Modeling and predicting OSWEC behavior using dynamic mode decomposition

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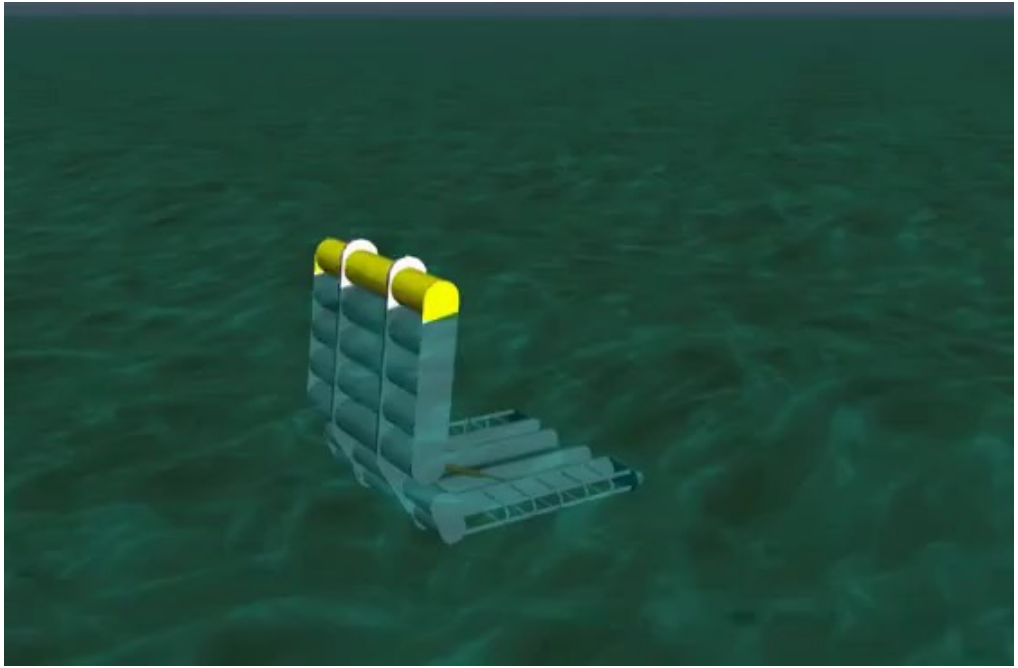
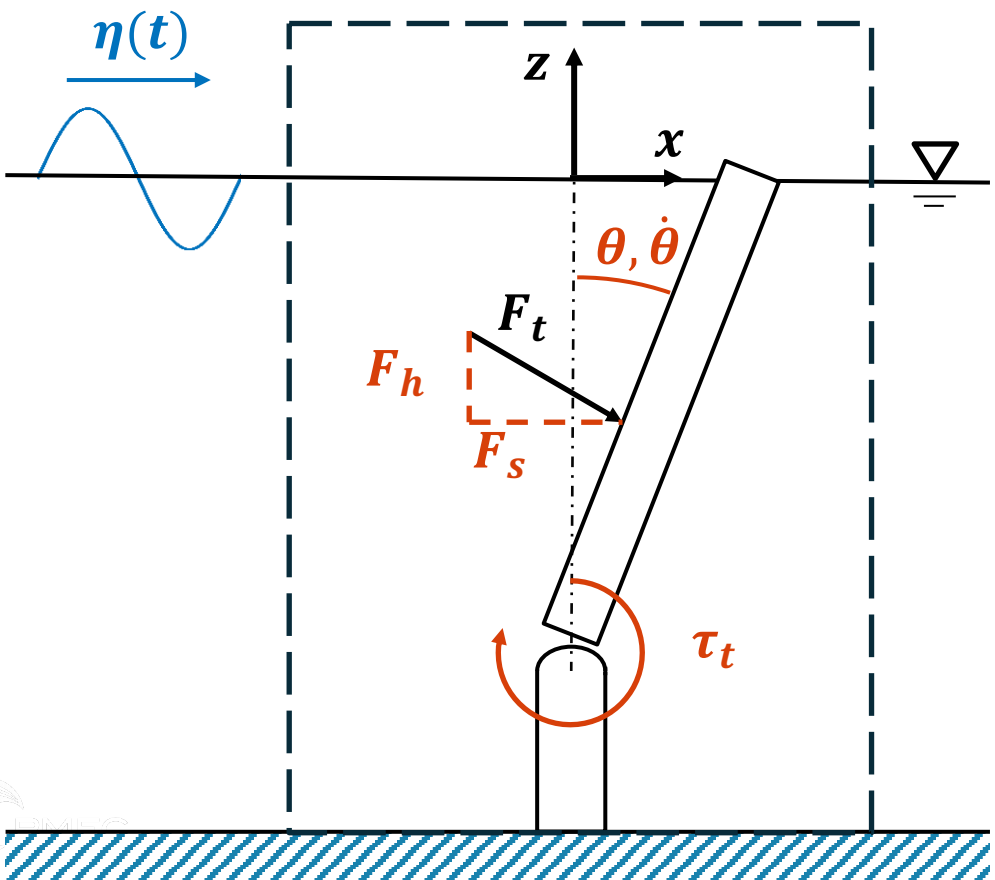
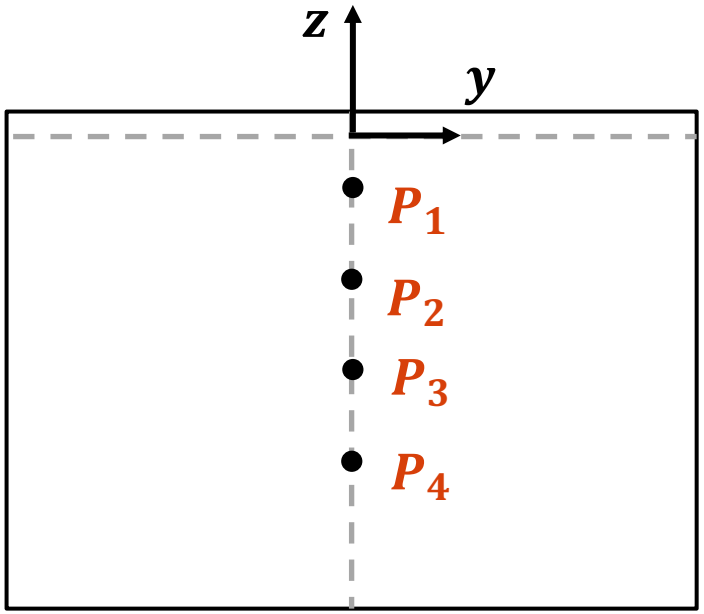
Oscillating Surge Wave Energy Converter



Maine Marine Composites, 2014

OSWEC System

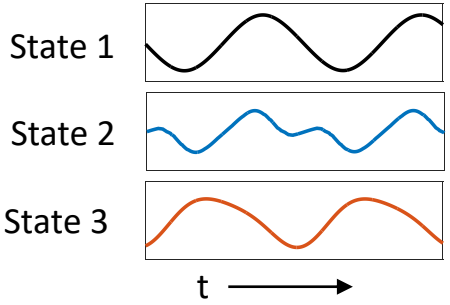




Dynamic Mode Decomposition (DMD)

$$\frac{d\boldsymbol{x}}{dt} = \mathcal{A}\boldsymbol{x} \longrightarrow \boldsymbol{x}_{k+1} = \boldsymbol{A}\boldsymbol{x}_k$$

1. Data



2. Arrange

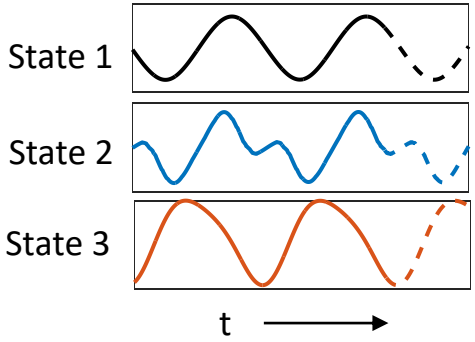
$$\boldsymbol{X}' \approx \boldsymbol{A}\boldsymbol{X}$$

$$\boldsymbol{X} = \begin{bmatrix} | & | & & | \\ \boldsymbol{x}_1 & \boldsymbol{x}_2 & \cdots & \boldsymbol{x}_{m-1} \\ | & | & & | \end{bmatrix}$$

$$\boldsymbol{X}' = \begin{bmatrix} | & | & & | \\ \boldsymbol{x}_2 & \boldsymbol{x}_3 & \cdots & \boldsymbol{x}_{m} \\ | & | & & | \end{bmatrix}$$

3. Future State Prediction

$$\boldsymbol{A} = \boldsymbol{X}'\boldsymbol{X}^{\dagger}$$



Time-Delay Coordinates

$$\boldsymbol{X}_{\text{aug}} = \begin{bmatrix} | & | & & | \\ \boldsymbol{x}_1 & \boldsymbol{x}_2 & \cdots & \boldsymbol{x}_{m-1} \\ | & | & & | \\ | & | & & | \\ \boldsymbol{x}_2 & \boldsymbol{x}_3 & \cdots & \boldsymbol{x}_m \\ | & | & & | \end{bmatrix}$$

Data Analysis Pipeline

Generate Data

- Data source
- Input wave

Preprocess Data

Choose states

↓

Normalize

↓

Partition training and testing data

DMD

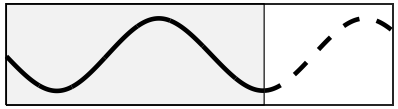
Run DMD on training data

Evaluate Performance

$$\varepsilon = \frac{\|\boldsymbol{X}_{DMD} - \boldsymbol{X}\|_2}{\|\boldsymbol{X}\|_2}$$

Training

↓



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Testing

Cases

Case 1: Weakly nonlinear flap

- Data source: WEC-Sim, nonlinear flap
- Sea State: Regular
- H = 2 m, T = 8 s

Cases

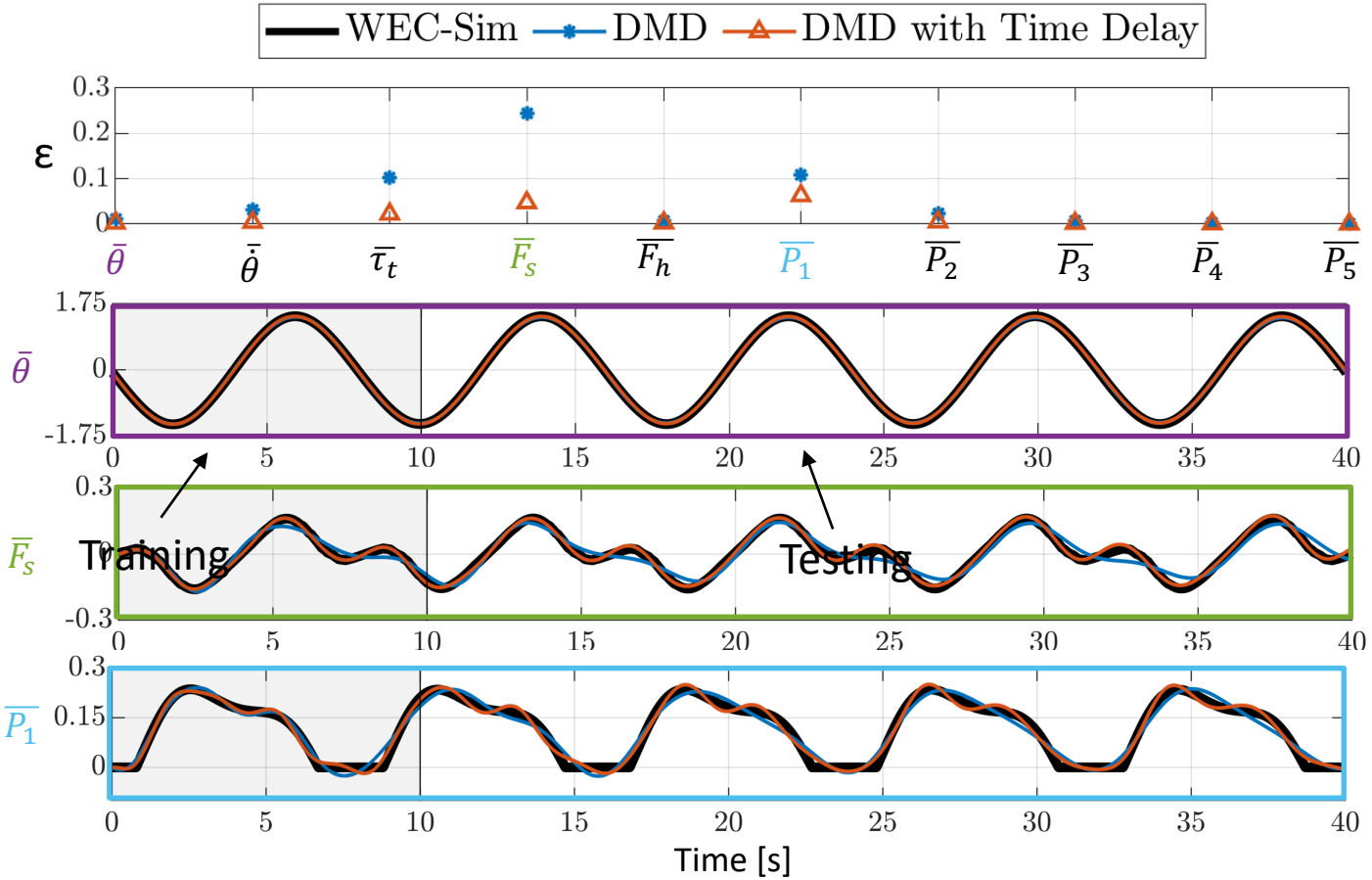
Case 1: Weakly nonlinear flap

- Data source: WEC-Sim, nonlinear flap
- Sea State: Regular
- H = 2 m, T = 8 s

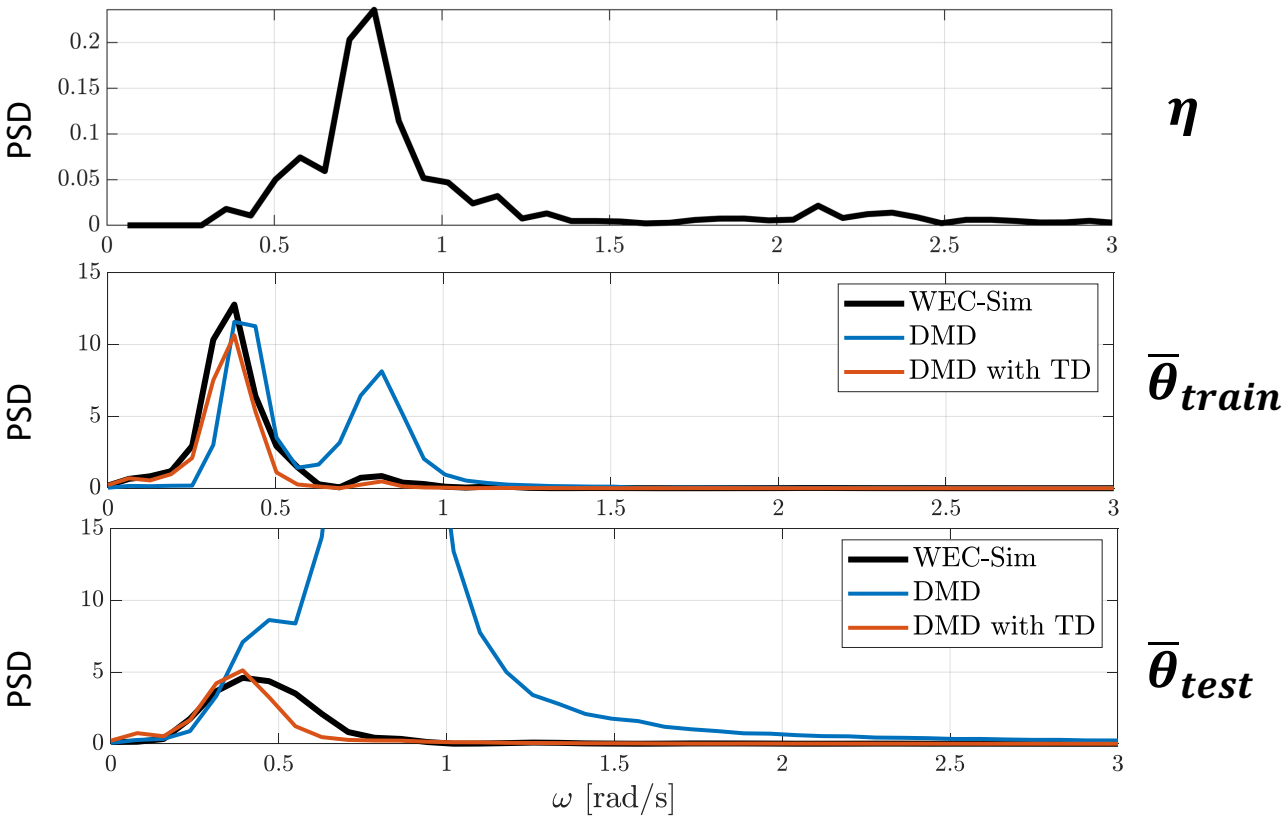
Case 2: Irregular wave field

- Data source: WEC-Sim, nonlinear flap
- Sea State: Irregular, real spectrum
- Hs = 0.94 m, Tp = 5.8 s

Case 1: Weakly nonlinear dynamics



Case 2: Irregular wave field



Summary and Future Work

- DMD shows promise for creating a fast, accurate model for OSWECs
  - Weakly nonlinear dynamics
  - Irregular waves

- Next Steps
  - Further investigation on irregular wave case
  - Using DMD model in for control optimization

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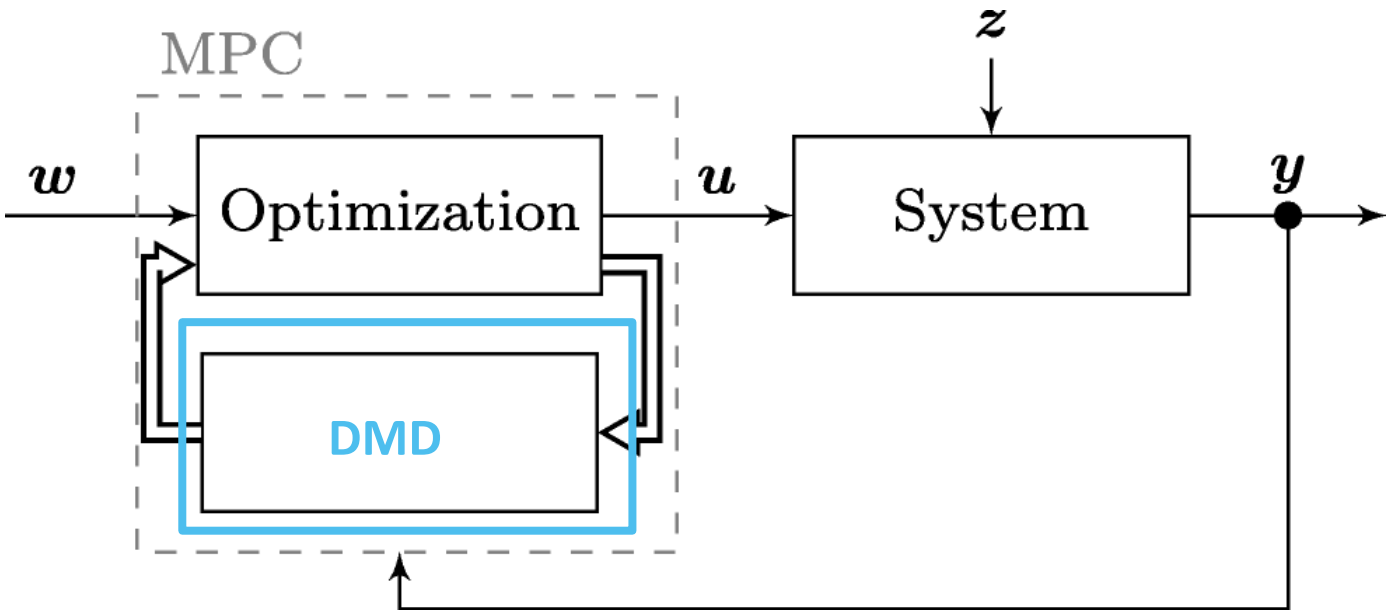
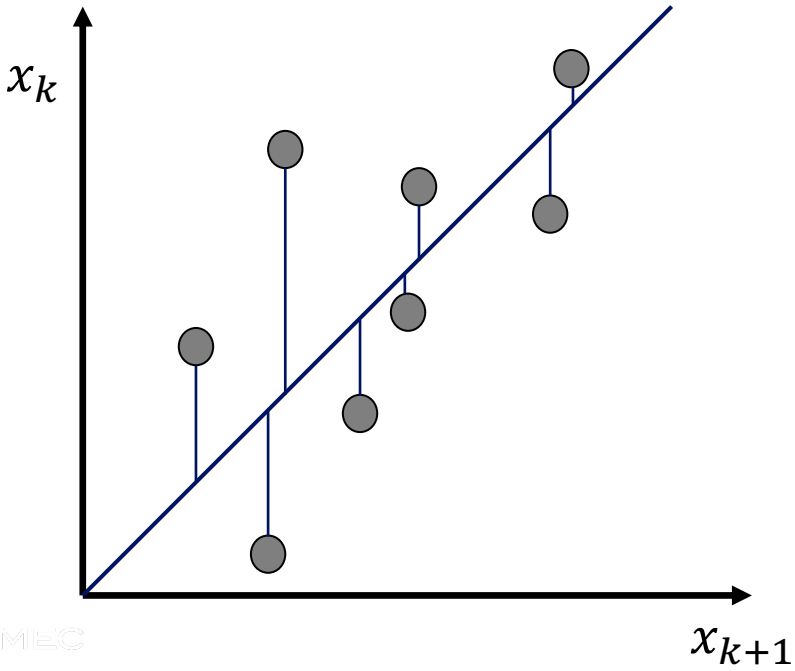
Model Predictive Control

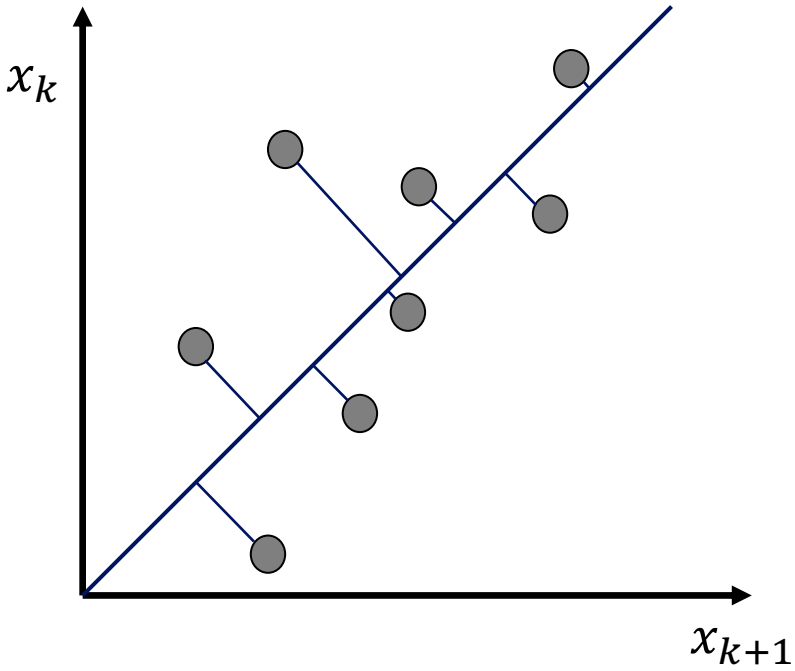


Schwenzer, et al., 2021

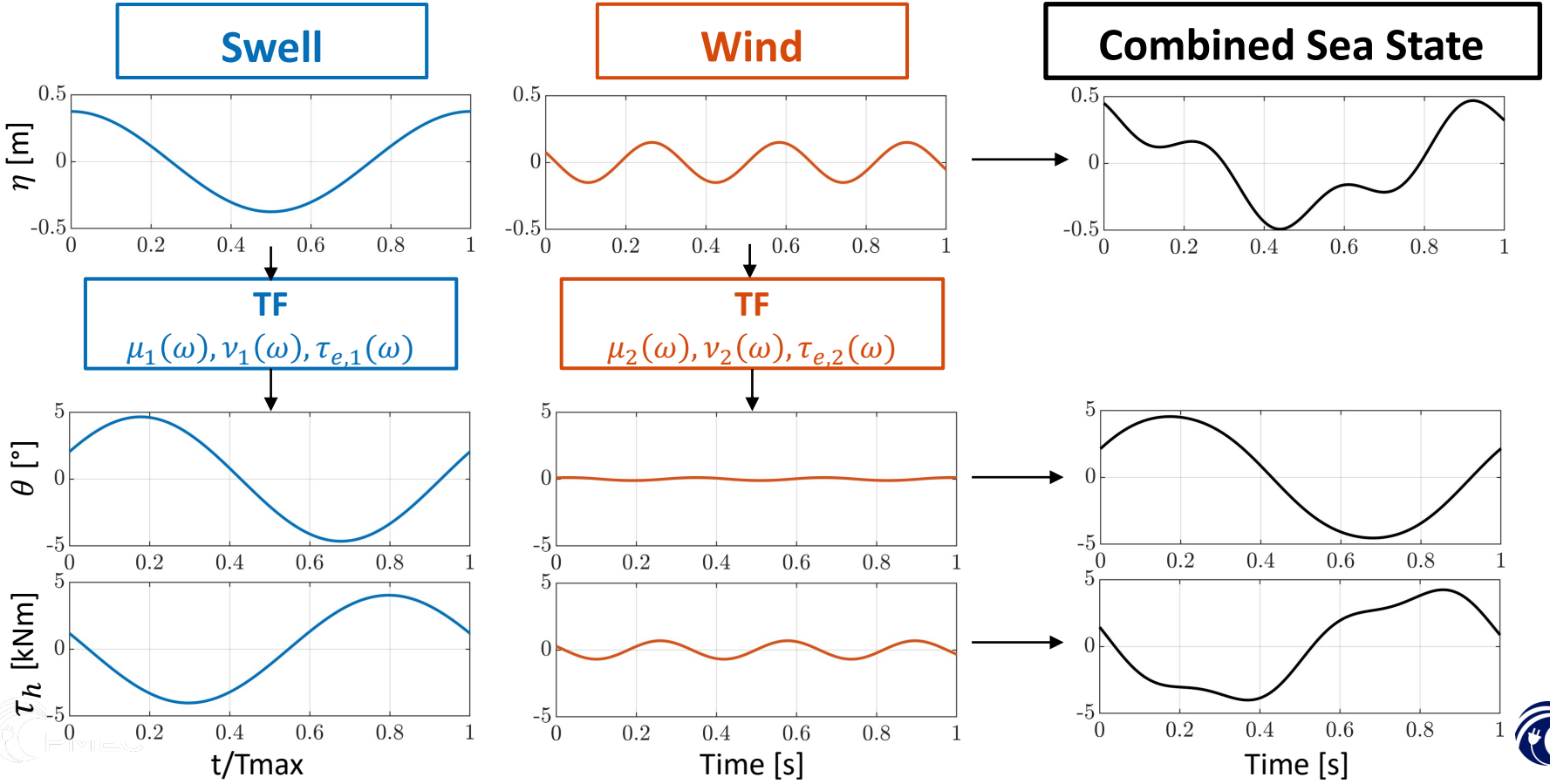
Total Least Squares DMD

$$\boldsymbol{x}_{k+1} = \boldsymbol{A}\boldsymbol{x}_k$$





Semi-Analytical Model



WEC-Sim

$$m\ddot{X}(t) = F_e(t) + F_r(t) + F_v(t) + F_{PTO}(t) + F_B(t) + F_{md}(t) + F_m(\mathrm{t})$$

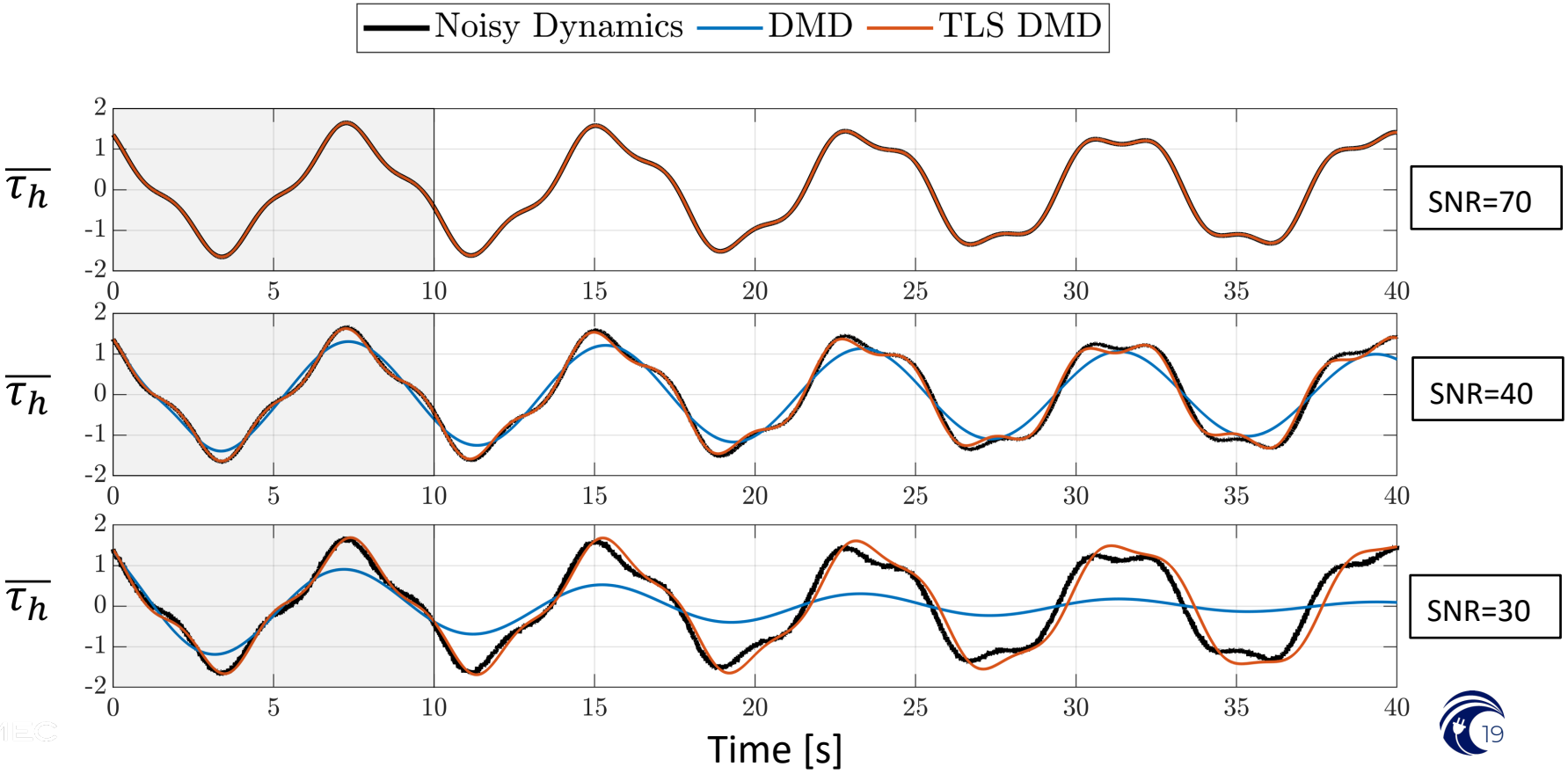
- Frequency domain analysis (BEM) for hydrodynamic parameters
- Time domain solver
- Capabilities
  - Weakly nonlinear flap dynamics
  - Irregular sea state
    - Real spectrum

Cases

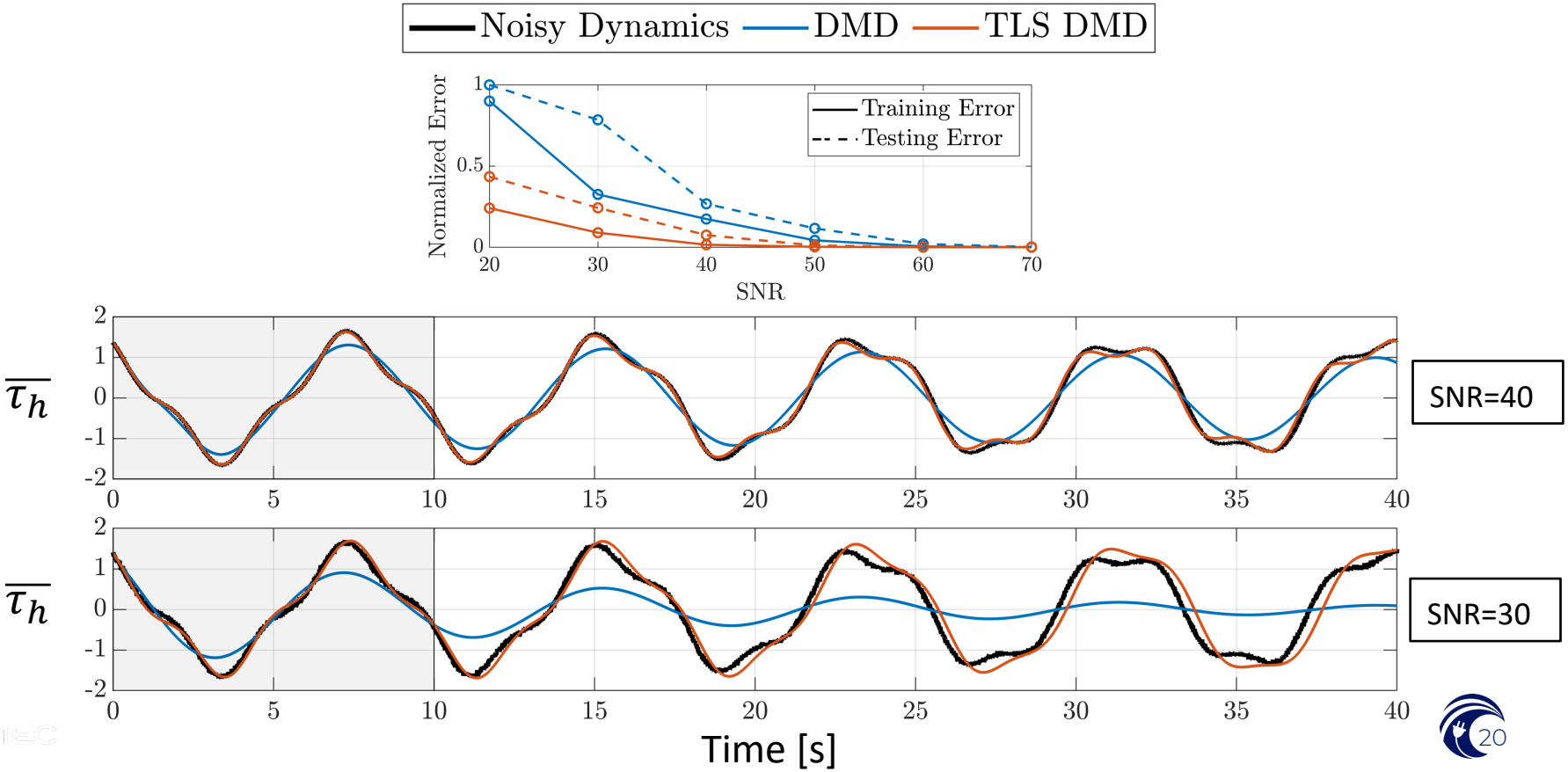
Case 1: Noisy signal

- Data source: Semi-analytical model
- Sea State: Polychromatic (2 frequencies)
- Noise: Added white Gaussian noise
- H1 = 0.7 m, H2 = 0.3 m, T1 = 8 s, T2 = 2.55 s

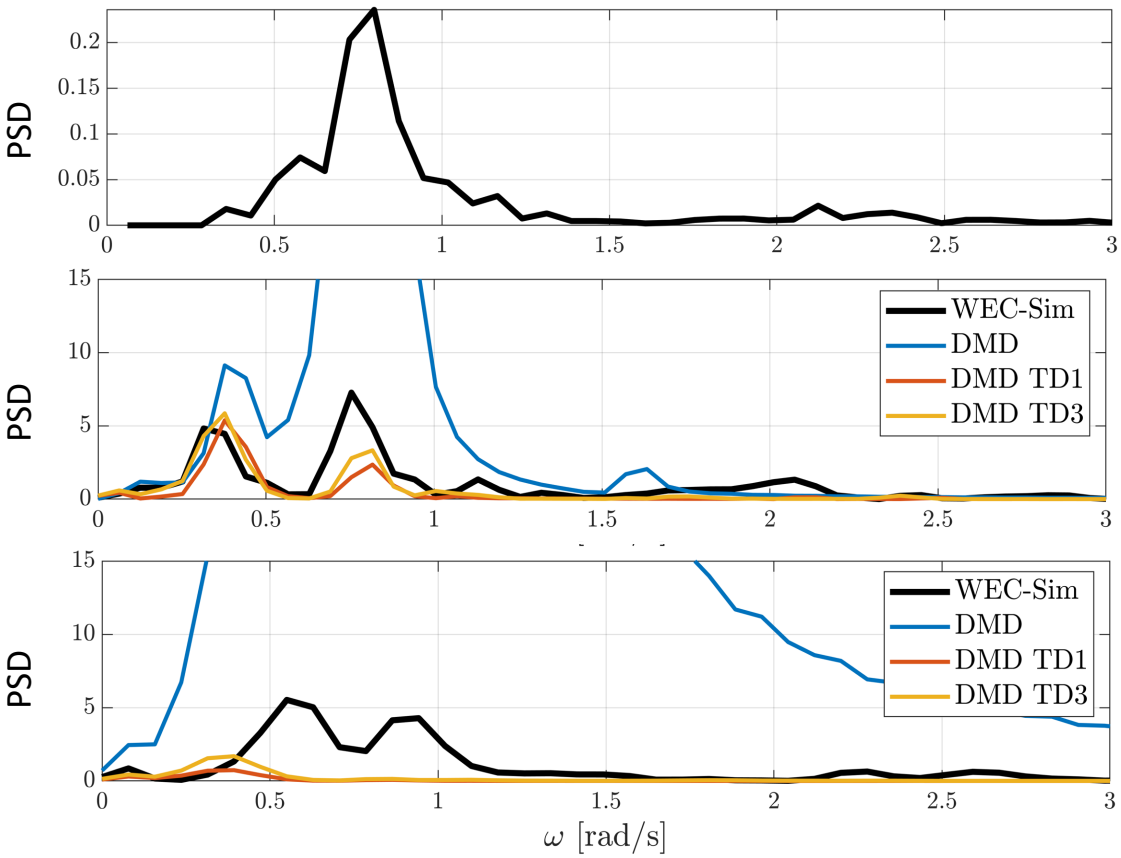
Case 1: Noisy Dynamics



Case 1: Noisy Dynamics



Case 3: Irregular wave field



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$\bar{\tau}_{h,\,train}$

$\bar{\tau}_{h,\,test}$