Evaluation of the Accuracy of RTDS VSC Models Determined from Frequency Scanning

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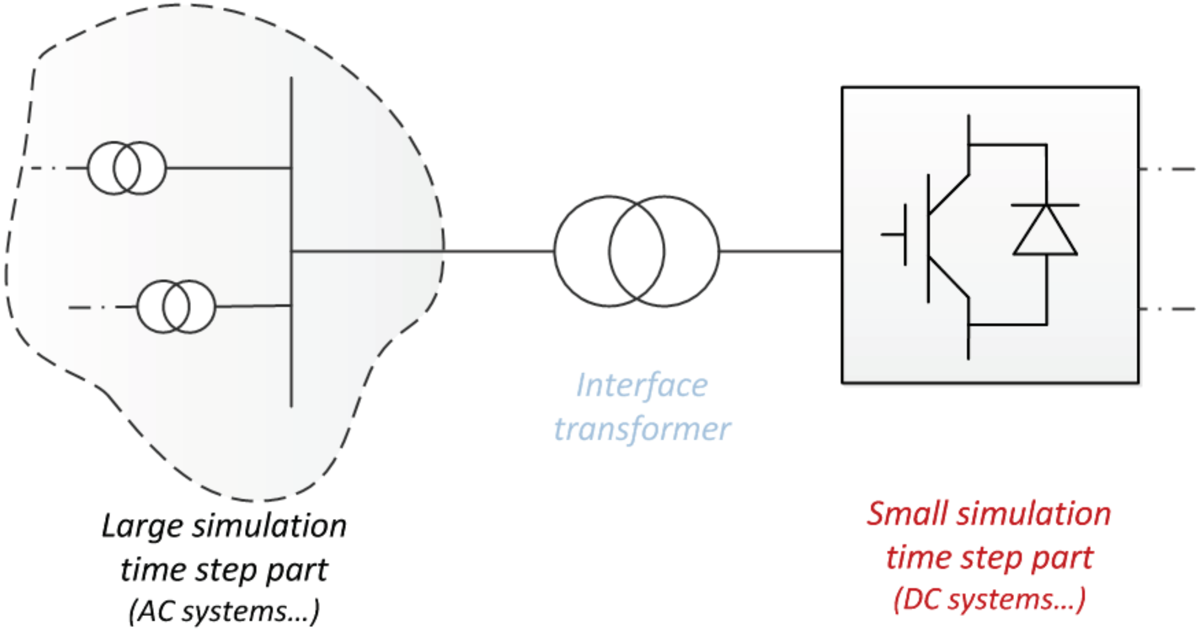
VSC models (IGBT based) in RTDS

Small time step module

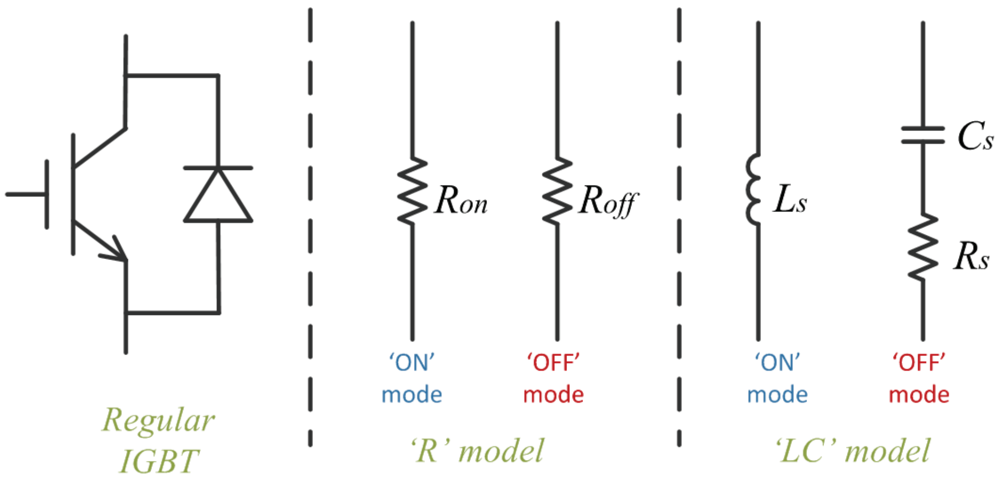


The 2-level converter is usually modeled using a small time step to improve accuracy…

Dommel Companion Circuit Representation for L and C

2-Level VSC models (IGBT based) in RTDS

Converter Model type ('R' and 'LC')



$$\frac{2L_s}{\Delta t_s} = \frac{\Delta t_s}{2C_s} + R_s$$

Dommel resistances are the same for 'ON' and 'OFF' states

LC Resonance?

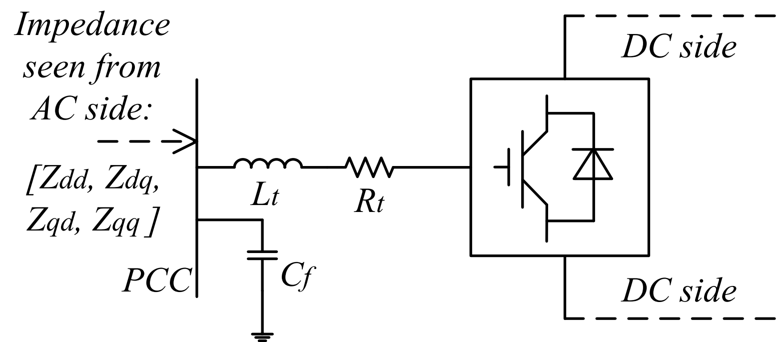
'R' Type: 'ON' as a small resistor and 'OFF' as a large one
'LC' type: 'ON' as a small inductor and 'OFF' as a small capacitor in series with a resistor [1-2]

Converter Model Evaluation

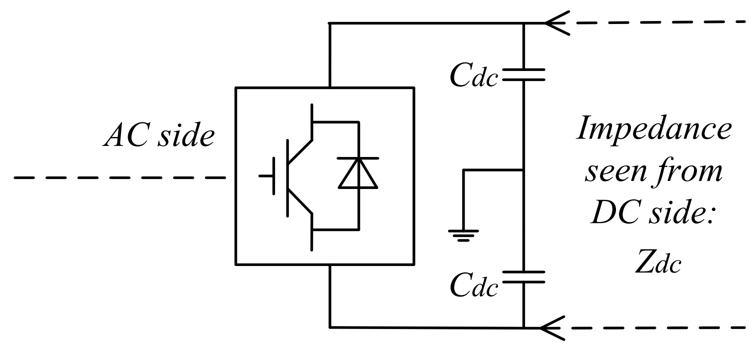
Methodology

Check the frequency response looking from the external terminals (ac and dc side) of the converter, which requires:

- A simple test system (for both 'R' and 'LC type')
- Frequency scanning method
- An analytical model for sanity check



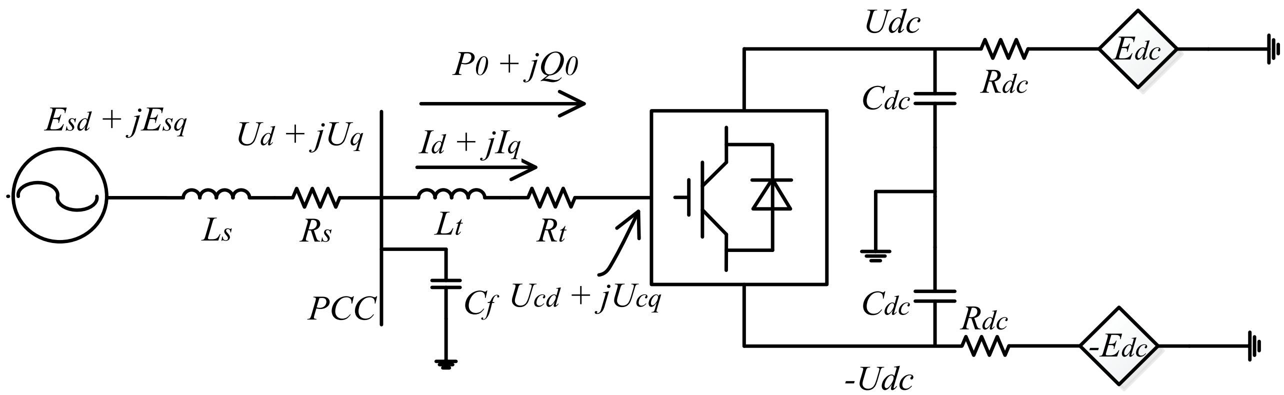
a. impedance seen from AC side



b. impedance seen from in AC side

Converter Model Evaluation

Case system

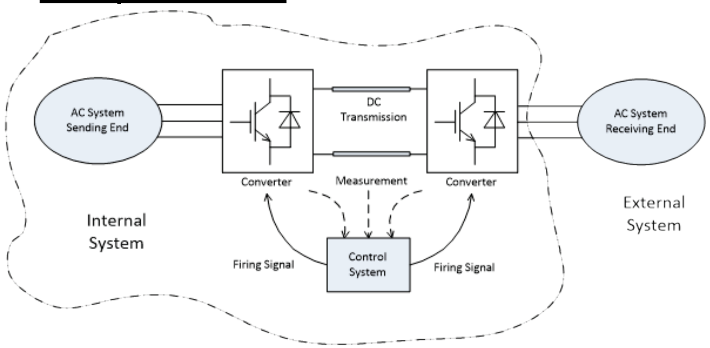


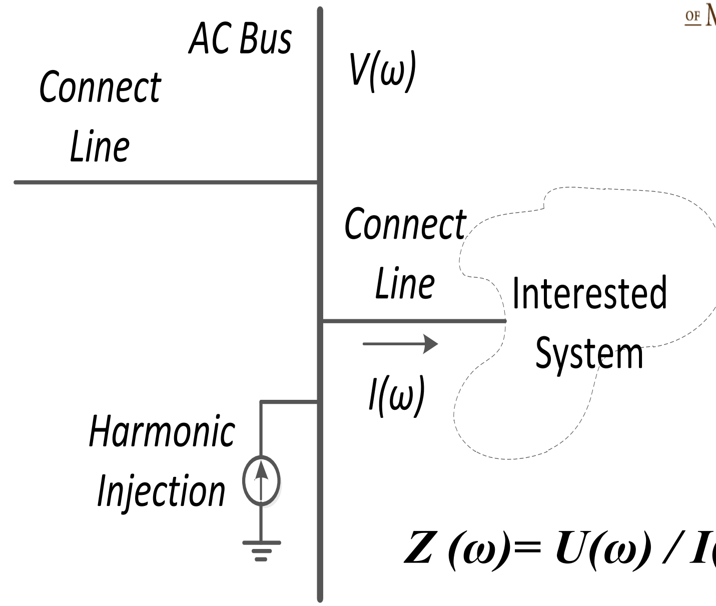
Case system: R-L ac system, ac filter, dc converter (either 'R' or 'LC'), dc capacitor and line resistance, a Phase Locked Loop as well as a decoupled controller.

Simulation time step: 50us for large step and 2us for small step

Network Stability using Impedance Scan (Yi Qi, M.Das)

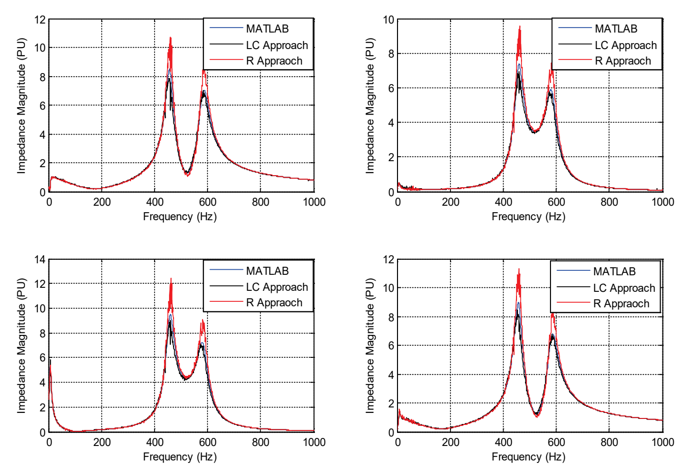
Ratio between *Voltage & current spectral components* under different *Frequencies.* [1-2]





$$Z(\omega) = U(\omega) / I(\omega)$$

✓ *Experimental approach to determine transfer function*



Converter Model Evaluation

Frequency scanning

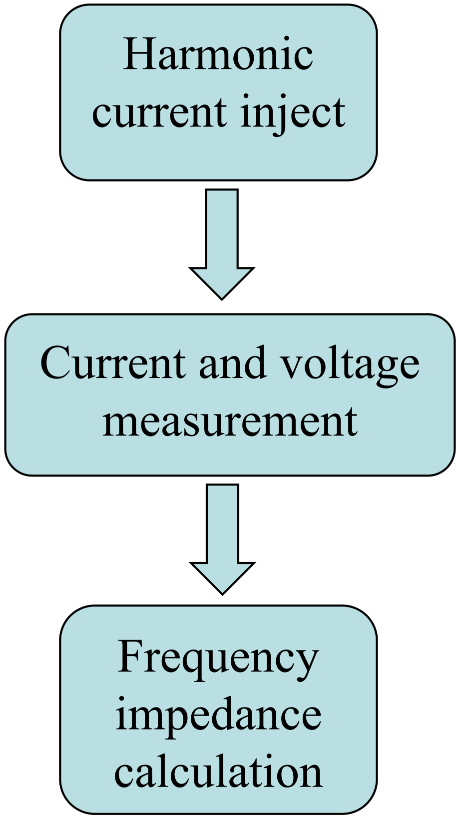
A. Multiple frequency injection [3]:

$$X_{inj}(t) = \sum_{f=fmin}^{fmax} X_{mag} \cos\left(2\pi f t + k_{inj} f^2\right)$$

B. Discrete Fourier Transform (DFT):

$$X_k = \frac{2}{N}\sum_{n=1}^{N} x_n e^{-j2\pi k\frac{n}{N}}$$

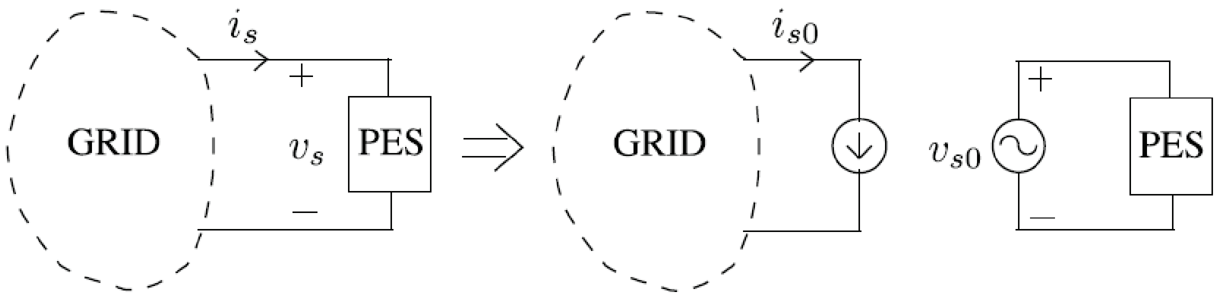
C. Impedance Result:



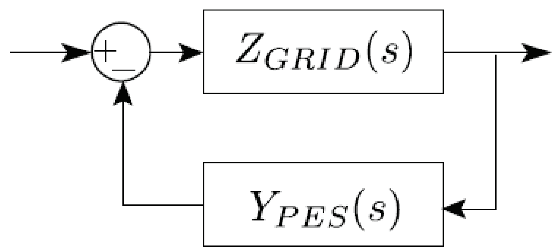
$$Y(f) = X(k\Delta f_o) / Xinj\ (k\Delta f_o) = I(\omega) / V(\omega)$$

Grid Interaction Studies

Power Electronic System (PES) Connected to Grid:



Small Signal Model:



Closed Loop Transfer function:

$$T.F = Z_{GRID}(s)(I + Y_{PES}(s)Z_{GRID}(s))^{-1}$$
$$= (Z_{GRID}(s)^{-1} + Y_{PES}(s))^{-1}$$

Converter Model Evaluation

Analytical model

The analytical model is built under

d-q domain [4]

considering the effect of *the 'ON' and 'OFF' resistance.*

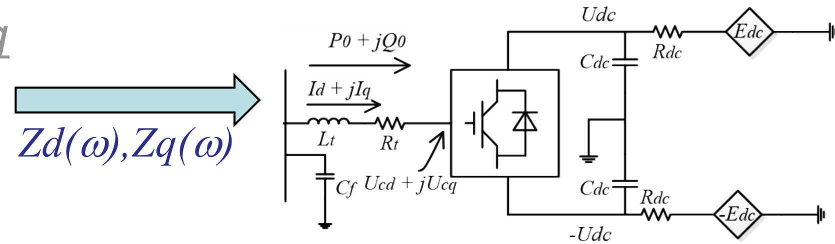
AC side and DC side voltage-current relationship:

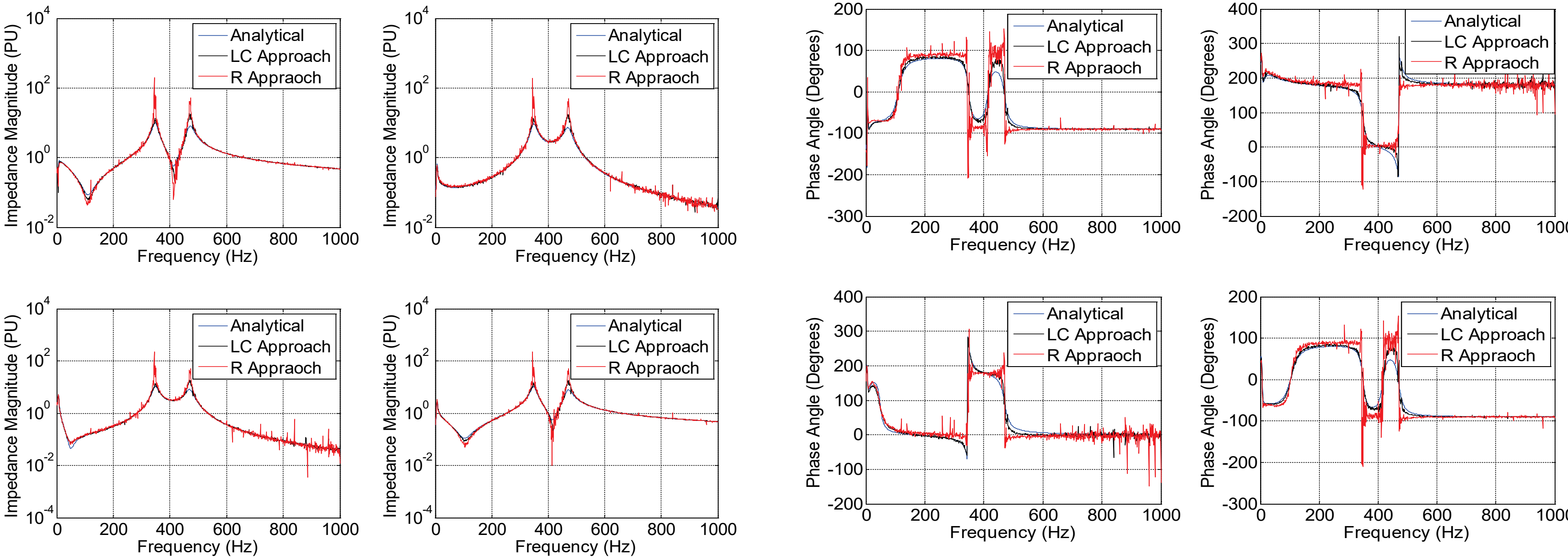
$$\begin{bmatrix}\Delta V_d(s)\\ \Delta V_q(s)\end{bmatrix} = \begin{bmatrix}\Delta V_d(s)\\ \Delta V_q(s)\end{bmatrix} = \begin{bmatrix}Z_{dd}(s) & Z_{dq}(s)\\ Z_{qd}(s) & Z_{qq}(s)\end{bmatrix}\begin{bmatrix}\Delta I_d(s)\\ \Delta I_q(s)\end{bmatrix}$$

$$\Delta V_{dc}(s) = Z_{dc}(s)\Delta I_{dc}(s)$$

This small signal result is dependent on the operating point.

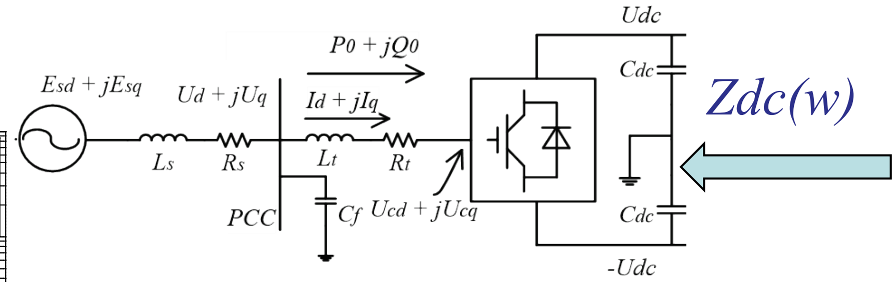
Comparison of Results, ac side: Operating point 1, $P0 = 1.0; Q0 = 0.0$

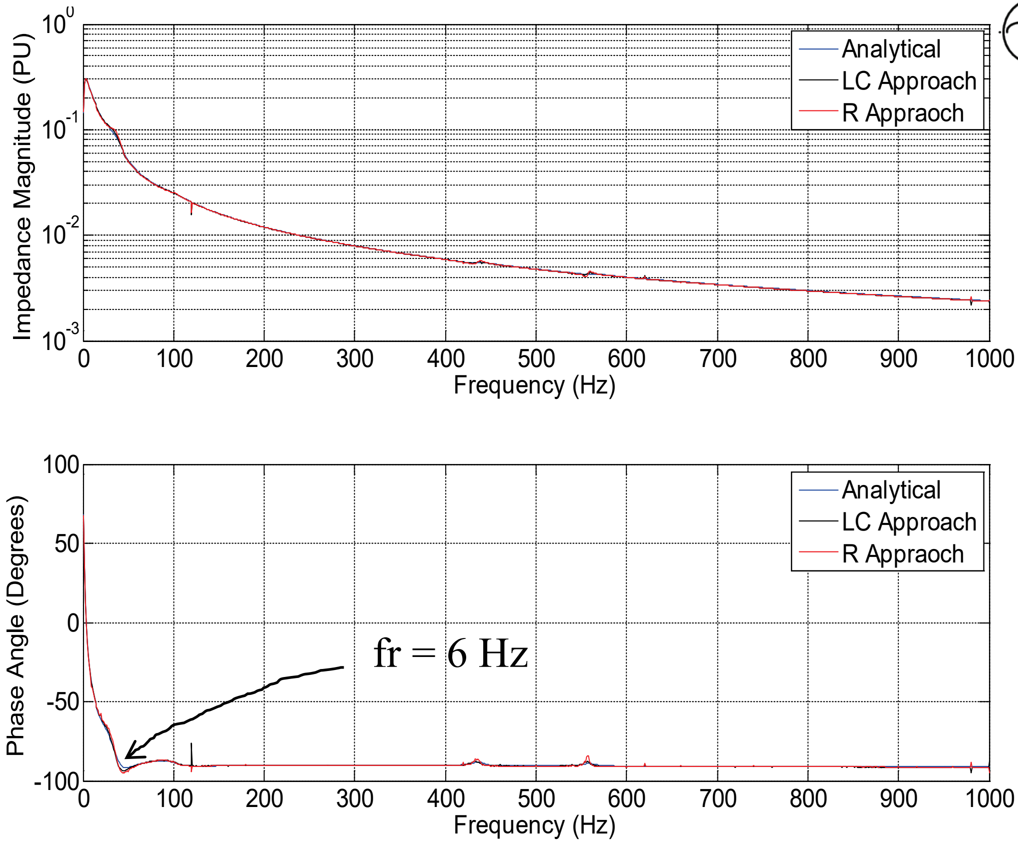




AC side impedance Zdd Zdq Zqd Zqq (OP 1), left: magnitude; right: phase angle

Comparison of Results, dc side: Operating point 1, $P0 = 1.0; Q0 = 0.0$

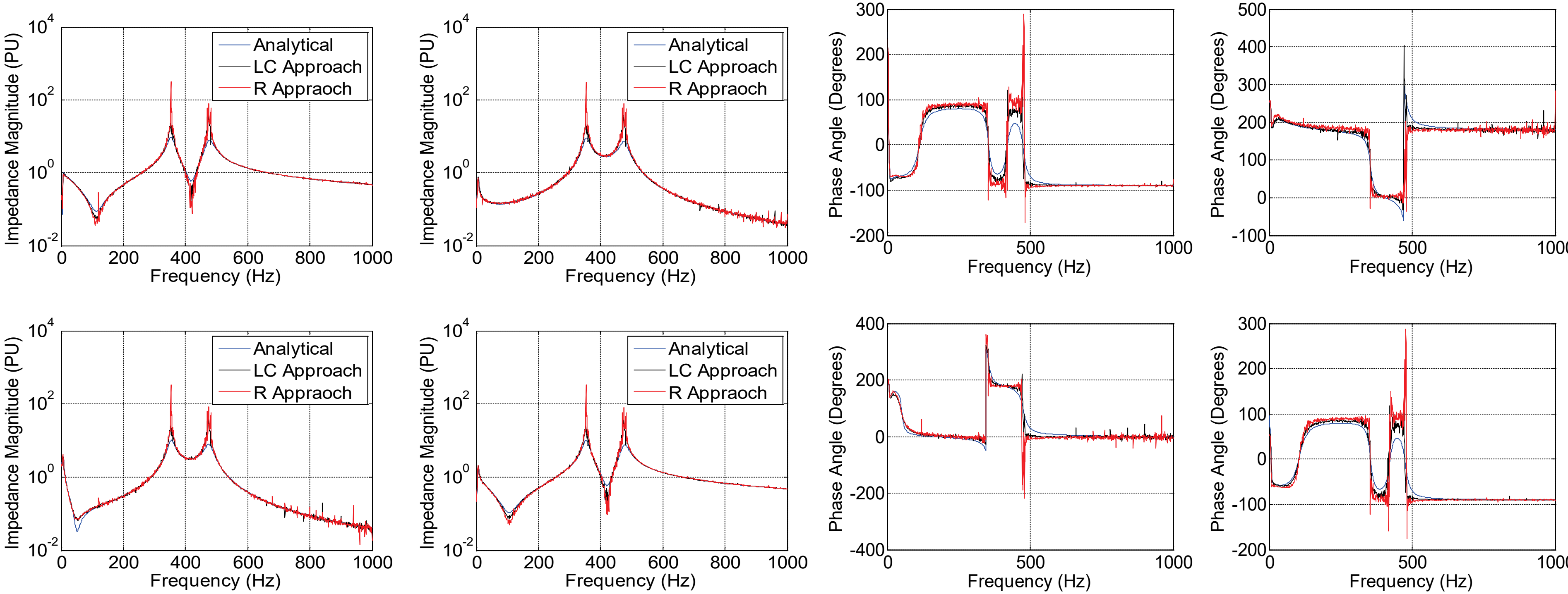




- *Operating Point 1:* $P0 = 1.0; Q0 = 0.0.$
- *resonance: 6Hz*

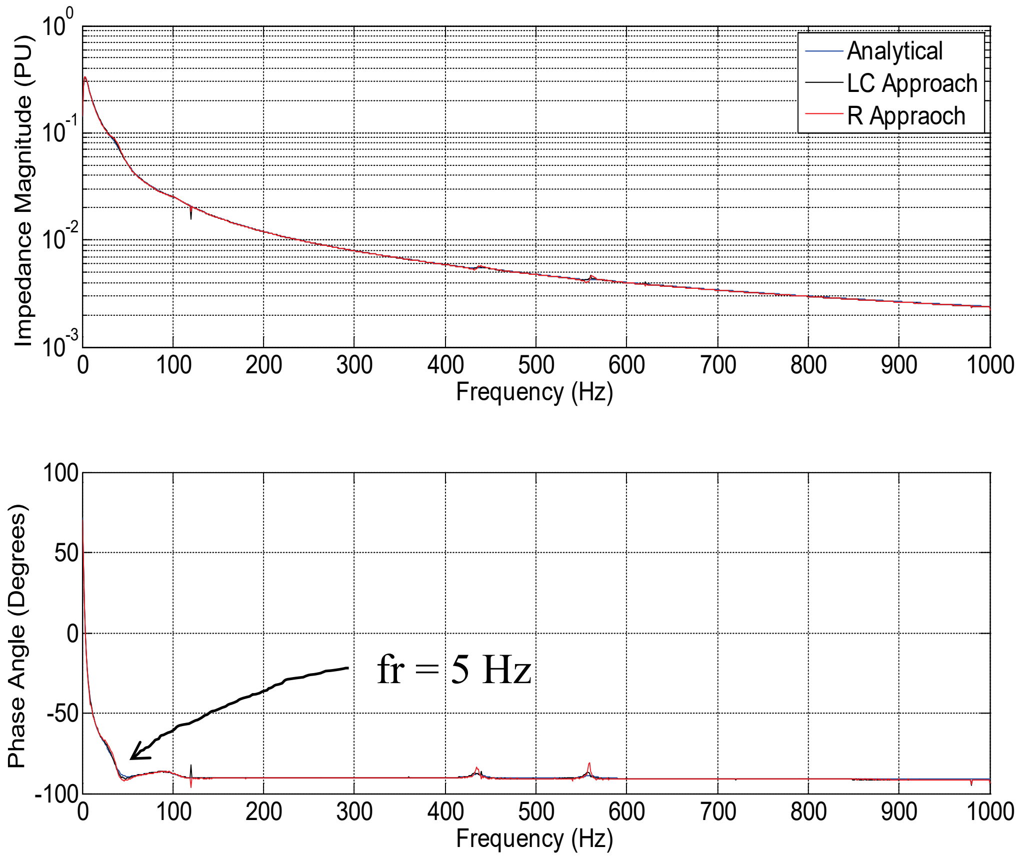
DC side impedance - Top: magnitude; Bottom: phase angle

Comparison of Results, ac side: Operating point 2, $P0 = 0.6; Q0 = 0.2.$



AC side impedance Zdd Zdq Zqd Zqq (OP 2), left: magnitude; right: phase angle

Comparison of Results, ac side: *Operating point 2, P0 = 0.6; Q0 = 0.2.*



DC side impedance - Top: magnitude; Bottom: phase angle

- *operating point 2: P0 = 0.6; Q0 = 0.2.*
- *resonance frequency: 5Hz*

Concluding Remarks

- **The frequency response of the Converter is essentially unaffected by the LC representation**
- **This allows Power electronic subsystems to be effectively modelled with low computation overhead**
- **Although the tests were conducted on a 2-level converter, it is likely that MMCs and other PE models will also show good accuracy.**

References

[1] RTDS Technologies, Real time digital simulation for the power industry manual set, Winnipeg, Canada, 2006.

[2] Trevor Maguire and James Giesbrecht, "Small Time-step (<2uSec) VSC Model for the Real Time Digital Simulator", Proceeding of IPST 2005, Montreal Canada, June 2005, Paper No. IPST-168-25c.

[3] Xiao Jiang and A. M. Gole, "A frequency scanning method for the identification of harmonic instabilities in HVDC systems," in IEEE Transactions on Power Delivery, vol. 10, no. 4, pp. 1875-1881, Oct 1995.

[4] J. Z. Zhou, H. Ding, S. Fan, Y. Zhang and A. M. Gole, "Impact of Short-Circuit Ratio and Phase-Locked-Loop Parameters on the Small-Signal Behavior of a VSC-HVDC Converter," IEEE Transactions on Power Delivery, vol. 29, no. 5, pp. 2287-2296, Oct. 2014.

[5] M. Mohaddes, A. M. Gole and S. Elez, "Steady state frequency response of STATCOM," in IEEE Transactions on Power Delivery, vol. 16, no. 1, pp. 18-23, Jan 2001.

[6] T. Li, A. M. Gole and C. Zhao, "Harmonic Instability in MMC-HVDC Converters Resulting From Internal Dynamics," in IEEE Transactions on Power Delivery, vol. 31, no. 4, pp. 1738-1747, Aug. 2016.

Thank you very much!
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