Experimentally Validated Numerical Modeling and Control for Optimizing PTO Efficiency in Wave Energy Converters

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Customizing PTO design presents significant opportunities to improve wave power harvesting efficiency; the proposed new control can effectively improve PTO efficiency by 48.5%.

Background & Objective

- One long-standing challenge of the state-of-the-art wave energy conversion technologies is the **inefficient mechanical to electrical power conversion**.
- Significant studies focus on mechanical power harvesting, while only limited research is dedicated to understanding the power electronics in the WEC PTO system (which is the major source of power losses).
- The research team has recently developed a high-fidelity wave-to-wire model with direct simulation of power electronics and varied types of losses.
- Significant opportunities have been presented for customizing PTO design for specific WECs to improve energy harvesting efficiency (**up to 61.78%** in our prior work).

Objectives of this research:

- Leveraging the experimental testing data to further **improve the accuracy of the high-fidelity PTO model.**
- Develop a **novel control to maximize the efficiency** in the PTO drivetrain.

Methodology

Complete system configuration:

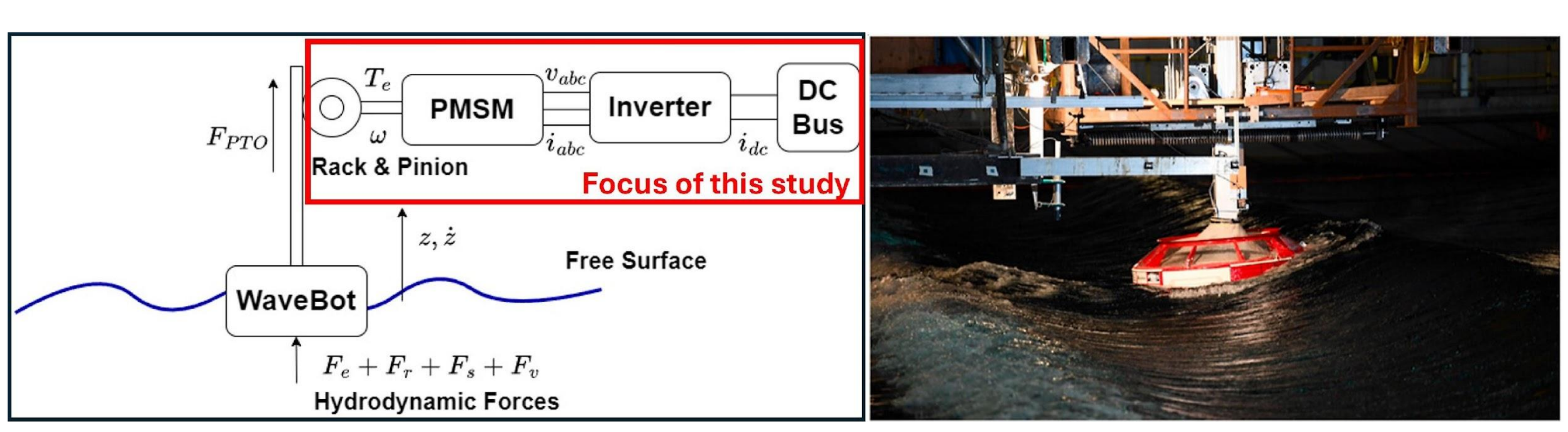

Fig. 1: Overall wave-to-wire configuration

PTO model (calibrated s.t. experimental data):

- **Permanent Magnet Synchronous Motor**

$$v_d = R_s i_d + L_d \dot{i}_d - n_p \omega i_q L_q$$

$$v_q = R_s i_q + L_q \dot{i}_q + n_p \omega (i_d L_d + \psi_m)$$

The motor torque is:

$$T_e = \frac{3}{2} n_p (i_q (i_d L_d + \psi_m) - i_d i_q L_q)$$

- **Motor Drive**

A piecewise linear model is applied to directly simulate the dynamic behavior of transistors:

$$i_{CE} = \begin{cases} \frac{v_{CE} - v_f (1 - R_{on} G_{off})}{R_{on}}, & \text{if } v_{CE} > v_f \text{ and } G > v_{th} \\ v_{CE} G_{off} & \text{Otherwise} \end{cases}$$

- **Motor conduction loss, inverter conduction and switching losses are all considered.**

Novel Control (varying DC bus voltage to maximize efficiency):

- Objective of the control is to minimize the DC bus voltage subject to the operation conditions (load requirement), such that to minimize the losses in the drivetrain.

$$V_{dc} \geq 2\left(\sqrt{V_d^2 + V_q^2} + |I_q| R_{on}\right)$$

RESULTS

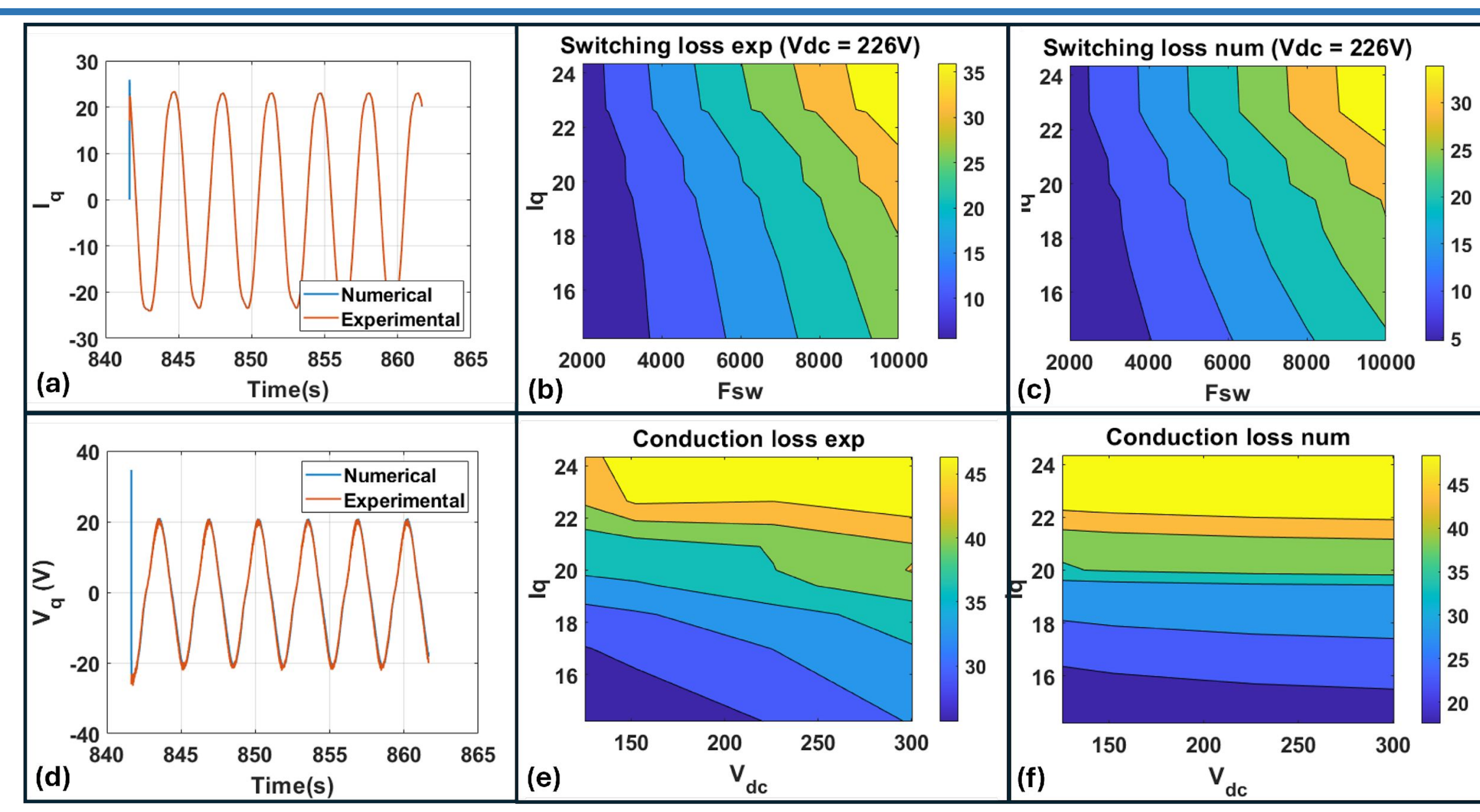

Fig. 2. Complete PTO unit performance against the experimental data after model calibration, which shows a good agreement.

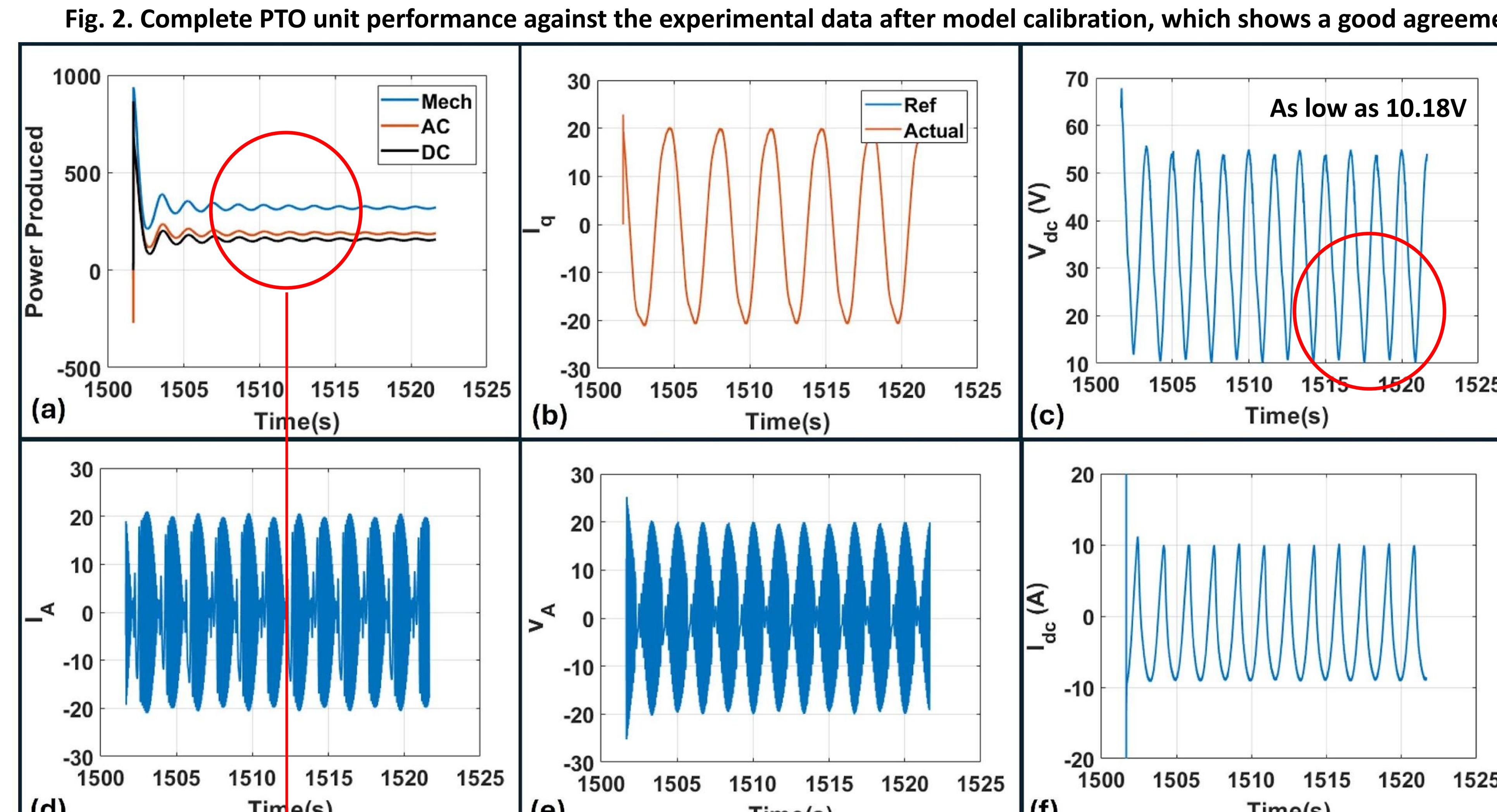

Fig. 3. PTO unit performance with the new varying DC bus voltage control.

	New control (Fsw = 2kHz, Vdc min)	Unoptimal setup (Fsw = 10kHz, Vdc = 300.5V)
Inverter conduction loss	30.4191W	40.5518W
Inverter switching loss	1.0196W	42.1738W
Overall PTO efficiency	49%	33%

Conclusion & Future work

- By adjusting the model parameters, the numerical model shows a good agreement with the experimental data in terms of system responses and losses.
- The novel DC bus voltage control is able to minimize the DC voltage while still being sufficient to support the required load and effectively reduce the inverter losses by 62%.
- Plans to test this new control with WaveBot in experiments.

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