SEMINAR ON HOW TO ESTABLISH RE CENTERED GRID SYSTEM FOR CARBON NEUTRALITY

Evaluation methodology of system strength (short circuit power) in Energinet

Jun Bum Kwon, Senior Engineer, Energinet systemansvar A/S

Agenda

- Introduction to short circuit calculations
- Maximum and minimum calculations
- Handling increasing short circuit currents

INTRODUCTION TO SHORT CIRCUIT CALCULATION

Use of short circuit calculation in TSO – annual report

- Calculate Short Circuit Current in general
- Design of devices in Transmission level (HVDC, etc)
- Design of components - Description of the severity of overcurrent that a device can reasonably be expected to withstand which applies to breakers, disconnects, conductors, etc.
- Breaker Duty Evaluations (Using the short circuit duty results, breakers are determined to be able to withstand the fault that it needs to clear with respect to X/R ratio)
- Indication of Relative classical “System Strength”
- DSO (Distribution System Operator) – Short circuit calculation report should be sent to DSOs
- Grid connection project – impedance polygon and voltage power quality.
- EMT studies to represent the rest of grid
- Earth current, etc.,,

System strength

ENERGINET

SHORT CIRCUIT CALCULATION METHODS

IEC 60909 vs Complete (superposition) – Using DigSilent PowerFactory

IEC: Planning

- Correction factors for:
  - Voltage (C-factor)
  - Transformer taps
  - Impedance
  - Shunt elements
  - Synchronous machines
- Inverter based generation disregarded

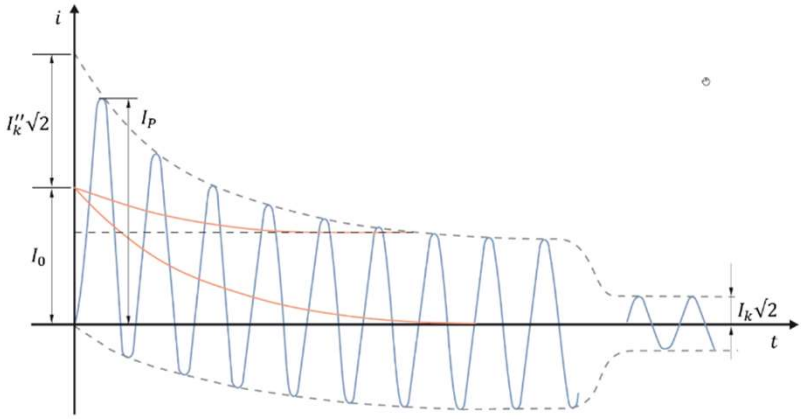
Complete: Operation scenarios

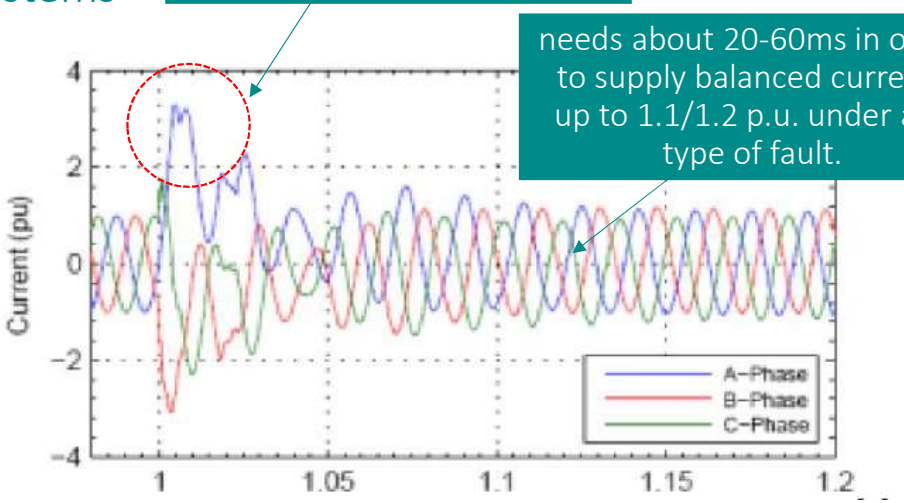
- Load flow instead of correction factors
  - If needed C-factors can still be used
- Inverter based generation included
  - Uses a current iteration to determine contribution

G-PST "Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance"

SHORT CIRCUIT CURRENT

Conventional power plants Vs inverter based systems





Example : 3phase fault with voltage dip of 0.2 p.u.

Short circuit current characteristics of conventional synchronous generators, where ip is short circuit surge current, ik'' is sub-transient short circuit current, ik is steady-state short circuit current

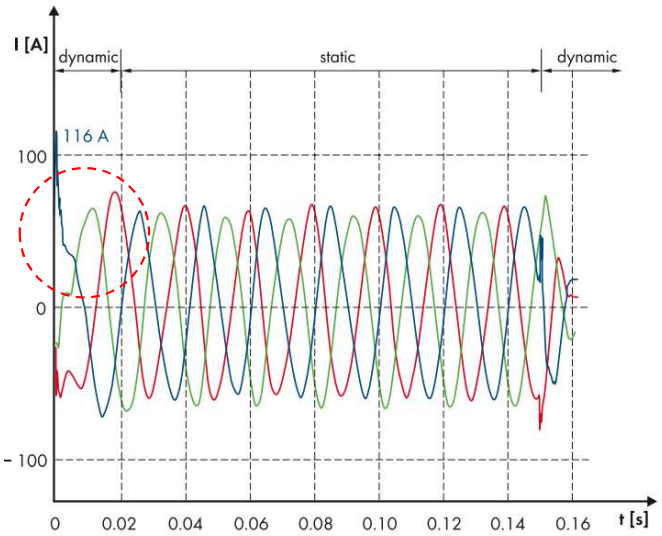
- Type 1-3 converters : the most of them are DSO connected and negligible
- LCC HVDC : should reduce current according to operational characteristic to avoid commutation failure
- Type 4 and VSC-HVDC has mainly short circuit contribution

GRID FOLLOWING CONVERTER -SHORT CIRCUIT CONTRIBUTION

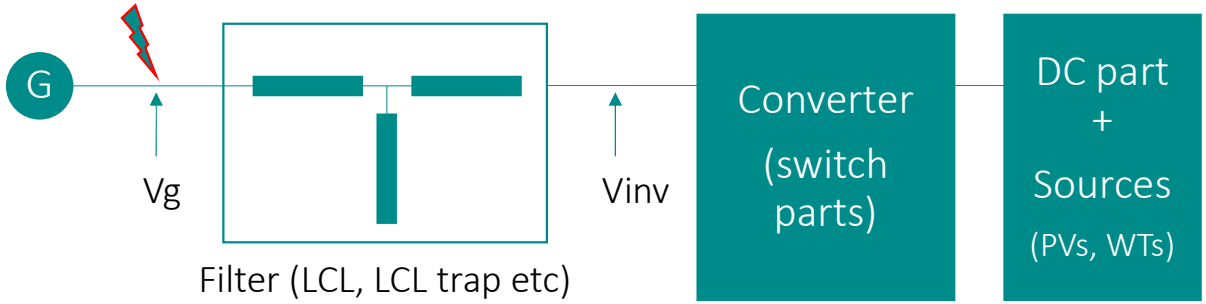
ENERGINET

Parameters (ip, ik, ikss)

Two dynamic parts + one static part



Typical short circuit current behaviour of Typr 4 converters (Ref : SMA)



- ip (peak short circuit current) is determined mainly by filter impedance.

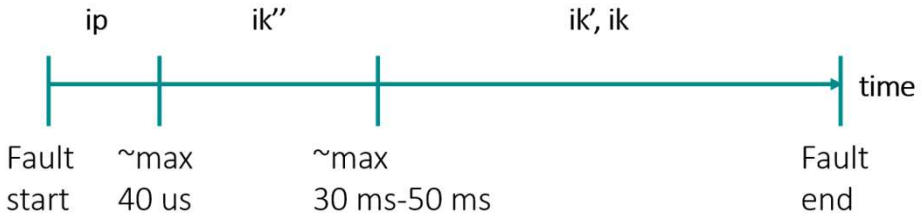
$i(t)=(Vg(t)-Vinv(t))/Zfilter \rightarrow \max(i(t)) = ip$

- Since converter filters are not able to hold big energy like rotating mass in Synchronous generator, duration of ip is quite short compared to classical synchronous generator.
- Static current magnitude is determined by controllers and grid codes.

METHODOLOGY

Short circuit characterisic measurement from EMT vendor models

	ip	Ikss	Ik
Magnitude (typical value)	Up to 5 p.u. x imax	Up to 1.4 p.u. x imax	1.0-1.05 p.u. x imax



Time frame used to measure short circuit current characteristic in EMT models, where ip is short circuit surge current, ik'' is sub-transient short circuit current, ik is steady-state short circuit current

Simulation scenario

Test conditions for WTs
- Residual voltage at PoC : 10%,20%,30%,40%,50%,60%,70%,80%,90%
- Fault cases : 3 phase, 1 phase for 100 ms
- WT operating points :
100%, 90%, 75%, 50%, 25%, 0% power production
- Different Thevenin grid configuration :
Strong grid (Short Circuit ratio (SCR)=10), weak grid (SCR=2)
- Reactive power controller modes are assumed that WTs use ac-voltage controller.

Test conditions for VSC-HVDCs
- Residual voltage at PoC: 10%,20%,30%,40%,50%,60%,70%,80%,90%
- Fault cases : 3phase, 1 phase for 100 ms
- HVDC operating points : 100%, 90%, 75%, 50%, 25%, 0% power production with different Q controller order.
- Different Thevenin grid configuration : Strong grid (SCR=10), weak grid (SCR=2)
- Q controller is assumed as reactive power controller.
- Directions of power transfer are also considered together for different operating points.

Test conditions for short circuit current characteristic of VSCs in EMT tools (a) Test conditions for WTs, (b) Test conditions for HVDCs.

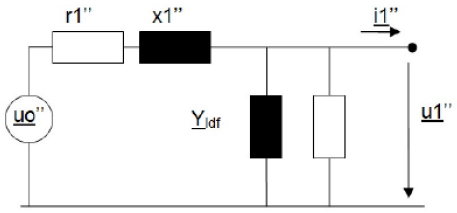
METHODOLOGY

ENERGINET

Short circuit characterisic measurement from Static short circuit model – ”Dynamic voltage support”

The dynamic voltage support model is used to reflect the requirement of various grid codes to support the voltage in case of a fault with reactive current. The short-circuit contribution is split up in two parts, the sub-transient and the transient/steady-state part.

Sub-transient short circuit current (=when Equivalent synchronous machine)



Model for sub-transient complete short-circuit with load flow initialization

$$x1'' = \frac{c''}{S_k'' \cdot \sqrt{1 + (R/X'')^2}} \text{ in p.u.}$$

$$r1'' = x1'' \cdot (R/X'') \text{ in p.u.}$$

$$c'' = |\underline{u}_{ldf}|$$

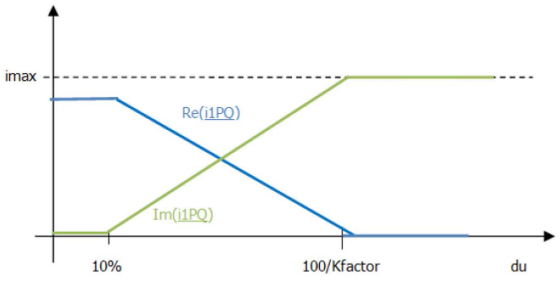
$$\underline{u0}'' = \underline{u}_{ldf}$$

$$\underline{Y}_{ldf} = \frac{\underline{i}_{ldf}}{\underline{u}_{ldf}}$$

Positive short circuit impedance

Transient and steady-state short circuit current

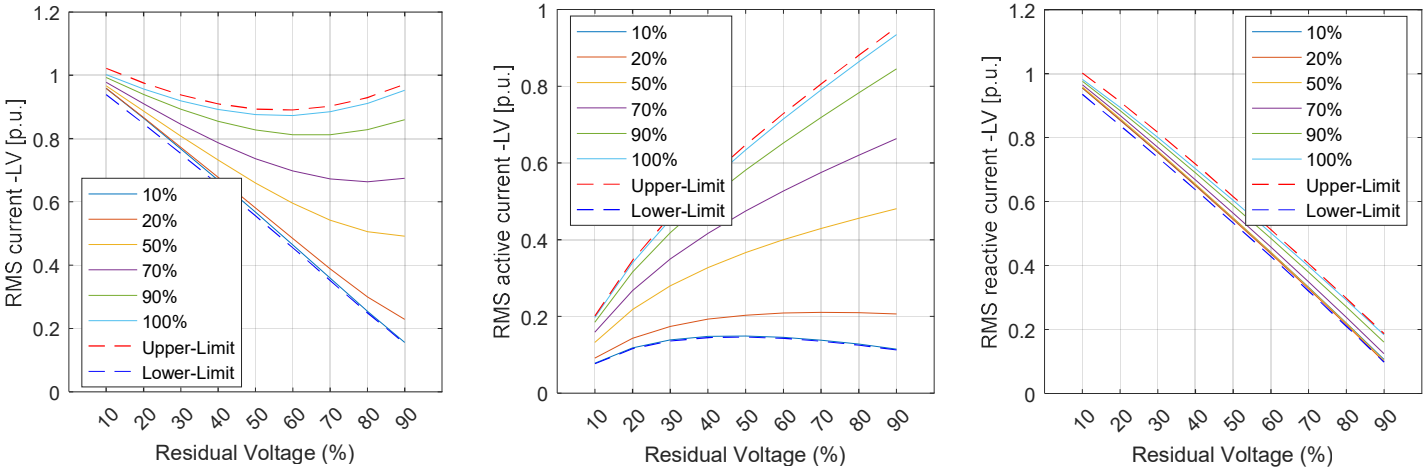
Dynamic voltage support (From German Grid code VDE)



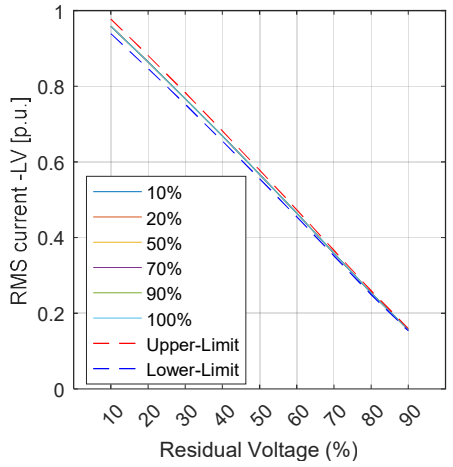
Based on load flow results, compare current and voltage level and determine the amount of active and reactive power during short circuit events.

SIMULATION RESULTS

Type 4 (wind turbine) model



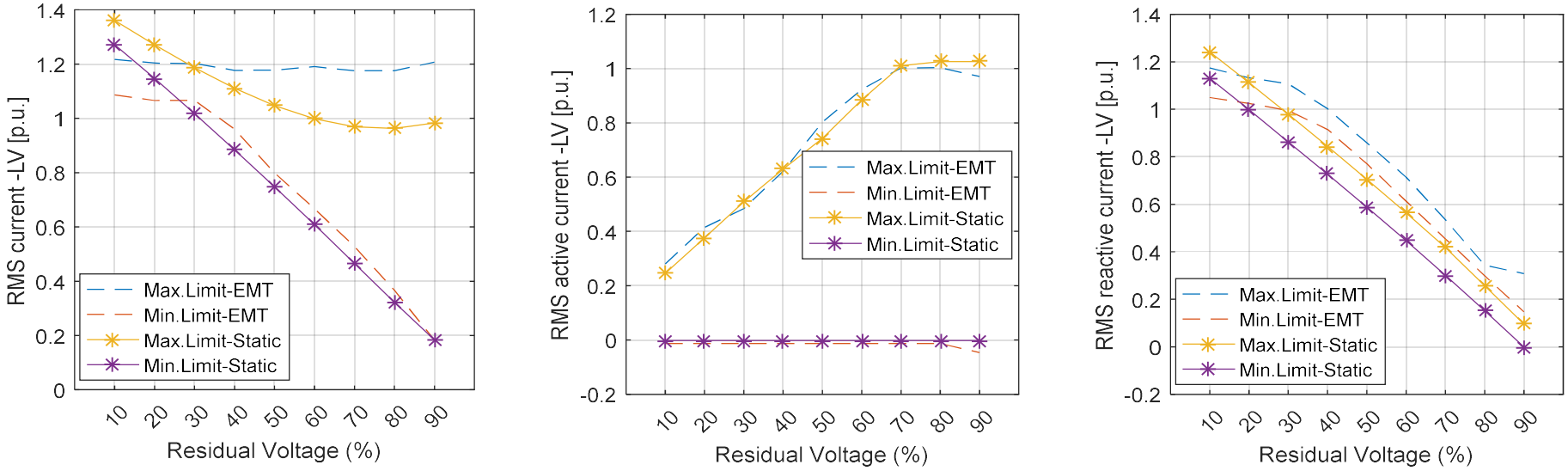
*S*hort circuit characteristic of WT static model considering different test conditions in Table 1 based on "Dynamic voltage support" in complete method, RMS values of (a) short circuit current, (b) active current, (c) reactive current.



*S*hort circuit characteristic of WT static model considering different test conditions based on classical IEC method

SIMULATION RESULTS

Type 4 (wind turbine) model – comparison between EMT and static models

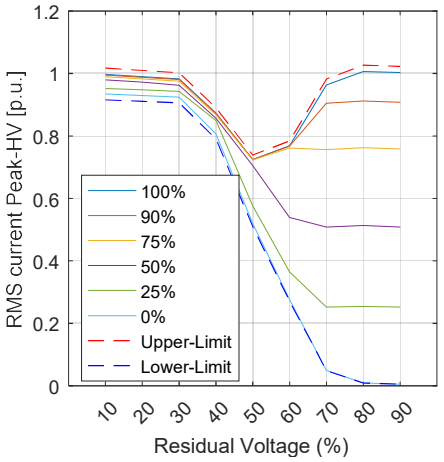


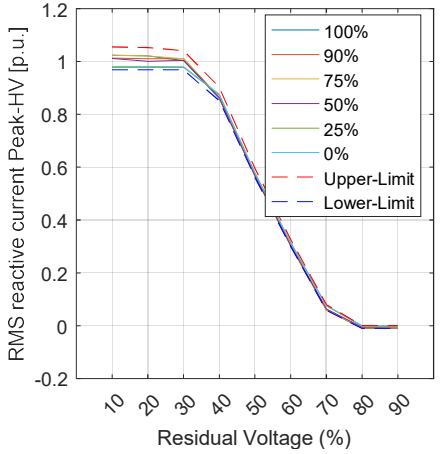
Max. Min. - short circuit characteristic comparison of EMT / static WT models considering different test conditions in Table 1, RMS values of (a) short circuit current, (b) active current, (c) reactive current

SIMULATION RESULTS

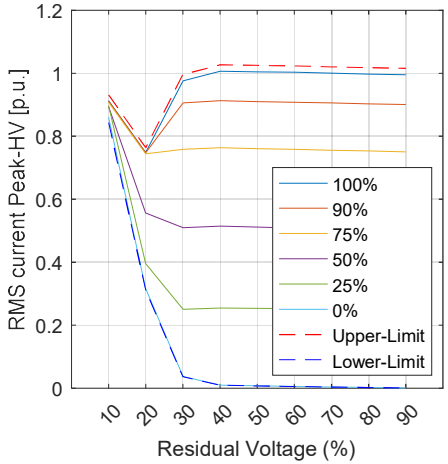
VSC-HVDC model – measurement at different grid conditions

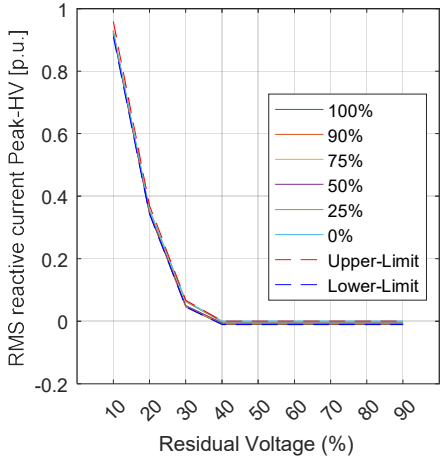
Strong Grid





Weak Grid





Short circuit characteristic of VSC-HVDC (at weak grid) considering different test conditions in Table 1-*(b)* by using EMT models, RMS values of (a) short circuit current, (b) active current, (c) reactive current.

PRECONDITIONS: MAXIMUM CALCULATIONS

- Screening to 2040
  - Grid configuration
  - Projected production and consumption
- ”Complete”-method with realistic load flow

Plant type	Operation scenario
External grids	Maximum SC contribution from TenneT and SvK
Synchronous condenser	All units in service
Central power plants	All units in service
CHP	All units in service
Grid configuration	Intact
HVDC VSC	All units in service
Wind	All units in service (50% production)
Solar	All units in service (50% production)

PRECONDITIONS: MINIMUM CALCULATIONS

- Screening from now to 2040.
- Performed using ”Complete”-method
  - C-factor approach using realistic minimum voltages
- Combination matrix follows minimum number of plants in services based on our System Operational Guidelines
- ”Intact” / N-1 / N-2

Plant type	Operation scenario
External grids	Minimum SC contribution from TenneT and SvK
Synchronous condenser	Combination matrix
Central power plants	Combination matrix
CHP	Out of service
Grid configuration	N-1 AC-interconnection
HVDC VSC	Combination matrix
Wind	Out of service
Solar	Out of service

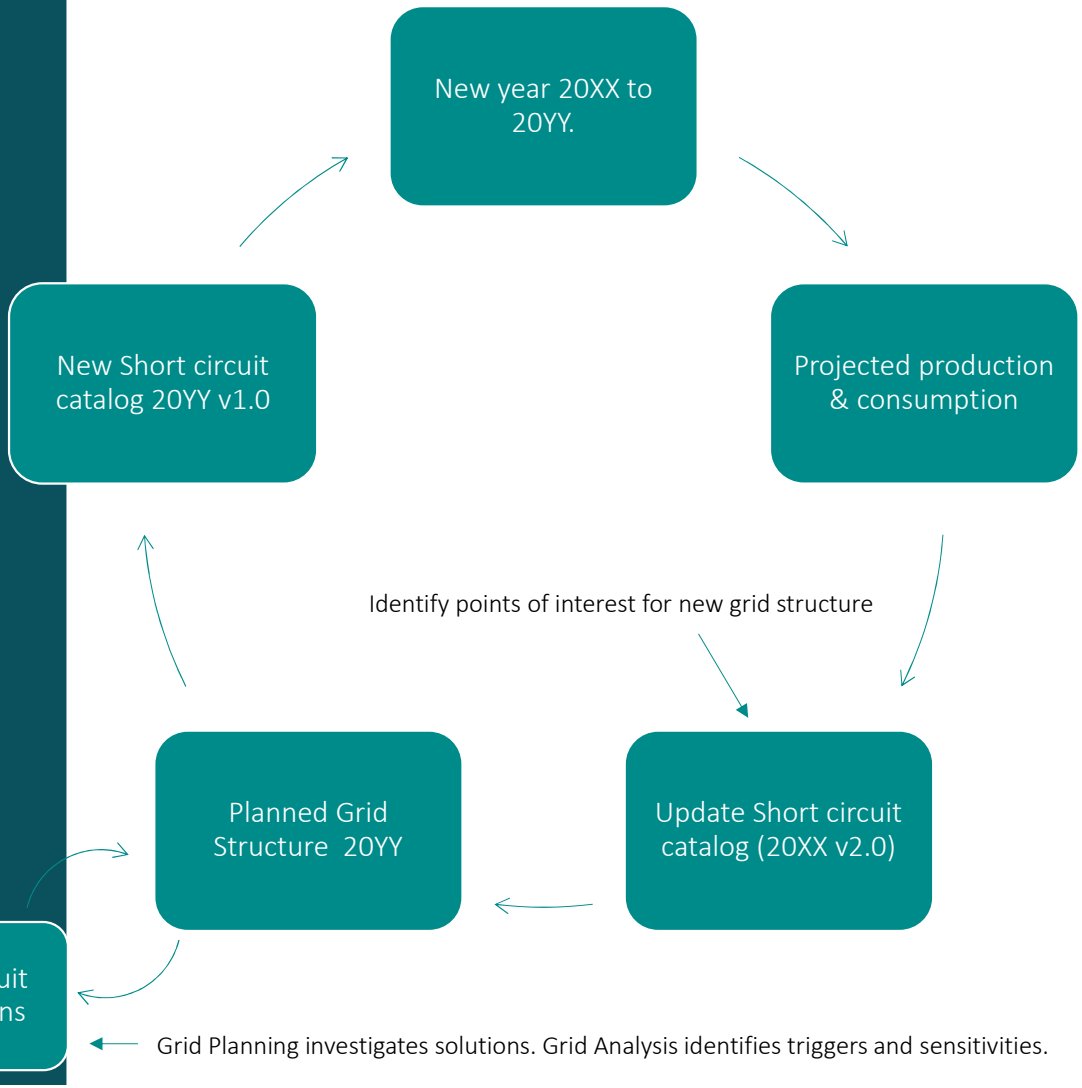
SHORT CIRCUIT CATALOG

PUBLICATION OF SHORT CIRCUIT LEVELS

- Working on releasing interactive PowerBI report on Energinet.dk
- Used internally in Energinet:
  - Planning of new components
  - Relay settings
  - Handling increasing SC-levels
- Used by DSOs, plant owner etc. in planning stages

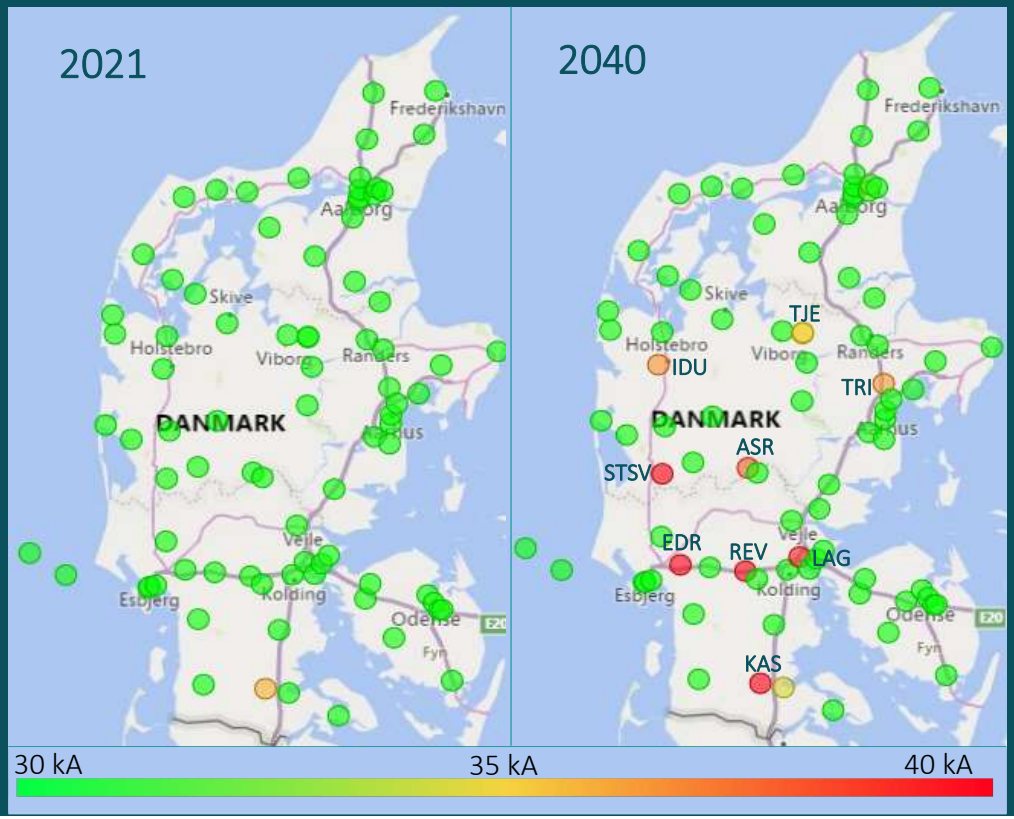
Coordination between Grid Planning and Short circuit calculations from Grid Analysis.

ENERGINET

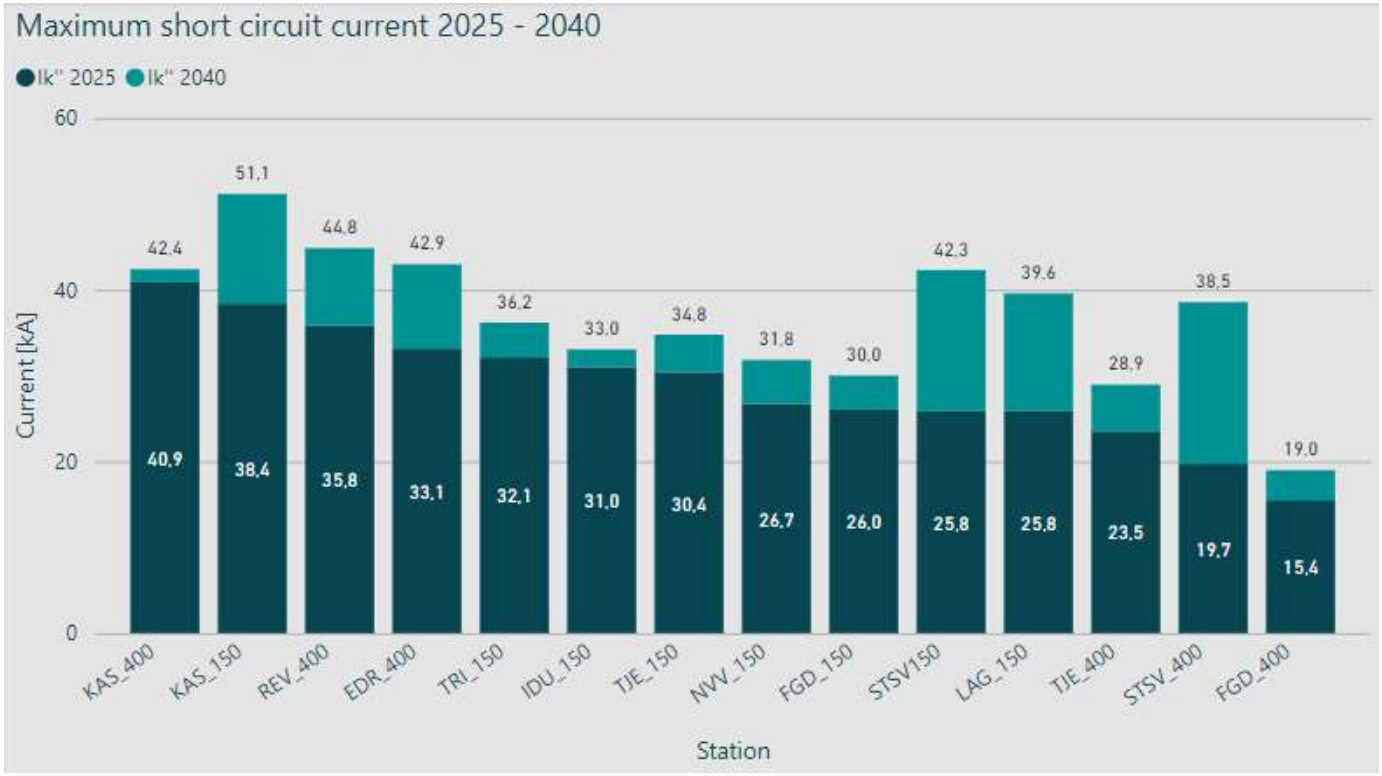


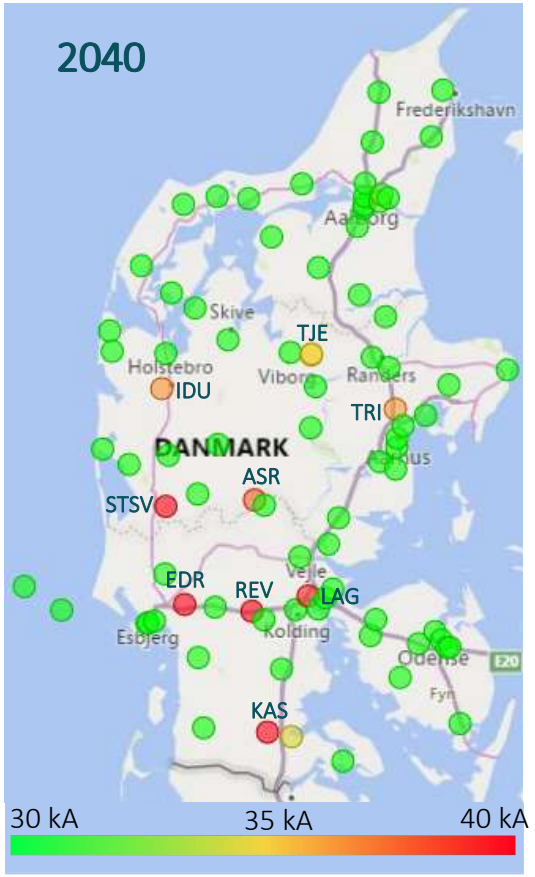
INCREASING SHORT CIRCUIT LEVELS

Sensitivity study



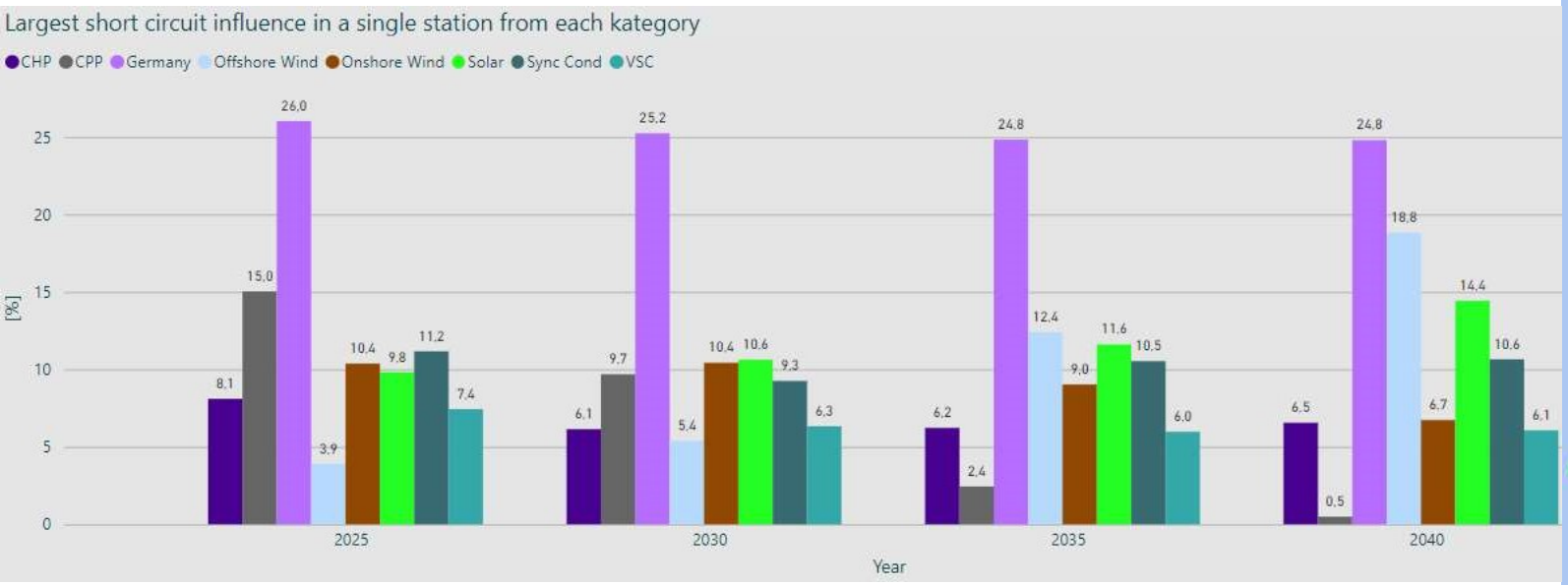
CHANGES FROM 2025 TO 2040

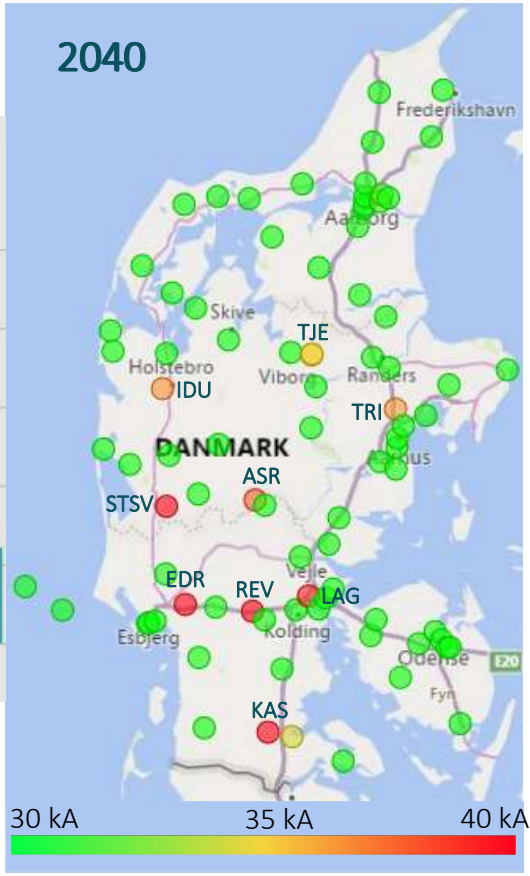




ENERGINET

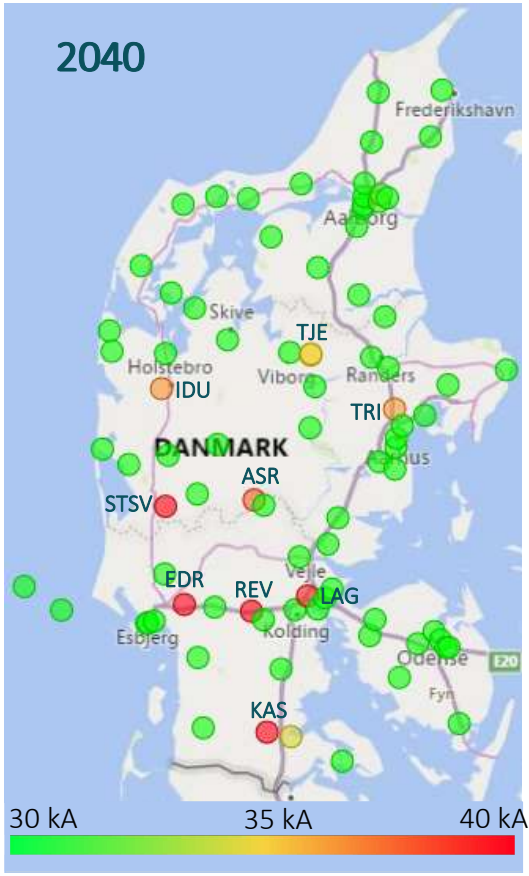
LARGEST SHORT CIRCUIT INFLUENCE IN A SINGLE STATION FROM EACH CATEGORY





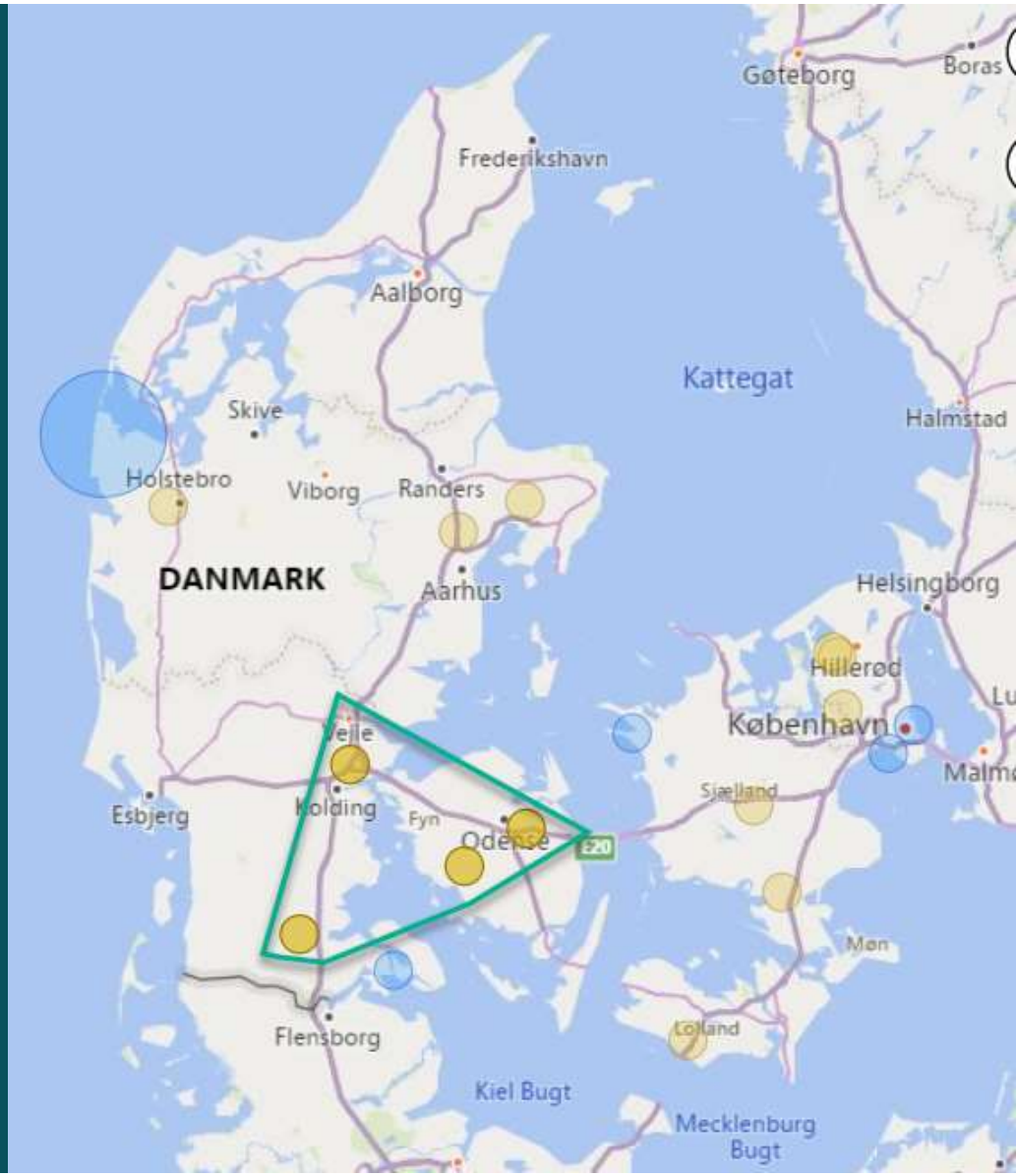
SUMMATION OF THE SENSITIVITY STUDY

- The SC-influence from the sources are locally:
  - Germany has a large influence in south
  - Wind has a large influence in the western part
  - Solar is spread throughout the system
  - Synchronous machines
- IBR results in expansion of the grid
  - Projected production
    - Pipeline exceeding expectations
  - Energy island



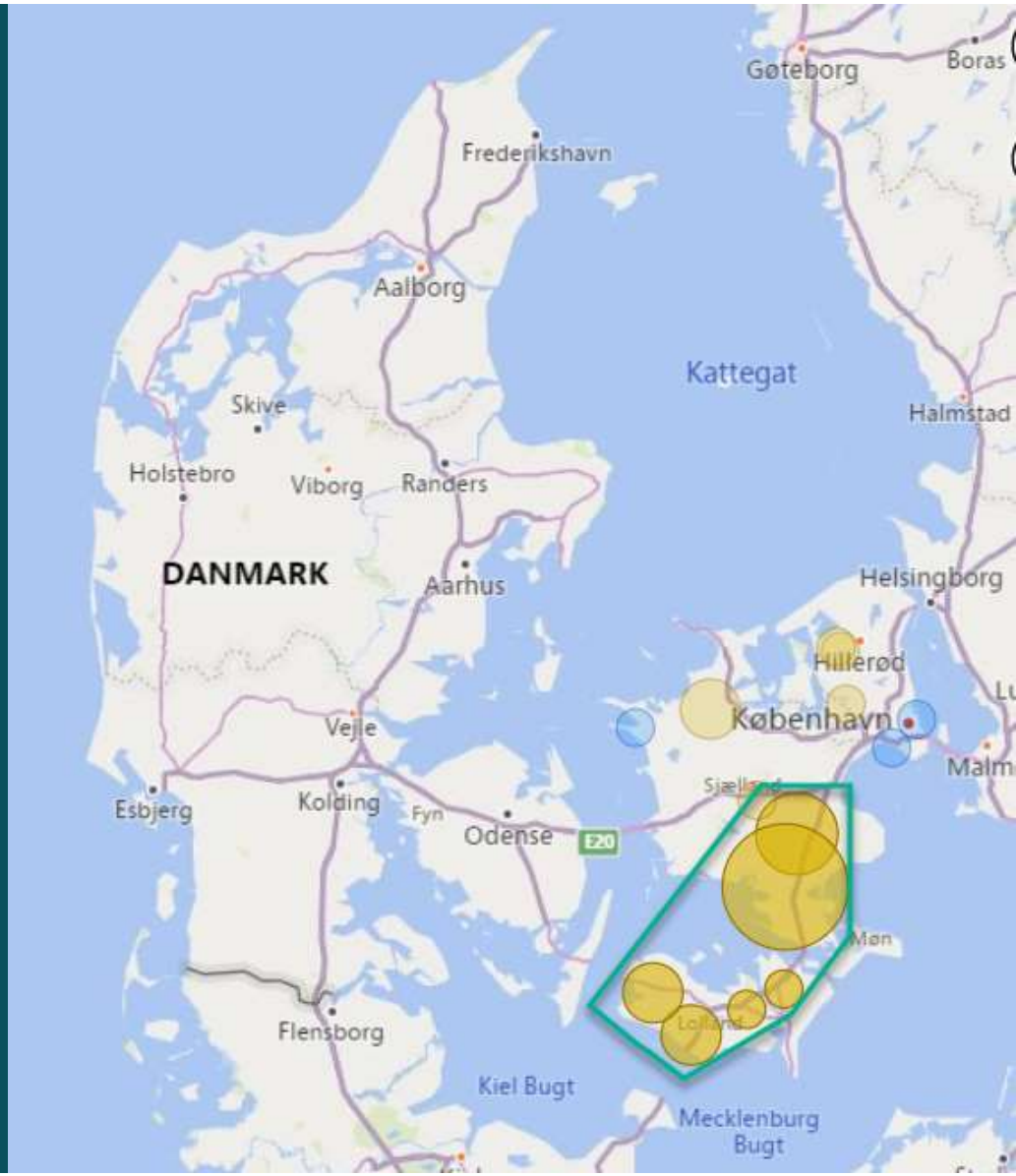
EXAMPLES OF UPCOMING SYSTEM STUDIES

- 4 large solar parks (1,1 GW)
- Voltage control
- Converter interactions
- System stability



EXAMPLES OF UPCOMING SYSTEM STUDIES

- Many large plants (800-1000 MW)
- Low short circuit levels
- Voltage regulation



CONCLUSION & DISCUSSION

- Accurate representation of short circuit contribution from inverter-based systems would become more and more important as the power system is governed by inverters.
- The best way to characterize short circuit characteristics is to use data directly from vendors as a part of grid connection requirement and use the data to build up models in TSO's database. If it is limited to ask data to vendors for some reasons like plants or HVDCs are already under operation, the proposed approach would provide similar results and give an overview of short circuit contributions of vendor specific models.
- the system strength issues are highly important to secure stability of power systems including protection equipment and power quality etc. However, high penetration of inverter-based systems does not always mean that system strength deteriorates since inverter-based systems are able to contribute reactive and active current actively to support voltage and frequency, meaning that inverter-based systems could give positive impact to stabilize voltage and frequency in the collective power systems. Therefore, representation of system strength based on short circuit current calculation alone would not be sufficient.
- The idea would be extended to system level short circuit calculations by considering many practical aspects. Therefore, Energinet currently updates all relevant data in model database based on characteristics obtained by the proposed approach in order to publish more accurate short circuit report annually

Questions