A Small-Signal Stability Index for Power System Dynamic Impact Assessment using Time-domain Simulations

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iTesla Innovative Tools for Electrical System Security within Large Areas

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Abstract— A small-signal stability index of three layers, which is used to assess power system dynamic simulations is presented.

The index is calculated from an estimate of the eigenvalues of the system, which are determined using time-series from dynamic simulations. The methodology assumes that no other information about the system (model) is available.

In the first layer, which is the main future of the index, a scalar indicates if any of the modes have a damping ratio less than a predefined value. In the second layer, a vector is used to specify which pre-defined damping ratios were violated and finally, in the third layer a matrix is used to retrieve precise information about which mode has violated the pre-defined damping requirements of the system.

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I. Motivation

- To develop offline criteria to support online analysis functions within the iTesla toolbox.
- To classify events on time-series performed from dynamic simulations.
- Fast computation and good measure of how severe the contingency affected the stability of the system.
- Simple to interpret without compromising information about the cause of the problem.

II. Small-signal Stability Index

- The index is based on the damping ratio of the estimated system's modes.
- The measure is the angular distance (in radians) from each mode to a pre-defined damping ratio.
- The index has three layers to facilitate its interpretation: the matrix Single Mode Index (SMI), the vector All Modes Index (AMI) and the scalar Global Modes Index (GMI)

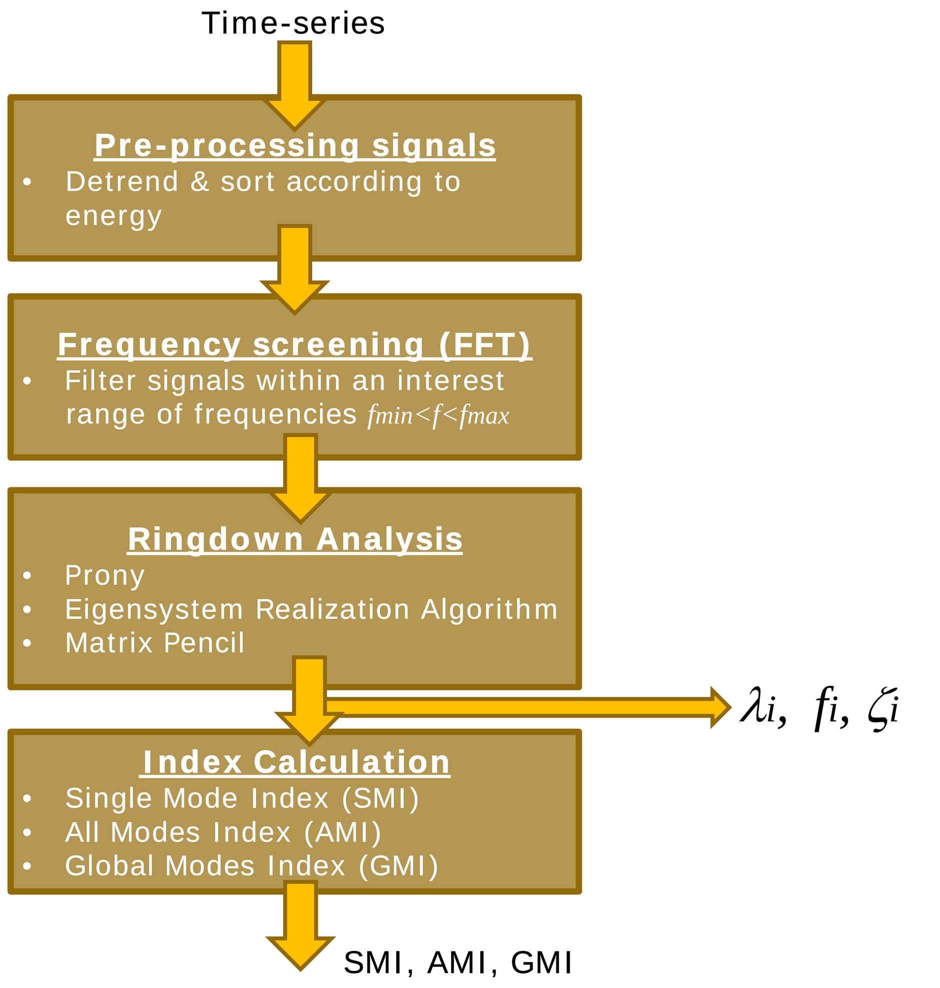

Figure 1. Flow chart of the index calculation

III. THE THREE-LAYER SSS INDEX

- The **SMI** provides the individual distance of each mode to a predefined damping ratio, e.g. $\zeta_0=0\%$, $\zeta_5=5\%$ and $\zeta_{10}=10\%$.
- **AMI** is a vector that gives the minimum distance of the modes with respect to each of the pre-defined damping ratios.
- **GMI** gives a global interpretation of the modes respect to all pre-defined damping ratios, is the minimum distance among all modes respect to all pre-defined ratios.

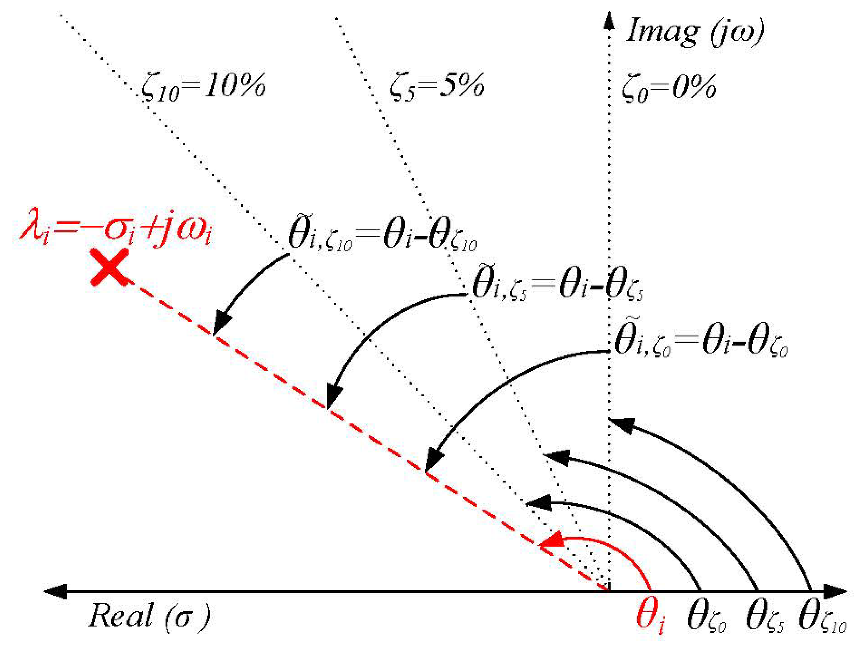

Figure 2. Angular distance from each mode to a pre-defined damping ratio

$$\underline{SMI} = \begin{bmatrix} \tilde{\theta}_{1,\zeta_0} & \tilde{\theta}_{1,\zeta_5} & \tilde{\theta}_{1,\zeta_{10}} & \cdots & \tilde{\theta}_{1,\zeta_j} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{\theta}_{i,\zeta_0} & \tilde{\theta}_{i,\zeta_5} & \tilde{\theta}_{i,\zeta_{10}} & \cdots & \tilde{\theta}_{i,\zeta_j} \end{bmatrix}$$

$$\tilde{\theta}_{i,\zeta_j} = \theta_i - \theta_{\zeta_j}$$
$$\theta_i = \cos^{-1}(\zeta_i)$$
$$\theta_{\zeta_j} = \pi - \cos^{-1}(\zeta_i)$$

$$\underline{AMI} = [\hat{\theta}_{\zeta_0} \quad \hat{\theta}_{\zeta_5} \quad \hat{\theta}_{\zeta_{10}} \quad \cdots \quad \hat{\theta}_{\zeta_j}], \quad \hat{\theta}_{\zeta_j} = min\left|\tilde{\theta}_{i,\zeta_j}\right|$$

$$\underline{GMI} = \Theta_{\zeta_j}, \quad \Theta_{\zeta_j} = min\left|\hat{\theta}_{\zeta_j}\right|$$

IV. Illustrative Example

- Two artificial signals, shown on Figure 3 (a), with 3 different frequencies and damping ratios were generated.
- The procedure described on Figure 1, was applied and the results are depicted on Table 1.
- Figures 3 (b), (c) and (d) describe the different steps of the method.

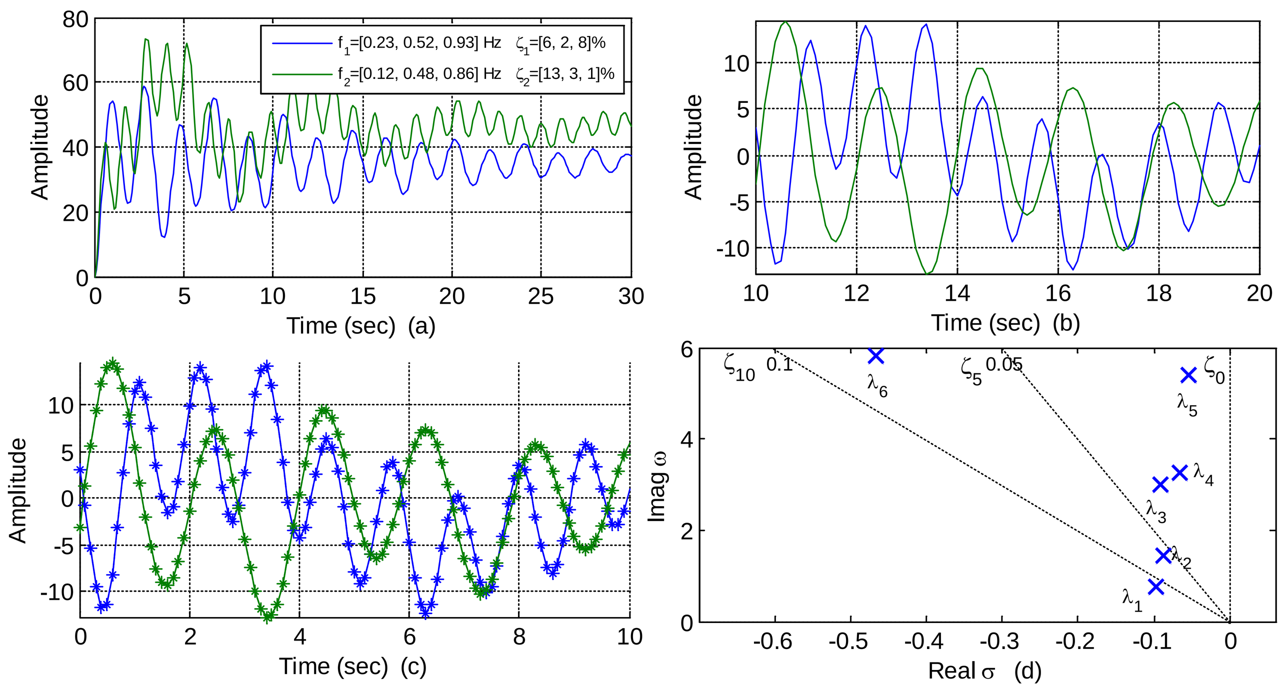

Figure 3. (a) Analyzed time series, (b) Detrended and selected data, (c) Signal estimation from ringdown analysis and (d) Estimated modes

	Θ_{ζ_j}
GMI	-0.0902

	$\hat{\theta}_{\zeta_0}$	$\hat{\theta}_{\zeta_5}$	$\hat{\theta}_{\zeta_{10}}$
AMI	0.0100	-0.0400	-0.0902

SMI	$\tilde{\theta}_{i,\zeta_0}$	$\tilde{\theta}_{i,\zeta_5}$	$\tilde{\theta}_{i,\zeta_{10}}$
λ1	0.1304	0.0803	0.0302
λ2	0.0600	0.0100	-0.0401
λ3	0.0300	-0.0200	-0.0702
λ4	0.0200	-0.0300	-0.0802
λ5	0.0100	-0.0400	-0.0902
λ6	0.0801	0.0301	-0.0201

Table 1. The three layer small-signal stability index

V. Application to the KTH-Nordic32 system

(a) *Case A*: One 3-phase fault of 100msec at each bus (32 simulations)

(b) *Case B*: Five 3-phase faults of random duration at each bus (160 sim)

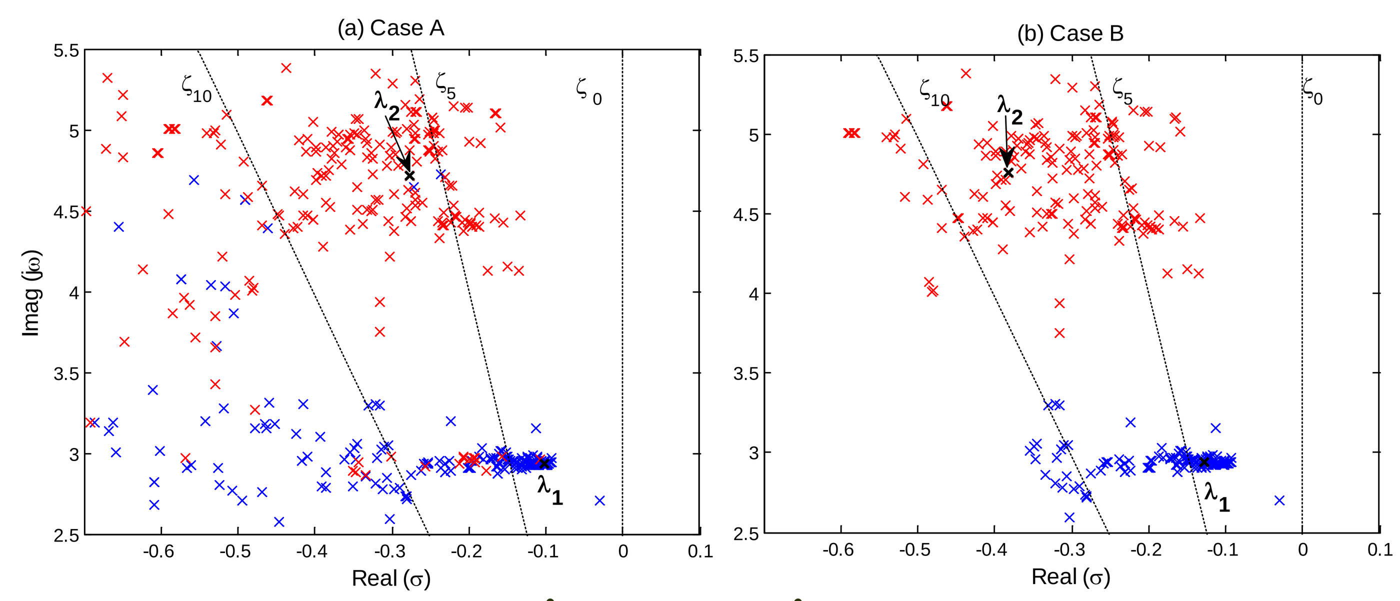

Figure 4. Estimated modes λ1 in red and λ2 in blue and median values in black for both: (a) Case study A and (b) Case study B

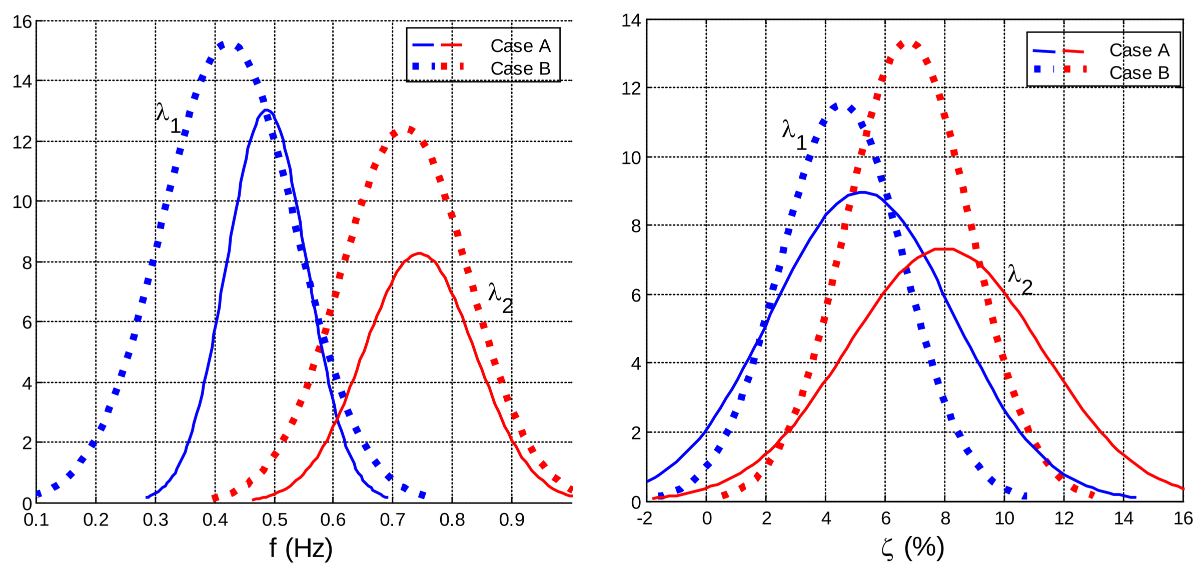

Figure 5. Fitted normal distribution of the estimated frequencies and damping ratios for both modes λ1 in blue and λ2 in red and both case studies

Case A

Mode	f(Hz)	ζ(%)	std
λ1	0.4763	4.56	0.0681
λ2	0.7609	6.99	0.1006

Case B

Mode	f(Hz)	ζ(%)	std
λ1	0.4698	3.98	0.0054
λ2	0.7566	5.94	0.0938

Table 2. Median of the estimated modes, frequencies and damping

Case A:

	Θ_{ζ_j}
GMI	-0.0545

	$\hat{\theta}_{\zeta_0}$	$\hat{\theta}_{\zeta_5}$	$\hat{\theta}_{\zeta_{10}}$
AMI	0.0456	-0.0044	-0.0545

SMI	$\tilde{\theta}_{i,\zeta_0}$	$\tilde{\theta}_{i,\zeta_5}$	$\tilde{\theta}_{i,\zeta_{10}}$
λ1	0.0456	-0.0044	-0.0545
λ2	0.0700	0.0199	-0.0302

Case B:

	Θ_{ζ_j}
GMI	-0.0652

	$\hat{\theta}_{\zeta_0}$	$\hat{\theta}_{\zeta_5}$	$\hat{\theta}_{\zeta_{10}}$
AMI	0.0349	-0.0151	-0.0652

SMI	$\tilde{\theta}_{i,\zeta_0}$	$\tilde{\theta}_{i,\zeta_5}$	$\tilde{\theta}_{i,\zeta_{10}}$
λ1	0.0349	-0.0151	-0.0652
λ2	0.0595	0.0095	-0.0406

Table 3. Small-signal stability indexes for median values of the Nordic system