Estimation of Participation Factors Using the Synchrosqueezed Wavelet Transform

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CONTRIBUTION

- Proposing a data-driven approach for estimating participation factors for power systems using simulation results.
- Estimation of participation factors using the Synchrosqueezed Wavelet Transform (SSWT) for both the electromagnetic transient model and phasor model and comparison with continuous wavelet transform and Prony analysis.
- Benchmarking with conventional model-based participation factors.
- Applicable to systems whose detailed, complete mathematical models are not available.

BACKGROUND INFORMATION

$$\dot{x} = f(x,u)$$

$$\Delta\dot{x} = A\Delta x + B\Delta u \qquad \Psi_i A = \lambda_i \Psi_i \qquad A\Phi_i = \lambda_i \Phi_i$$

$$p_{ki} = \Phi_{ki}\Psi_{ik}$$

RESPONSE-BASED PARTICIPATION FACTORS USING WAVELETS

System response for kth state variable

$$x_k(t) = \sum_{i=1}^{n} \Phi_{ki}\,\Psi_i\,x(0)\,e^{\lambda_i t} = \sum_{i=1}^{n} B_{ki} e^{\lambda_i t}$$

$$\mathbf{x}_0 = \mathbf{e}_k \overset{\text{def}}{=} \begin{bmatrix} 0 & \dots & 0 & \underset{k\text{th element}}{1} & 0 & \dots & 0 \end{bmatrix}^{\mathrm{T}}$$

$$x_k(t) = \sum_{i=1}^{n} \Phi_{ki}\,\Psi_i\,e_k\,e^{\lambda_i t} = \sum_{i=1}^{n} p_{ki} e^{\lambda_i t}$$

Continuous Wavelet Transform (CWT)

$$W(a,b) = \int_{-\infty}^{+\infty} s(t) a^{-1/2} \Psi^*\left(\frac{t-b}{a}\right) dt$$

Instantaneous frequency

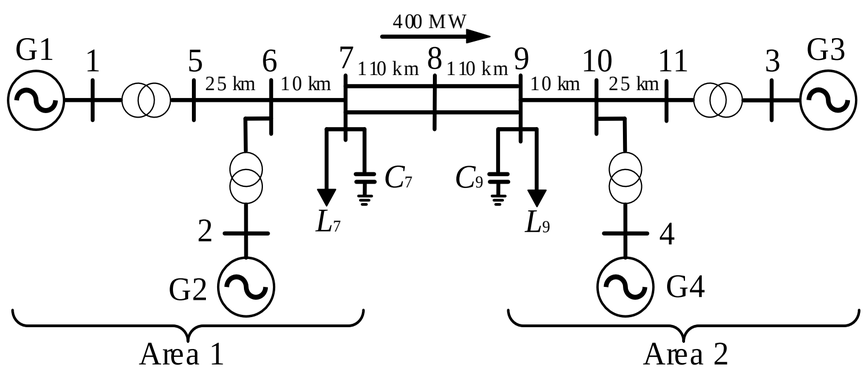
$$\omega(a,b) = -iW(a,b)^{-1}\frac{\partial W(a,b)}{\partial b}$$

Synchrosqueezed Wavelet Transform (SSWT)

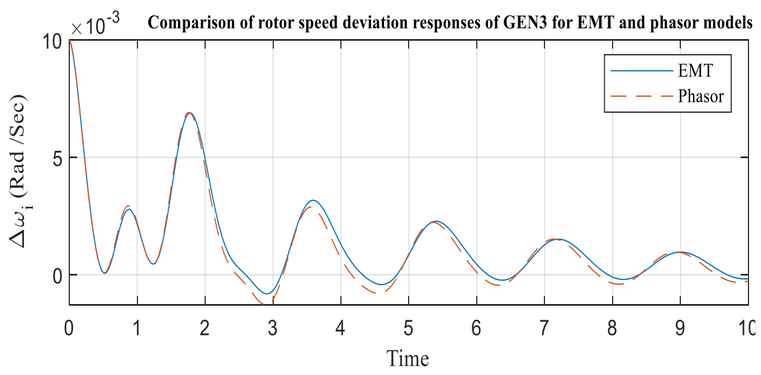
$$SSWT(\omega_l,b) = (\Delta\omega)^{-1} \sum_{a_k:\left|\omega(a_k,b)-\omega_l\right|\le\Delta\omega/2} W(a_k,b)\,a_k^{-3/2}(\Delta a)_k$$

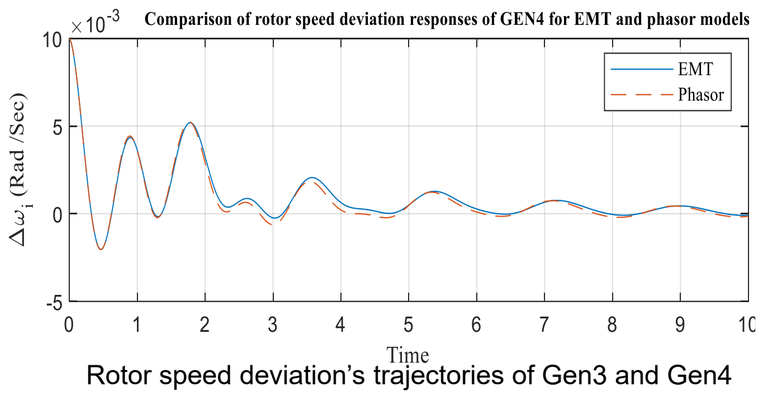
CASE STUDY

Kundur's two-area system

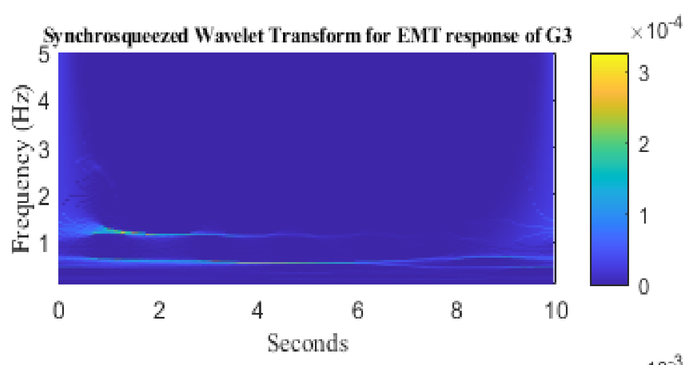


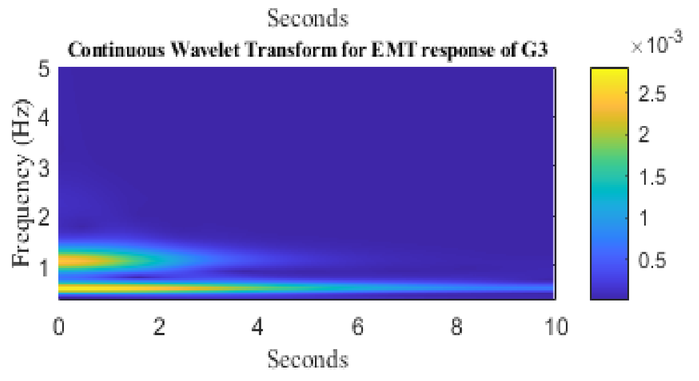
RESULTS





Rotor speed deviation's trajectories of Gen3 and Gen4





SSWT and CWT spectrum of EMT response for G3

CONCLUSION

- The time-frequency spectrum of SSWT is sharper and more focused compared to that of the CWT, which results in easier estimation of mode-frequency and PFs.
- Estimated PFs results obtained by SSWT is closer to the benchmark model-based approach compared to CWT and Prony analysis.
- For a large-scale power grid with IBRs located in multiple areas, the proposed data-driven participation factors can help to decide which areas highly participate in an oscillation mode of interest so that EMT simulations can be performed in those areas for more detailed dynamics of IBRs.
- The accurate match between participation factors from simulations on the phasor model and EMT model of a power system indicates that participation factors on electromechanical modes can be estimated from much faster simulations on the phasor model, which can accelerate the identification of highly participating areas.

PFs for EMT and phasor using SSWT

Gen.	Inter-area mode 0.565 Hz		Local mode 1 ~ 1.10 Hz		Local mode 2 ~1.2 Hz	
	EMT	Phasor	EMT	Phasor	EMT	Phasor
1	0.685	0.671	0.739	0.733	~ 0	~ 0
2	0.328	0.326	**1.000**	**1.000**	~ 0	~ 0
3	**1.000**	**1.000**	~ 0	~ 0	0.511	0.504
4	0.471	0.454	~ 0	~ 0	**1.000**	**1.000**

Model based PFs for the phasor model

Gen.	**0.564 Hz**	**1.097 Hz**	**1.265 Hz**
1	0.5779	0.7465	0.00058
2	0.3399	**1.0000**	0.0047
3	**1.0000**	0.005097	0.5550
4	0.4769	0.000284	**1.0000**

Absolute error of estimated PFs

Gen.	Inter-area mode			Local mode 1			Local mode 2		
	SSWT	CWT	Prony	SSWT	CWT	Prony	SSWT	CWT	Prony
1	0.093	0.148	0.130	0.0135	0.0035	0.0605	0.000	0.000	0.065
2	0.0139	0.076	0.0501	0.000	0.000	0.000	0.0047	0.0047	0.128
3	0.000	0.000	0.000	0.005	0.005	0.383	0.051	0.136	0.011
4	0.023	0.0651	0.0351	0.000	0.000	0.099	0.000	0.000	0.000

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