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A Control Strategy for Tidal Current Turbine Arrays Considering Both Power and Load Aspects

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OUTLINE

RESEARCH OVERVIEW

- **Research Motivation**
  1) Wake effects in arrays
  2) Reduce the levelized cost of energy (LCOE)
- **Research Objectives**
  1) Propose an axial induction factor (AIF) based control methodology for a tidal current turbine (TCT) array
  2) Mitigate fatigue loads, whilst guaranteeing a high level of power extraction
- **Research Contribution**
  1) Dynamic response of time-variable flow velocity
  2) Trade off between output power and fatigue loads

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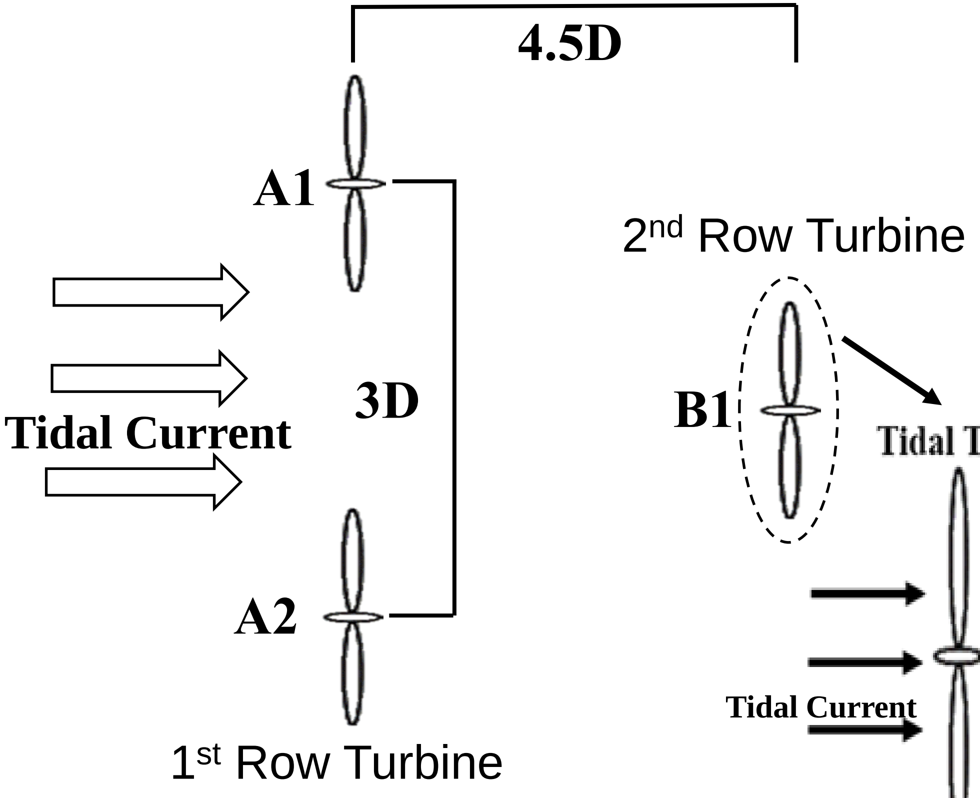
TIDAL CURRENT TURBINE ARRAY MODELLING

Table 1. Tidal Turbine Parameters

Parameter	Symbol	Value
Rotor radius	R_t	11.5m
Maximum power coefficient	C_p	0.4778
Rated velocity	V_{rated}	2.5m/s
Rated power	P_{rated}	1.5MW
Optimal tip-speed ratio	λ	7.95
Gearbox ratio	r	66.667



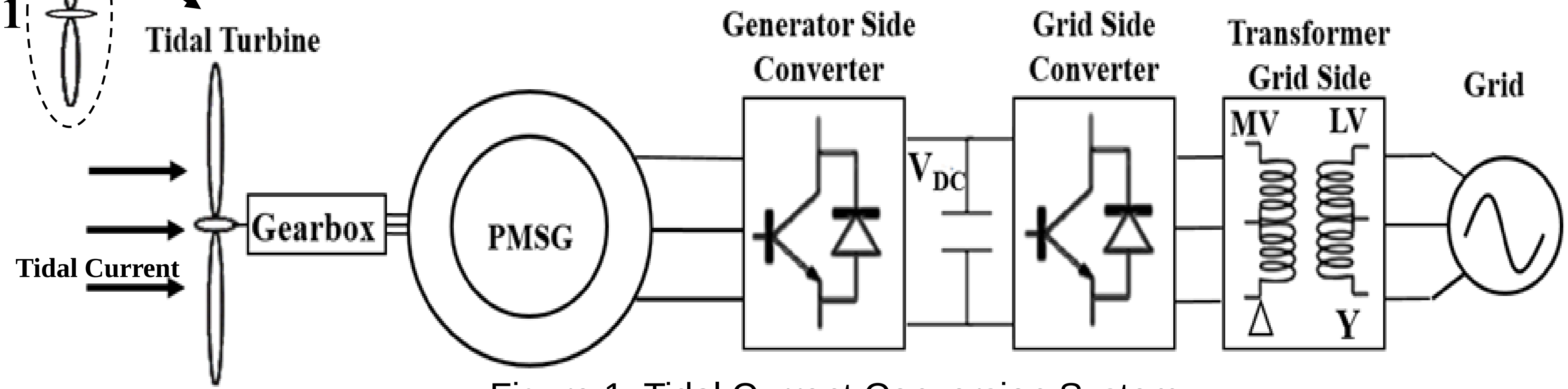


Figure 1. Tidal Current Conversion System

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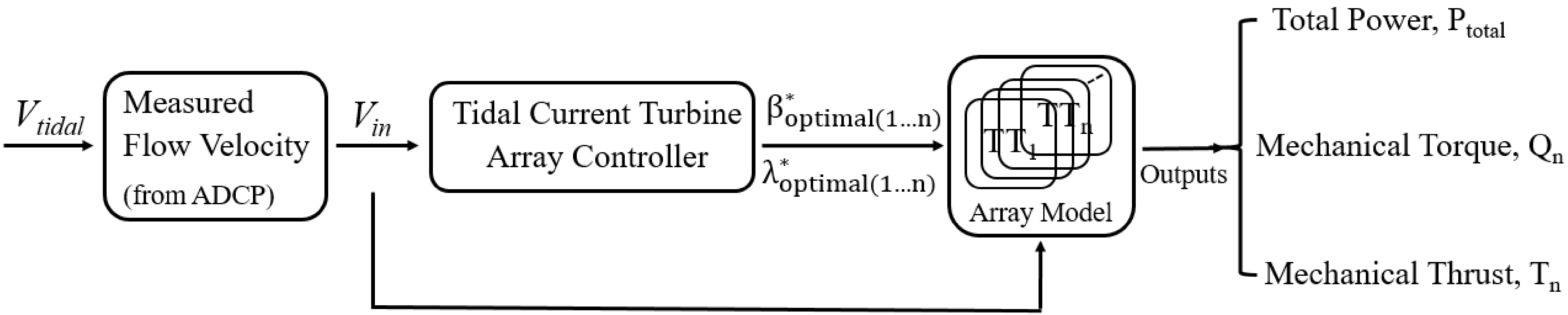
OVERALL CONTROL SYSTEM



1) Flow velocity measurement
2) Array Controller
3) Array Model and simulation
4) Outputs measurements

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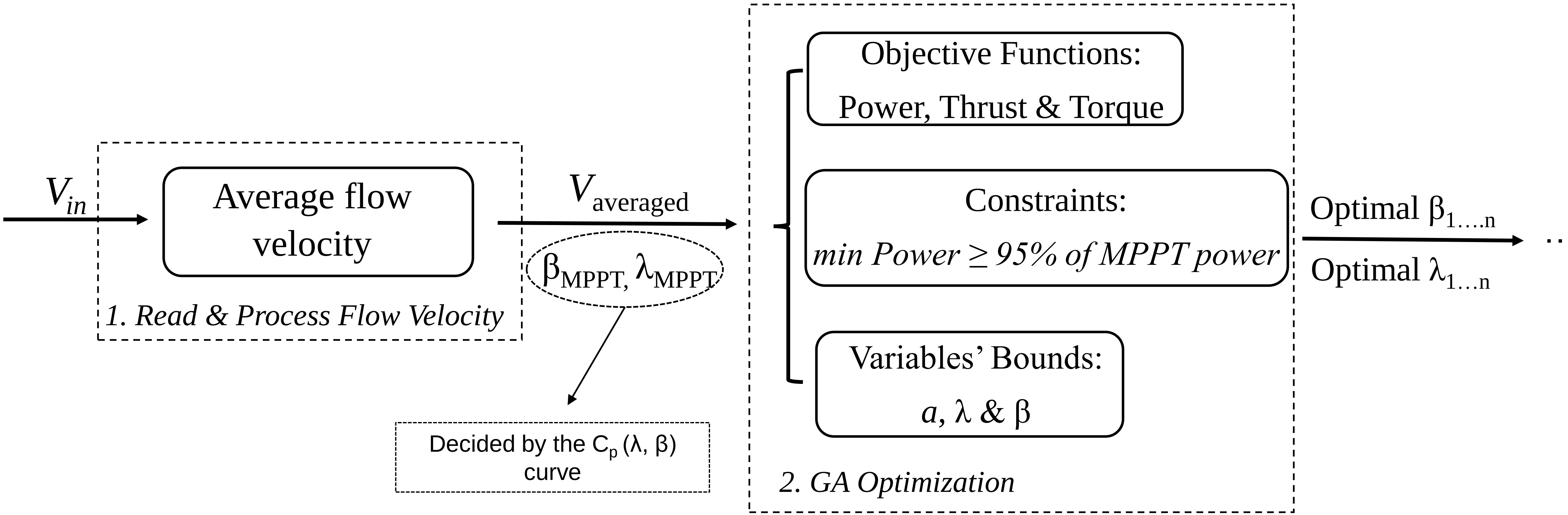
OPTIMIZATION METHODOLOGY

1. Average incoming flow velocity
2. Genetic algorithm (GA) optimization



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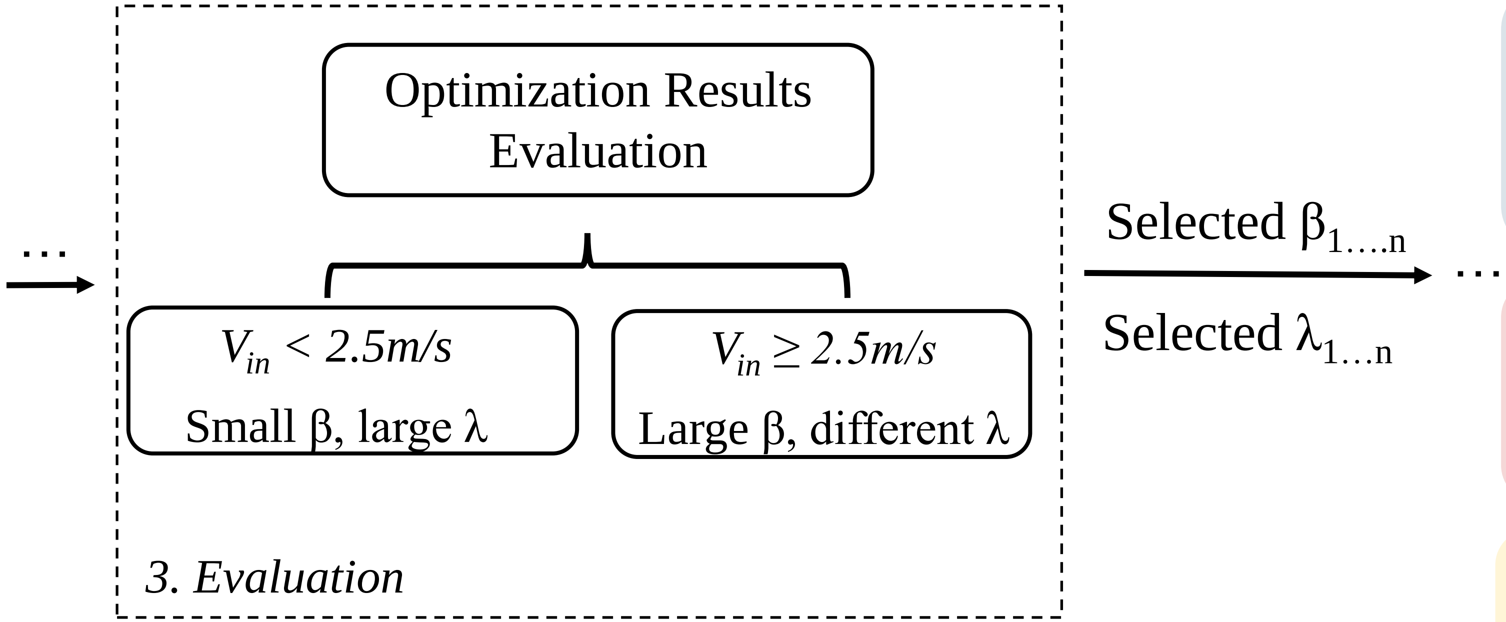
OPTIMIZATION METHODOLOGY

3. Evaluation of GA optimization results



Equation (1): Power coefficient

$$\begin{cases} C_p(\lambda,\beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3 \times \beta - c_4\right)e^{\frac{c_5}{\lambda_i}} + c_6 \times \lambda \\ \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08 \times \beta} - \frac{0.035}{\beta^3 + 1} \end{cases}$$

Equation (2): Total array power

$$P_{total} = \sum_{i=1}^{n} P_{TT_i}$$

Equation (3): Torque coefficient

$$C_Q = \frac{Q}{0.5\rho\pi V_{tidal}^3 R_t^3} = \frac{4a(1-a)^2}{\lambda}$$

Equation (4): Thrust coefficient

$$C_T = \frac{T}{0.5\rho V_{tidal}^2 A} = 4a(1-a)\left[\frac{2a(1-a)}{\lambda^2} + 1\right]$$

OPTIMIZATION METHODOLOGY

4. Selection of most proper optimal results for each turbine

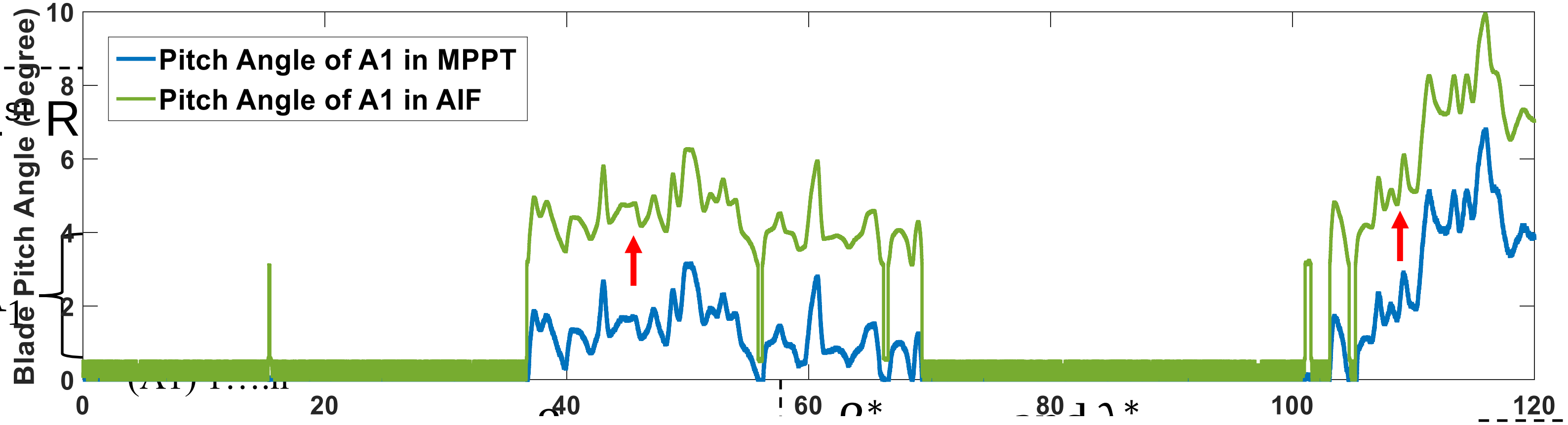


Figure 2. Blade pitch angle of turbine A1 in MPPT and AIF control

Model

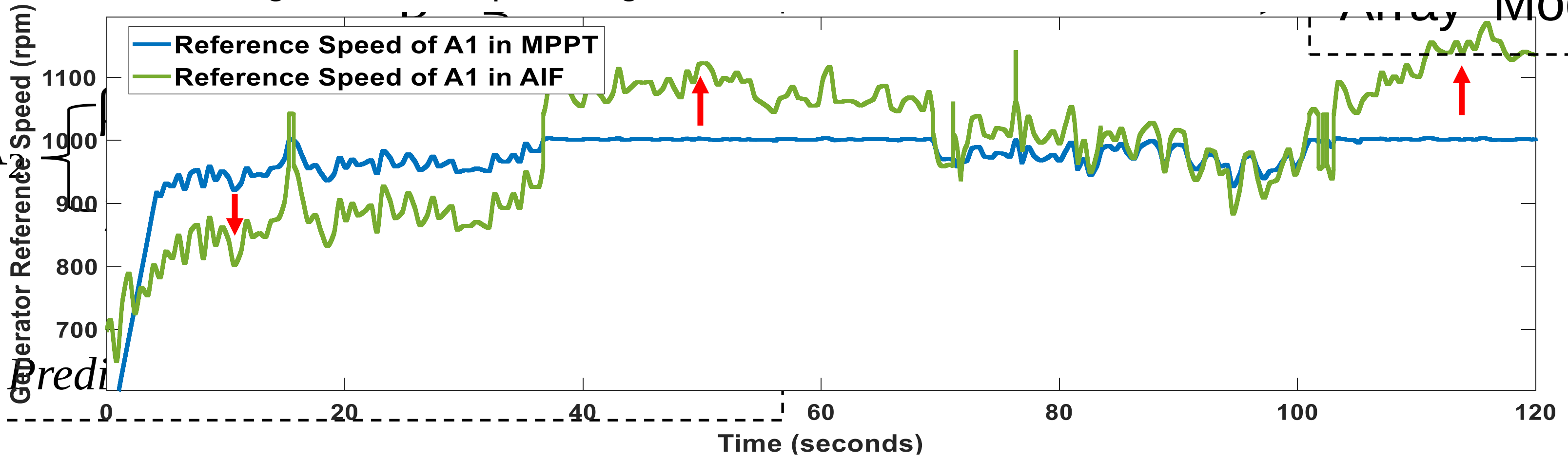


Figure 3. Generator reference speed of turbine A1 in MPPT and AIF control

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RESULTS

1. Incoming flow velocitv
2. Output power

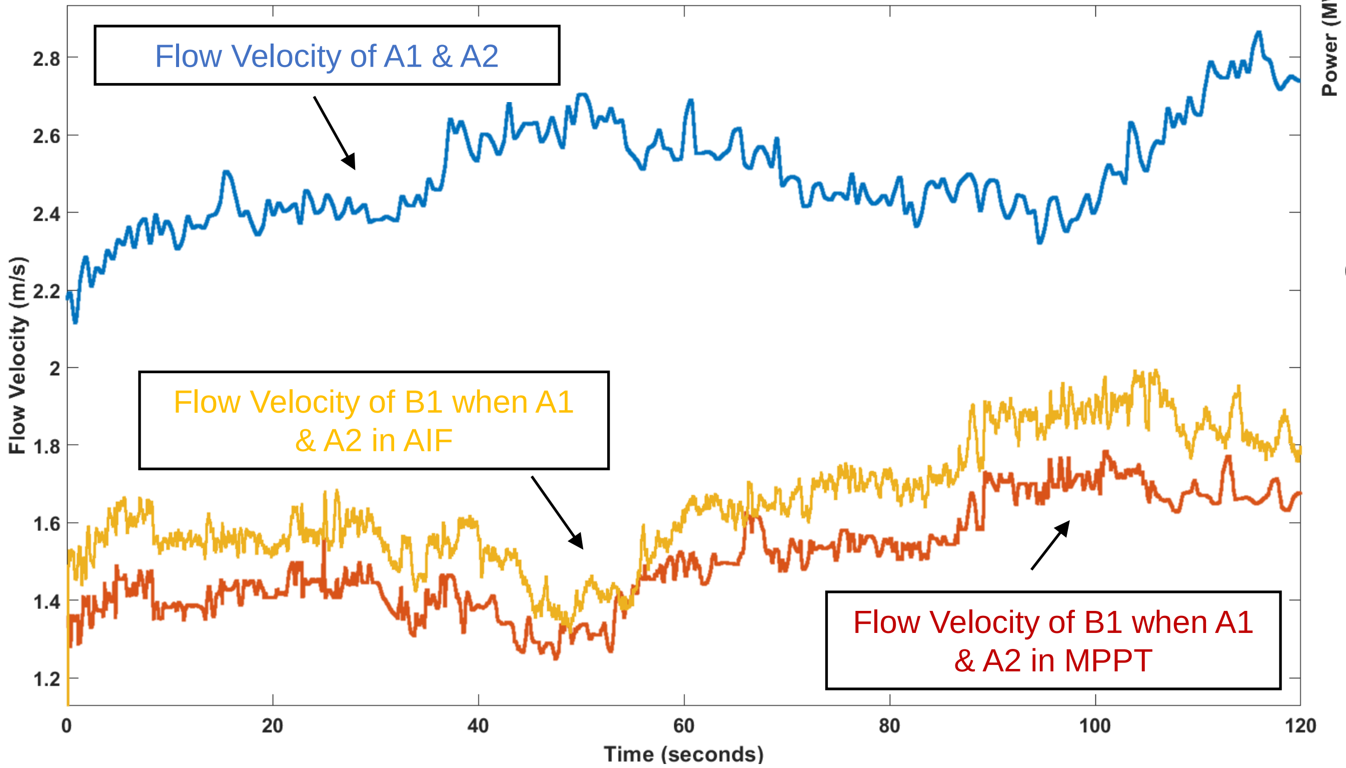

Figure 4. Incoming flow velocity

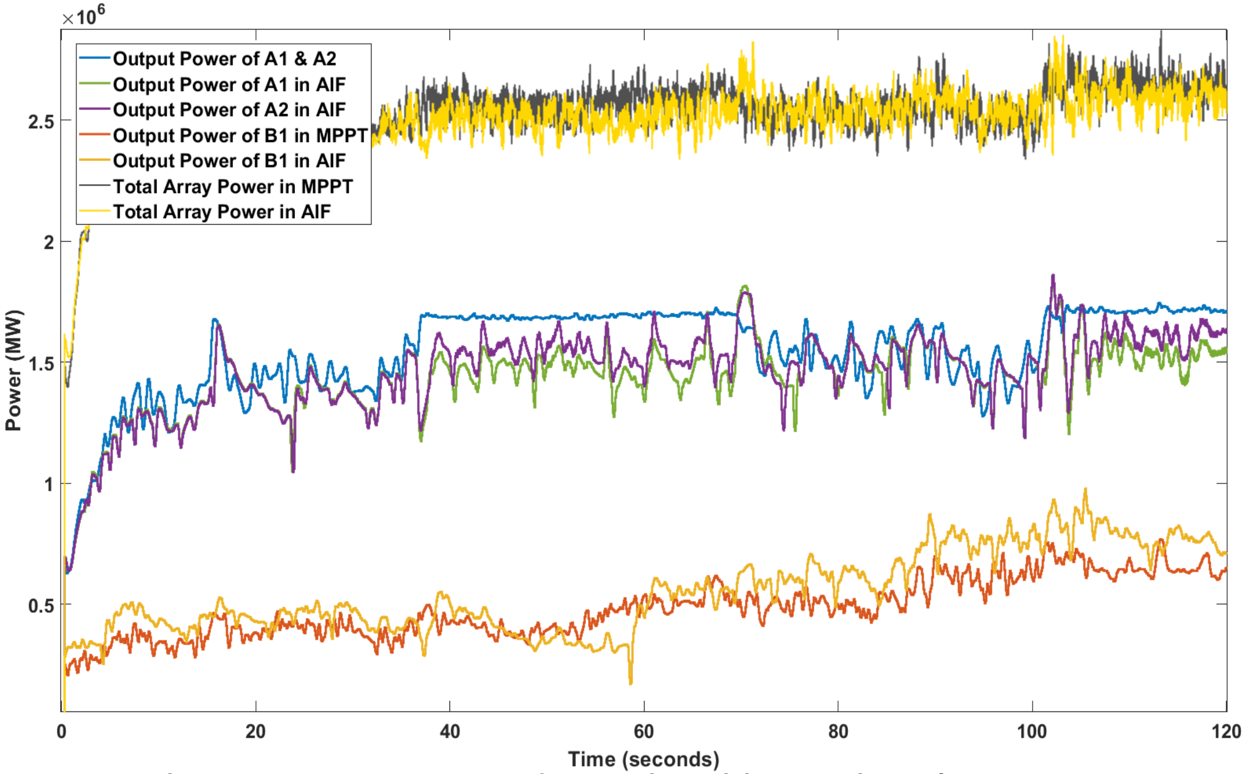

Figure 5. Output power for each turbine and total array power

Average Total Power	MPPT Control	AIF Control
	2.5279MW	2.5060MW

Table 2. Average total array power in MPPT and AIF control

- Less than 1% power reduction in AIF control

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RESULTS - Torque

Turbine A1	MPPT	AIF	Reduction
Stress Range (Nm)	[8.2e5,10.7e5]	[5.8e5, 7.8e5]	**27.1%**

(a)

Turbine A2	MPPT	AIF	Reduction
Stress Range (Nm)	[8.2e5,10.7e5]	[6.2e5, 7.6e5]	**29%**

(b)

Turbine B1	MPPT	AIF	Reduction
Stress Range (Nm)	[5.9e5,8.3e5]	[3.9e5,5.2e5]	**37.3%**

(c)

Table 3. Rainflow counting analysis of mechanical torque (a) A1, (b) A2, (c) B1.

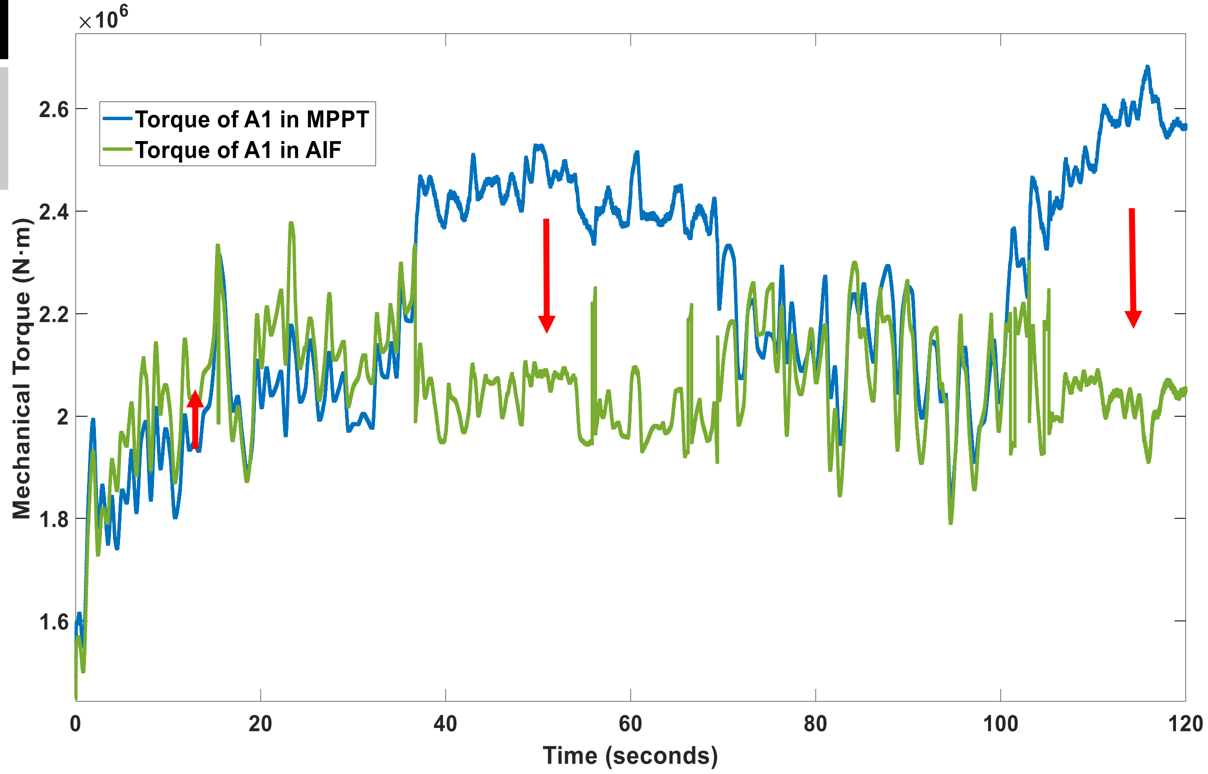

Figure 6. Mechanical torque of turbine A1 in MPPT and AIF

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RESULTS - Thrust

Turbine A1	MPPT	AIF	Reduction
Stress Range (Nm)	[6.2e5,6.7e5]	[3.5e5, 5.5e5]	**17.9%**

(a)

Turbine A1	MPPT	AIF	Reduction
Stress Range (Nm)	[6.2e5,6.7e5]	[3.6e5, 5.8e5]	**13.4%**

(b)

Turbine A1	MPPT	AIF	Reduction
Stress Range (Nm)	[3e5,4.65e5]	[2e5, 4.35e5]	**6.5%**

(c)

Table 4. Rainflow counting analysis of mechanical thrust (a) A1, (b) A2, (c) B1.

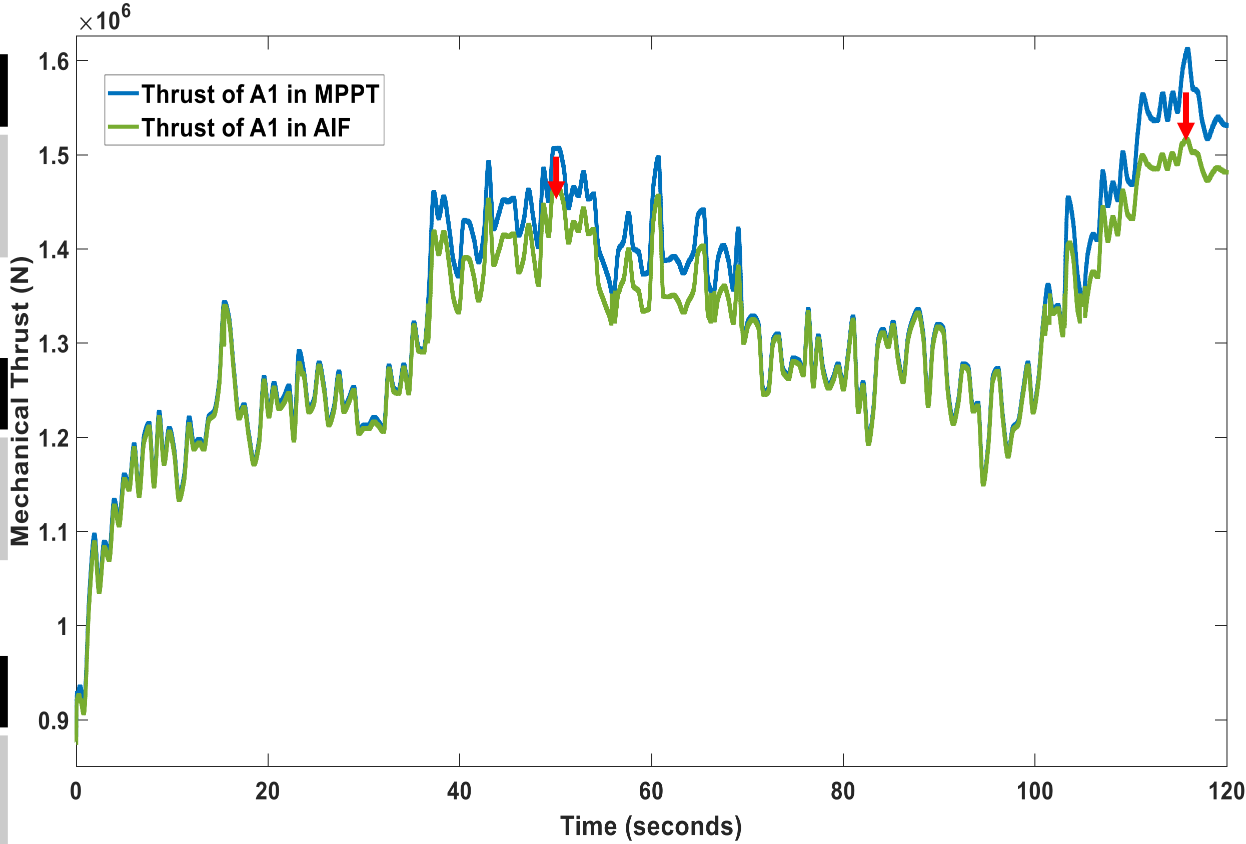

Figure 7. Mechanical thrust of turbine A1 in MPPT and AIF

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CONCLUSION

1. Enable to response real-time incoming flow velocity.

2. The proposed control strategy optimizes and assigns the references signals of β and λ for each turbine controller.

Thank You!

3. The proposed array controller enables the mitigation of fatigue loads, whilst guaranteeing a high level of power extraction

   - 30-40% stress range of torque reduction in AIF control
   - 6-18% stress range of thrust reduction in AIF control
   - Almost as much power as produced in AIF control, less than 1% power reduction