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Evaluation of Probing Signals for Implementing Moving Horizon Inertia Estimation in Microgrids

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PowerJacks

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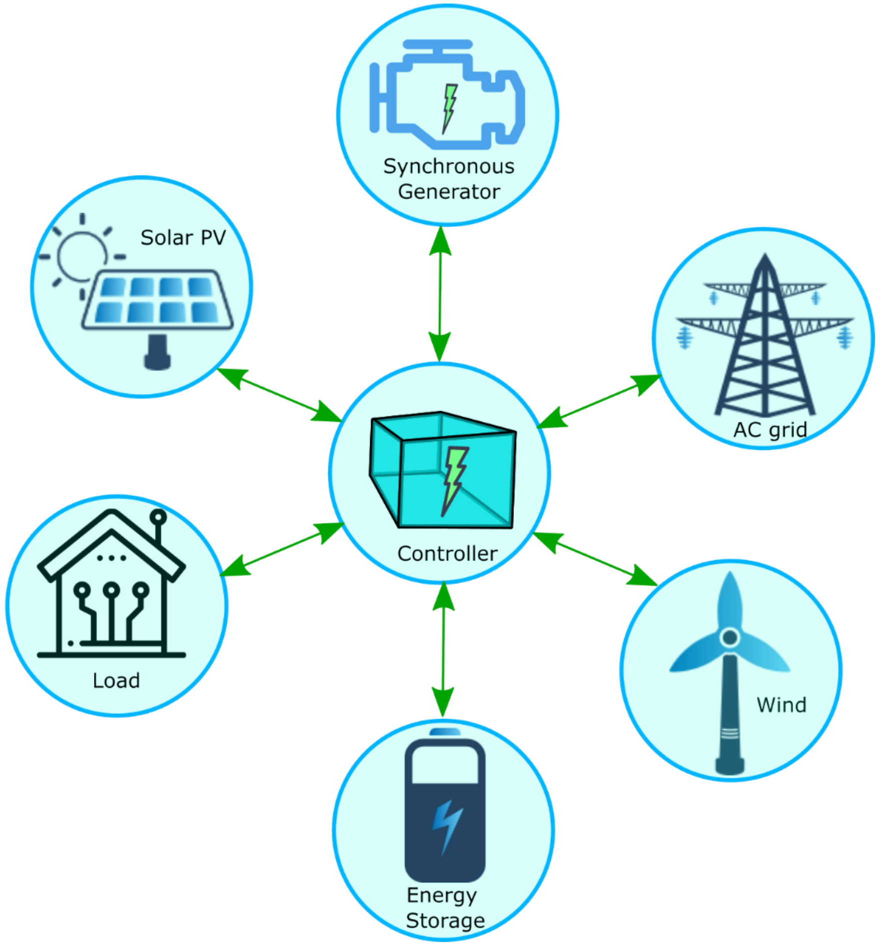
Inverter based-grid and Parameter Estimation

- increase in converter-based renewable energy sources
  - low and time-varying power system inertia (M)
  - susceptible to changes in load
  - large rate of change of frequency (ROCOF)
- accurate estimation of M and damping coefficient (D) required
  - proper grid control and dispatch of energy storage systems
  - fast-frequency support strategies
  - support ancillary services
- moving horizon estimation (MHE) estimates online plant states and parameters
  - based on phase locked loop measurements(PLL)
- efficacy of MHE depends on excitation signal



Objective

- evaluate performance of MHE for inertia estimation using different excitation signals
    - MHE proposed for online estimation

Moving Horizon Estimation

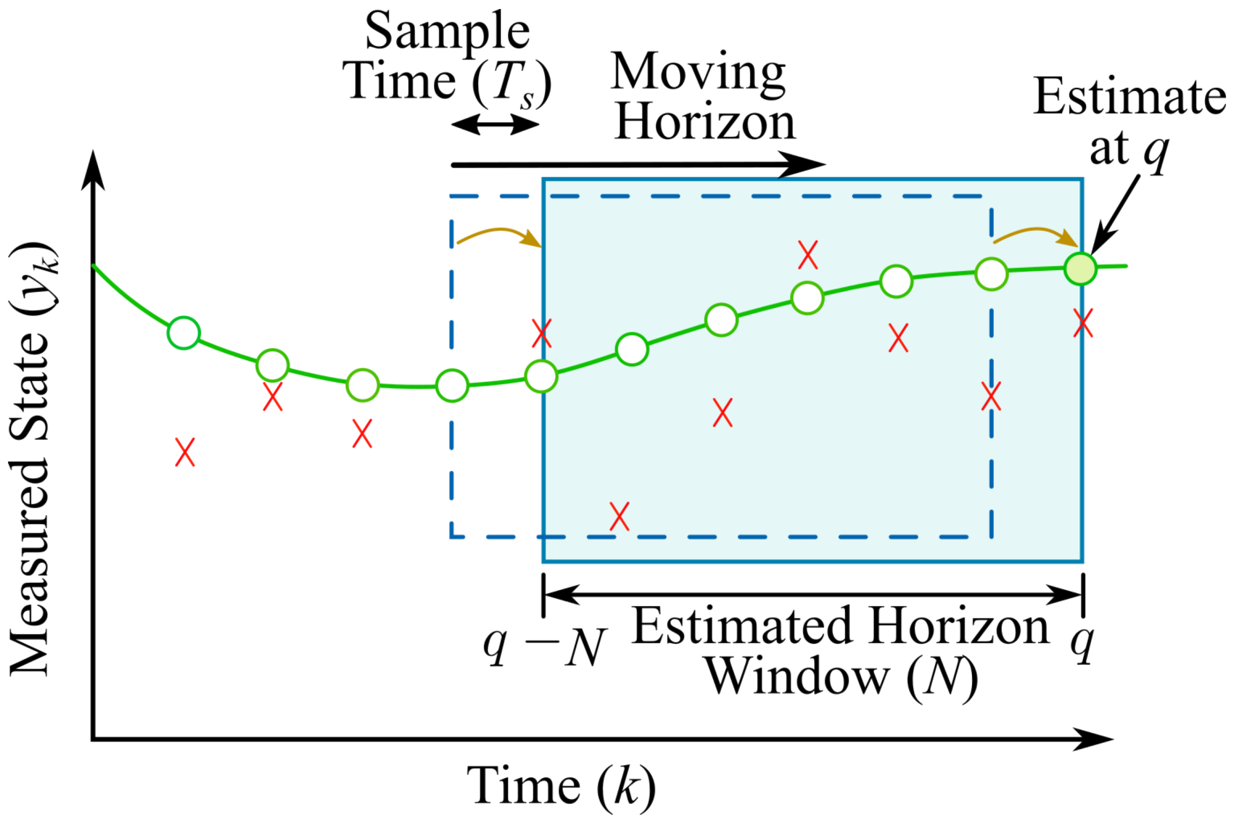
- finite horizon optimization-based estimation process
- infer state variables and parameters of system from measurements of system

where,

N= horizon length

T_s= sampling time of MHE

y_k= measured states at discrete time instant k



Inputs : measurements of system

Outputs : state and parameters estimates

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× represent measurements and O represent the estimated values

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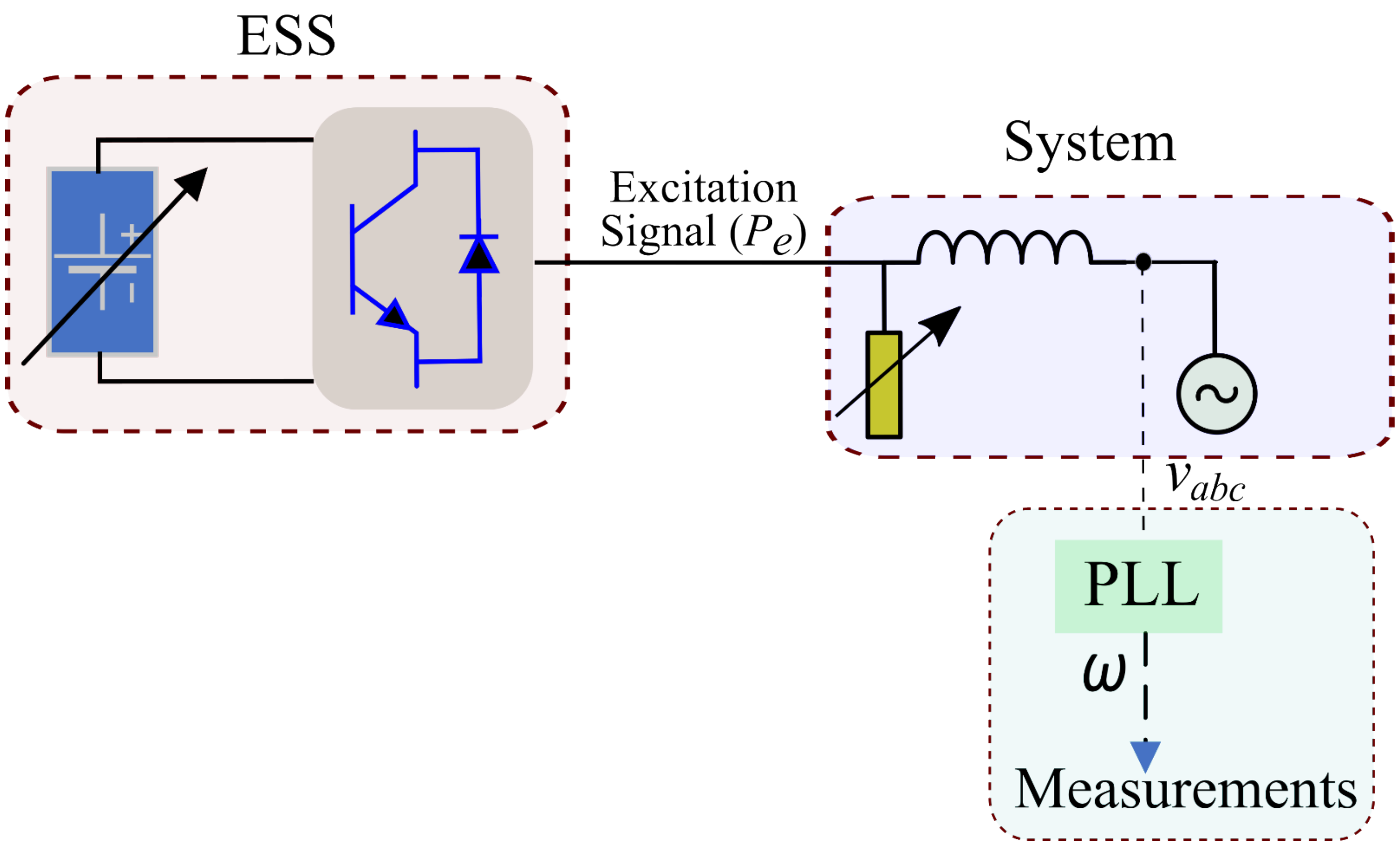
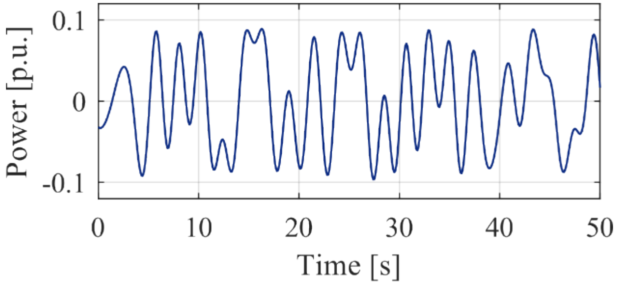
System Perturbation using Probing Signals

- energy storage system (ESS) used to inject probing signal
- probing signal perturb frequency of system
  - online measurements of frequency using PLL
  - ROCOF measured from frequency perturbation

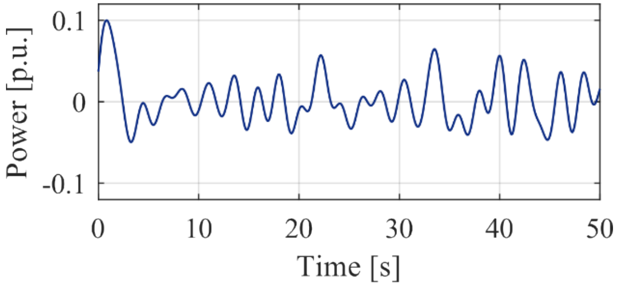


Excitation Signals : Time Domain Design

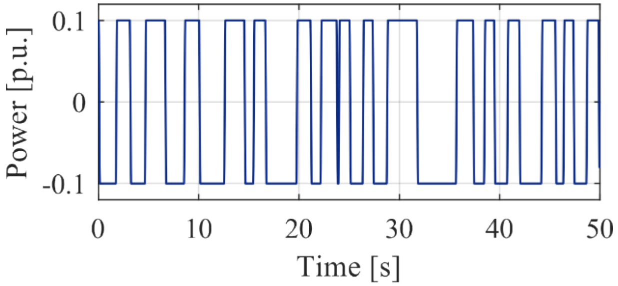
Multisine wave signal



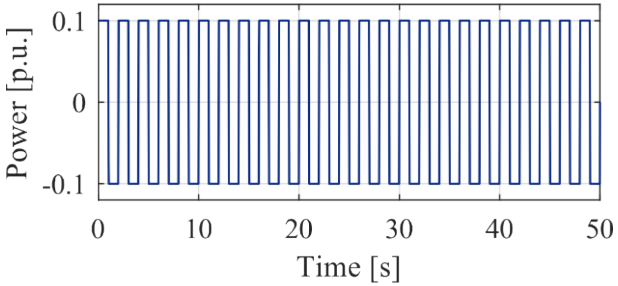
FWGN signal



PRBS signal



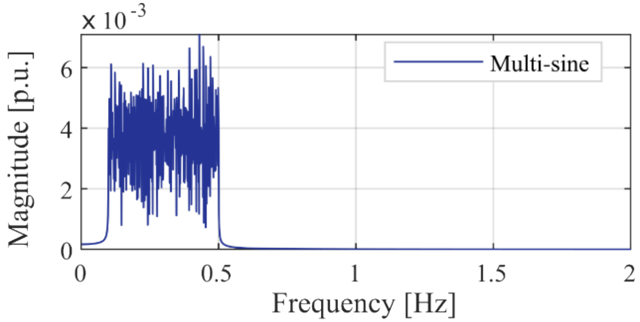
Square signal



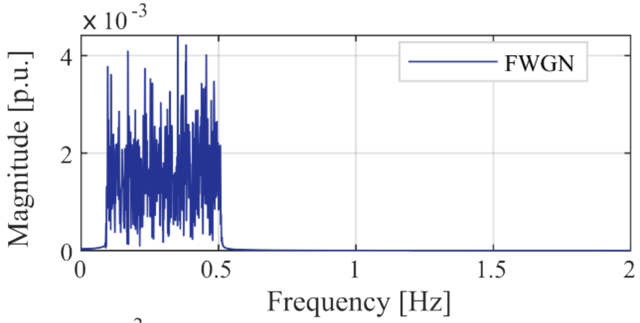
- design and evaluation of excitation signal to give accurate estimates
- minimize impact on operation of power system and system security
- minimal value of crest factor (C_r)
- avoid sharp transitions and high ramp rates
- small peak amplitude

Excitation Signals : Frequency Spectral Energy

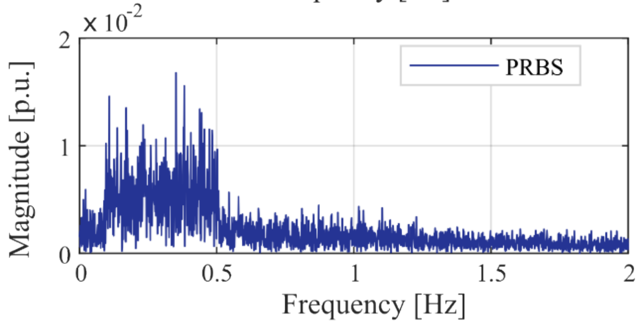
Multisine wave signal



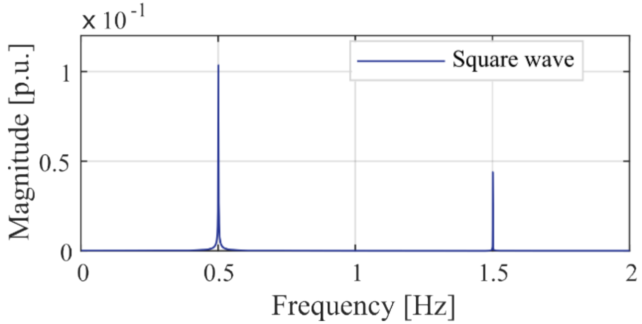
FWGN signal



PRBS signal



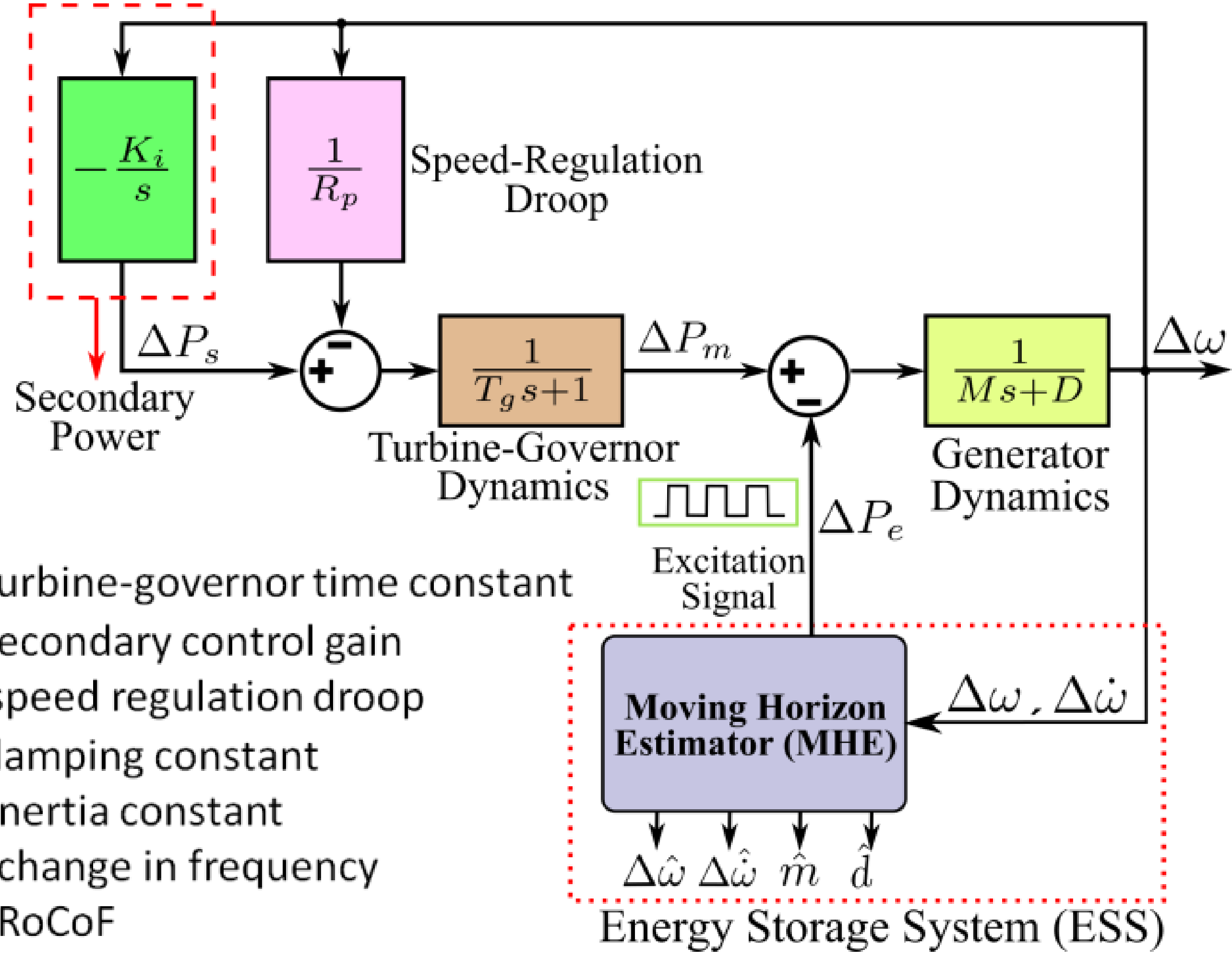
Square signal



- frequency band corresponds to inertial constant range
  - 2 – 10 s
- square wave and PRBS have similar time domain shape and spectral energy
- percentage energy concentration in frequency band
  - multisine wave signal : 98%
  - filtered white gaussian noise (FWGN) signal : 97%
  - pseudo random binary signal (PRBS) : 38%
  - ramp limited square wave : 23%

Simulation Setup: MHE and Parameter Estimation

- white Gaussian noise added
- isolated power system model
- state and parameter estimation
- true value of inertia set to 10s which changes to 5s after 25s
- damping constant is 1.5 throughout simulation
- evaluate estimation accuracy of designed probing signals



T_g= turbine-governor time constant
K_i= secondary control gain
R_p= speed regulation droop
D= damping constant
M = inertia constant
$\Delta\omega$= change in frequency
$\Delta\dot{\omega}$= RoCoF

states: $\Delta\omega, \Delta\dot{\omega}$
parameters: M, D

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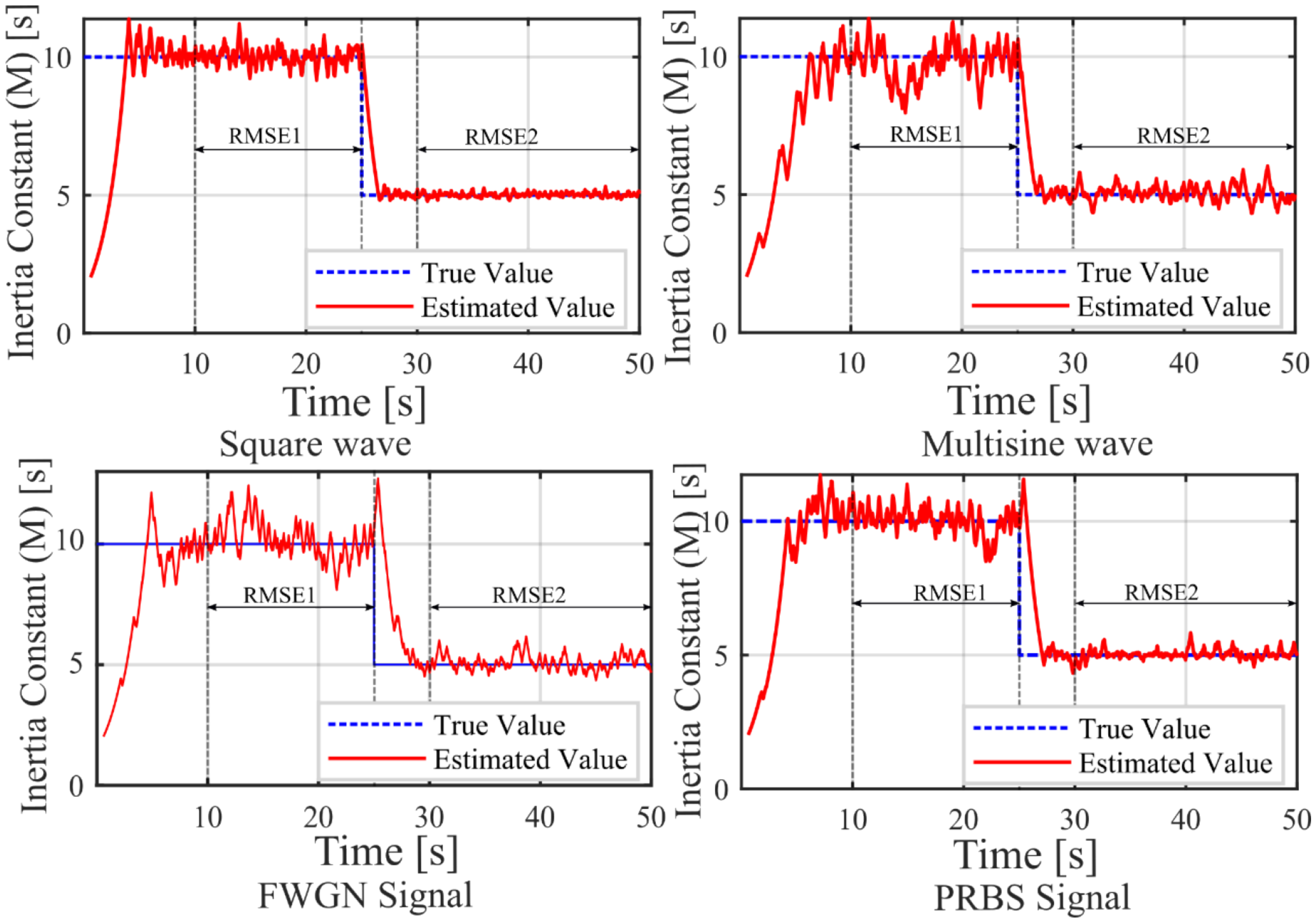
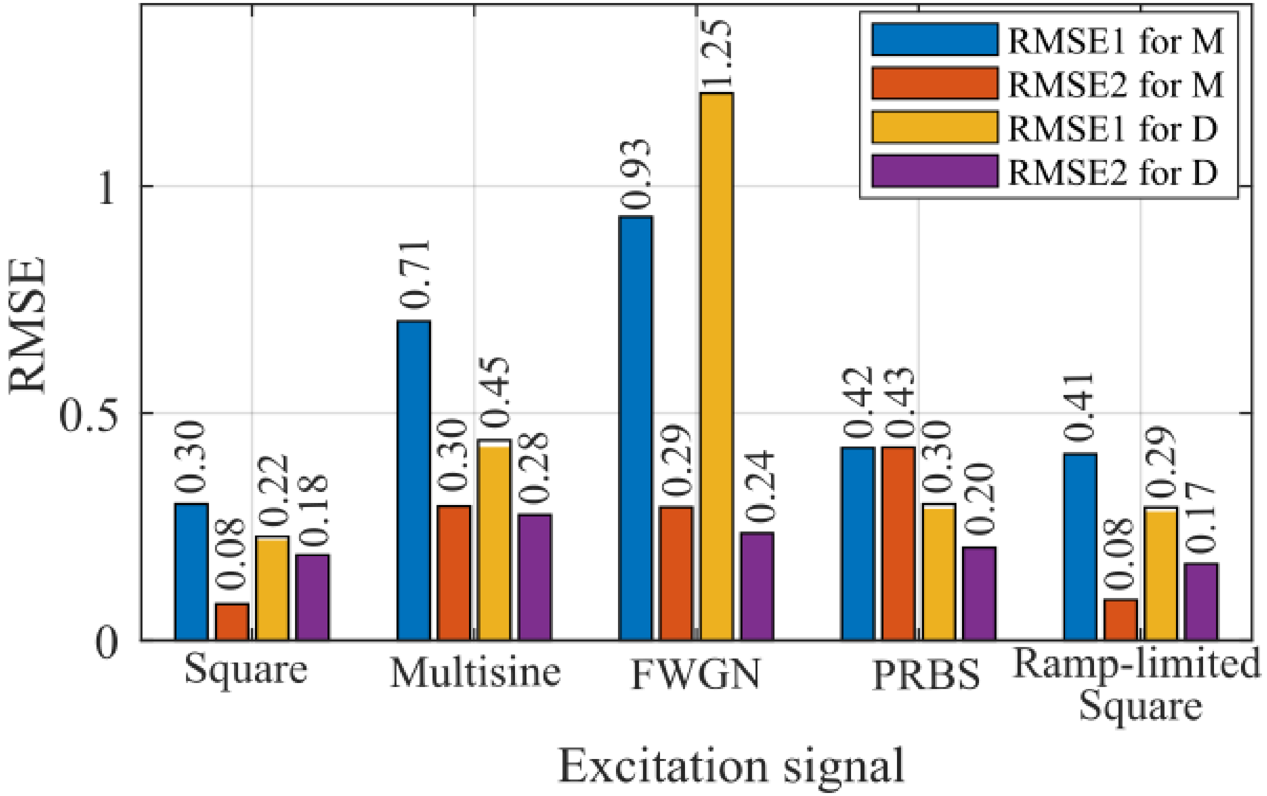
Results on Inertia Estimation



- true value of inertia set to 10s which changes to 5s after 25s
- damping constant is 1.5 throughout simulation
- MHE estimates true value of M and D accurately in 3-4 s
- accuracy of estimation is different for each probing signal

Performance Metrics : Result Analysis



- stochastic, non-periodic signals yielded poor estimation
  - FWGN and PRBS signal
- square wave give better estimation than PRBS
  - square wave : higher frequency components
- FWGN has high C_r than multisine
- higher error for $M = 10\ s$ than $M = 5\ s$
- when M ↓ , change in frequency and ROCOF ↑

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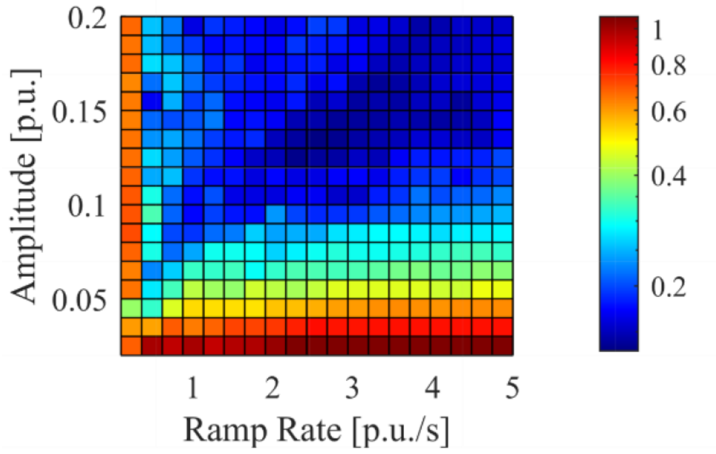
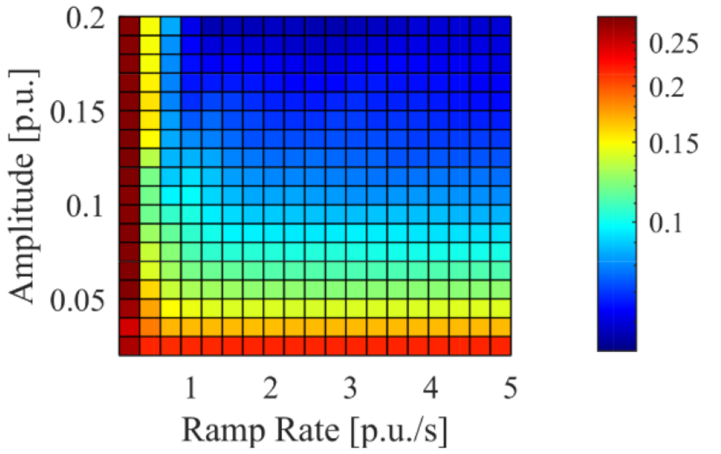
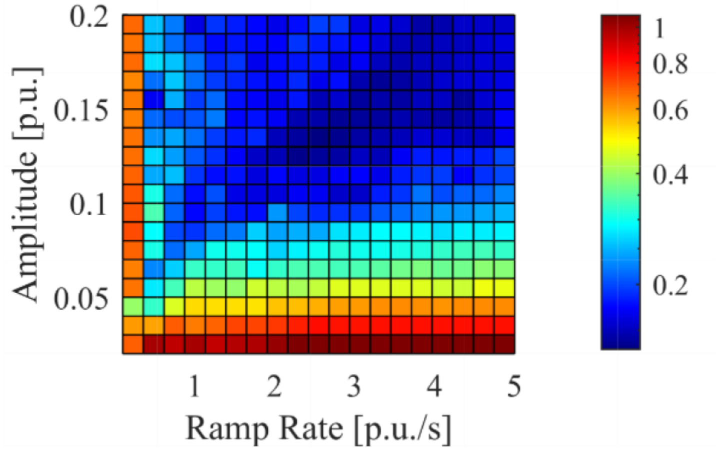
Performance Metrics : Result Analysis



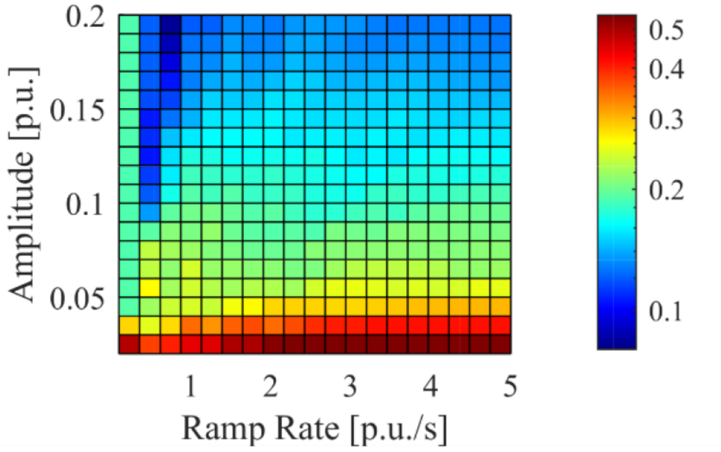
Square wave



Multisine wave



FWGN signal



PRBS signal

- square wave signal shows highly accurate estimation
- lower (i.e., blue) is better for variations in RMSE
- higher amplitude excitation signals produced better estimation
  - higher SNR
- accuracy of estimation decreases for amplitude less than 0.05 p.u.
- ramp-limited square waves still showed high accuracy
  - peak amplitude was not affected by limiting the ramp rate

Conclusions

- higher the amplitude of excitation signal produce better estimation results
  - ↑ in signal to noise ratio
- FWGN with higher C_r shows RMSE of 0.93
- square waves shows higher accuracy with minimum RMSE of 0.3
  - may be limited to preserve lifetime of ESS
  - reduces the impact on power system operation

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