National HVDC Centre
University of Strathclyde
Joint Research Programme

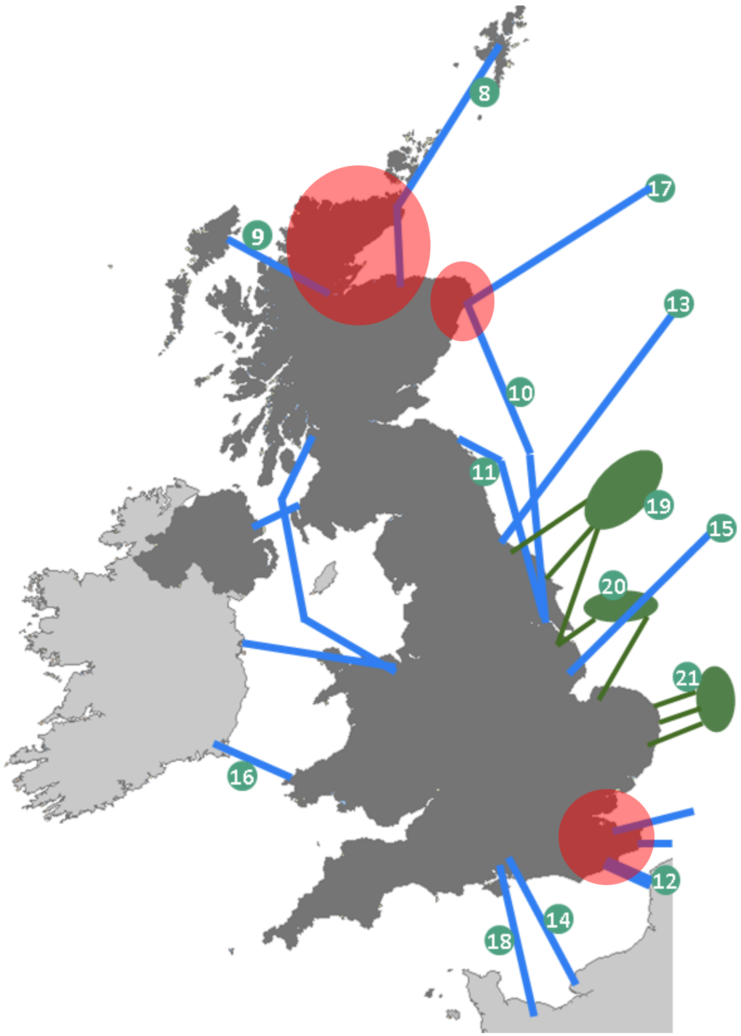
Assessment and Mitigation of Converter Interactions

27 June 2019

Contents

HVDC Schemes in GB Network

2027 > 16 GW Total Installed HVDC Capacity



New Island Links
8) Shetland
9) Western Isles

New Embedded Links
10) Eastern Link 1
11) Eastern Link 2

New Interconnectors
12) ElecLink
13) NSL
14) Aquind
15) Viking
16) GreenLink
17) NorthConnect
18) IFA2

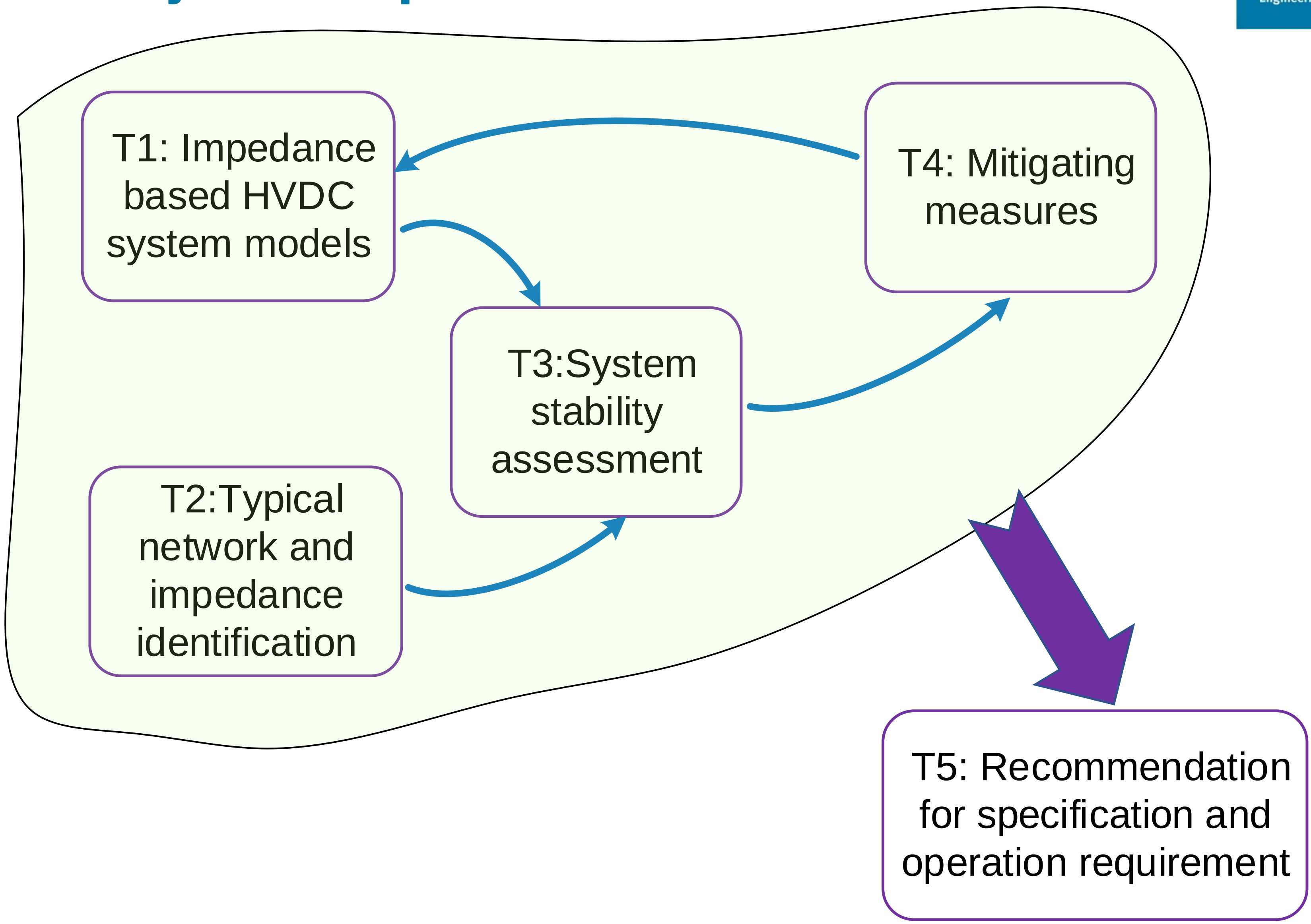
New Offshore Wind Connections
19) Dogger Bank
20) Hornsea
21) Norfolk Vanguard

University of Strathclyde Engineering

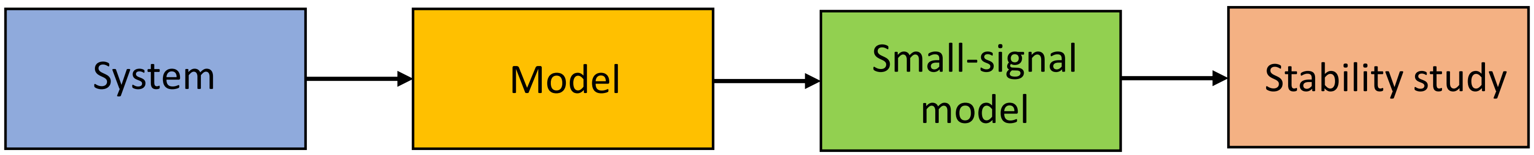
1. Project background

- The rapid growth of converter-interfaced renewable sources and HVDC transmission links in the GB grid.
- The gradual reduction of conventional synchronous machine based generations in the GB network.
- Converter dynamics are mainly determined by the converter configuration, the control structure and gains.
- The wide timescale control dynamics of converters can lead to adverse interactions among converters located in close vicinities and the power networks, potentially leading to oscillations across a wide frequency range.

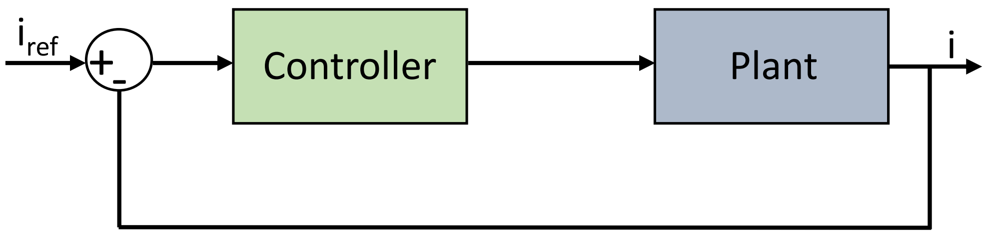
1. Project Scope



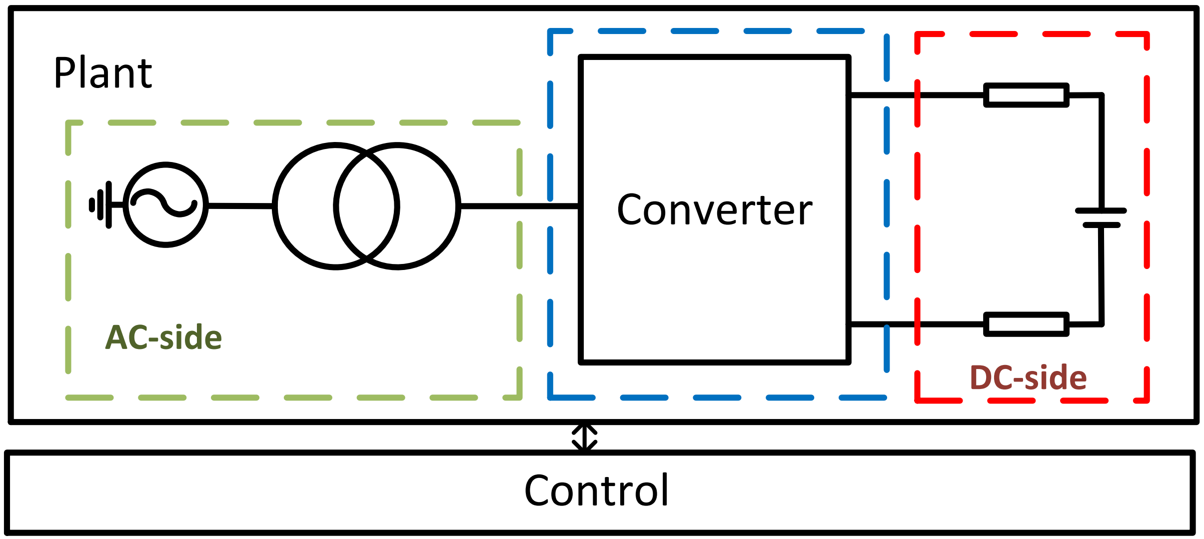
Study of system stability

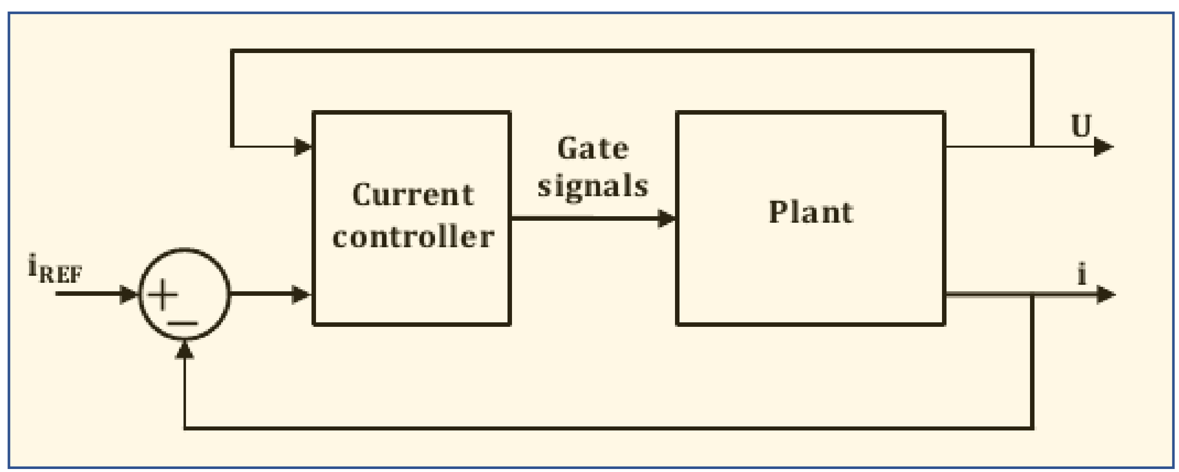


- Develop system model – usually non-linear (understand the system/plant)
- Develop a small-signal model of the system in the frequency domain (model linearlisation)
- Apply classic feedback control theory to study the system stability

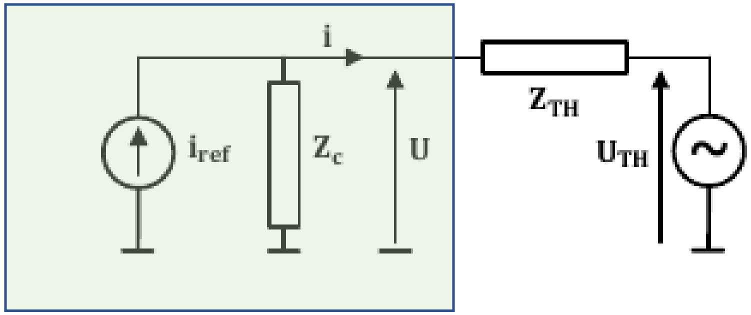


Modelling of grid connected converter system





Impedance based stability analysis



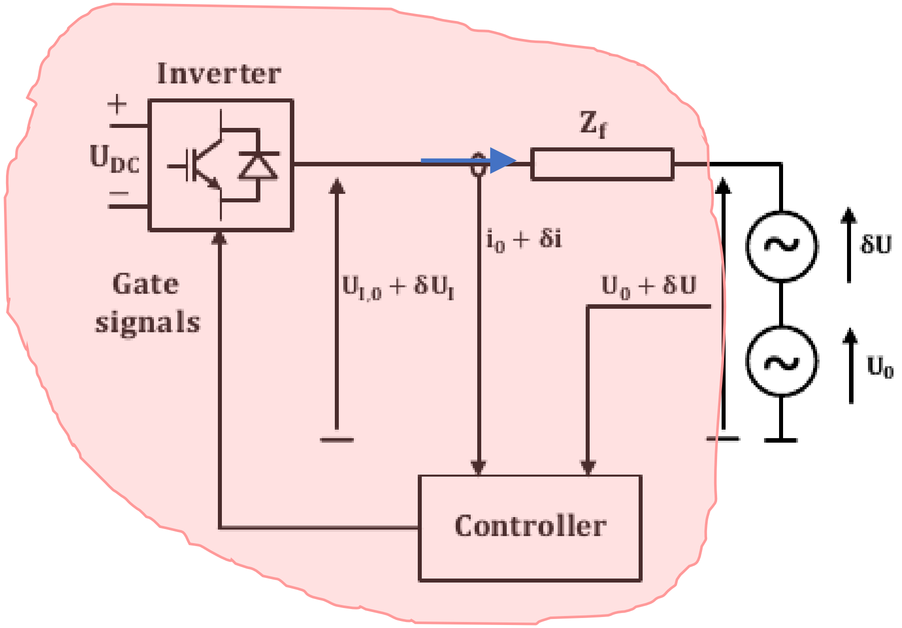
Impedance based Small-signal equivalent circuit

Why impedance based method:

- The converter is represented by a Norton equivalent circuit
- The converter is described in terms of its impedance or, equivalently, admittance.
- No detailed device control parameters are required.
- It only requires information on the equivalent impedance of the grid.

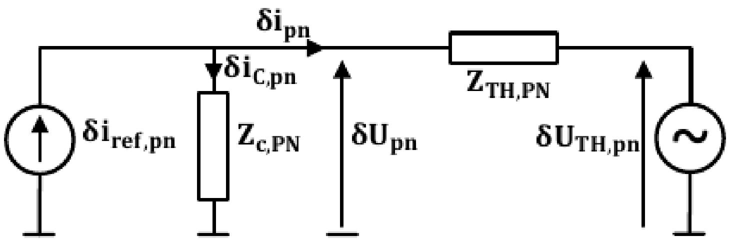
Impedance based stability analysis

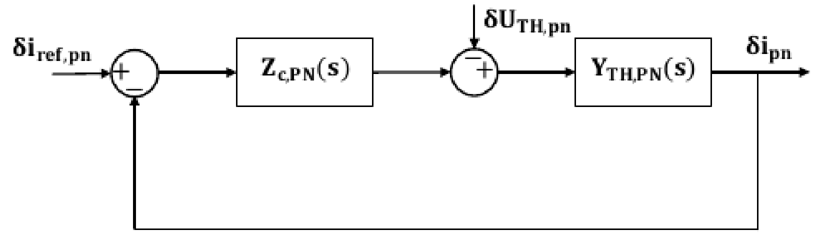
$$Y_C(s) = -\frac{\delta i(s)}{\delta U(s)}$$



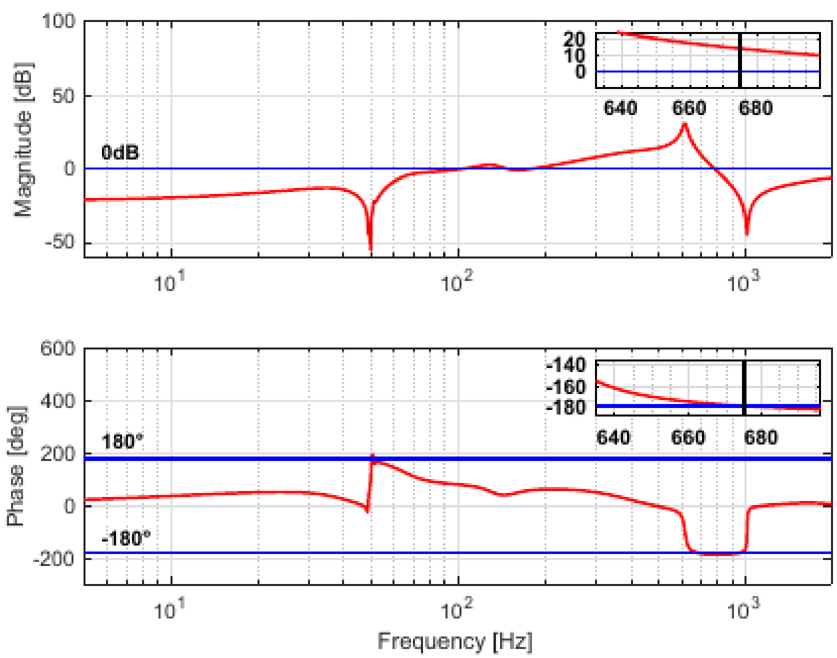
- It is defined based on small-signal quantities, hence, it describes the linearised dynamics of the converter, at its operating point
- It takes into account the controller dynamics, regardless of its internal structure.

Impedance based stability analysis





The stability assessment calculates the open-loop gain of the system

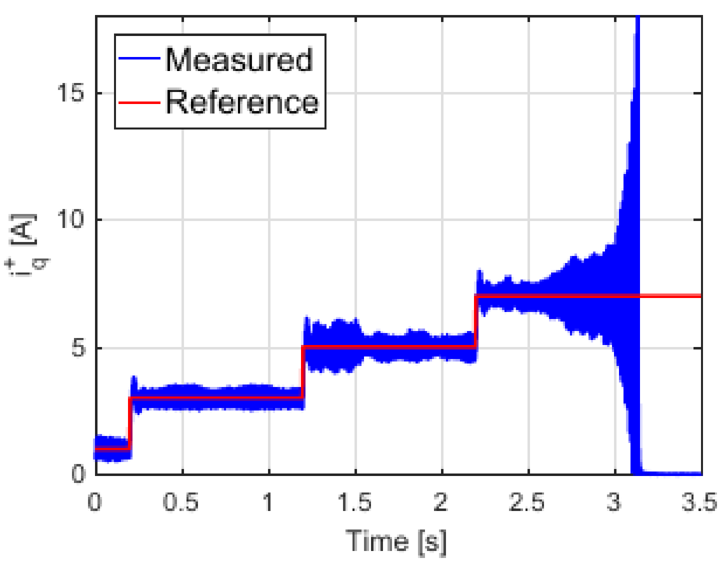


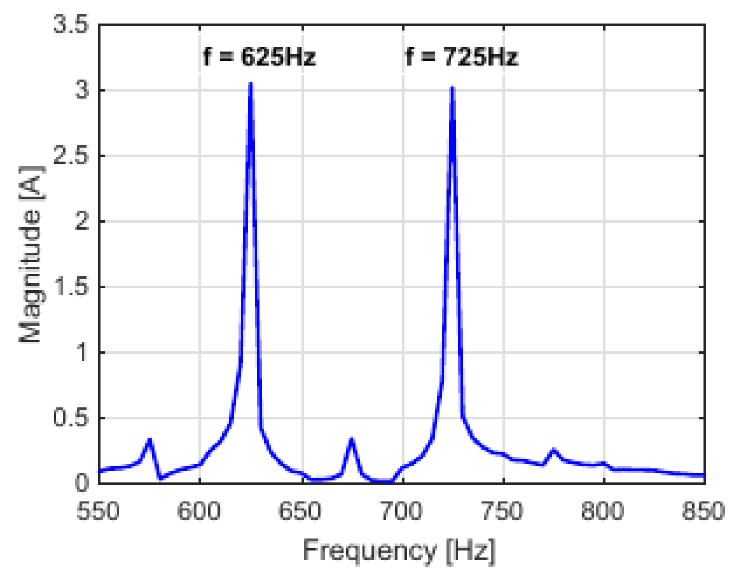
Bode plot of the system eigenvalues (positive sequence)

The resonance of the system is predicted to be at $675Hz$

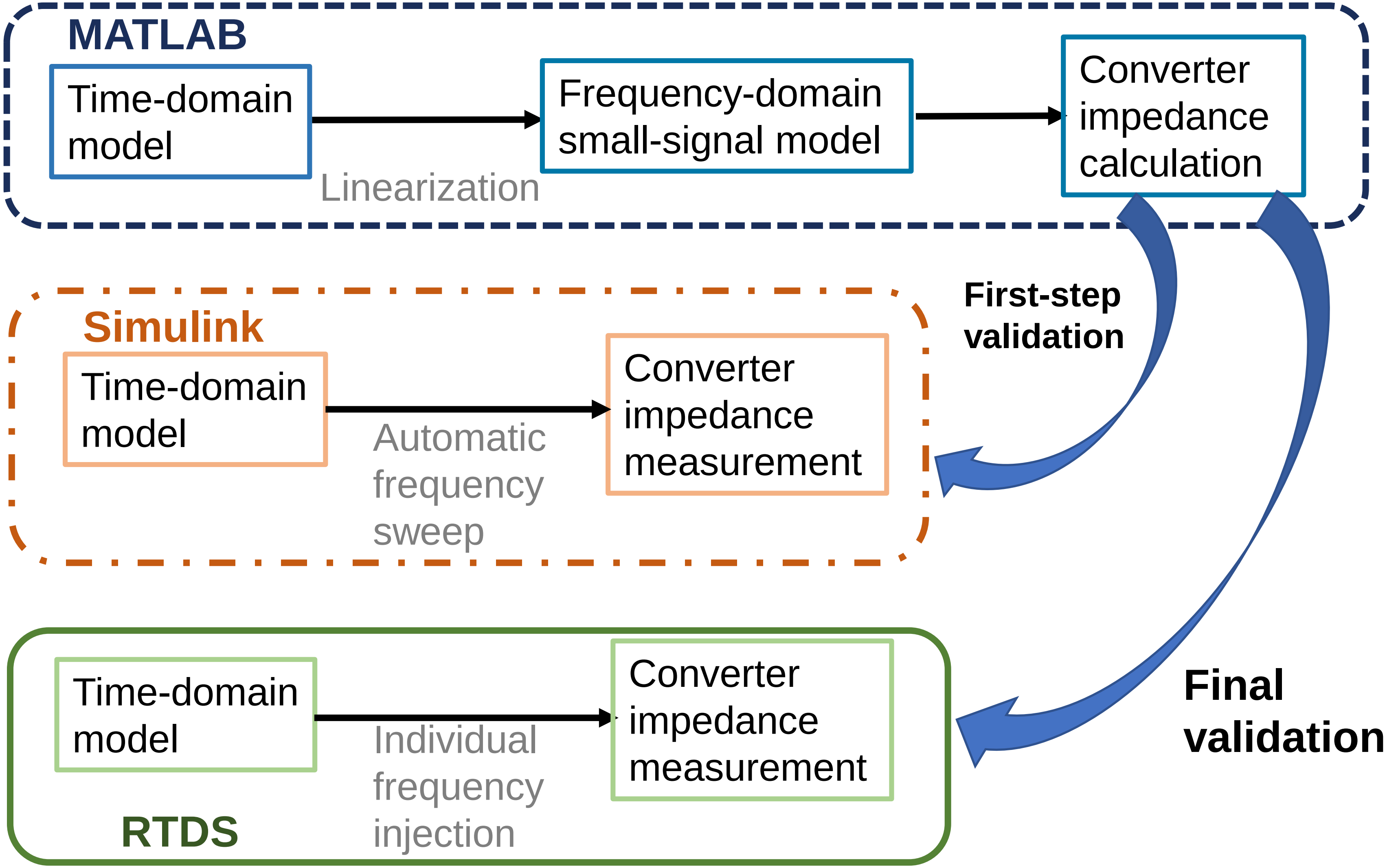
Model validation

- Increasing the power injected into the grid leads to system resonance.
- The spectral analysis of the signal reveals the excitation of a resonance at $675Hz$ (675 Hz in dq refer to 725Hz and 625Hz in abc)





MMC impedance calculation & validation:

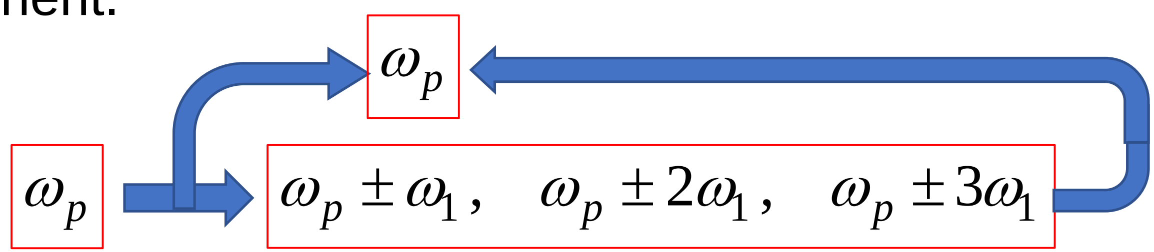


MMC Small-signal modelling -challenges

- For 2-level converters, the response of the system is linear

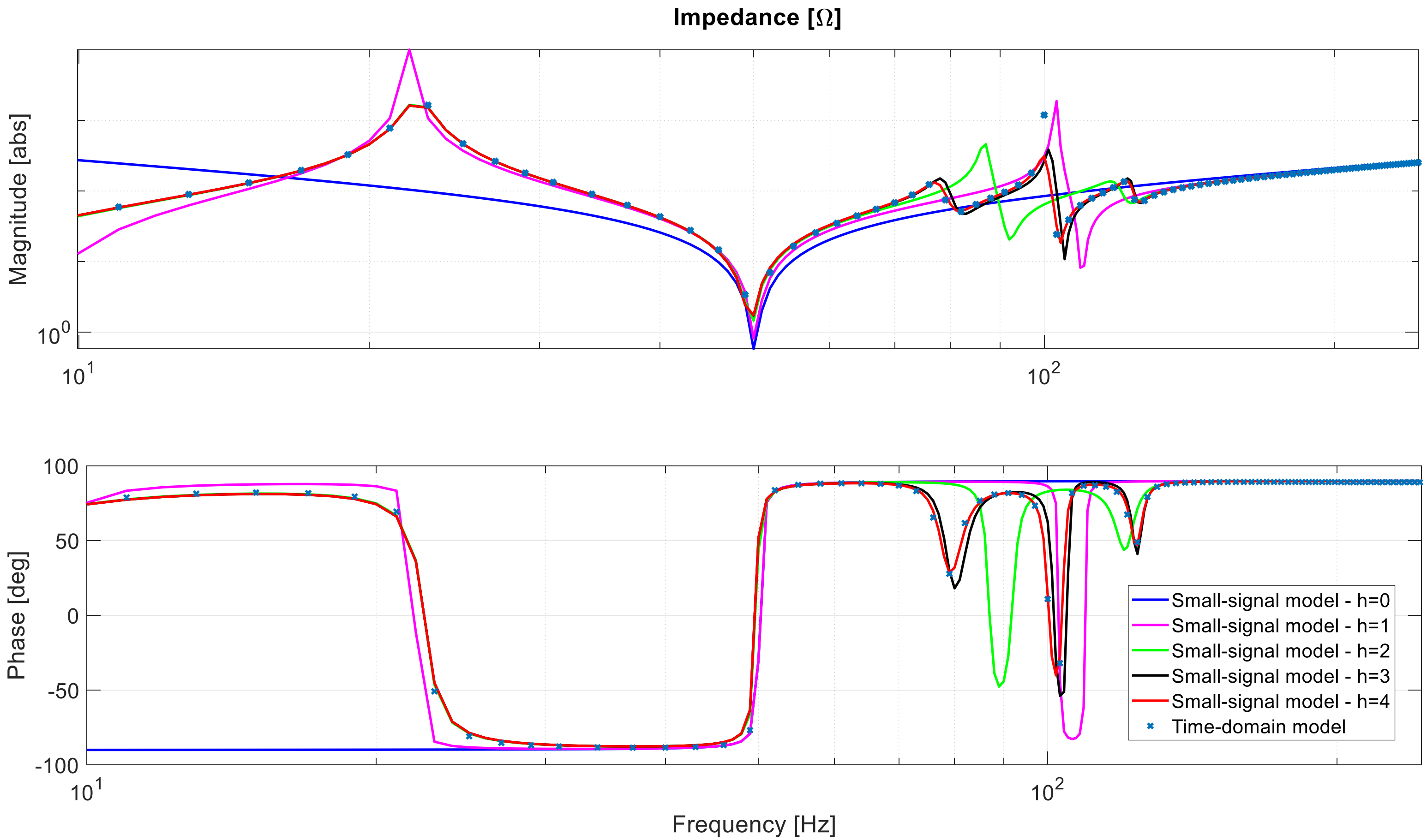
$$\omega_p \rightarrow \omega_p$$

- MMC internal circuits involve multiple harmonic components, e.g. 2nd harmonic at the arm current and arm capacitor voltage.
- The internal interaction between different harmonics in MMC means different frequency components can be excited by a single frequency component.



- This requires to model the internal harmonic interactions.
- Harmonic State Space (HSS) modelling is thus used.

MMC impedance



H - the number of harmonic orders considered in the interaction modelling

Ongoing work

- MMC converter impedance model has been developed.
- Integrate typical MMC controller into the converter model.
- Model validation using time domain RTDS simulation.

- Network model and impedance identification
- ….
- ….