EMT Modelling and Simulation – Who Needs an EMT Model for Doing Stability Studies?

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Which of the following statements is correct?

1. Electromagnetic transient (EMT) models are always more accurate than the phasor-domain models.
2. With correct parametrisation and tuning, phasor-domain models can achieve the same level of accuracy as the EMT models.
3. EMT models are impractical to develop and use for large power systems.
4. EMT and phasor-domain models will play a complementary role during the energy transition.

EMT season

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Electromagnetic transient simulation models for large-scale system impact studies in power systems having a high penetration of inverter-based resources

June 10, 2019 by Babak Badrzadeh - Australian Energy Market Operator

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Is electromagnetic transient modelling and simulation of large power systems necessary and practical?

July 6, 2020 by Babak Badrzadeh - Australian Energy Market Operator

Key questions on EMT modelling for stability studies

Why

When

Where

Who

How

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Focus of today's webinar

Phasor-domain vs EMT models

EMT value proposition

Criteria and conditions

Vendor-specific vs generic models

Model validation

Wide-area network model development

Offline vs real-time EMT

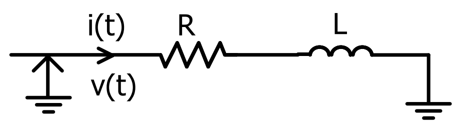
TB CIGRE WG C4.56 (to be published in Q3 2022)

Work in progress

The chronology of EMT modelling applications: A personal story

2007	Sub-synchronous resonance and torsional interactions
2008	Harmonic resonances, tidal generator design
2009	OOS/LOE protection coordination for synchronous generators
2010	Develop detailed EMT model of wind turbines, WF insulation coordination
2011	Sub-synchronous control interaction, the use of real control code in model
2012	DMAT, commissioning and R2 testing requirements
2013	Connection of a wind farm to weak remote network
2014	Black start studies for Australian network
2015	Extended commutation failure of an LCC HVDC interconnector
2016	South Australian (SA) blackout investigation
2017	Wide-are network model of SA power system
2018	Power system model guidelines, system strength and inertia guidelines
2019	Wide-area EMT modelling of NEM regions, SA synchronous condensers
2020	Sub-synchronous interactions, constraints, more synchronous condensers
2021	Grid-forming inverters, cloud computing
2022	See what's next slide

EMT vs phasor-domain models



$$v(t) = R.i(t) + L\frac{d}{dt}i(t)$$

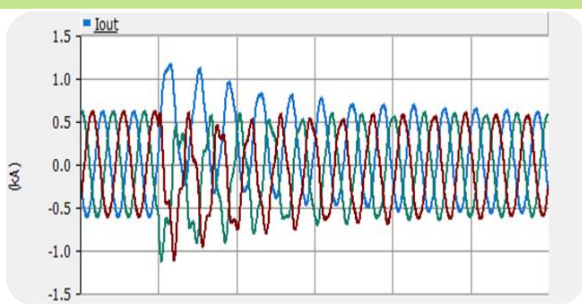
$$V(\omega) = R.I(\omega) + j(L\,\omega).I(\omega)$$

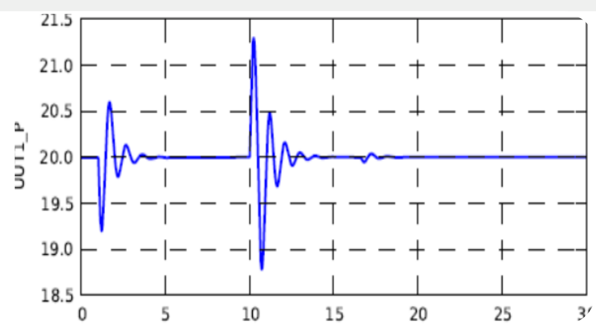
Electromagnetic transient (EMT)

- Instantaneous values (waveforms)
- Differential equations
- Accounts for both the fundamental frequency component and harmonics
- Slower

Phasor-domain transient (PDT)

- Phasor-domain values
- Algebraic equations
- Account for fundamental frequency component
- Faster





RMS vs PDT:

- **RMS calculation is performed to provide a single value for the time-varying waveforms where the magnitude of quantity varies with respect to time**
- **Phasors comprise magnitude and phase angle which is a more accurate representation of what is sought here.**

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Details excluded in PDT modelling

- Instantaneous values → Slides 9-10
- Harmonics and inter-harmonics
- Asymmetries
- Fast controllers → Slides 11-13

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How do the actual IBR controls operate?

- **<u>Steady-state conditions</u>**: phase voltage and currents have sinusoidal waveshapes, whose frequencies are constant and equal and all are neatly separated by phase angle of 120°.

- **<u>Dynamic conditions</u>**: The voltage and currents are no longer sinusoidal and the term ***<u>phase angle</u>*** does not have its usual meaning.

- The currents and voltages in each of the three phases should be considered **<u>individually</u>** on an instantaneous basis, and for both the **<u>stator and rotor circuits</u>** (if applicable).

- In addition to the magnitude and phase angle of the voltage, current and flux (if applicable), their **<u>instantaneous position</u>** is also needed.

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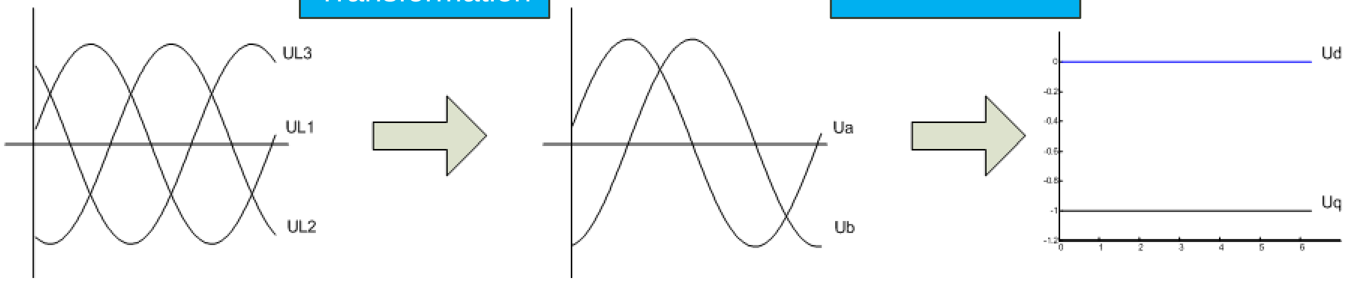
Reference frame transformations

Clarke Transformation

Park Transformation



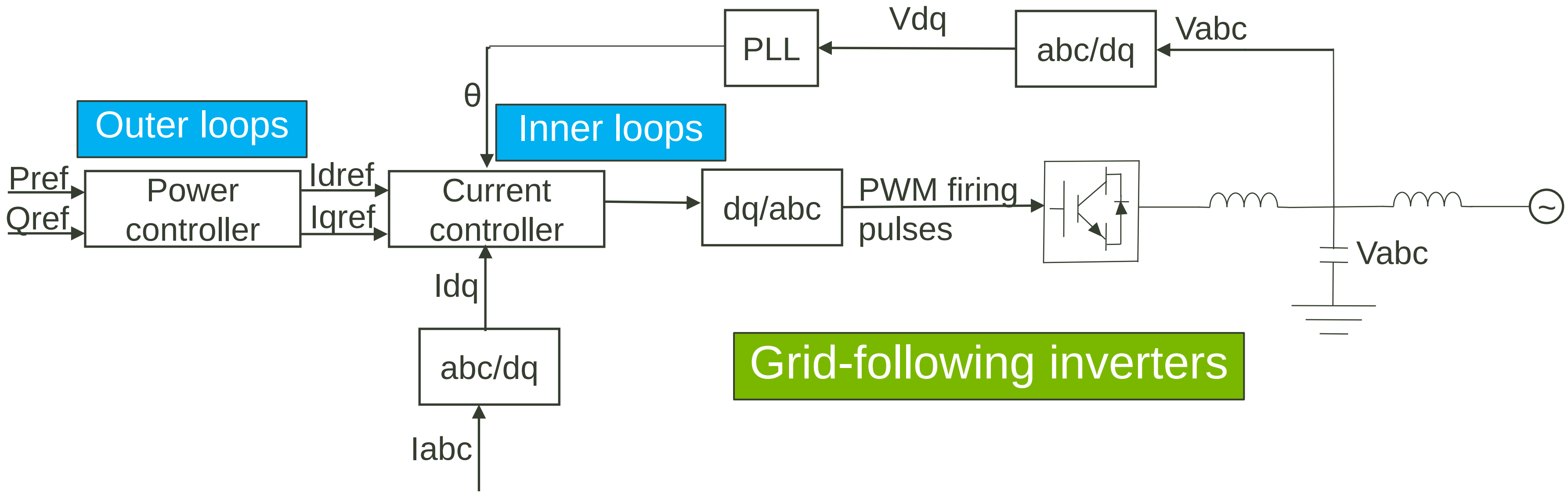
- Converting the three-phase AC system into a DC-like machine
- Indepedent control of active and reactive power.
- Easier to design PI controllers for DC quantities.
- Angle θ is the basis of PLL.

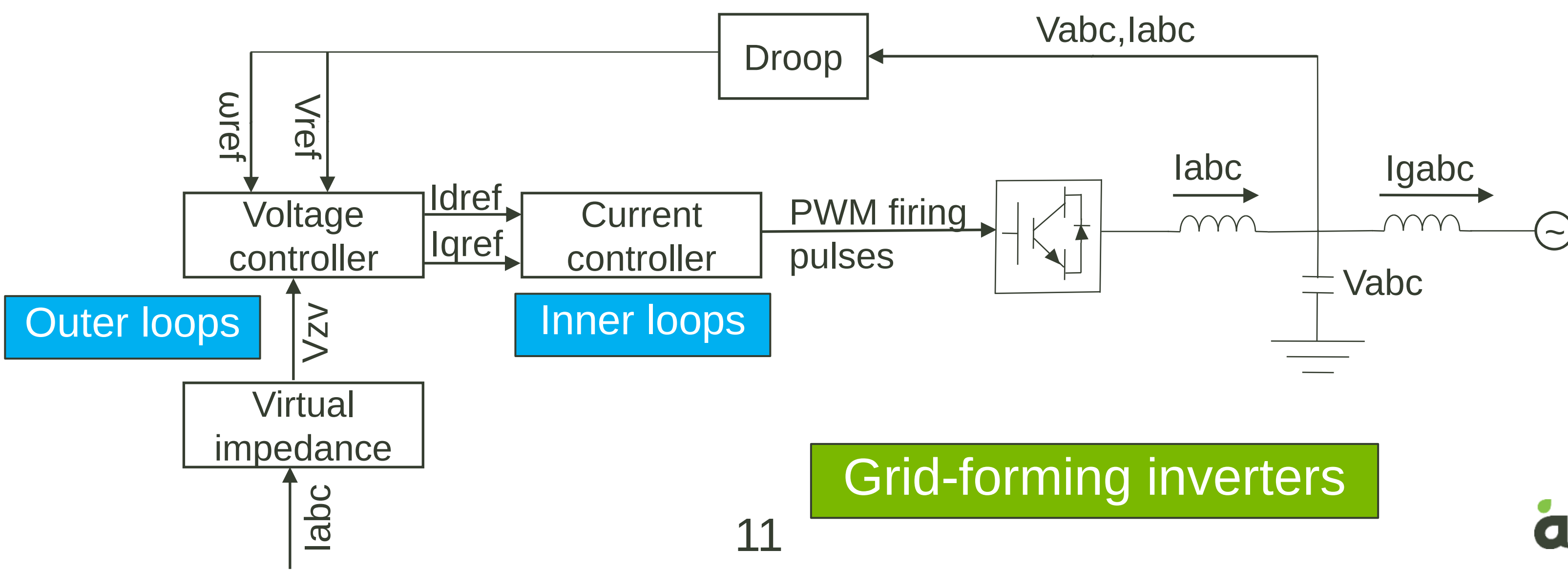
$$[f_{qd0}] = [T_{qd0}(\theta)] * [f_{abc}]$$

$$\left[T_{qd0}(\theta)\right] = \frac{2}{3} * \begin{bmatrix} \cos\theta & \cos(\theta + \frac{2\pi}{3}) & \cos(\theta - \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta + \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

Park Transformation

Cascaded control of inverter-based resources

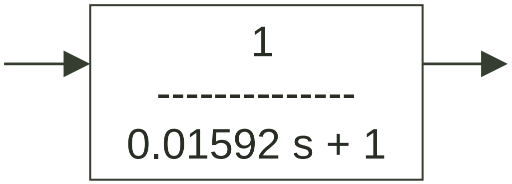




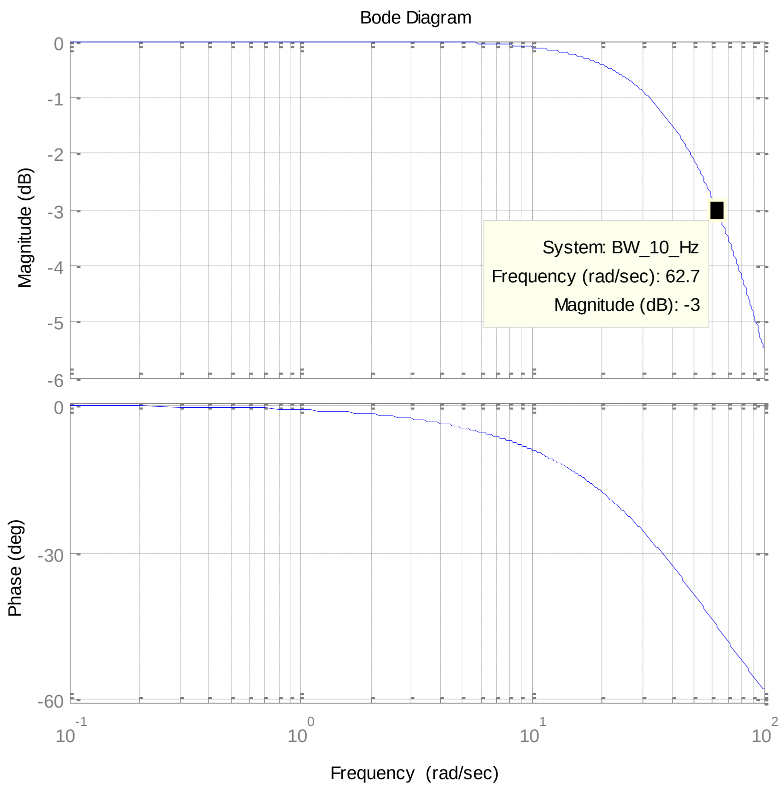
Bandwidth vs time constants vs frequency

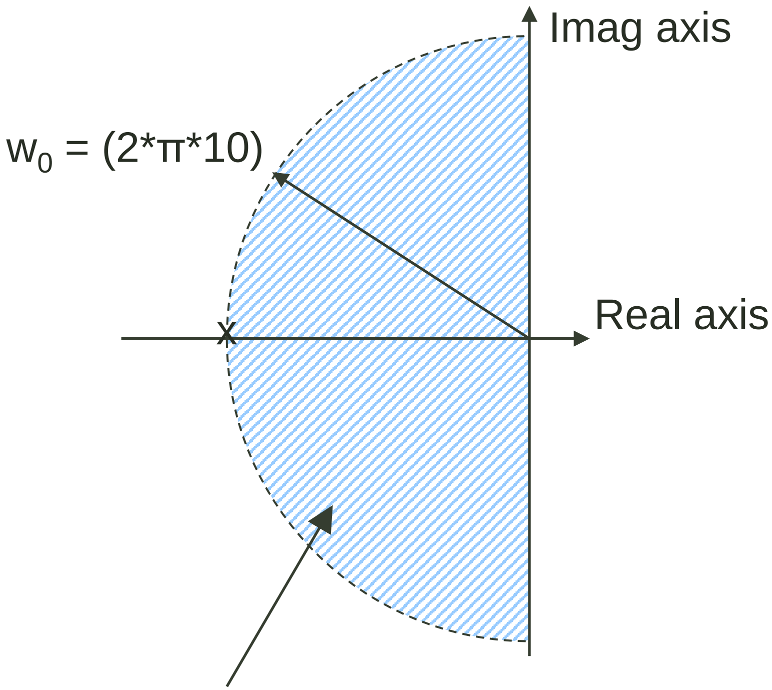
The time-constant of a first order system with 10 Hz bandwidth is:

$t = 1/w0 = 1/(2*\pi*f_o) \approx 16$ ms



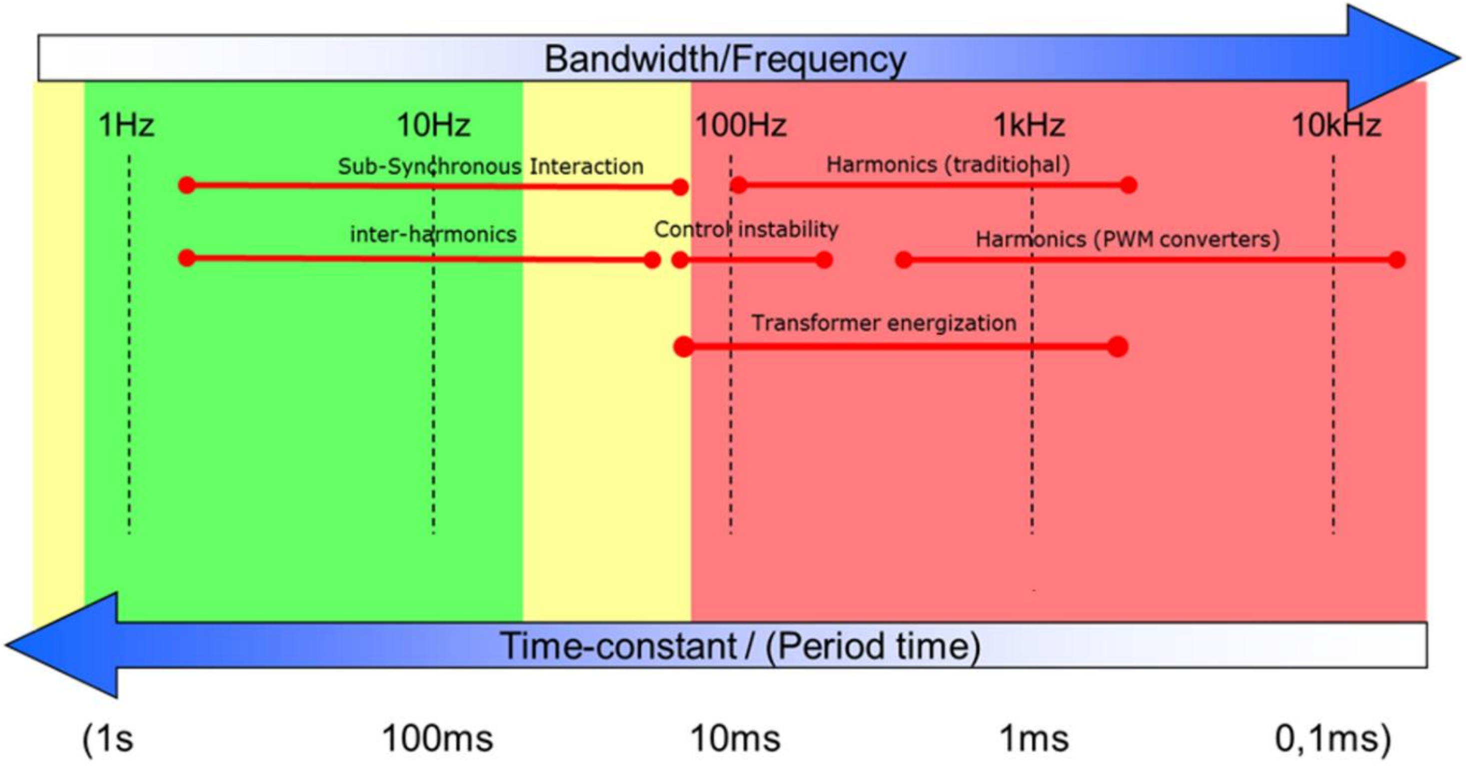
Damping is -20 dB/decade for a first order system, meaning that a 100 Hz signal will be attenuated by a factor 10.





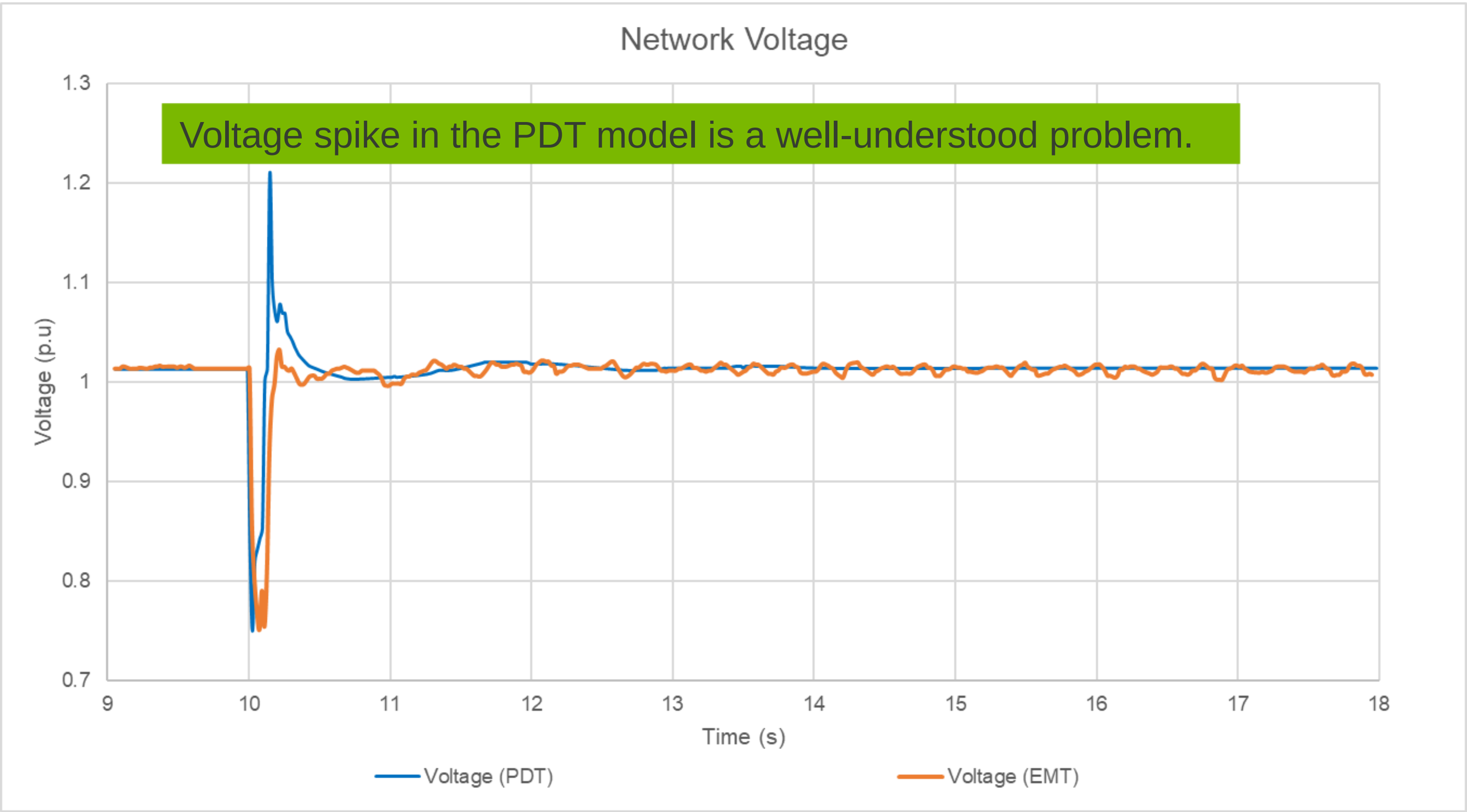
This area represents all possible pole locations for stable systems having bandwidth <= 10 Hz

Applicability range of PDT and EMT tools



A bandwidth of around 10 Hz is typically stated for PDT tools

EMT and PDT model accuracy in predicting control system instabilities



Sustained post fault voltage oscillations with a frequency of less than 10 Hz.

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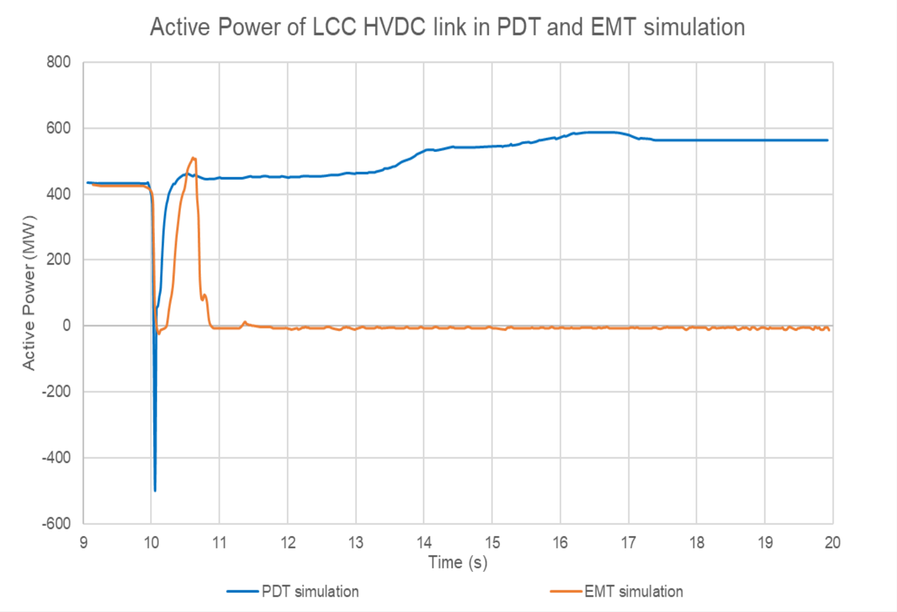
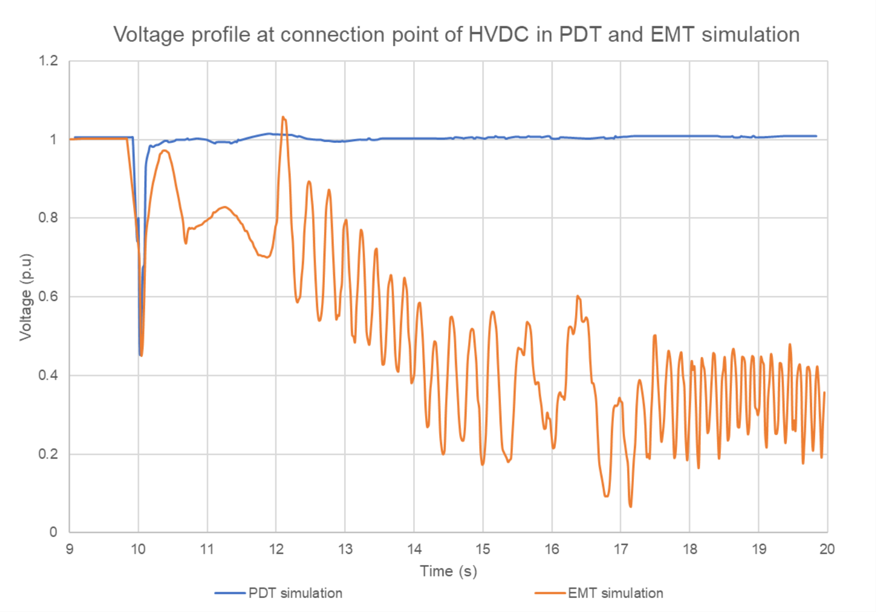
EMT and PDT model accuracy: HVDC link response to a credible fault





PDT model does not predict sustained commutation failure and subsequent disconnection of the HVDC link

The need for detailed whole-system EMT modelling for systems with high IBR penetration

Changing power system and generation mix and new/emerging phenomena

overly optimistic responses usually predicted by conventional tools

Account for the interactions between system stability, power quality and protection

More certain (but slower) generator connection process

More certain long-term system planning with sufficient understanding of future system and equipment needs

Optimise solutions with a whole system view noting the interactions between the power system and emerging technologies

When

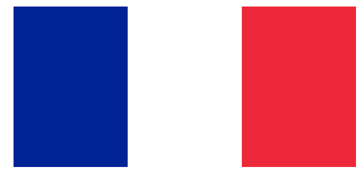
- **Short circuit ratio (SCR)** and its various aggregate forms have been historically used, however, setting a SCR threshold only works if one is looking for a known problem, rather than unknown unknowns.
- Also SCR does not currently account for the differences associated with grid-forming inverters.
- Interactions between control systems of multiple IBR can occur in weak or strong systems. They are just exacerbated under weaker conditions.
- **System non-synchronous penetration (SNSP)** has also been used, however, it is primarily relevant to islanded power systems.
- Improved screening methods can have an important role in reducing the number of simulation studies required rather than providing definite answer on when EMT studies are a must or when PDT modelling might be sufficient.
- The need for EMT studies is inevitable, but the key question is how to run them more judiciously and efficiently.

Vendor specific vs generic EMT models

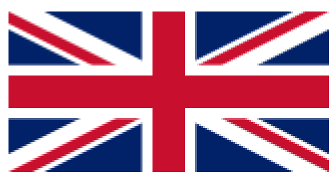
Vendor-specific	Generic
▪ Reflects the exact controls implemented by each OEM	▪ Presents an acceptable way of implementing controls
▪ Black-box	▪ Open-box
▪ User cannot modify the control systems and often not the settings as well	▪ User can modify control systems and associated settings
▪ Most suitable for operational and generator interconnection studies	▪ Most suitable for power system planning studies, including the definition of future power system and equipment technical needs
▪ Most often vendor-specific models will also need to be site-specific	

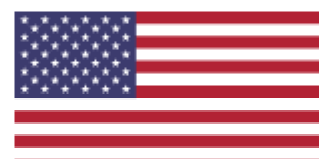
Where (examples only)

Whole-system



Partial modelling





What's next?

Modelling activities

- Faster speed
- Protection system integration
- More systematic development of boundary buses
- More detailed DER modelling

Analysis activities

- Determining the mix of grid-forming and grid-following inverters
- Determining the future power system and equipment technical needs

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