Distributed Generation & Hosting Capacity
Need for stochastic analysis

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Goals for Delivering Electric Energy

**PRIMARY GOALS (Objectives)**
- Voltage Quality
- Reliability
- Tariffs

**SECONDARY GOALS (Engineering)**
- Overload
- Stability
- Operational security
- Current quality
- ...

**Power System**

- Consumers
- Delivers electric energy
- Commands Equipment
- Performance Indicators (Indices)

- Transmission System Operators
- Distribution System Operators
- Regulator
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Hosting capacity

Performance index (PIdx)

Limit of Improvement

IMPROVEMENT
NORMAL OPERATION
ACCEPTABLE DETERIORATION
UNACCEPTABLE DETERIORATION
IRREVERSIBLE DAMAGE

Amount of generation (AG)

Definition
The amount of distributed generation for which the performance becomes unacceptable.
Hosting capacity

Definition

The amount of distributed generation for which the performance becomes unacceptable.
Hosting capacity

**Definition**

The amount of distributed generation for which the performance becomes unacceptable or does not improve.
Reference level: The probability of equipment failure is low. International standards.

If the Reference level is moved there are no incentives to improve the network.

\[ \uparrow \text{Planning Level} \rightarrow \uparrow \text{Hosting Capacity} \rightarrow \uparrow \text{Emissions} \rightarrow \uparrow \text{Risk System Operator} \]
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Overloading Feeder

No Distributed generation

\[ P_{\text{consumed}} = P_{LB} + P_{LC} \]
\[ P_{\text{delivered}} = P_{AB} + P_{BC} \]
No overload conditions
\[ P_{\text{max delivered}}^{\text{delivered}} < P_{LB}^{\text{max}} + P_{LC}^{\text{max}} \iff \text{Consumers} \]
\[ P_{\text{max delivered}}^{\text{delivered}} < P_{AB}^{\text{max}} + P_{BC}^{\text{max}} \iff \text{Ampacity} \]

Hosting capacity

\[ P_{\text{delivered}} = P_{\text{consumed}} - P_{\text{generated}} \]
\[ P_{\text{max1 delivered}}^{\text{delivered}} = P_{\text{max consumed}}^{\text{max}} - P_{\text{min generated}}^{\text{min}} \iff \text{Same case that no generation} \]
\[ P_{\text{max2 delivered}}^{\text{delivered}} = P_{\text{max generated}}^{\text{max}} - P_{\text{min consumed}}^{\text{min}} \iff \text{Change direction of power flow} \]
\[ P_{\text{max generated}}^{\text{generated}} = P_{\text{max delivered}}^{\text{delivered}} + P_{\text{min consumed}}^{\text{min}} \]
No overload conditions
\[ P_{\text{max generated}}^{\text{generated}} < P_{\text{max consumed}}^{\text{max}} + P_{\text{min consumed}}^{\text{min}} \iff \text{1st Hosting capacity (HC1)} \]
\[ P_{\text{max generated}}^{\text{generated}} < P_{\text{max feeder}}^{\text{max}} + P_{\text{min consumed}}^{\text{min}} \iff \text{2nd Hosting capacity (HC2)} \]

Example

A \[ P_{AB}^{\text{max}} = 9\text{MW} \]
B \[ P_{BC}^{\text{max}} = 3\text{MW} \]
C
\[ P_{LB}^{\text{max}} = 4\text{MW} \]
\[ P_{LB}^{\text{min}} = 1\text{MW} \]
\[ P_{LC}^{\text{max}} = 2\text{MW} \]
\[ P_{LC}^{\text{min}} = 1\text{MW} \]

Example

A \[ P_{AB} \]
B \[ P_{BC} \]
C
\[ P_{LB} \leq 7\text{MW} \]
\[ P_{LC} \leq 4\text{MW} \]
\[ P_{GB} \]
\[ P_{GC} \]
\[ P_{HC1}^{AB} = (4 + 2) + (1 + 1) = 8\text{MW} \]
\[ P_{HC1}^{BC} = (2) + (1) = 3\text{MW} \]
\[ P_{HC2}^{AB} = (9) + (1 + 1) = 11\text{MW} \]
\[ P_{HC2}^{BC} = (3) + (1) = 4\text{MW} \]
Managing the risk

- Limits are deterministic.
- Minimum consumption is only a few hours per year.
- Maximum production occurs over a fraction of time.
- Probability of reaching the worst case scenario (maximum production, minimum load) is very low.
- Stochastic approach
  - Measurement: Accurate data of consumer patterns.
  - Consumer: Acknowledge possible interruptions.
  - System Operator: Penalties for interruptions.
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# Voltage regulation

## Parameters
- Cross-section \((A)\)
- Length, location \((l)\)
- Reactance \((\alpha)\)
- Power factor \((k)\)
- Nominal voltage \((U)\)

## Definition

\[
R = \rho \frac{l}{A}
\]

\[
\alpha = \frac{X}{R}
\]

\[
k = \frac{Q}{P}
\]

\[
Z_L = R + Xj = R(1 + \alpha j)
\]

\[
I = \frac{1}{V} (P + Qj) = \frac{P}{V} (1 + kj)
\]

## Equations

\[
\Delta V = |U - V| = |Z_L I|
\]

\[
\Delta V = |R(1 + \alpha j) \frac{P}{V} (1 + kj)|
\]

\[
\Delta V = \frac{PR}{V} |1 - \alpha k + (\alpha + k)j|
\]

\[
\frac{\Delta V}{V} = \frac{PR}{V^2} \sqrt{(1 - \alpha k)^2 + (\alpha + k)^2}
\]

\[
P = \frac{\delta V^2}{R} \frac{1}{\sqrt{(1 - \alpha k)^2 + (\alpha + k)^2}}
\]
Voltage regulation
Cross-section & Length

1. Voltage (p.u.) vs. P Hosting Capacity (MW)
   - Lines for different cross-sections: 50 mm², 100 mm², 200 mm²

2. Voltage (p.u.) vs. Position (km)
   - Lines for different lengths: 500 m, 1 km, 2 km

3. P Hosting Capacity (MW) vs. Cross-section (S mm²)

4. P Hosting Capacity (MW) vs. Position (km)
Voltage regulation
Nominal Voltage & Reactive power

![Graphs showing voltage regulation with different nominal voltages and hosting capacities.](image-url)
Factors

- $HC \propto \text{cross-section}$.
- $HC \propto \frac{1}{\text{location}}$.
- $HC \propto \text{voltage level}$.
- $HC \propto \frac{X}{R}$ and $Q$.

Stochastic approach

- The deterministic method:
  - Overvoltage: Lowest consumption and maximum production.
  - Probability of suffering overvoltage or undervoltage is zero.
- Worst-case scenario is highly unlikely.
- Voltage regulators decrease HC, and increase uncertainty.
- Risk analysis. Immunity level is high: Probability of failure is low.
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Hosting Capacity & Protection

Margin of coordination

Coordination

No generation

\[ I_{\text{down}}^{\min} > I_{\text{trip}} \quad I_{\text{up}} = 0 \]

Generation

\[ I_{\text{down}}^{\min} > I_{\text{trip}} > I_{\text{up}}^{\max} \]
Summary

- ↑ Generation ⇒ Uncoordination.
- ↑ length feeder ⇒ ↓ HC.
- Generation far from substation ⇒ ↑ HC.
- Current protection is not a solution when the penetration is high.

Stochastic approach

- Different type of generation ⇒ Different contributions of faulty currents.
- Generation is not present in the system at all times.
- ↑ # trips ⇒ ↑ # failures loads.
- Controlled island operation ↑ reliability.
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conclusions

Hosting capacity calculation

- The Hosting capacity concept can be applied to any other performance index that can be measured in the network such as harmonics (THD, TDD,...), imbalance, reliability (voltage sags, outages...).

- A deterministic approach to calculate the hosting capacity underestimates the potential of the current distribution system to integrate distributed generation in most of performance indices.
Bibliography

Thank you for your attention.

Are there any Questions?