Grid Forming Control for Stable Power Systems with up to 100 % Inverter Based Generation: A Paradigm Scenario Using the IEEE 118-Bus System

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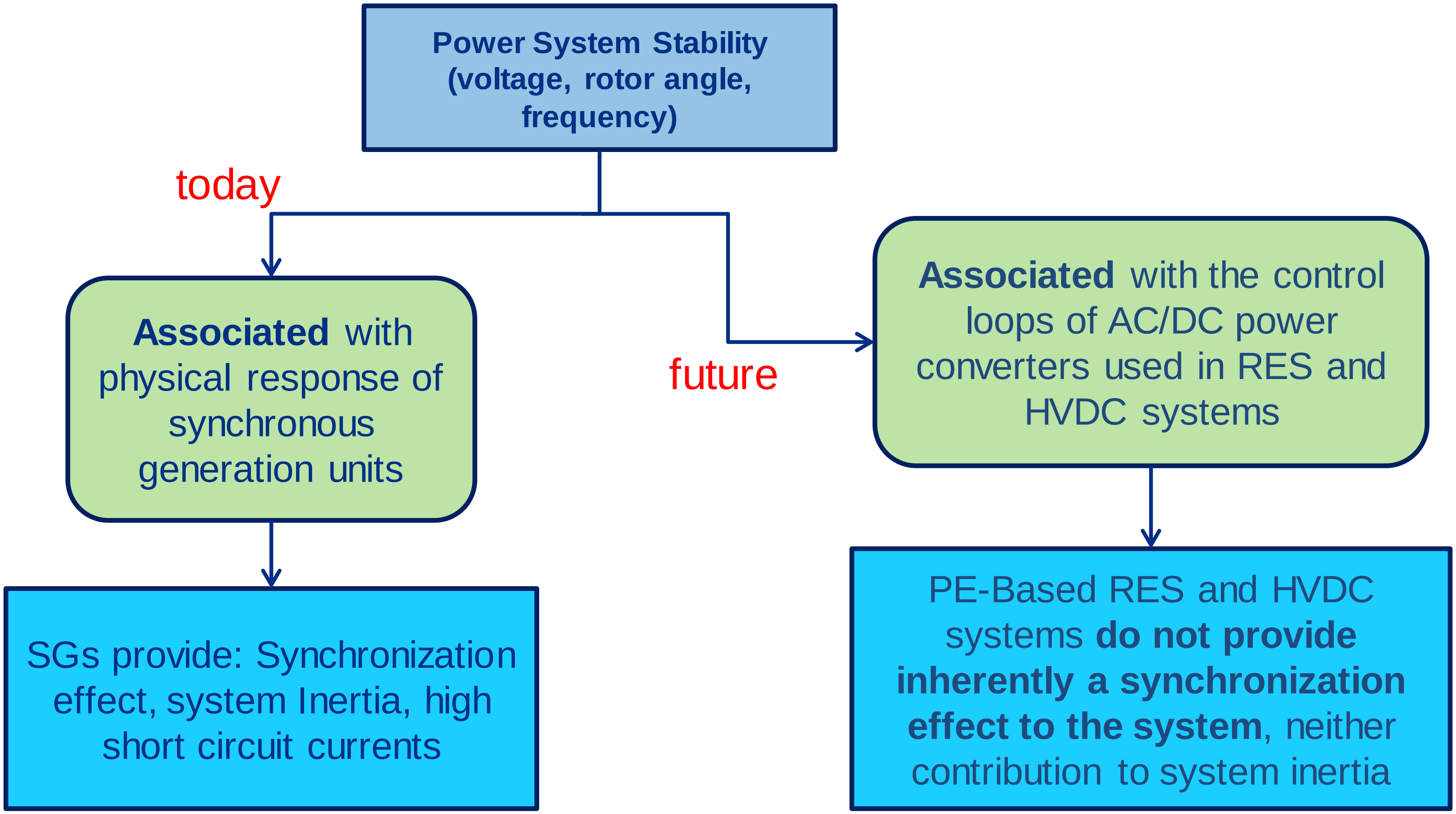
Power System Stability with High Level of Power Electronic Interfaced Generation (PEIG)



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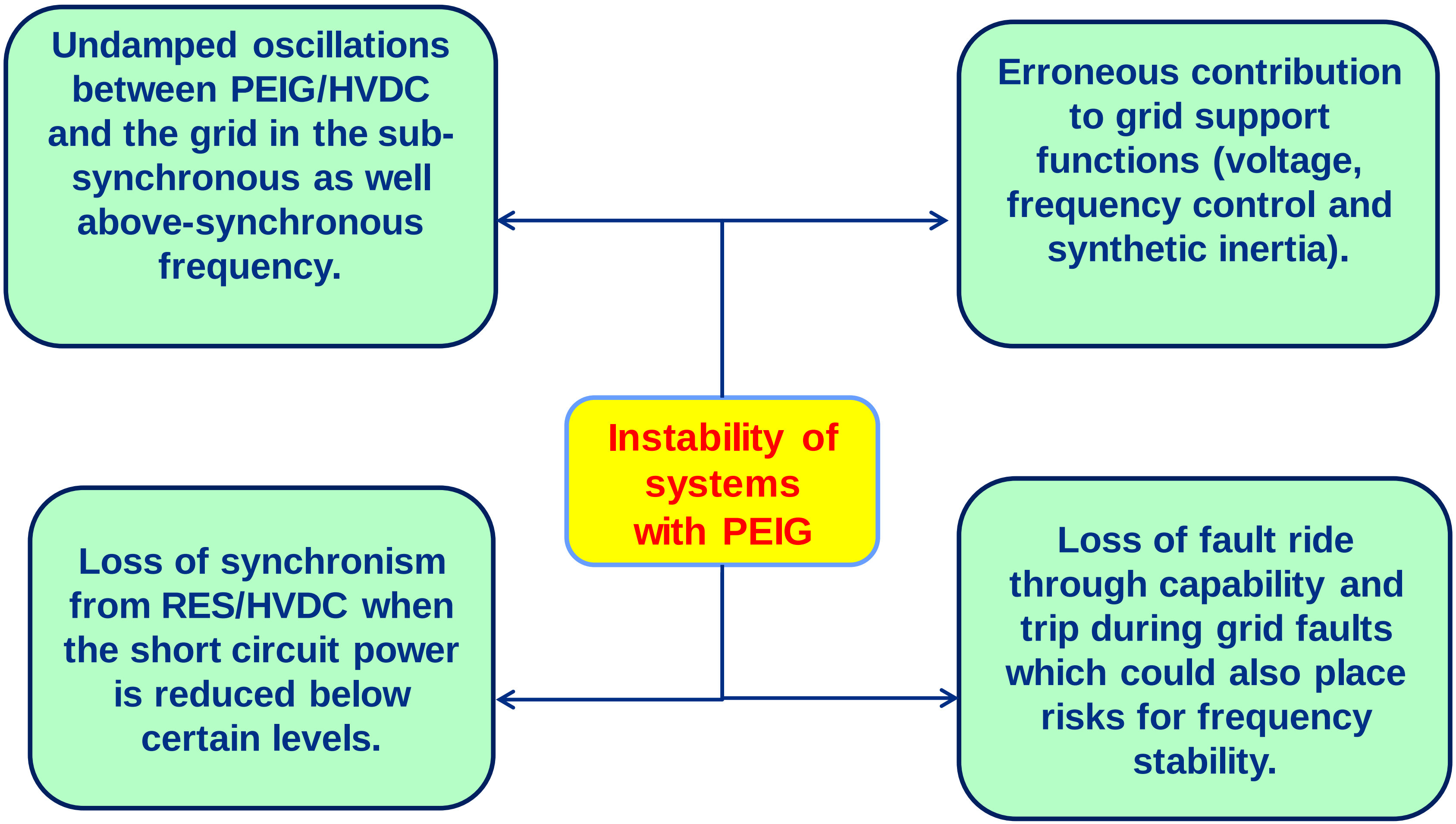
PEIG Main Characteristics?

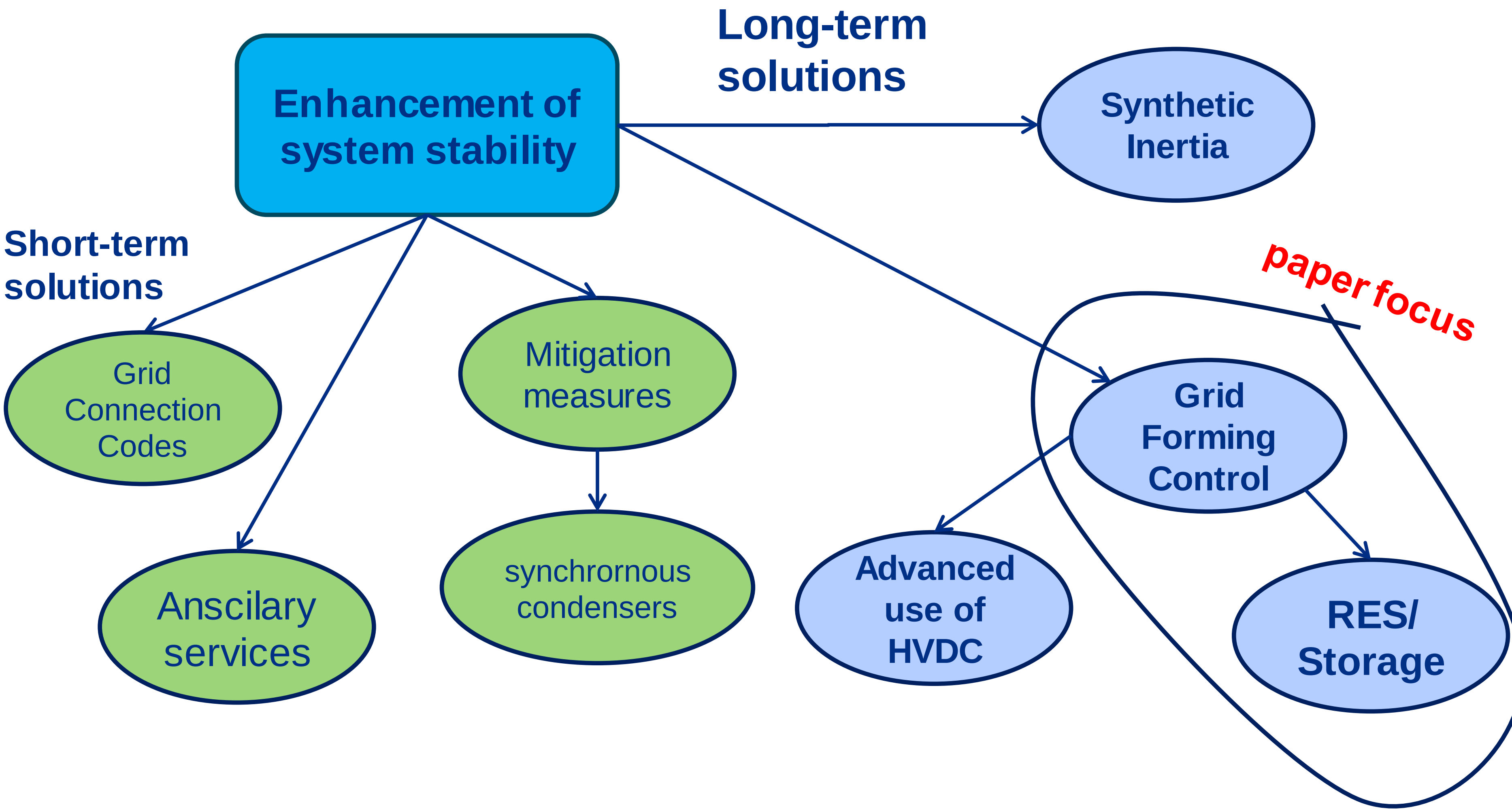
Power Electronic Interfaced Generators

- Need a minimum short circuit power level in order to properly synchronise to the grid (during normal and fault conditions)
- Highly controllable non-linear modules which interact dynamically with the grid resonance in the sub- and super-synchronous region
- The prime mover is generally decoupled from the grid through the power electronic interfaces – Possible to release stored energy via control loops
- Exhibit limited overloading capacity and fault current injection – highly controllable in the positive and negative sequence

Instability of Power Electronic Dominated Grids



Realising a PE-Dominated Power System

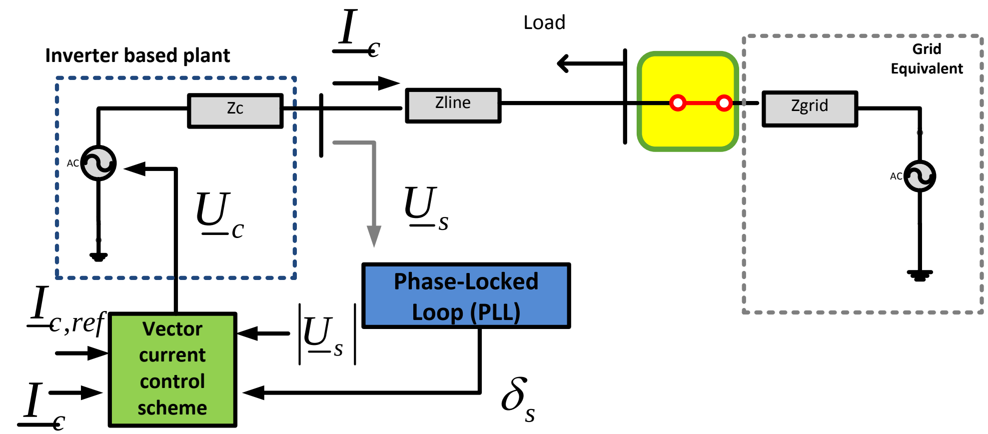


Grid Forming Control Concept

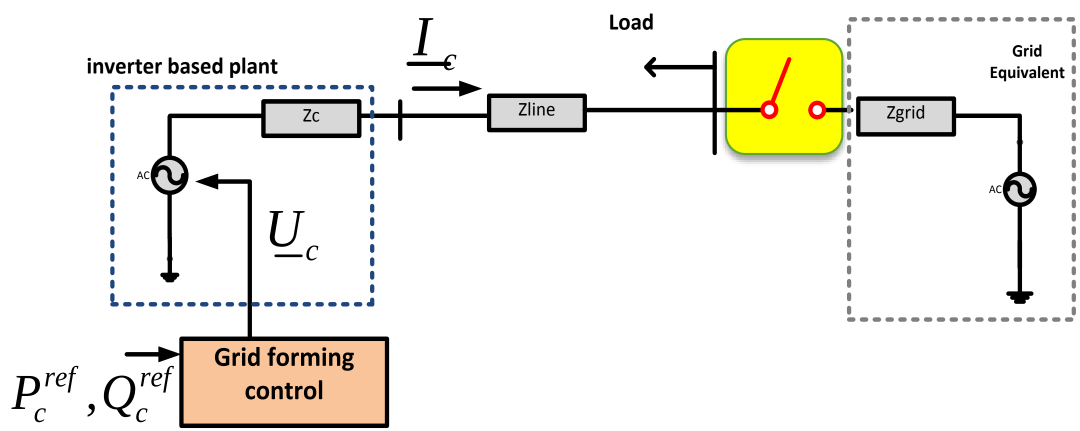
Generic illustration of a **Grid following** VSC unit:

Sources of instability

1. PLL
2. AC current controller



Grid forming Control for power systems with up to 100% PE based generation units



Grid Forming Control Schemes

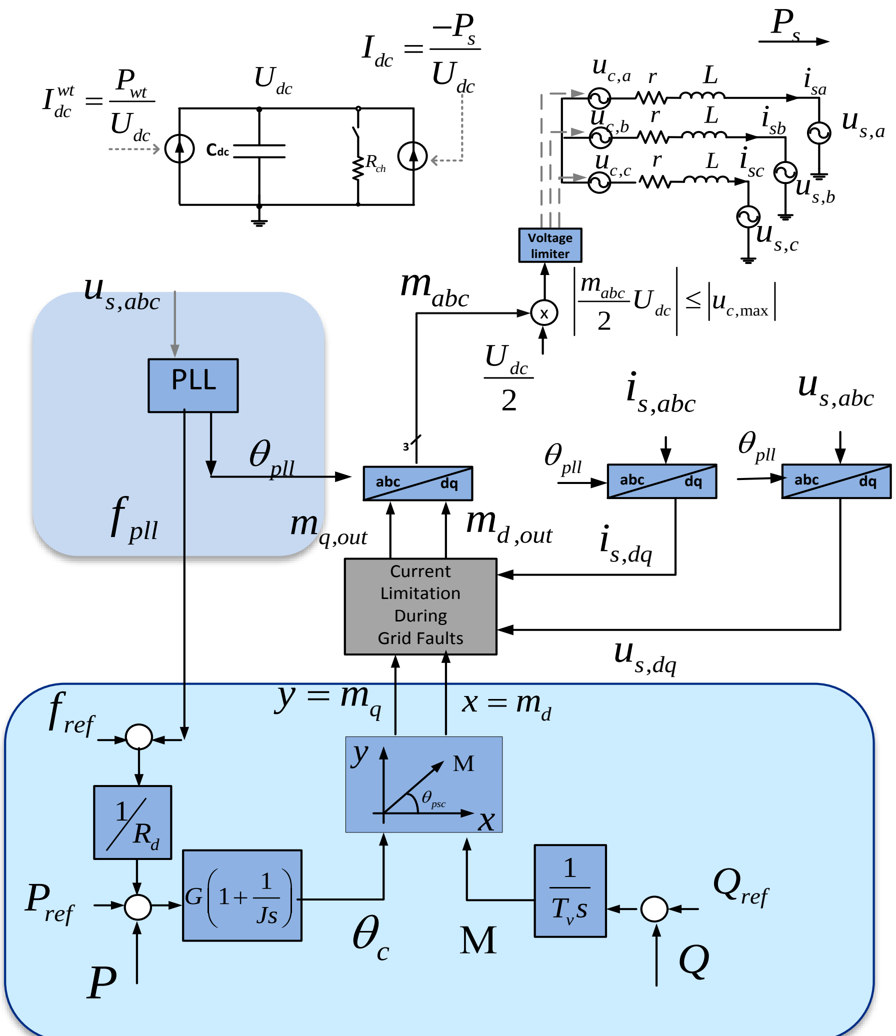
Available grid forming control concepts:

- **Virtual Synchronous machine (VSM)**
  - Mimics the swing equation of the synchronous generator
  - Usually does not use a PLL during normal operation
  - Provides inherent inertia without frequency measurements
  - Fault response not well studied in the literature

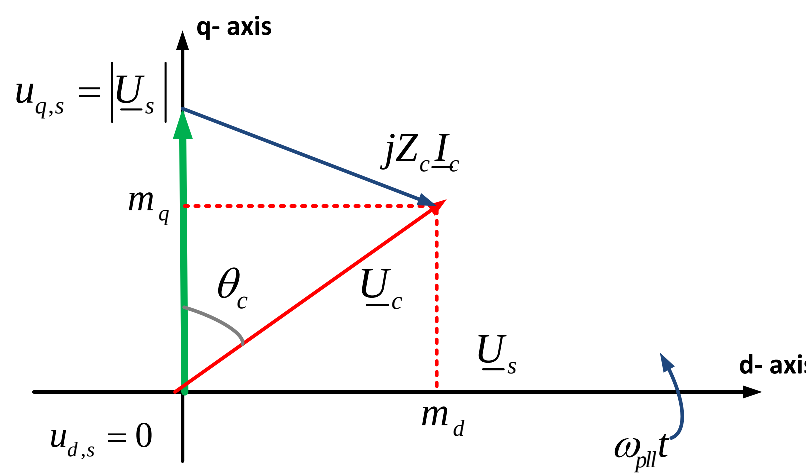
- **Power Synchronization Control (PSC)**
  - Does not use a PLL for normal operation but requires a back-up PLL during faults in order to limit the current
  - Demonstrate proven response for very weak grids
  - During grid faults, shifts to current control with PLL
  - Provides inherent inertia through the power synchronization loop

- **Direct power control (DPC)**
  - It controls the voltage and angle of the converter
  - very simple in its use and implementation
  - used widely for stand alone applications and UPS systems

Enhanced DPC

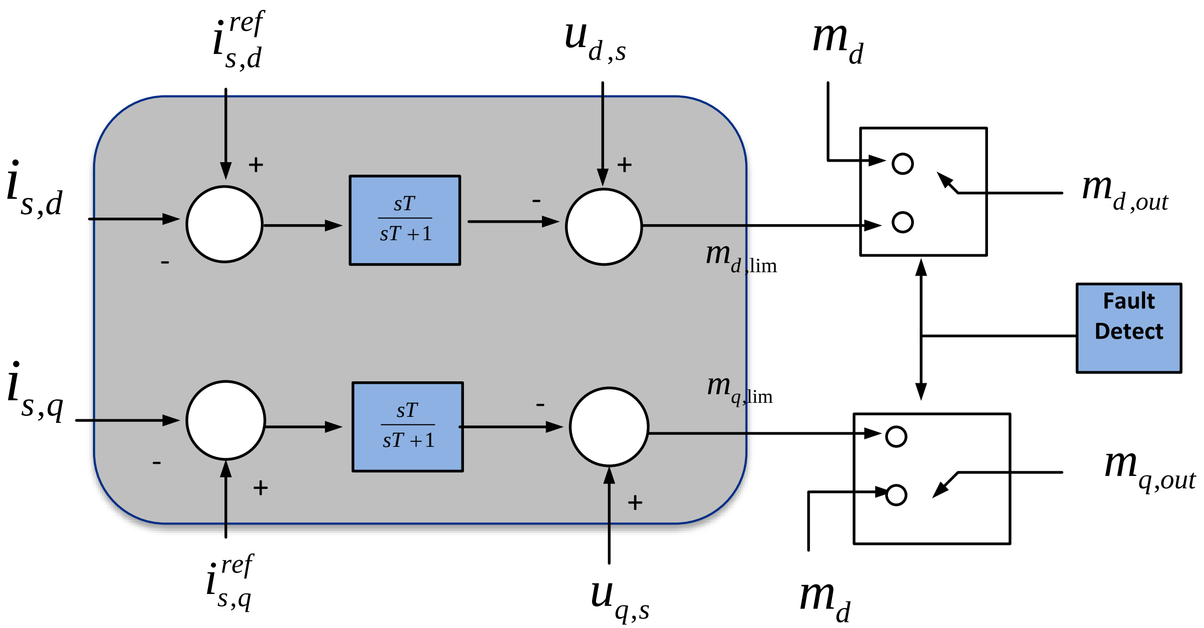


- The VSC unit during normal operation regulates the active and the reactive power via controlling its internal voltage angle and amplitude.
- The output current is the result of voltage drop across the phase reactor.
- During faults, a current controller is used to limit the current.



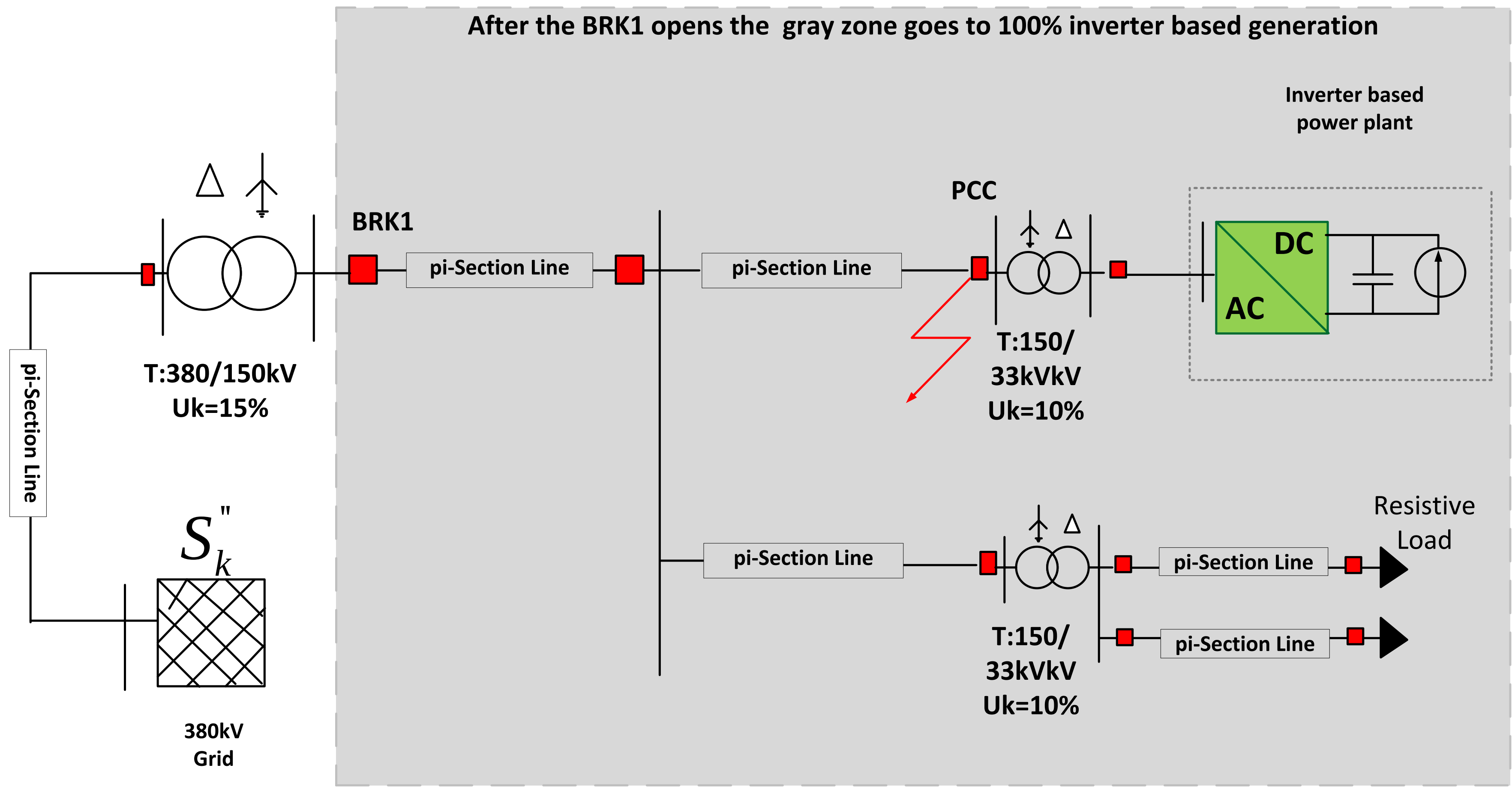
Enhanced DPC

Control block which enables fault current limitation



During grid faults, the converter shifts its operation to current limiting mode.
No need to activate and deactivate the PLL
No angle jumps

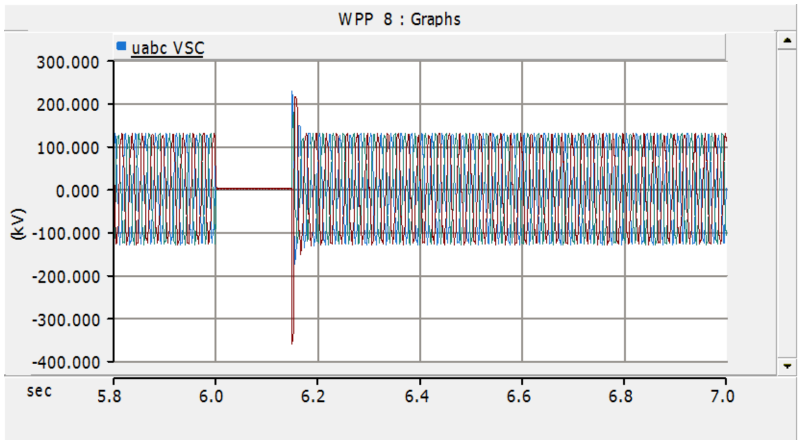
Simple Test System- Proof of Concept

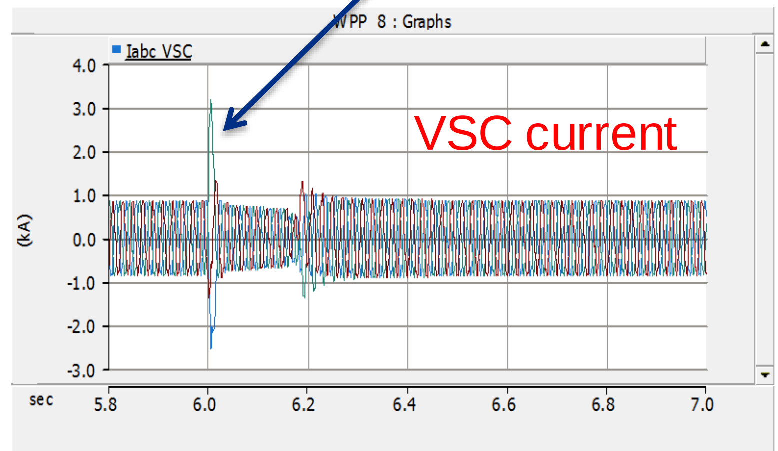


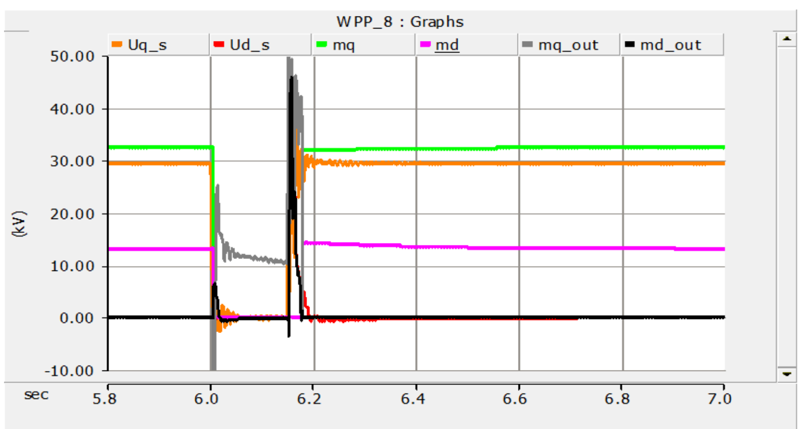
Simple Test System- Proof of Concept

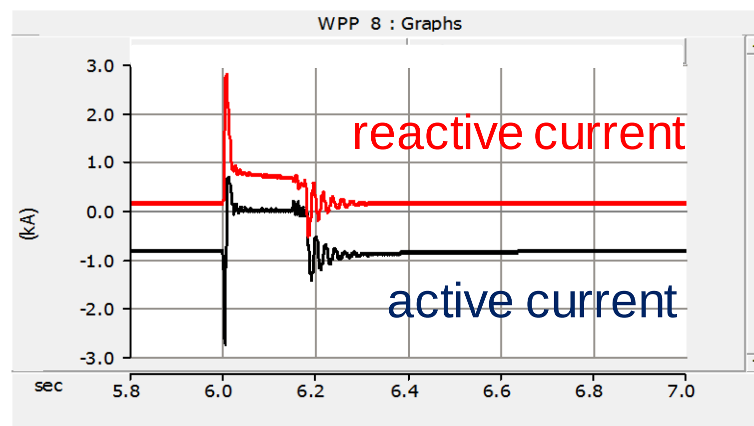
VSC response for a 150s fault (at t=6s)

Spike due to detection delay









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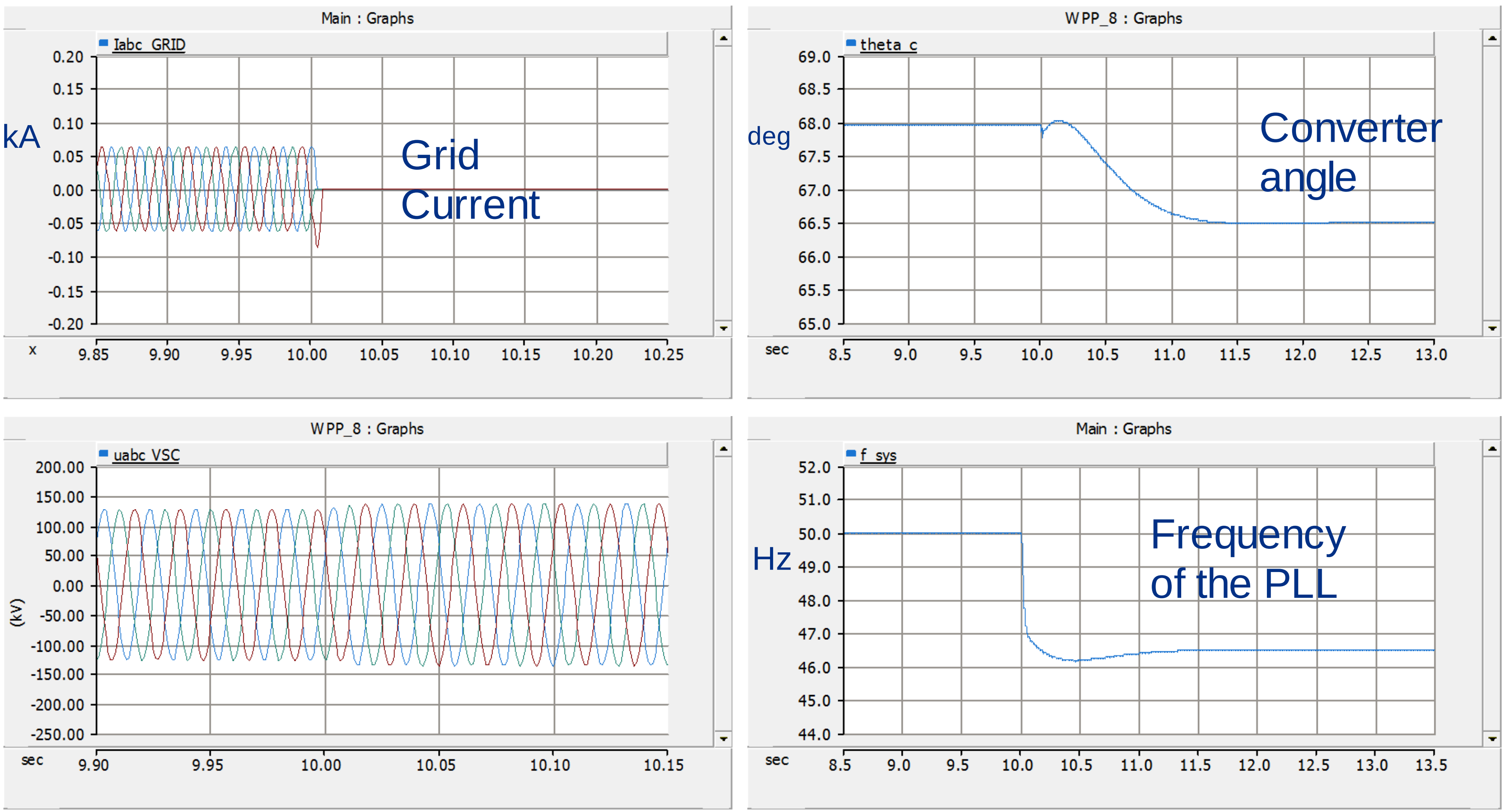
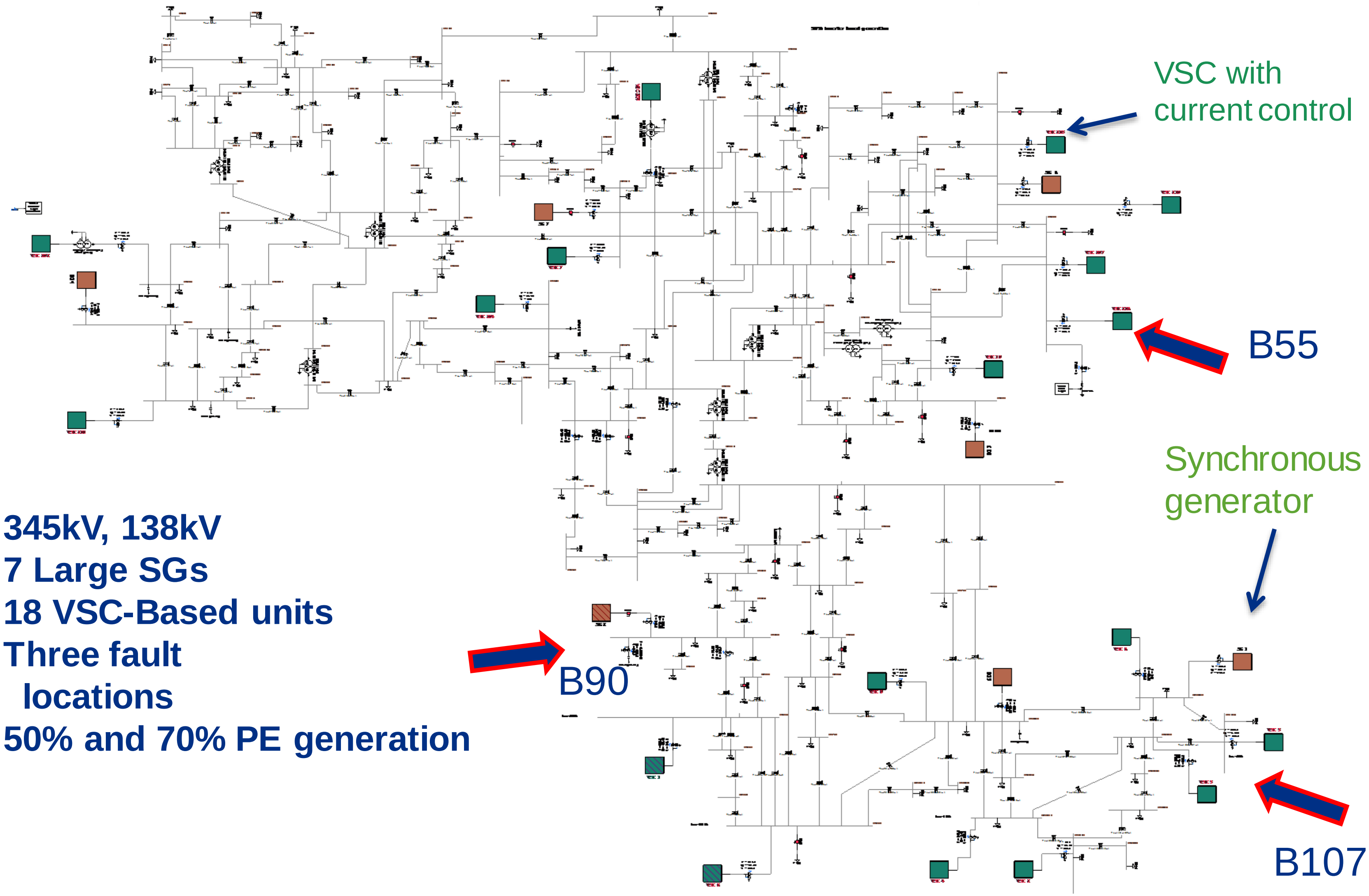
Simple Test System- Proof of Concept

VSC response for **islanding**



Voltage Stability Assessment – IEEE 118-Bus

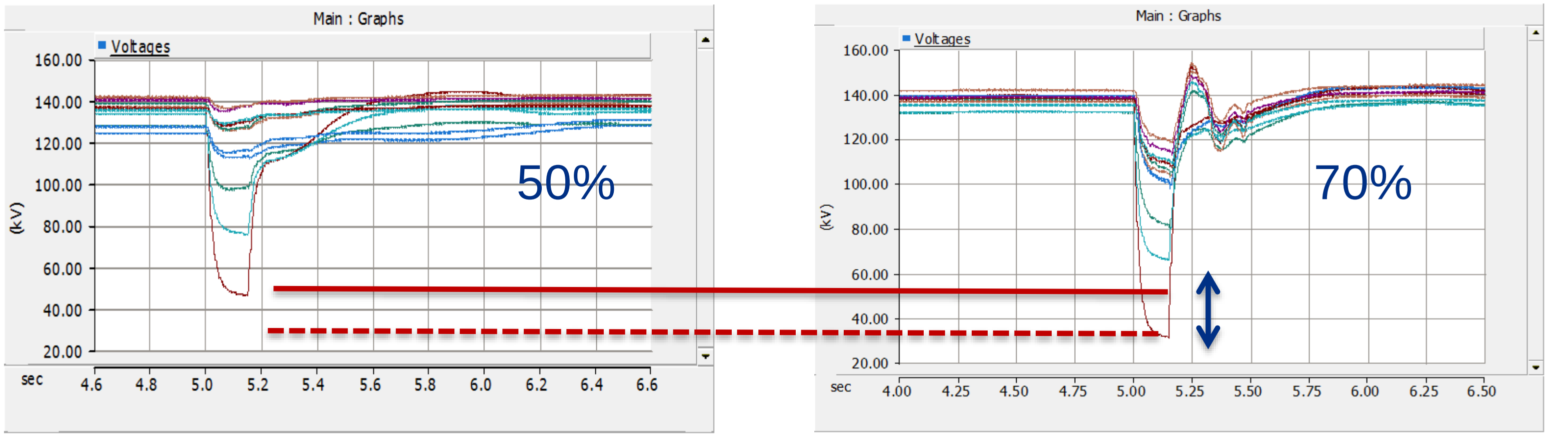


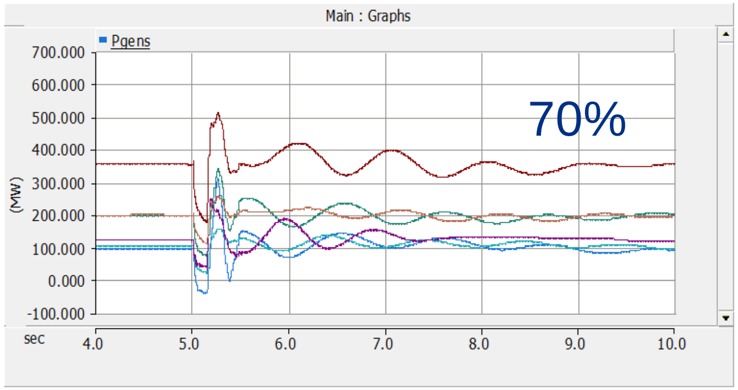
- **345kV, 138kV**
- **7 Large SGs**
- **18 VSC-Based units**
- **Three fault locations**
- **50% and 70% PE generation**

Voltage Stability Assessment – IEEE 118-Bus

>> 150ms fault at **B55** – Voltage and angle response at the HV level

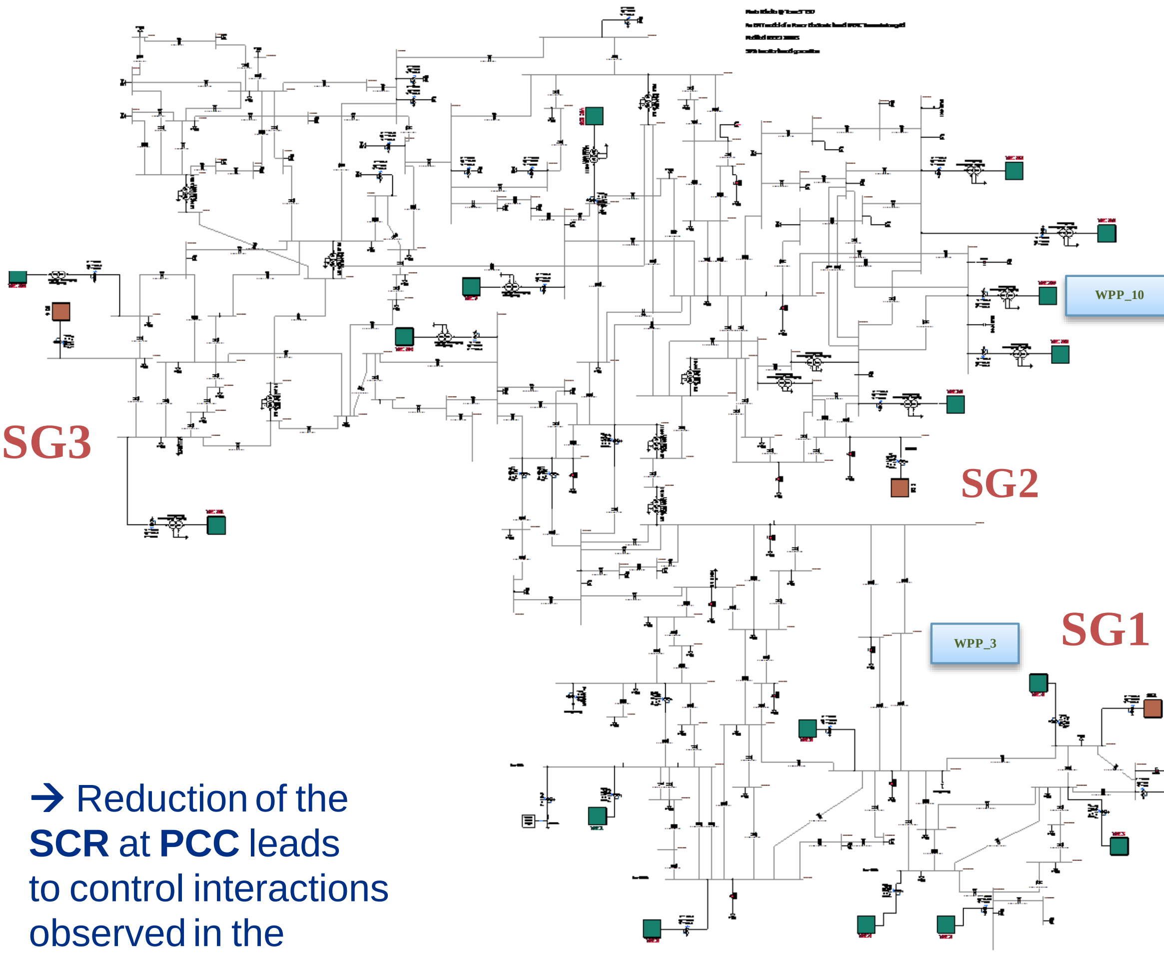
The simulations are for the case that the VSCs apply conventional control

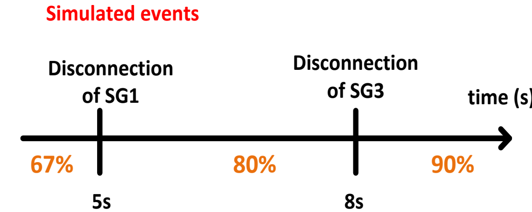


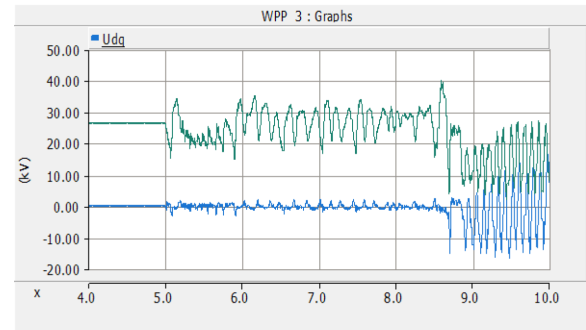


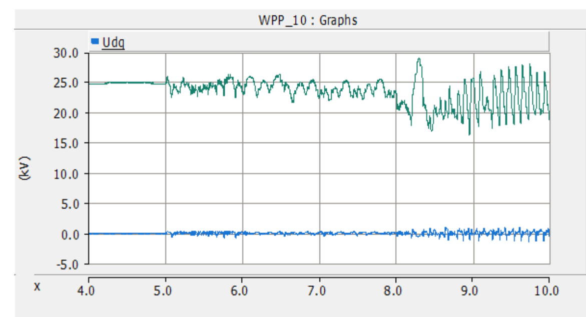
- In the 70% case, the voltage drops are bigger and the effect a wider area.

Effect of high levels of PE – Above 70%









→ Reduction of the **SCR** at **PCC** leads to control interactions observed in the sub-synchronous range

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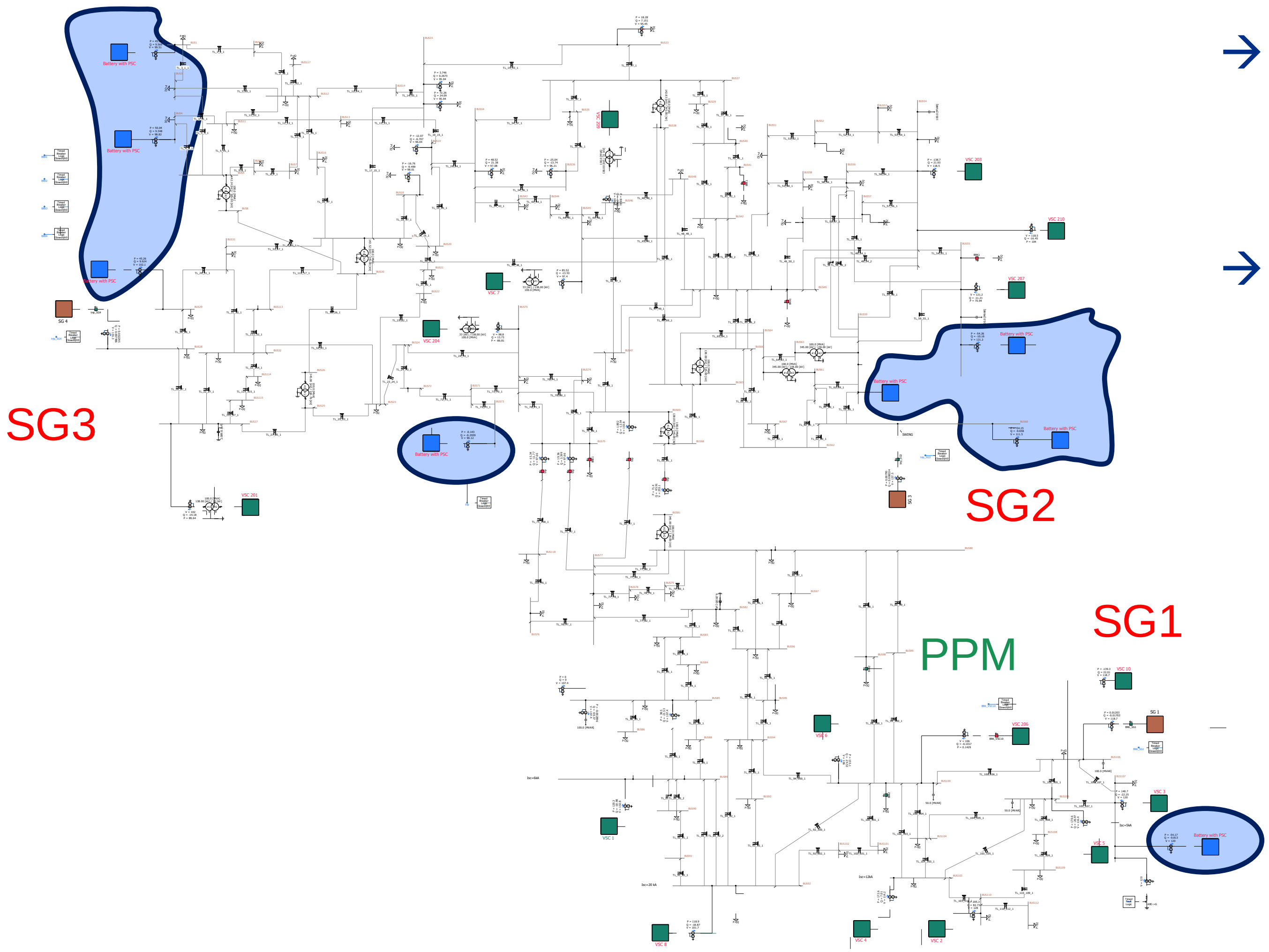
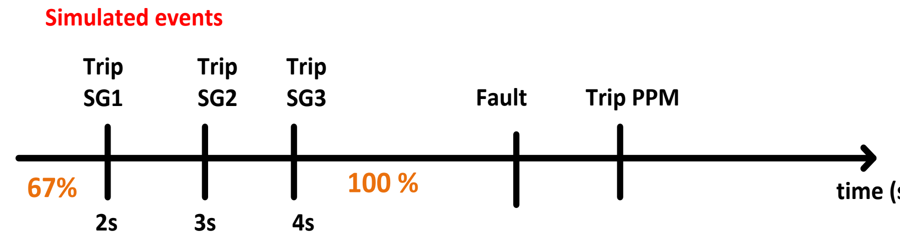
Grid forming to mitigate instability



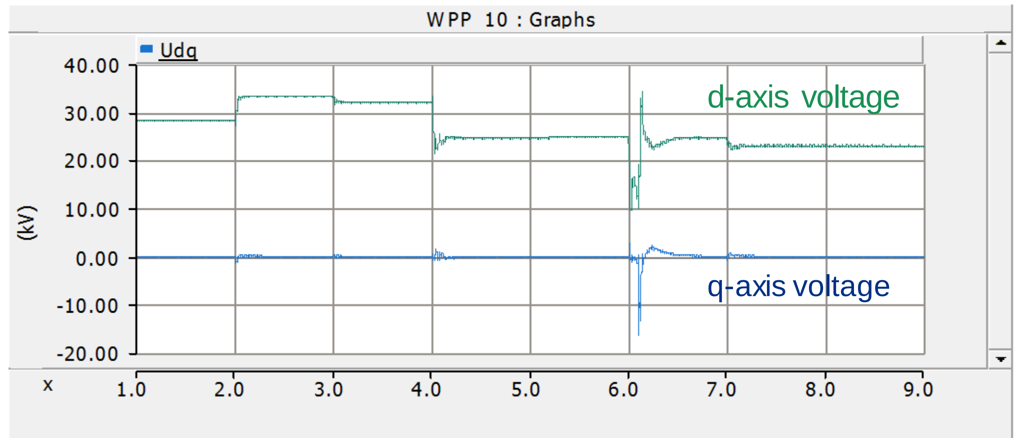
→ part of the unstable PPMs are replaced by PPMs using grid forming control.

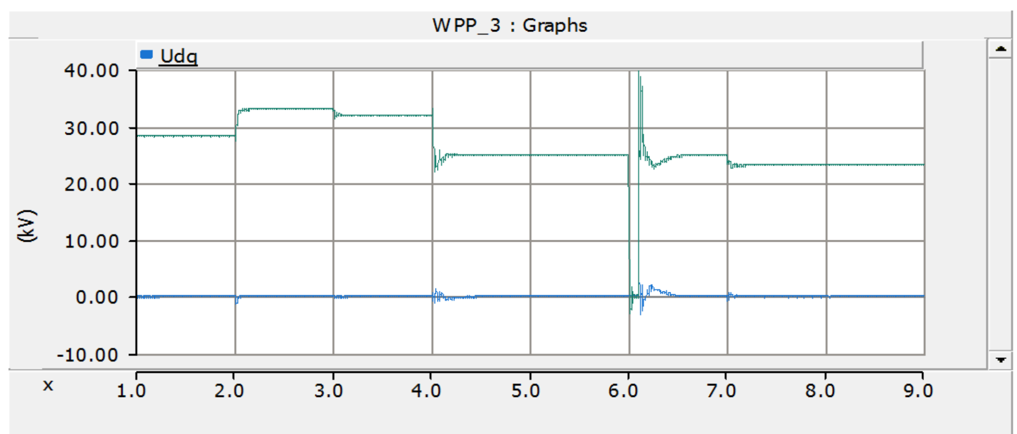
→ It is assumed here that the DC voltage is constant and there is storage element available.

Effect of high levels of PE – Use of Grid forming



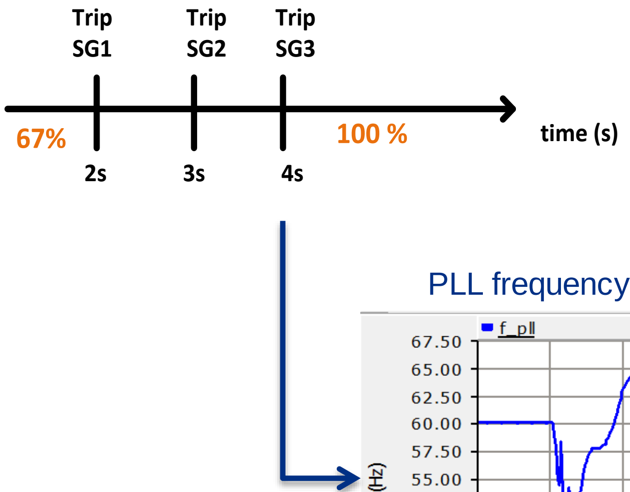
- The system is stable when part of generated power from PPMs is with grid forming control
- Grid forming units can change P and Q (assuming DC constant voltage)
- The lower voltage profiles are due to lack of reactive power flow in the network.



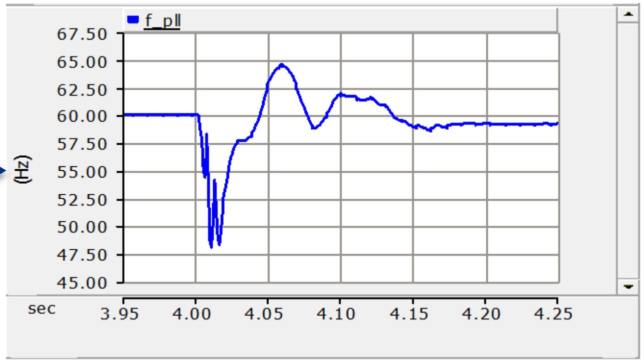


Effect of high levels of PE – Use of Grid forming

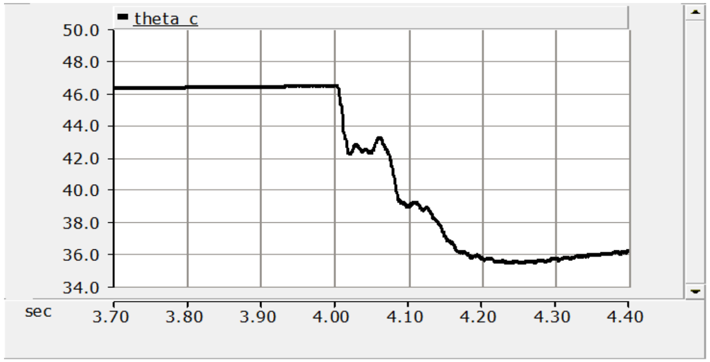
Simulated events

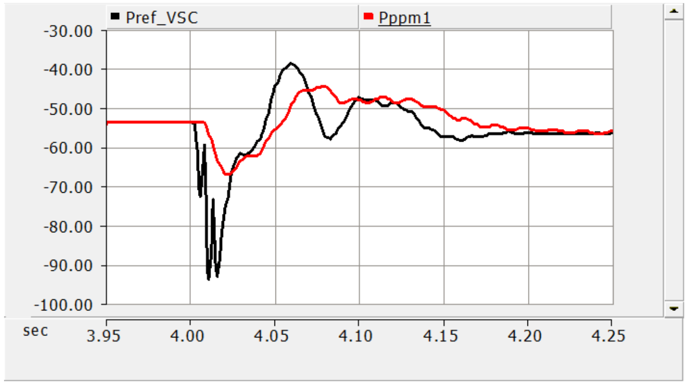


PLL frequency of grid forming PPM

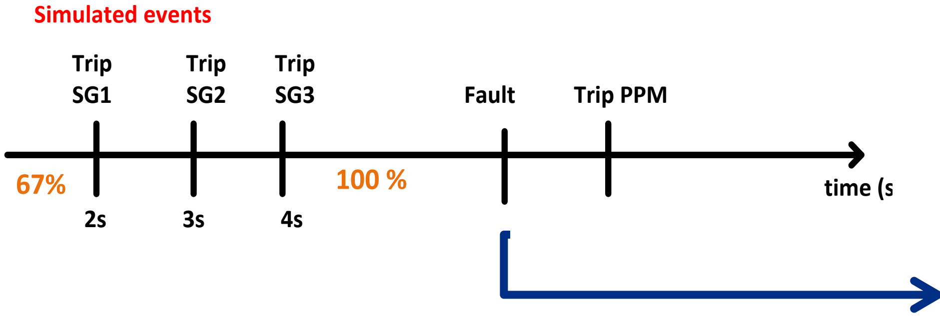


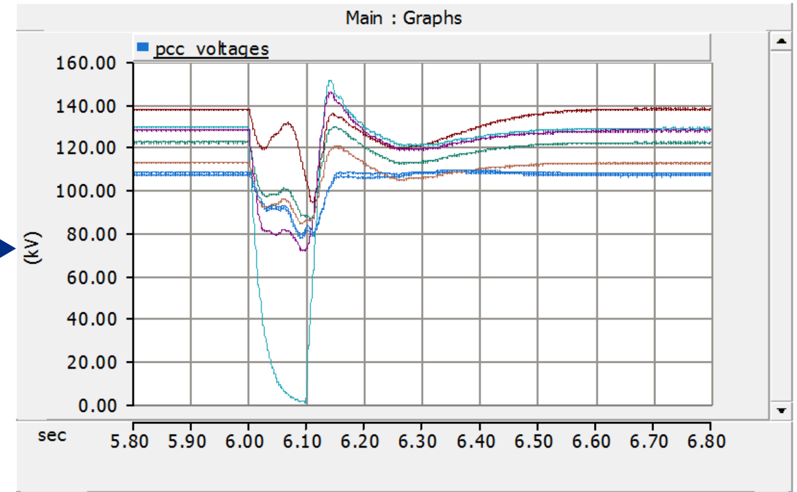
Internal voltage angle of grid forming PPM





Effect of high levels of PE – Use of Grid forming

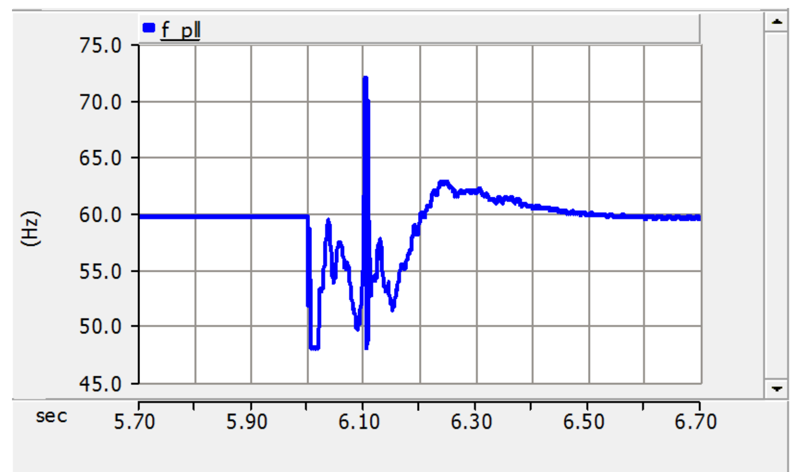




- Time domain response of selected voltages in the IEEE-118 for a three phase fault in the case of 100% PE.

- The fast reactive current injection provides a voltage boosting at all monitored nodes.

PLL frequency of grid forming PPM



Note: In the 100% PE case the frequency variation reflects the changes in the voltage angles in the system

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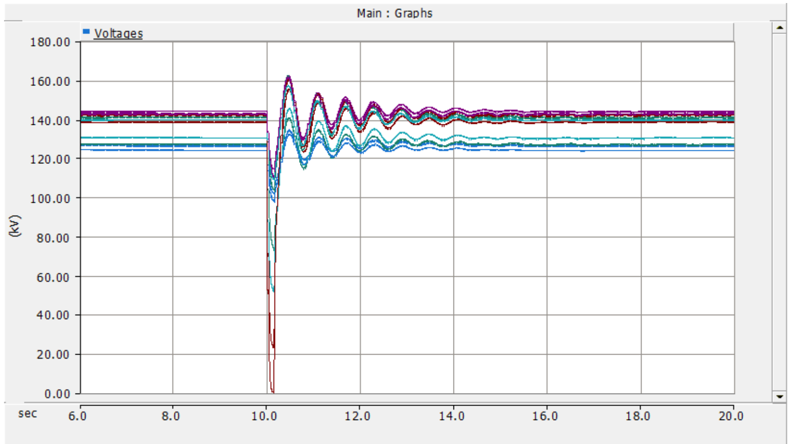
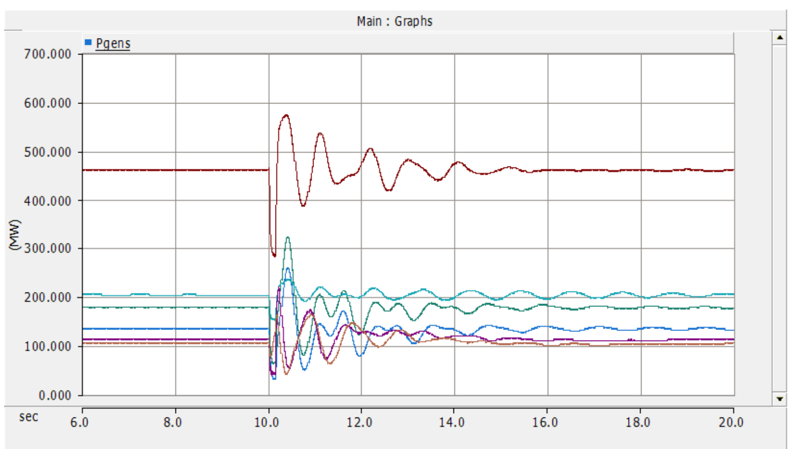
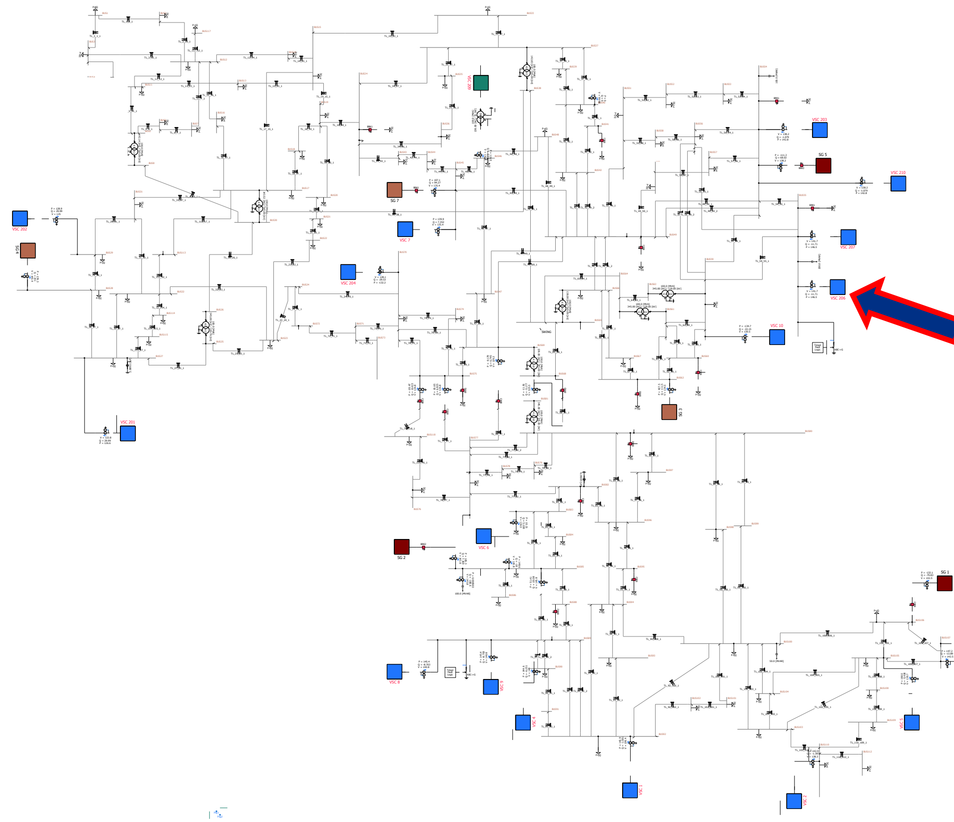
70% Penetration and VSCs with grid forming on the IEEE 118 – Compatibility with SGs







Summary

- The presented results with the IEEE 118-Bus shows that bulk transmission systems are stable when part of the PEIG applies grid forming control.
- Balancing active power in the case of the 100% PE-based network is performed using the PLL frequency.
- The PLL frequency reflects the changes in the voltage angles as a result of changes in the power flow.
- The stability of the 100% PE-Based system lies in the ability to maintain the voltage angle stability.
- The provision of rated reactive current injection from VSCs with grid forming control requires additional control and fast fault state detection to avoid over-current spikes.

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