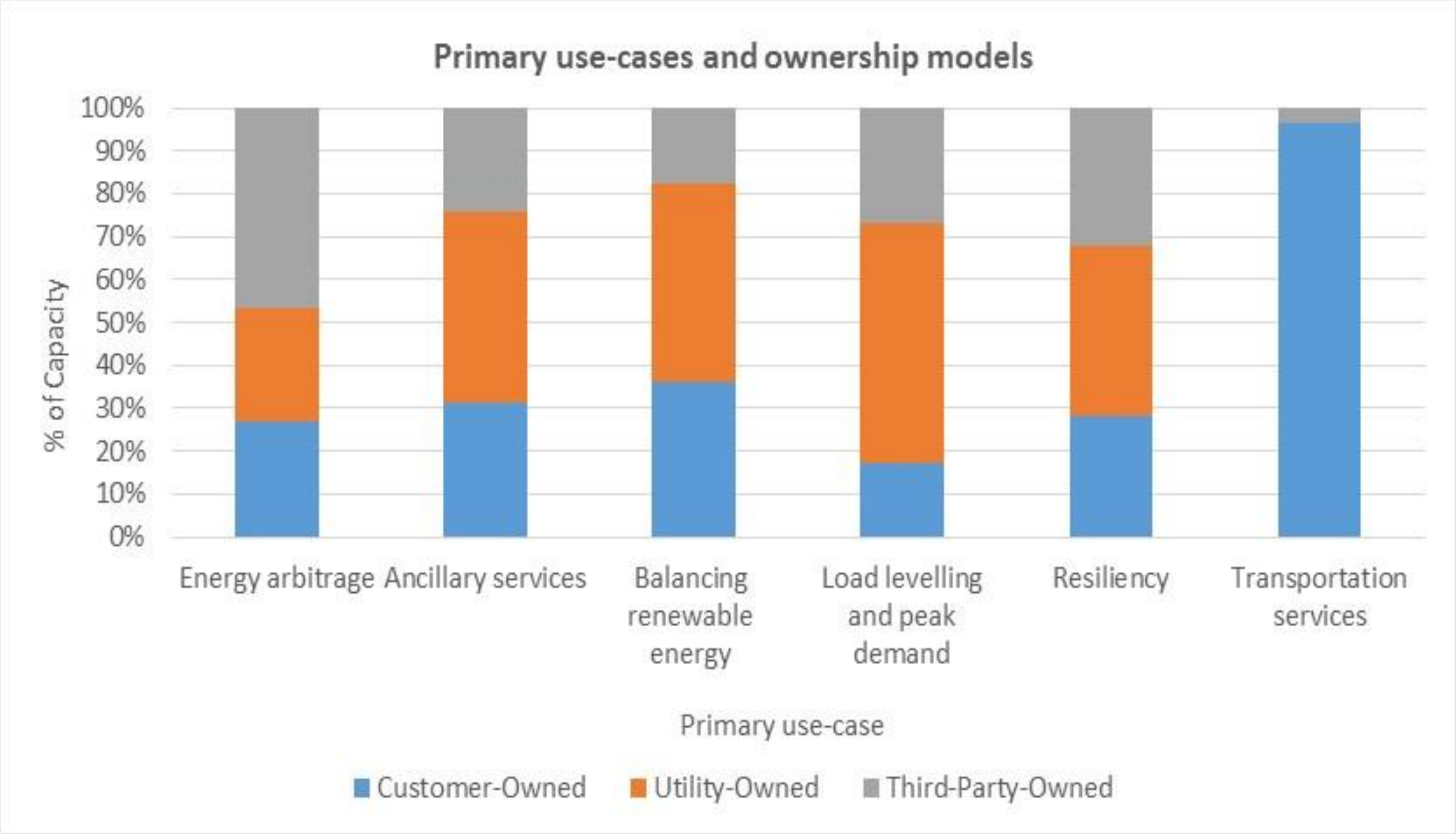

35% of project entries have only one high-level use case category, equivalent to 49% of the installed capacity.

Source: CIGRE WG C6-30 brochure

Demonstration projects – Japan

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- Purpose: demonstration of Battery SCADA
- Location: Substation and customer side
- Battery: Li-Ion (300 kW, 100 kWh), Li-Ion (100 kW,100 kWh), Li-Ion (250 kW,250 kWh) at Substation; Li-Ion (45 kWh), Li-Ion (8.4 kWh) x 3 on customer side
- Applications:
  - Short period change adjustment
  - Long period adjustment of the day interval
  - Spinning reserve
  - Demand response (without load control) – customer side
- Commissioning: 2010 - 2014
- Learning experiences
  - BESS can replace conventional generators in cases of severe supply and demand imbalance, provide peak load shifting

Source: CIGRE WG C6-30 brochure

Demonstration projects – UK

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- Purpose: demonstration and trial of BESS
- Location: distribution grid/feeder
- Battery: Li-Ion (6 MW, 10 MWh)
- Applications:
  - Peak Shaving – maintain demand within security-of-supply limits
  - Reactive Power (Voltage) Support
  - Dynamic frequency response and static frequency response
  - Reserve – short term operating reserve
  - Long term market optimization – flexible commercial arrangements, business models
- Commissioning: December 2014
- Learning experiences: quantification of value streams; investment deferral; system loss reduction; support for the integration of renewable resources; increased operational flexibility

Source: CIGRE WG C6-30 brochure

Demonstration projects – Italy

- Purpose: demonstration of the benefits of BESS
- Location: Industrial district, with generation mix: wind, PV, combined heat and power (CHP), MV grid, in parallel with a large PV plant (1 MW)
- Battery: Li-Ion (1 MW, 200 kWh)
- Applications:
  - Primary frequency regulation
  - Allowing PV generation to follow contracted daily profiles, compensating deviations
  - Buying and selling energy according to market price
- Commissioning: 2013
- Learning experiences: demonstrating possibility of combining various grid services in one single storage system, integrating the output of a PV system; economical feasibility of storage system projects

Source: CIGRE WG C6-30 brochure

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CLOSING REMARKS

BESS deployment – practical issues

- Electric energy storage – justifications
  - Balancing variable generation from renewable energy resources – if no alternative
  - Ancillary services provision – if market exists for such products
  - Participation in electricity markets: leveraging prices, time of use pricing – if option exists
- Considerations in justifying the deployment of energy storage
  - Alternative approaches – demand response/management, curtailing renewable generation
  - Cost of operation, economics – steady state losses, store/retrieve efficiency, maintenance
  - Life cycle (considering utility infrastructure), replacement, battery disposal, repurposing
  - Dynamic performance – limitations
- Other issues
  - Ownership and operation
  - Reliability, availability, maintainability

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