Grey-Box Parameters Estimation for State-Space Power Plants Dynamic Equivalents

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1 Introduction

The increasing integration of inverter-based generation has reduced system inertia, amplifying the sensitivity of modern power systems to disturbances.

Transmission System Operators (TSOs) require accurate **dynamic models** to perform stability studies.

Parametrization of these models is challenging due to limited data availability, undocumented tuning of controllers, and restricted access to proprietary manufacturer information.

2 Proposed Method

- Grey-box linear state-space dynamic equivalent model (synchronous machine & regulators)

$$\begin{bmatrix} \dot{E}'_q \\ \dot{E}'_d \\ \dot{\delta} \\ \dot{\omega} \\ \dot{E}_{fd} \end{bmatrix} = \mathbf{A} \begin{bmatrix} E'_q \\ E'_d \\ \delta \\ \omega \\ E_{fd} \end{bmatrix} + \mathbf{B} \begin{bmatrix} \omega_s \\ P_m \\ V_{ref} \\ V_d \\ V_q \end{bmatrix} \qquad \begin{bmatrix} I_d \\ I_q \end{bmatrix} = \mathbf{C} \begin{bmatrix} E'_q \\ E'_d \\ \delta \\ \omega \\ E_{fd} \end{bmatrix} + \mathbf{D} \begin{bmatrix} \omega_s \\ P_m \\ V_{ref} \\ V_d \\ V_q \end{bmatrix}$$

- Parameter estimation from terminal measurements
  - I. Estimation in steady-state → initialize state variables
  - II. Estimation in transient response → identify parameters

$$\min_{\mathbf{A},\mathbf{B},\mathbf{C},\mathbf{D}} \sum_{t=T_{start}}^{T_{end}} \sum_{i=1}^{p} w_i^2 \,||y_{t,i}^{obs} - (\mathbf{C}x_t + \mathbf{D}u_t)_i||_2^2$$

$$\text{s.t.} \quad x_{t+1} = \left(I - \frac{\Delta t}{2}\mathbf{A}\right)^{-1} \left[\left(I + \frac{\Delta t}{2}\mathbf{A}\right) x_t + \frac{\Delta t}{2}\mathbf{B}\,(u_t + u_{t+1}) \right]$$

- Parameters = non-zero matrix elements
  *Impossible to recover physical machine parameters
- Weighted least-squares

3 Convergence Validation

- Identification problem is nonconvex
  - Global optimum cannot be guaranteed
  - Sensitivity to initialization of parameters
- Ground truth of parameters is unknown
  - Numerical validation of parameter identifiability
- Convergence validation tests:
  - Single-parameter estimation $\epsilon_k < 1\%;\ \sigma_k < 10^{-5}$
  - Multi-parameter estimation $\epsilon_k < 10\%;\ \sigma_k < 10^{-4}$
  - Full-parameter estimation

Average relative error

$$\epsilon_k = \frac{1}{N}\sum_{i=1}^{N} \left| \frac{\hat{\theta}_k(i) - \theta_k^*}{\theta_k^*} \right|$$

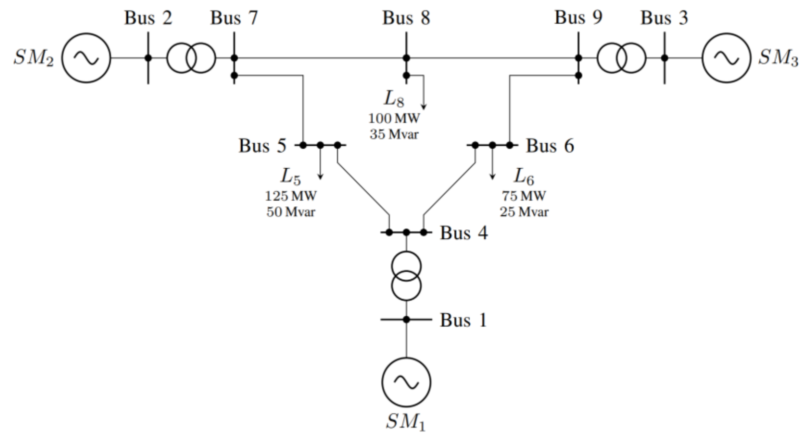
Standard deviation

$$\sigma_k = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} \left(\hat{\theta}_k(i) - \bar{\theta}_k\right)^2}$$

- Estimated parameters are perturbed by maximum of 10% or 100% to initialize the convergence validation tests

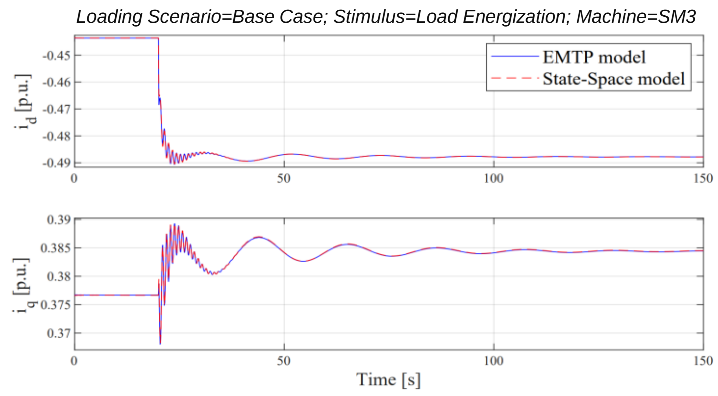
4 Application Examples

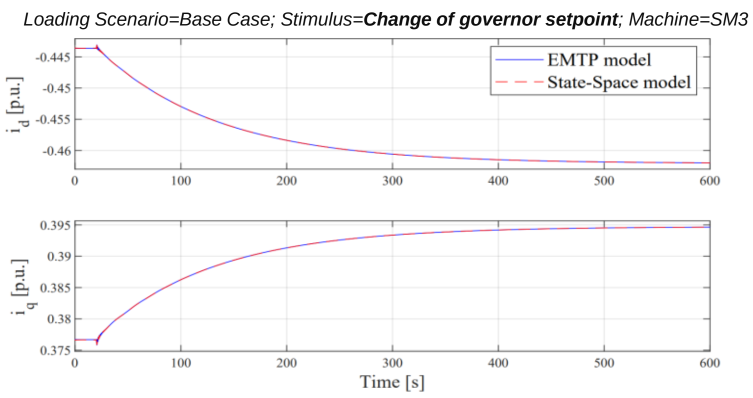
State-space equivalent model for each of the machines.



Loading scenario	Stimulus
Base case	Load energization (0.05 p.u. of total system load)
75% loaded	
50% loaded	Change of governor setpoint (5% step in active power reference of SM3)
25% loaded	

5 Results





➢ Our method is recommended for identification of **individual parameters or small groups of parameters**, preferably for smoother transients.

Current & Future Research

My current research focuses on Power System Dynamics and the stability challenges posed by the increased integration of Inverter-Based Resources in the grid.

- Harmonic Power Flow – expansion to transmission grids
- Grid Following Converters & Harmonic Coupling
- Beyond Droop Control – exploring the stability and harmonic performance of grid-forming converters without traditional droop control

Partner/Sponsor: swissgrid

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