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Efficient WEC Array Buoy Placement Optimization with Multi-Resonance Control of the Electrical Power Take-off for Improved Performance

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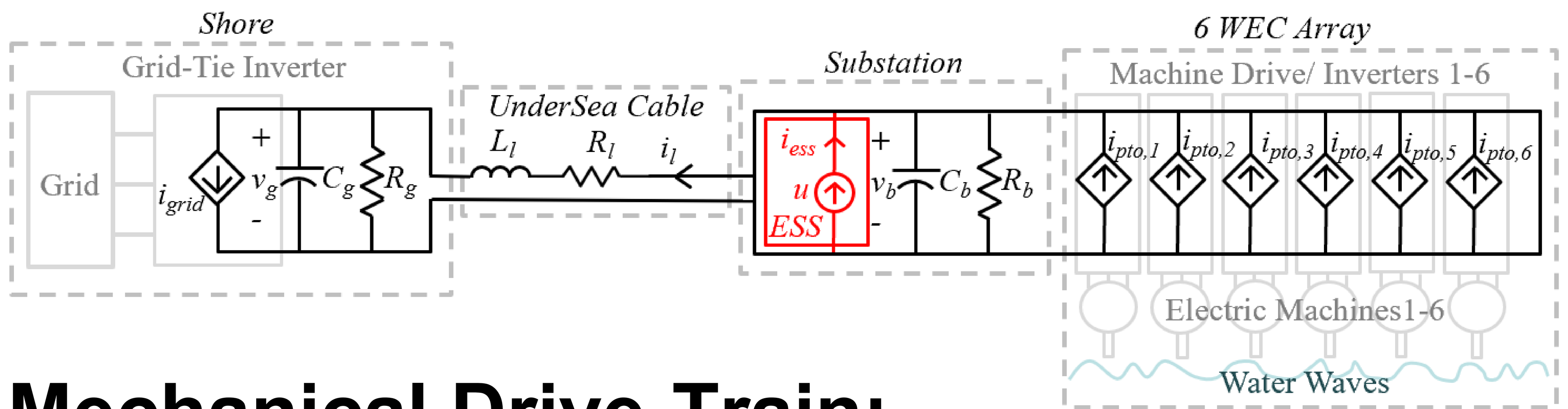
Introduction

An array of Wave Energy Converters (WECs) is required to supply a significant power level to the grid. However, the control and optimization of such an array is still an open research question. This paper analyzes two aspects that have significant impact on the power production: the spacing of the buoys and the angle at which the wave force interacts with the array. A cost function is then explored to minimize the power variation and energy storage while maximizing the delivered energy to the onshore point of common coupling to the electrical grid.



Mechanical Drive-Train:

$$m\ddot{x}_i + c_i\dot{x}_i + kx_i = f_{e,i} + f_{u,i}$$

Where:

$$f_{u,i} = \frac{\tau}{r} = \frac{i_{a,i}K_m}{r}$$

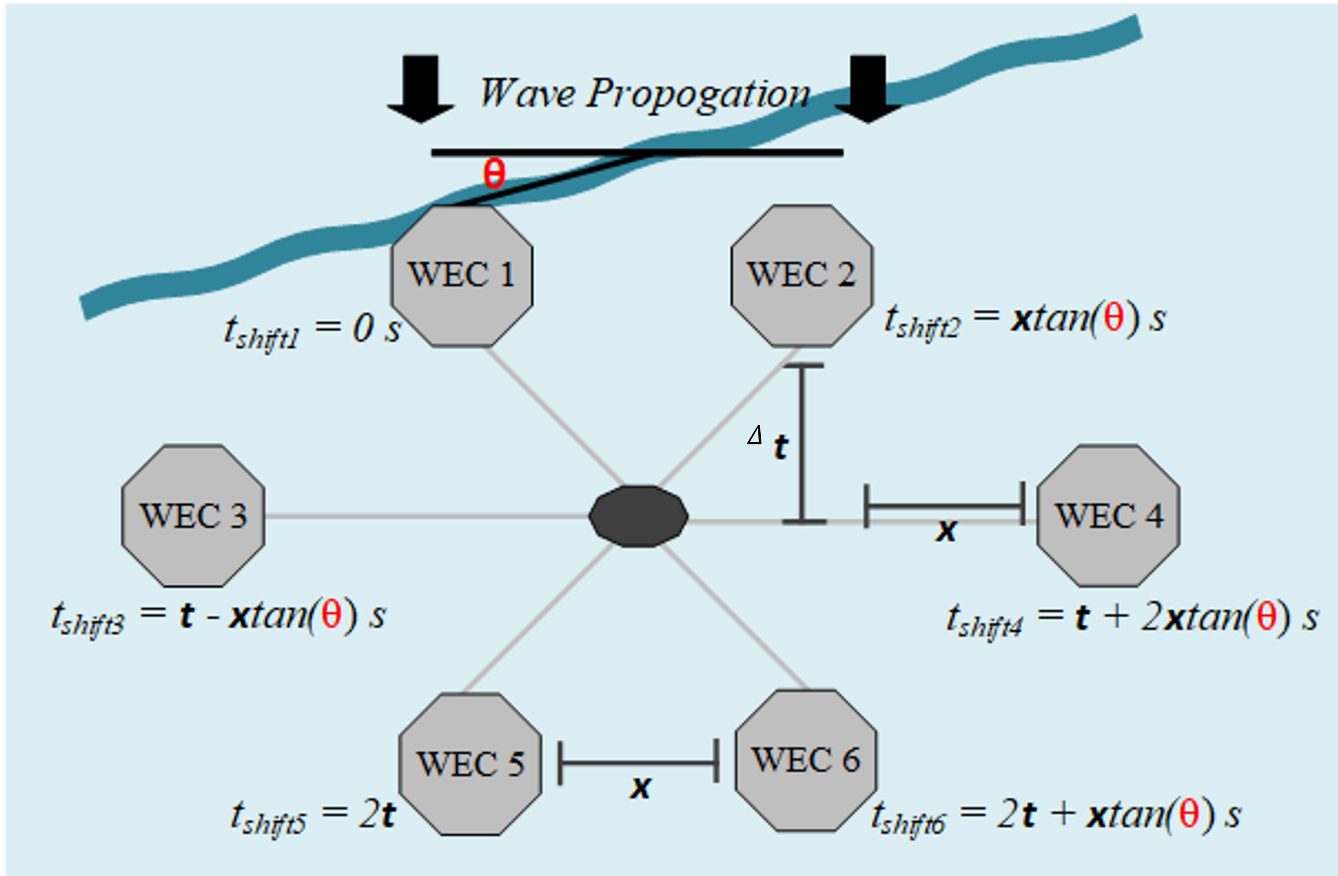
Electrical Drive-Train:

$$i_{a,i} = \frac{1}{L_a}\left(v_{a,i} - i_{a,i}R_a - \frac{K_m v_i}{r}\right)$$

$$i_{pto,i} = \frac{P_{pto,i}}{v_b} = \frac{v_{a,i}i_{a,i}}{v_b}$$

$$i_{ptosum} = \sum_{i=1}^{N} i_{pto,i}$$

Buoy Shifting and Electrical Phasing



$$P_{array} = \sum_{i=1}^{N} p_i(t)$$

$$= \frac{1}{2}(\csc(\phi)\sin(N\phi)\cos(2w_n t + \phi(1-N))) + N)$$

Constant power:

$$\csc(\phi)\sin(N\phi) = 0$$

when:

$$\phi \in \left\{\frac{\pi}{N}, \frac{2\pi}{N}\right\}$$

Optimization Strategy

- Inputs: buoy time shift (Δt), wave angle (θ), and grid update rate (g_{ts})
- Minimize: ESS size and noise in the bus voltage
- Maximize: energy delivered to the onshore grid

$$J = {}^{x_{GE}}/_{GE} + {}^{ESS_E}/_{x_{ESSE}} + {}^{\Delta V_b}/_{x_{V_b}} + {}^{ESS_P}/_{x_{ESSP}}$$

Buoy Shifting Results

Δt [s]	Degree [°]	ΔV_b [%]	ESS Energy [kJ]	Grid Power [kW]
0		3.19	157.07	2.36
1		3.61	92.80	2.12
2		2.52	240.53	2.68
3	~60	0.79	69.11	4.09
4	~60	1.22	69.13	4.28
5		1.44	135.20	4.06
6		0.80	422.32	2.29
7	~120	2.00	396.05	2.32

Optimized Cost Input Variables

Δt [s]	θ [°]	Grid Update Rate [s]
3.91	1.20	2.46

Optimized Cost Power/Energy Variables

ΔVb	ESS Energy	ESS Power	Grid Energy	Avg. Grid Power
0.72 %	60.8 kJ	9.48 kW	462.3 kJ	3.92 kW

Conclusions

- Buoy placement effects electrical signal phasing
- 60° phase shift of electrical signals corresponds to minimum power variation
- Angling WEC array creates additional sequencing in electrical signals

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