Frequency Security Index-Based State of Health Monitoring of a Microgrid using Energy Storage Systems

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Motivation and Objectives

- Frequency reflects ability of a grid to balance supply and demand
- Frequency stability: ability of a system to maintain nearly constant
  - ➢ Recover from imbalance conditions that may result in frequency changes
- Necessary to evaluate frequency security index (FSI) to monitor state of health of a microgrid
- Frequency trajectory utilized to evaluate FSI[1]
  - ➢ Necessitates repetitive frequency deviation curve generation

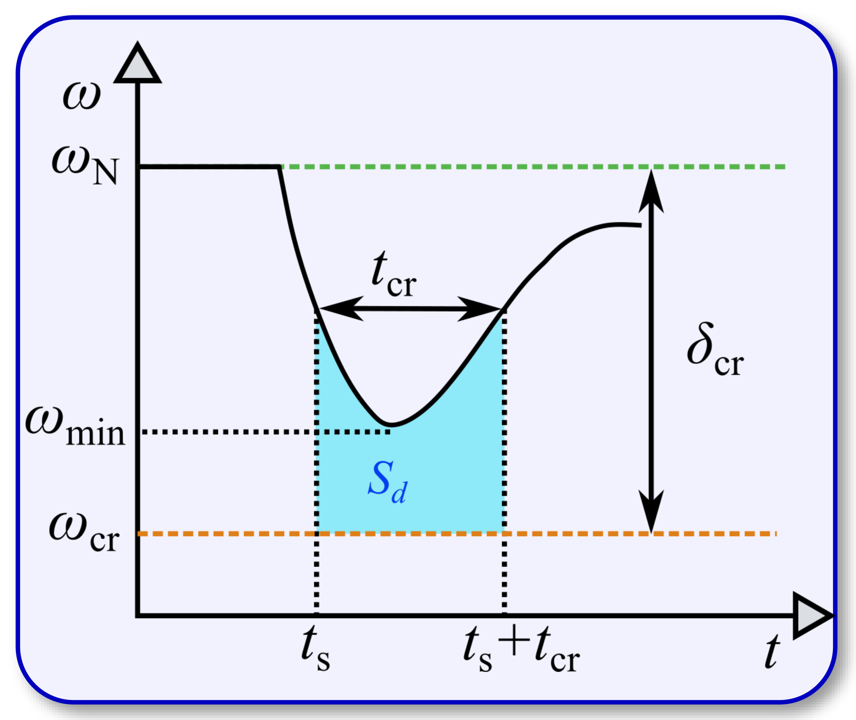
Frequency Security Index:

- Ability of power system to maintain system freq
- FSI mathematically defined as[2]:

$$\gamma = \frac{S_d}{(\omega_N - \omega_{cr})t_{cr}}$$

$$S_d = \min \int_{t_s}^{t_s+t_{cr}} (\omega - \omega_{cr})dt$$

Where, ω_N=nominal frequency, ω_{cr}=critical frequency



FSI Analytical Formula:

- Frequency deviation for a given load change can be calculated analytically[3]
- FSI can be calculated from frequency deviation

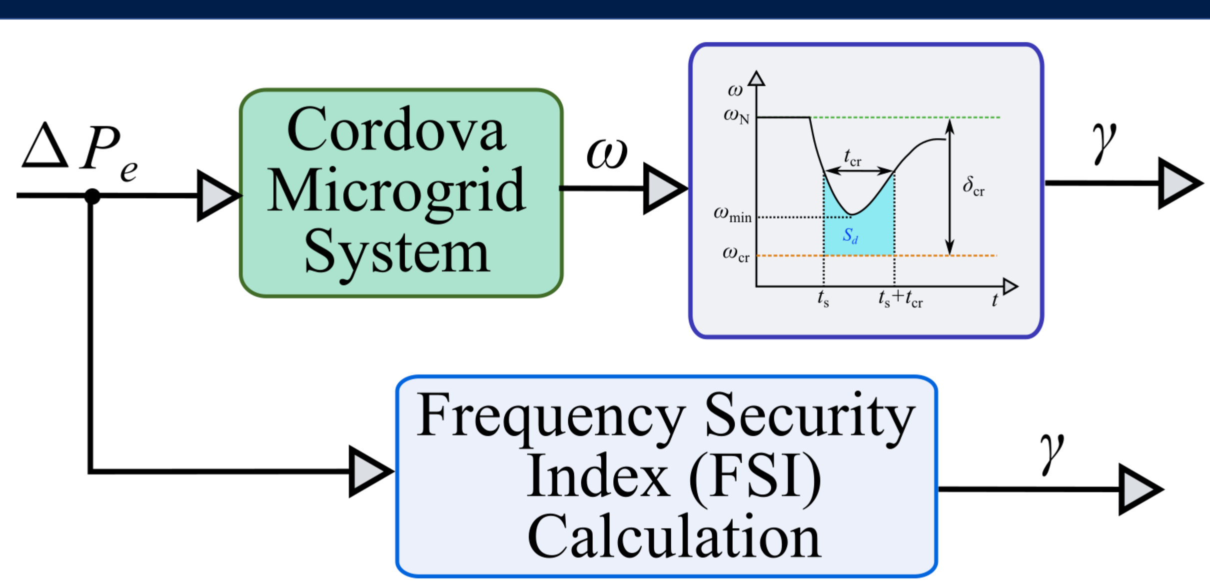
$$\gamma = 1 - \Delta P_e K \frac{S_1 - S_2 - \omega_0 t_{cr} \sin\phi}{\delta_{cr}\omega_0 t_{cr} \sin\phi}$$

Where,

$$S_1 = \sin(\theta + \sigma_2 t_s + \phi)e^{-\sigma_2 t_s \cot\theta}$$

$$S_2 = \sin(\theta + \sigma_2(t_s + t_{cr}) + \phi)e^{-\sigma_1(t_s+t_{cr})}.$$

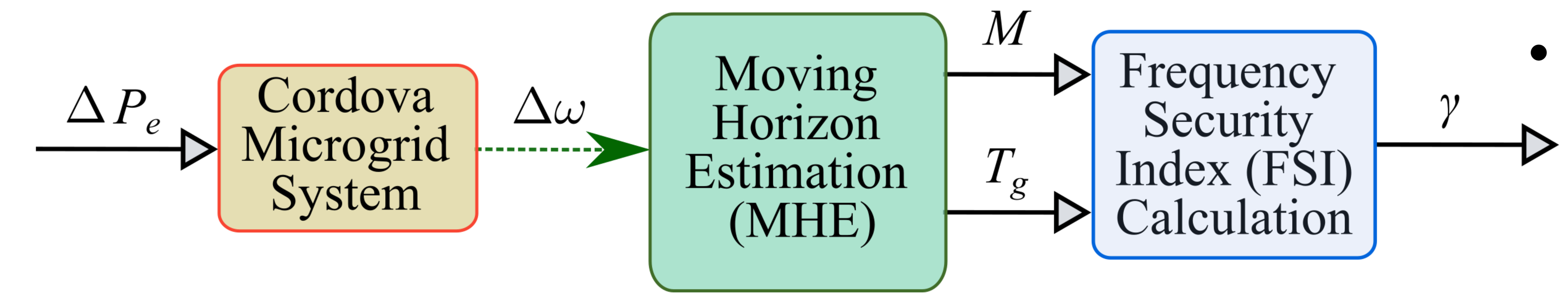
Energy Storage System (ESS) Probing to Estimate the FSI



- Step load change of different value
- FSI calculated from freq deviation data
- FSI compared with analytical solution
- FSI calculated for different microgrid parameter → M, D, T_g, R_p

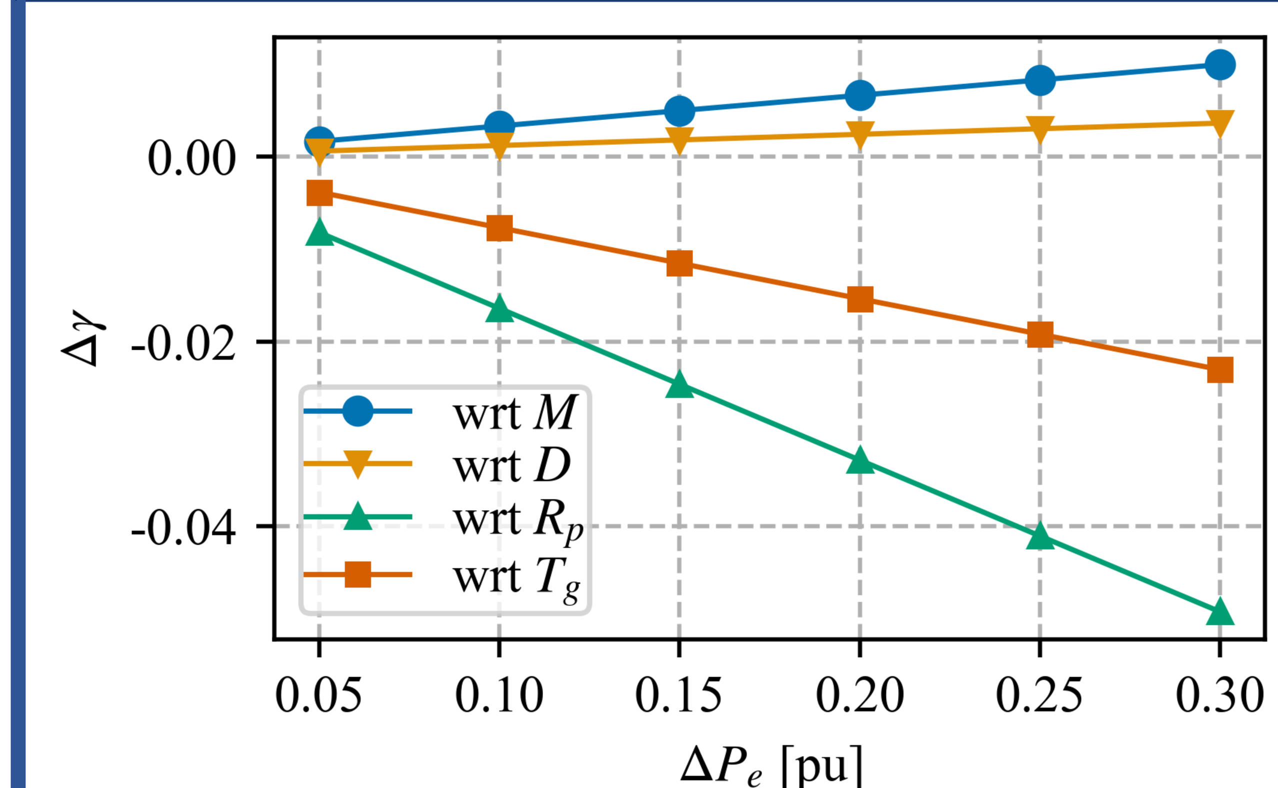
M, D = Inertia and Damping constant, T_g = Governor time constant , R_P = Speed-regulation droop

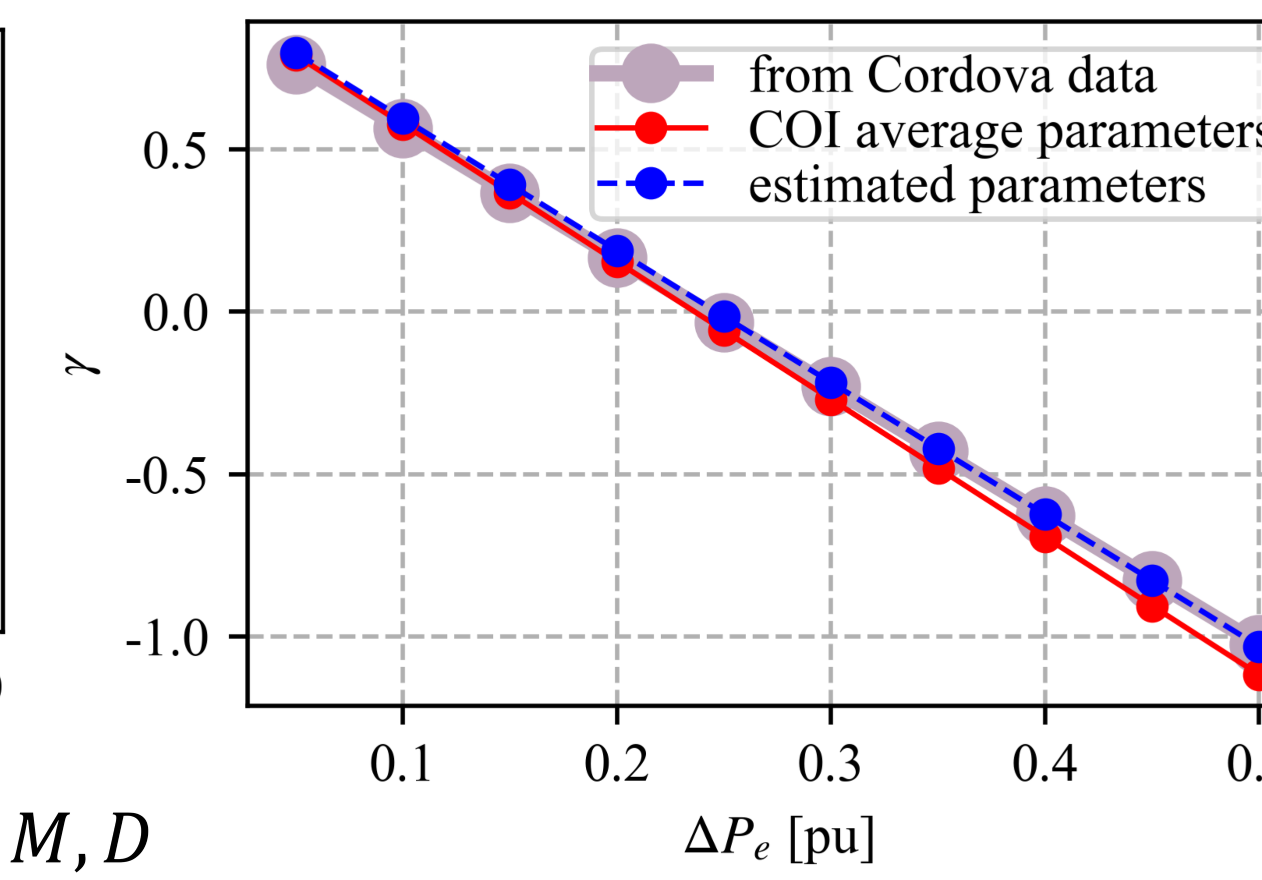
- Determine what parameter mostly affects the FSI
- Change in FSI for 5% change is parameter considered
- Only M and T_g is considered (R_p is externally set, sensitivity with D very small)



- Use MHE to estimate parameters to calculate FSI
- Online optimization approach → uses past measurement data to estimate by minimizing a cost function while satisfying the constraints

FSI Sensitivity and Estimation Result





- Sensitivity in decreasing order: R_p, T_g, M, D
- Improved FSI calculation with MHE estimated parameters as compared to COI
- Calculated FSI closer to the one from data even for large load change
- MHE based parameter estimation approach can be applied to assess the frequency security of the power system

Conclusion and Future Work

- Mathematical formula for FSI derived and validated
  - ➢ Reliable estimate of the FSI
- Inertia and governor time constant affects FSI significantly
- Future work includes developing data-driven model to estimate FSI

References

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