

2nd International Summer School on IBR-dominated Power Systems



清华大学
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IMPERIAL

Risk-Based Mode Flagging from EMT-Derived Models in VSC-Integrated Grids Post-processing eigenstructure analysis from the open-source STAMP Toolbox for targeted stability screening



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Small-Signal Stability

Definition (in this work)

- Stability margin is defined as the distance between the rightmost eigenvalue and the positive real axis.

Why is modal analysis interesting?

- Reveals hidden dynamics in VSC-rich grids, enabling risk-informed grid operation & planning.

Drivers:

- Transition to power-electronics-based generation, introducing new oscillatory modes.
- Need for stability maps under uncertainty, anticipating future scenarios of currently unthinkable replacements.

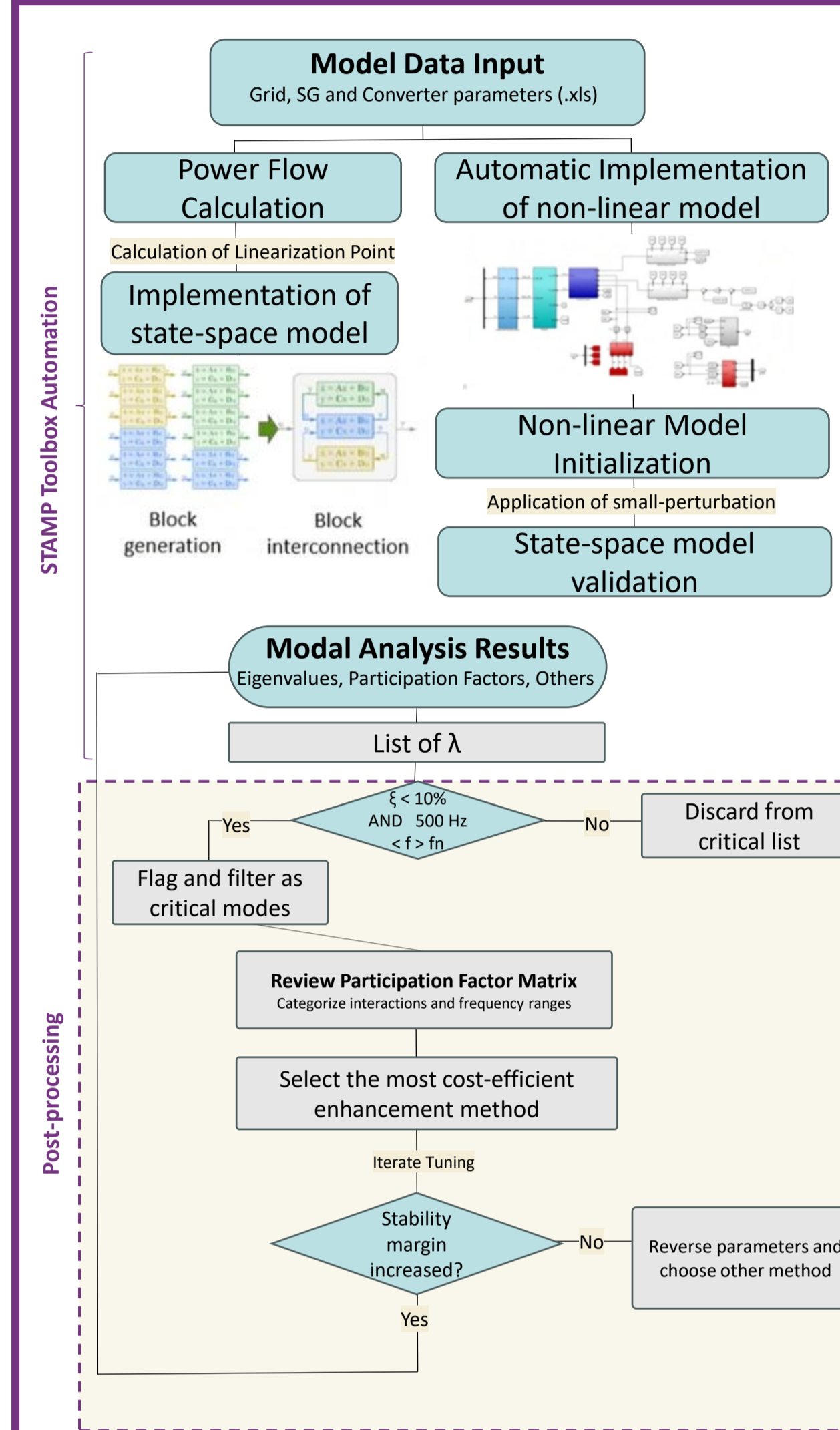
Objectives:

- ✓ Fast pre-screening of critical modes.
- ✓ Focus enhancement on cost-efficient mitigation.

摘要 (中文)

用电电压源换流器 (VSC) 替换同步发电机会改变系统动态特性和稳定裕度。基于开源工具 STAMP 得到的 7 节点巴西基准网络 EMT 线性化模型, 对振荡模式进行风险排序, 以支持稳定性增强的决策制定。这种优先级排序有助于运行人员将缓解措施集中在最能提升系统整体稳定性的地方。

Methodology



Oscillation Type	Frequency Range	Typical Cause	Involved Elements
Interarea at very low frequency	0.1 – 0.3 Hz	(Global Instability) Generators swinging against each other.	All generators of the system, split in 2 areas.
Interarea at higher frequency	0.4 – 0.7 Hz		Subgroups of generators.
Control Modes	0.7 – 1 Hz	Control of equipment (inadequate tuning of the control systems).	SG excitation systems, HVDC converters, static var compensators.
Interplant / intermachine	0.7 – 2 Hz	Rotors of generations close to each other.	Two or more generator in same area/ other areas.
Torsional Mode	10 – 60 Hz	Control Systems interaction with the turbine shaft.	Turbine-Generator Shaft System

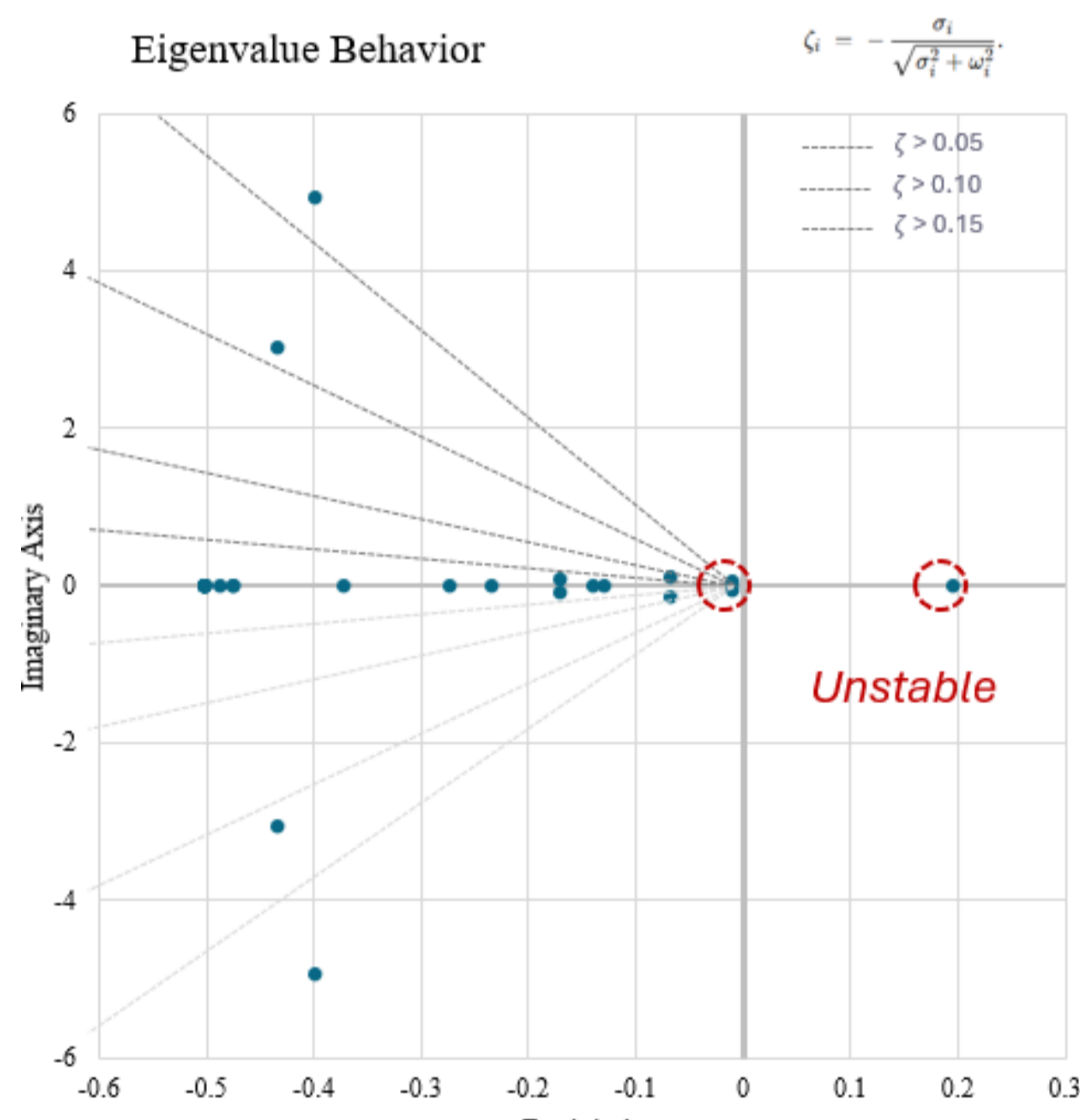
Oscillation Type	Frequency Range	Typical Cause	Involved Elements
Converter Control	0.1 – 0.8 kHz	Current control with grid impedance, PLL or Voltage control	VSC and Load Voltage Control, Inner current loop
Voltage Control Interaction	0.7 – 0.9 kHz	Cross-axis voltage control coupling, damping	VSC voltage control – Load
Converter Capacitance	0.8 – 1.5 kHz	Resonance LC filter and grid impedance, current control gain	VSC – Load – AC filter
Inner-loop Mode	3.0 – 4.0 kHz	Converter Switching Dynamics	Load – VSC Inner current control

Index Terms — Small-signal stability, modal analysis, generator replacement, mode flagging, risk-oriented grid planning.

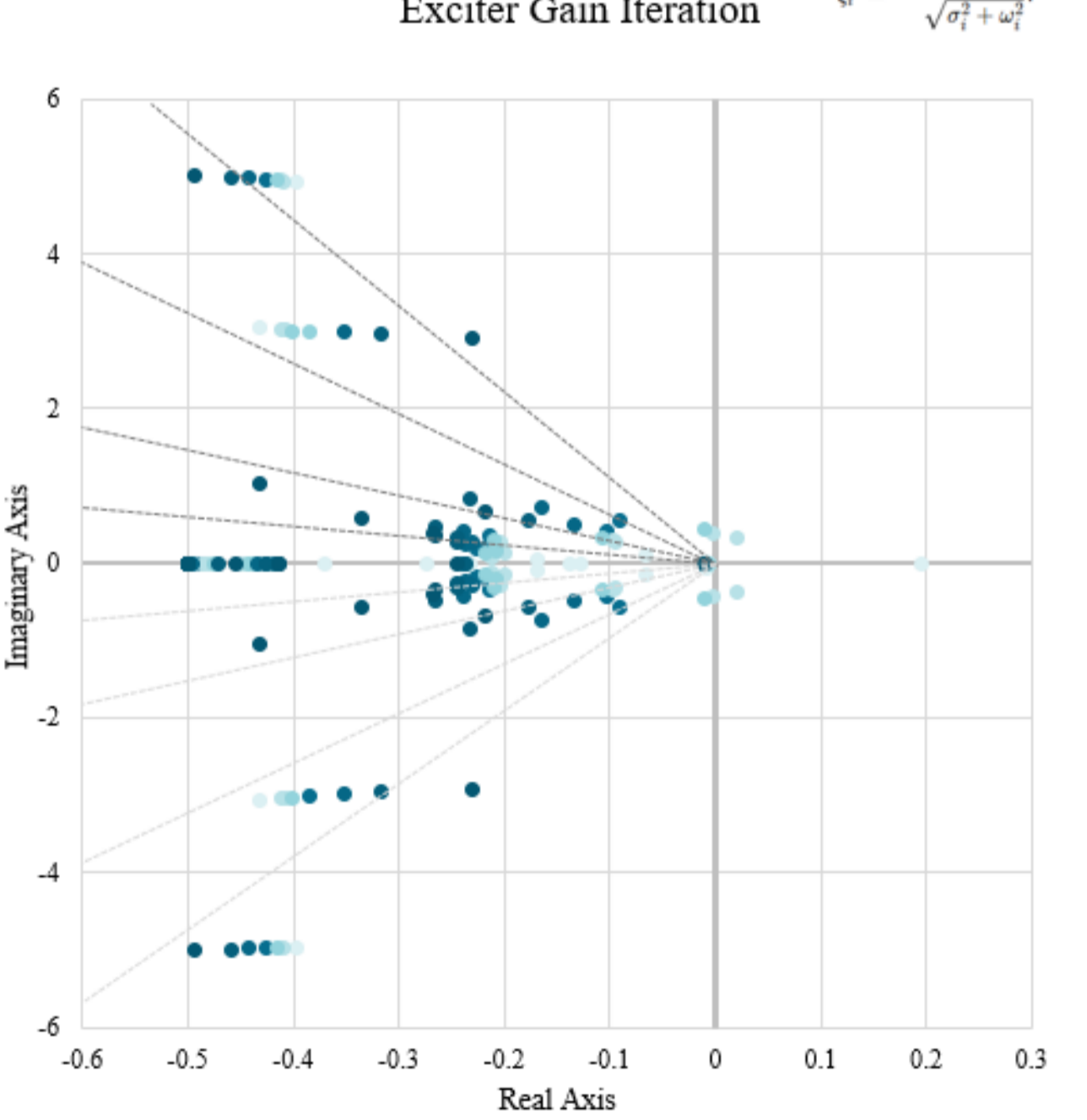
Experimental Results & Analysis

Study Case 1: Brazilian 7-bus IEEE benchmark

Mode No.	Real	Imaginary	Frequency	Damping
1	0.195314522	0	0	-100%
13	-0.397541089	4.942051305	0.786552	8%
14	-0.397541089	-4.94205131	0.786552	8%
51	-7.662950493	376.824746	59.97352	2%
52	-7.662950493	-376.824746	59.97352	2%
61	-9.706702522	376.8215356	59.97301	3%
62	-9.706702522	-376.821536	59.97301	3%
74	-12.74209665	376.9725535	59.99705	3%
75	-12.74209665	-376.972554	59.99705	3%
77	-16.23913093	376.9048339	59.98627	4%
78	-16.23913093	-376.904834	59.98627	4%
87	-27.27893905	376.9890989	59.99968	7%
88	-27.27893905	-376.989099	59.99968	7%
98	-456.8432021	5420.476869	862.6957	8%
99	-456.8432021	-5420.47687	862.6957	8%
100	-456.9243339	4666.505901	742.6975	10%
101	-456.9243339	-4666.5059	742.6975	10%
110	-1135.986844	20559.44184	3272.137	6%
111	-1135.986844	-20559.4418	3272.137	6%
112	-1136.026849	19805.46538	3152.138	6%
113	-1136.026849	-19805.4654	3152.138	6%

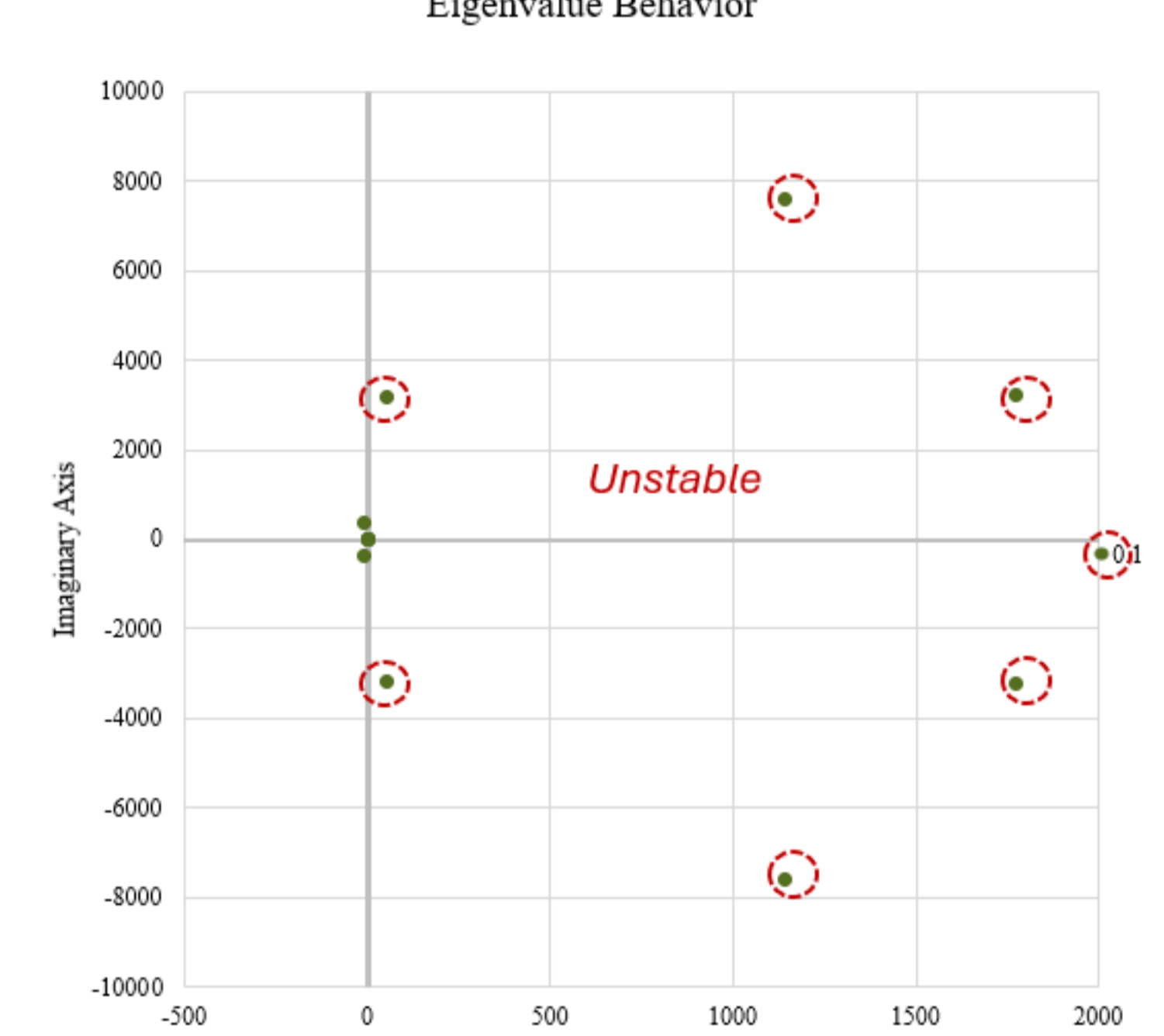


Conjugate Pairs:	$\lambda_{1,2}$	$\lambda_{13,14}$	$\lambda_{51,52}$	$\lambda_{61,62}$	$\lambda_{74,75}$	$\lambda_{77,78}$	$\lambda_{87,88}$	$\lambda_{98,99}$	$\lambda_{100,101}$	$\lambda_{110,111}$	$\lambda_{112,113}$
Real	0.1953	-0.3975	-456.8432	-456.9243	-1135.9868	-1136.0268					
Imaginary	0.0000	4.9421	5420.4769	4666.5059	20559.4418	19805.4654					
Frequency	0.0000	0.7866	862.6957	742.6975	3272.1368	3152.1377					
Damping	-100%	8%	8%	10%	6%	6%					

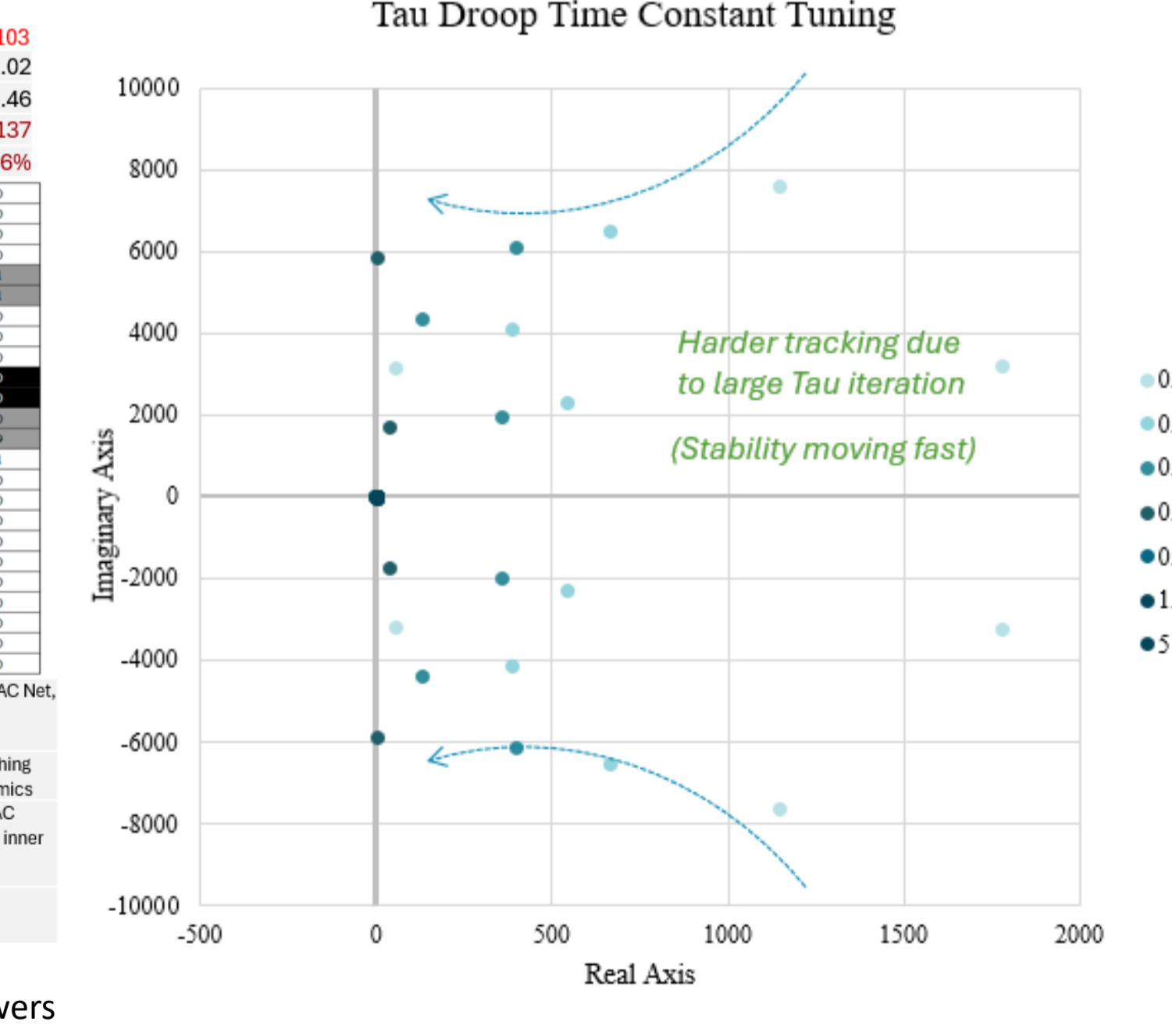


Study Case 2: Generator Replacement

Mode No.	Real	Imaginary	Frequency	Damping
1	1776.07072	3210.361	510.945	-48%
2	1776.07072	-3210.361	510.945	-48%
3	1142.30355	7606.1668	1210.56	-15%
4	1142.30355	-7606.167	1210.56	-15%
5	52.30648	3166.6716	503.991	-2%
6	52.30648	-3166.672	503.991	-2%
10	-0.24937	2.83391	0.45103	9%
11	-0.24937	-2.83391	0.45103	9%
27	-0.54267	5.39463	0.85858	10%
28	-0.54267	-5.39463	0.85858	10%
49	-8.09193	376.81791	59.9724	2%
50	-8.09193	-376.8179	59.9724	2%
59	-12.74053	376.9715	59.9969	3%
60	-12.74053	-376.9715	59.9969	3%
68	-15.98885	376.89233	59.9843	4%
69	-15.98885	-376.8923	59.9843	4%
78	-27.27014	376.98834	59.9996	7%
79	-27.27014	-376.9883	59.9996	7%
88	-421.97853	4678.2539	744.567	9%
89	-421.97853	-4678.254	744.567	9%
90	-430.49772	5432.2956	864.577	8%
91	-430.49772	-5432.296	864.577	8%
100	-1135.98449	20559.446	3272.14	6%
101	-1135.98449	-20559.45	3272.14	6%
102	-1136.02485	19805.46	3152.14	6%
103	-1136.02485	-19805.46	3152.14	6%



Conjugate Pairs:	$\lambda_{1,2}$	$\lambda_{3,4}$	$\lambda_{5,6}$	$\lambda_{10,11}$	$\lambda_{27,28}$	$\lambda_{49,50}$	$\lambda_{59,60}$	$\lambda_{68,69}$	$\lambda_{78,79}$	$\lambda_{88,89}$	$\lambda_{90,91}$	$\lambda_{100,101}$	$\lambda_{102,103}$
Real	1776.071	1142.304	52.30648	-0.24937	-0.54267	-8.09193	-12.74053	-15.98885	-27.27014	-421.97853	-430.49772	-1135.98449	-1136.02485
Imaginary	3210.361	7606.1668	3166.672	2.83391	5.39463	376.81791	376.9715	376.89233	376.98834	4678.2539	5432.2956	20559.446	19805.46
Frequency	510.9448	1210.559	503.9914	0.45103	0.85858	59.9724	59.9969	59.9843	59.9996	744.567	864.577	3272.137	3152.137
Damping	-48%	-15%	-2%	9%	10%	2%	3%	4%	7%	9%	8%	6%	6%



- τ droop (~0.5 kHz): moves the outer-loop pole and lowers gain where the mode lives, mitigating converter-grid interaction driven by i_g, q .

New dynamics and Stability Enhancement

- Baseline:** Dynamics dominated by SG-network interactions, predictable LF modes, no significant HF instabilities.
- VSC GFOL:** Introduces fast control-driven modes (0.5–1.2 kHz) inherent to GFOL operation, adding new stability constraints in planning.

This loop can be extended as far as planning scope and resources allow, enabling stability enhancement as an integrated part of grid expansion and converter replacement strategies.

Acknowledgements

This study uses the Small-Signal Toolbox for Analysis of Modern Power Systems (STAMP), a MATLAB-based toolbox for automatic EMT modeling and small-signal analysis of hybrid AC/DC power systems. Developed at CITCEA-UPC, Universitat Politècnica de Catalunya.

License: MPL-2.0 GitHub: <https://github.com/CITCEA/stamp>

