Hydrodynamic Investigation on an Array of Wave Energy Converters Integrated into an Aquaculture Cage

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Objectives

A hybrid system of WECs intergrated into aquaculture cage is proposed in this paper:

- The WECs array replaces the traditional floating pipe frame part to provide buoyancy;
- The annular sinker replaces the gravity block to provide stability;
- The mooring system connectes to sinker to provide mooring stiffness;
- The linear power-take-off (PTO) model is used to calculate the captured power.

Research objectives: (1) decrease cage motion amplitude; (2) optimise captured power.

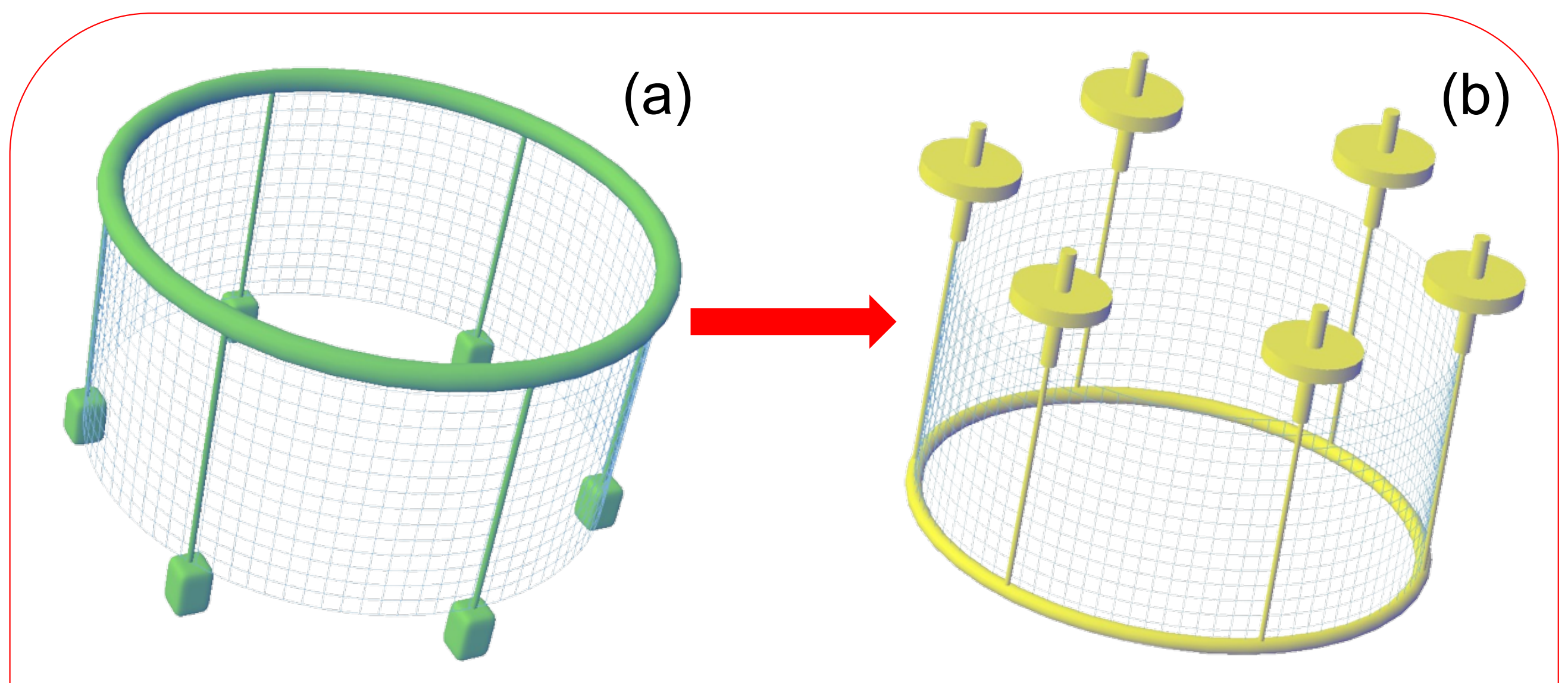

Figure 1 (a) traditional gravity aquaculture cage model; (b) new type WECs-cage hybrid system model

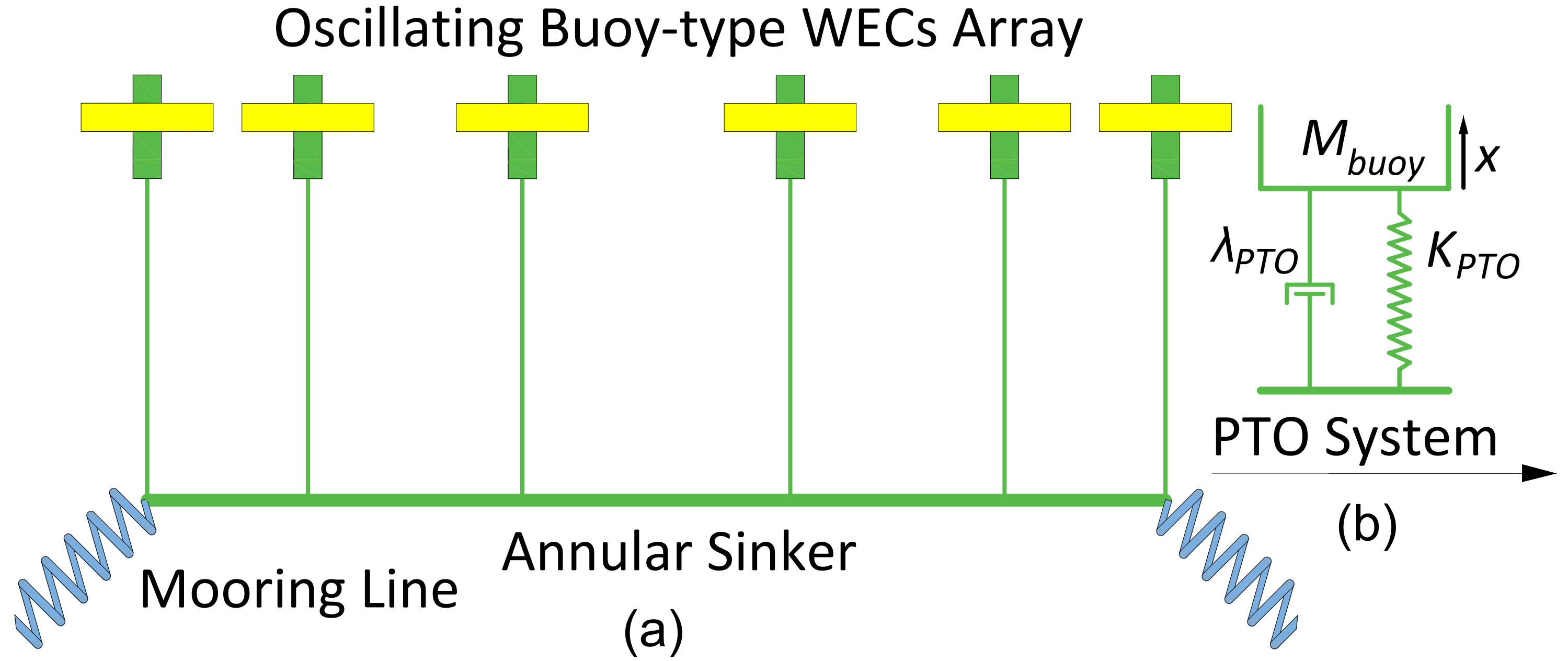

Figure 2 (a) plan view of the numerical model of the hybrid system;(b) the calculation mode of PTO system, it could be simplified to PTO stiffness and damping

Hybrid system synergy effect:

- Share infrastructure and mooring system;
- Provide electricity requirements for production;
- Play a buffering role to the cage motion;
- The economic benefits make WECs sustainable.

Methods

Assume that the fluid is inviscid, irrotational and incompressible, the seabed is flat, and both the incident wave and structural motion are of small amplitude. Based on the linear potential flow theory, the frequency domain motion response equation can be written as:

$$\left[-\omega^2\left(M_1+\mu_1^1\right)-i\omega\lambda_1^1+K_{mooring}\right]\xi_1+\sum_{n=2}^{N}\left(-\omega^2\mu_1^n-i\omega\lambda_1^n\right)\xi_n=F_{ex,1}+\boxed{\sum_{n=2}^{N}\left(-i\omega\lambda_{PTO}+K_{PTO}\right)\left(\xi_n-\xi_1\right)}\longrightarrow F_{PTO}=K_{PTO}\left(\xi_n-\xi_1\right)+\lambda_{PTO}\left(\dot{\xi}_n-\dot{\xi}_1\right)$$

$$\left\{-\omega^2\left(\begin{bmatrix}M_2&&\\&\ddots&\\&&M_N\end{bmatrix}+\begin{bmatrix}\mu_2^2&\cdots&\mu_2^N\\\vdots&\ddots&\vdots\\\mu_N^2&\cdots&\mu_N^N\end{bmatrix}\right)-i\omega\begin{bmatrix}\lambda_2^2&\cdots&\lambda_2^N\\\vdots&\ddots&\vdots\\\lambda_N^2&\cdots&\lambda_N^N\end{bmatrix}+\begin{bmatrix}K_{s,2}&&\\&\ddots&\\&&K_{s,N}\end{bmatrix}\right\}\begin{pmatrix}\xi_2\\\vdots\\\xi_N\end{pmatrix}+\begin{pmatrix}-\omega^2\mu_2^1-i\omega\lambda_2^1\\\vdots\\-\omega^2\mu_N^1-i\omega\lambda_N^1\end{pmatrix}\xi_1=\begin{pmatrix}F_{ex,2}\\\vdots\\F_{ex,N}\end{pmatrix}-\boxed{\left(-i\omega\begin{bmatrix}\lambda_{PTO}&&\\&\ddots&\\&&\lambda_{PTO}\end{bmatrix}+\begin{bmatrix}K_{PTO}&&\\&\ddots&\\&&K_{PTO}\end{bmatrix}\right)\begin{pmatrix}\xi_2-\xi_1\\\vdots\\\xi_N-\xi_1\end{pmatrix}}$$

The total capture power: $P(\omega)=\sum_{n=2}^{N}\frac{1}{2}\omega^2\lambda_{PTO}\left|\xi_n-\xi_1\right|^2$ The average cage motion: $\xi=\sum_{n=2}^{N}\xi_n\Big/N$ Opposite-phase force in the PTO

#1 for the sinker, #2~7 for the WECs. During the numerical analysis, the net clothing was neglected due to its small effect on heaving-mode WEC, the hydrodynamics of the annular sinker was neglected due to its submerged depth *d>L/2*, and the mass term and stiffness term of the PTO are neglected due to the consideration of passive control only. r=5m, R=20m, $M_{sinker}=3M_{buoy}$, $K_{mooring}=3K_s$ in the poster.

Results

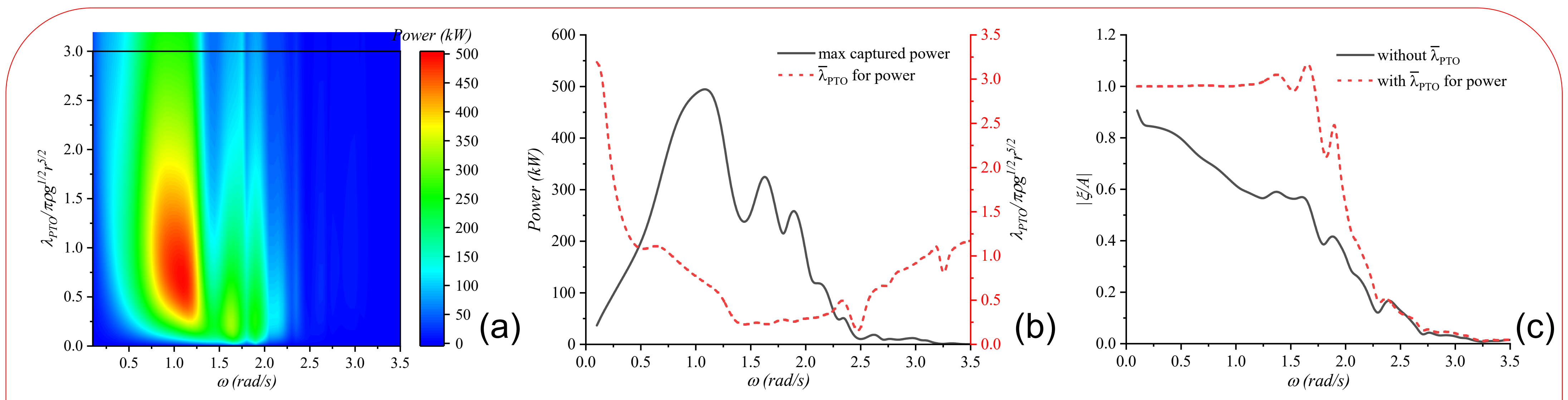

Figure 3 optimised λ_{PTO} for maximum captured power: (a) cloud plot of WECs array captured power variation with λ_{PTO} ; (b) maximum captured power variation in the frequency domain and the λ_{PTO} of this state; (c) cage motion amplitude in this state vs. without PTO.

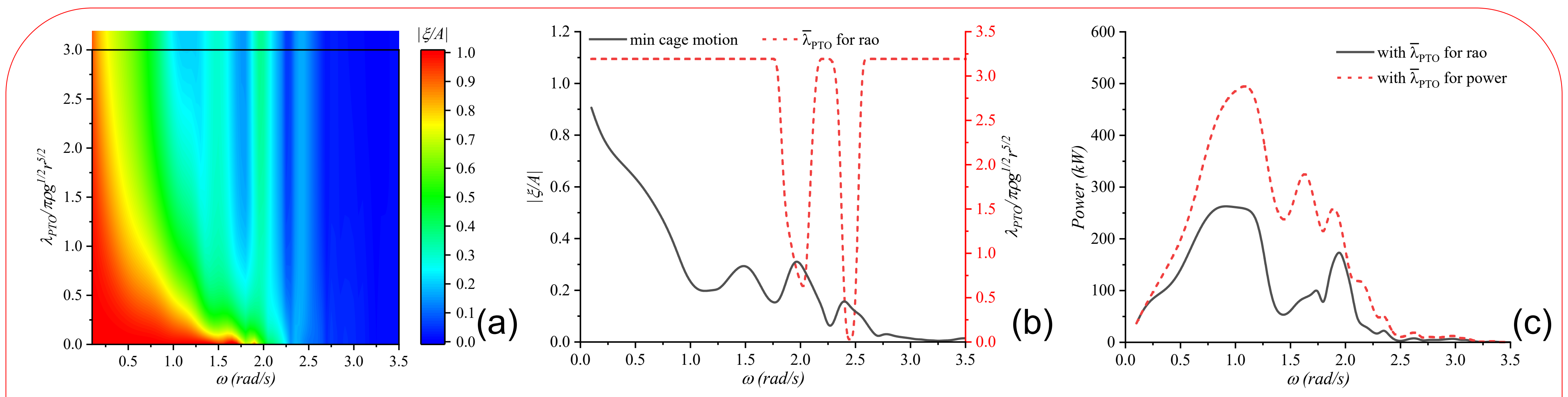

Figure 4 optimised λ_{PTO} for minimum cage heave motion: (a) cloud plot of cage motion amplitude variation with λ_{PTO} ; (b) minimum cage motion amplitude variation in the frequency domain and the λ_{PTO} of this state; (c) captured power in this state vs. maximum.

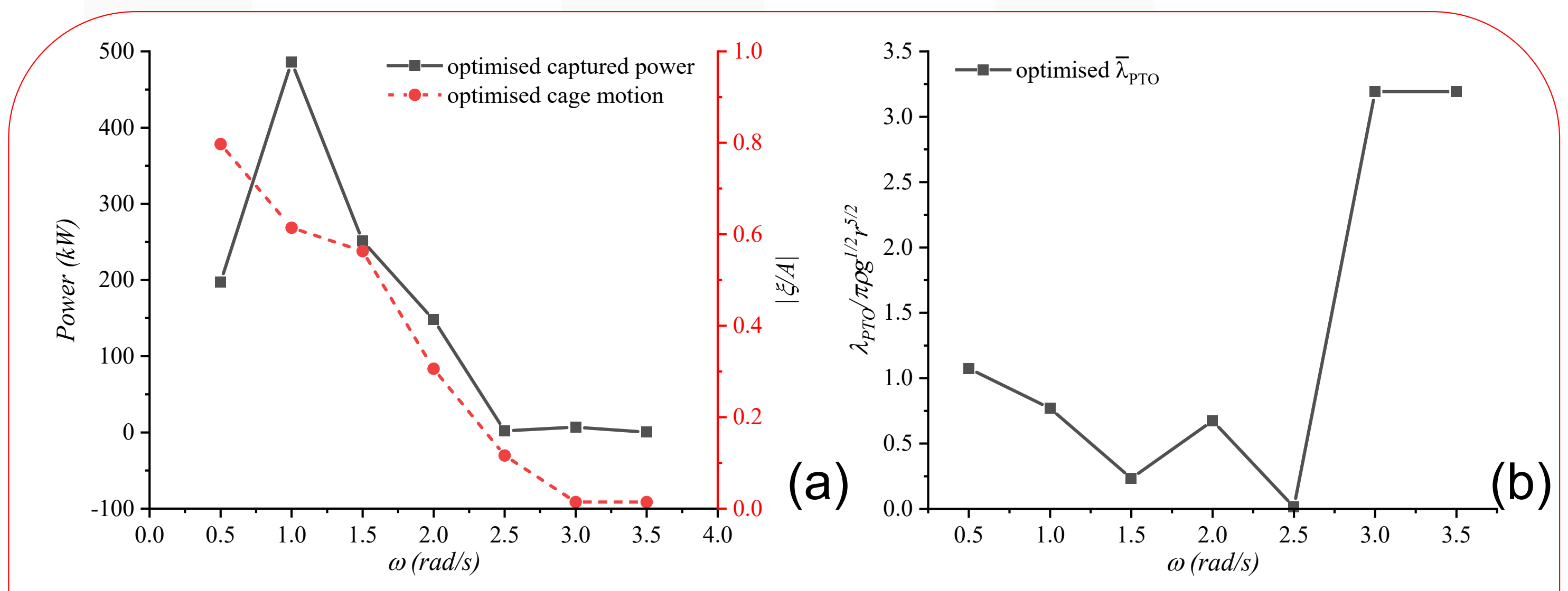

Figure 5 ω<2.0rad/s focused on captured power, ω>2.0rad/s focused on cage motion: (a) optimised captured power and cage motion amplitude; (b) optimised λ_{PTO} in this state.

Conclusions

- Under the action of optimised λ_{PTO}, the WECs array captured power above 200 kW in the frequency bandwidth of ω = 0.5~2.0 rad/s;
- Significant reduction in average cage motion amplitude of ω = 0.5~2.5 rad/s;
- Research objectives overlapped in frequency bandwidth, demonstrated good synergy of the hybrid system.