MIGRATE WP1:

Mitigation Approaches to Enable the Transition Towards High Levels of Power Electronic Interfaced Generation

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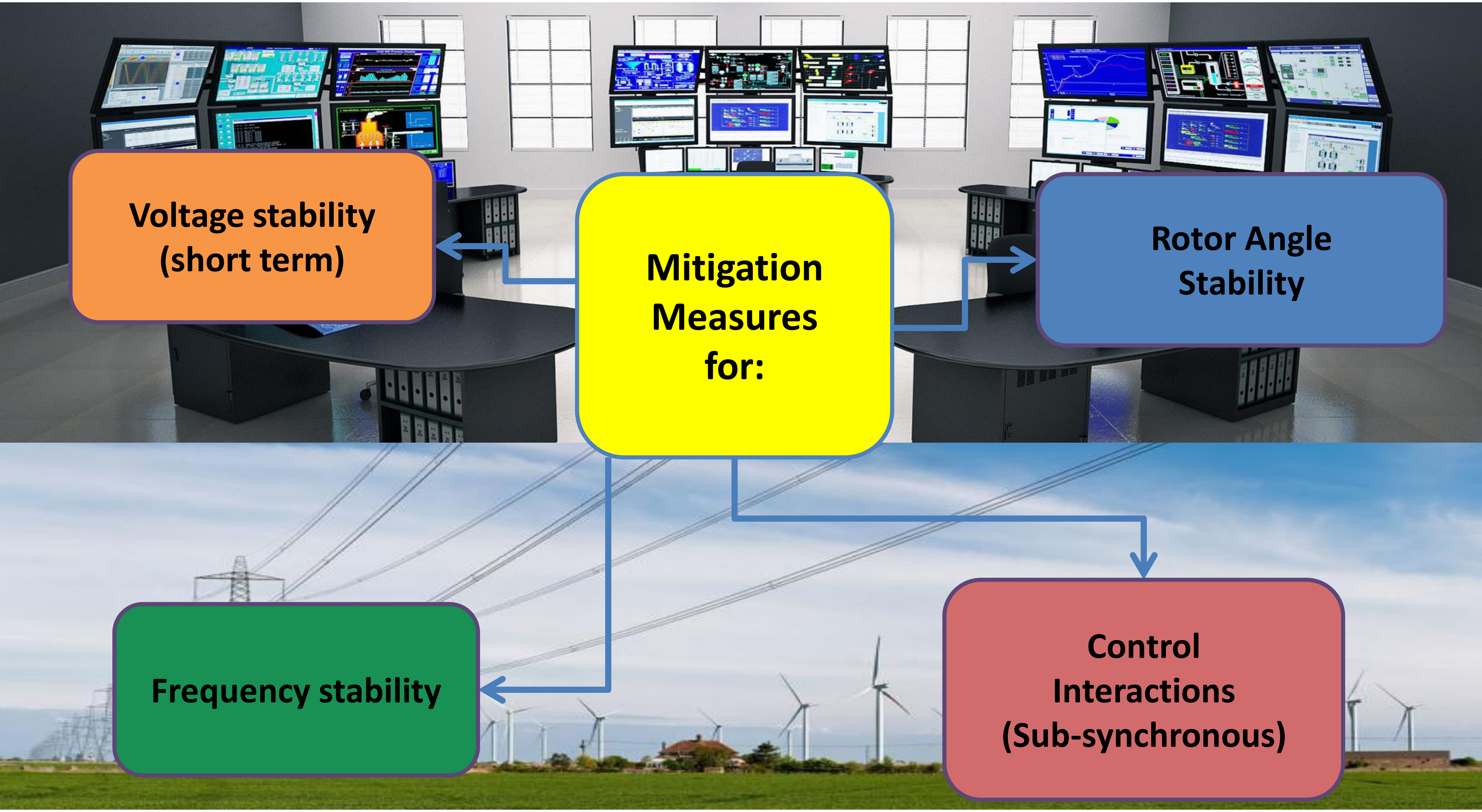
Power system stability mitigation approaches

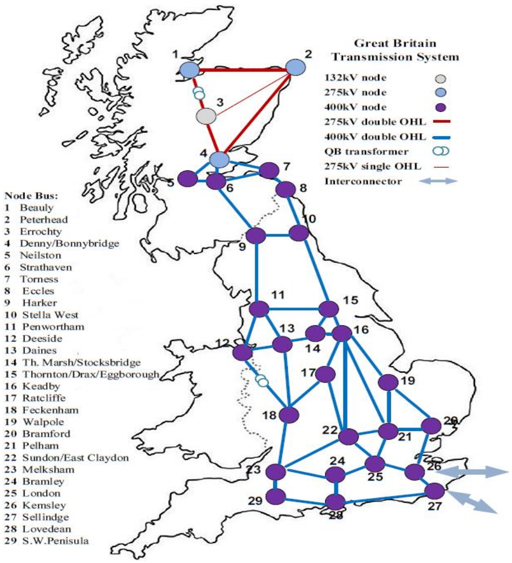


Short term voltage stability: Approach

Short-term Voltage Stability

- **Evaluate mitigation measures** using todays technology in order to enhance short-term voltage stability under high levels of PE-Based generation
- Introduction of **control concepts with grid forming functionality (direct power control)**
- Assessment of the **GB test system with grid-forming control** on wind power plants

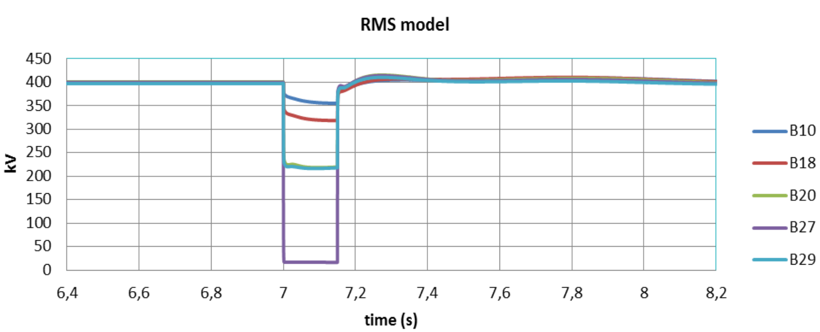
EMT-Model of GG2030 Scenario of GB

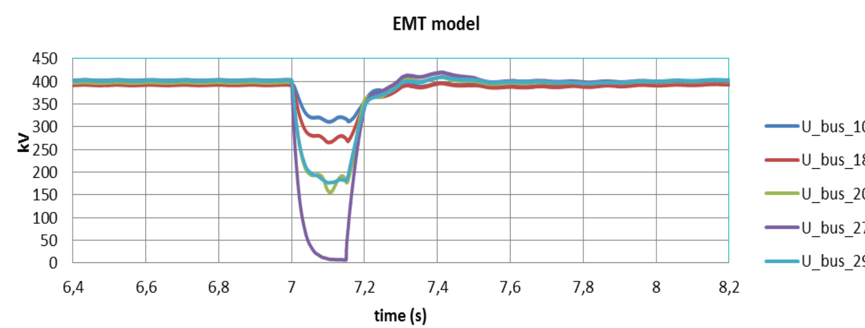


Assumptions of the EMT model

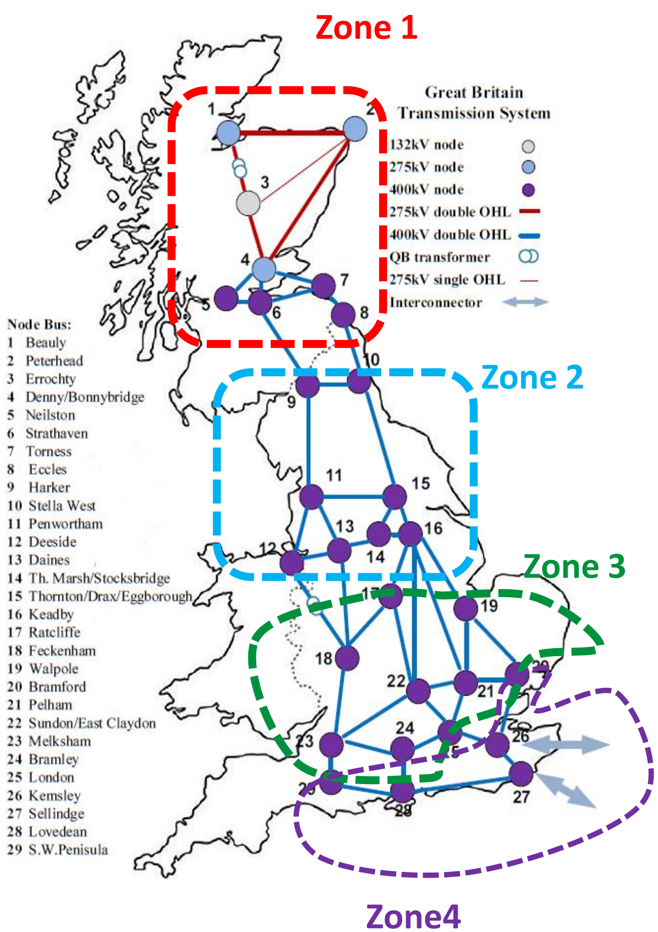
1. 29-Nodes each with Generation (SG,WND) and Load
2. EMT line models (Bergeron, distributed parameters)
3. EMT wind turbine type 3-4 models with IEC 61400 control loops (Manitoba HVDC research center)
4. EMT Synchronous generator models with AVR, GOV and PSS (common PSCAD library models)
3. Starting point the 2030 GG scenario
4. Base scenario of 50% PE-Based Generation

Model validation RMS vs EMT





Short term voltage stability assessment: Defining max penetration of PEIG before the system is unstable



49% PEIG → 57% PEIG → MAX levels of PEIG: 68%

classifications: stable, unstable, marginally stable

Zone 1

Fault Node	1	2	3	4	5	6	7	8
49%	s	s	s	s	s	s	s	s
57%	s	s	s	s	s	s	s	s
68%_A	ms	ms	ms	ms	ms	ms	ms	ms
68%_B	ms	ms	ms	ms	ms	ms	ms	ms

Zone 2

Fault Node	9	10	11	12	13	14	15	16
49%	s	s	s	s	s	s	s	s
57%	s	us	us	s	ms	ms	us	ms
68%_A	ms	ms	ms	ms	ms	ms	ms	ms
68%_B	ms	ms	ms	ms	ms	ms	ms	ms

Zone 3

Fault Node	17	18	19	20	21	22	23	24
49%	s	s	s	s	s	s	s	s
57%	ms	s	s	s	s	s	s	s
68%_A	ms	ms	ms	ms	ms	ms	ms	ms
68%_B	ms	ms	ms	ms	ms	ms	ms	ms

Zone 4

Fault Node	25	26	27	28	29
49%	s	s	s	s	s
57%	s	s	s	s	s
68%_A	ms	ms	ms	ms	s
68%_B	ms	ms	ms	ms	ms

Short term voltage stability assessment: Main findings

- For the given PSCAD models, short term voltage stability cannot be guaranteed above **68% of instantaneous power electronic based generation** defined in terms of installed generation capacity in MVA.

- Above this PE level, either:
  1. remaining generators are loosing their synchronization during grid faults (reduced CCT due to less inertia)
  2. wind turbines are demonstrating significant control interactions observable mainly in the sub-synchronous zone

Short term voltage stability assessment: Enabling high levels of PE in the grid

What can we do then?

1. **Apply short term solutions:**

   - synchronous condensers in the grid to keep minimum level of MVA needed
   - increase the participation of RES in the grid support functions
   - increase the damping of SSCI

2. **Apply long terms solutions (Grid-forming inverters at RES):**

   - capability to operate at extremely weak connection points (SCR below 1)
   - provide inherent inertia emulation without a need to measure frequency
   - provision of fault currents from RES (reactive/active current injection during faults)
   - compatibility with grid-following RES
   - negative sequence current sink

Short term voltage stability assessment: Enabling high levels of PE in the grid

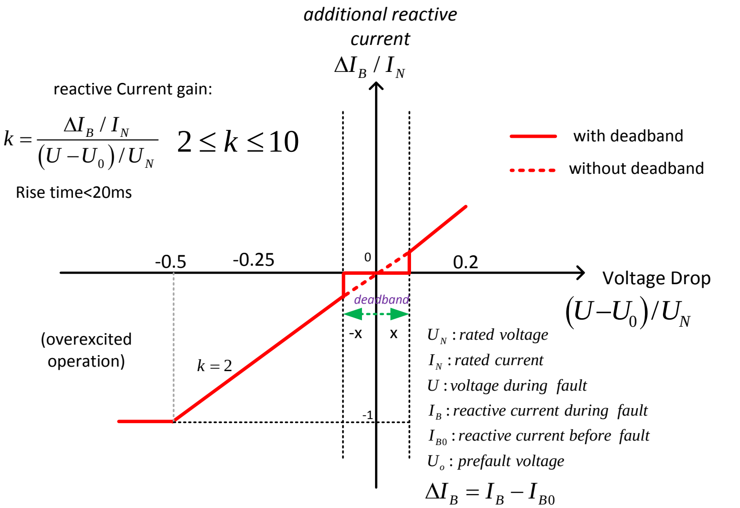
Short term mitigation measures:

How much can we improve the short term voltage stability using PEIG technology as it is in the market today?

Methodology:

Parametric sensitivity analysis of key Grid Code related control parameters:

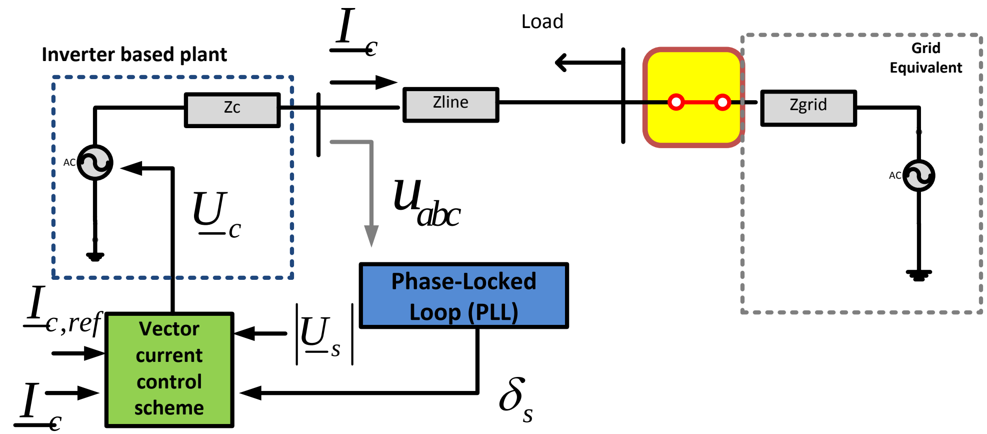
- Reactive current boosting gain k
- Current limitation strategy (active power versus reactive power priority) during grid faults
- Choice of the Deadband for the provision of fast reactive current
- I_{max} of wind turbines used for reactive current injection



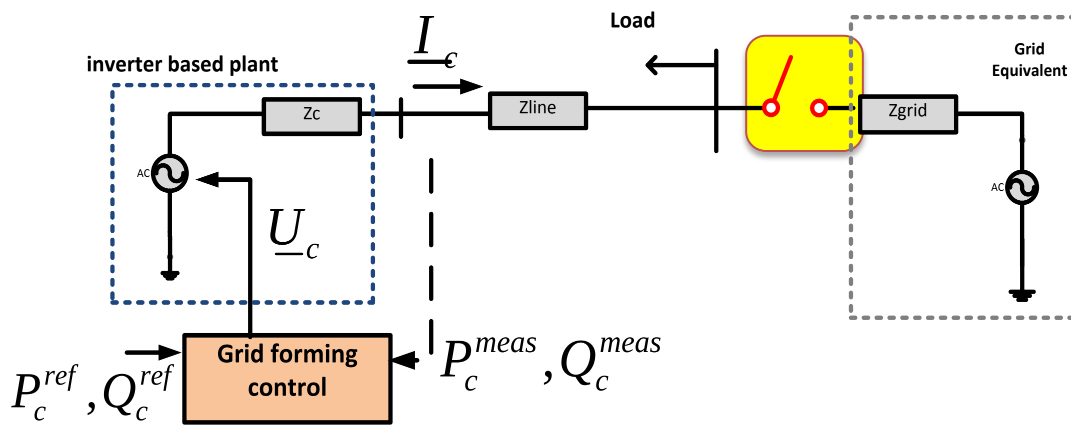
Short term voltage stability assessment: Enabling high levels of PE in the grid

Grid Following **vs** Grid Forming

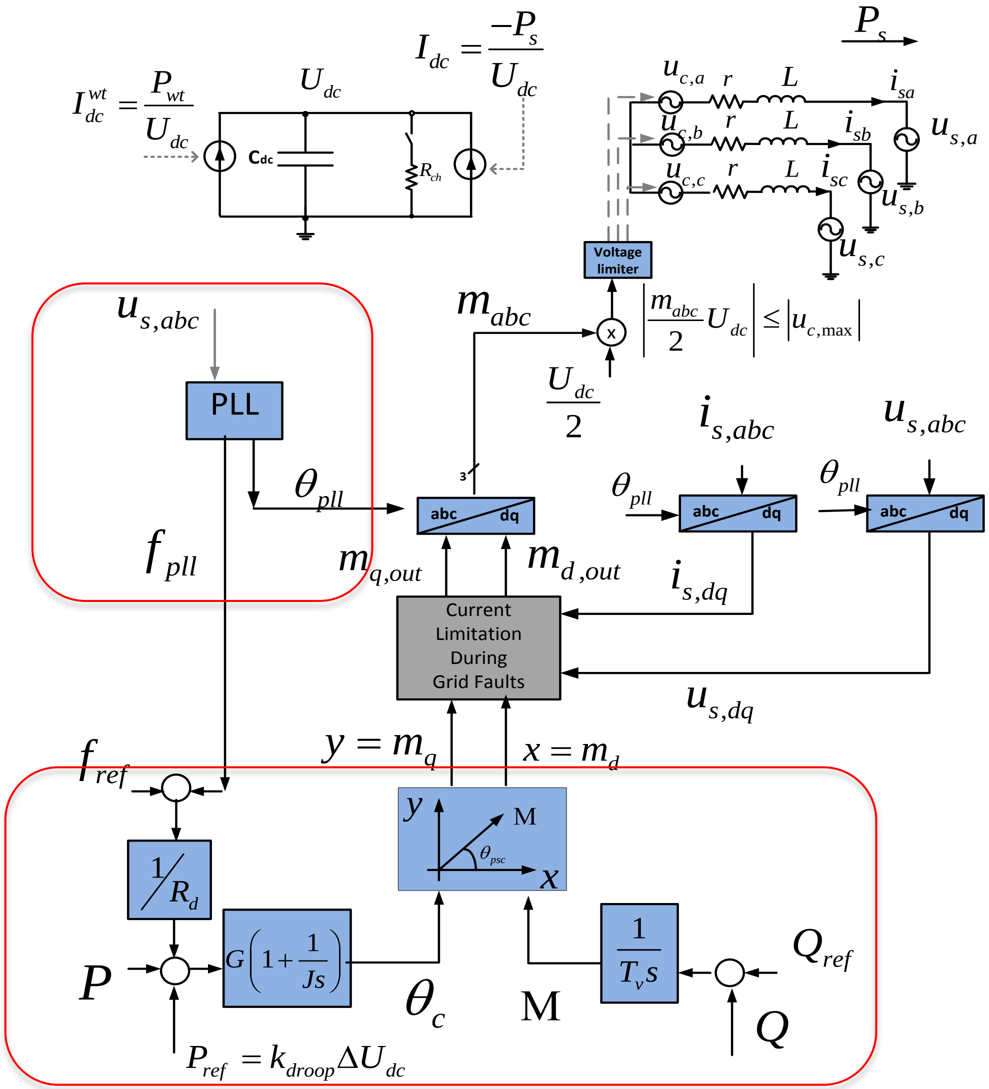
Generic illustration of a **Grid following** VSC unit:

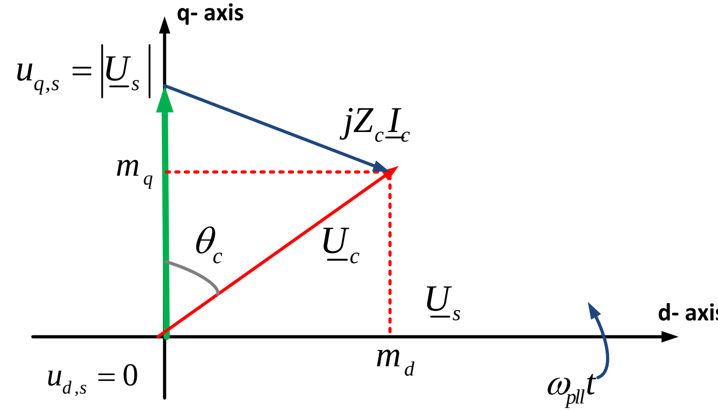


Grid forming Control for RES



Short term voltage stability assessment: Enabling high levels of PE in the grid with DPC





- DPC enables operation with very low SCR (below 1)
- It provides FRT capability in a wide range of SCR
- it enables inherent active power response to grid frequency variations
- It is compatible with grid following control schemes
- It provides grid synchronisation in cases of 100% PE systems

Short term voltage stability: summary

- The Maximum level of instantaneous power electronic based generation is identified with short-term voltage stability as boundary condition using EMT type simulations.
- For the given PSCAD models, and given assumptions, the GB benchmark model is marginal stable with up to **aprox. 68%** instantaneous power electronic based generation defined in terms of installed capacity in MVA.
- Up to 68% PEIG, the increase of reactive current boosting capability during grid faults from PEIG could support voltage stability.
- Using grid forming control schemes in RES has improved local control interaction problems and enables higher levels of PEIG

Frequency performance in containment period

Goal: Inertia emulation control of wind power plants to provide fast frequency response (FFR) to help the system to stay within acceptable limits for ROCOF and Nadir when integrating more power electronic interfaced generation (PEIG).

APPROACH

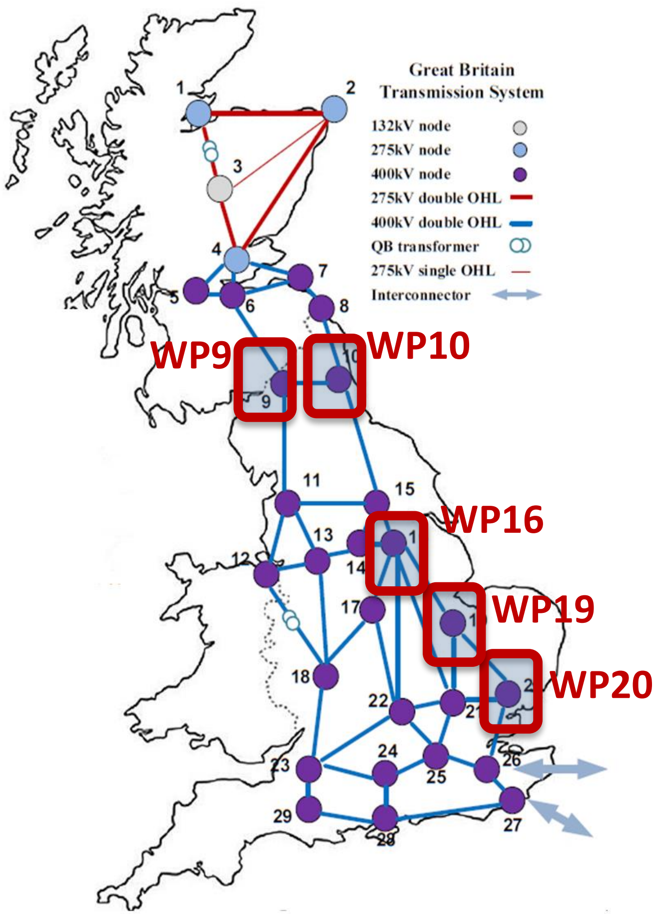
Reference: Values of ROCOF/Nadir for increased penetration of PEIG, when wind power plants operate without virtual inertia (only synchronous generation cope with imbalances).

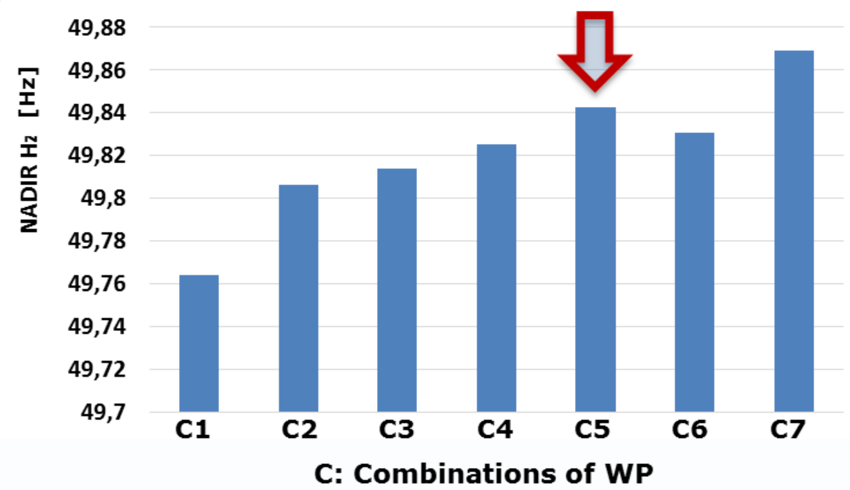
Part 1 –Re-tuning of existing Inertia Emulation (IE) control of wind turbine

Part 2 –Modifications (evolution) of existing inertia control of wind turbine

Ongoing work: Use of grid forming control to enhance ROCOF

Frequency stability: Best set of wind power plants with active Inertia emulation



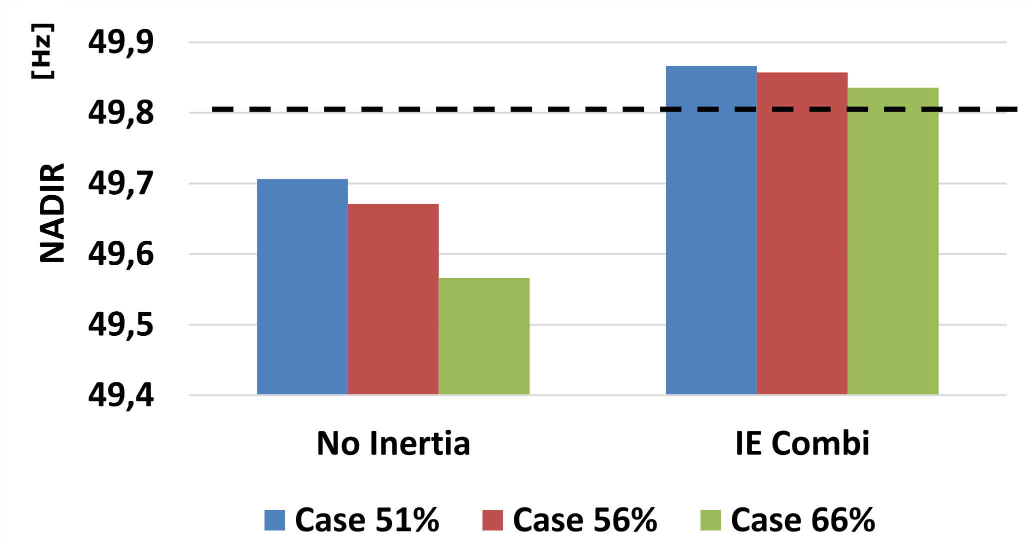


- C1: WP10, WP20
- C2: WP10, WP16, WP20
- C3: WP10, WP19, WP20
- C4: WP10, WP16, WP19, WP20
- **C5: WP9, WP10, WP16, WP19, WP20**
- C6: WP10, WP14, WP16, WP19, WP20
- C7: All WP with active IE

- **GB system, case with 66% of penetration**
- **Most critical fault:** Outage of biggest generation (G15), 4110 MW lost
- **Available reserve:** 6000 MW

Frequency stability: Best set of Wind power Plants with active Inertia emulation

Maximum penetration level reached (66%)



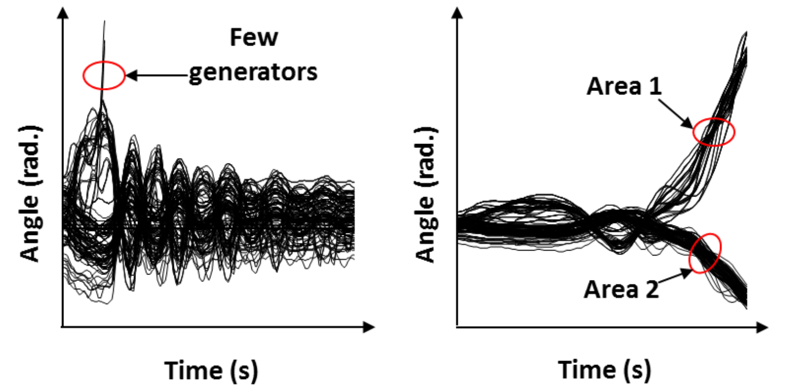
- According to ENTSO-E evaluation criteria, frequency deviation, NADIR, considered between 49.8 Hz and 50.2 Hz during common contingencies.

- Maximum penetration is up to 66% for GG2030 scenario.

Transient Stability: Effect of LVRT control Settings

Goal:

1. Identifying best values **of WT voltage control** that can help to increase wind penetration level.
2. Modify **existing wind turbine controls** to improve large-disturbance rotor angle stability.



APPROACH

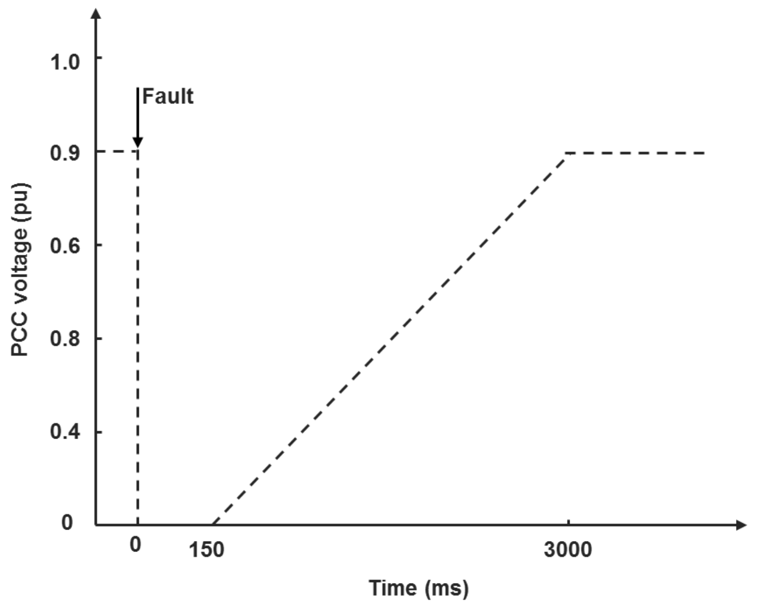
- Sensitivity analysis in order to find best parameters
- re-tuning of voltage control of wind turbine.

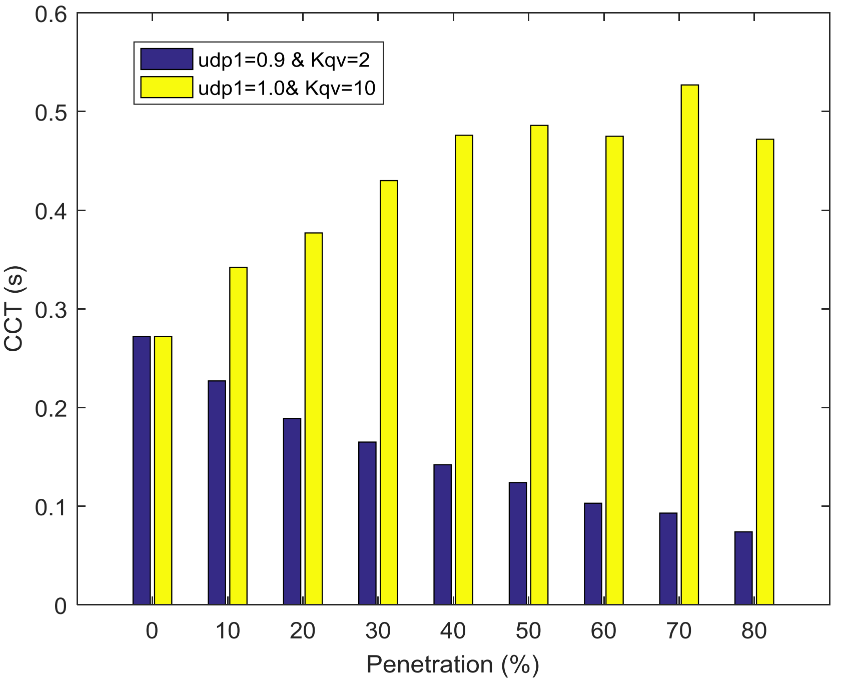
Assumptions

- Synchronous generator controls (speed and voltage) are not modified.
- Inter-area power exchange is constant.
- Distribution system is modelled as constant P power.
- Only bulk wind power plants are connected to transmission network.

Transient Stability: Effect of LVRT control Settings

- When the penetration level is larger than 20%, CCT(189 ms) is below 200 ms,
- To increase penetration level, **use best LVRT parameters** (k-factor, dead-band).,



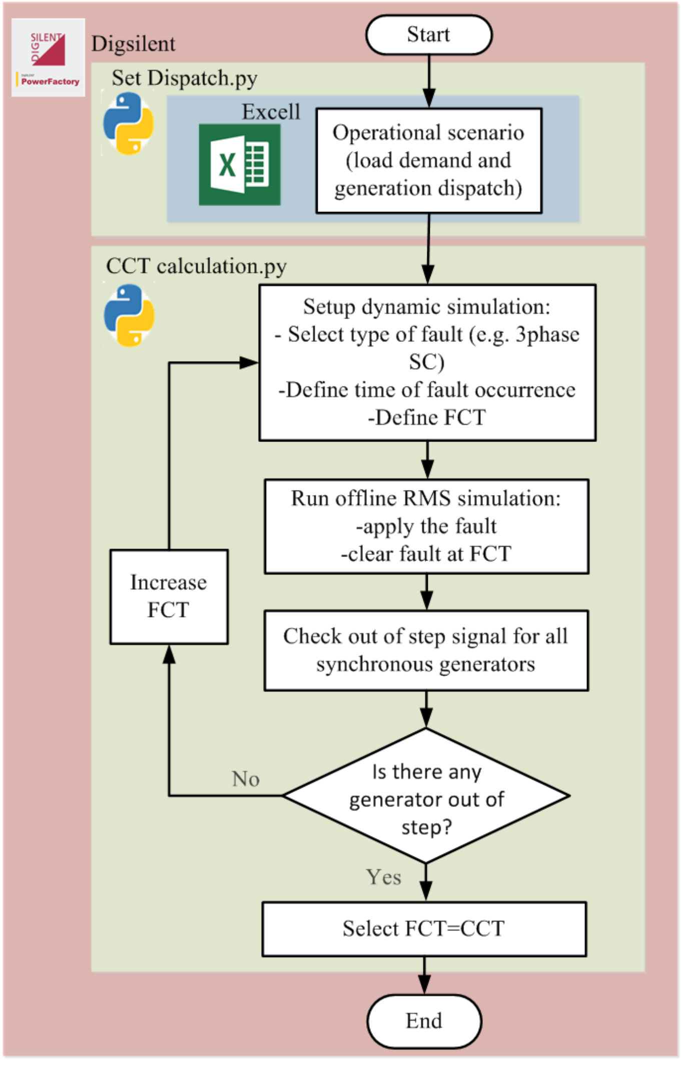


Increasing transient stability margin: Effect of LVRT control Settings

- Systematic approach based on iterative procedures to have best selection of the LVRT parameters

- Find the set of LVRT parameters for type-4 wind turbines that enhances transient stability margin.

- Application of sensitivity analysis on GB system



Summary

- Definition of the max levels of PEIG on the reduced GB test system that is critical for voltage (68%) and frequency stability (66%)
- Mitigation measures to enhance voltage, frequency, transient stability and control interactions using todays technology
- Assessment of grid forming control schemes and proof of concept for improving system stability (voltage)

Thank you!

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