Distributed Energy Resources

Challenges and Opportunities

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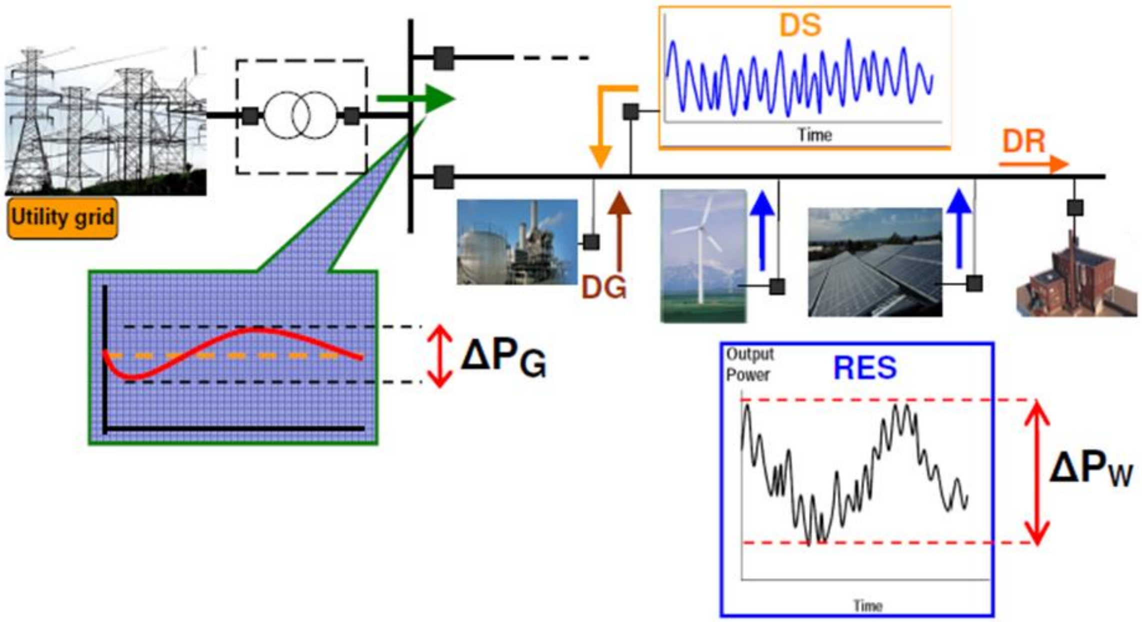
Distribution Systems are Changing

- The ongoing evolution of power distribution systems is introducing new challenges to operations and planning activities
  - Bi-directional power flow, power fluctuations, actively controlled networks,…
- Addressing these issues requires in-depth understanding of the impacts and behavior to determine and apply new approaches and technologies to ensure a reliable and secure supply to end users



DER Definition and Types

- **DERs definition (IEEE 1547 rev):**
  - A source of electric power that is not directly connected to a bulk power system
  - DER includes both generators and energy storage technologies capable of exporting active power to an electric power system (EPS)
  - An interconnection system or a supplemental DER device that is necessary for compliance with this standard is part of a DER
- **Other emerging distributed resources:**
  - Controllable load (via demand response)
  - Power-electronic based power conditioning units:
    - D-STATCOM, Solid-state transformers, …
  - Grid-edge devices
    - DER aggregation and controls

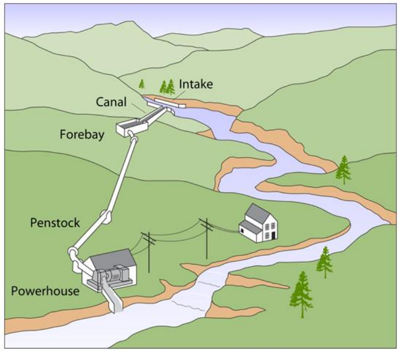
Most Common DER Types and Technologies

- **Distributed Generation**
  - Conventional (synchronous generators):
    - Diesel engines
    - Gas turbines
    - Small hydro plants
  - Modern and emerging (inverter-based):
    - Solar PV systems
    - Wind turbines
    - Others (fuel cells, microturbines, etc.)
- **Energy Storage**
  - Battery Energy Storage Systems (BESS)

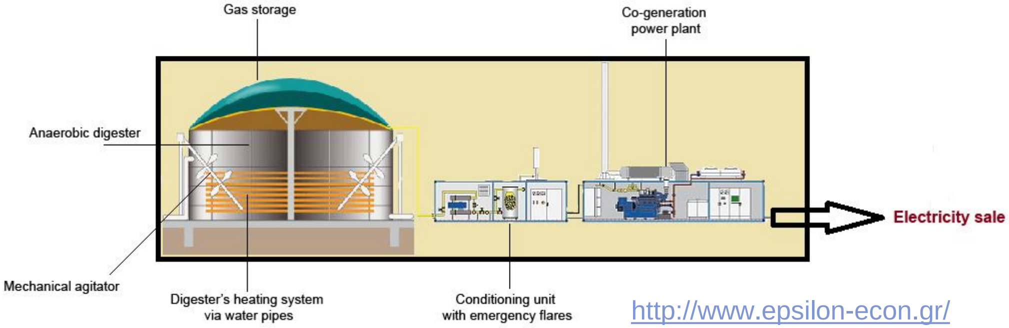
http://www.epsilon-econ.gr/

DG Technologies

- Renewables
  - Photovoltaic
  - Wind
  - Biomass
  - Hydro
- Gas-fired
  - Reciprocating engines
  - Microturbines
- Emergent
  - Vehicle-to-Grid (V2G)

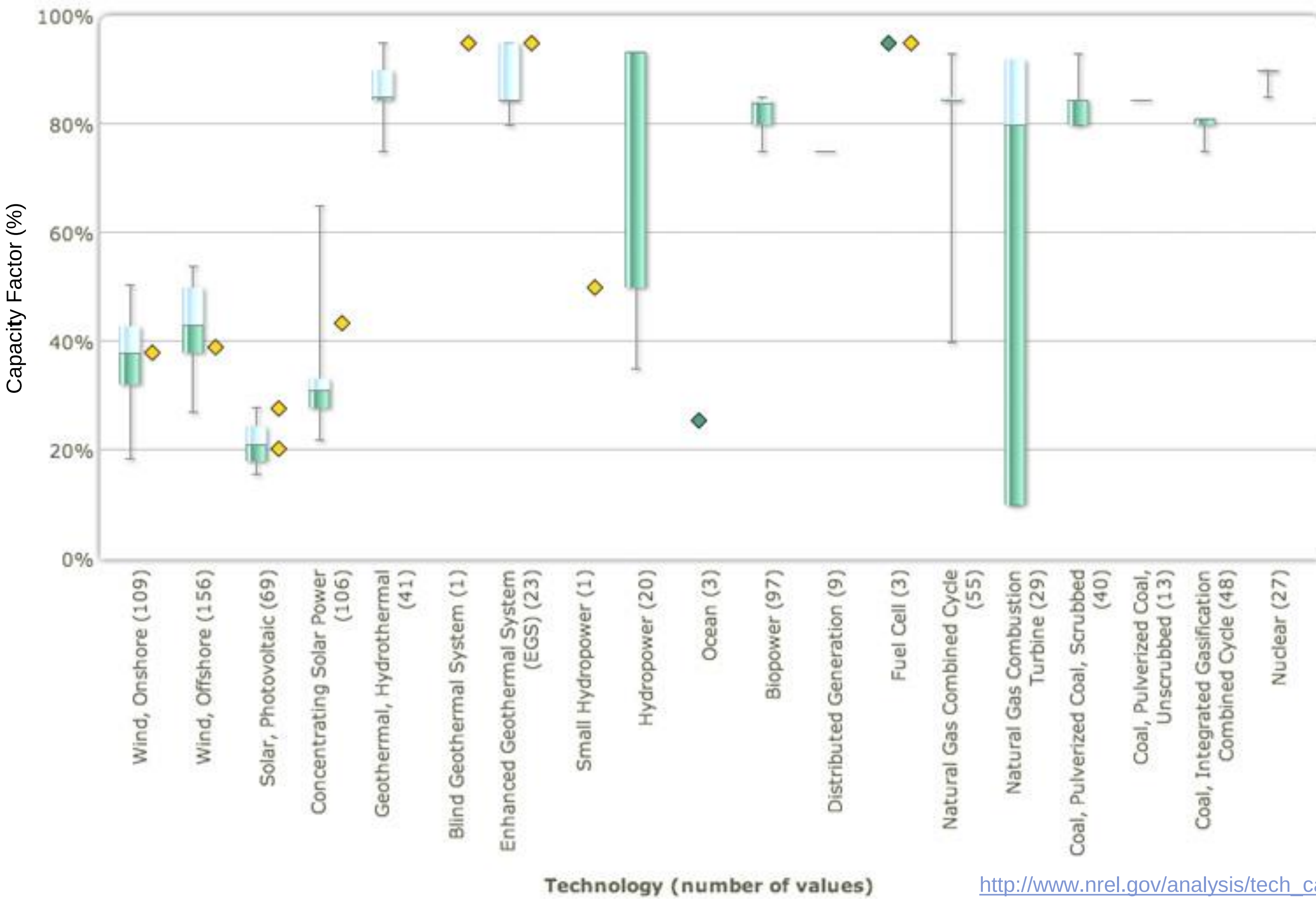


http://www.nrel.gov/learning/eds_distributed_energy.html



http://www.epsilon-econ.gr/

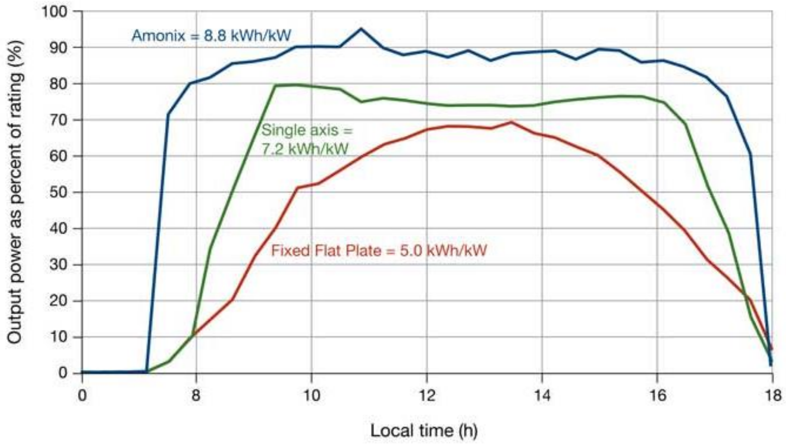
DG Technologies – Annual Production Level

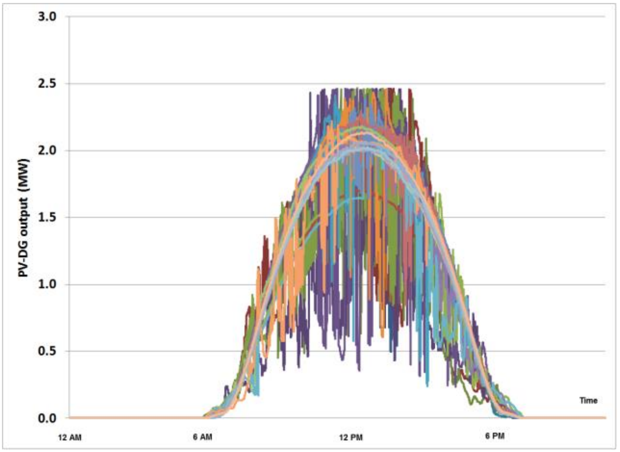


http://www.nrel.gov/analysis/tech_cap_factor.html

Key Characteristics of Renewable DERs

- Intermittent and variable generation
- Low capacity factor
  - PV systems: between 10% - 25%
  - Wind turbine systems: between 25% - 55%
- Low fault current contribution:
  - PV systems: usually between 110% - 130% times I_n
  - Wind systems: depending on technology, can be in range of 120% - 220% x In
- Relatively higher capital cost compared to traditional systems





Source: http://solarprofessional.com/articles/products-equipment/racking/pv-trackers

DG Size and Ownership Models

- **Utility scale DG:** large commercial DG plants with capacities usually larger than 1 MW (three-phase generation)
- **Medium scale DG:** small commercial DG with capacities usually between 10 kW and 1 MW (it can be three-phase or single-phase)
- **Small scale DG:** small residential DG under NEM agreements. Capacities usually less than 10 kW (single-phase generation)
- **Ownership:**
  - Customer owned (behind the meter - BTM DG):
    - Applications: Net metering, on-site load offset or feed-in tariff)
  - Suppliers/Aggregators:
    - Applications: Virtual net metering, or market services
  - Developer (third party) owned (in front of meter – IFM DG):
    - Power Purchase Agreement or Market Services
  - Utility owned and operated (not applicable for de-regulated utilities)

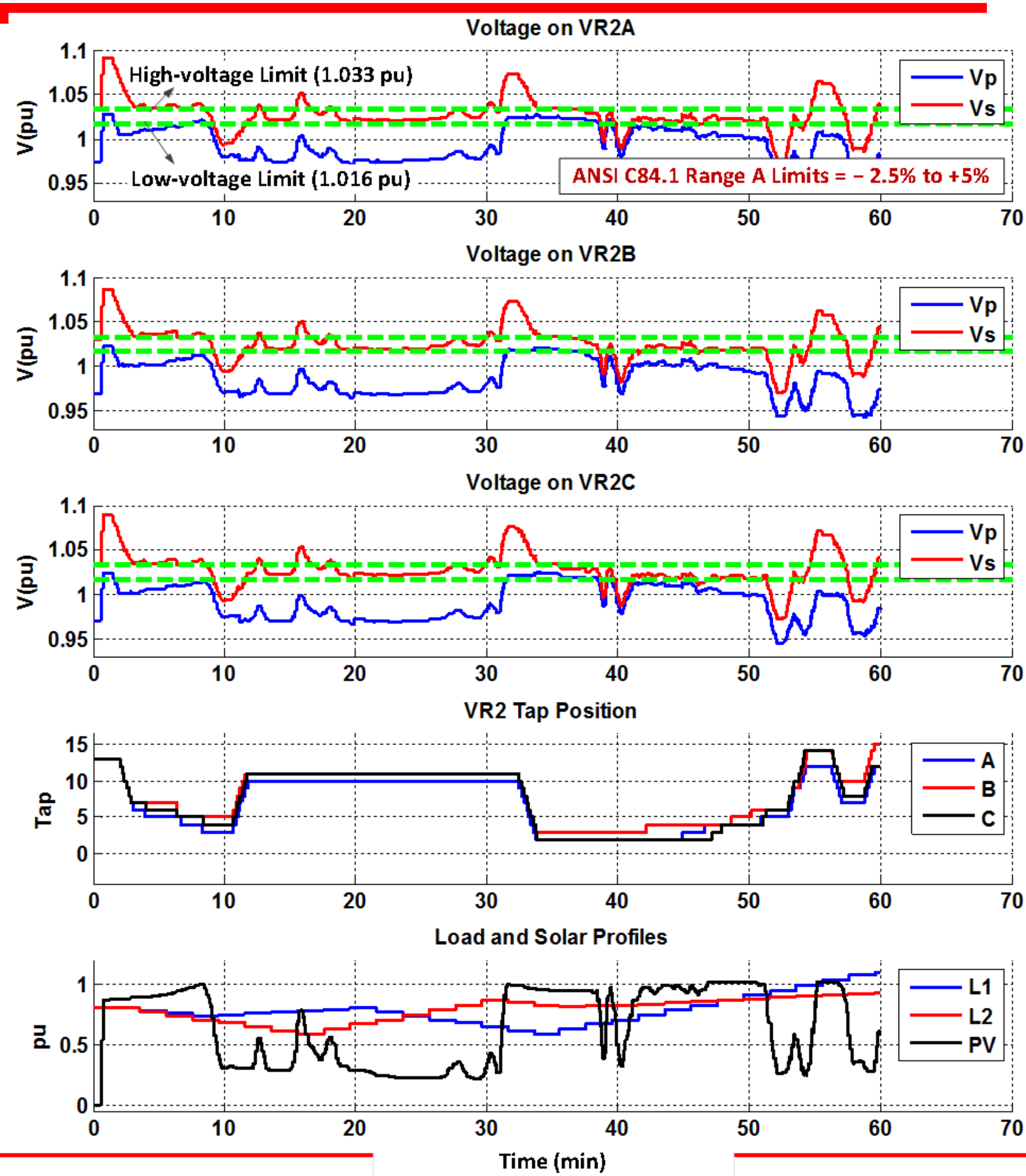
DER Integration Challenges and Impacts

- Depending on size, type, technology, location, and penetration level DER may have various impact (positive / negative) on the utility grid and/or bring in numerous benefits
  - **Main concerns:** Voltage impact, Exceeding thermal ratings, protection issues, load masking issues, wear and tear of circuit apparatus (tap changers and switches)
  - **Main benefits:** supporting voltage (especially toward the end of the feeders), reducing congestion in peak load time (potential for investment deferral), reducing losses, potential for forming intentional island (microgrid) to enhance reliability, emission reduction (renewables)
- DERs changing the dynamics of the grid and day-to-day utility business
  - Bidirectional power flow, and backfeeding
  - Additional study requirements
  - Sophisticated load and generation forecasting

QUANTA TECHNOLOGY

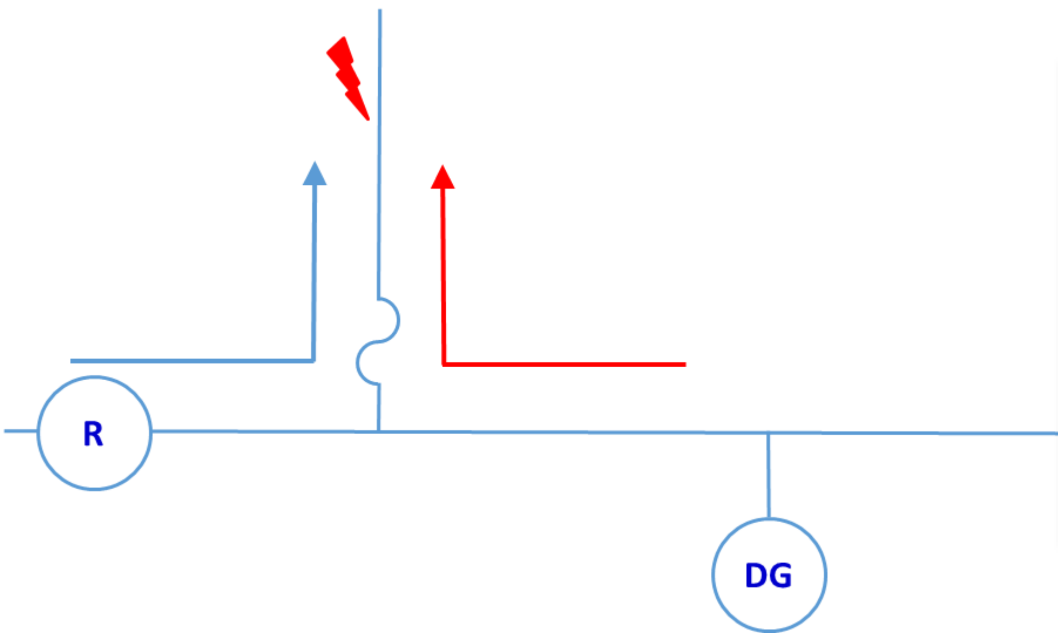
DG Impacts on Voltages and Operations

- Voltage goes beyond permissible range
- In-line voltage regulators (VRs) are trying to re-adjust voltages across a circuit
- Significantly increased number of tap operations (e.g. about 1 tap per min, vs. 1 tap per 20 min)
- Increased dv/dt (flicker)



DG Impacts on Protection Coordination

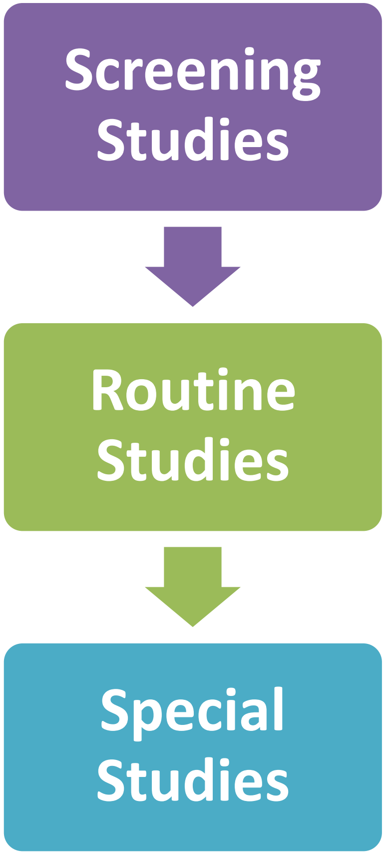
- Impact on distribution system overcurrent protection: DG fault current contribution may have an adverse impact on “fuse saving” overcurrent protection schemes
- During a temporary fault, DG fault current contribution may melt fuses before first fast trip operation of reclosers



Note:
- Locally, fault current increases.
- Globally, there will be decrease in fault current, because of power electronic based DERs replacing synchronous machines

DER Interconnection Studies

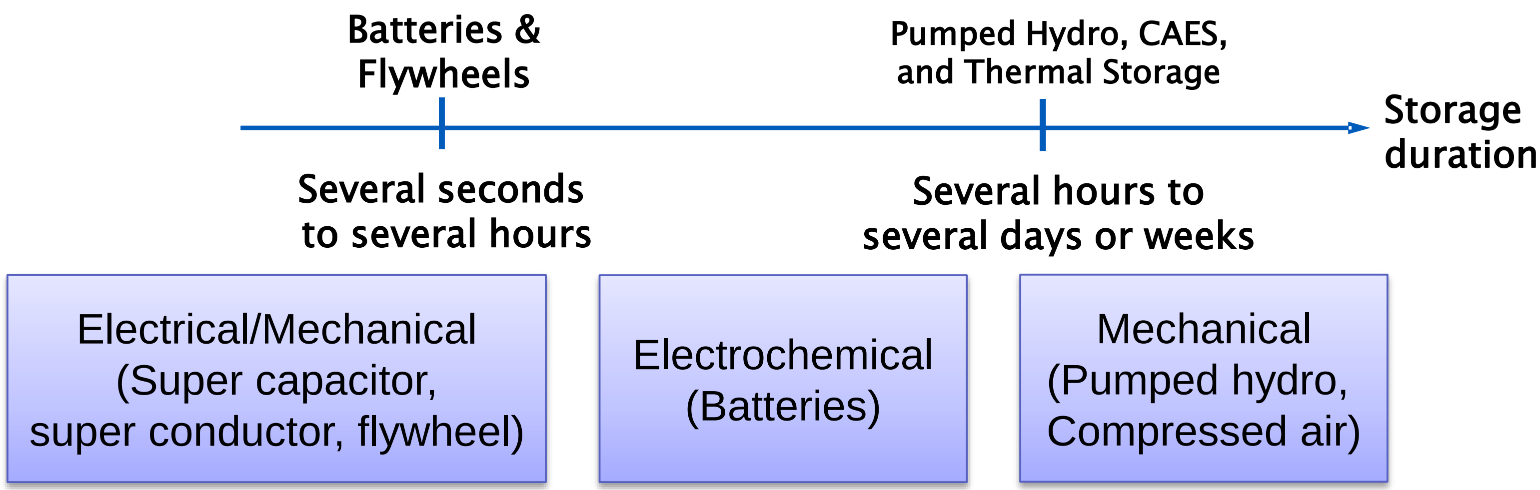
- **Type of Studies**
  - Screening
  - Routine, steady state analyses
  - Dynamic/transient analyses
  - Overcurrent and overvoltage protection
  - Special studies: harmonic, stability, etc.
  - Hardware-in-the-loop testing in laboratory setting
    Advanced applications (energy storage, microgrids)
- **Typical Scope of Studies**
  - Identify local and/or system-wide impacts of DG on distribution systems
  - Develop guidelines regarding the expected impacts as a function of the penetration degree of DG
  - Determine potential mitigation measures for any problems discovered in the study



Mitigation Solutions

- **Conventional methods**
  - Re-conductor part of a circuit
  - Upgrade switchgears or transformers
  - Adjust settings or location of voltage control devices
  - Transfer loads
  - Re-locate DG
  - Build express feeders for DG
  - Others …
- **Advanced Mitigation Solutions**
  - Power electronic based power conditioning systems
  - Energy Storage Systems
  - Active controls (curtailment or change of reactive power) of DERs (e.g., using DER management systems - **DERMS**)

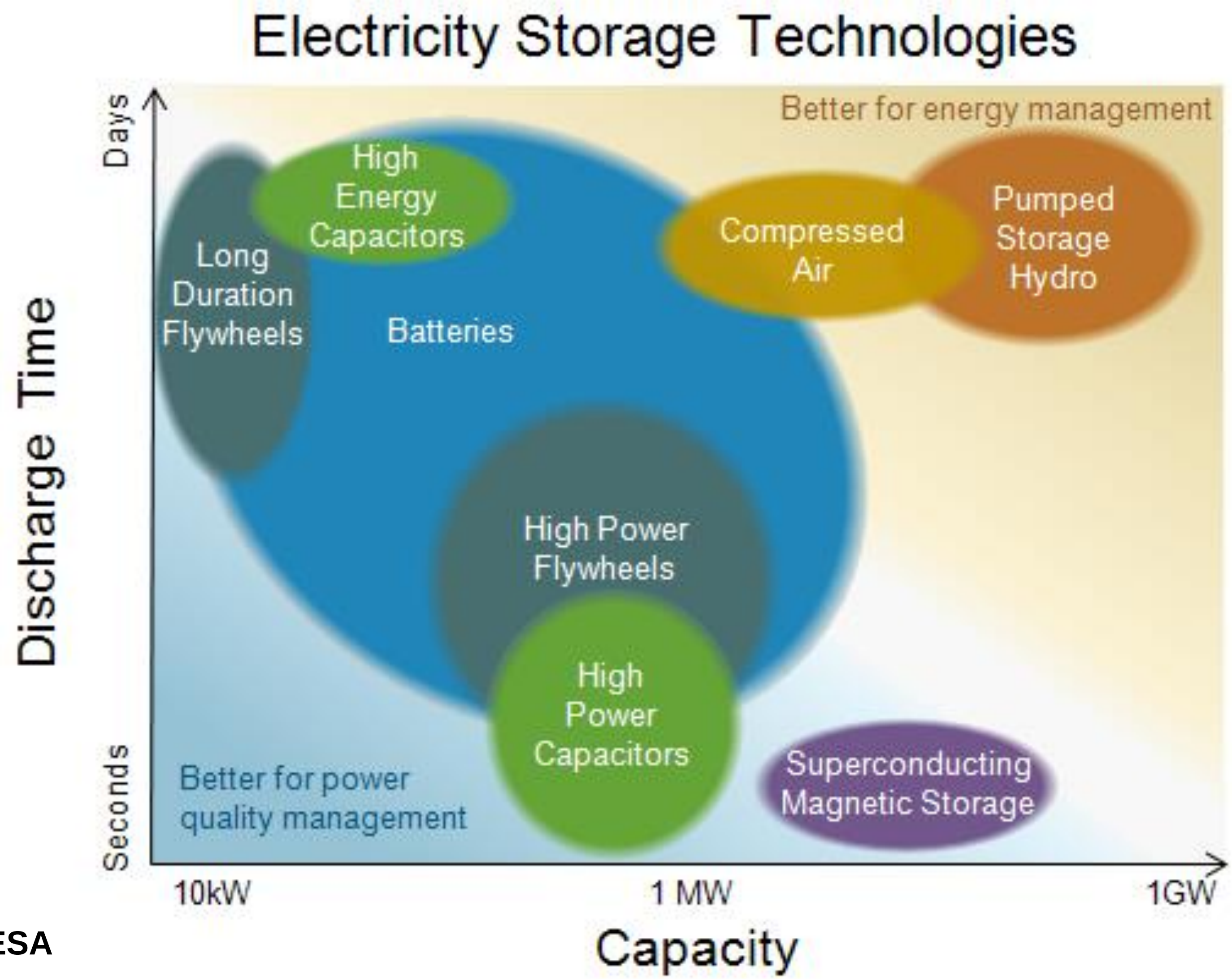
Energy Storage Systems



- **Power Capacity - Short-term storage:** for applications requiring large amount of power for a short period (kW), e.g.: frequency regulation, shock absorbing, voltage sag/swell compensation

- **Energy Capacity - Long-term storage:** for applications requiring continuous power over long period (kWh) – e.g.: Peak shaving, utilizing excess renewable energy during off-peak
  - Lithium-ion battery is gaining momentum for utility and electric vehicle applications

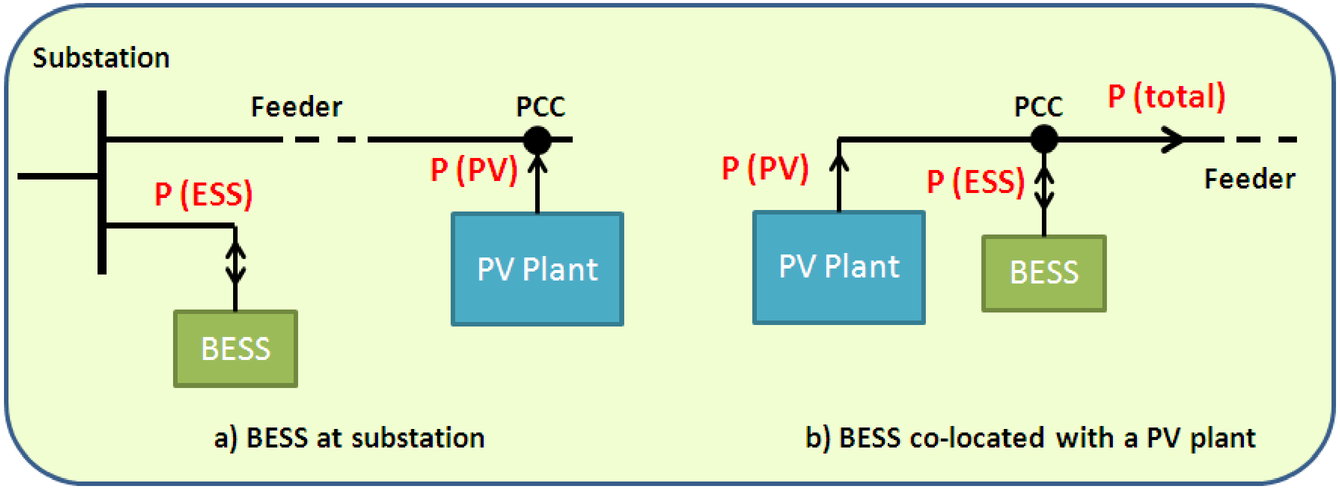
Energy Storage Systems: Technology



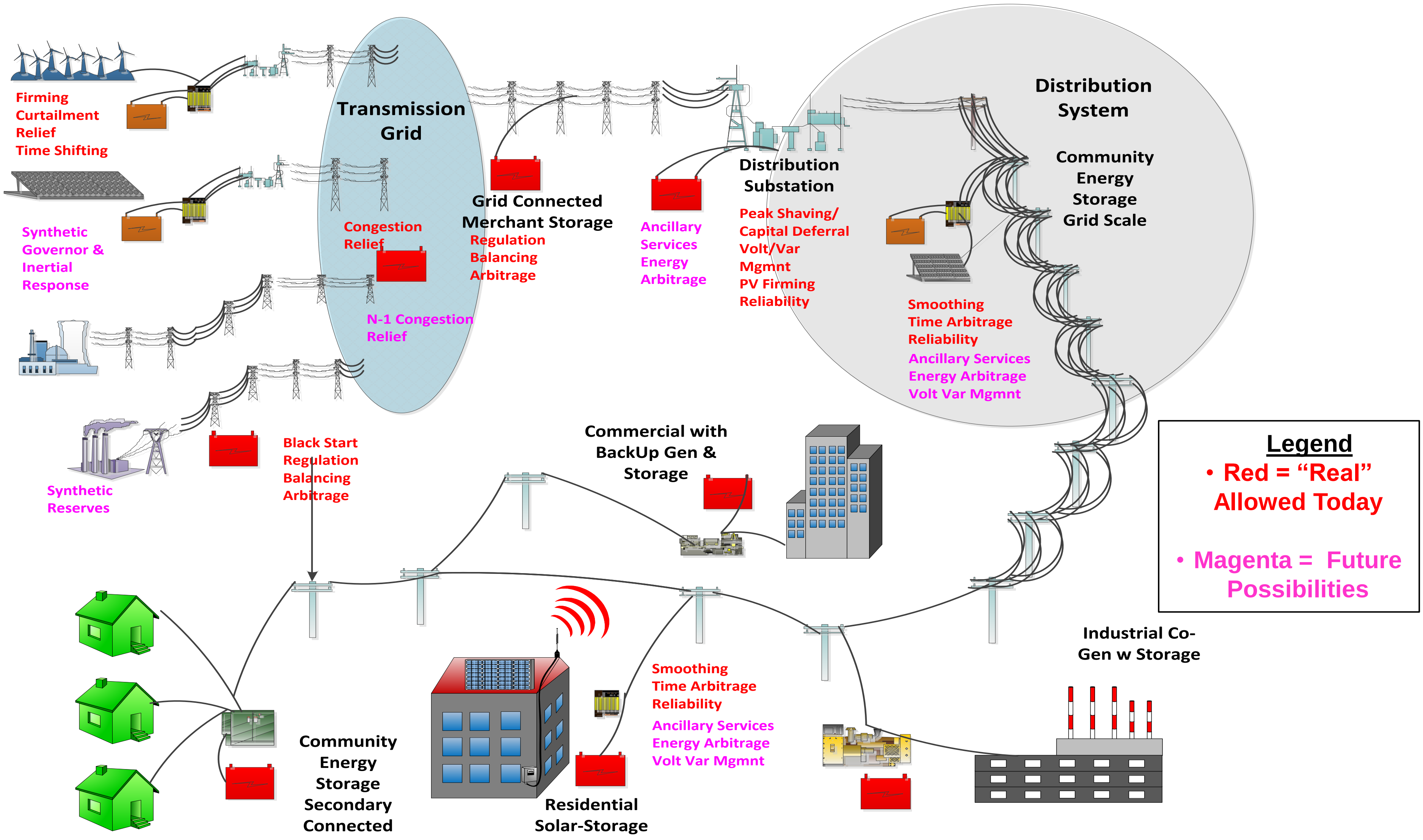
Source: ESA

BESS Locations

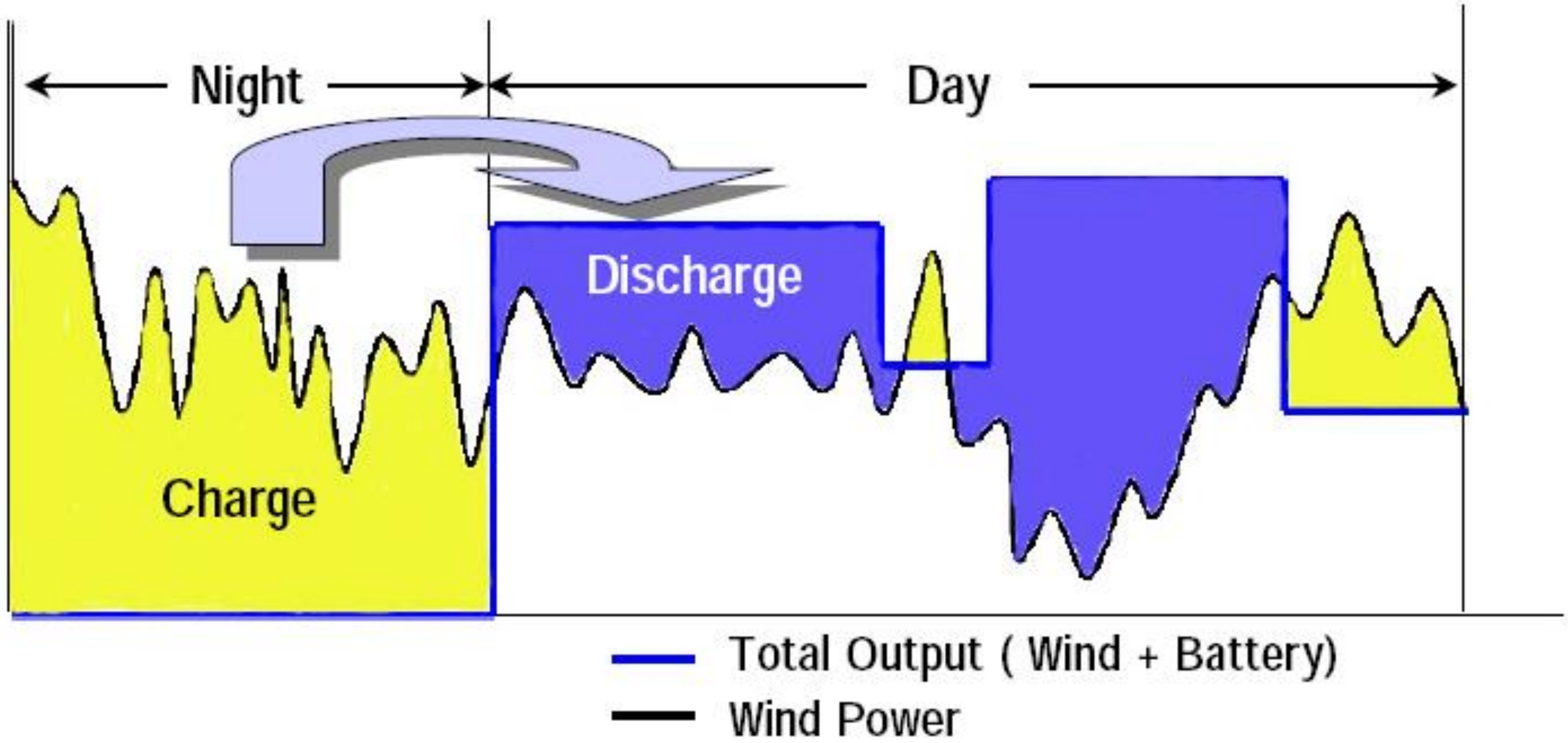
- Centralized BESS co-located with PV / Wind plant (MW size)
  - PV smoothing, Ramp rate control, generation shifting
- Centralized BESS at substation (additional control features)
  - Feeder relief (load shedding), Power dispatch, etc.
- Distributed Energy Storage Systems (small size)
  - Community storage, Ancillary services



Energy Storage Systems: Applications

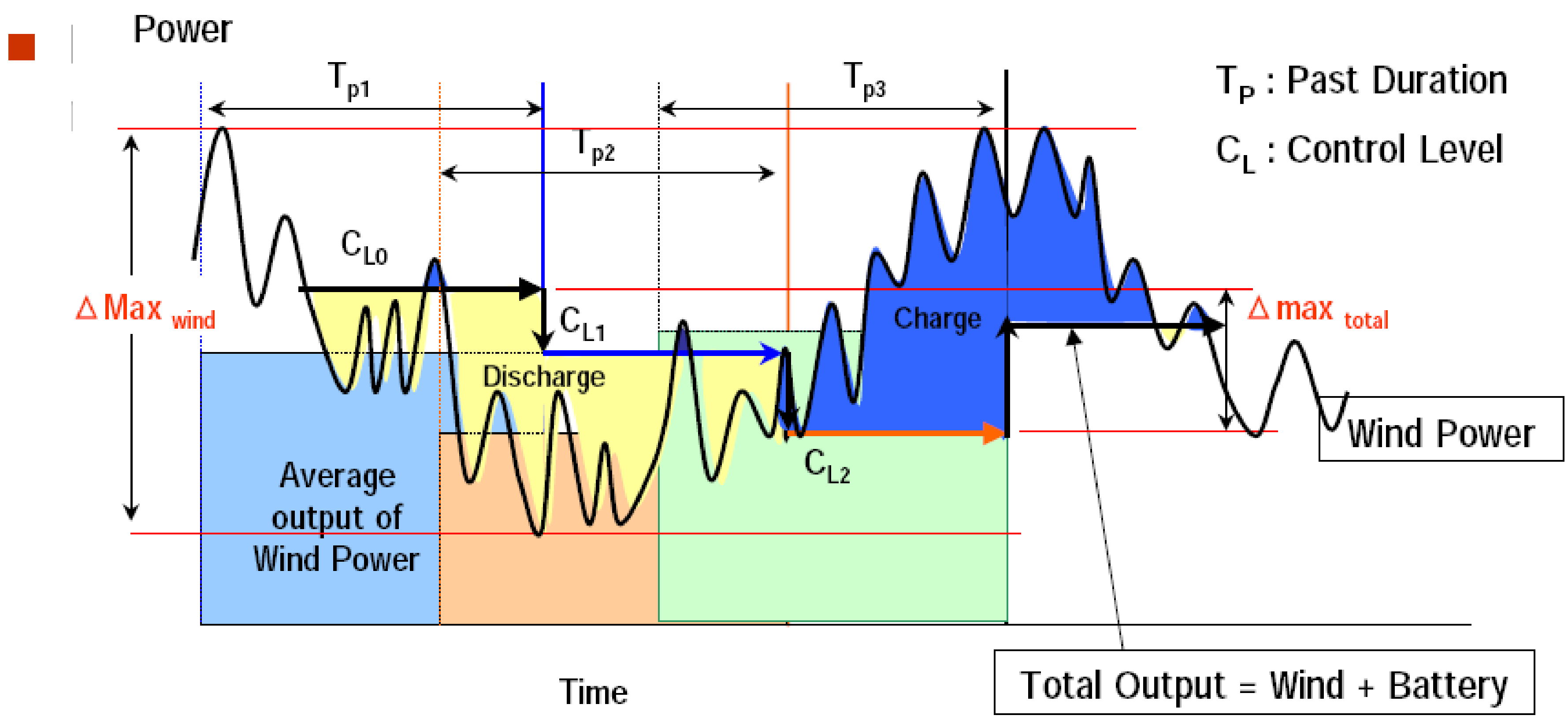


Energy Storage - Generation Shifting



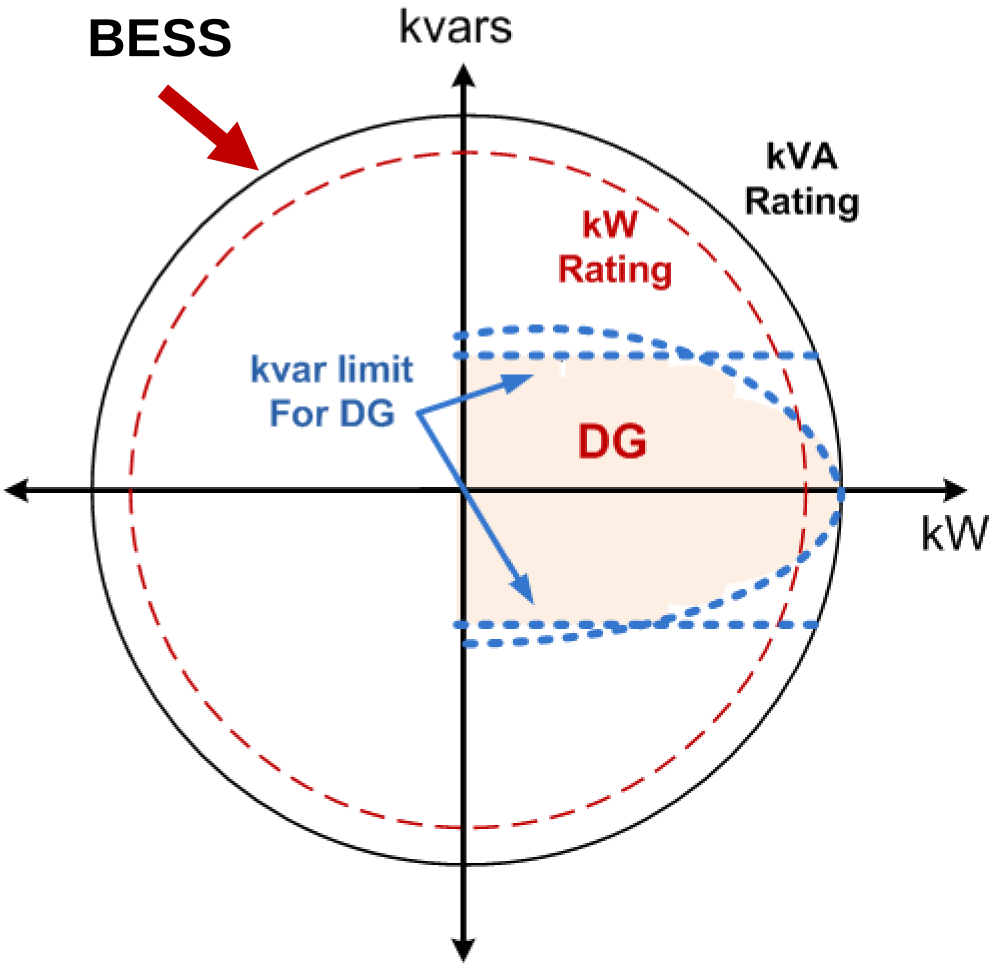
- Resource availability: e.g. wind is stronger at night
- Load profile: e.g. lower load demand at night

Renewable Smoothing and Stabilization

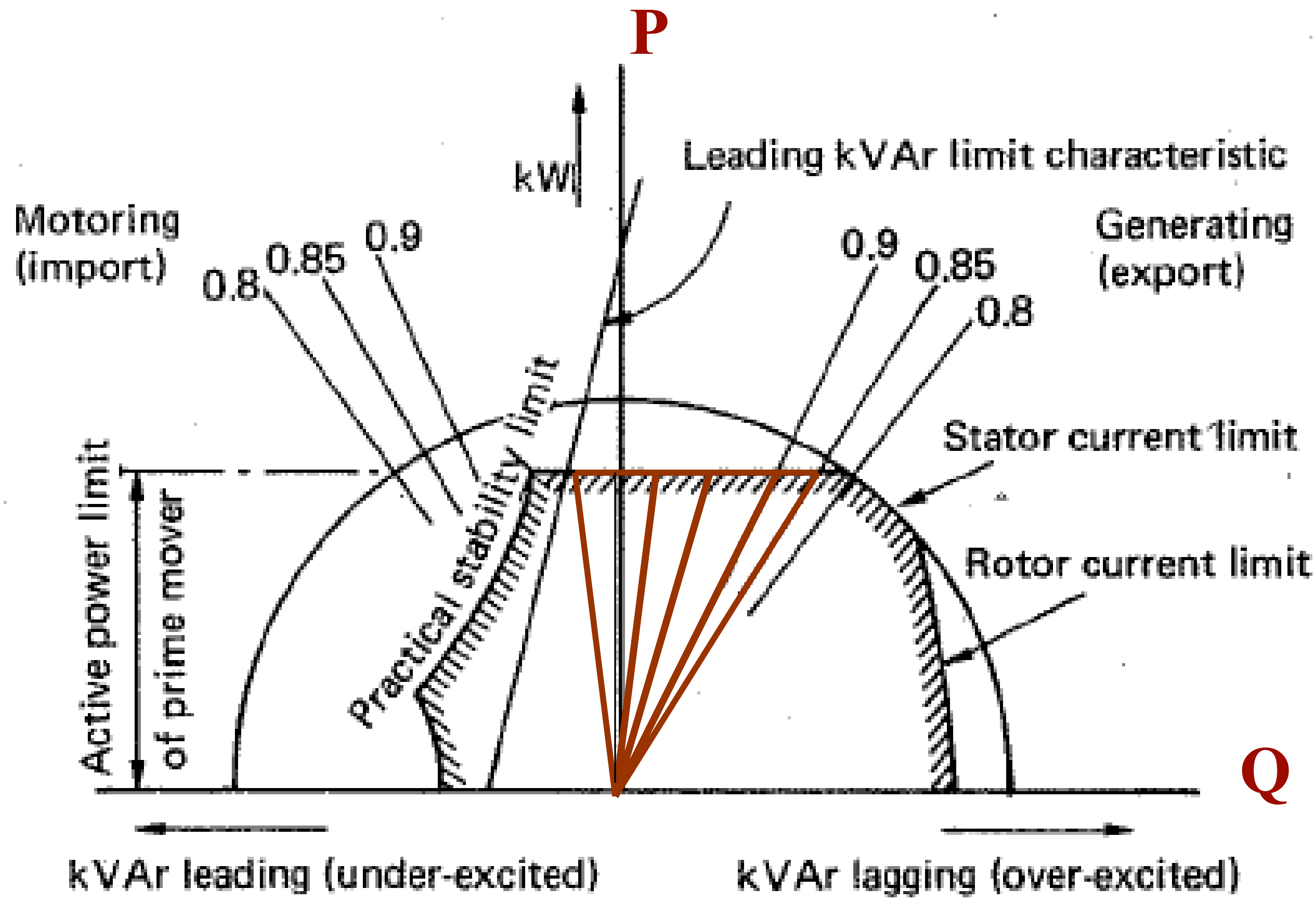


Combining Functionalities – Increasing Values

- 4-Quadrant Operation
  - DG + DVR
  - Ramp control & smoothing
- Controls for ancillary services
  - Participation in Voltage and Frequency Regulation market
  - Intentional islanding (Microgrid)
- ***Key Considerations:***
  - MVA rating: limiting capacity for MW vs. Mvar supply
  - Reactive power characteristics differ by vendors design
  - Standby operation

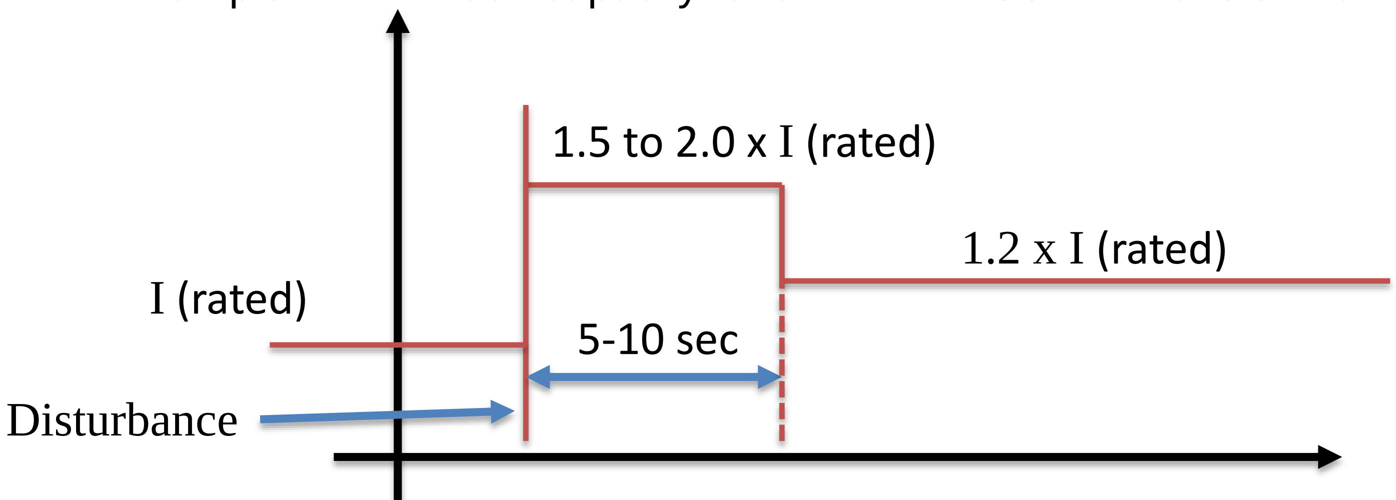


Synchronous Generator - Operating Region



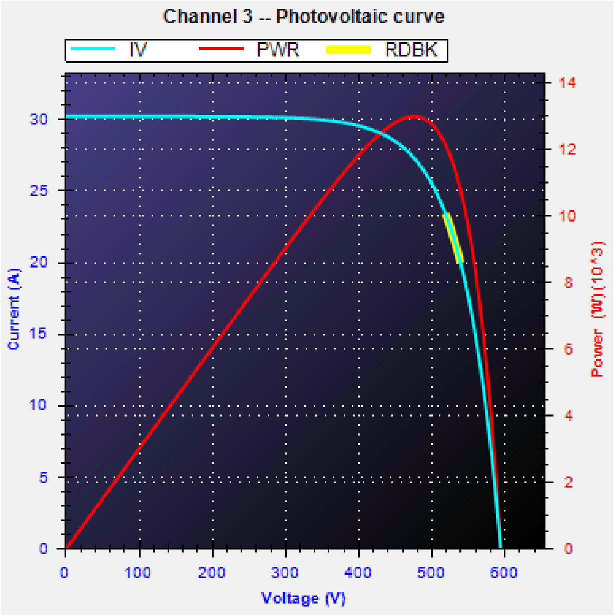
Transient Rating and Fault Current

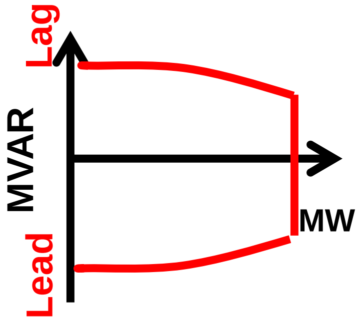
- Normally higher capacity is required for:
  - Black start
  - Step load changes
  - Fault detection and coordination
- Transient rating will be applied for normal operating voltages
  - Example: 150% to 200% of rated MVA for 5 to 10 seconds
- Transient rating will increase fault capacity; however duration will be lower, depending on voltage drop at terminal of BESS
  - Example: 2 MVA fault capacity for a 1 MW BESS with transient rating of 2 pu



Smart Inverter Controls

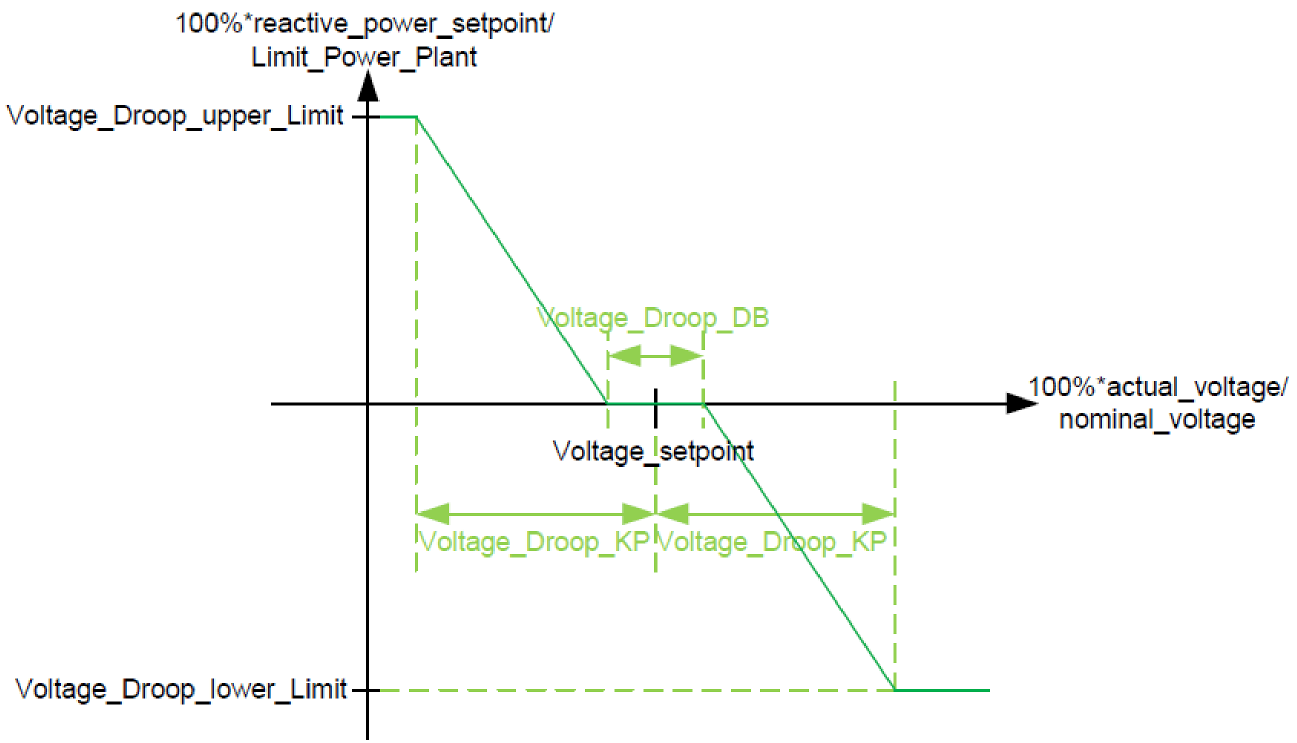
- **Active power control**
  - Maximum Point of Power tracking
  - Curtailment
  - Dispatch (or charge/discharge)
- **Reactive power control**
  - Power factor (typically ± 0.8)
  - Q set point
- **Voltage control: V set point, V(P) function, or V-Q droop**
- **Frequency control: f set point, f-P droop**





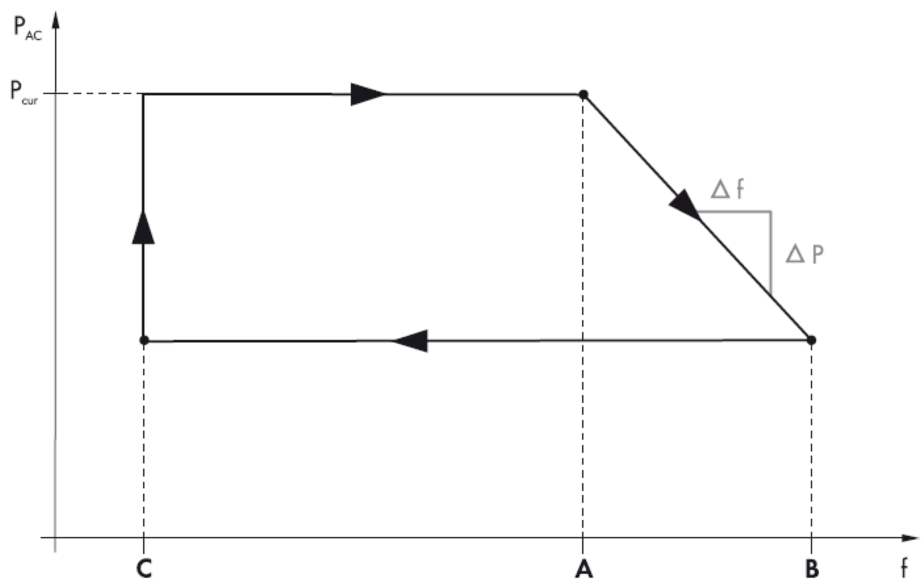
Q (V) Characteristics

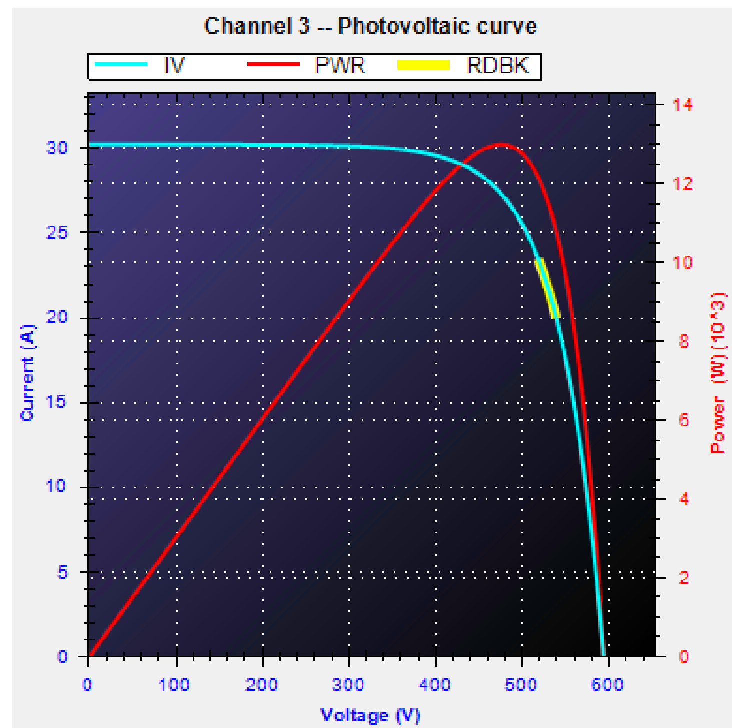
- Droop control:
  - Dead band (1 to 2%)
  - Droop coefficient (2-5%) , with Q limits
  - Response time: similar to AVR in synchronous generator



Power Curtailment

- Reducing Active Power if:
  - Frequency is above certain range
  - Priority is on Q, and inverter reaches rated current
  - Operator sends a curtailment set-point (e.g. to reduce voltage or manage congestion)



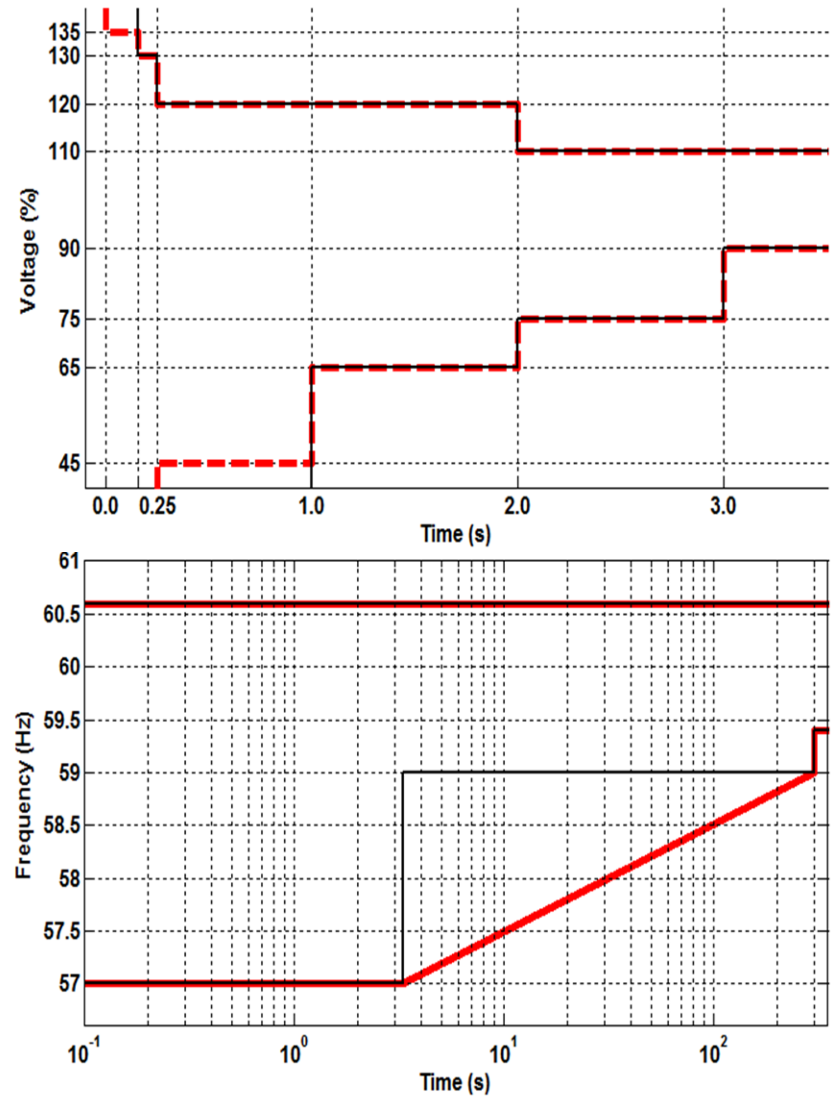


Voltage & Frequency Response

- Voltage:
- LVRT / HVRT

Adjustable Settings, Multiple Curves
(See IEEE 1547 rev. for details)

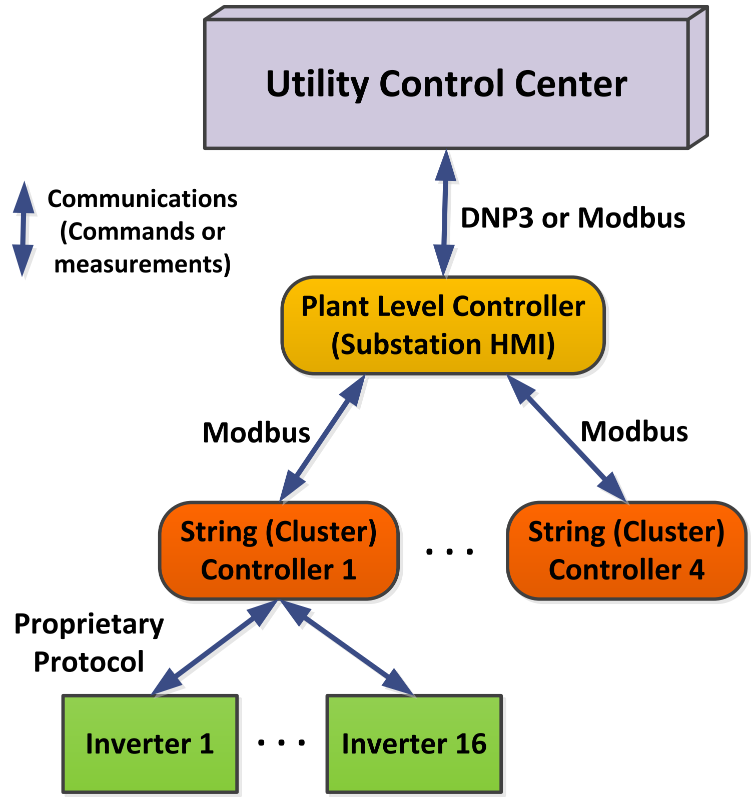
Frequency
Ride-through:



Smart Inverters: Controls & Communications

- Distributed controls:
  - Power Plant control (interface to utility)
  - Multi-inverter (cluster) control
  - Individual inverter (device level) control
  - Examples:
    - Utility sends Vref to PPC
    - PPC determines ΔV and calculates Qref per cluster
    - Cluster controller receives Qref and determines setpoints for inverters according to availability

DERMS Platform



DER Controls, Communications & Aggregation

- **Emerging Approach:** Utilizing DERs (Non-Wire Alternatives) as part of the distribution capacity planning and evaluating them with traditional upgrade solutions:
  - Reliable
  - Affordable
  - Environmentally compliant

Step 1 – Alternative Solutions

- Evaluate DER services along with traditional approaches

Step 2 – Least Cost / Best Fit

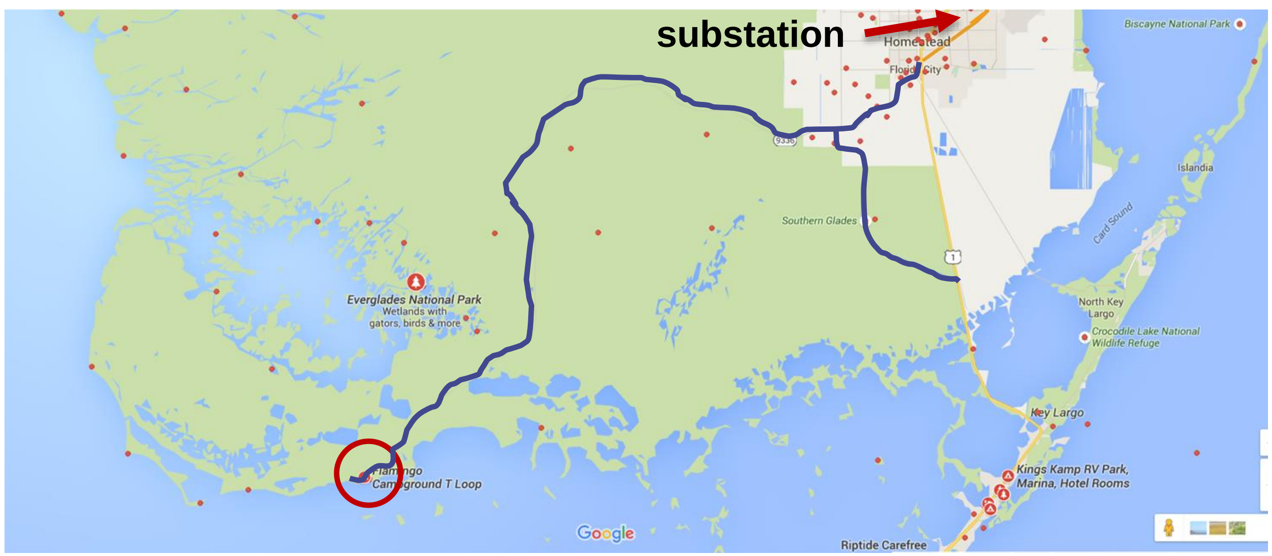
- Identify least cost / best fit portfolio of solutions

Step 3 – Deploy and Monitor Performance

- Procure services, monitor and verify the services and adjust portfolio as needed

Example: Microgrid for Reliability – Non Wire Solutions

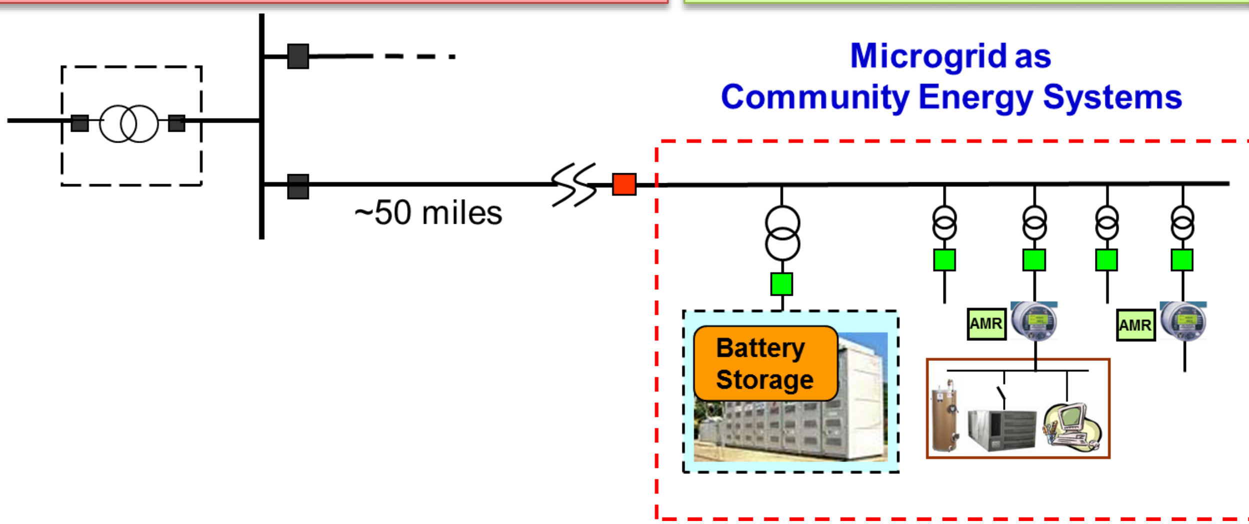
- A small community within a national park at the end of a long radial feeder was experiencing extended power outage several times per year.
- Some customers have small diesel engines as individual backup supply, but it is not enough; also pollution and fuel delivery are some issues
- Proposed solution has been to utilize a battery energy storage system:
  - Supply the community load during outage time
  - Perform peak shaving and voltage profile adjustment during normal operation



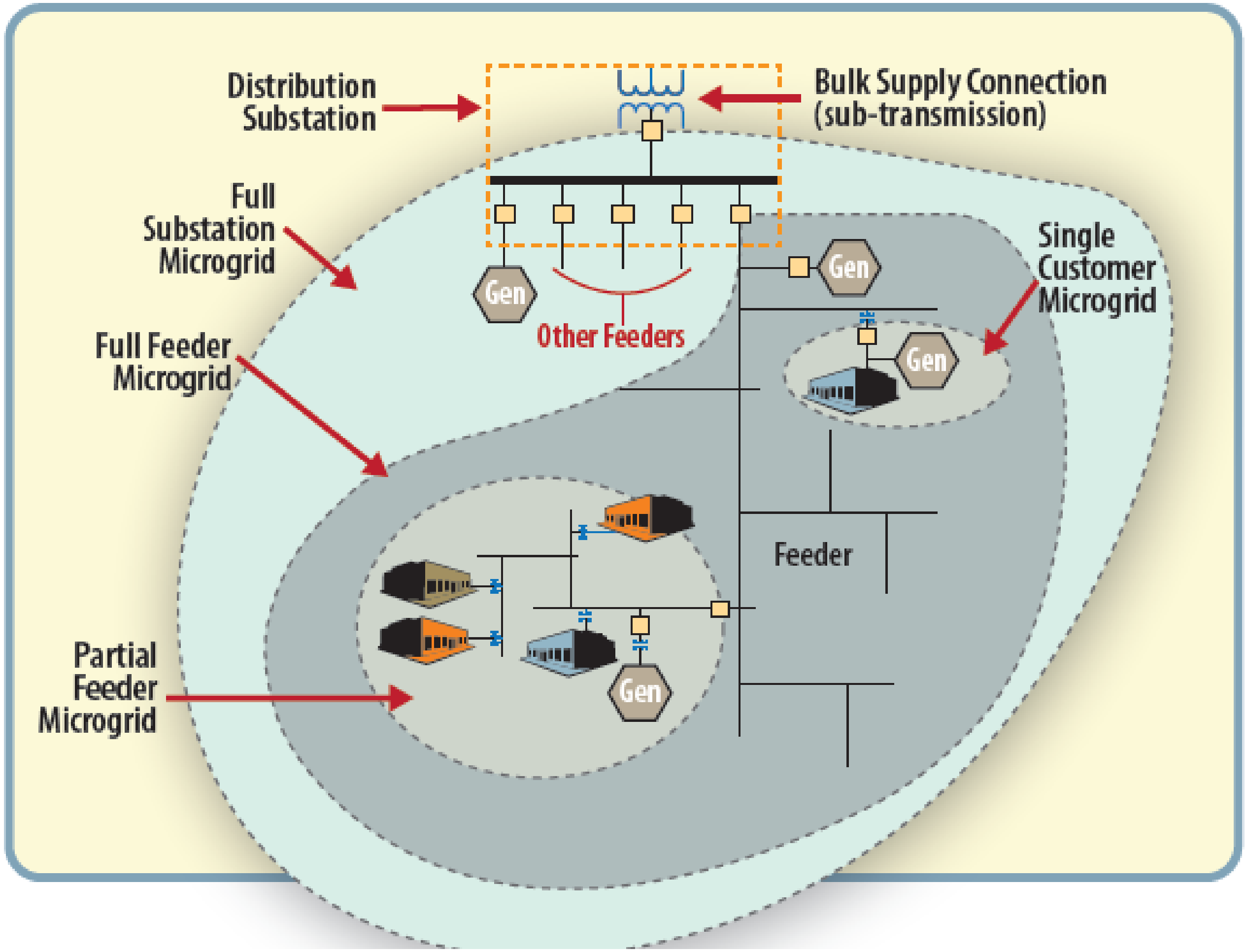
Energy Storage Based Microgrid

- **Existing conditions:**
  - SAIDI: 152 minutes per customer per year
  - SAIFI: 2.3 interruptions per customer per year
  - CAIDI: 66 minutes per interruption
- **Traditional planning approach:**
  - Build a new feeder (about $8 million estimated)

- **Proposed solution:**
  - Use an ESS to serve the community during outages as an island
  - Add auto-reclosers and switches
  - Improving SAIDI & SAIFI (SAIDI =10 minutes or lower, SAIFI = 0.1)
- **Cost:**
  - $ 1.8 million (ESS + additional reclosers and switches)



Microgrids: Basic to Advanced



Source: Sandia National Labs Energy Surety Microgrid TM
http://energy.sandia.gov/?page_id=819

Microgrids Applications and Benefits

- **Customer benefit:**
  - Enhancing customer-based Reliability on extended power outages:
    - Power outage due to faults on long single-supply feeders,
    - Scheduled maintenance on substation or HV feeders
  - Reducing the system downtime for DG owners,
  - Secure power supply for critical loads – Premium power
- **Utility benefit:**
  - Manageable feeder restoration and maintenance schedules
  - Resource coordination and utilization in high penetration scenarios
  - Opportunity to defer capital investments for reliability improvement
    - Avoid fines on Power Interruption indices: CAIDI, SAIDI, etc.
  - Assist the grid restoration: less load upon feeder restoration, black-start

Summary and Conclusions

- Growing penetration of DERs in distribution systems is creating a major paradigm shift in distribution system planning and analysis
  - Introducing new technologies, designs, solutions and markets
  - Increasing system complexity and making it highly dynamic
  - Non-Wire Alternatives: Microgrids and community owned energy systems
- Successful deployment of emerging technologies and full utilization of DER functionalities need extensive studies, testing and evaluation prior to field deployment
  - Configuration, logic and settings verifications
  - Investigating possible contradictions and/or interactions among functions
- Key success factors
  - Understand system issues and design accordingly
  - Testing and performance evaluation – be flexible to enhance design
  - Training and knowledge transfer to utility personnel and system operators

Thank You!

Thank You!

Question ?