Participation Factor-Based Adaptive Model Reduction for Fast Power System Simulation

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This paper presents an approach to analyze and rank participation factors of each system state variable into dominant system modes excited by a disturbance so as to determine which regions or generators can be reduced without impacting the accuracy of simulation for a study area.

State space representation

$$\begin{cases} \Delta\dot{x} = A\Delta x + B\Delta u \\ \Delta y = C\Delta x + D\Delta u \end{cases}$$

Modal Analysis

$$\begin{cases} \boldsymbol{\Psi}_i \mathbf{A} = \lambda_i \boldsymbol{\Psi}_i \\ \mathbf{A}\boldsymbol{\Phi}_i = \lambda_i \boldsymbol{\Phi}_i \end{cases}$$

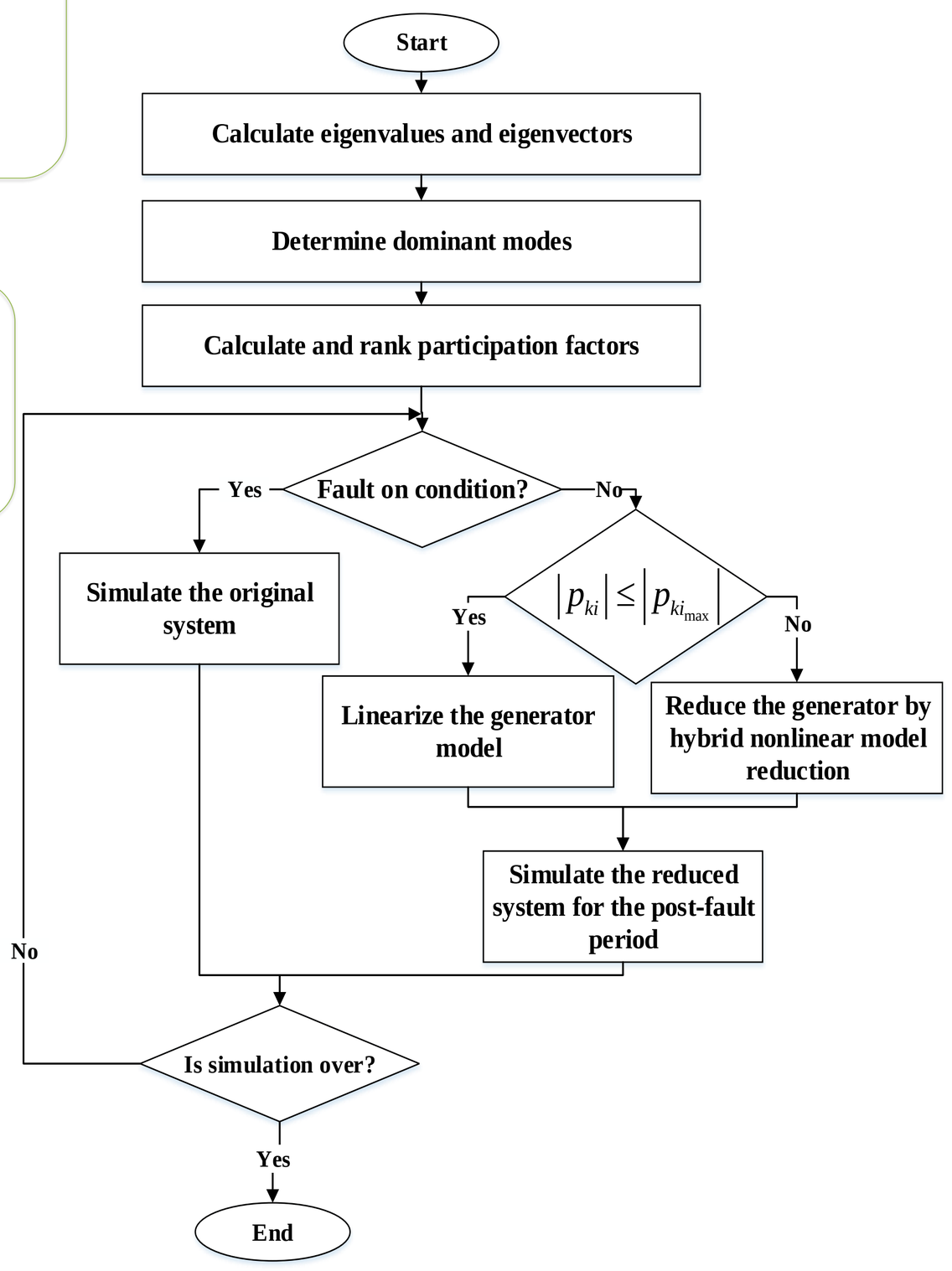
Reduced model

$$\begin{cases} \dot{\tilde{x}} = \mathbf{T}\begin{pmatrix} \tilde{f}(\tilde{\mathbf{T}}\tilde{x},\, u) \\ \tilde{\mathbf{A}}\Delta\tilde{x} + \tilde{\mathbf{B}}\Delta u + \hat{x}_0 \end{pmatrix} \\ y = \tilde{\mathbf{T}}\tilde{x} \end{cases}$$

Participation factor

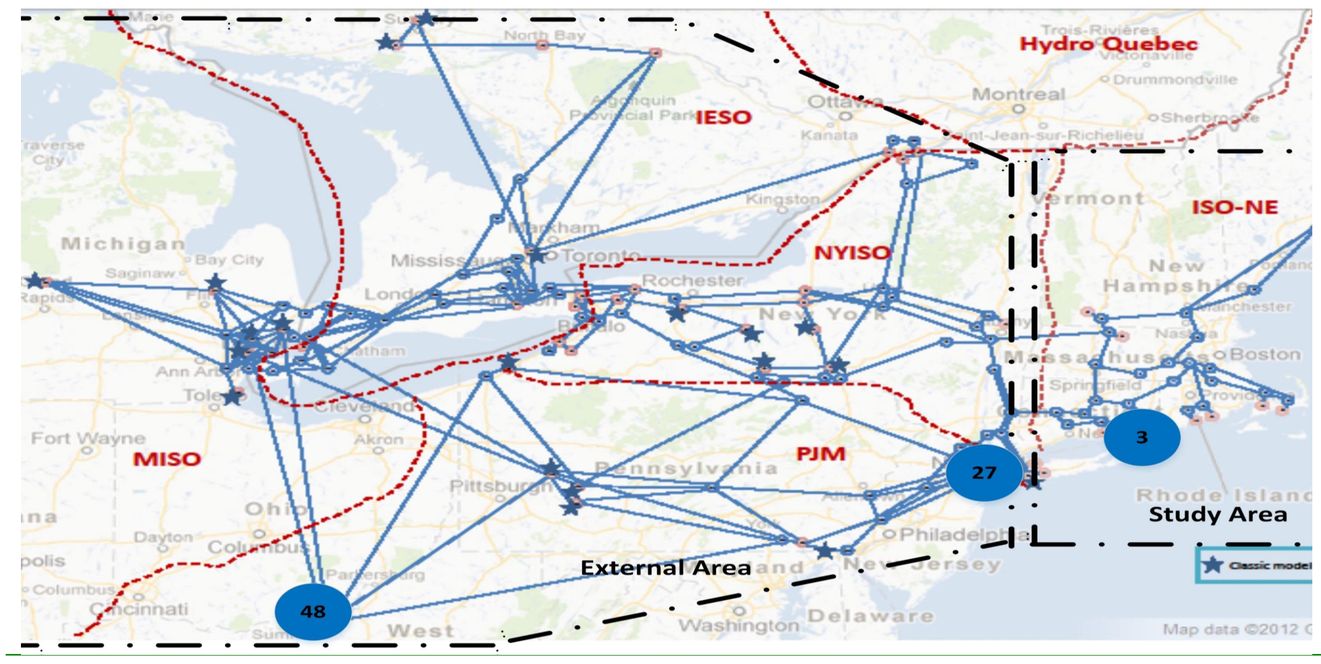
$$p_{ki} = \boldsymbol{\Phi}_{ki}\boldsymbol{\Psi}_{ik}$$

Proposed Process



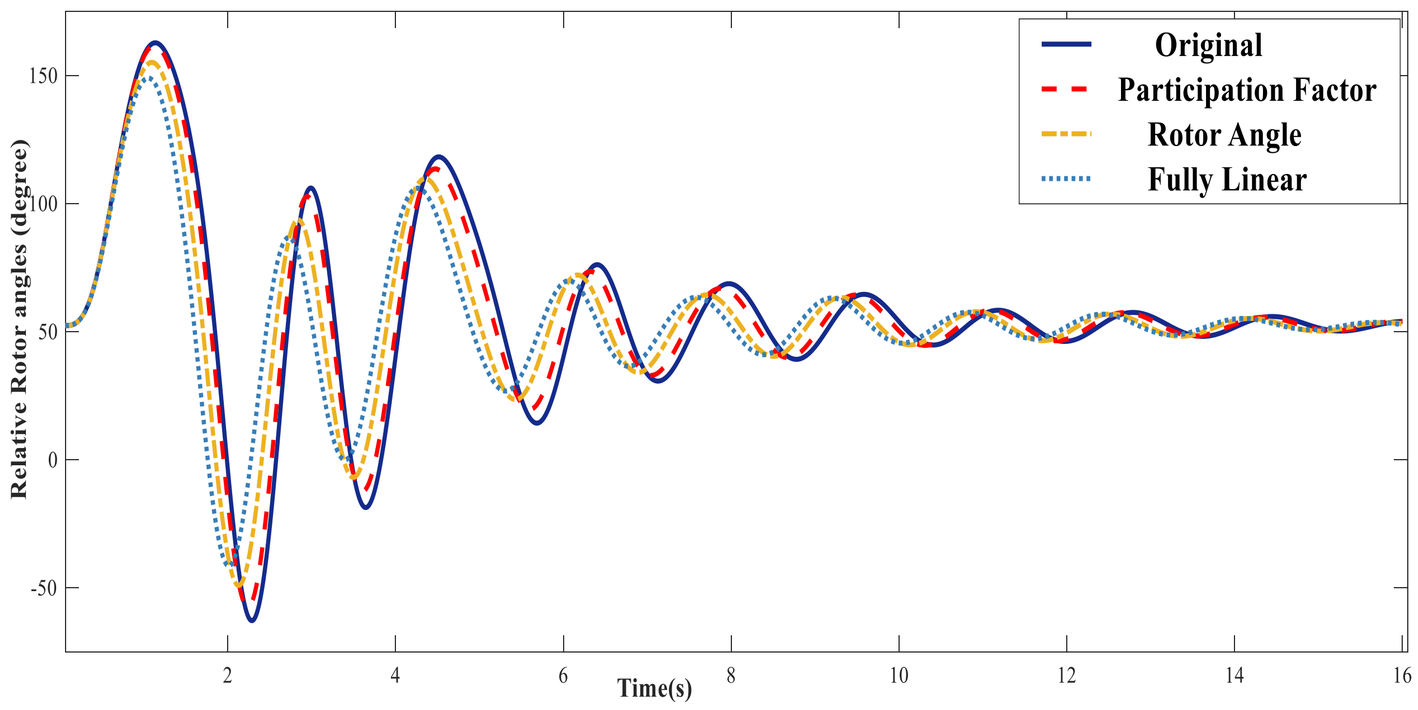
Case Study

The Northeastern Power Coordinating Council (NPCC) system



Simulation Results

The rotor angle mismatch error for the reduced-order model obtained by the fully linearized approach and rotor angle deviation-based approach is relatively large, while the participation factor-based method is capable of closely following the rotor angle of the original full-order model.



Dominated Mode	Participation factor of selected Generators	
	Generator 27	*Generator 48*
Mode 1	0.9978	0.0009
Mode 2	0.5003	0.9996

States	Error of each approach		
	Fully linear	*Rotor-angle*	*Participation factor*
δ, degrees	2.59×10^{1}	17.13×10^{0}	5.77×10^{0}
P_m, p.u.	1.70×10^{-3}	1.70×10^{-3}	7.00×10^{-4}
P_{gv}, p.u.	1.98×10^{-2}	1.30×10^{-2}	4.50×10^{-3}
V_R, p.u.	1.71×10^{-1}	1.14×10^{-1}	4.02×10^{-2}
R_f, p.u.	1.34×10^{-2}	8.40×10^{-3}	3.10×10^{-3}
E_{fd}, p.u.	1.01×10^{-1}	6.50×10^{-2}	2.34×10^{-2}
$E_d^{'}$, p.u.	7.09×10^{-2}	4.64×10^{-2}	1.61×10^{-2}
$E_q^{'}$, p.u.	1.13×10^{-2}	7.20×10^{-3}	2.60×10^{-3}
ω, p.u.	4.20×10^{-3}	2.80×10^{-3}	9.00×10^{-4}