

Verbundvorhaben: “Netzregelung 2.0”

**Abschlusskonferenz
Mi 6.7. - Do. 7.7.2022**

**Short-term and long-term dynamics of inverter dominated grids
Dr. Luis Pabón**

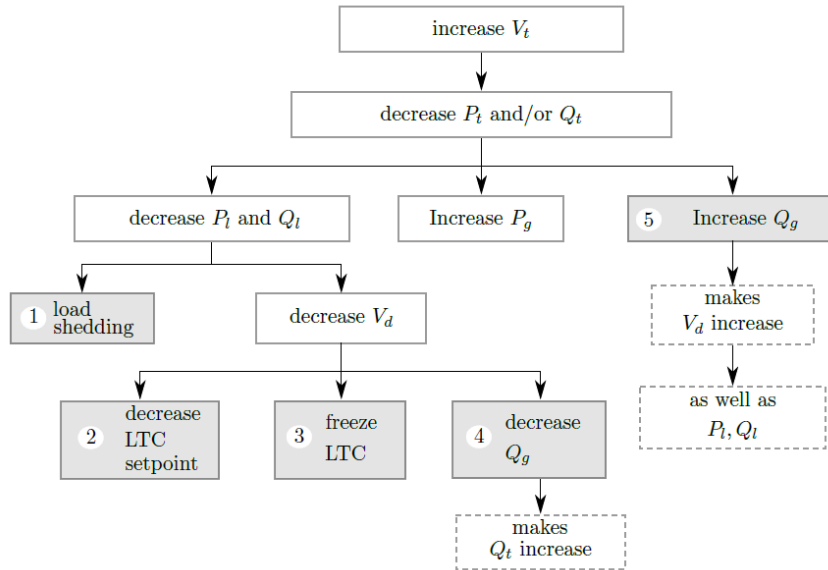


- This presentation is focused on two main aspects.
 1. Long-term stability of inverter dominated grids
 2. Short-term stability of inverter dominated grids



Long-term stability of inverter dominated grids

- Summary of achieved milestones
 - A novel emergency control against long-term instability was designed and successfully tested in systems with high shares of IBGs (considering reverse power flow, up to 200% penetration level).
 - Details can be found in:
 - Luis Pabon and Thierry Van Cutsem. “Emergency support of transmission voltages by active distribution networks: a non-intrusive scheme”. IEEE transactions on power systems
 - Unlike state-of-the-art emergency controllers, it supports the transmission system while minimally affecting or overusing the distribution network assets.
 - Patent pending.

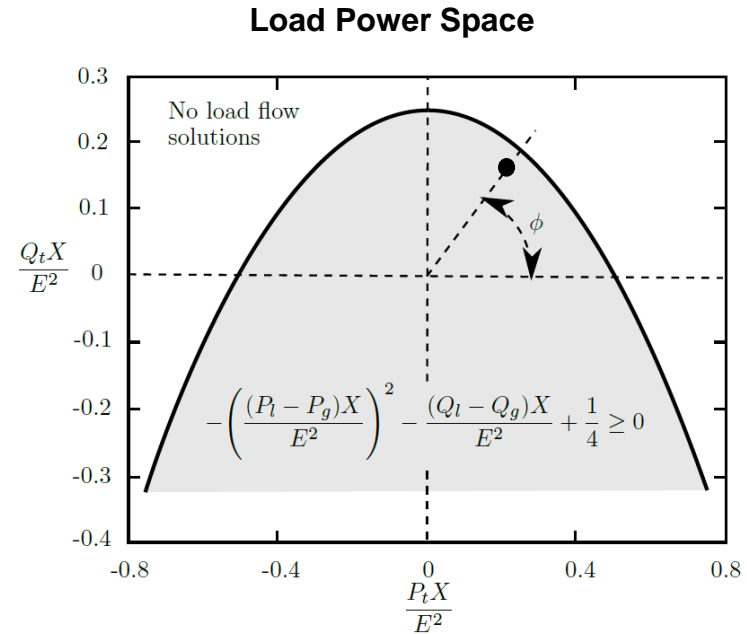
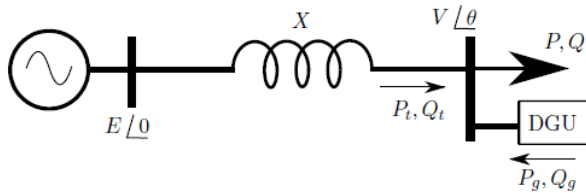


Trade-offs of previously proposed controllers

- It overcomes the trade-offs of previously proposed emergency controllers.

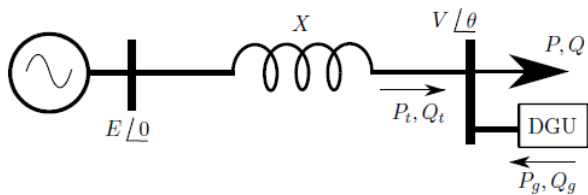


- The controller is based in the feasible region concept

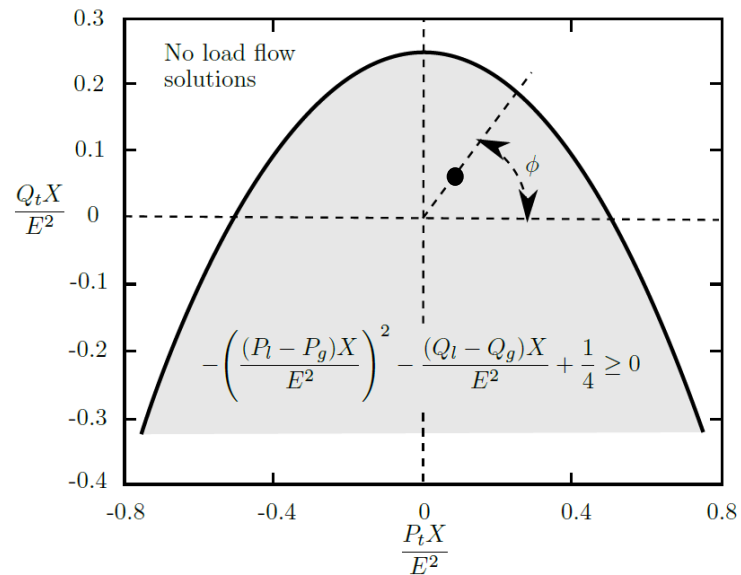




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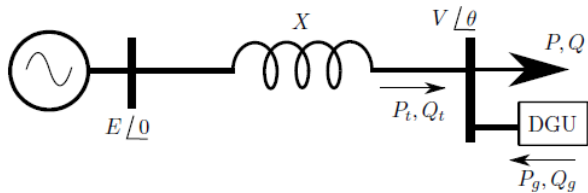


Load Power Space

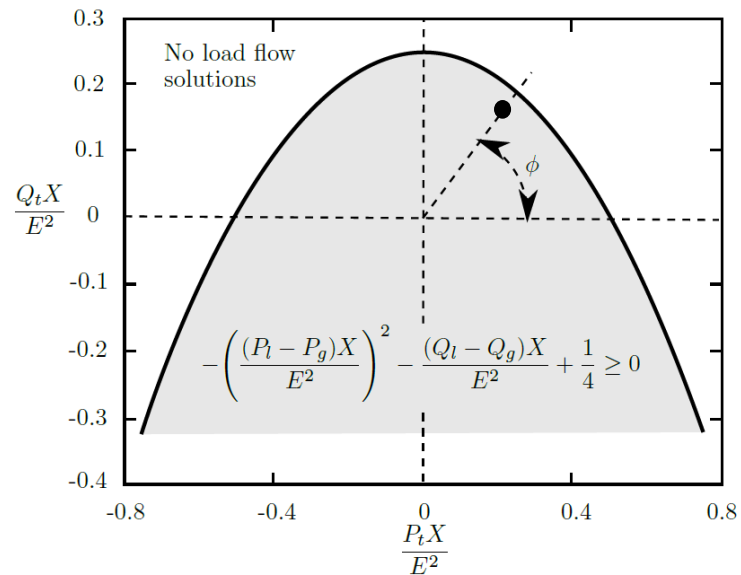




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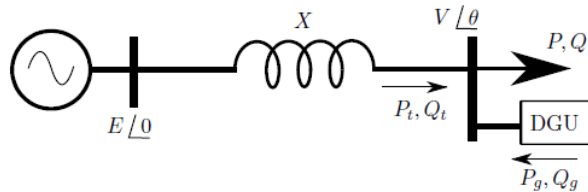


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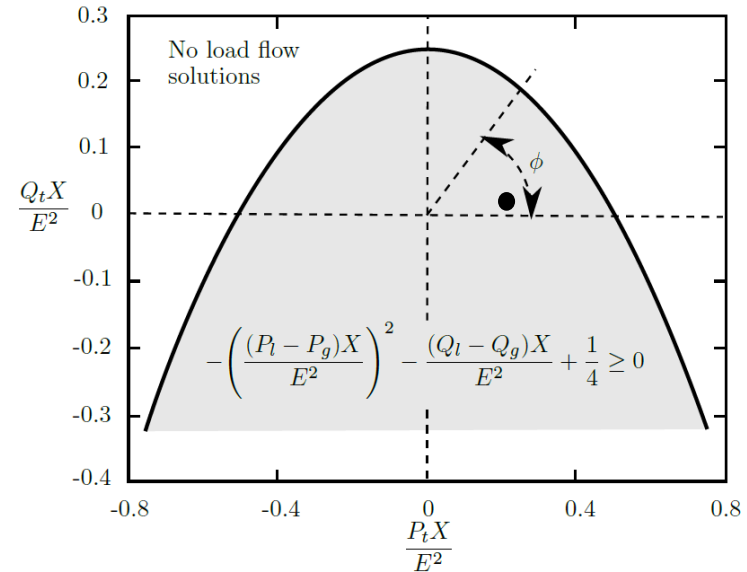


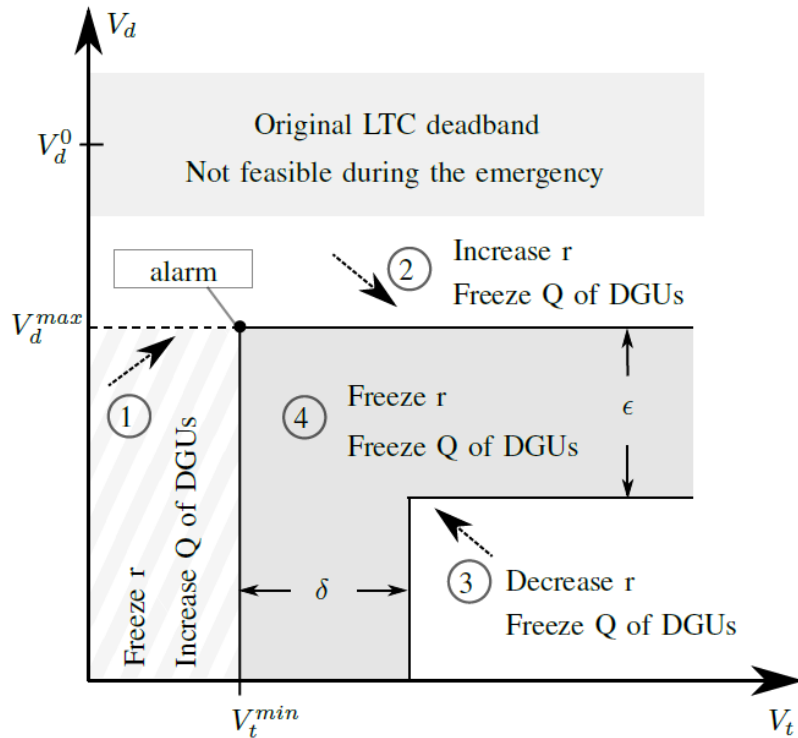


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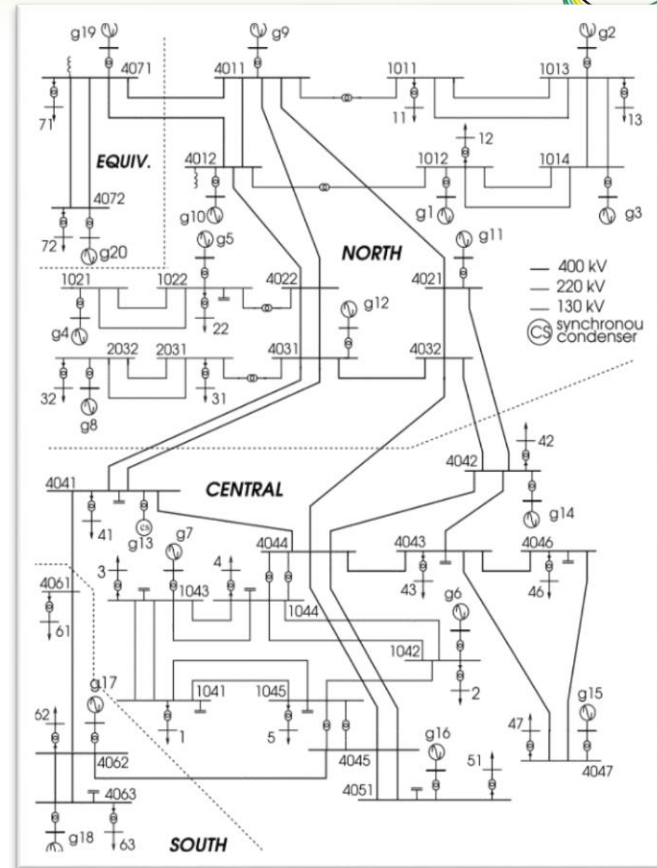
Load Power Space



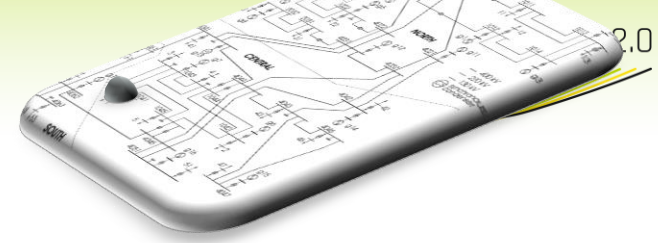


- Coordinates LTC and DGU control actions according to the V_d - V_t space

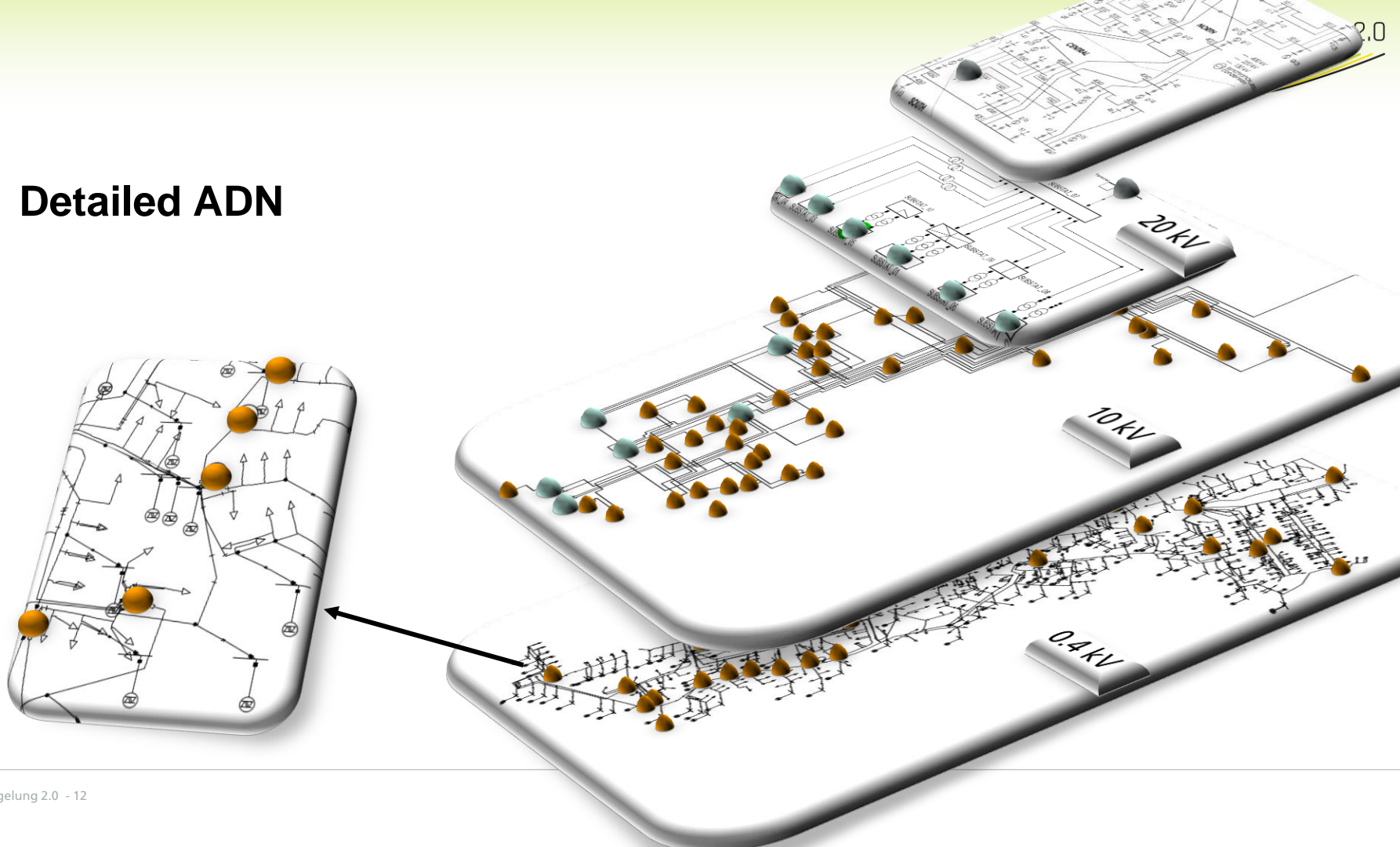
Detailed ADN



Detailed ADN

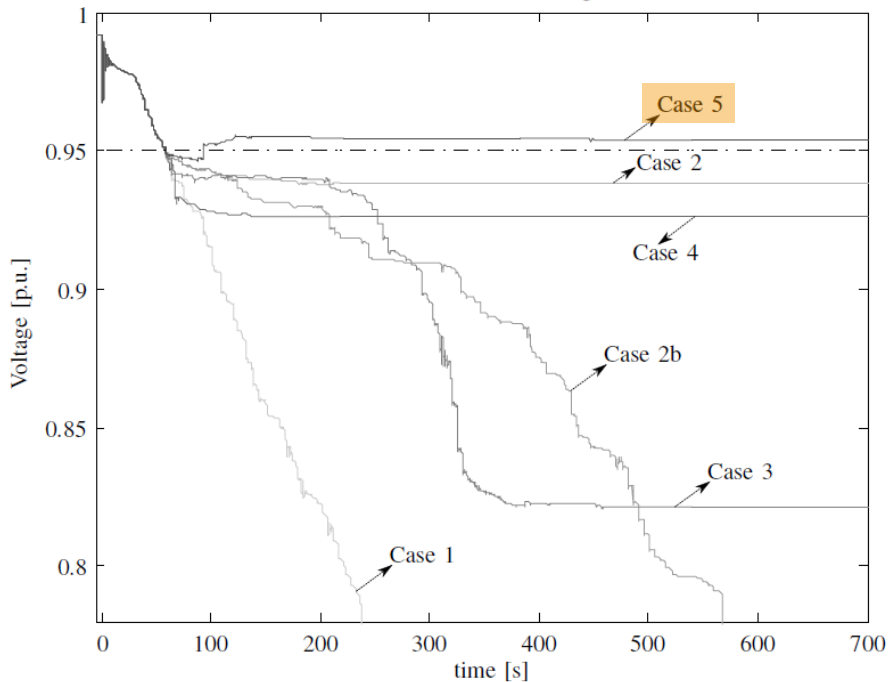


Detailed ADN

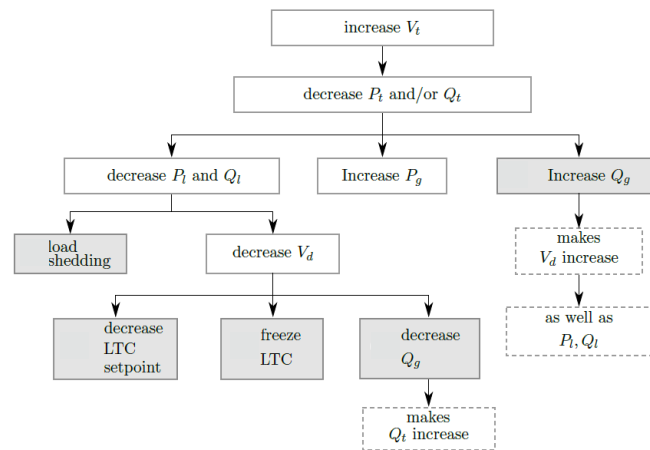




Evolution of transmission voltage 1041

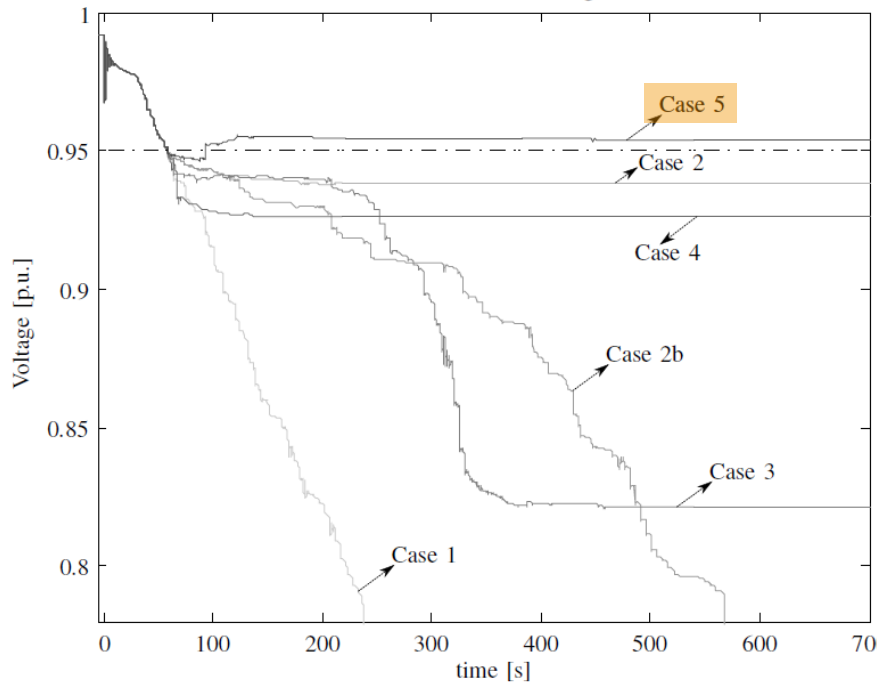


Simulation results

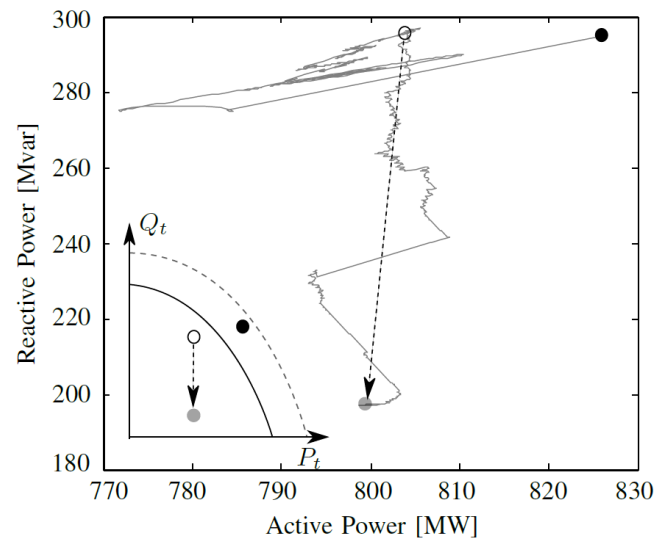




Evolution of transmission voltage 1041

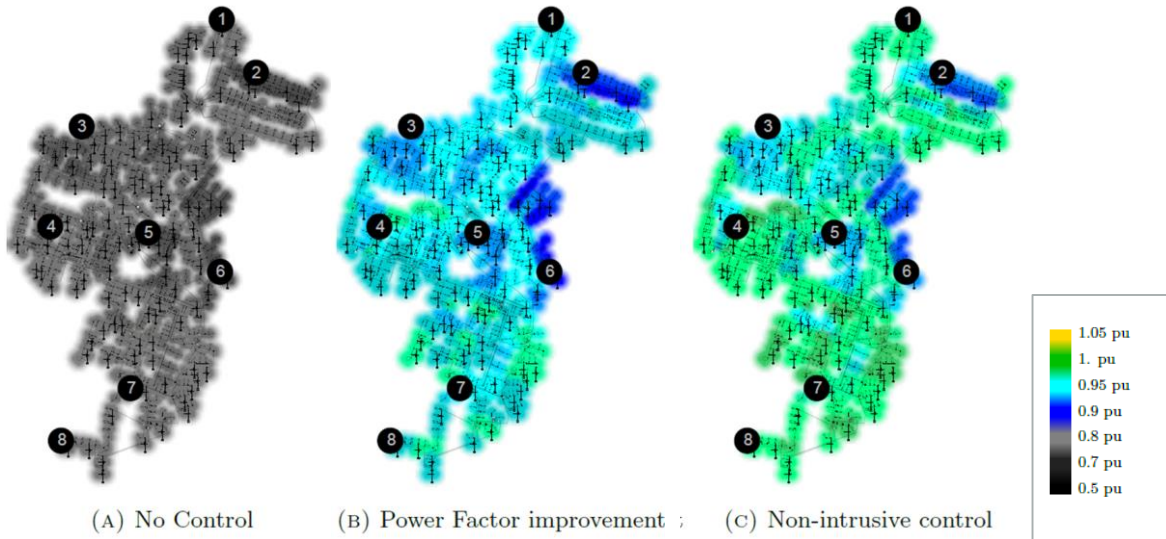


Simulation results



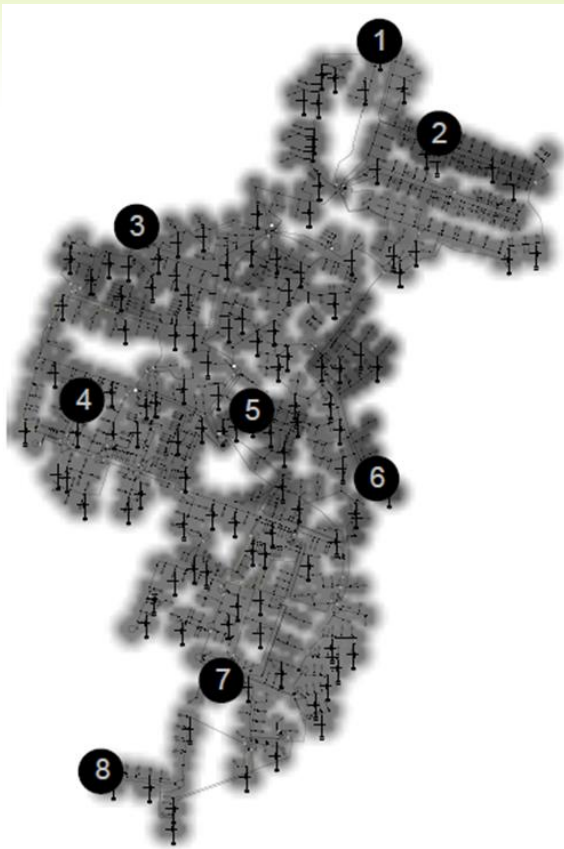


400 V network After the control action

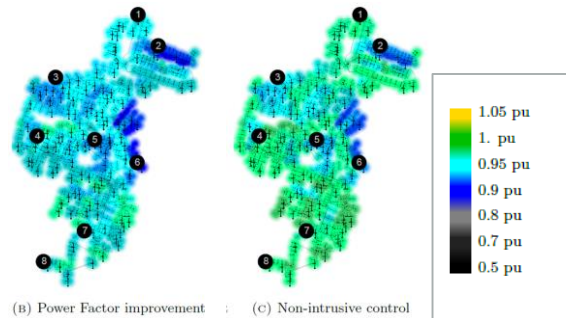




400 V network After the control action



(A) No Control



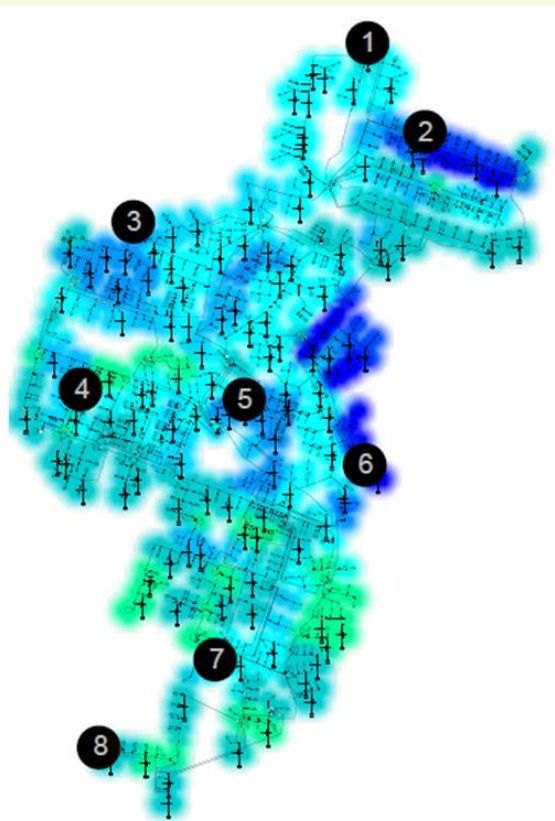
(B) Power Factor improvement : (c) Non-intrusive control



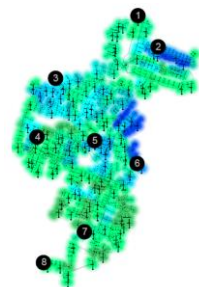
400 V network After the control action



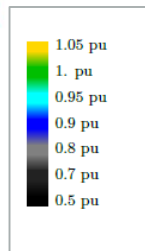
(A) No Control



(B) Power Factor improvement



(c) Non-intrusive control

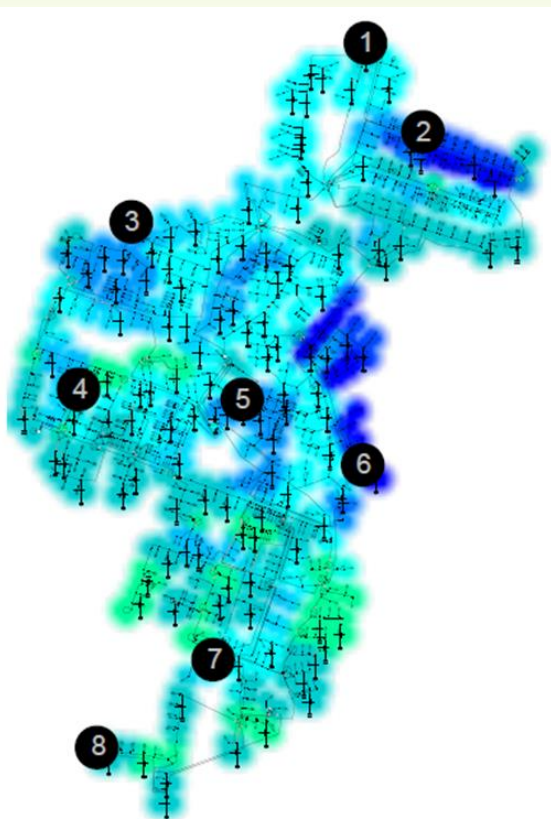




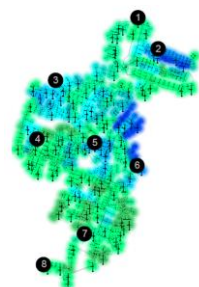
400 V network After the control action



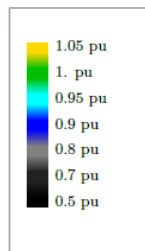
(A) No Control



(B) Power Factor improvement

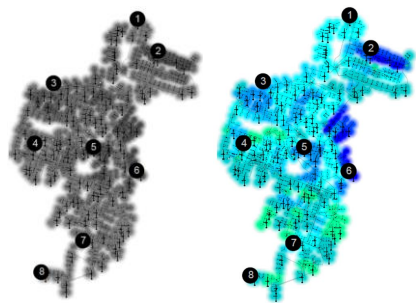


(c) Non-intrusive control



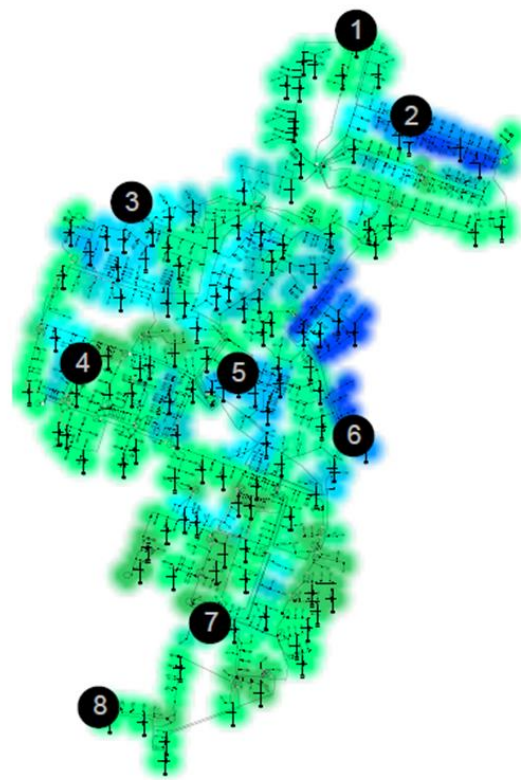


400 V network After the control action

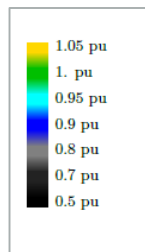


(A) No Control

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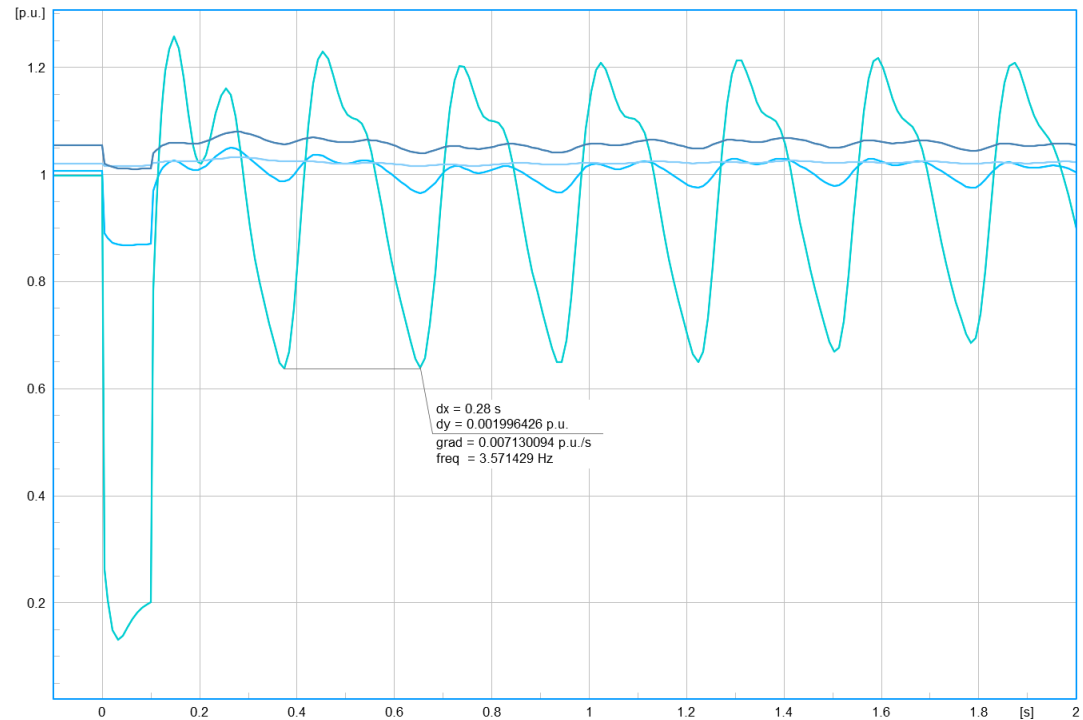
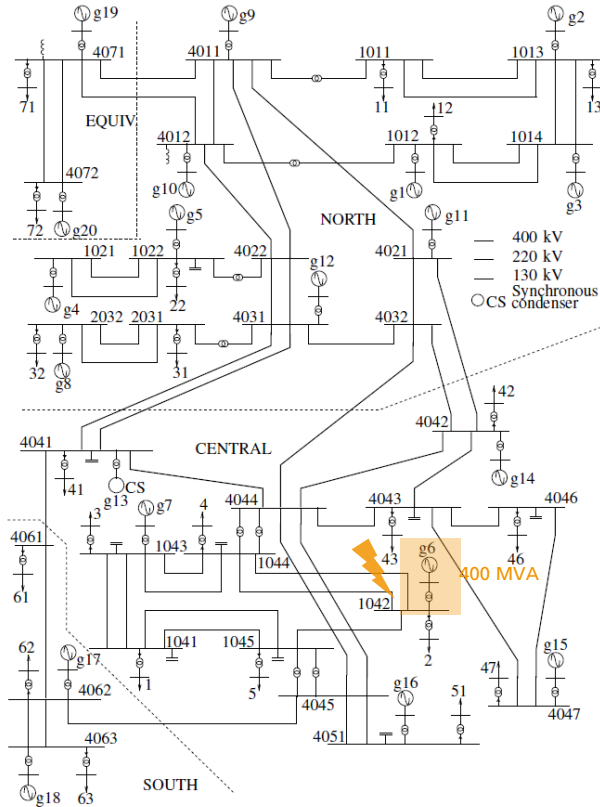


Short-term stability of inverter dominated grids

- Summary of achieved milestones
 - The PLL dynamics of grid-following units can cause short-term instability in inverter-dominated grids even in the presence of grid-forming units if the PLL bandwidth is not properly considered.
 - This instability has been classified as slow-interaction converter-driven instability.
 - An extended IBG model was implemented in order to capture the phenomenon. The model is inspired by the WECC REGC version C.
 - A methodology for the estimation of the required amount of grid-forming units has been proposed.
 - The methodology takes into account several variables, including the most important one, i.e., the PLL bandwidth of existing grid-following units.
 - “Plausibility and implications of converter-driven oscillations induced by unstable long-term dynamics”. IEEE Transactions on Power Systems – Under review.



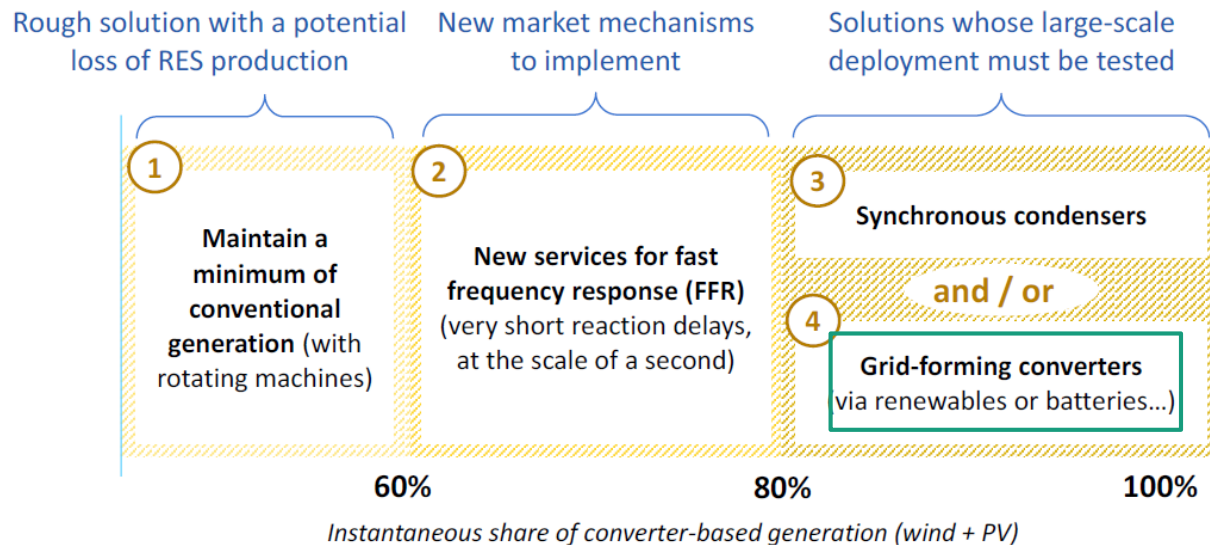
- In systems with considerable amounts of IBG, the system **dynamics become very fast**.
- The PLL of traditional grid-following units **faces challenges** when trying to track the voltage angle of a very fast moving system.
- If the PLL cannot properly track the voltage angle, **the inverter injects power out of phase** leading to poorly or even undamped oscillations.
- The IEEE Power System Dynamic Performance Committee has classified this phenomenon as **slow-interaction converter-driven instability**.
- It has been observed in real systems as undamped oscillations with frequencies typically in the range from **3 Hz to 10 Hz**.



- 1041\1041: Voltage, Magnitude
- 1042\1042: Voltage, Magnitude
- 4012\4012: Voltage, Magnitude
- 4062\4062: Voltage, Magnitude



How to counteract the phenomenon?



IEA and RTE - Conditions and Requirements for the Technical Feasibility of a Power System with a High Share of Renewables in France Towards 2050



Research question

- What is the minimum share of grid-forming units that is needed to avoid converter-driven oscillations?



- The frequency and damping of the oscillation highly depends on the PLL bandwidth.
- Therefore, a sensitivity on the necessary grid-forming units was made as a function of the PLL bandwidth.
- In this case, the integral gain of the PLL is increased to modify the bandwidth.

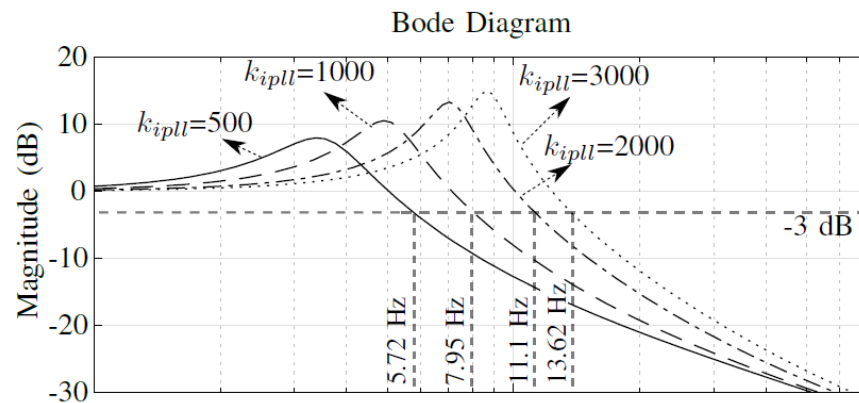
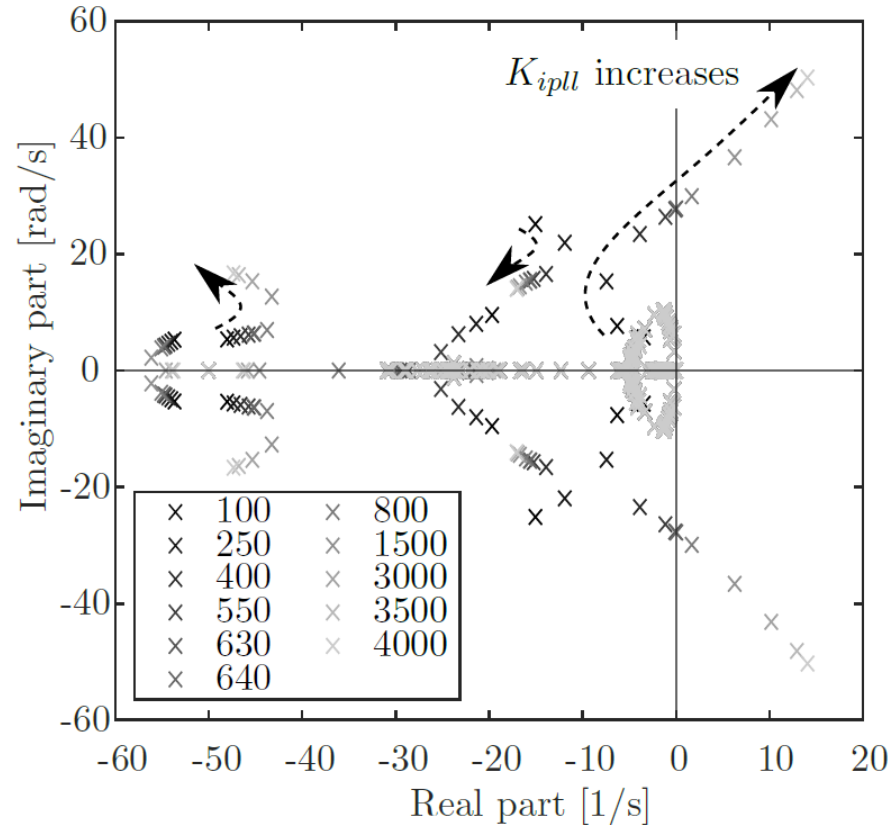
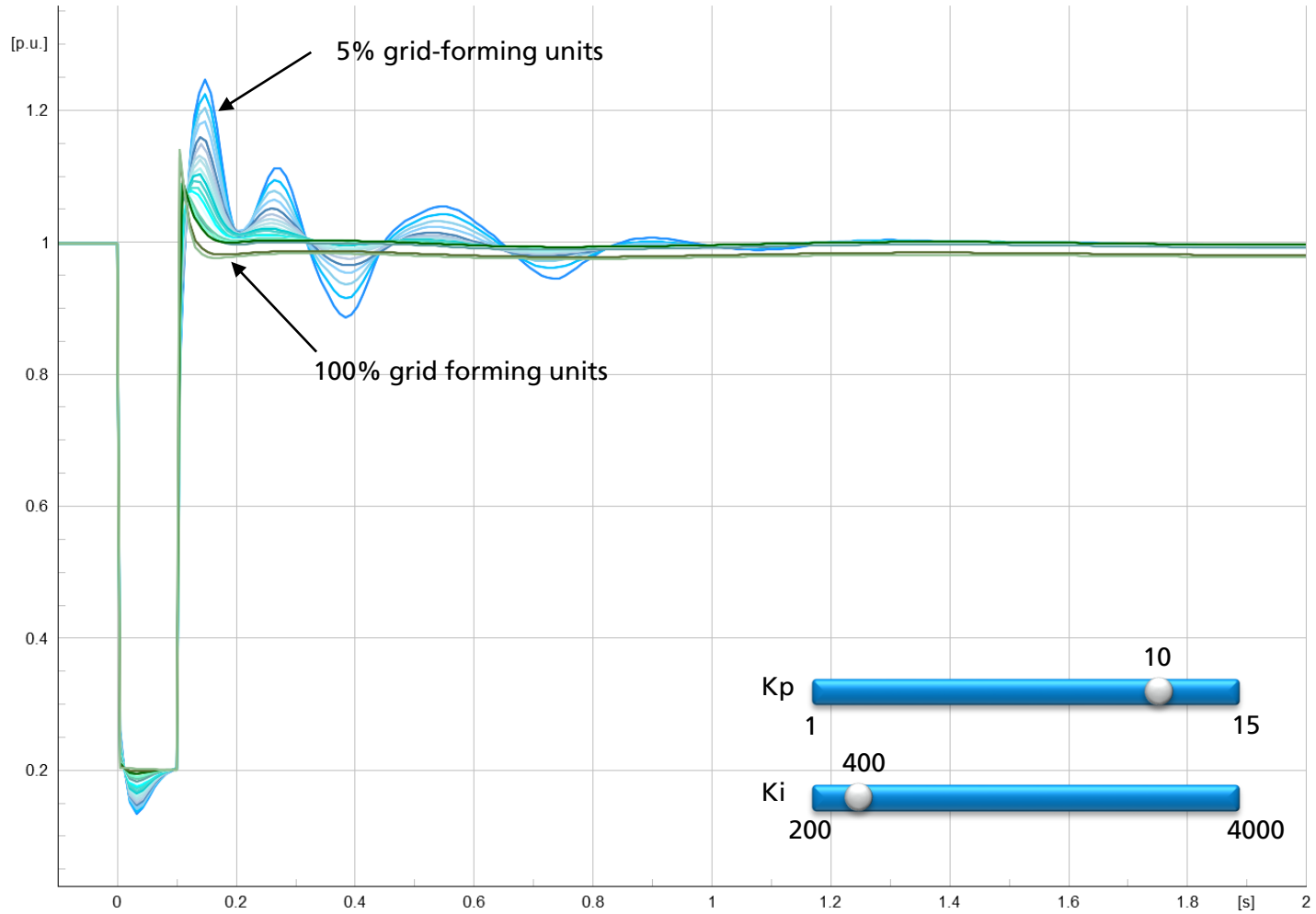


Fig. 13: Bode diagram of the used PLL - different values of k_{ipll} and $k_{ppll}=10$.



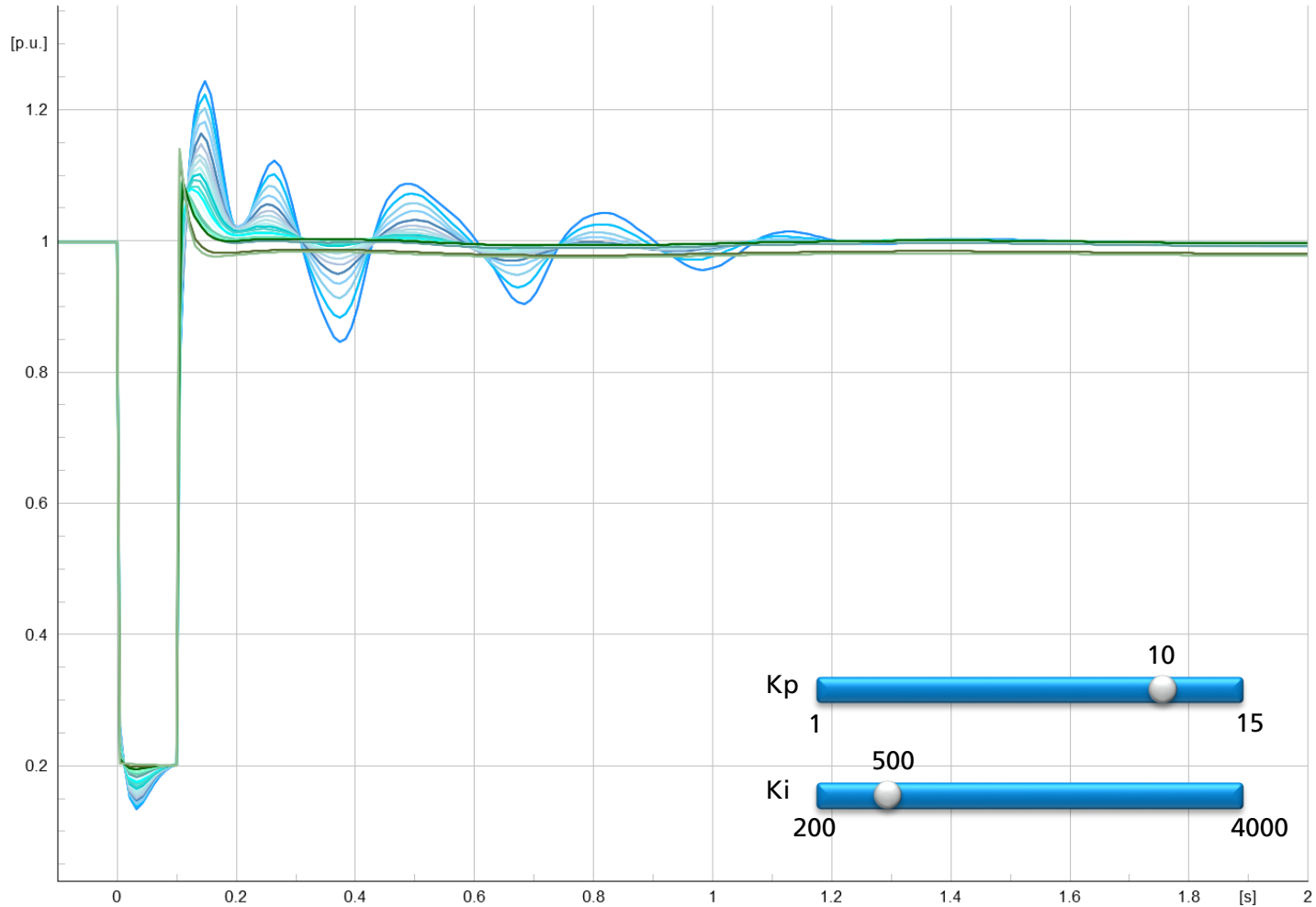
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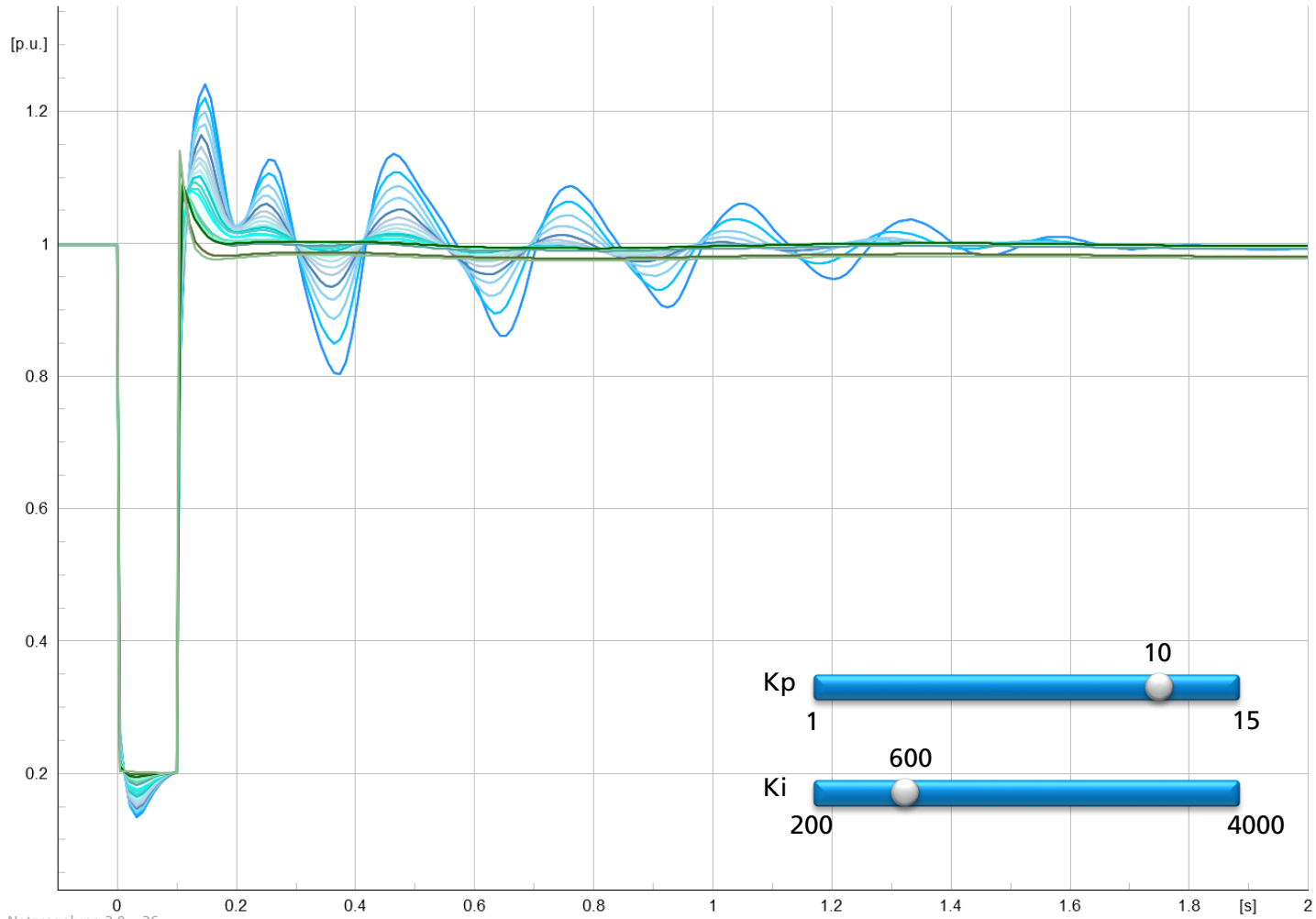
% of Grid-forming Units

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- 55 %
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- 70 %
- 75 %
- 80 %
- 85 %
- 90 %
- 95 %
- 100 %



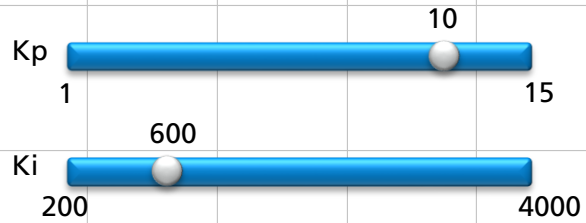
% of Grid-forming Units

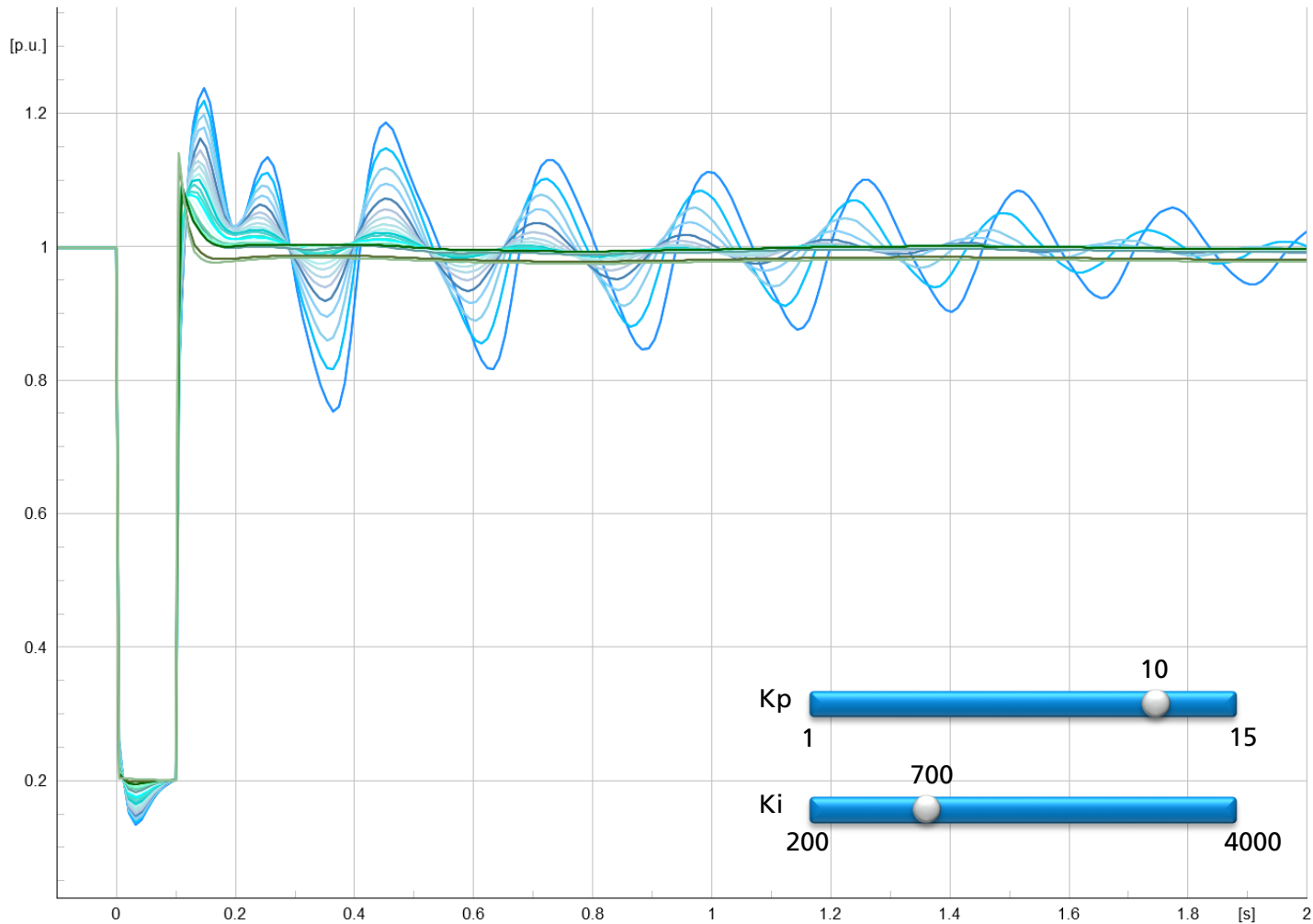
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% of Grid-forming Units

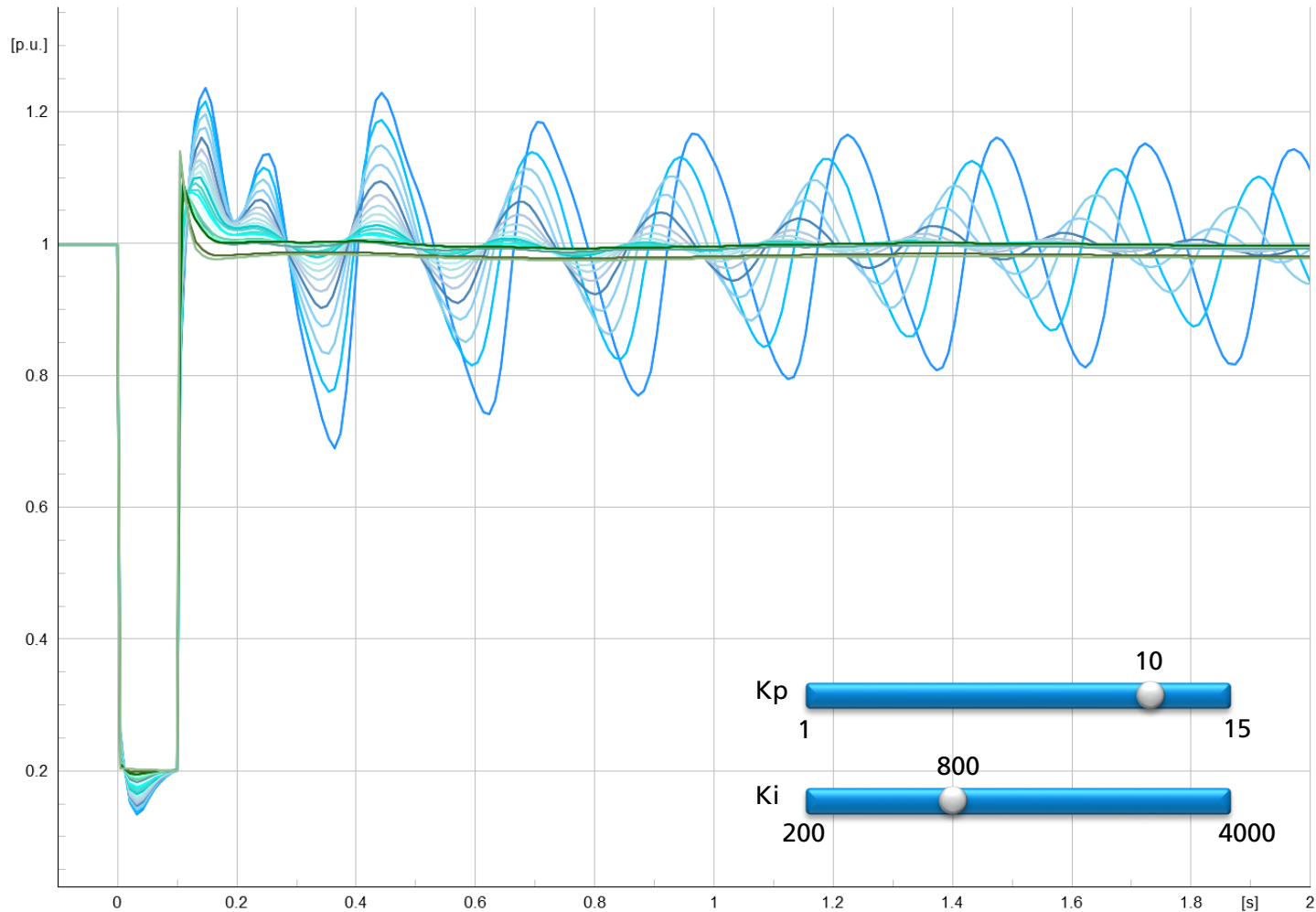
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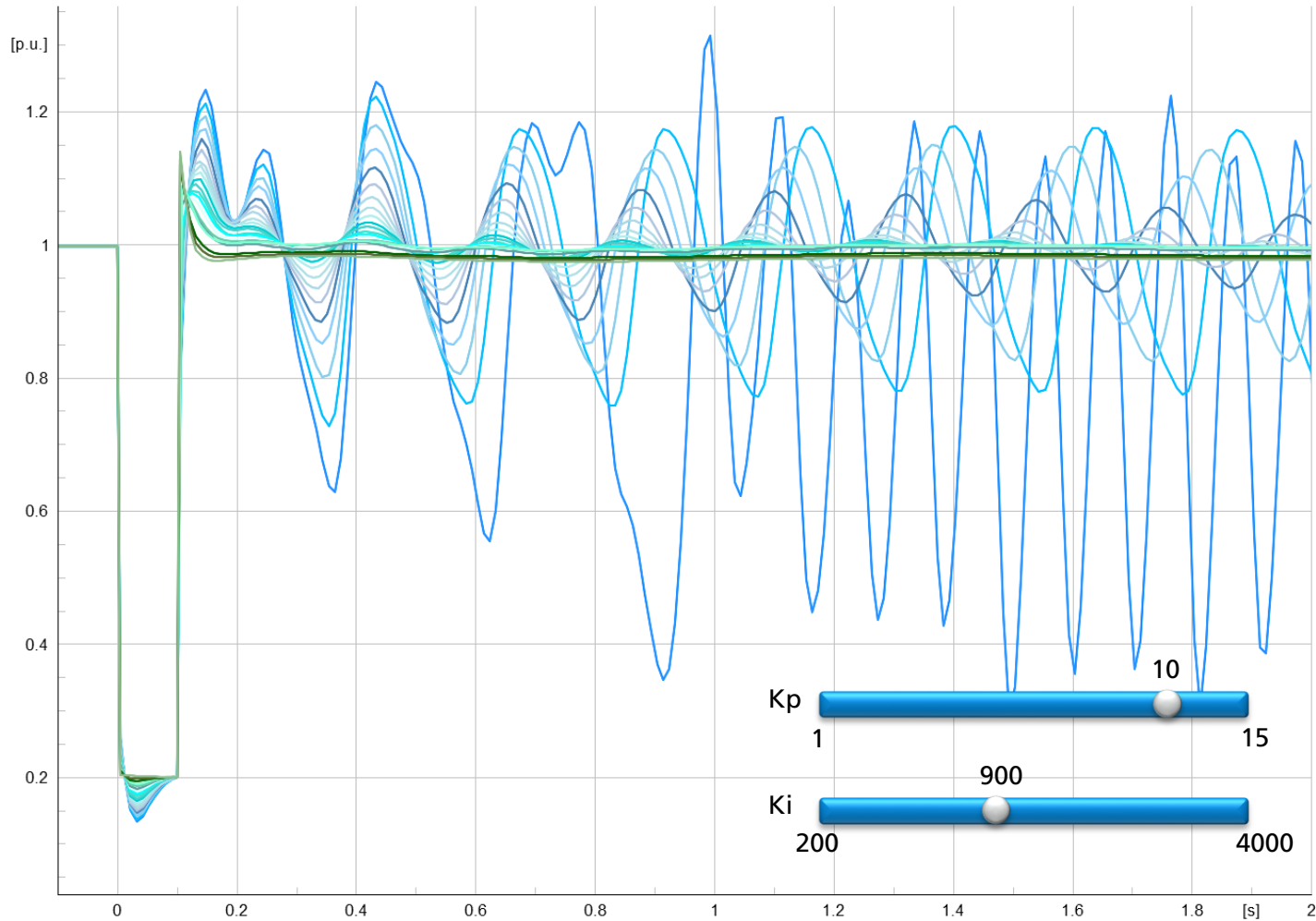
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% of Grid-forming Units

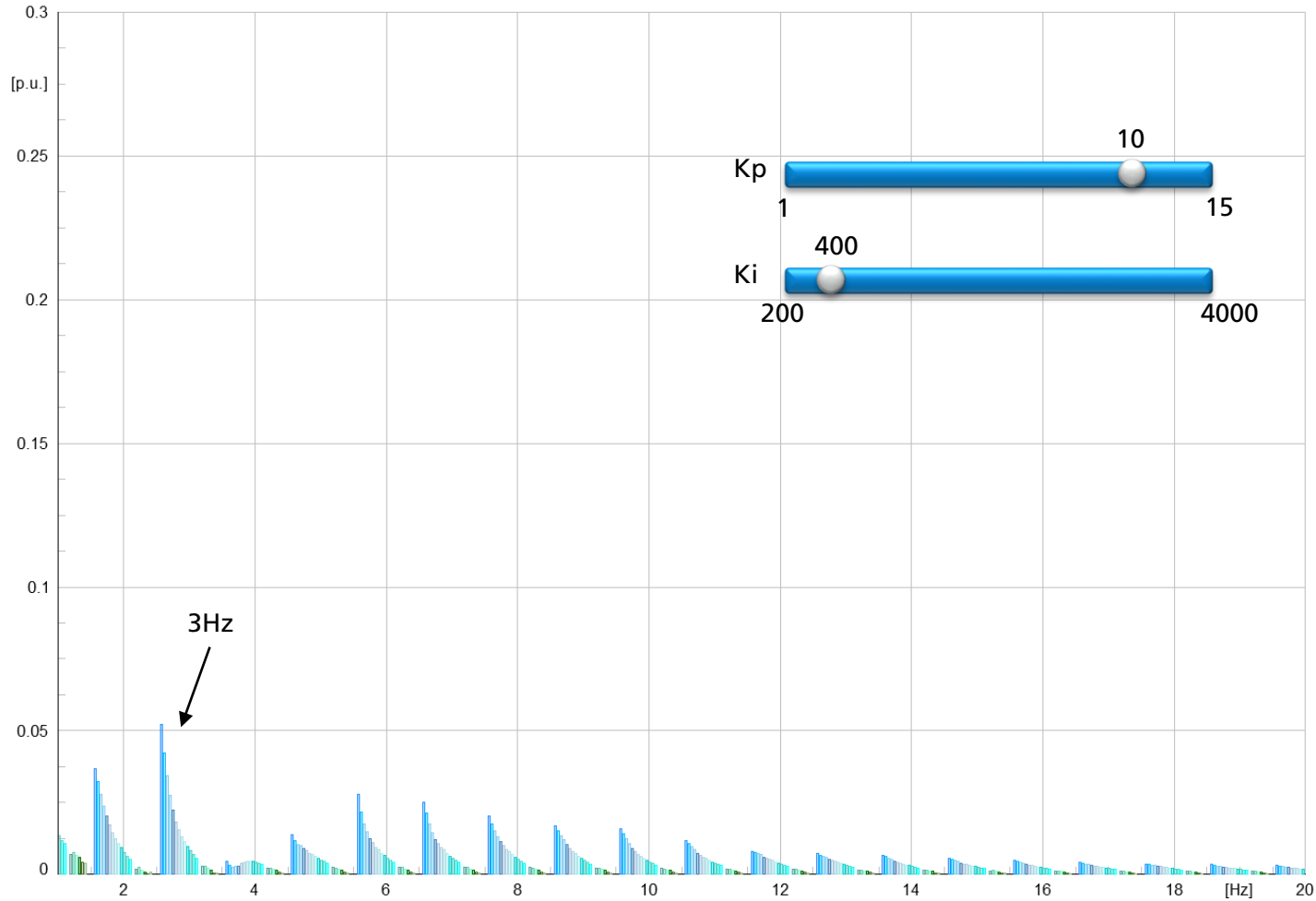
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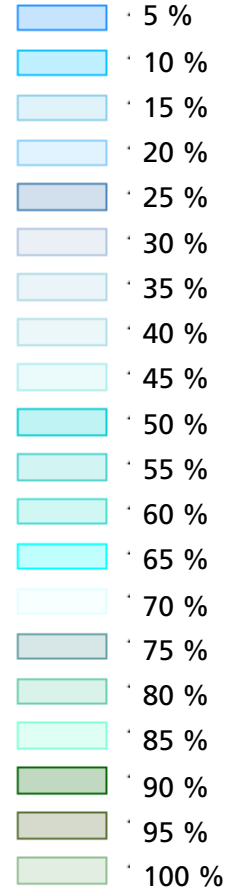
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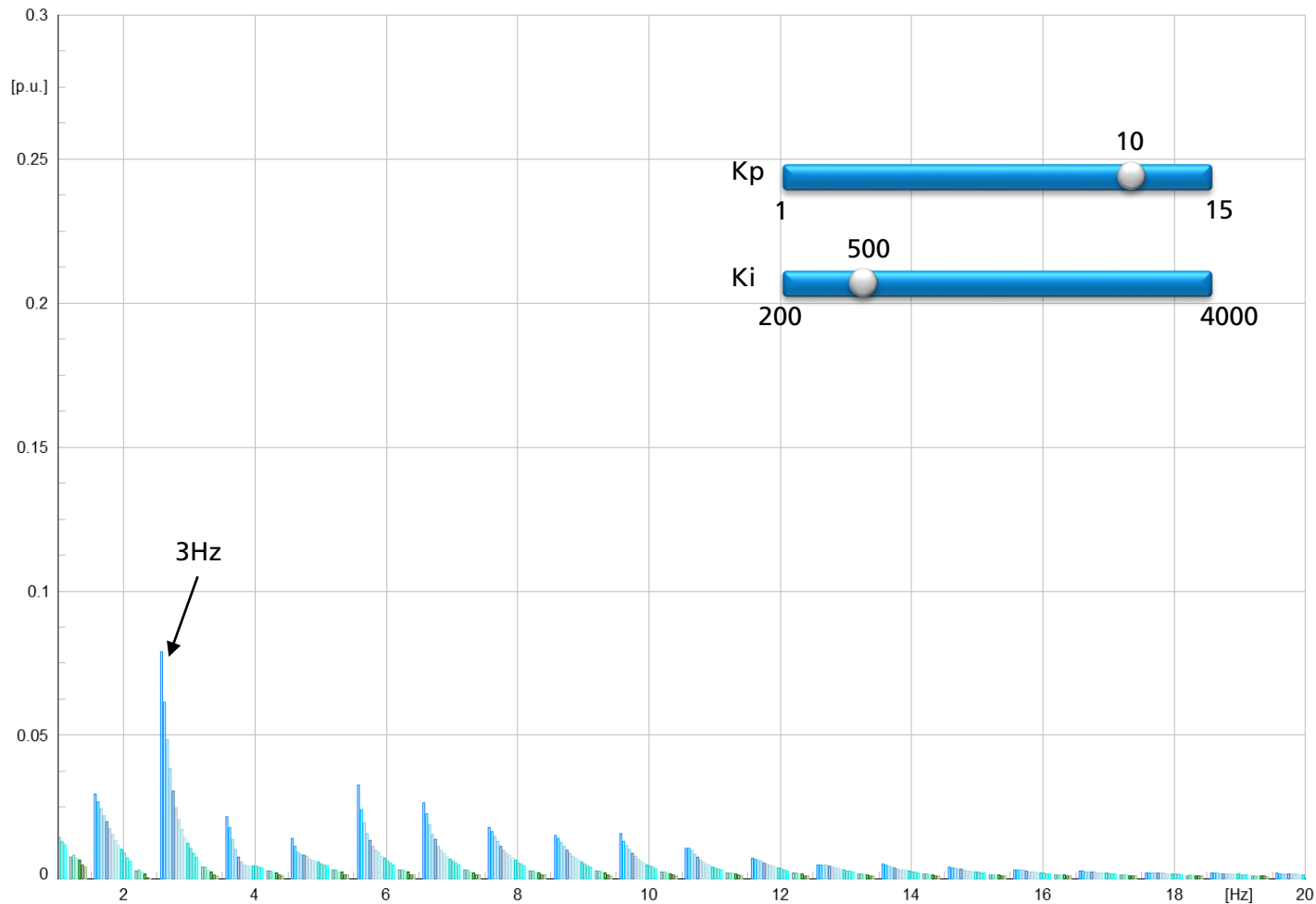
Fourier Coefficient - Magnitude



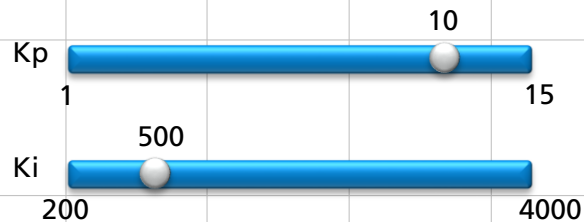
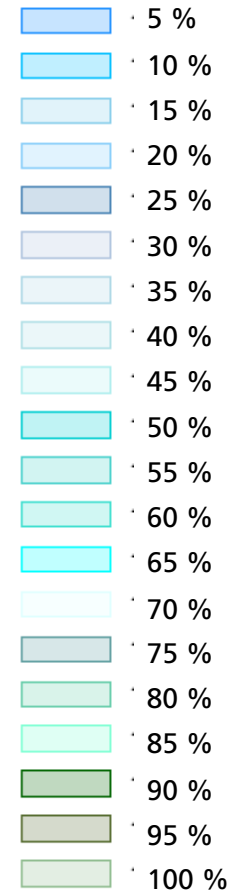
% of Grid-forming Units



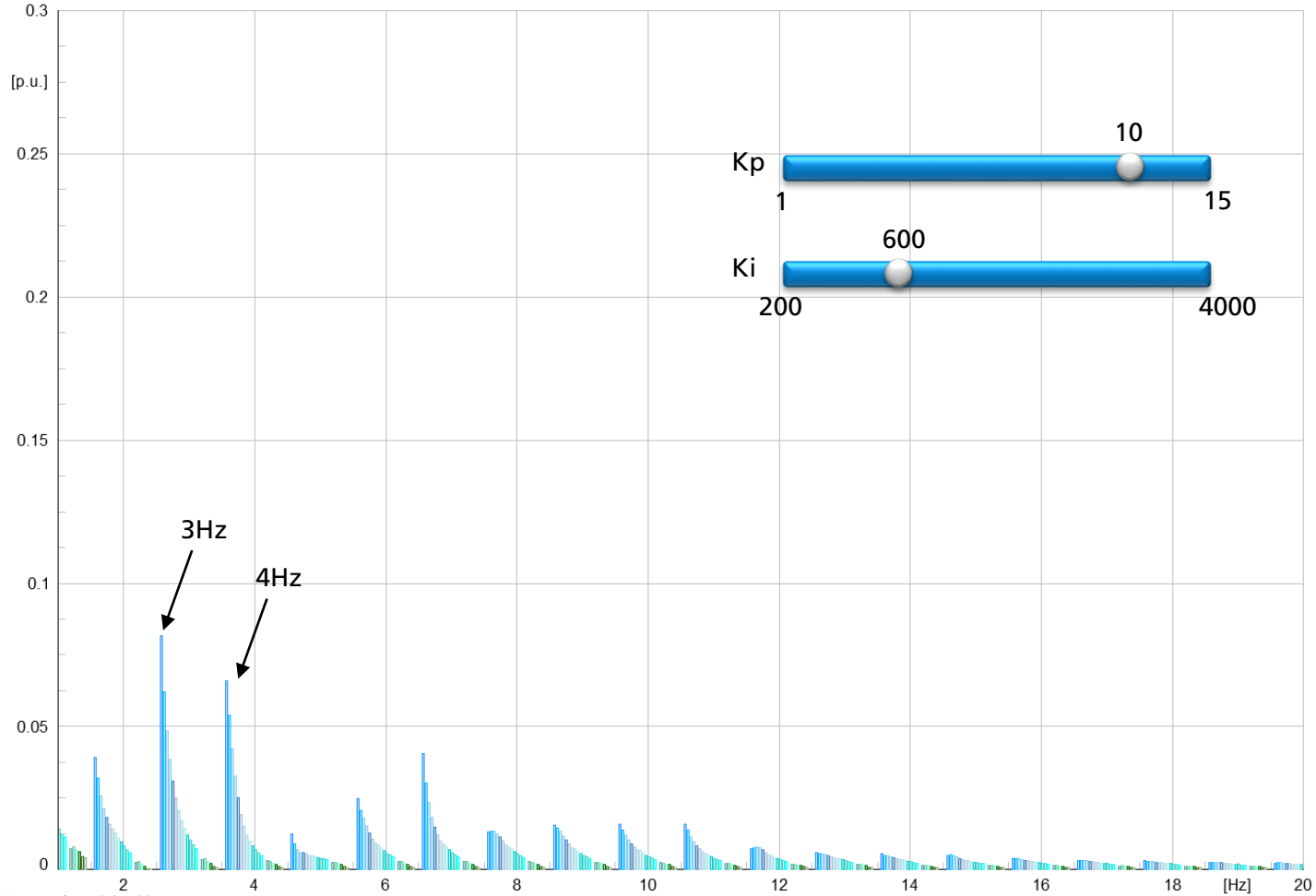
Fourier Coefficient - Magnitude



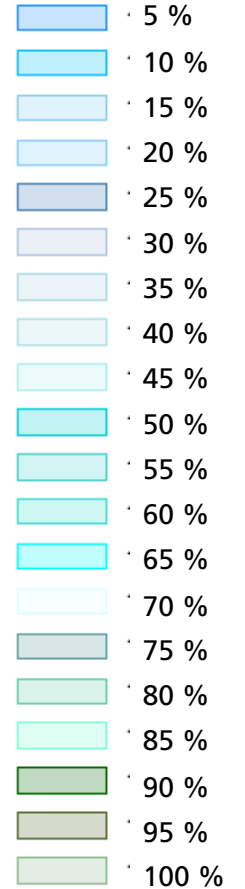
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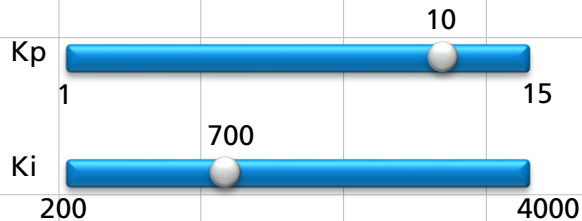
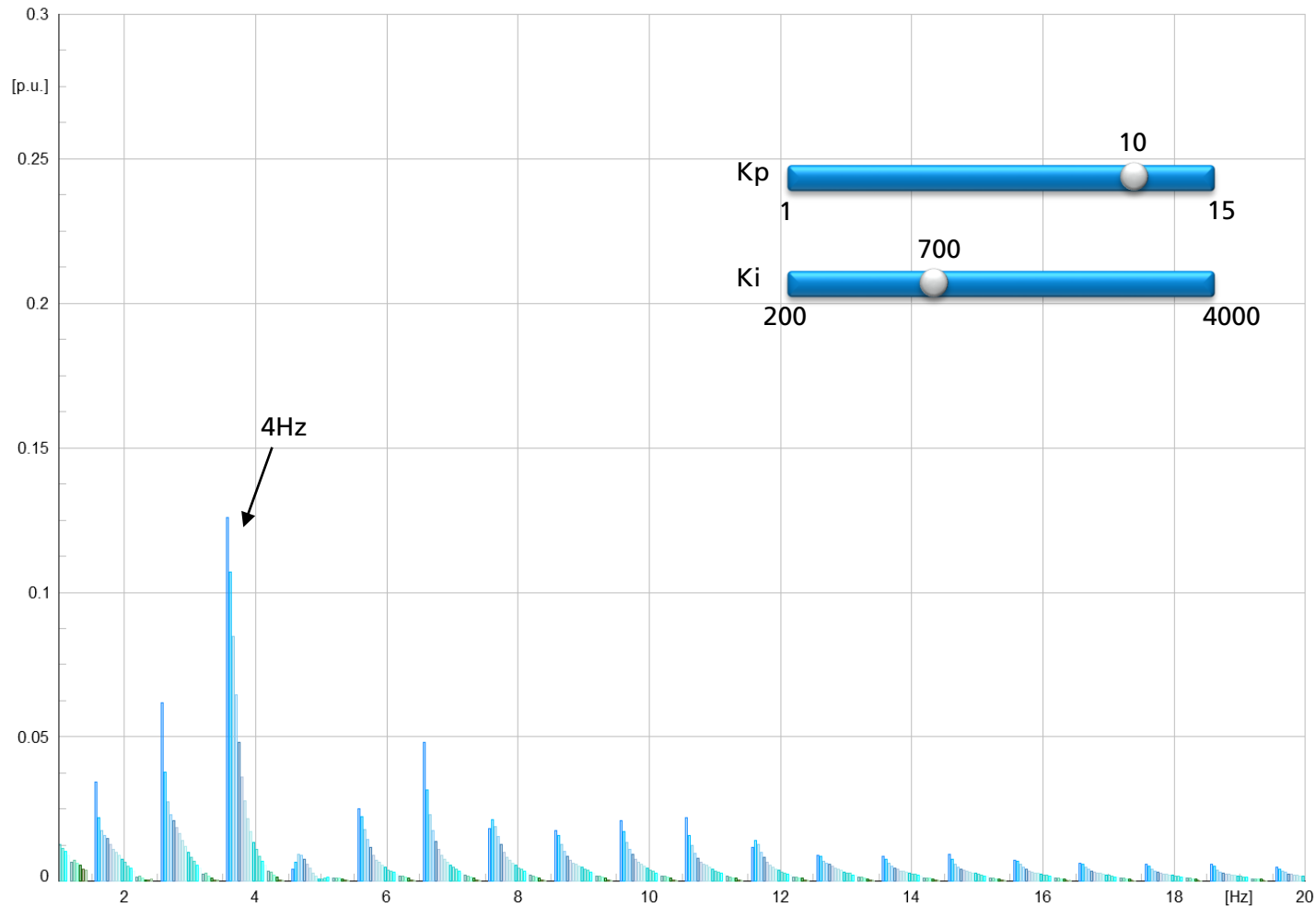
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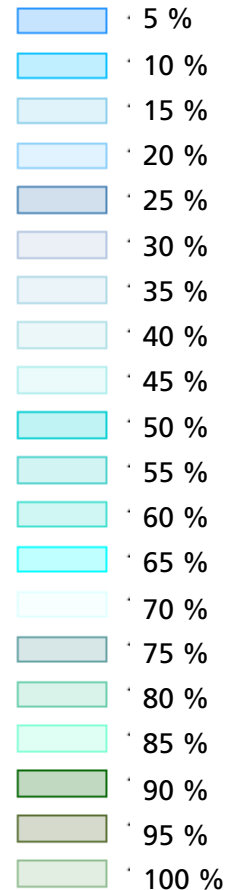
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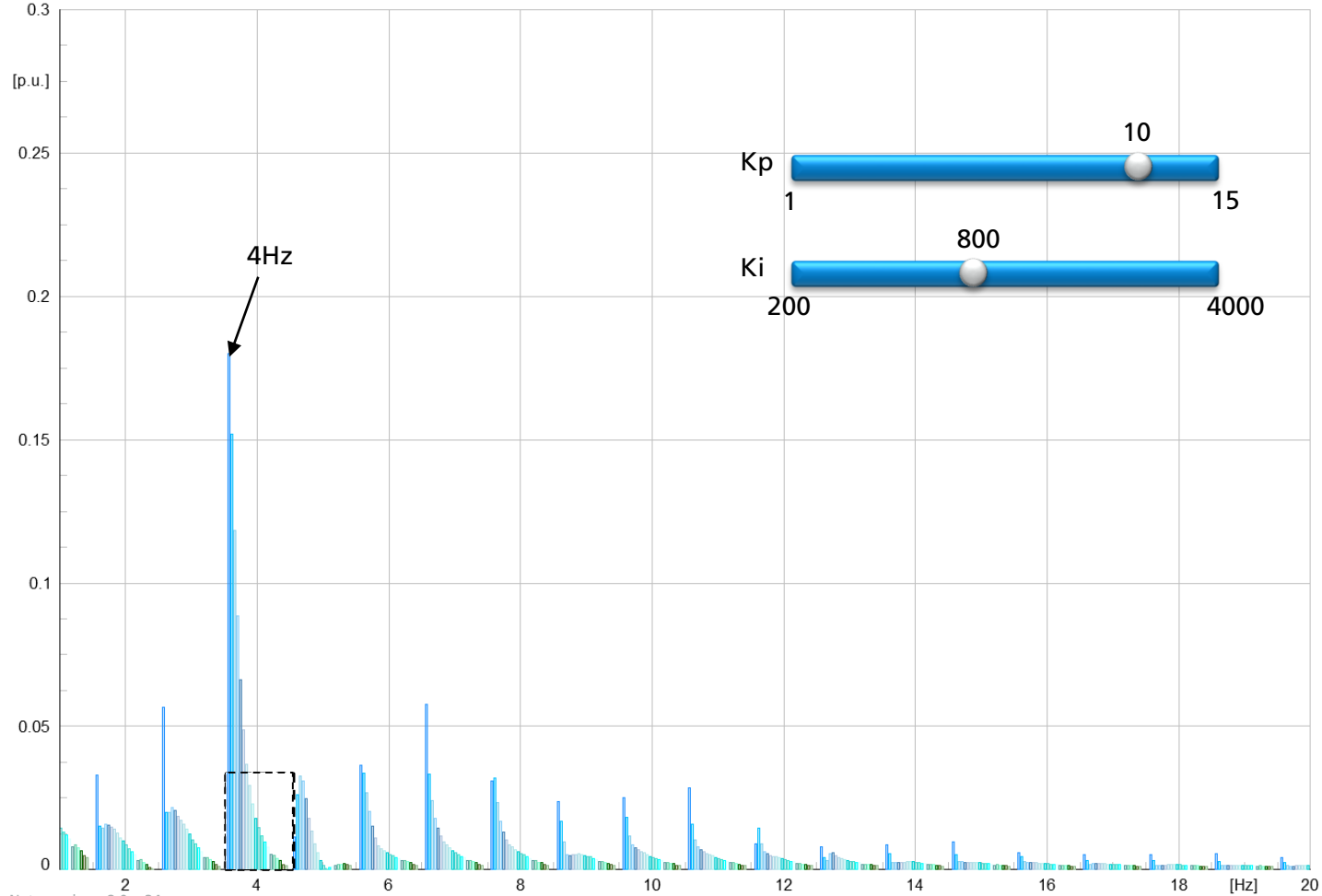
Fourier Coefficient - Magnitude



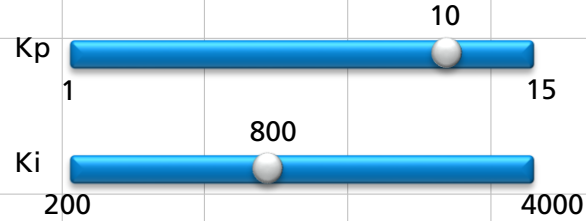
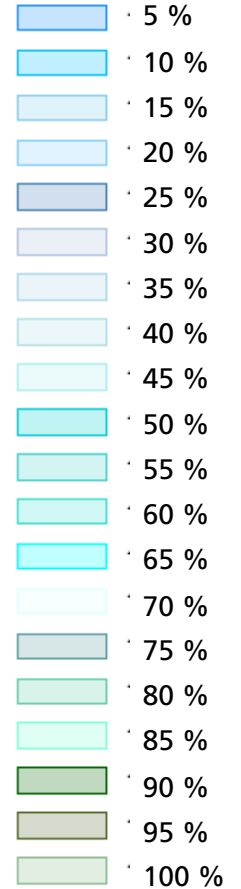
% of Grid-forming Units



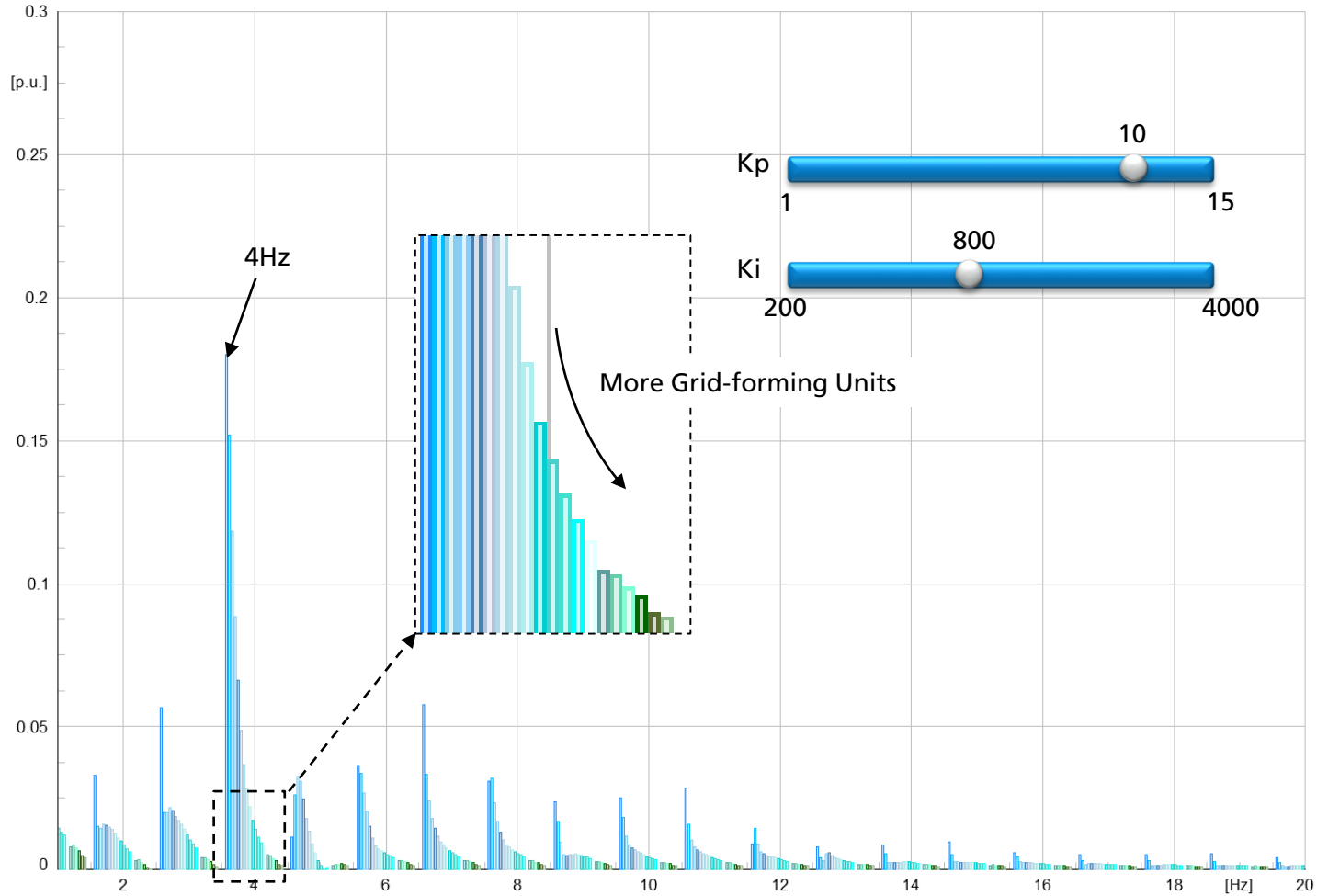
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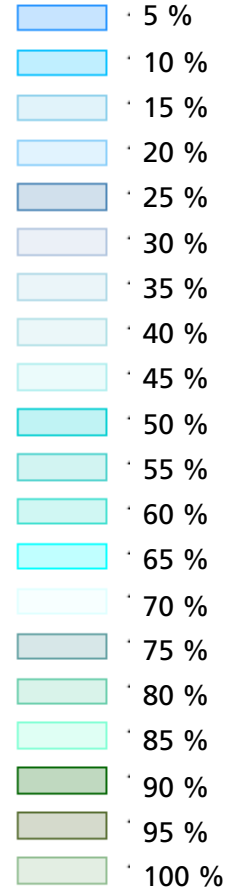
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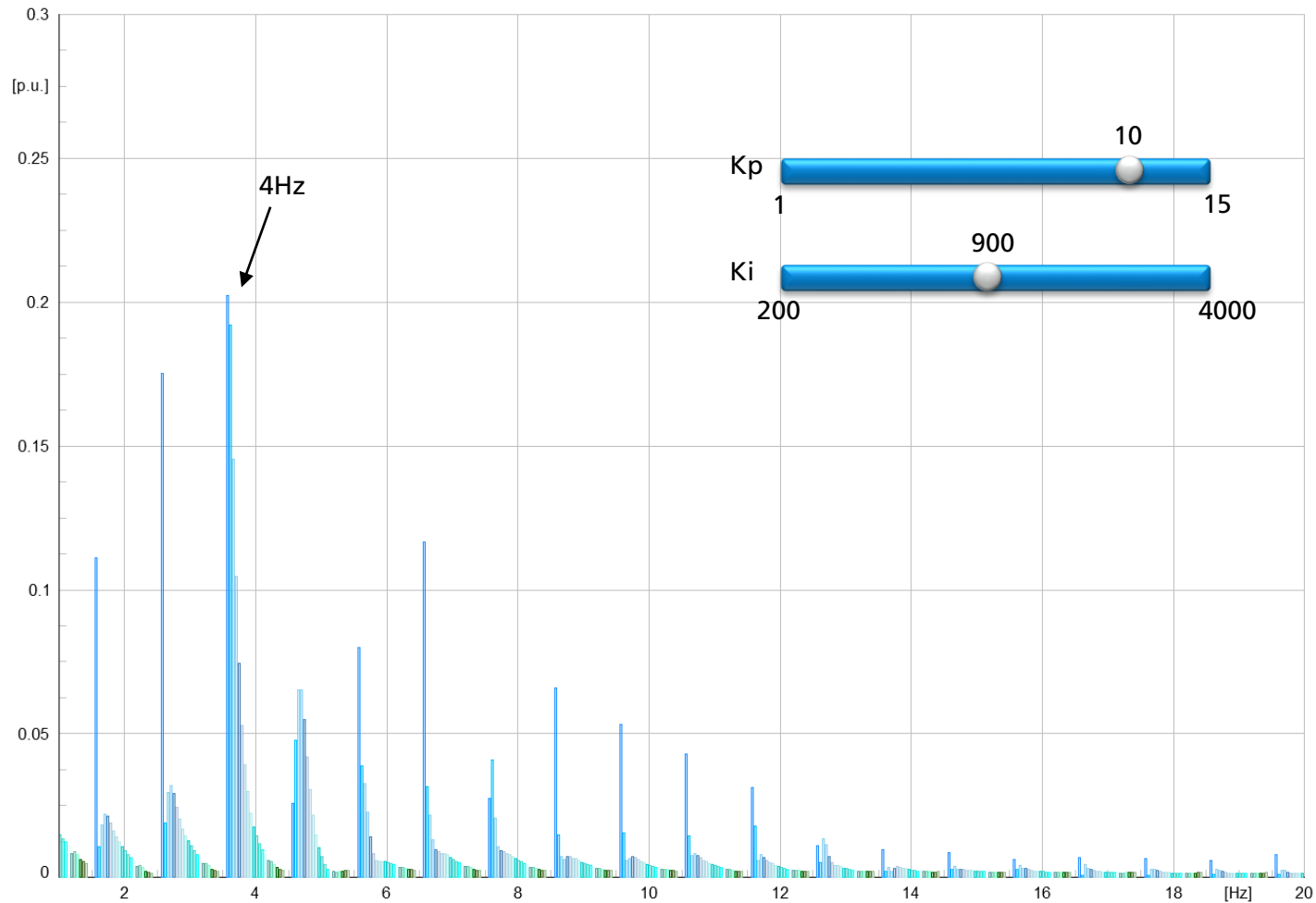
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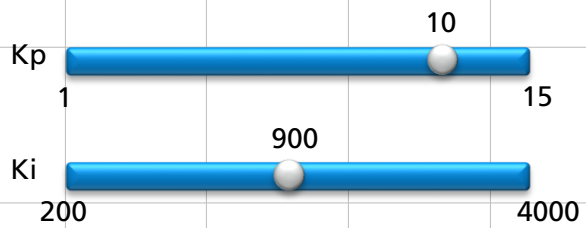
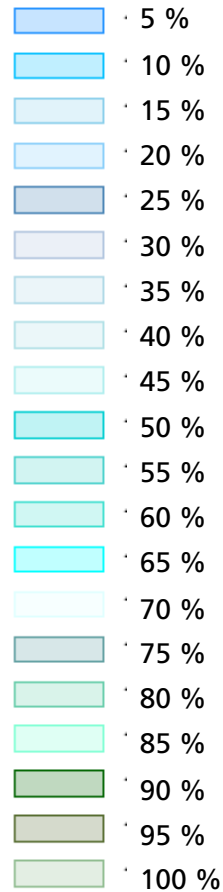
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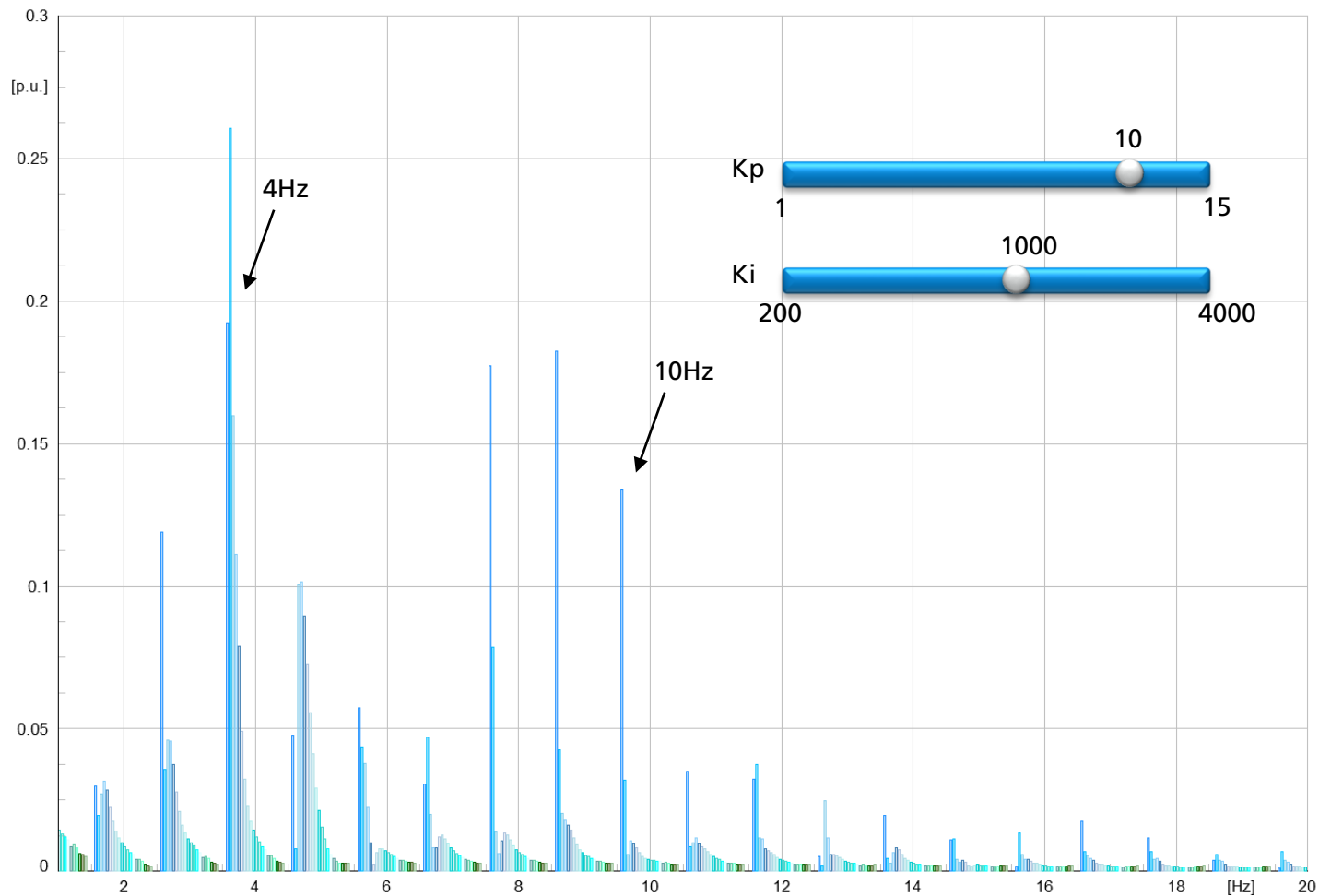
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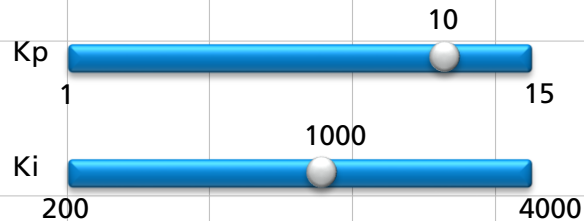
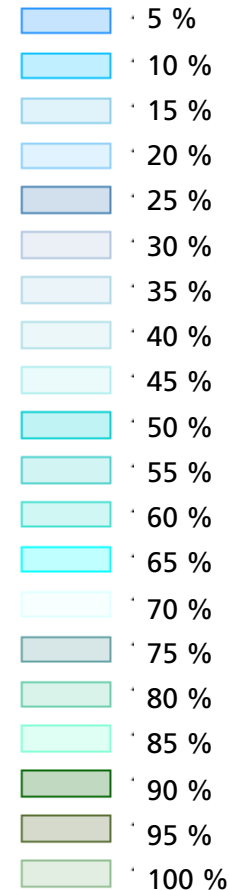
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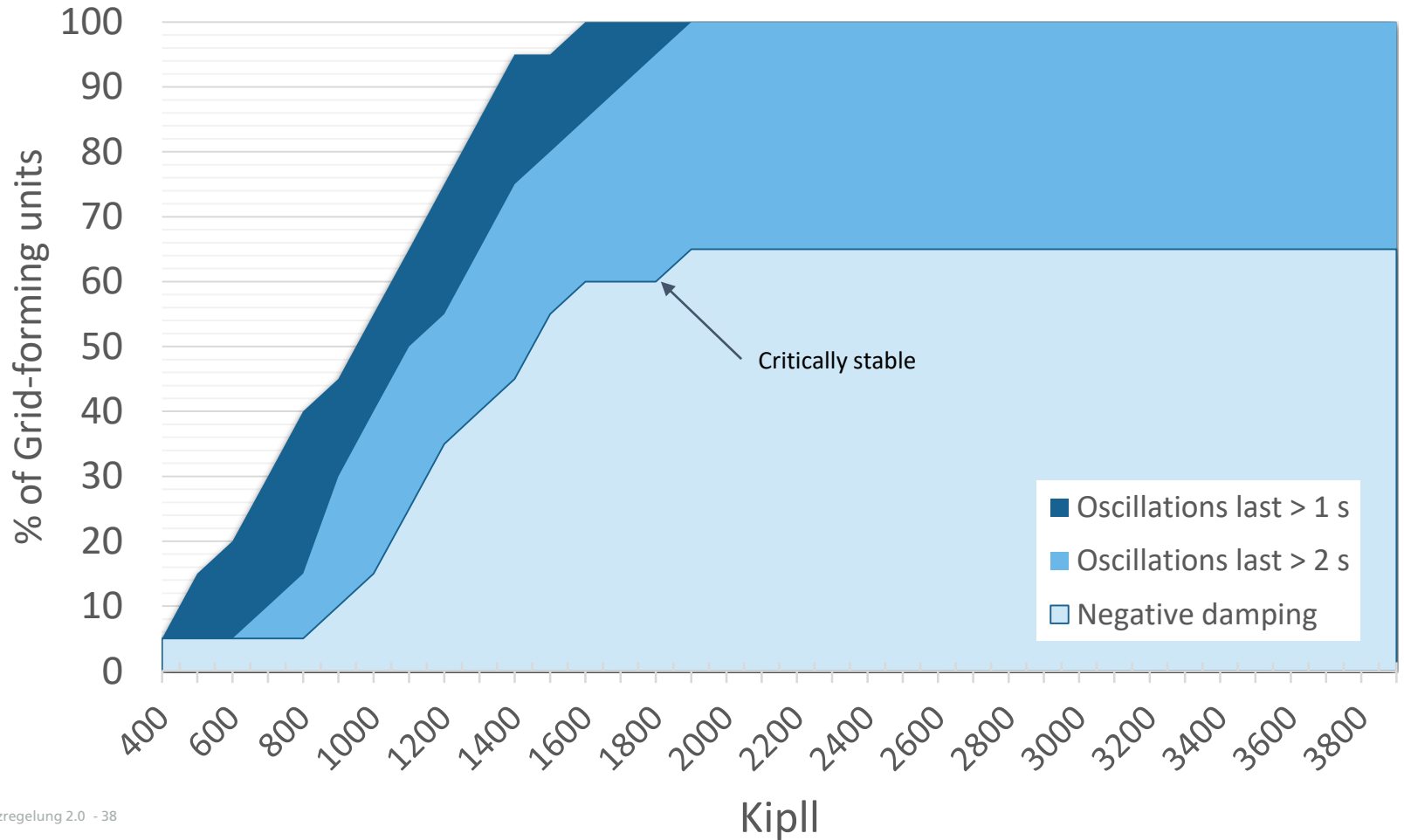


Fourier Coefficient - Magnitude



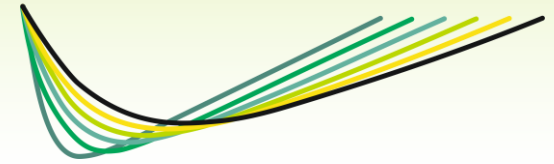
% of Grid-forming Units





Publications

- Luis David Pabón Ospina and Thierry Van Cutsem. “Emergency support of transmission voltages by active distribution networks: a non-intrusive scheme”. IEEE Transactions on Power Systems.
- Luis David Pabon Ospina, Valeria Usuga, Daniel Pabon. “Dynamic equivalents of nonlinear active distribution networks based on Hammerstein-Wiener models: an application for long-term power system phenomena”. IEEE Transactions on Power Systems.
- Luis David Pabón Ospina and Thierry Van Cutsem. “Power factor improvement by active distribution networks during voltage emergency situations”. Elsevier Electric Power Systems Research Journal.
- Luis David Pabon Ospina, Daniel Pabon and Valeria Usuga “Plausibility and implications of converter-driven oscillations induced by unstable long-term dynamics”. IEEE Transactions on Power Systems – Under review.
- “Modelling of Inverter-based Generation for Power System Dynamic Studies”, JOINT WORKING GROUP C4/C6.35/CIRED
- “Impact of low inertia network on protection and control” CIGRE WORKING GROUP WG B5C4-61.
- Luis David Pabon Ospina, “Long-term voltage stability of electric power systems hosting inverter-interfaced energy sources”. PhD dissertation – University of Kassel
- Valeria Usuga, “Dynamic Equivalent of Nonlinear Active Distribution Networks based on Hammerstein-Wiener Models: Application for Bulk Electric Power Systems Long-term Stability Phenomena”. Master Thesis – University of Magdeburg
- Daniel Pabon, “Slow-Interaction Converter-Driven Stability in Weak AC Networks: An Approach for Detection and Counteraction in Bulk Power System Studies”. Master Thesis – University of Magdeburg.



Thank you for your attention

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Konsortium Netzregelung 2.0



Budget: ca. 10.5 Mio. €
 Laufzeit: 12/2017-08/2022
 Koordination: Fraunhofer IEE
 Dr. Philipp Strauß, Dr. Thomas Degner
 netzregelung-2.0@iee.fraunhofer.de



Das diesem Bericht zugrundeliegende Vorhaben wird mit Mitteln des Bundesministeriums für Wirtschaft und Klimaschutz unter den Förderkennzeichen 0350023A-G gefördert. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt bei den Autoren und spiegelt nicht notwendigerweise die Meinung des Projektkonsortiums Netzregelung 2.0 wider.

Gefördert durch:



aufgrund eines Beschlusses
des Deutschen Bundestages