PV String Inverters with Shapeable Output Impedance Capabilities

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Key Objectives:

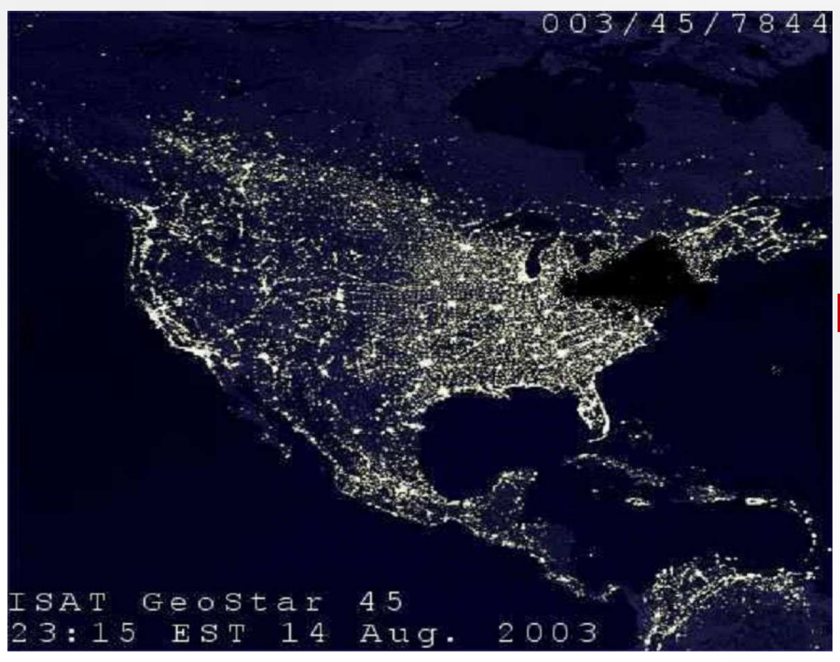
- **Improving the inclusion of Power Electronics** in the Power System
- **Leverage** the Power Electronic Devices' **high bandwidth**
- **Removing** the **harmonics perturbations** and **resonances**
- **Impedance Shaping**

Abstract:

Stability is **key** in the inclusion of renewable energies in the Power System. The **increase of available bandwidth** due to power electronics brings **new challenges**. With the **impedance shaping**, several selected frequencies can be filtered. The use of **resonant controller for tracking** offers the possibility to **choose the impedance response behaviour**, using the extra freedom degree which appears in the transfer function: **the damping coefficient.**

Introduction:

A big fault in the grid implies a black-out in modern life. Therefore, stability and robustness are critical. In the Power System transition to Renewable Energies, Grid Forming plays a main role.

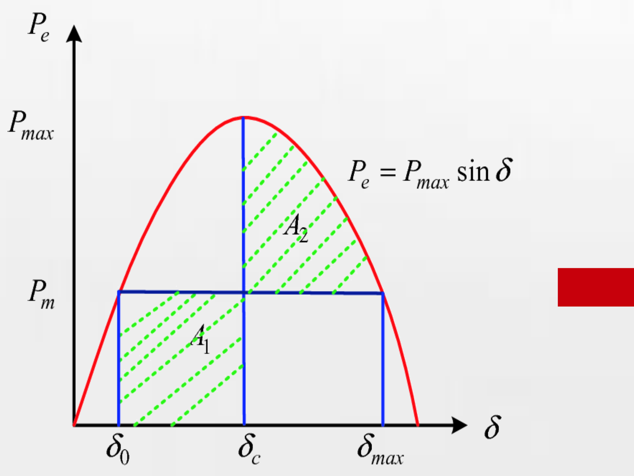


[1] Massive black-out, 2003, in the north-east of North-America

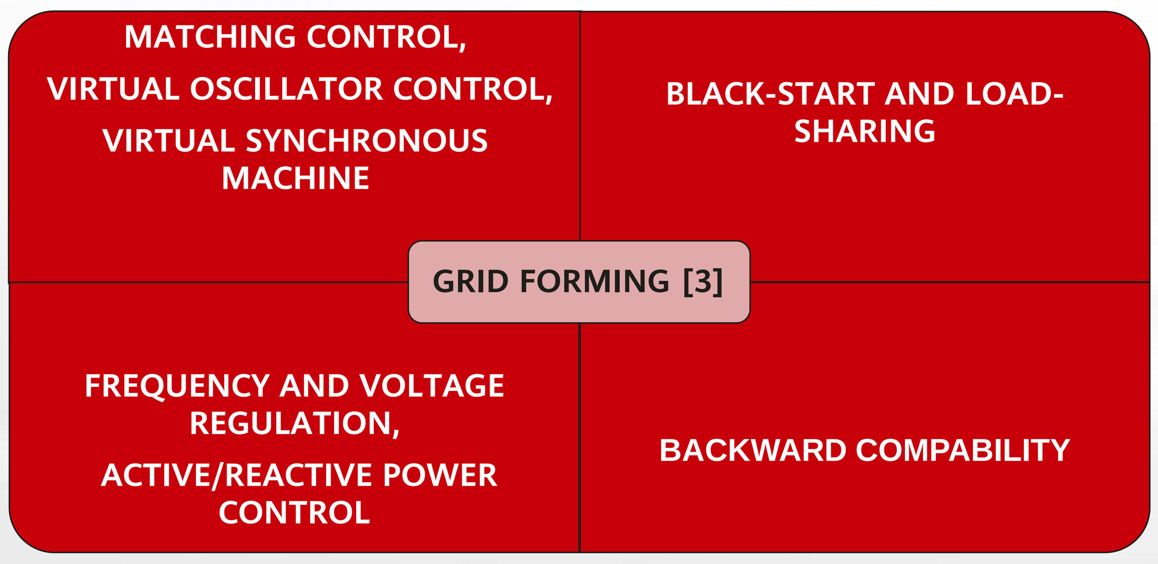
$$\frac{2H}{\omega_0}\frac{d\omega}{dt} = P_g - P_c$$

ω is the grid frequency
ω_0 is the reference grid frequency
P_g is the generated power
P_c is the consumed power
H is the inertia constant

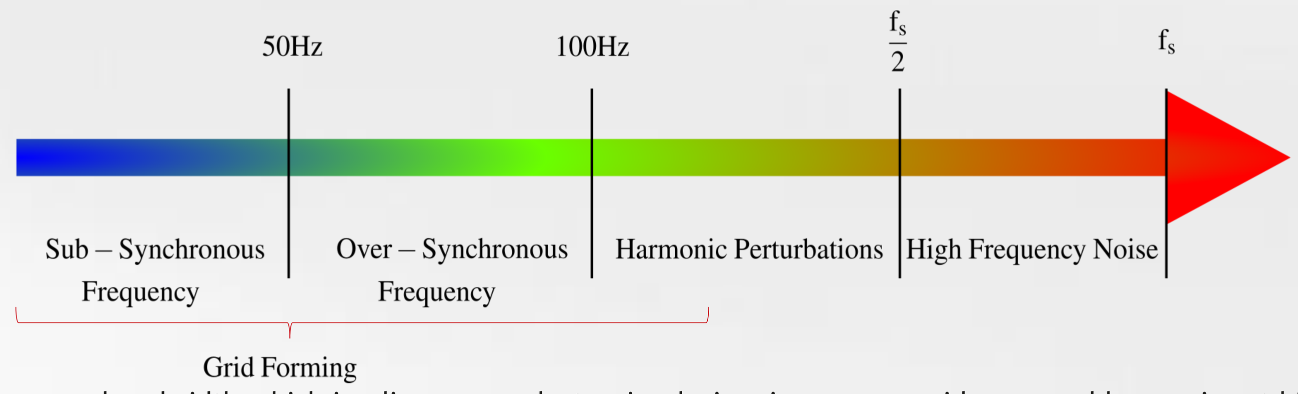
[2] Swing Equation



[2] Critical Angle in a Synchronous generator



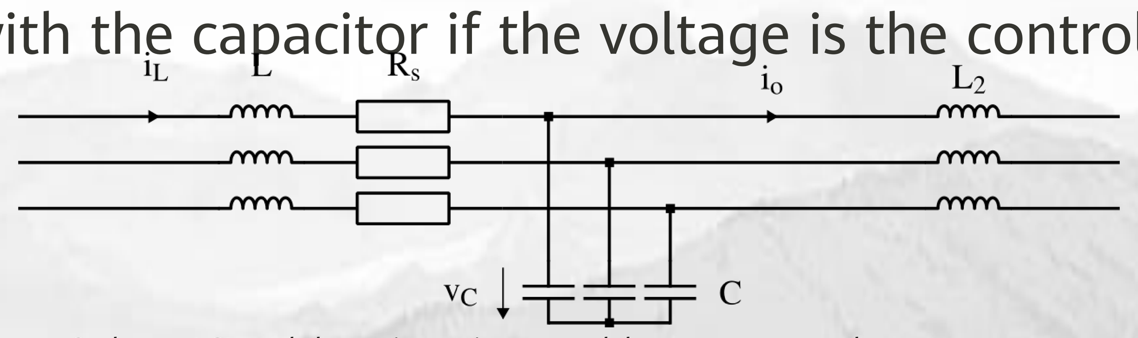
The wider bandwidth compromises stability. The state of the art proposal is passivity [4]. But resonances can appear due to the connection between a capacitive behaviour grid and an inductive one [5,7].
An impedance shaping method for converters with LCL filter is proposed, which enables impedance adjustment at selected frequencies.



Frequency bandwidth which implies power electronics devices in a power grid, new problems arise at high frequency

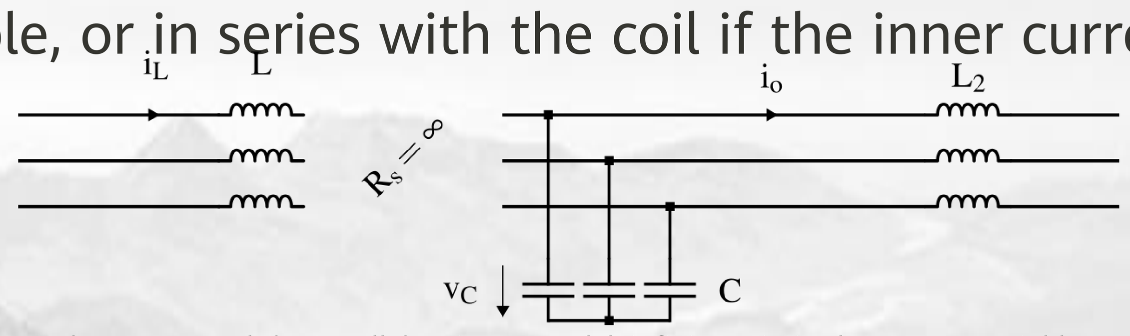
Key Progress:

Resonant controllers are used to track a signal reference. Resonant gain can be understood as a resistor, in parallel with the capacitor if the voltage is the controlled variable, or in series with the coil if the inner current is the one controlled.

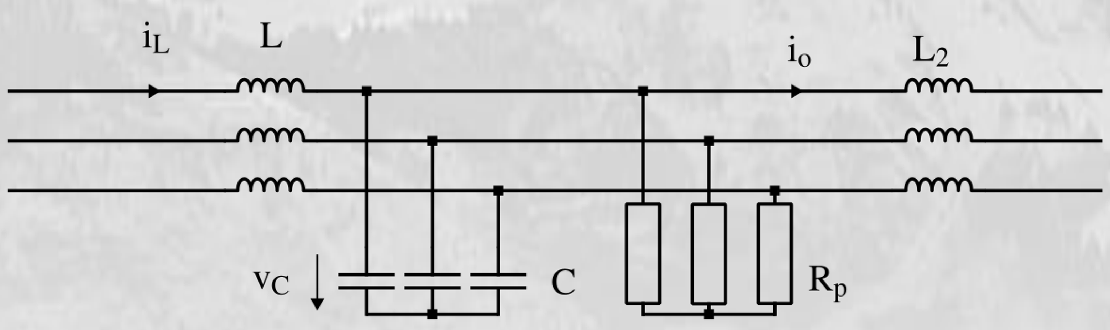


3 phases LCL and the series resistors model, resonant control on i_L

Infinite Gain Capacitive Behaviour

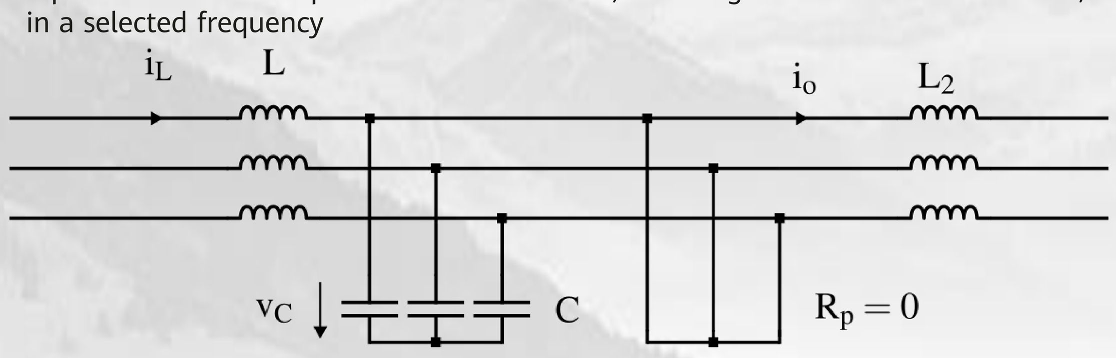


3 phases LCL and the parallel resistors model, infinite gain in the current variable, in a selected frequency

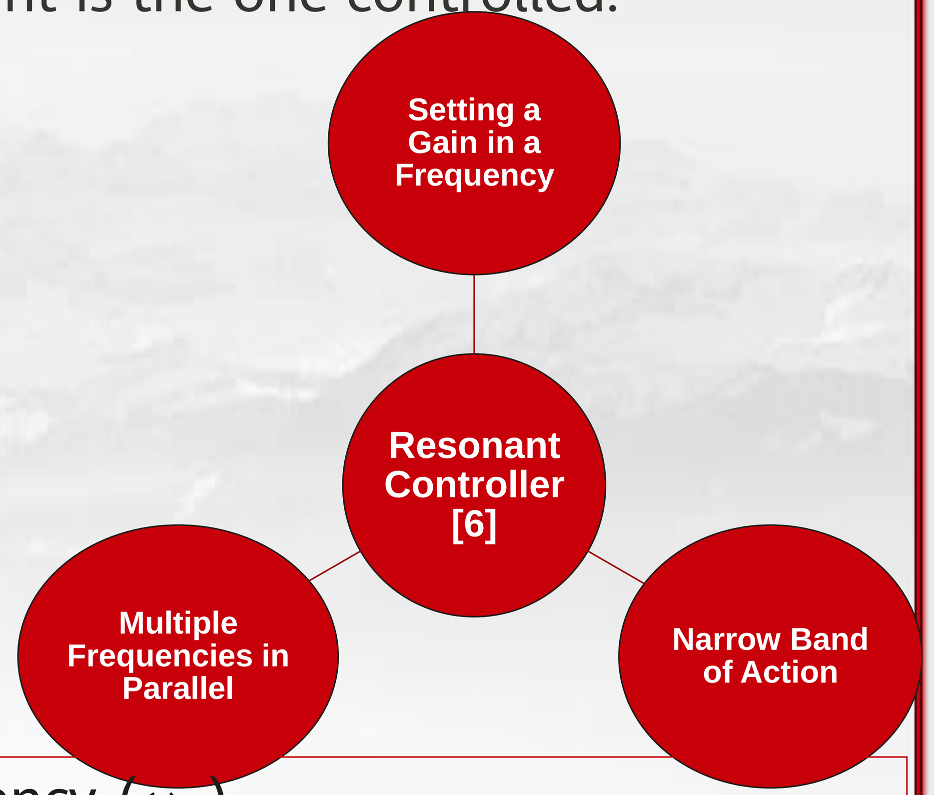


3 phases LCL and the parallel resistors model resonant control on V_C

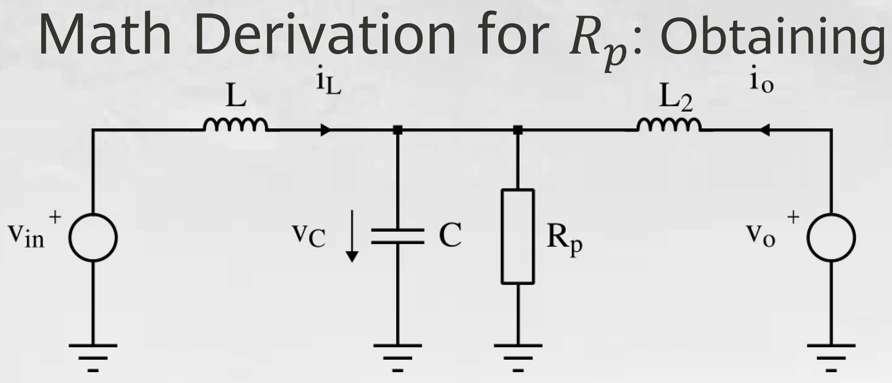
Infinite Gain Inductive Behaviour



3 phases LCL and the parallel resistors model, infinite gain in the voltage variable, in a selected frequency



Math Derivation for R_p: Obtaining ξ



LCL and the parallel resistor model

$$L\omega j i_L = v_{in} - v_C$$
$$C\omega j v_C = i_L + i_o$$

In the Resonant Frequency (ω_n)

$$v_{in}(s) \cong \frac{K_2 s + K_1}{s + 2\xi\omega_n s + \omega_n^2} e^{-\tau s} v_C(s) \xrightarrow[\text{Polar}]{\{s=j\omega\}} v_{in} \cong -\left(\frac{K_2}{2\xi\omega_n} + \frac{K_1}{2\xi\omega_n^2 j}\right) e^{-\tau\omega_n j} v_C$$

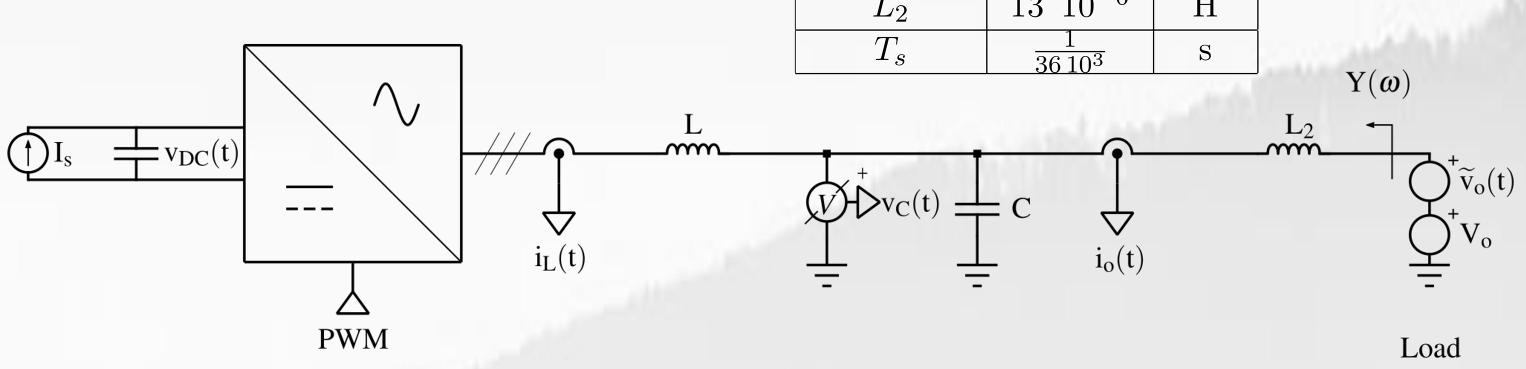
$$\left(\frac{K_2}{2\xi\omega_n}\cos(\omega_n\tau) - \frac{K_1}{2\xi\omega_n^2}\sin(\omega_n\tau)\right) = -1 \qquad \left(\frac{K_2}{2\xi\omega_n^3 L}\cos(\omega_n\tau) - \frac{K_1}{2\xi\omega_n^2 L}\cos(\omega_n\tau)\right) = \frac{1}{R_p}$$

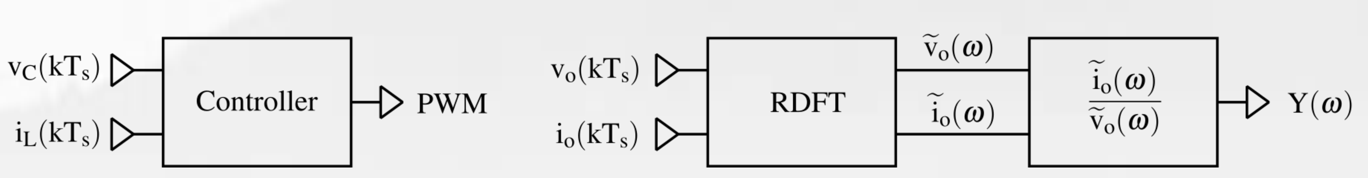
Simulations:

Impedance response by perturbation frequency sweep

$$K_{RES\,fund} = [K_{f1} \quad K_{f2}] = [-0{,}02 \quad 0{,}0199960]$$
$$K_{RES\,ind} = [K_{i1} \quad K_{i2}] = [-0{,}01 \quad 0{,}000673]$$

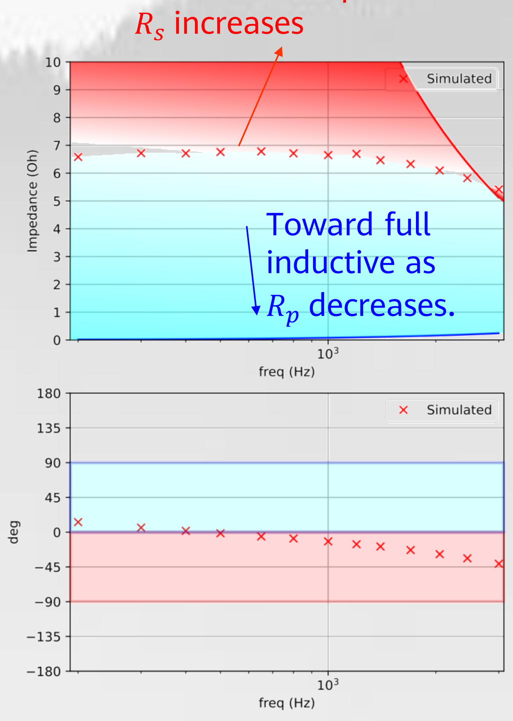
Parameter	Value	Unit
L	$320\ 10^{-6}$	H
C	$9{,}9\ 10^{-6}$	F
L_2	$13\ 10^{-6}$	H
T_s	$\frac{1}{36\ 10^3}$	s



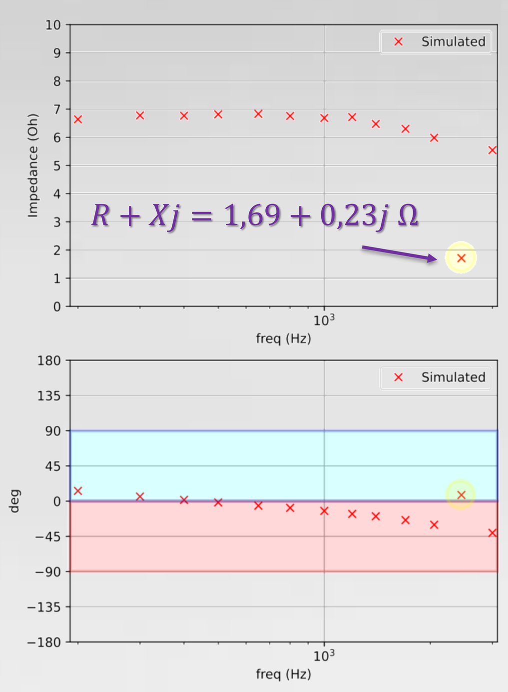


Capacitive

Inductive

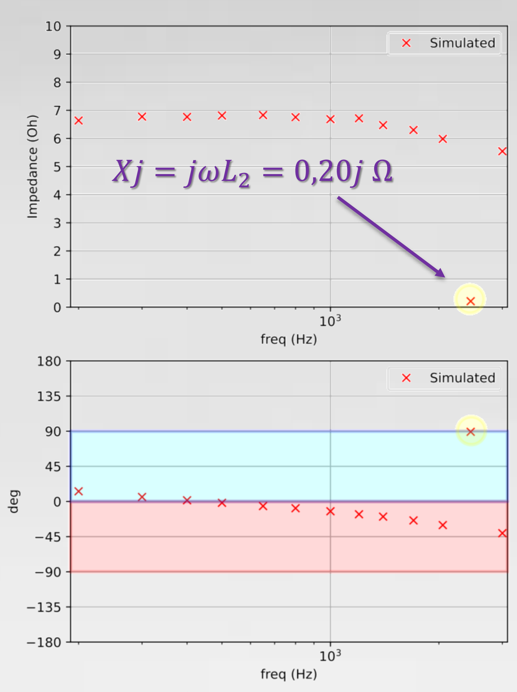


Definition of the Shaping Region



Resistive Behaviour

$\xi = 0{,}002$



Inductive Behaviour

$\xi = 0$

Conclusions:

The **proposed method** allows to **modify grid impedance**, hence reducing **harmonics perturbations** and **resonances in selected frequencies**. This is achieved by **adding the damping factor** to the resonant controller used for tracking.

References:

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HUAWEI

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