CIGRE Green Book: Power System Dynamic Modelling and Analysis in Evolving Networks

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ESIG Webinar
22 January 2025

Overview of Power System Dynamic Modelling and Analysis in Evolving Networks

Key Highlights

- The 14th (16 to date) CIGRE Green Book series to date
- Among few considered as a Major Reference Work
- First Green Book led by SC C4
- At approximately 900 pages, it is the second longest Green Book published to date.
- More than 70% of the contents were newly developed.
- Original planned to be delivered in five years with up to 800 pages
- Completed in three and half years with approximately 900 pages
- With more than 50 authors, it features one of the highest author/page ratio among Green Books
- Contributions from 11 countries

Real heroes

Miguel Cova Acosta
Udaya Annakkage
Babak Badrzadeh
Hitesh Bavarva
Jean Bélanger
Yunzhi Cheng
Sébastien Dennetière
Zia Emin
Marta Val Escudero
Lingling Fan
Inalvis Alvarez Fernandez
Ioni Fernando
Gabriel M. Gomes Guerreiro

Sorrell Grogan
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Aboutaleb Haddadi
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Andrew Isaacs
Chavdar Ivanov
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Adrian Kelly

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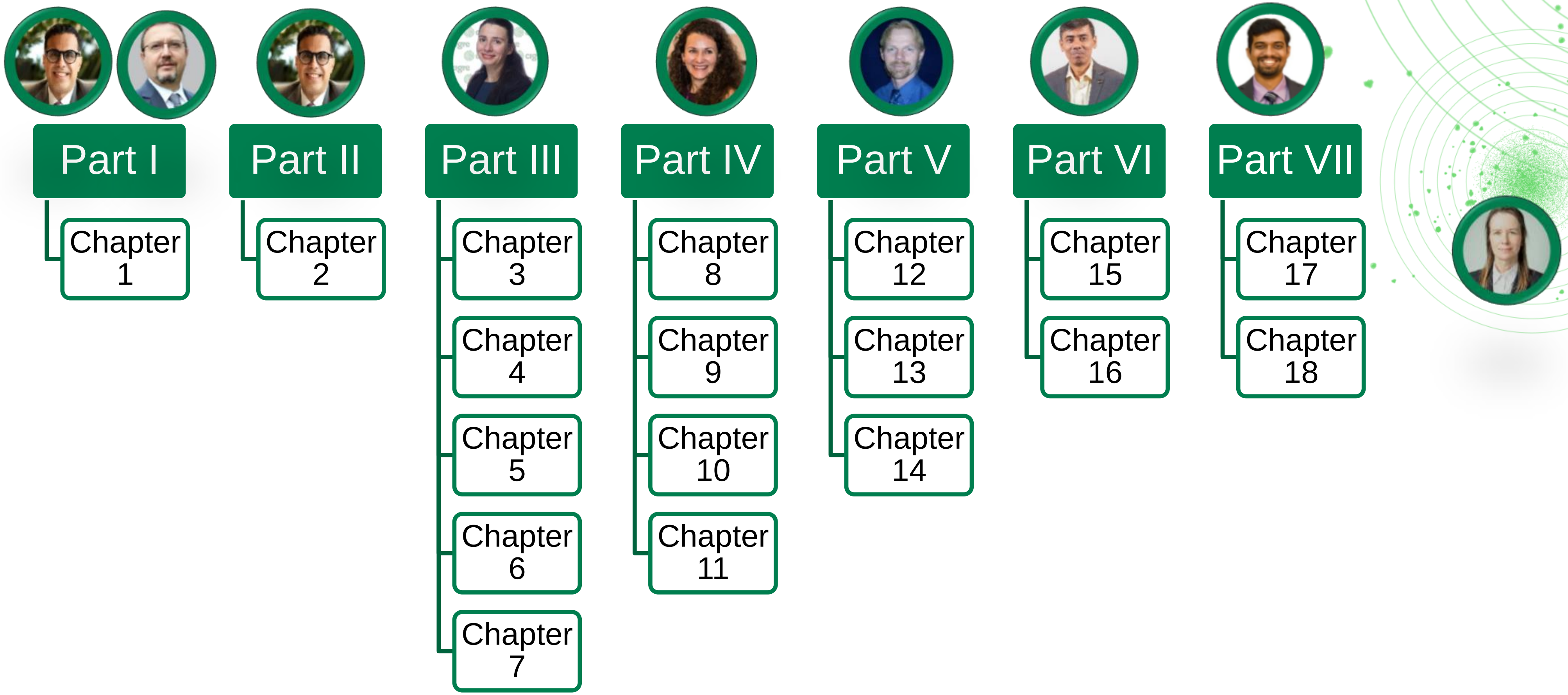
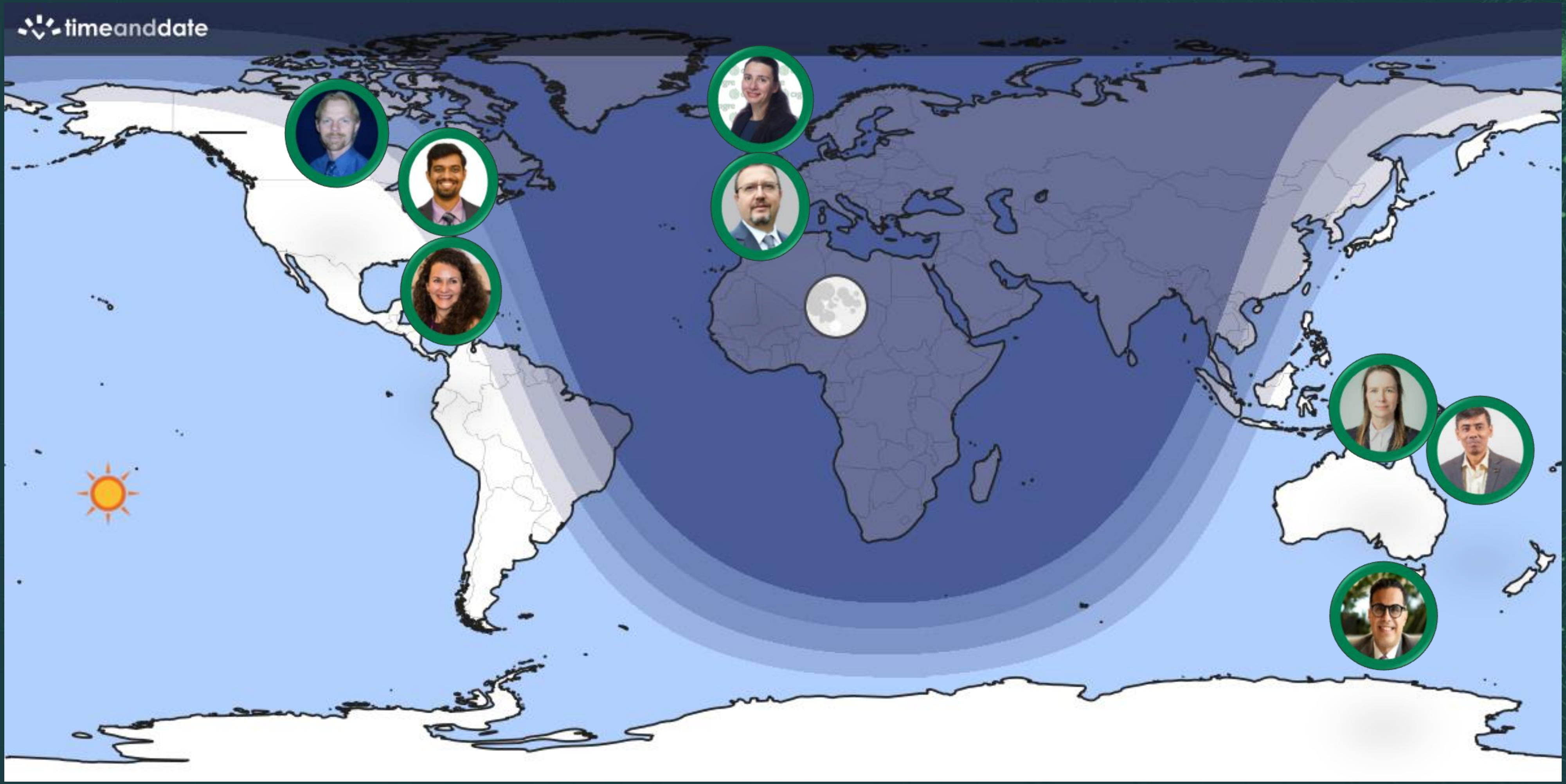
Amer Mesanovic
Parag Mitra
Nilesh Modi
Ulrich Muenz

Deepak Ramasubramanian
Hani Saad
Kasun Samarasekera
Jayapalan Senthil
Alex Shattuck
Douglas Wilson
Qiang "Frankie" Zhang
Qiming Zhang
Song Zhang
Yue Zhu
Dimitrios Zografos

Book structure

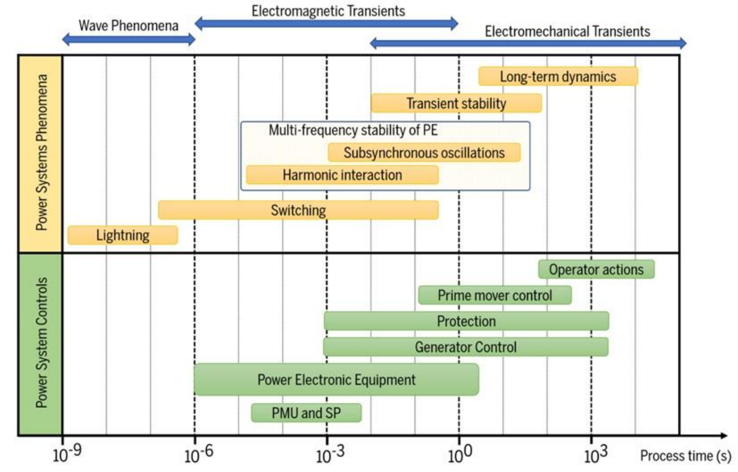


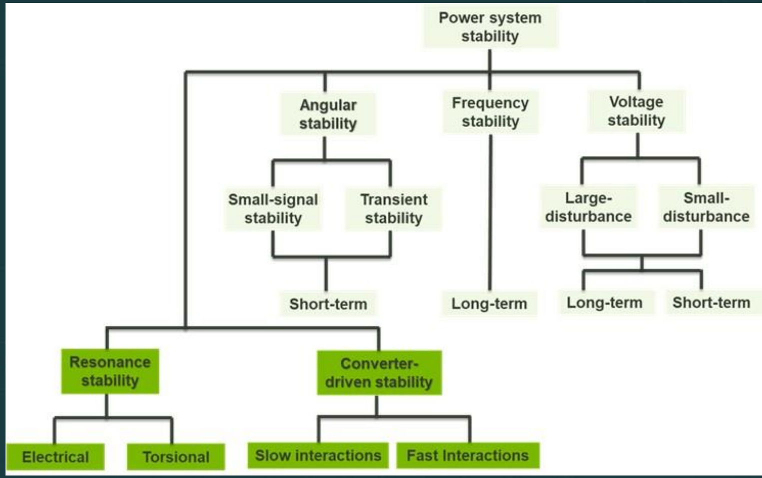
The fun part

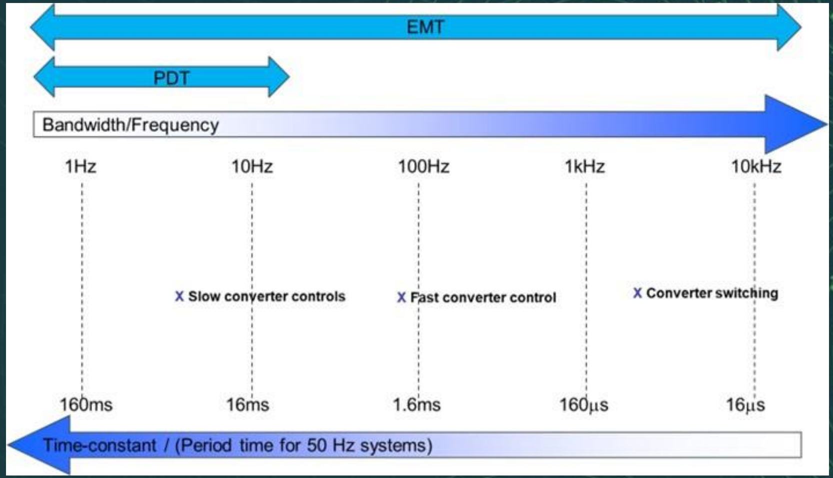


Part I – Changing Power Systems and Impact on Power System Dynamic Phenomena and Analysis Methods

Chapter 1
Changing Power Systems and Impact on Power System Dynamic Phenomena and Analysis Methods



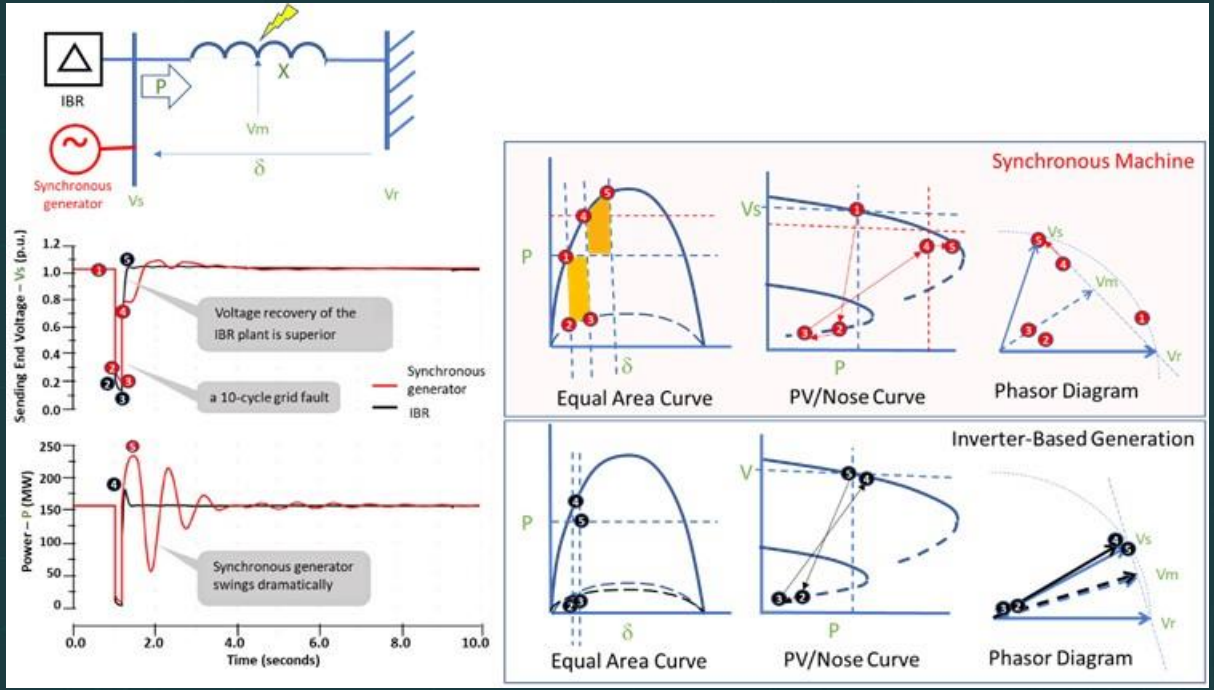


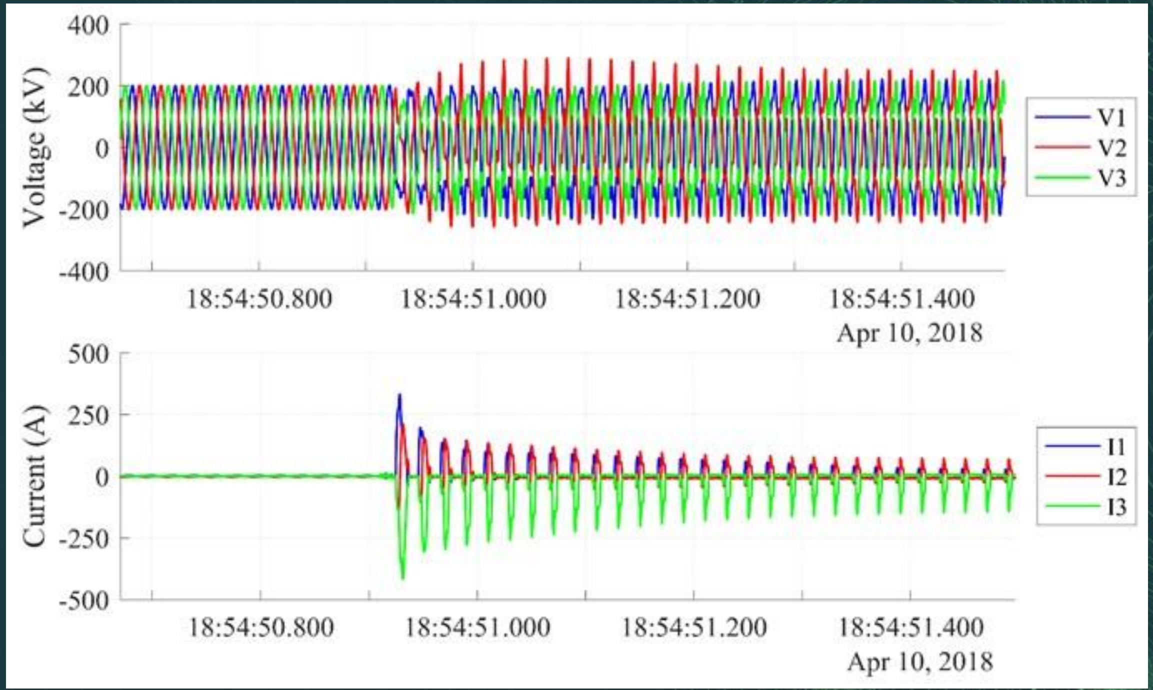


- Transition from classical to contemporary power system analysis
- Type of dynamic phenomena
- Type of tools
- Consideration on high IBR share
- Other drivers for new approaches

Part II – Power System Studies Under a High Penetration of Power Electronic Interfaced Devices

Chapter 2
Power System Dynamic Studies Under a High Penetration of Power Electronic Interfaced Devices





- Consideration in system stability analysis
- Interactions between system stability and power quality and system protection

Part III – Power System Dynamic Analysis Tools and Techniques and Their Evolution in Practice

3 Principles and Practical Considerations for the Use of Time-Domain Simulation Software Programs in Power System Dynamics Analysis

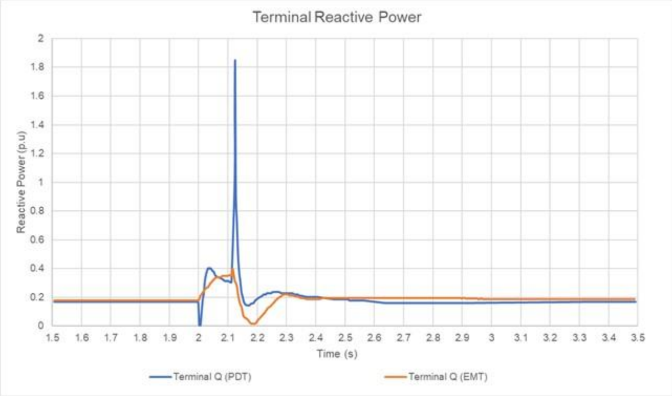
4 Practical Examples of the Use of PDT and EMT Simulation Including Their Unique Applications and Complementary Use

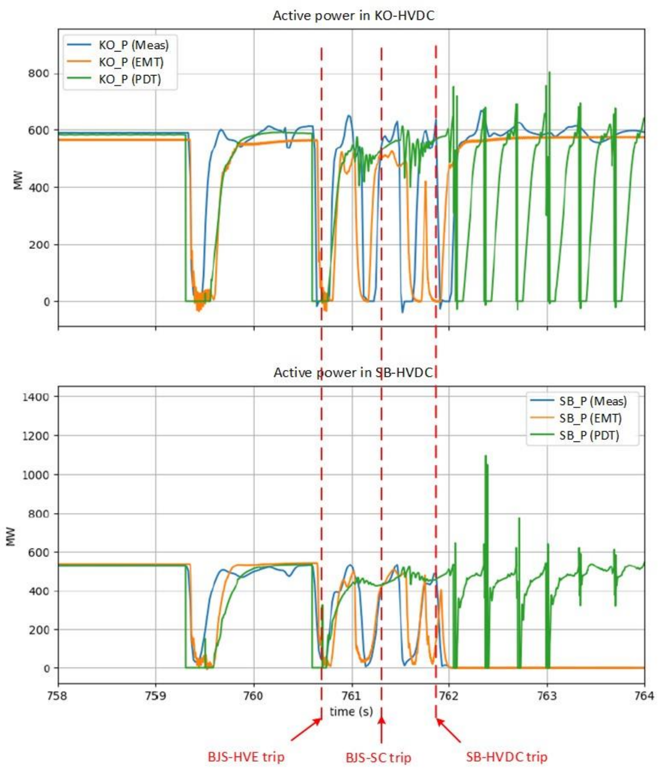
5 Screening Methods as Preliminary Calculations to Determine the Level and Type of Dynamic Modeling Required

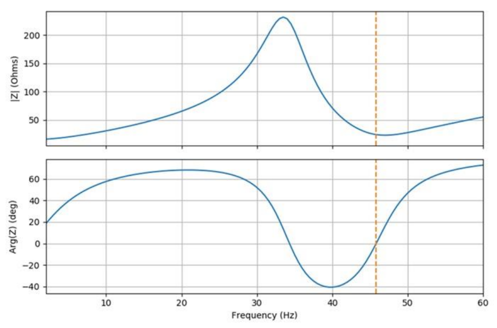
6 Linear Analysis Methods to Characterize Inherent Small-Signal Behavior of the Plant and Overall Power System

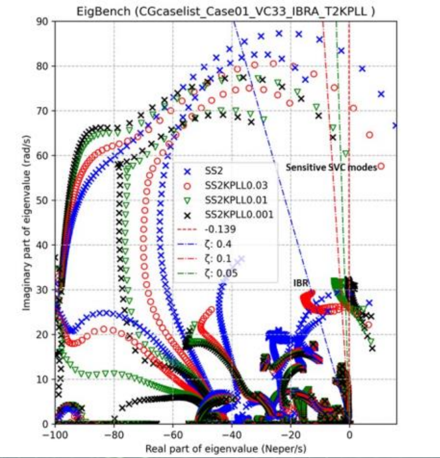
7 Operational Decision Support Tools for System Dynamic Response Awareness in Real-Time and Near-Real-Time Power System Operations

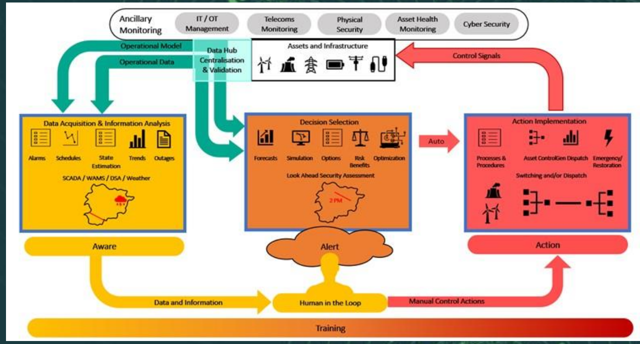
- Overview of PDT & EMT, differences, methods, real-time, co-simulation
- HVDC, system level EMT, low frequency interarea and complementary use of PDT & EMT examples
- Fault level, interaction based and other screening methods
- Eigenvalue and frequency domain (transfer function, impedance and passivity)
- WAM, state estimation and situational awareness



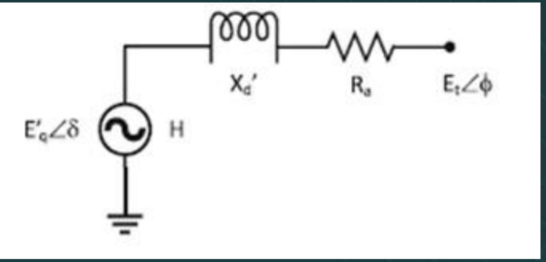


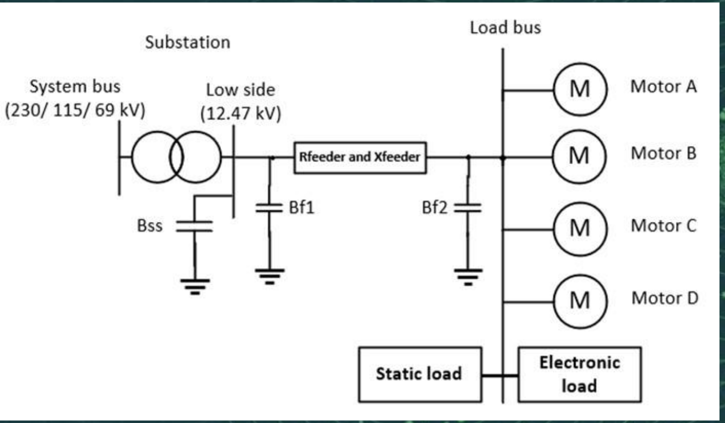


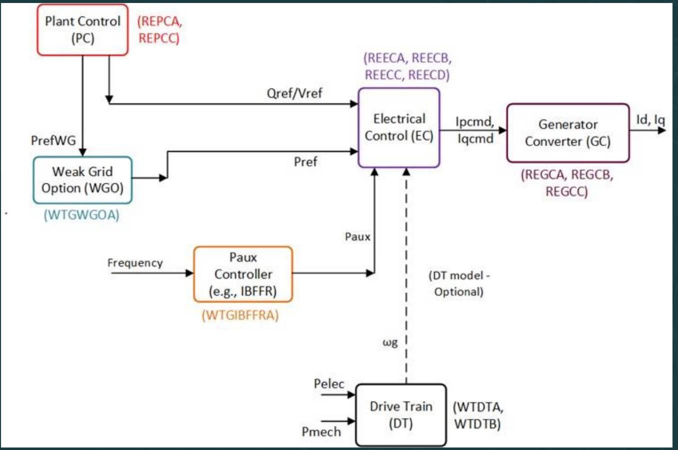




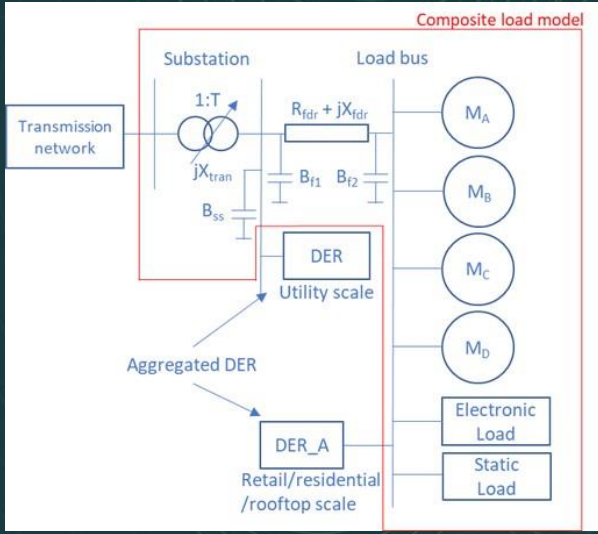
Part IV – Model and Data Requirements in Power Systems with a High Share of Power Electronic Interfaced Devices

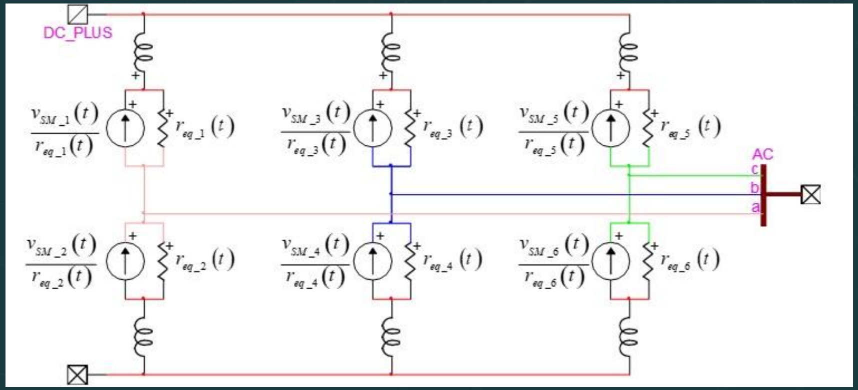






- Overview of IBR and synchronous machine modelling, generic vs vendor specific
- Physics based, full detailed, switchable, detailed equivalent etc for converter and upper/lower level control models
- Load models, DER models
- Network modelling, protection modelling



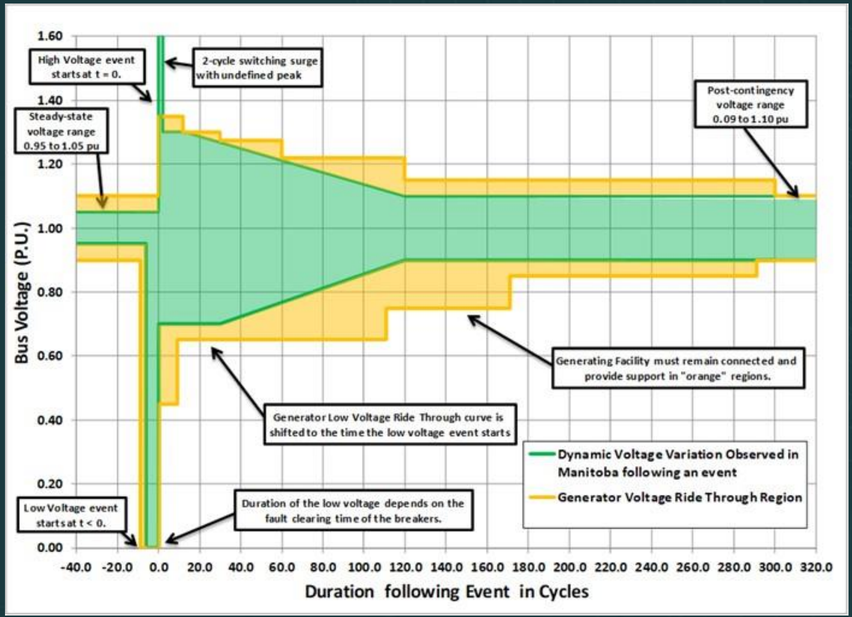


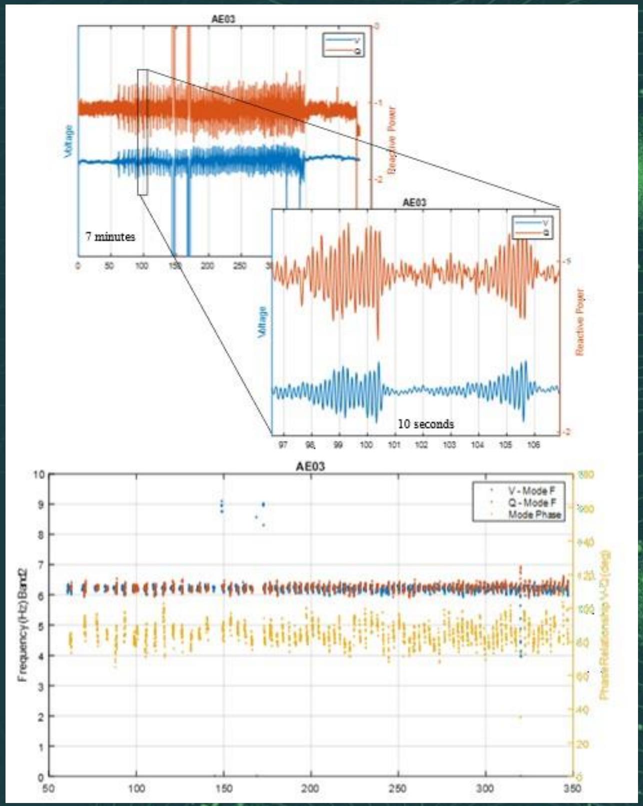
Part V – Dynamic System Study Guide from Operations to Planning

12 Grid Interconnection Study Procedures with Practical Examples for IBRs, HVDC and FACTS

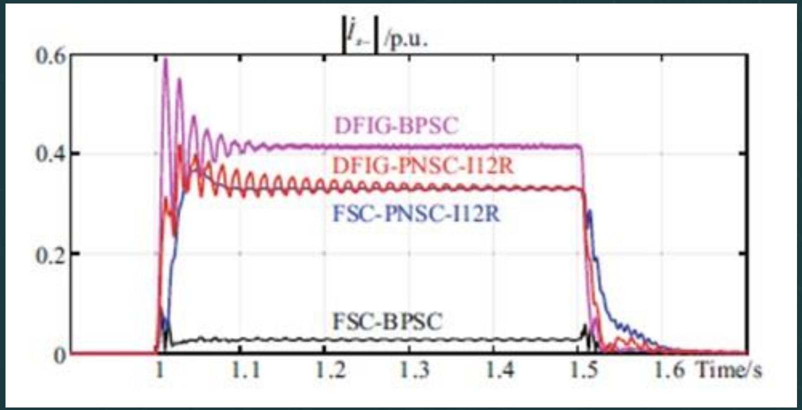
13 Power System Planning and Operational Studies in Inverter-Dominated Networks: Interactions and Oscillation Studies, System Strength, and Inertia Determination

14 The Impact of Power System Plants Other Than Large-Scale Generation and Transmission Network on Wide-Area Power System Dynamic Performance Using Case Studies of DER, Microgrids, Industrial Power Systems, and Network Protection Systems





- IBR, HVDC and FACTS interconnection studies, grid code requirements, case studies
- Practical examples of SSR, interaction studies and HVDC high-frequency interactions
- Impact of IBR on various protection systems, impact of DER and microgrids etc

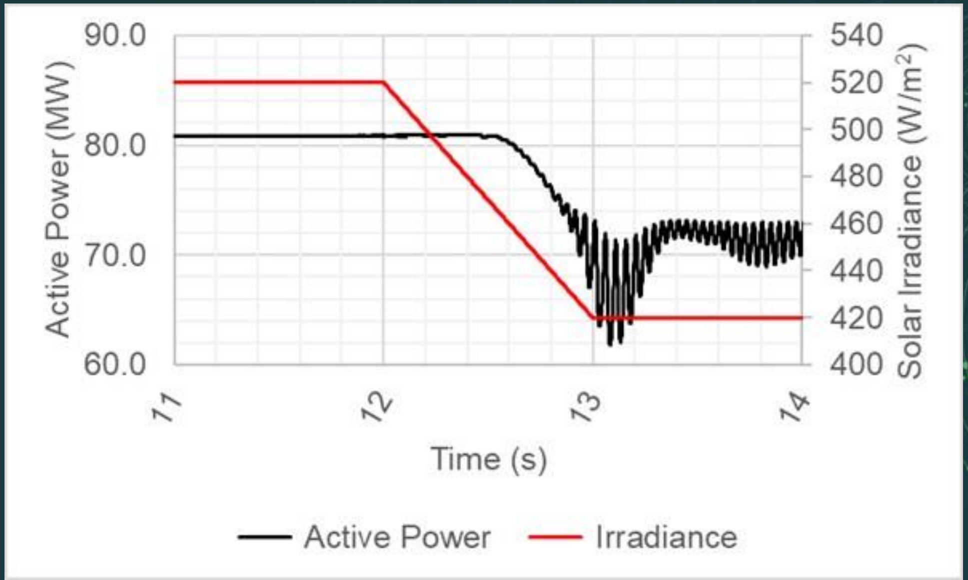


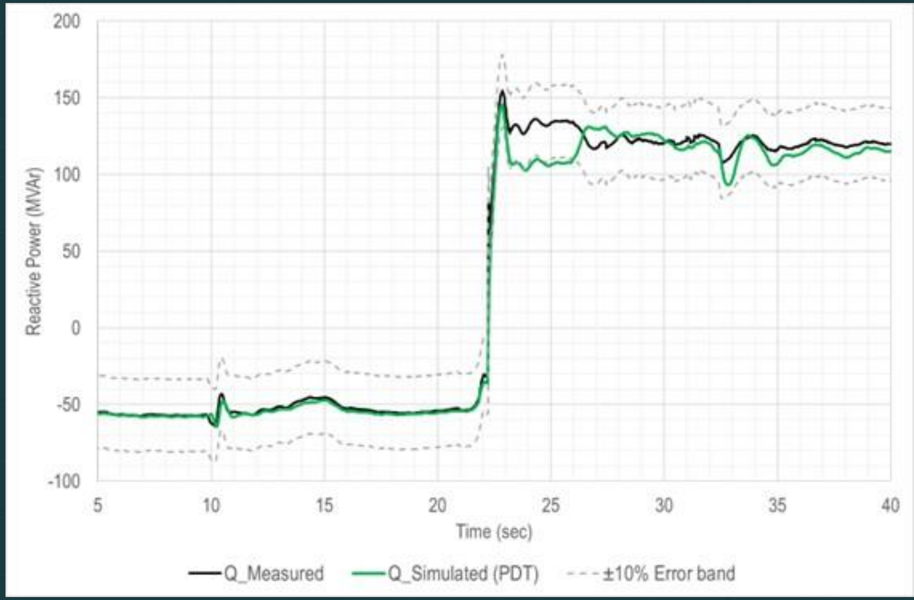
Part VI – Confidence in the Accuracy of Plant and Power System Models

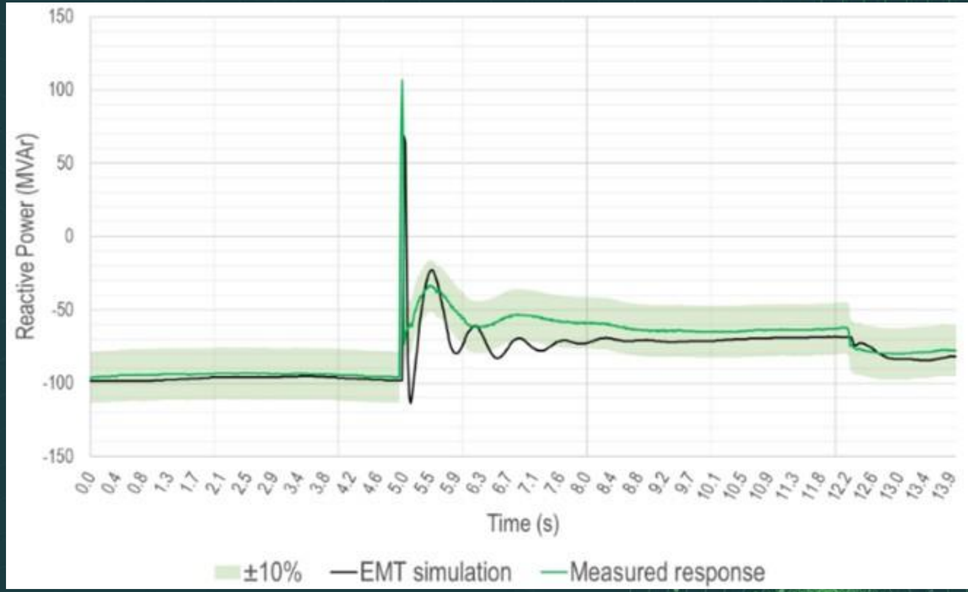
15 Model Acceptance Testing

16 Power System Plant and Network Dynamic Model Validation

- Testing methodologies, general requirements and examples
- Importance of model validation, life cycle, how to get to a validated model





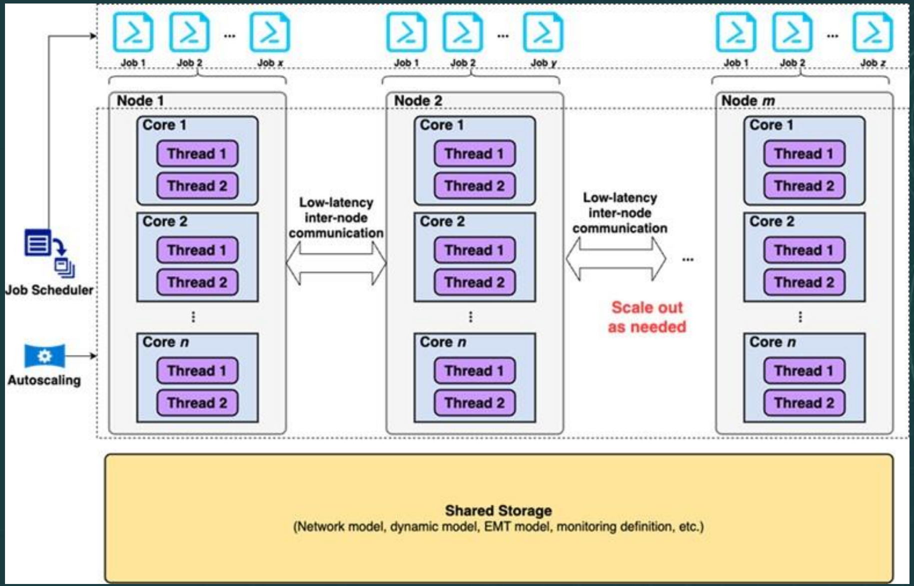


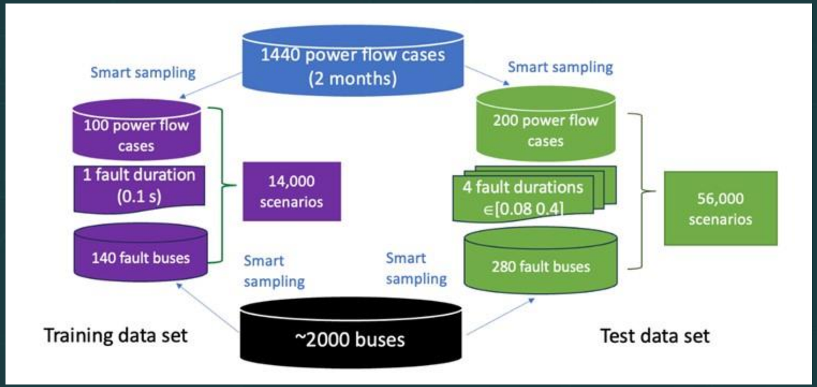
Part VII – Contemporary Enablers on Dynamics in Evolving Power Systems

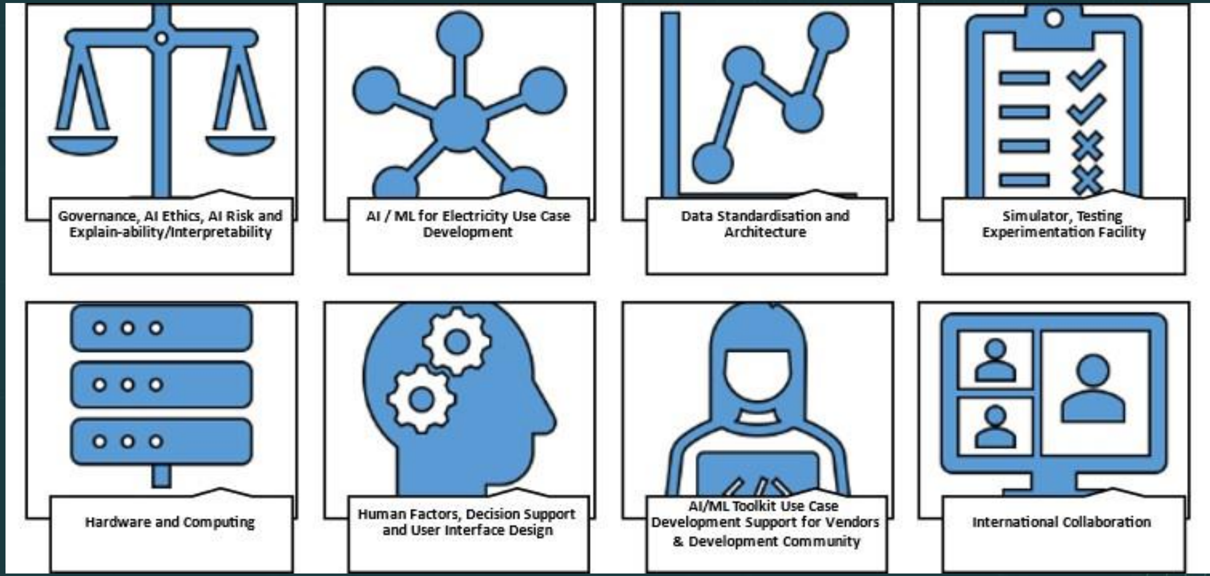
17 Computational Intelligence-Based Learning Techniques to Handle Uncertainty and Large Data Sets

18 Improving Case Creation Robustness Using Optimisation and Standardisation Techniques

- Cloud enabled scalable computing, artificial intelligence, machine learning, application examples
- Optimisation, big data analysis, standardisation, interoperability and conformity







Part I: Changing Power Systems and Impact on Power System Dynamic Phenomena and Analysis Methods

Drivers for the need to revisit power system dynamic modelling and analysis

Changing large-scale generation mix and types

Emergence of new technologies which are not well understood

Increased penetration of distributed energy resources and power electronic interfaced loads

Changing transmission and distribution networks

Increasing interactions between tools/phenomena

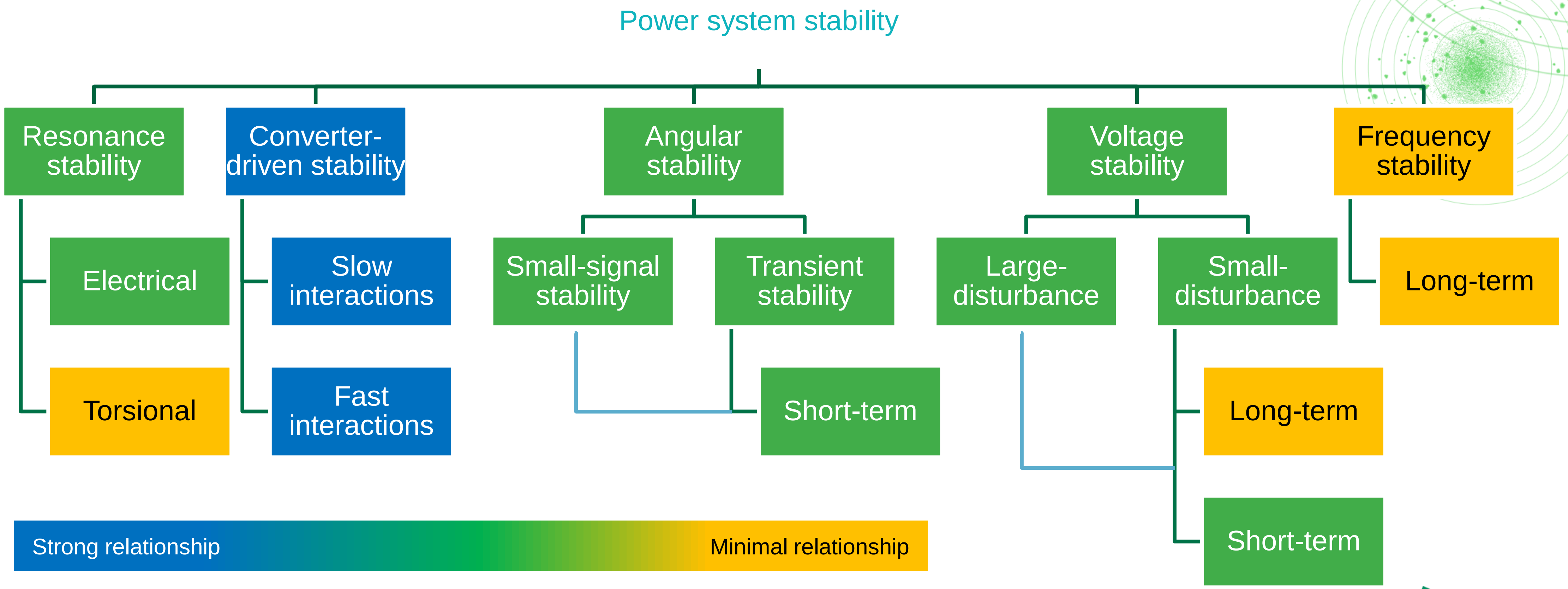
Commonly used methods cannot usually address emerging complexities

Power system phenomena

Phenomena	Typical frequency range	Circuit theory	Relation to control bandwidth	Factors influencing	Overall impact
System stability (inc. protection)	< ≈300 Hz	I_F → Z SCR = 1/Z	Within	☑ Control systems ☑ Circuitry	
Power system harmonics	>50/60 and < ≈10 kHz	$V_h = I_h \times Z_h$	Often outside	? Control systems ☑ Circuitry	
High-frequency transients	> ≈3 kHz and up to a few MHz	L ↔ C	Outside	☒ Control systems ? Circuitry	

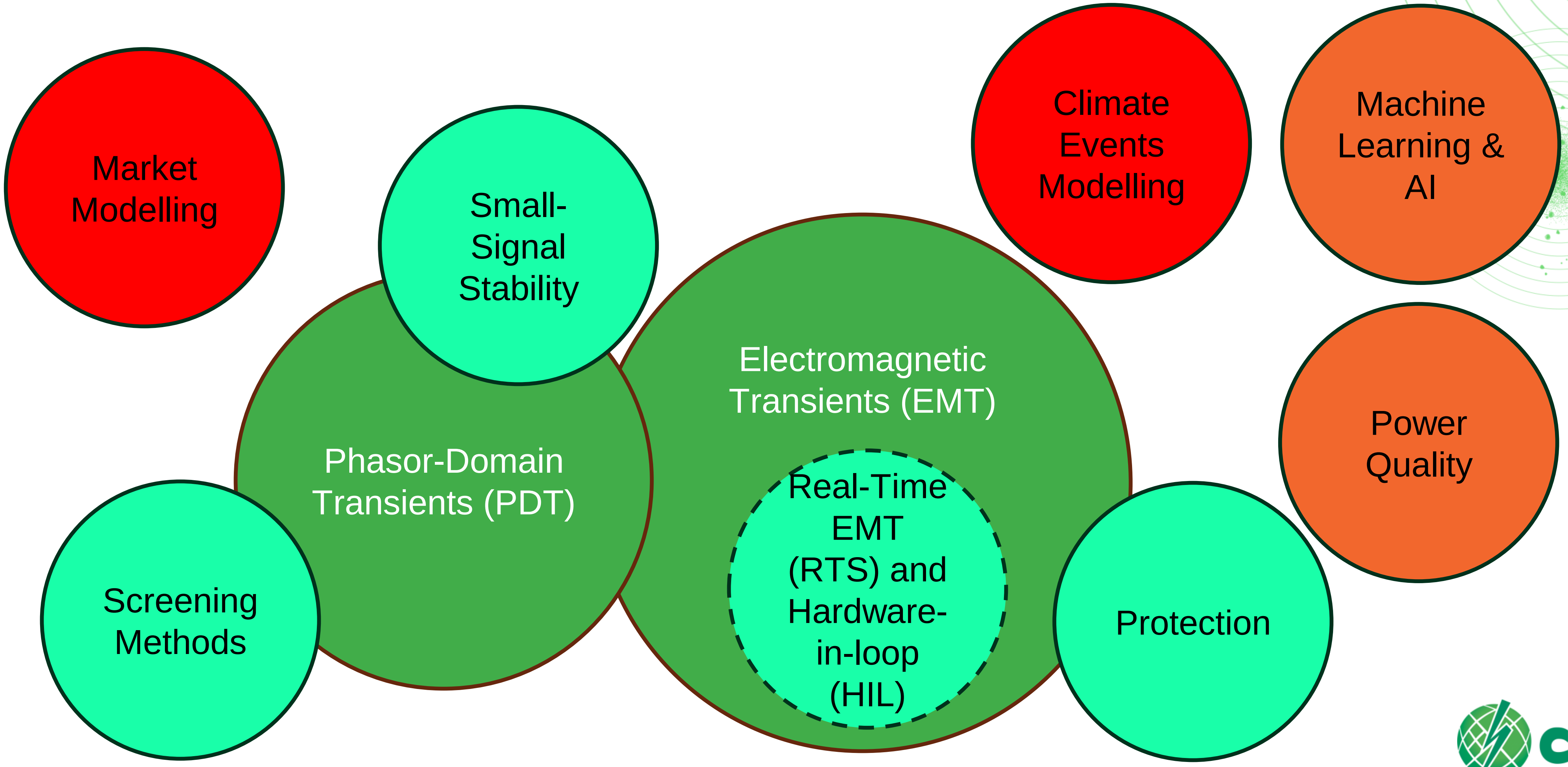
Circuitry includes transformers, lines, cables, filters and converter bridges (inc. PWM)

System strength vs system stability

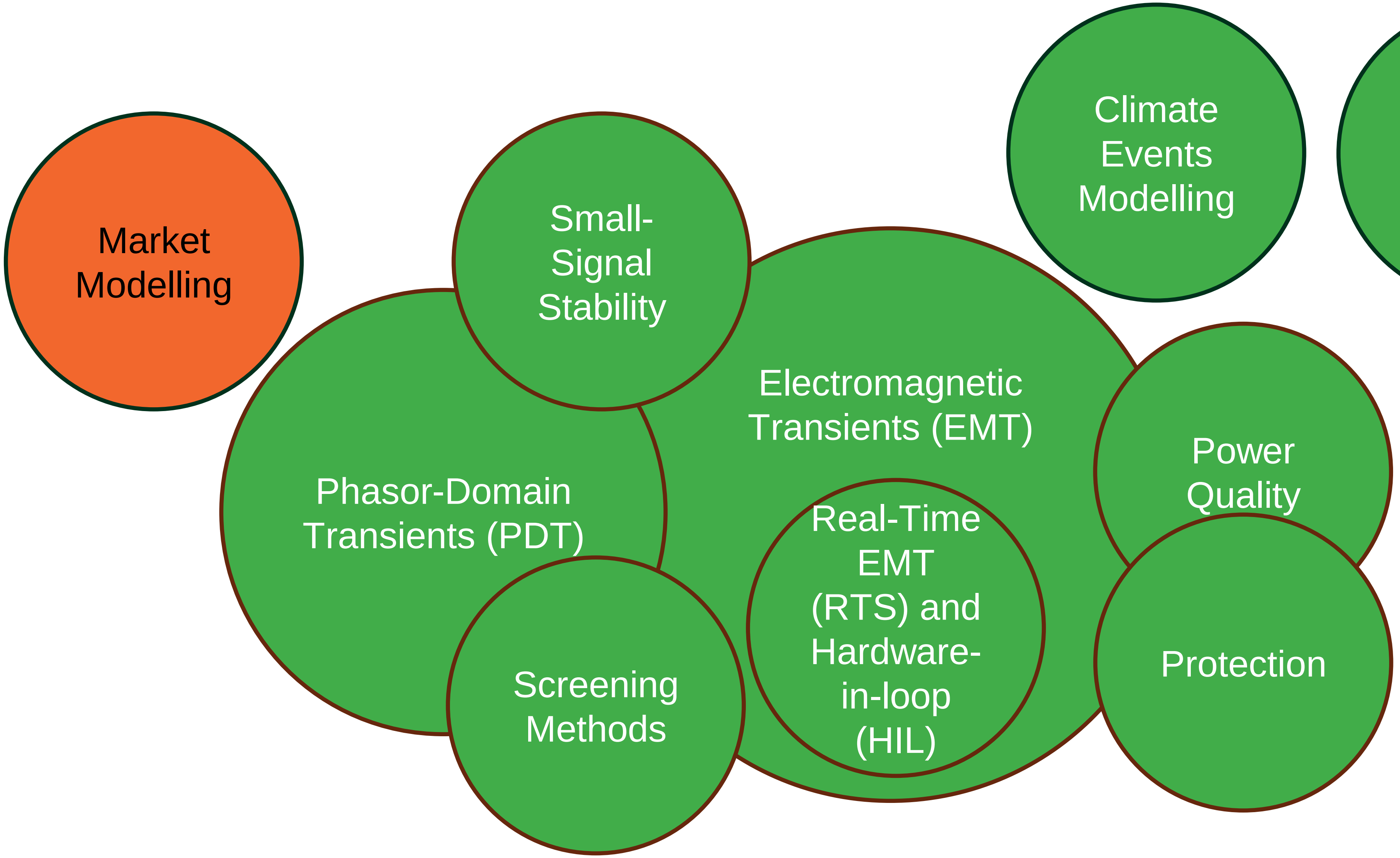


Classification of power system stability phenomena – 2020 version (IEEE TR77)

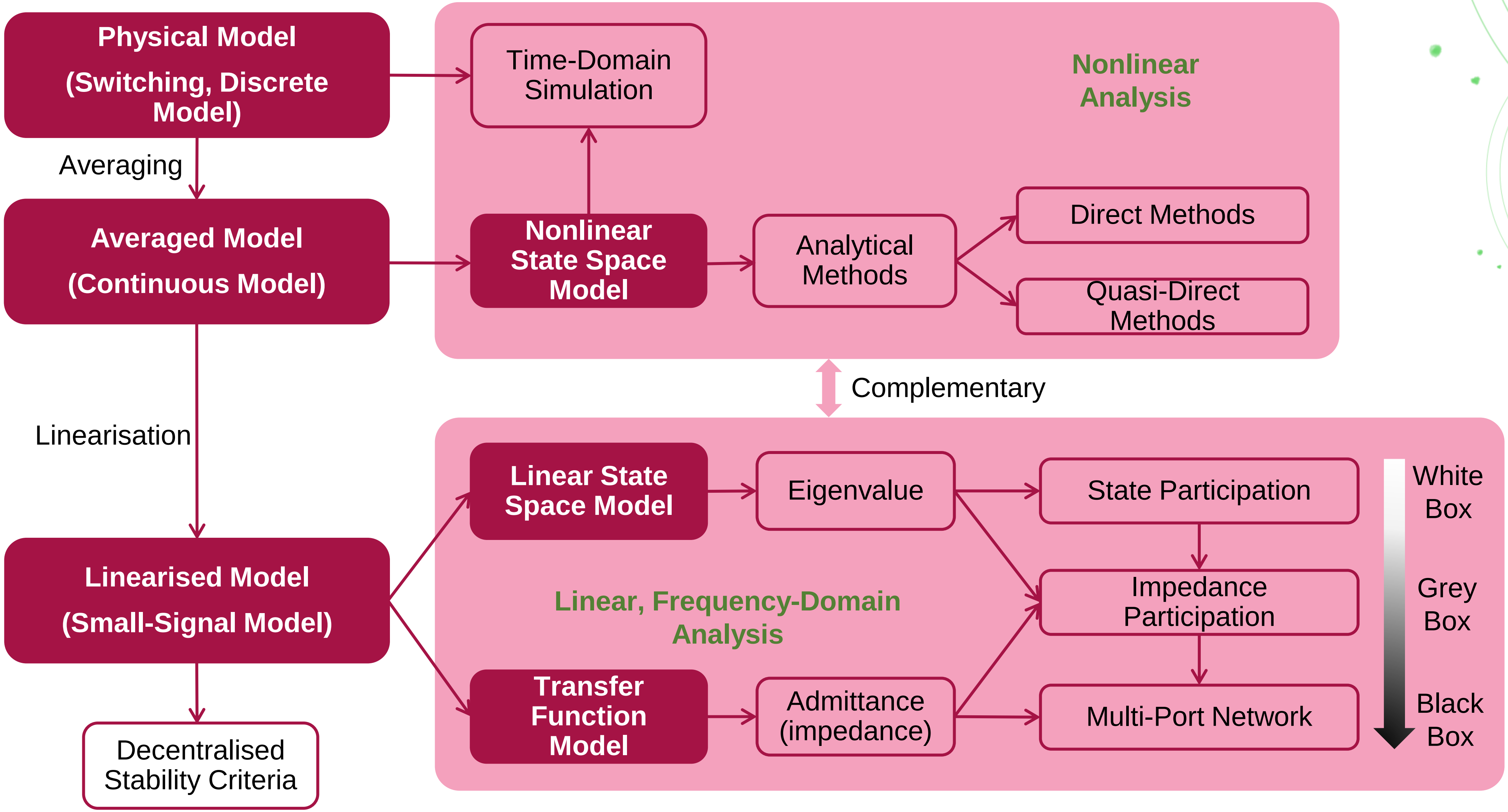
Simulation tools: today



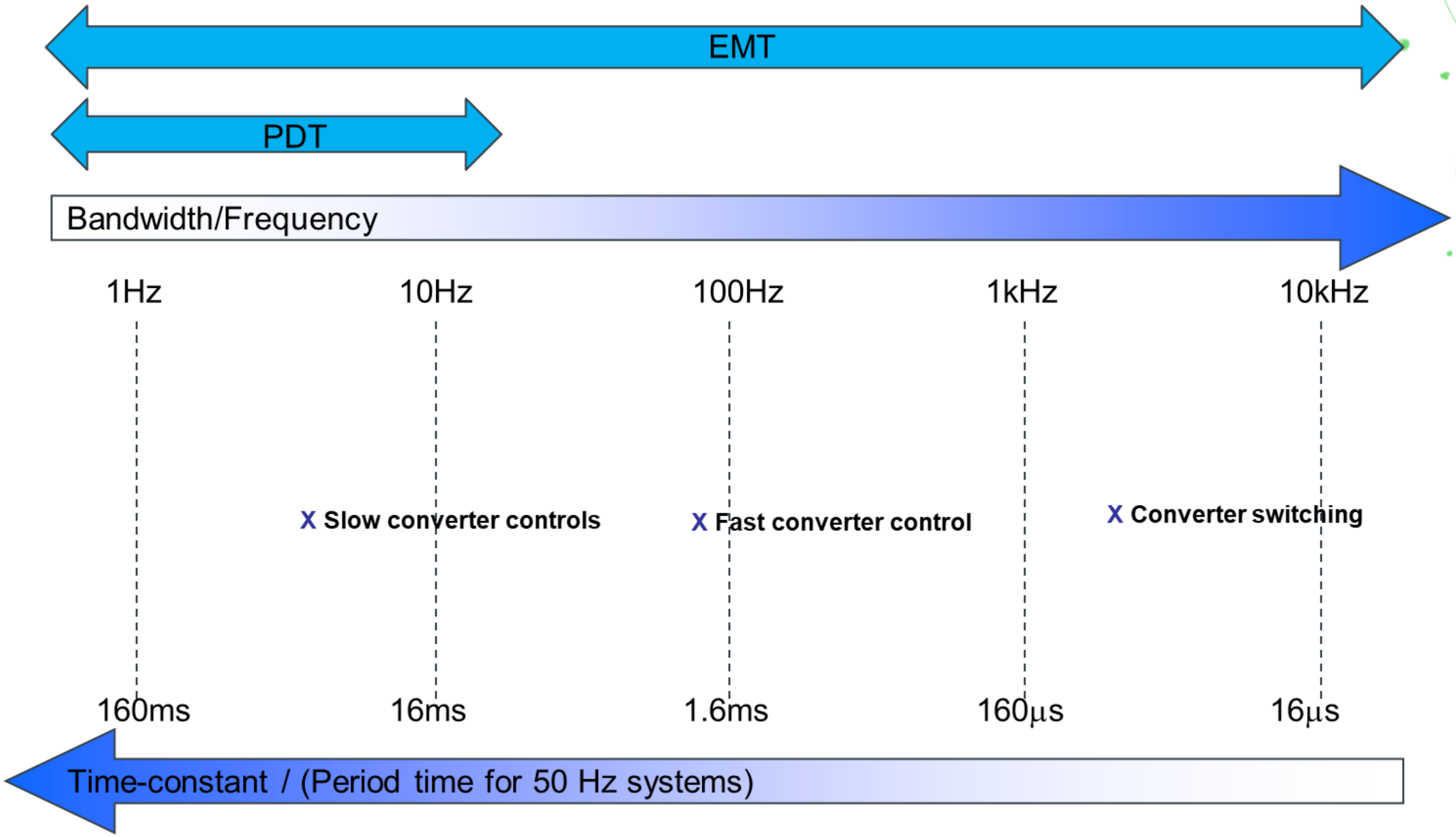
Simulation tools: moving forward



Dynamic analysis methods



Bandwidth of phenomena/control loops in IBRs



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Part II: Power System Studies under a High Penetration of Power Electronic Interfaced Devices

Considerations for analysing different types of system stability

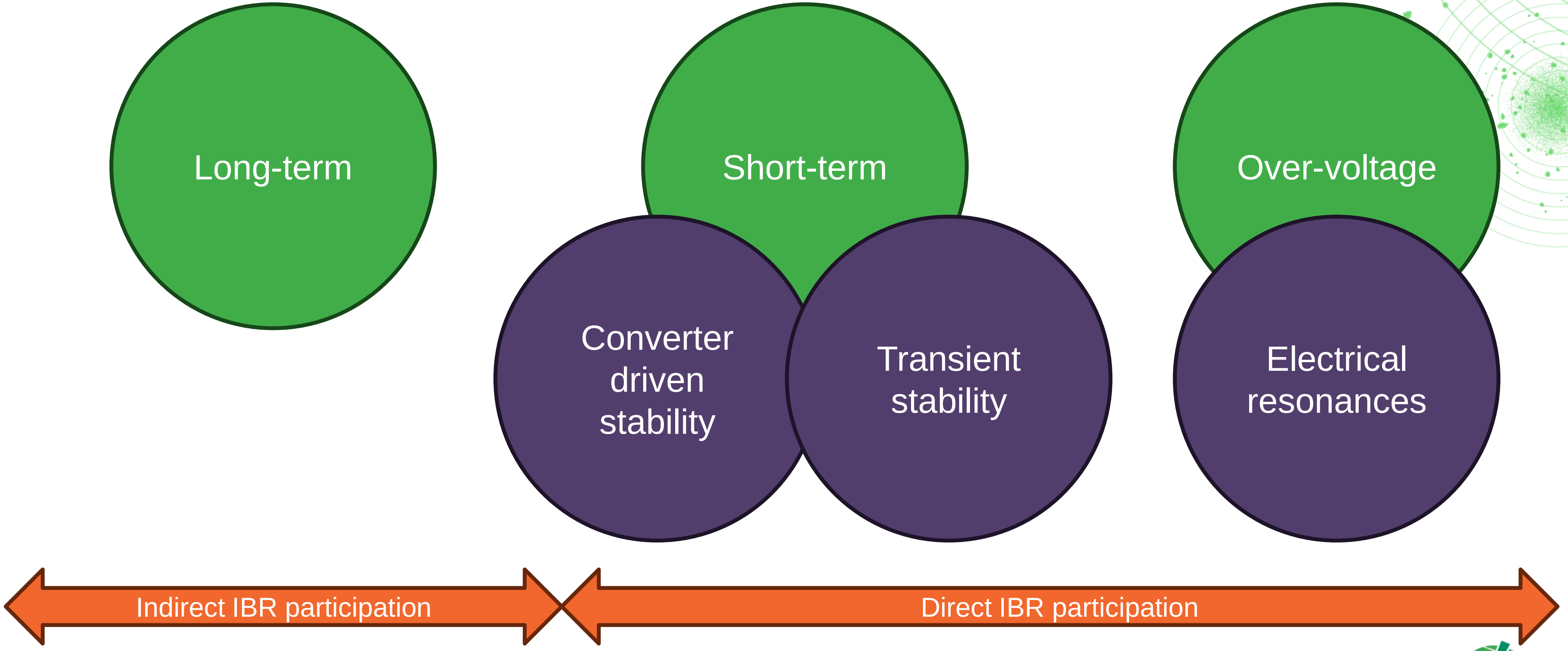
Cause

Contributing factors

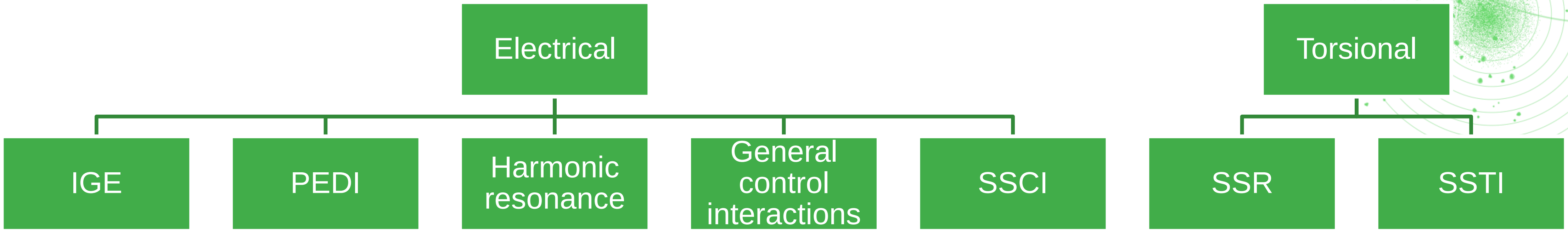
Consequence

Counter measures

Type of voltage stability

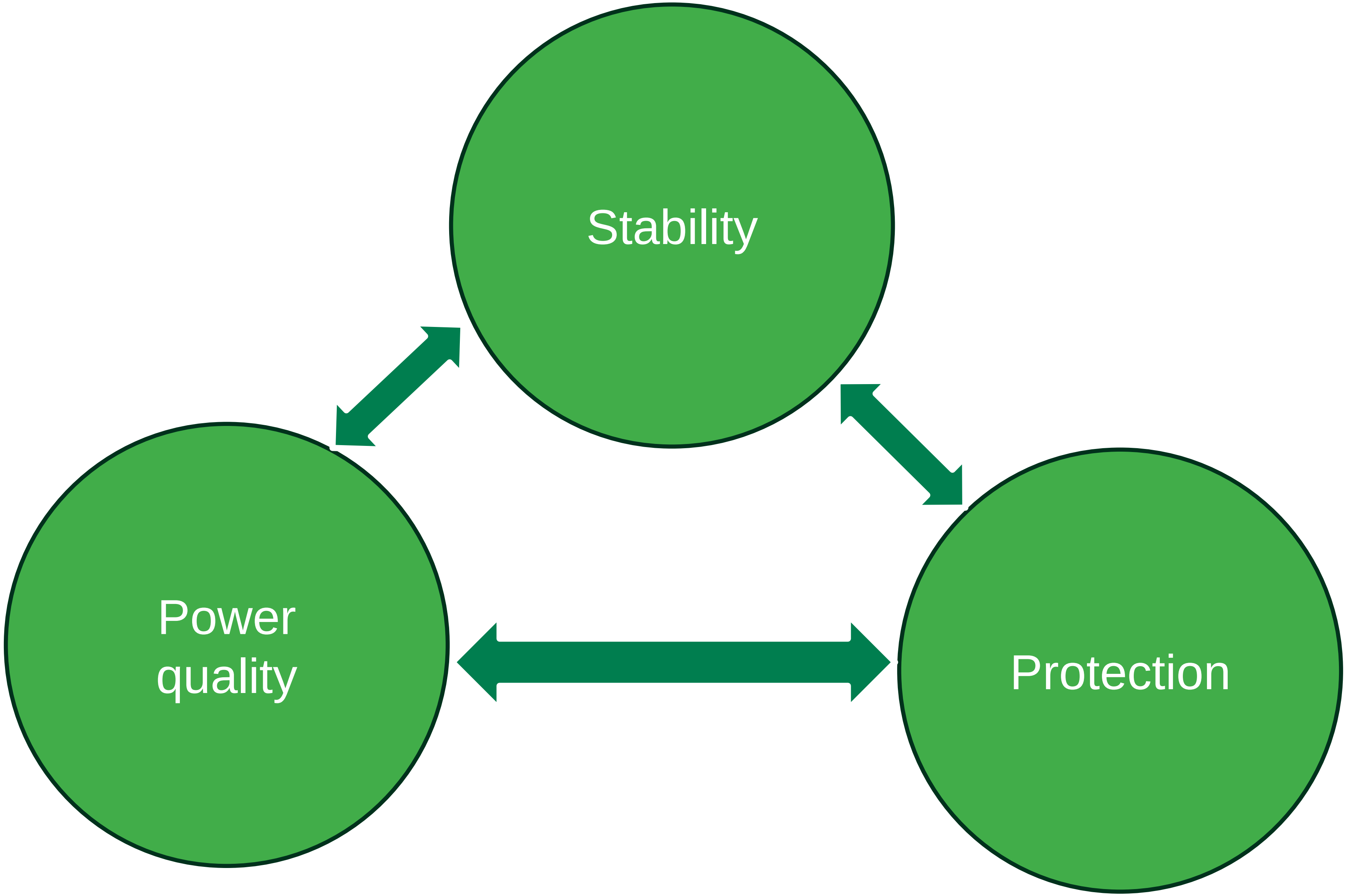


Sub-synchronous interactions

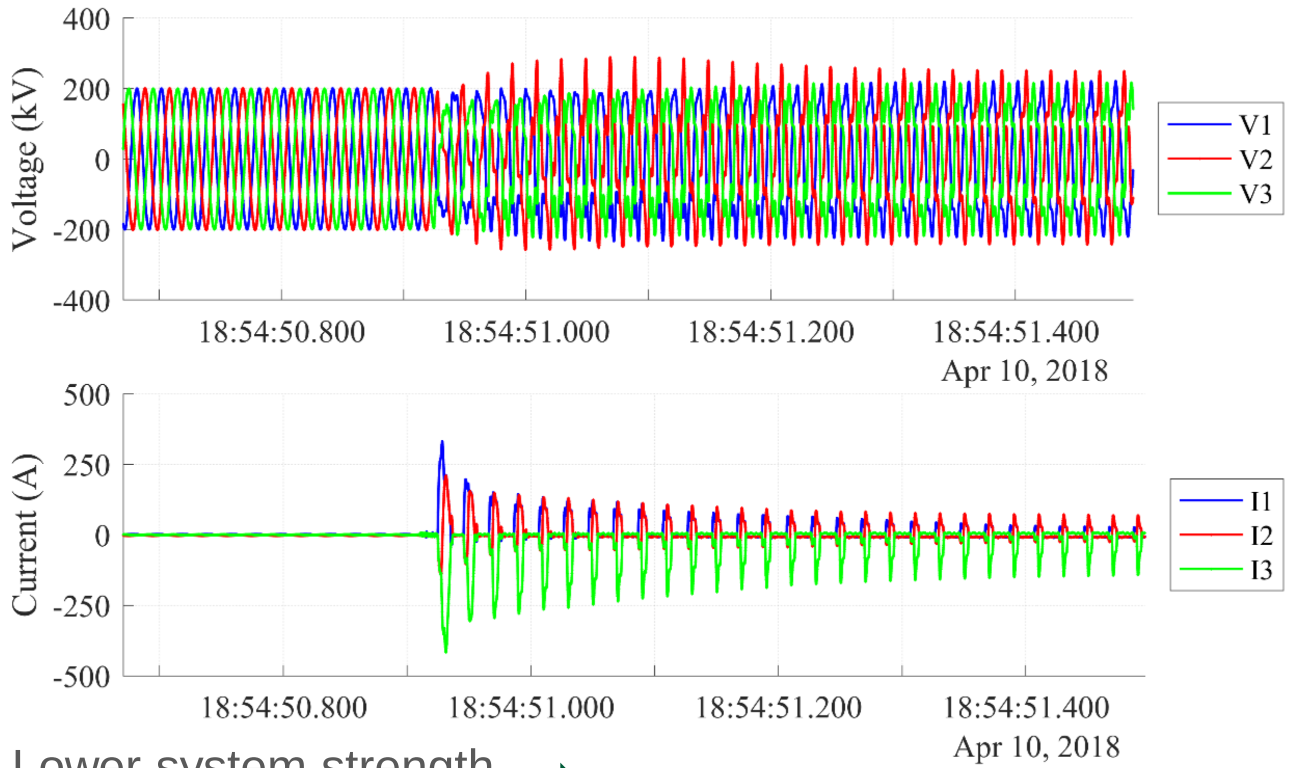


- IGE: Induction generator effect
- PEDI: Power electronics device interaction
- SSCI: Sub-synchronous control interactions
- SSR: Sub-synchronous resonance
- SSTI: Sub-synchronous torsional interactions

Interactions between different phenomena



Interaction between power quality and system stability



Lower system strength

Higher Thevenin impedance

Higher harmonic voltage distortion even for the same harmonic current injection

New observed phenomena

Reduced system strength conditions

Interactions involving series compensated lines

Interactions involving rotating masses of turbine generators

Interactions between multiple IBRs

Incorrect settings of slow or fast control loops used in IBRs

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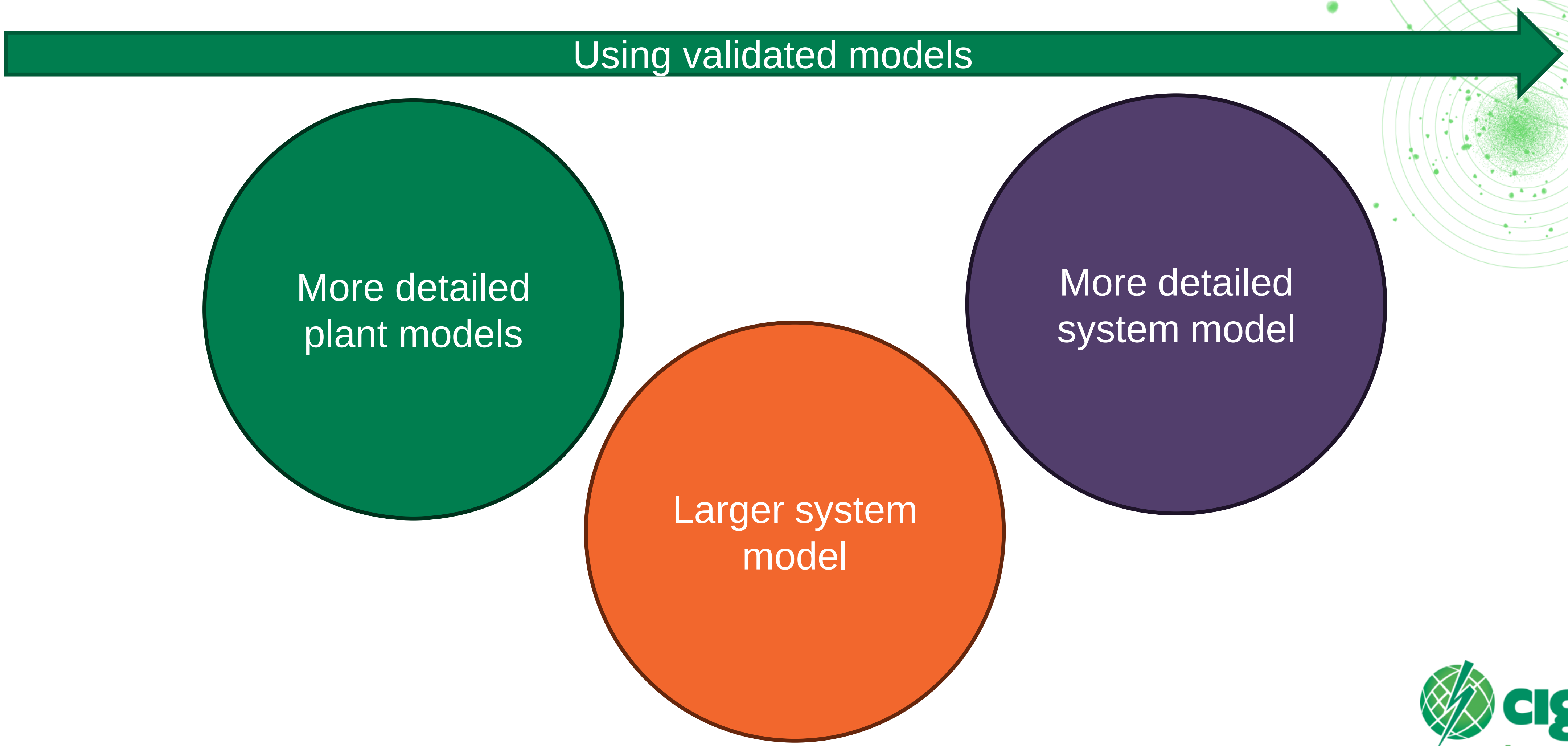
Selected Topics

How to obtain higher accuracy?



Summary of key aspects deciding the use of EMT or PDT models

Phenomena-based

Application-based

Screening-based

Data and model availability-based

Models of interest are not always available

Evolution of the use of screening methods

SMIB individual

Wide-area individual

Wide-area Collective

Low system strength

Other relevant conditions

A gauge of stability of an IBR under <u>low system strength conditions</u>

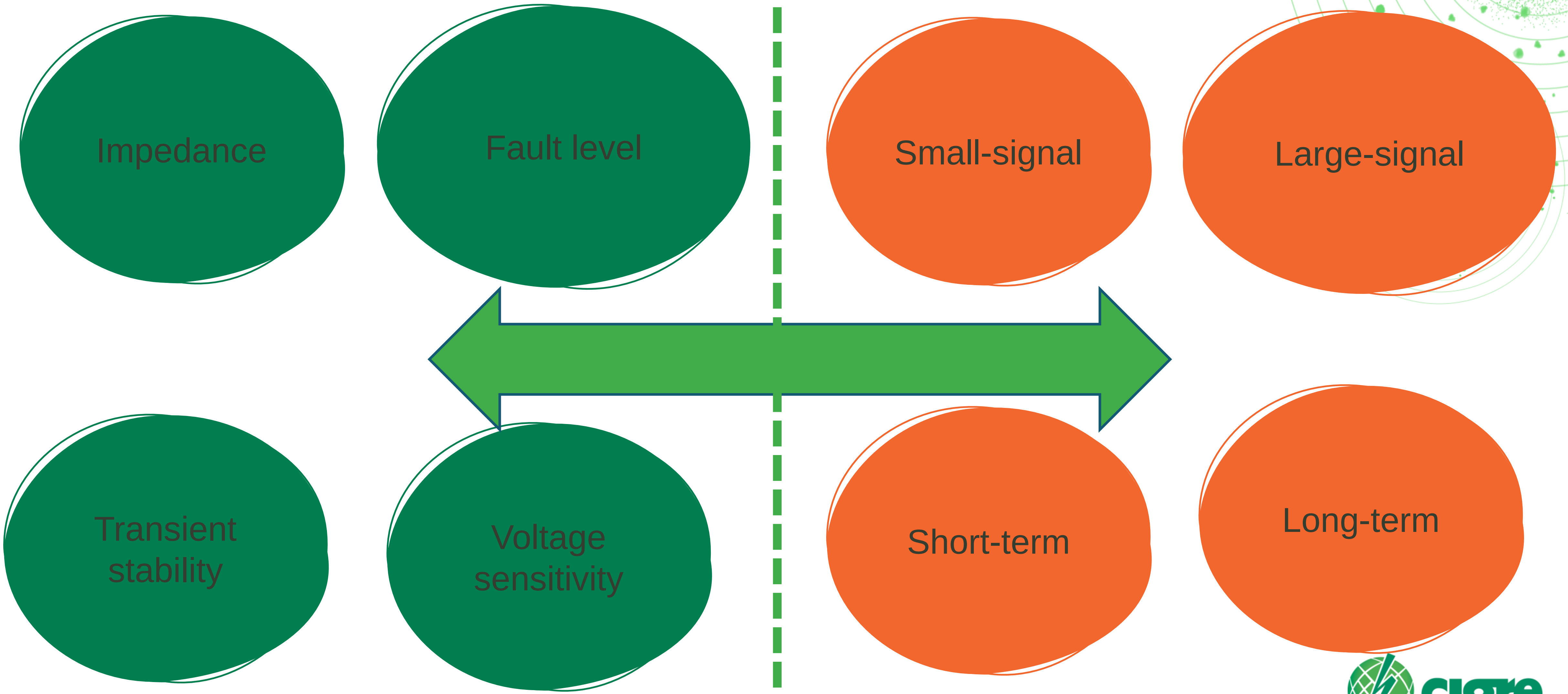
If EMT studies are required

Determining vertical and horizontal study area

Reducing the number of wide-area EMT studies

Assessing the likelihood of interaction between <u>relevant</u> converters

Principles of existing screening methods



Tools and techniques to analyse interactions

EMT studies

Eigenvalue

Participation factor

Eigenvalue

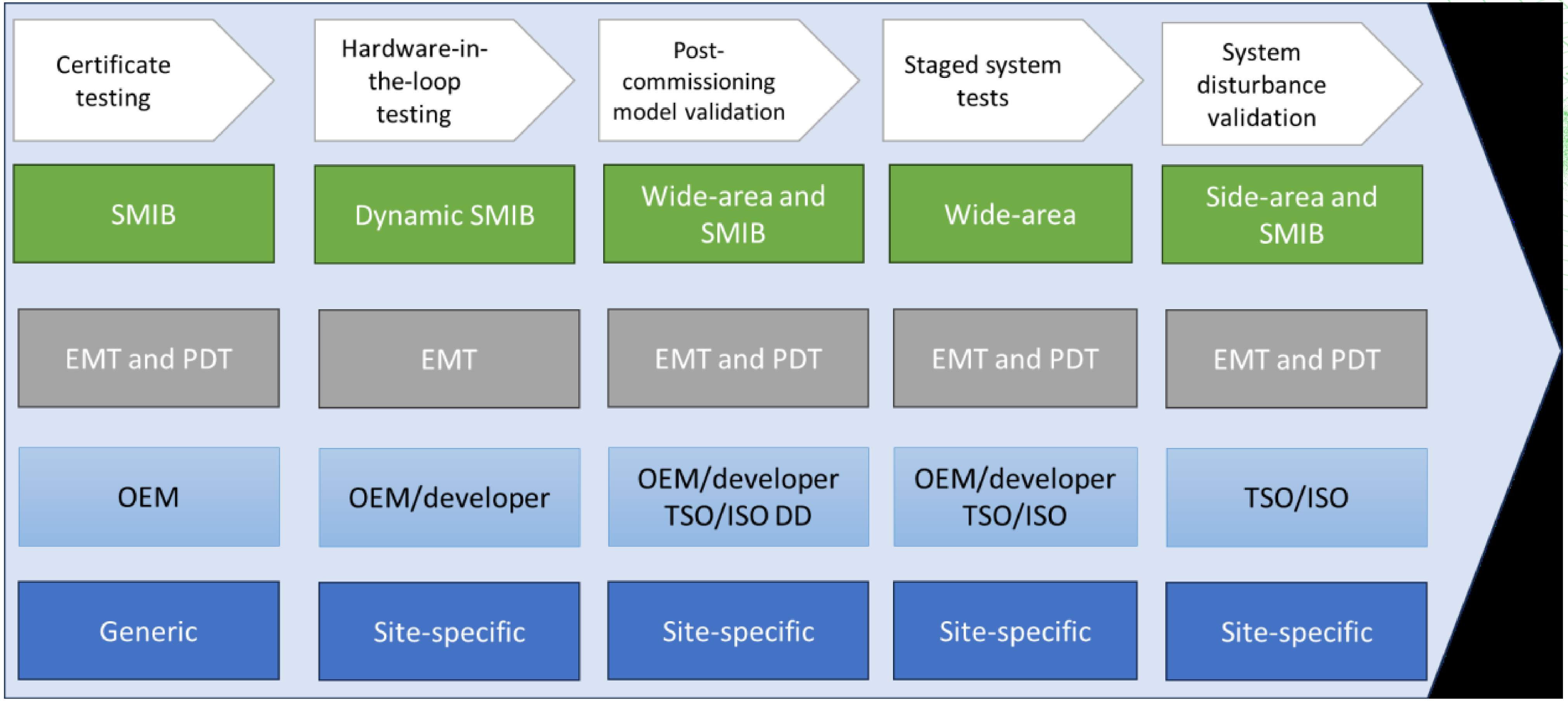
Apparent impedance

Passivity

Transfer function

Frequency domain

Model validation life-cycle



Advancing power system modelling: The push for detail and efficiency

Enhanced modelling techniques

Advanced computational tools

Collaboration and data sharing

Standardisation and interoperability

Clear objectives, processes and success criteria

Improved decision making and optimisation

Screening methods

Model validation and testing

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