Achieving High Reliability: Design Considerations for Microgrids

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Why Microgrid

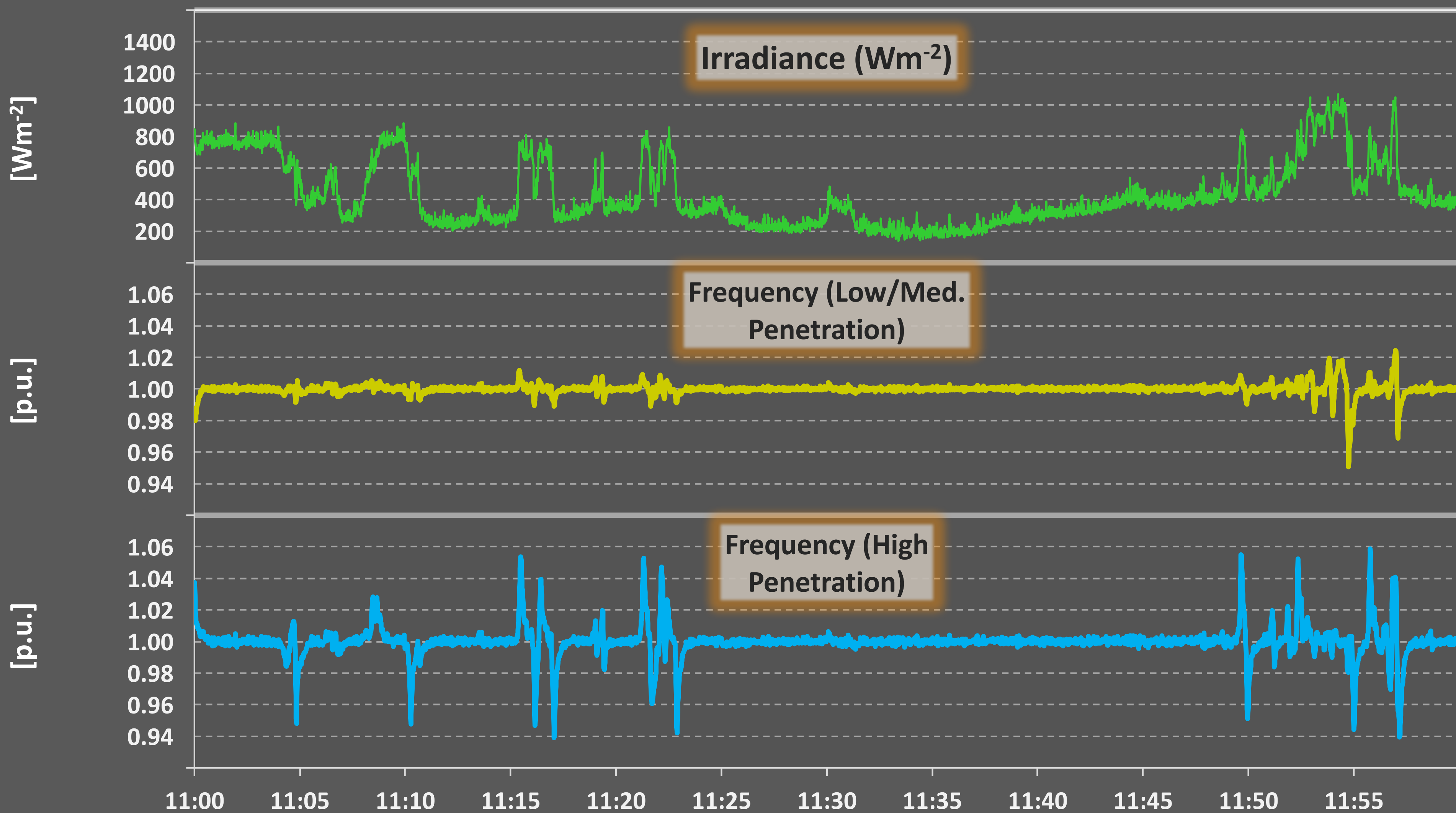
- Improve operational security & reliability (SS / transient)
- Adoption of renewables to reduce environmental impact and improve self sustainability, reduce dependencies of fuel supply

- Especially b… s (eg. hospitals, airports, military applications)

Image: Dillon Thompson Design

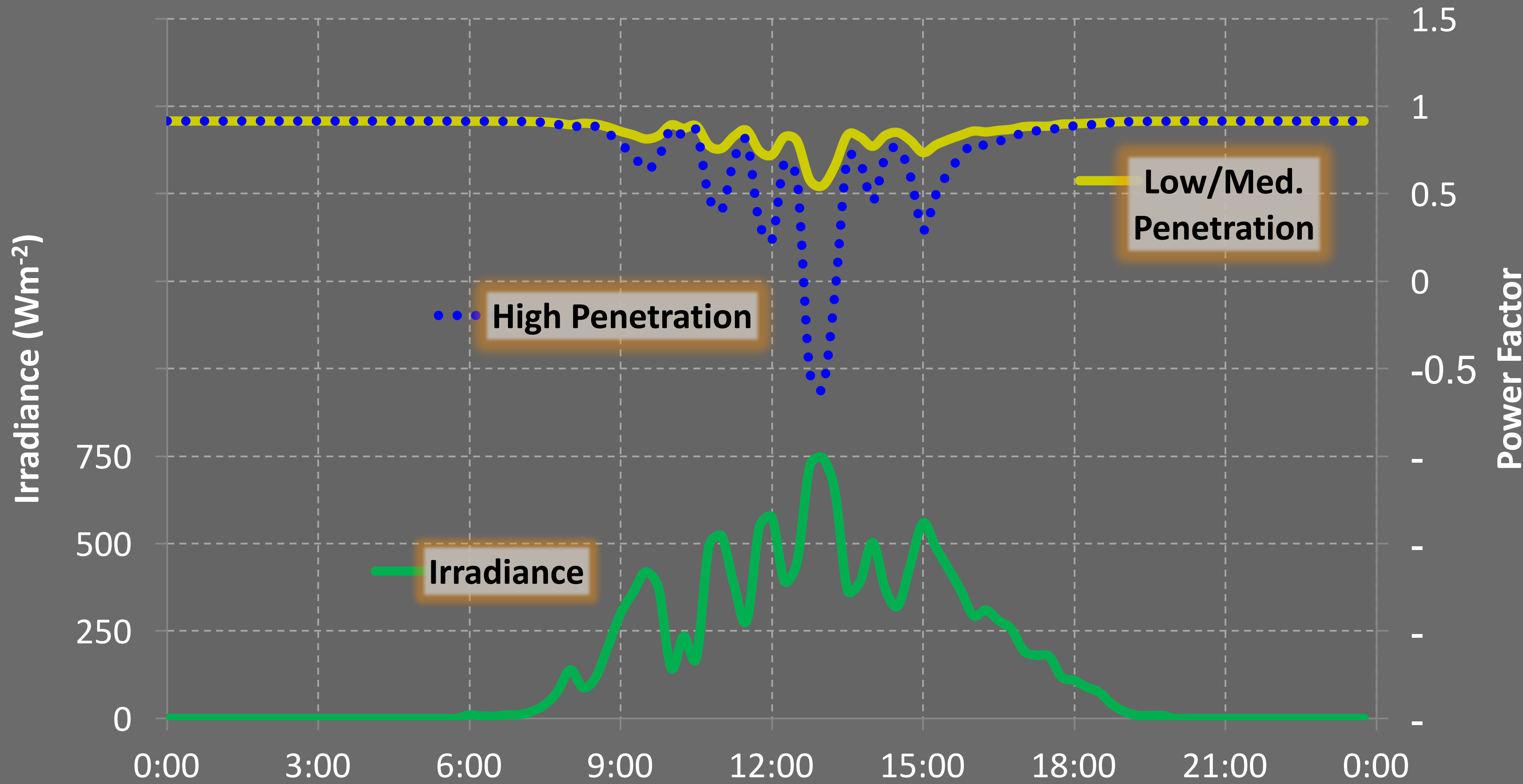
Microgrid Design Dilemma

- Sustainability vs. system stability



Microgrid Design Dilemma

- > Sustainability vs. system stability
- v More effective power from renewables vs. power quality



Microgrid Design Dilemma

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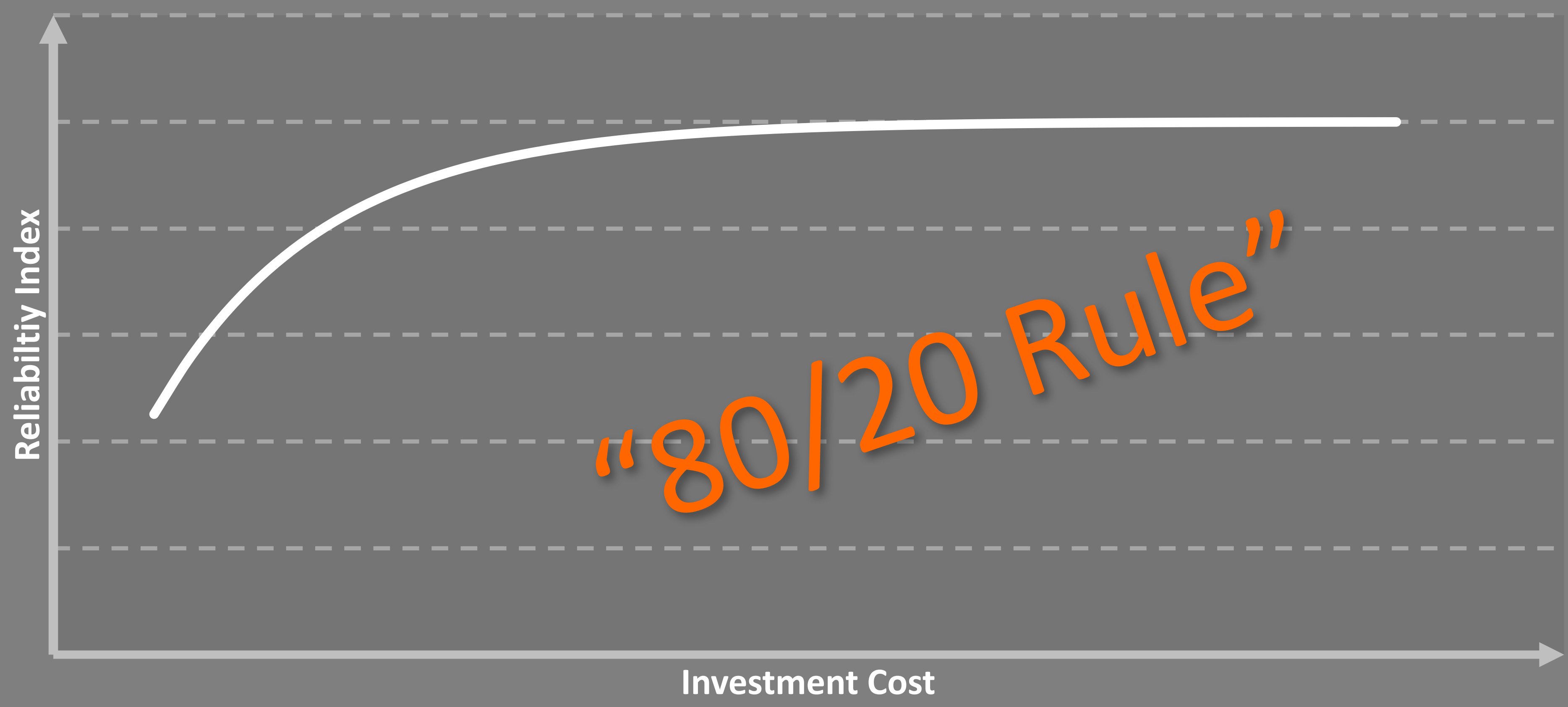
> Sustainability vs. system stability

> More effective power from renewables vs. power quality

v Reliability vs. economy



Graph extracted from: Mosteller R., Budget-constrained Power System Reliability Optimization

Improving Power Reliability

- **Basic Design Considerations**

- Modification or New Design
- Power availability requirements
- Renewables intermittency and desired penetration
- Operation mode (islanded, grid-connected or both)

Improving Power Reliability

> Basic Design Considerations

v Further Design Considerations

- 'Strength'/'rigidity' of microgrid
  - Electrical inertia
- Network protection requirements
  - Bidirectional power flow requires bidirectional protection consideration
  - Non-radial network further complicate the problem
- Load demand & type
- Placement / Sizing of ESS & required functionalities

Improving Power Reliability

> Basic Design Considerations

> Further Design Considerations

v Operation Considerations

- Impact of geographic and temporal characteristics of the renewables on the scheduling & dynamic behavior
- Interconnection of multiple microgrids

High Adoption of Renewables in a Traditional Distribution Level Microgrid

Case Study

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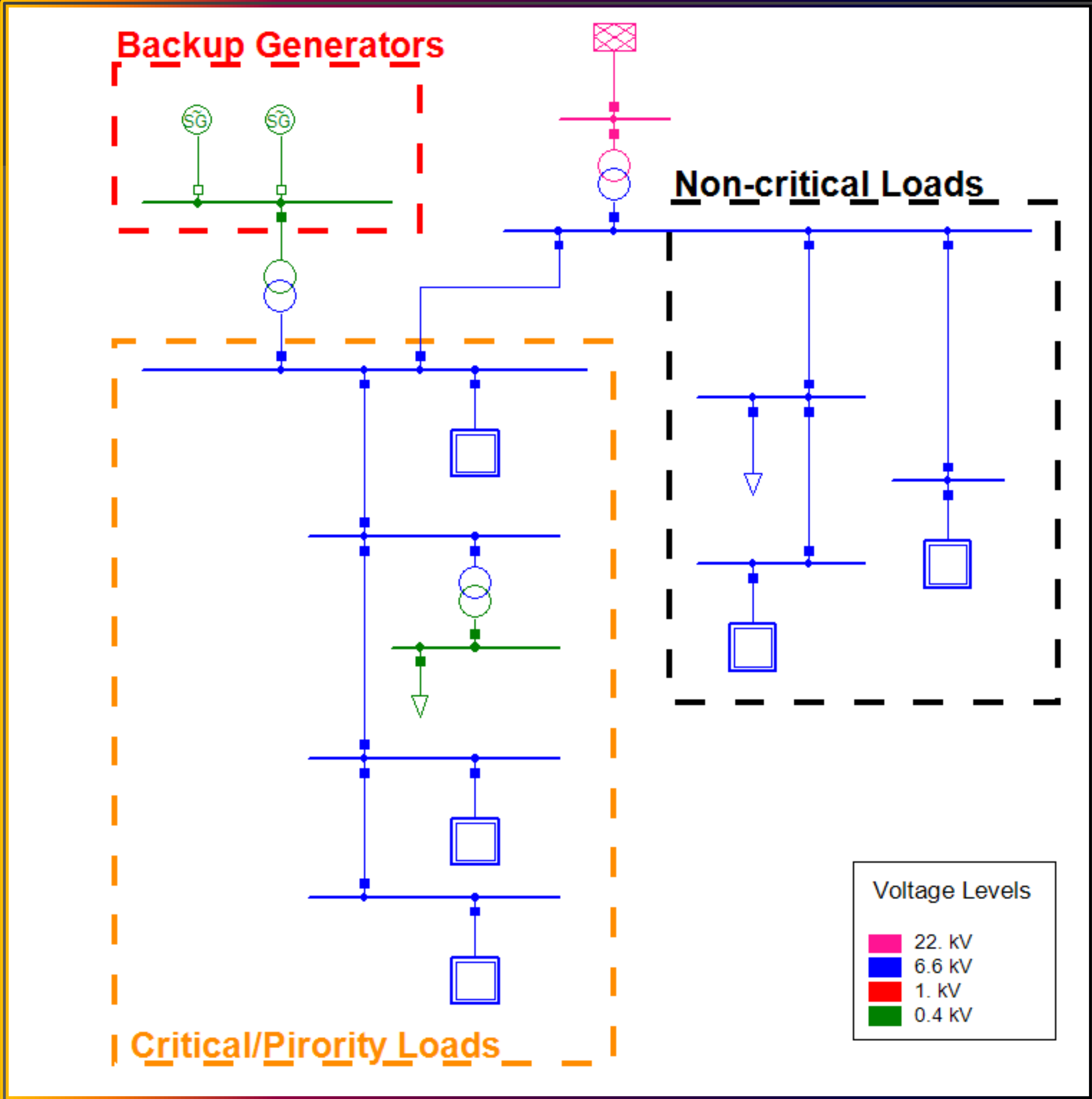
Case Network

- Distribution level (6.6 kV – 400 V)
- Radial network
- Single Point of Failure
- Critical / Non-critical Loads
- Modelled in PowerFactory



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Design Requirements

- High reliability and resiliency against internal and external failures
  - Unplanned islanding
  - Faults on microgrid network
  - Potential communication failure
- Integrate as much PV as possible
- Ensure system remains stable
- Minimise fuel cost during islanded scenario

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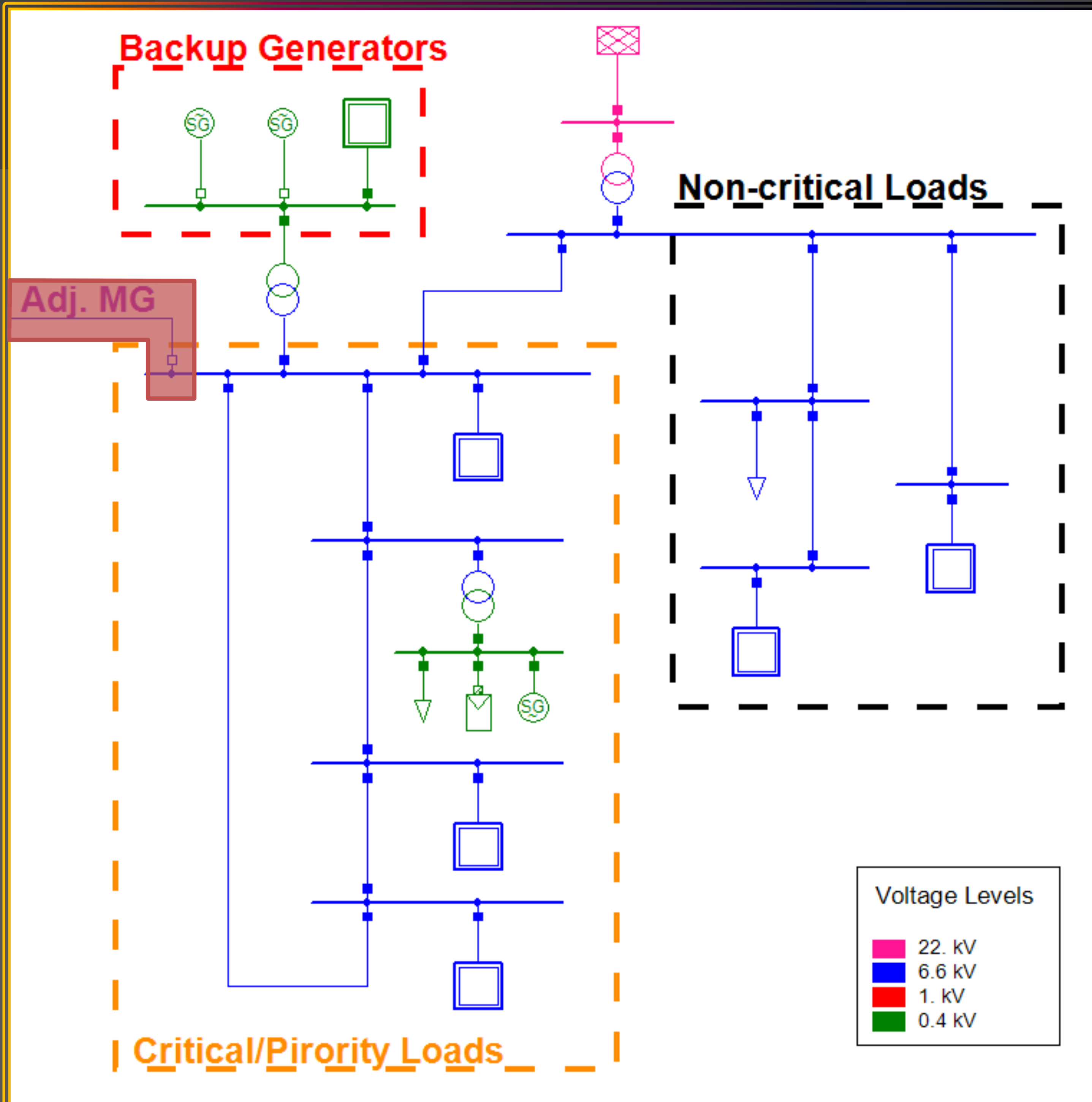
Network Modification

- PV Installation
- Loop Cable Installation
- LV DG Installation
- ESS Installation
- Adjacent MG Cable Installation
- Distributed control architecture



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PV Penetration Study

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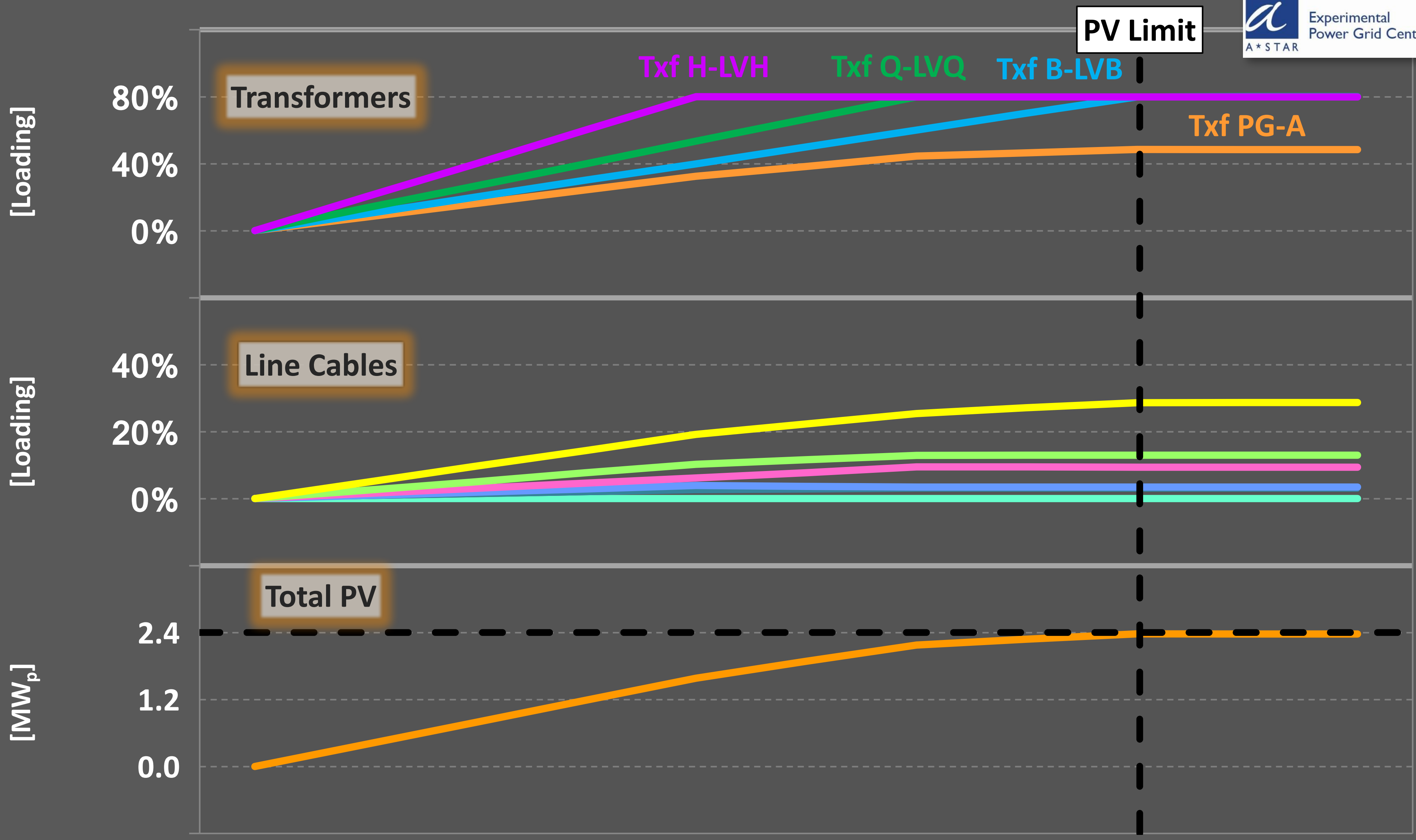
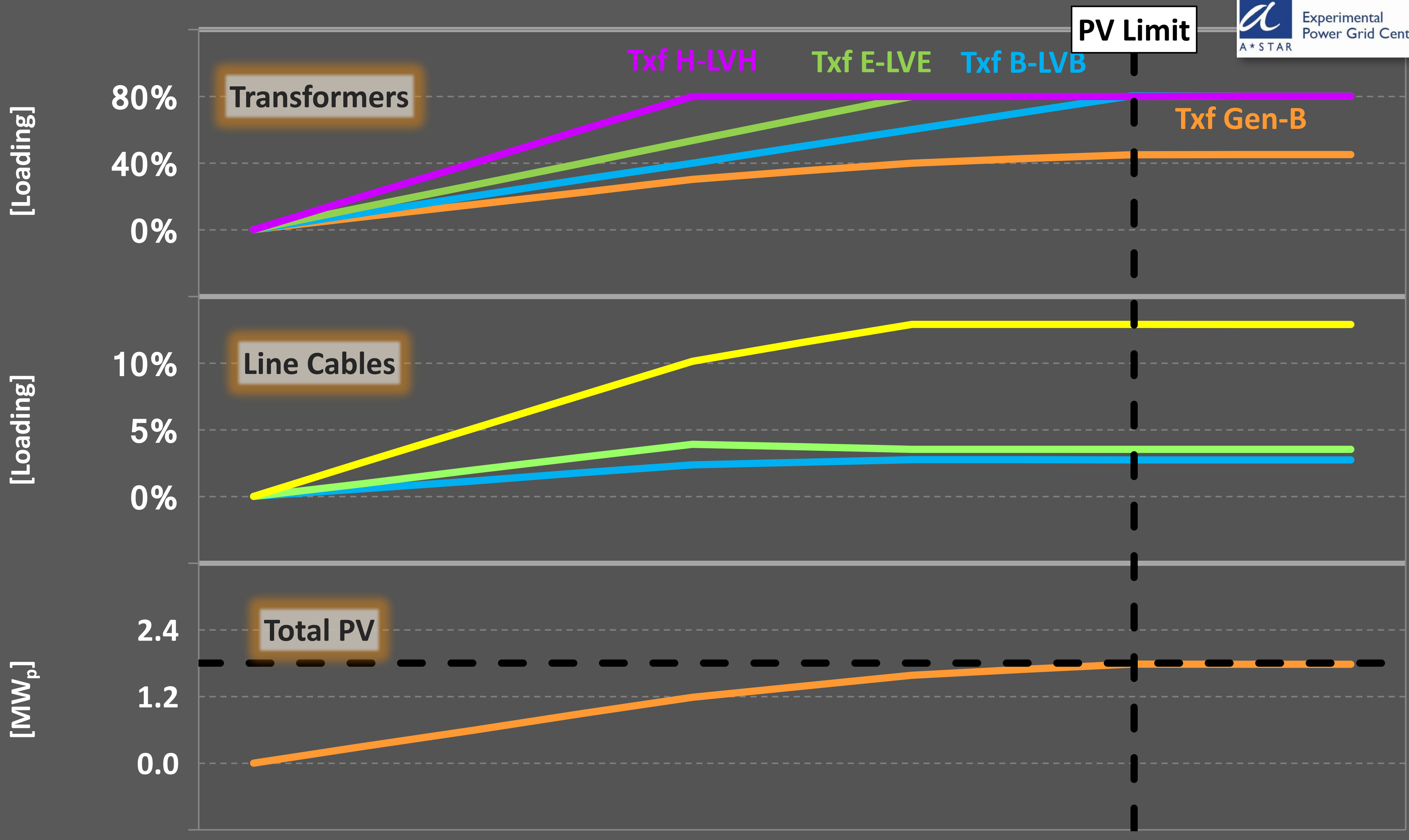


PV Penetration Study (Islanded)



Component Failure Rate

Component	Failure Rate, λ_{years} (1/y)	MTTR (h)
Cable (LV / HV)	0.02670 / 0.02017	7.60 / 5.13
Switchgear (LV / HV)	0.00949 / 0.01794	7.29 / 2.27
DGs	0.58269	25.74
Inverters	0.00482	26.00

Failure (f)
The termination of the ability of a component/system to perform a required function

Failure rate (λ)
Arithmetic average failure per unit exposure time

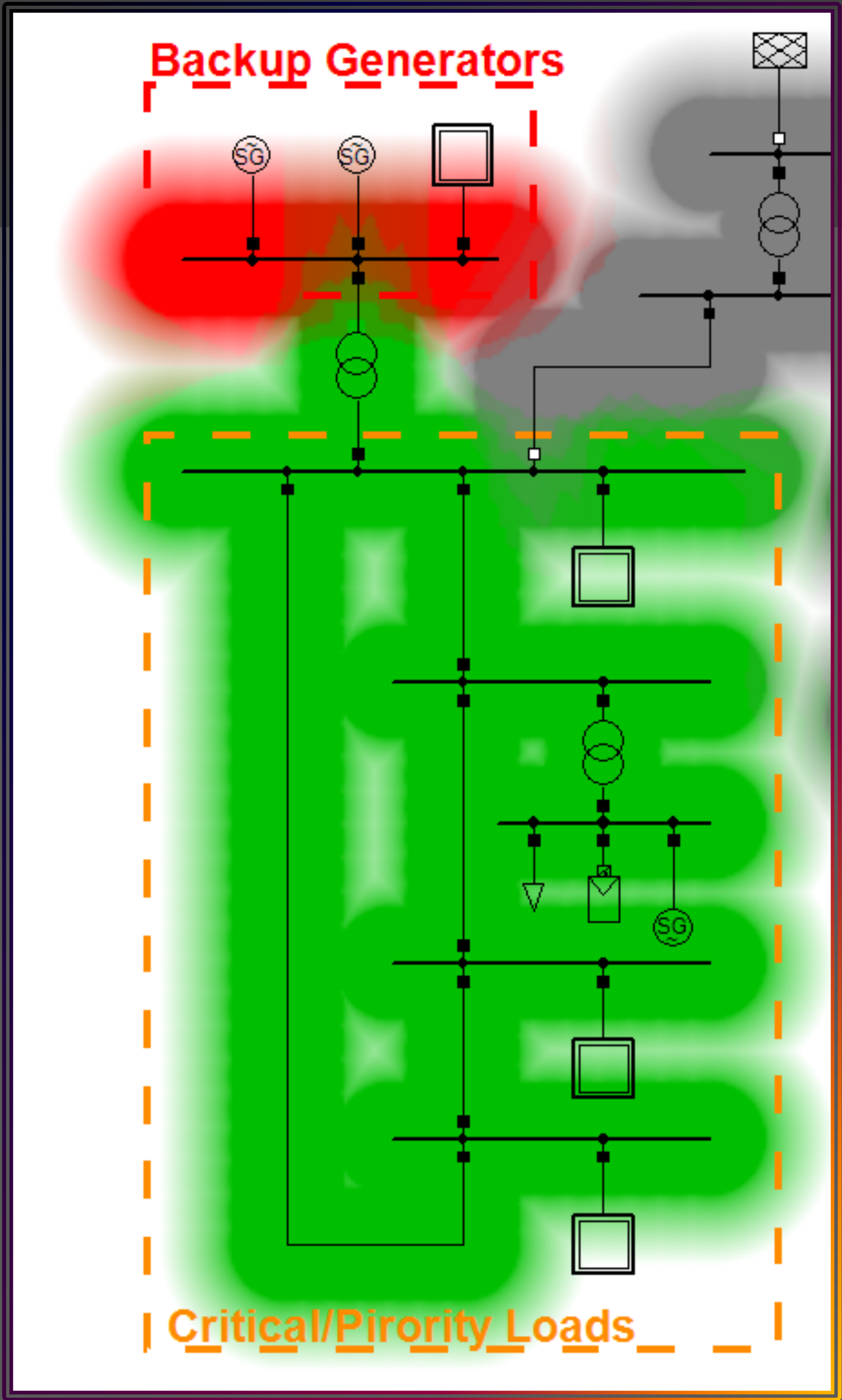
$$\lambda_{hours} = \frac{T_{failure}}{T_{period}} \text{ or } \lambda_{years} = \frac{T_{failure}}{T_{period} * 8760}$$

Mean Time to Repair (MTTR)
Total downtime for unscheduled maintenance (excluding logistics time) for a given period

$$MTTR = \frac{R_{downtime}}{T_{failure}}$$

IEEE Standard 493-2007

Power Security Improvement



	SAIFI	SAIDI
Base	0.028813	0.181
Loop	0.021437	0.147
ESS	0.009490	0.069

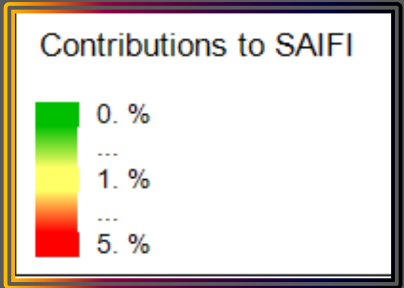
System Average Interruption Frequency Index

$$= \frac{\sum Total\ No.\ of\ Customer\ Interrupted}{Total\ No.\ of\ Customers\ Served}$$

System Average Interruption Duration Index

$$= \frac{\sum Customer\ Minutes\ of\ Interruption}{Total\ No.\ of\ Customers\ Served}$$

IEEE Standard 1366



Seamless Unplanned Islanding

PV Penetration Study

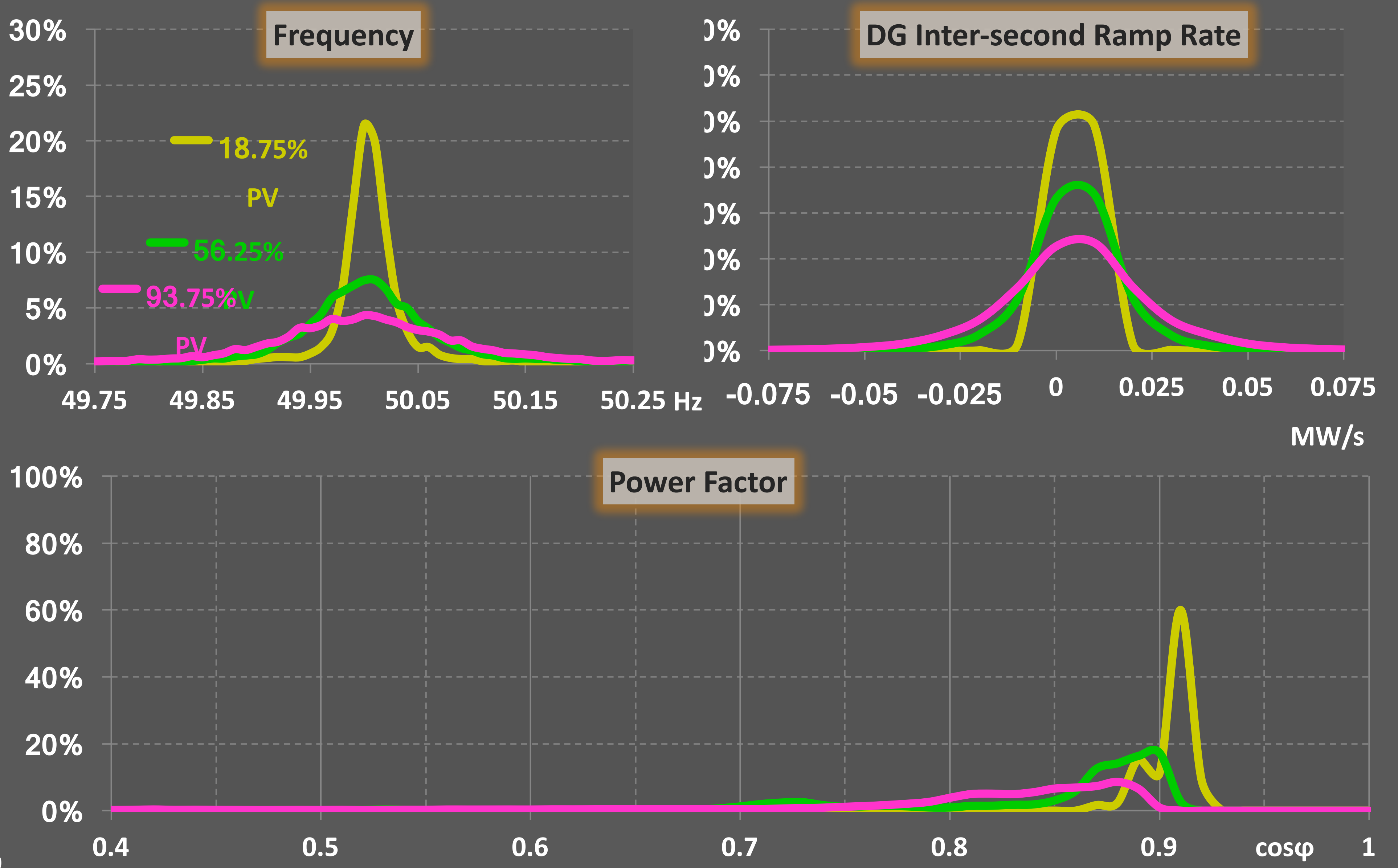
- Total Load
  (1.44 MVA @ 0.92 pf)
  - 0.50 MVA @ 0.95 pf
  - 0.20 MVA @ 0.85 pf
  - 0.25 MVA @ 0.95 pf
  - 0.50 MVA @ 0.90 pf

- Diesel Generator
  - 2 x 1 MVA @ 0.80 pf

- PV Penetration Test
  - 0.3 MW_p
    (18.75% Penetration)
  - 1.5 MW_p
    (93.75% Penetration)

*Penetration is defined as ratio of installed PV capacity to DG rating

Power Quality Analysis



Increasing PV Penetration

Problems Faced

- Network Stability:
  - Introduced network instability (frequency deviations)
  - Constant ramping of DGs
  - Deterioration of power factor at PCC and DG substation
  - Voltage rise during low loading

- Protection:
  - Change in flow of power in the network (due to PV and network topology changes)
  - Disparity between available fault current in grid-connected and islanded mode & changes in fault current flow

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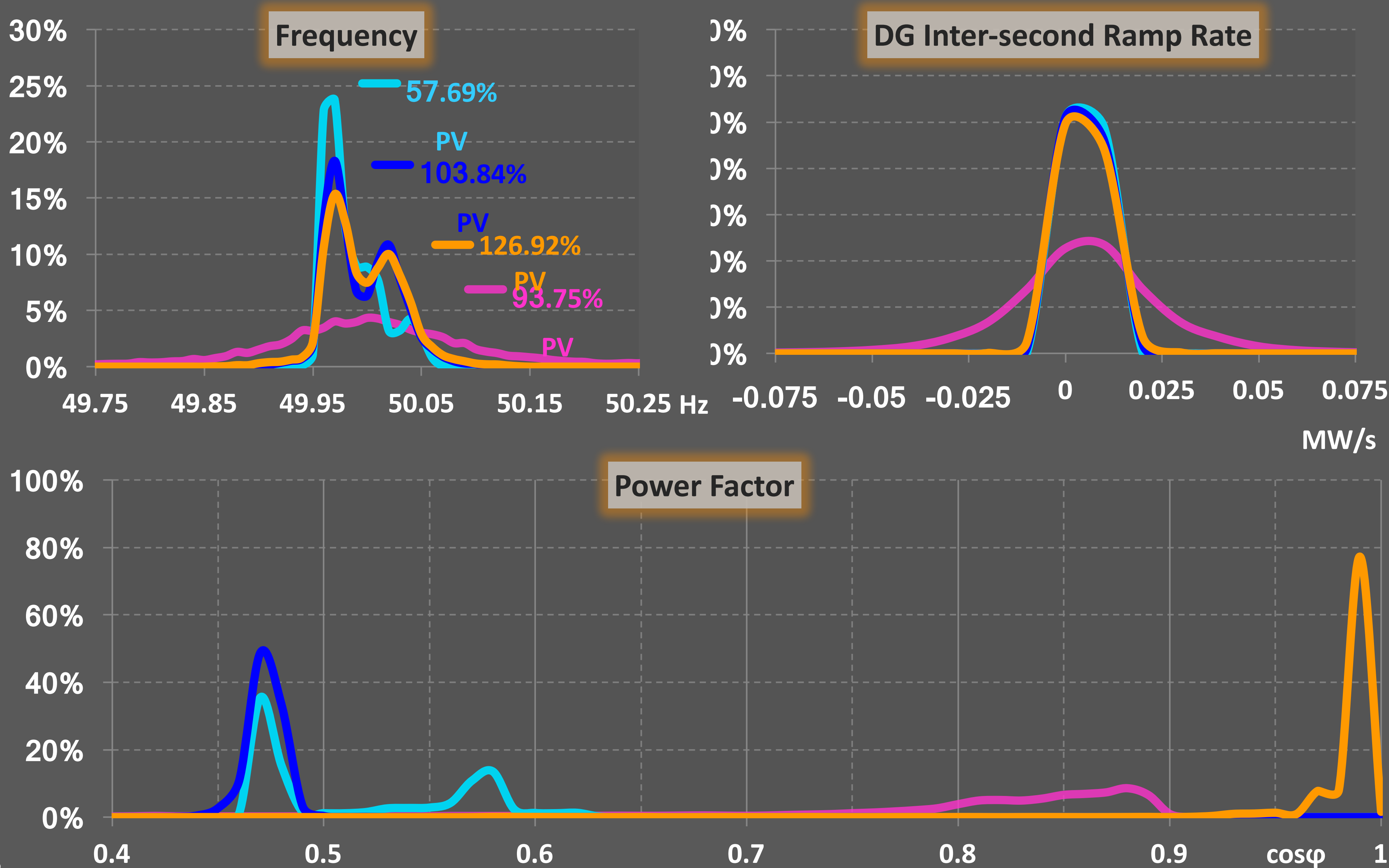
PV Penetration Study (ESS)

- Total Load
  (1.44 MVA @ 0.92 pf)
  - 0.50 MVA @ 0.95 pf
  - 0.20 MVA @ 0.85 pf
  - 0.25 MVA @ 0.95 pf
  - 0.50 MVA @ 0.90 pf
- Diesel Generator
  - 2 x 1 MVA @ 0.80 pf
- ESS
  - 2 MVA, 1 MWh

- PV Penetration Test
  - 1.5 MW_p
    (57.69% Penetration)
  - 2.7 MW_p
    (103.84% Penetration)
  - 3.3 MW_p
    (126.92% Penetration)

*Penetration is defined as ratio of installed PV capacity to DG rating

Power Quality Analysis with ESS



Protection Challenge

Issues

- Bi-directional & multiple power flow
- Changes in available fault currents

Results in

- Impartial discrimination of faults

Potential Solutions

- Method 1:
  - Change to differential protection
  - Directional sensitivity for over current relays
  - Over current relays forms the backup protection
- Method 2:
  - Make use of “loop” cable as a backup tie-breaker
- Method 3:
  - Adaptive protection

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MULTIPLE MICROGRIDS

ESS Placement, Sizing & Scheduling

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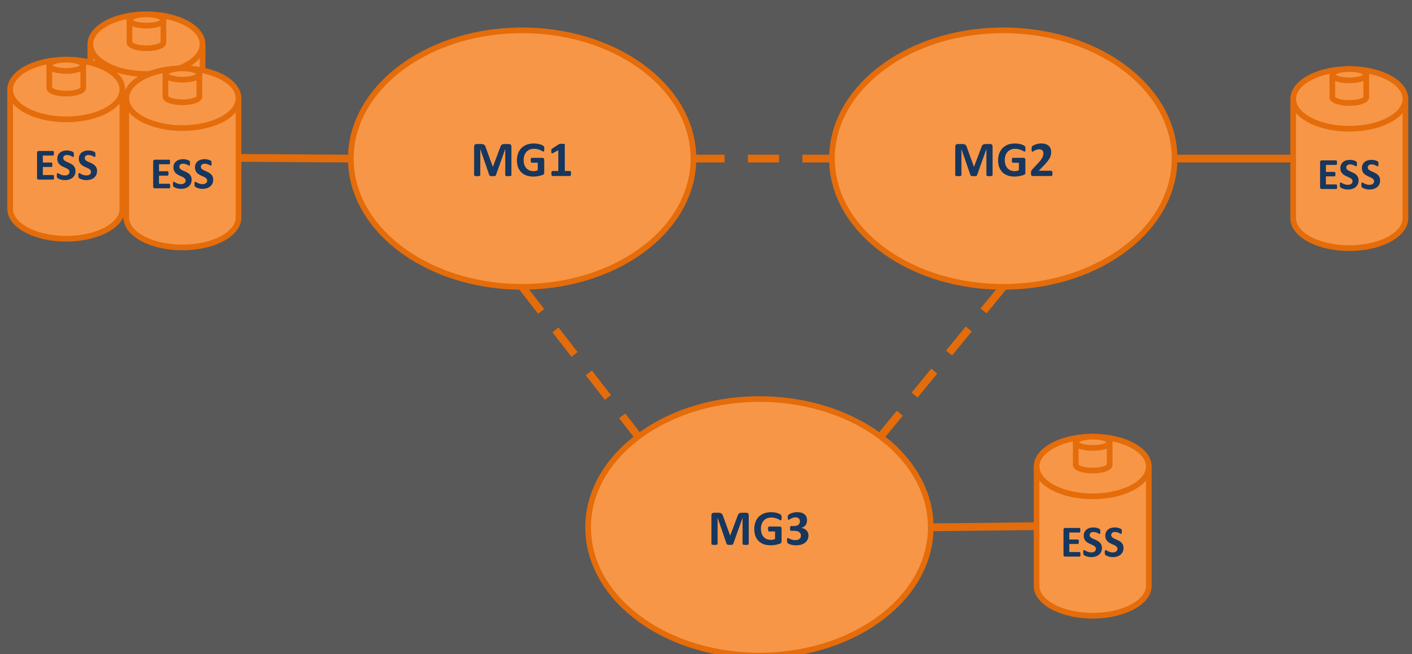
ESS – Multiple Microgrids

v Placement location

- Single ESS vs. Multiple ESS
  - Isolated MG with individual GESS
  - Connected MG with single GESS



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ESS – Multiple Microgrids

> Placement location

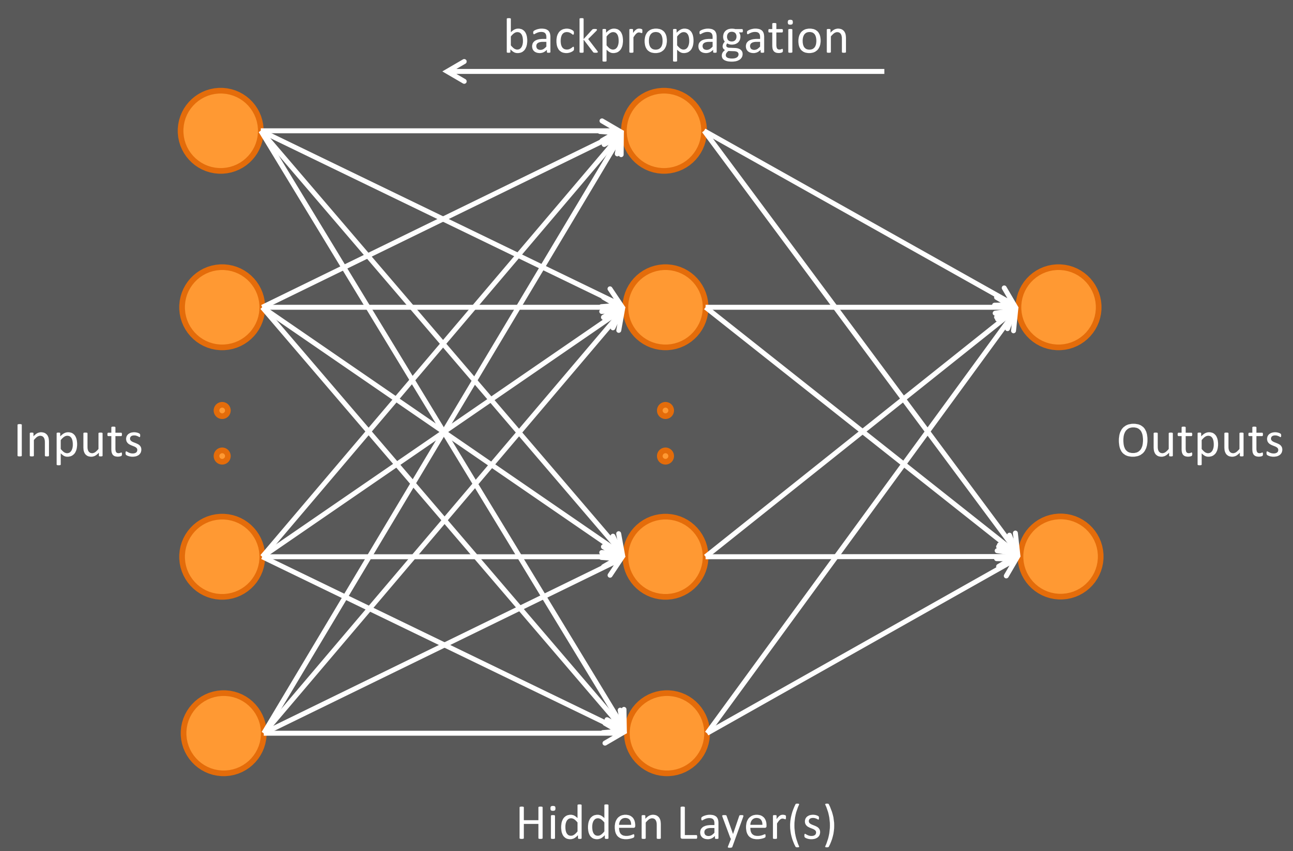
v Sizing & Scheduling

- Objective:
  - Minimise total fuel cost
- Using simple PV prediction based on ANN
- Considerations
  - Operations
    - Load profile
    - PV prediction accuracy
    - DG fuel efficiency and ramp cost
    - Levelised GESS cost
    - GESS efficiency
    - Power losses (transfer)
- Simulation
  - 3 days with varying PV condition

PV Prediction

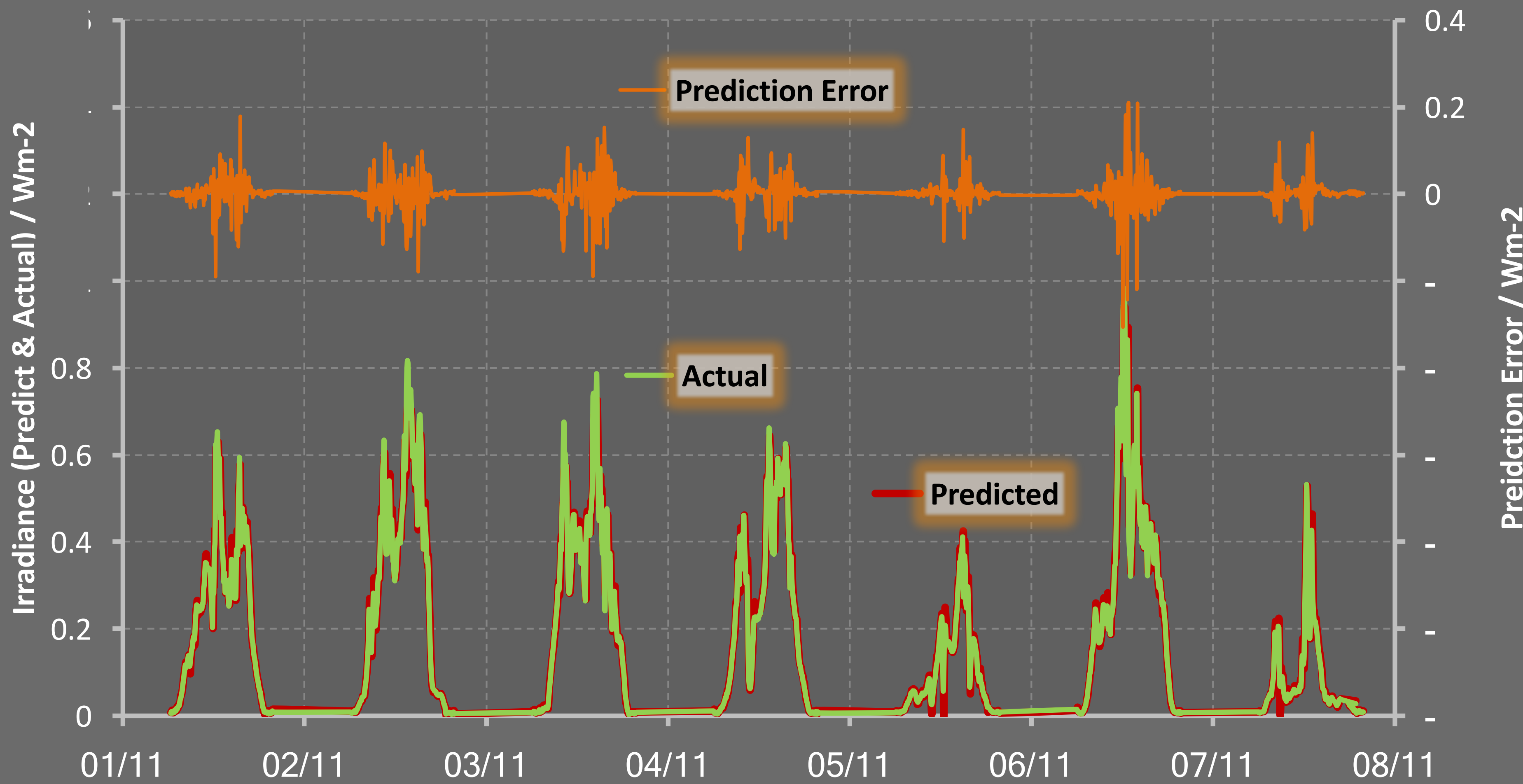
> Artificial Neural Network based

- Consideration of time-series irradiance and weather data
- Training through backpropagation



PV Prediction

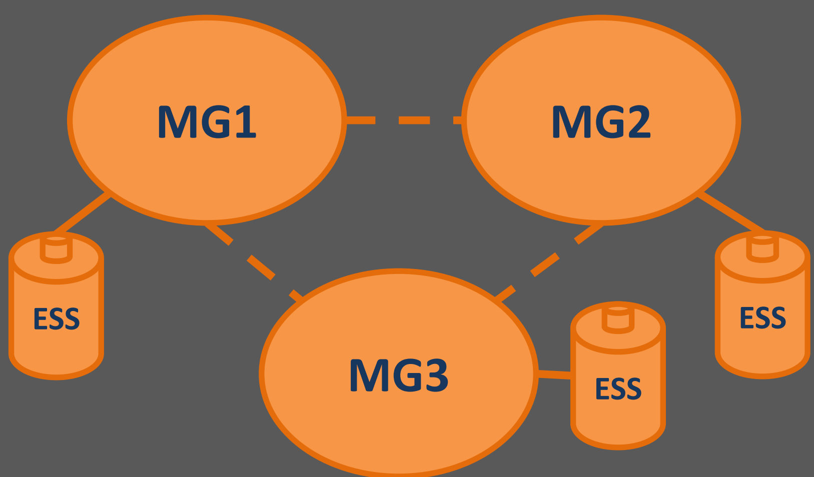
- Artificial Neural Network based
  - Prediction Results



ESS Study

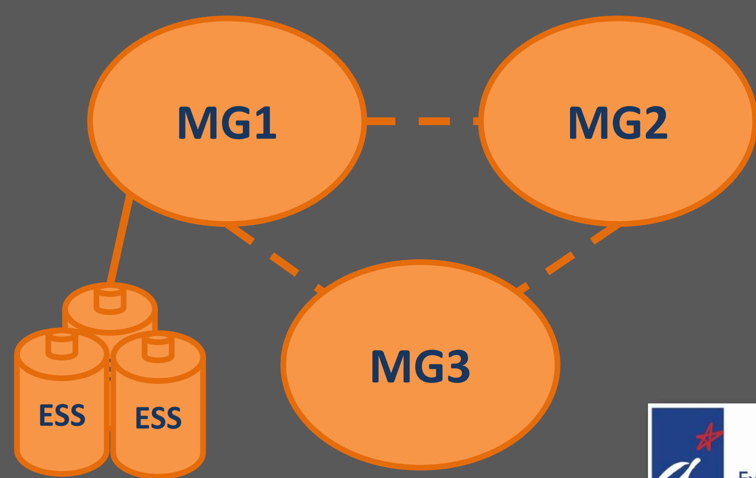
Individual ESS

- Individual ESS on each MG interconnected together reduces total required ESS capacity & inverter rating
- Allows for higher reliability



Aggregated ESS

- Lower operating cost
- Aggregate nature of load and PV allows for DG to operate at more efficient point



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Summary

- Determine RER capacity and variability
- Evaluate power reliability and quality requirements
- Provide network redundancy
- Provide power / energy redundancy
- Install corrective DERs
- Ensure network remains properly protected

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End of Presentation

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