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Towards Optimal System Scheduling with Synthetic Inertia Provision from Wind Turbines

Zhongda Chu, Dr. Fei Teng

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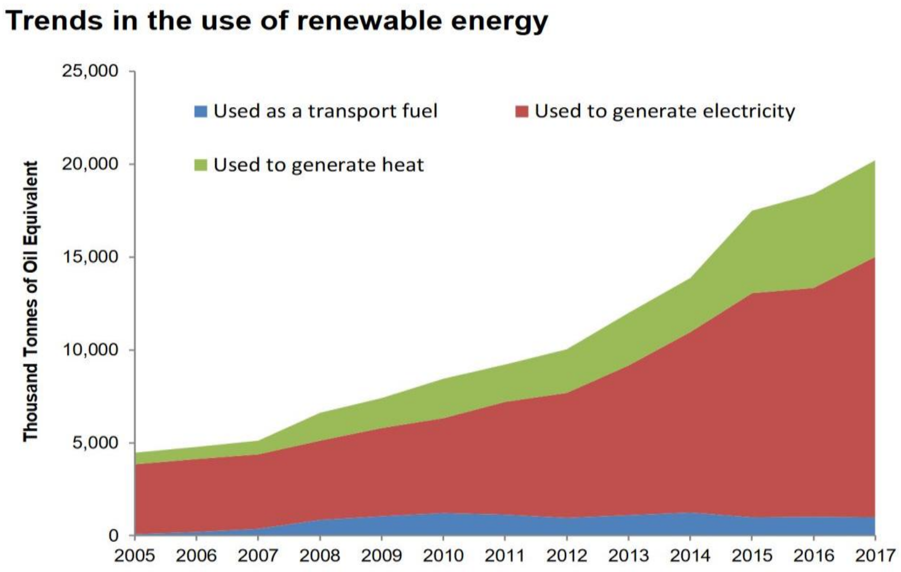
Background



Solution: Frequency Support from Wind Turbines

Frequency Support from Wind turbines

- Deloading: Optimum → Suboptimum
  - Long term support (mins), e.g. frequency response

- Overproduction:
  - Short term support (seconds), e.g. inertia response

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Over rated wind speed — Pitch Control (without rotor speed recovery)

Below rated wind speed — Kinetic Energy Extraction (with recovery)

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Problem Overview

- Recovery Effect

- System Risks

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  - Secondary frequency dip
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  - Total wind power
  - Available synthetic inertia (SI)
  - Mechanical loss due to rotor deceleration

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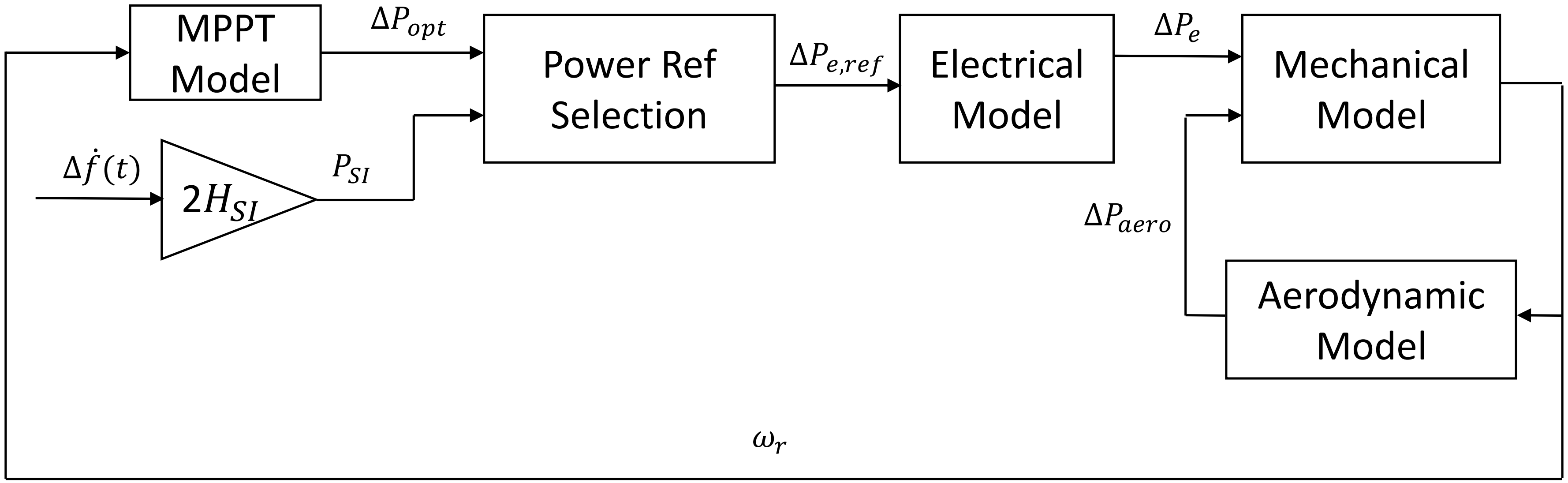
- Recovery Effect
  - Secondary frequency dip — Eliminated by introducing a novel control frame
- System Risks
  - Total wind power
  - Available synthetic inertia (SI) — Predicted by the Bayesian Algorithm
  - Mechanical loss due to rotor deceleration — Predicted by the Bayesian Algorithm

SI Provision Control Frame



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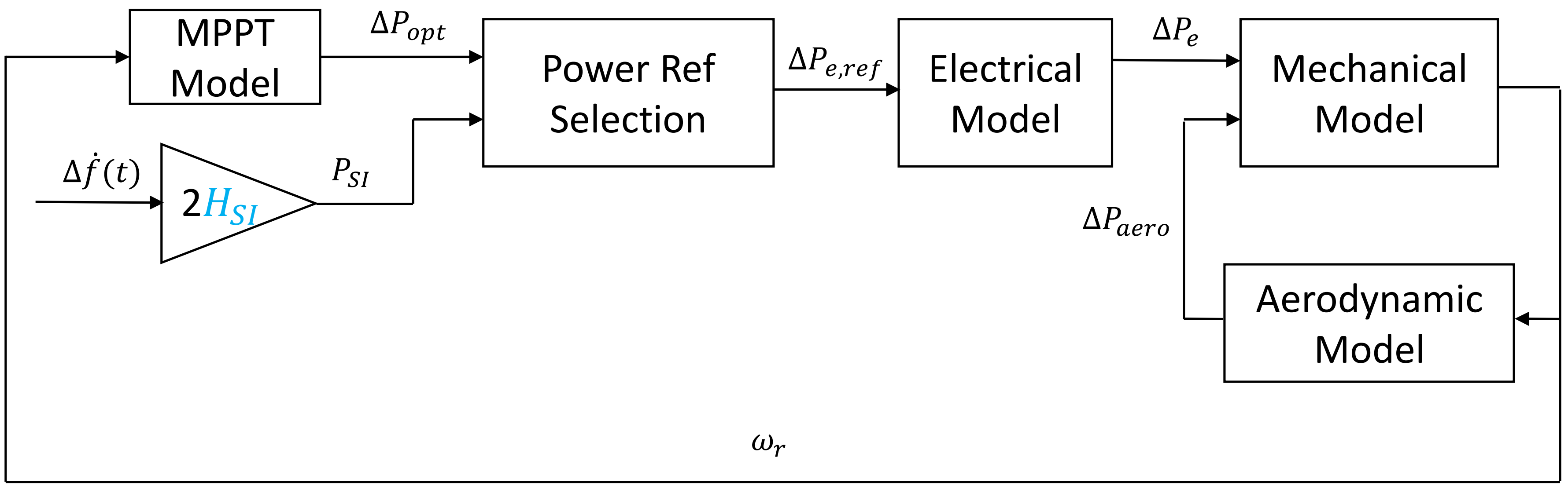

System frequency dynamics:

$$2(H + H_{SI})\Delta \dot{f}(t) = -D\Delta f(t) + R(t) - P_L \qquad , t \in (0, t_1)$$

H: Inertia from synchronous machine
D: load-dependent damping
R(t): primary frequency response ($\frac{R}{T_d}t$)
P_L: system disturbance
t_1: time instant when SI provision stops

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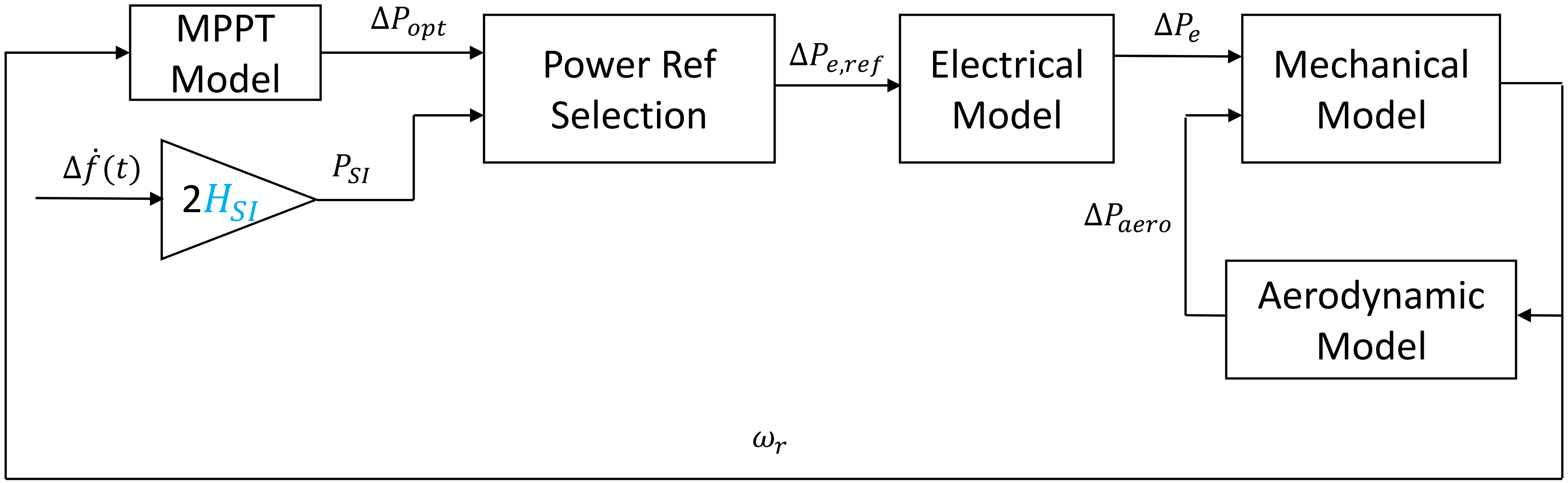

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$\Delta P_{aero}(t_1)$: min loss of generation for recovery

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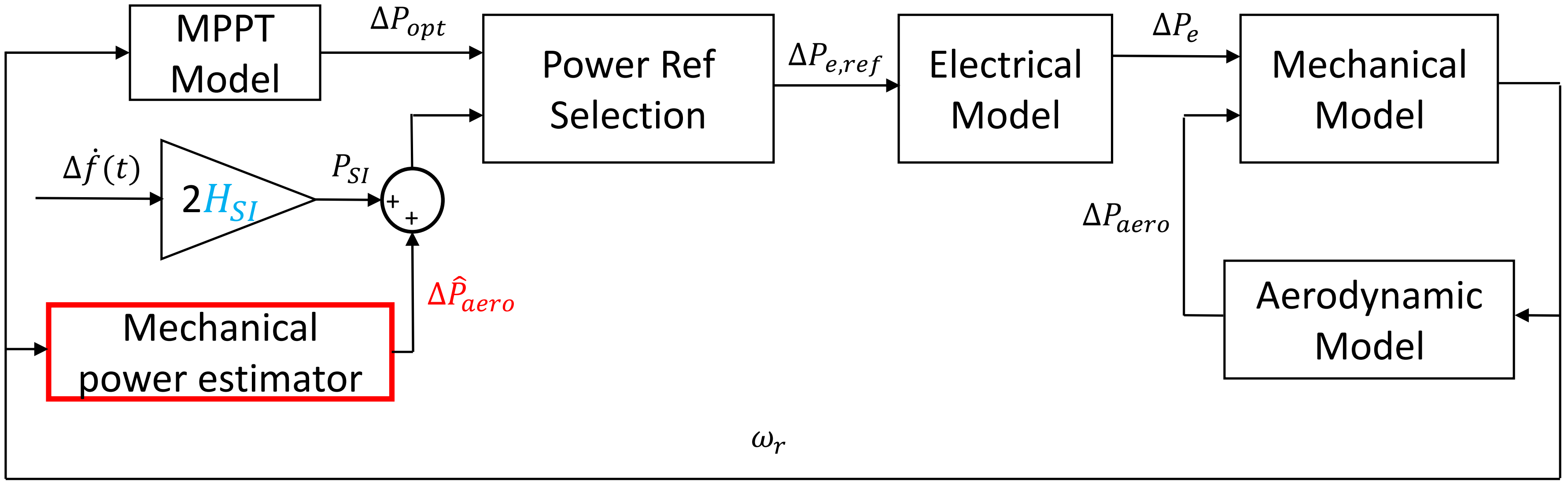

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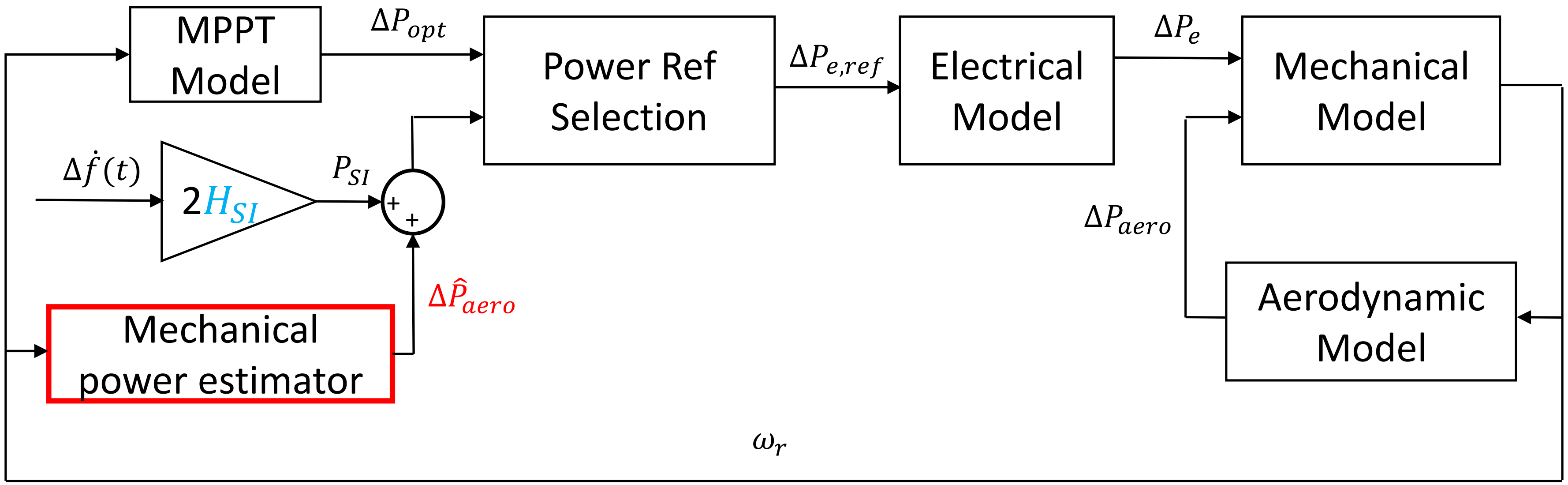

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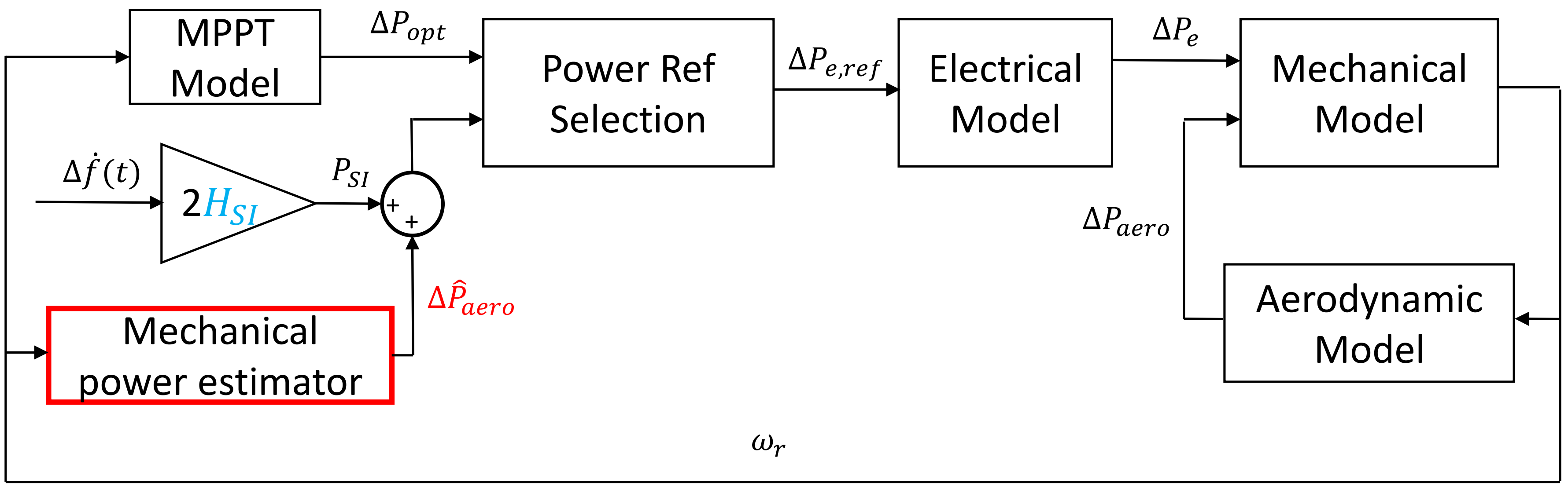

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Aggregated SI Capacity Under Wind Uncertainty

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$$\begin{cases} H_{SI} = H_{SI}(\omega_{r0}) \\ \omega_{r0} = \omega_{r0}(v_w) \end{cases}$$

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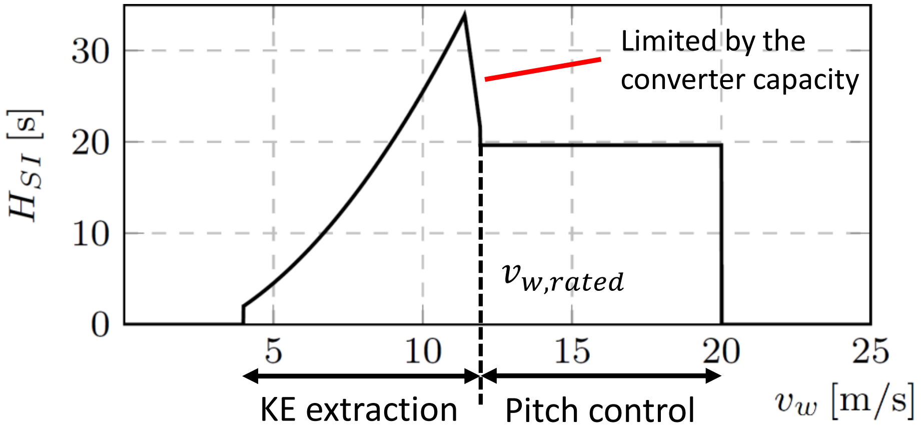

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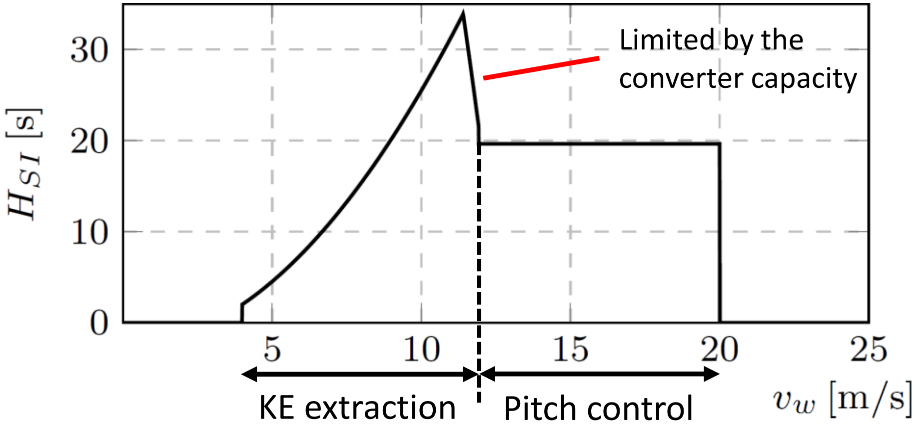
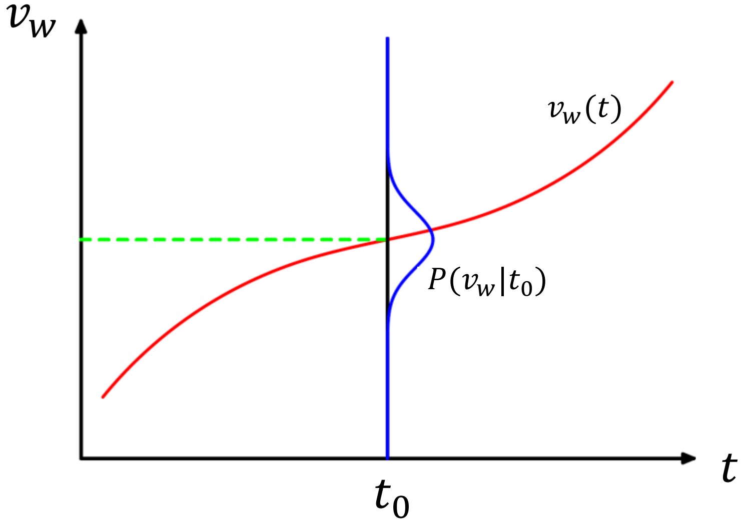


- Wind Speed Forecasting



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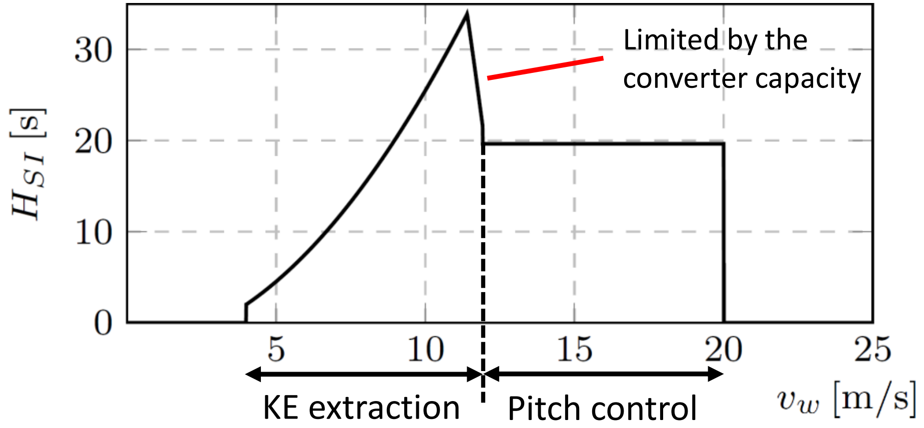

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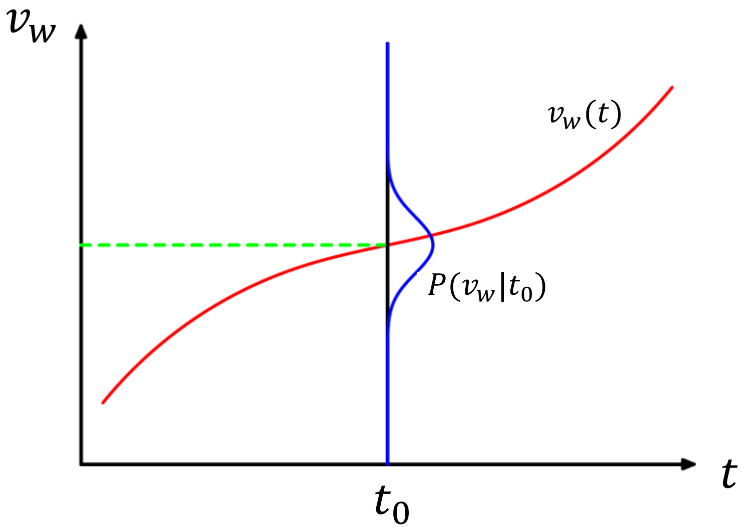
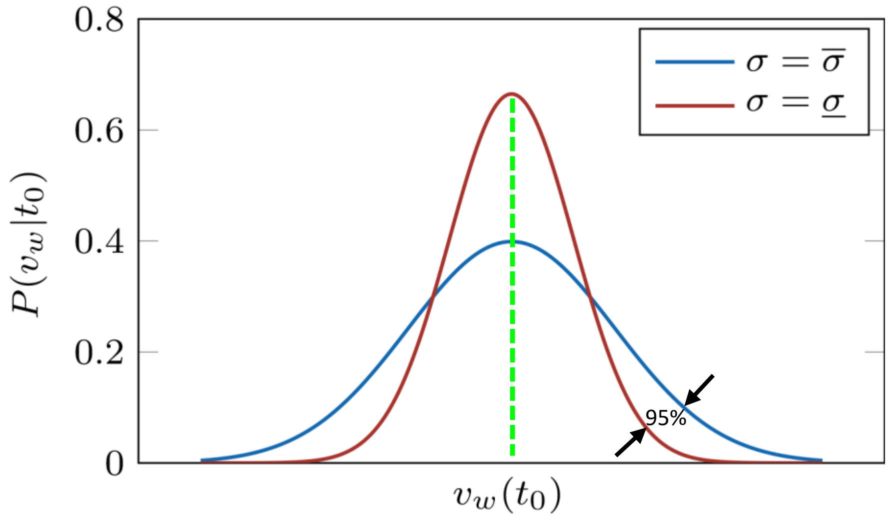


Bayesian Algorithm

$\sigma \backsim N(\sigma_0, \tau)$



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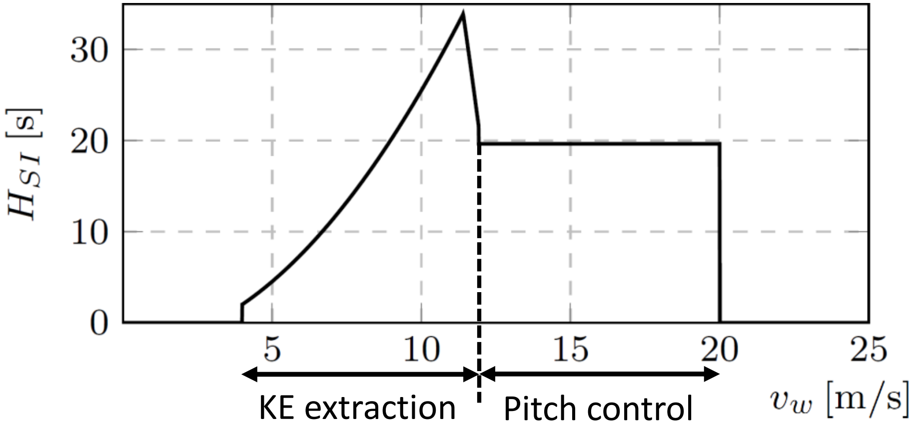

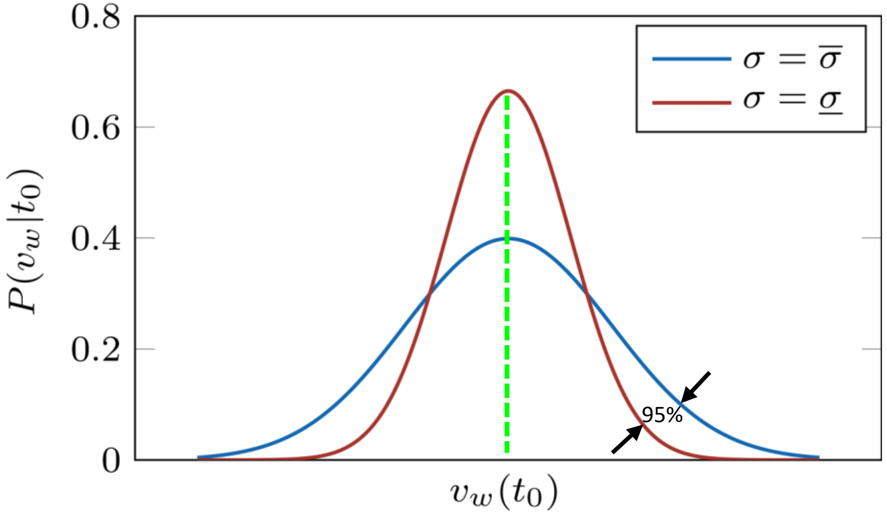

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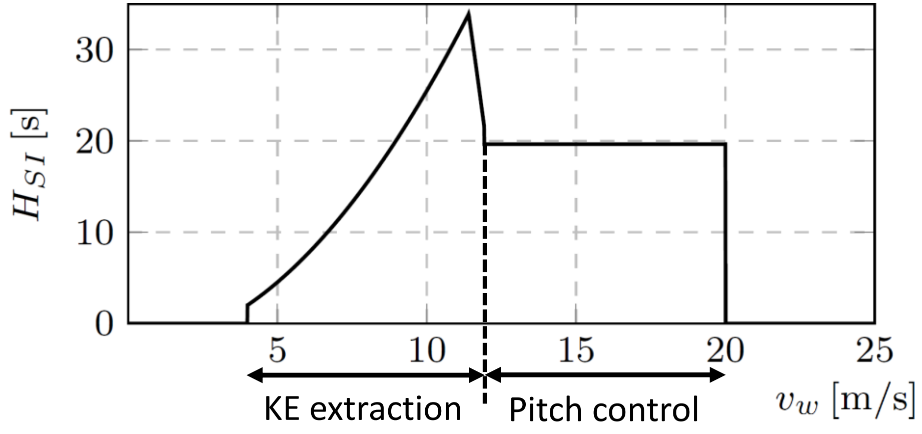

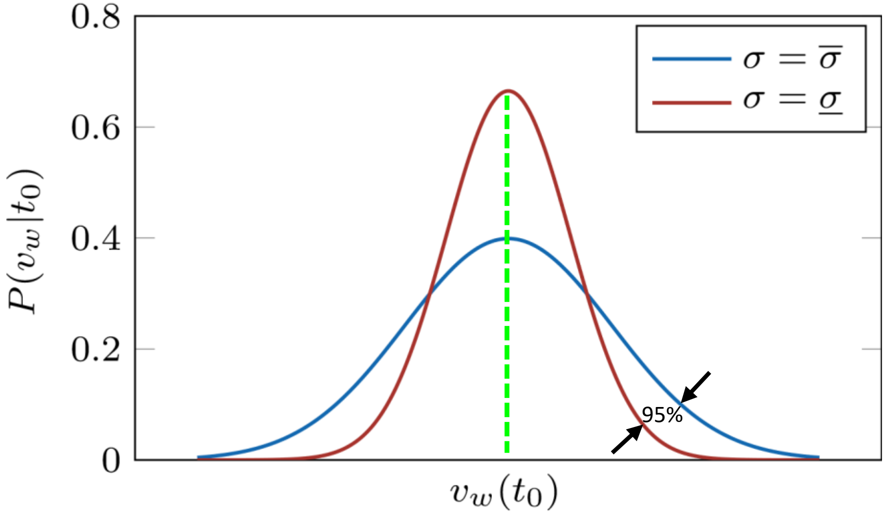

$$H_{SI}(\sigma) = N\int_0^{\infty} H_{SI}(v_w)P(v_w|\sigma)dv_w$$

N: number of total wind turbines

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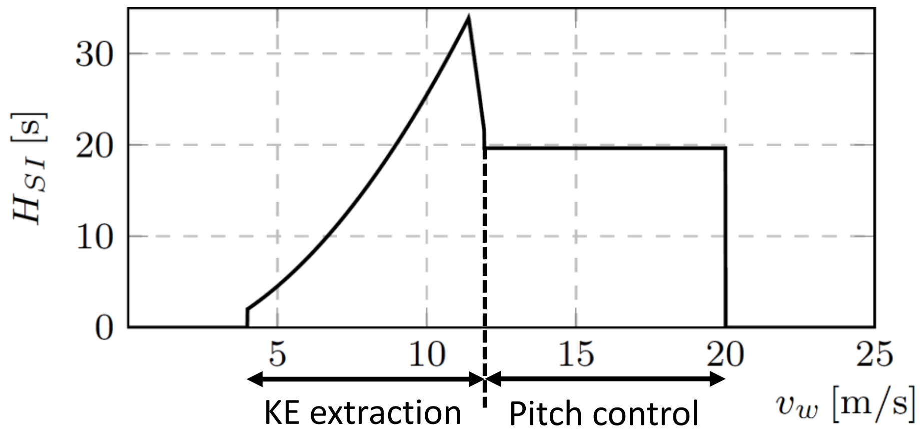

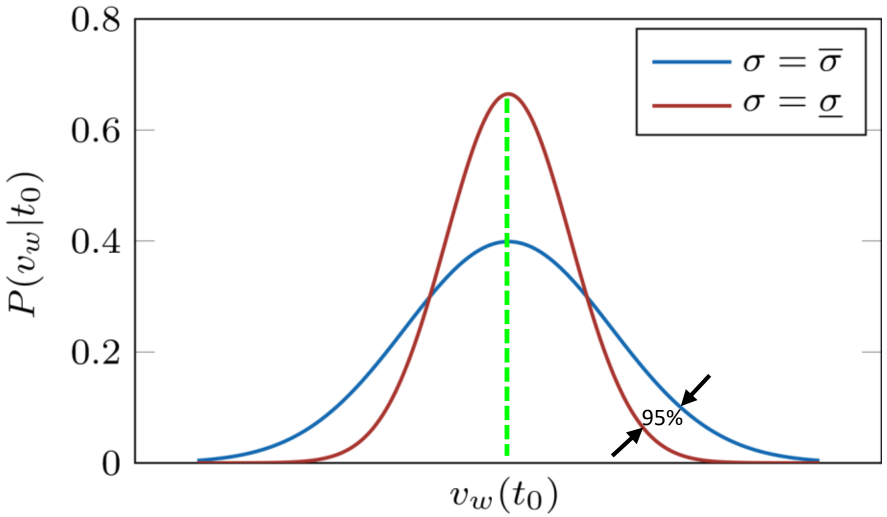

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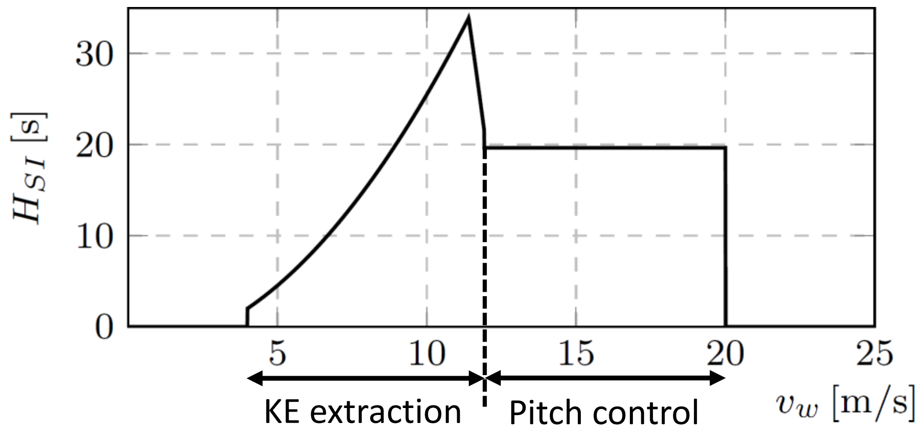

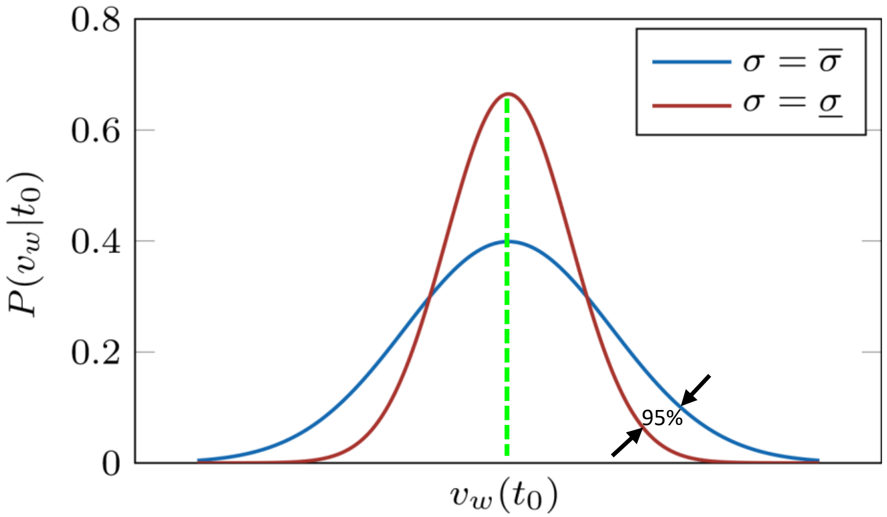

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Choose the aggregated SI capacity, H_{SI}^C
s.t. $P\left(H_{SI} \geq H_{SI}^C\right) \geq 95\%$

System Scheduling

Objective: **min** system operation cost

Constraints:
- frequency constraints
- power balance
- generator constraints
- transmission constraints
- …

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$$\Downarrow \; -\Delta\hat{P}_{aero}(t) \approx D_{SI}\Delta f(t)$$

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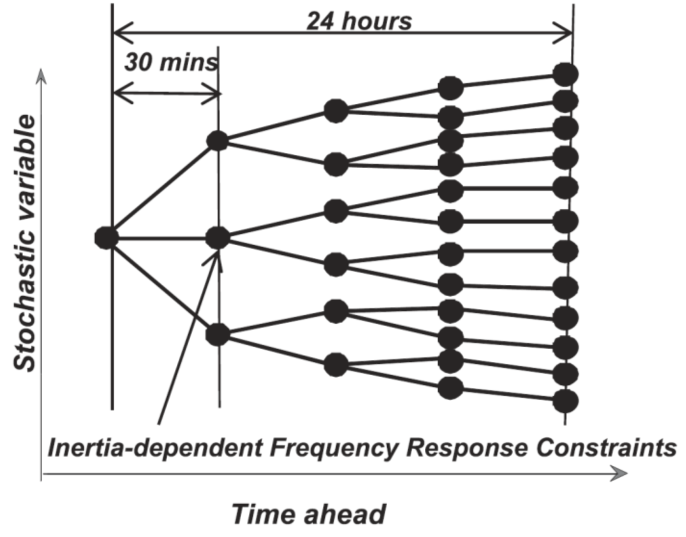
$$|\Delta f_{nadir}| = |\Delta f(H_{SI})| \le \Delta f_m$$

$$H_{SI} \le H_{SI}^{C}$$

System Scheduling



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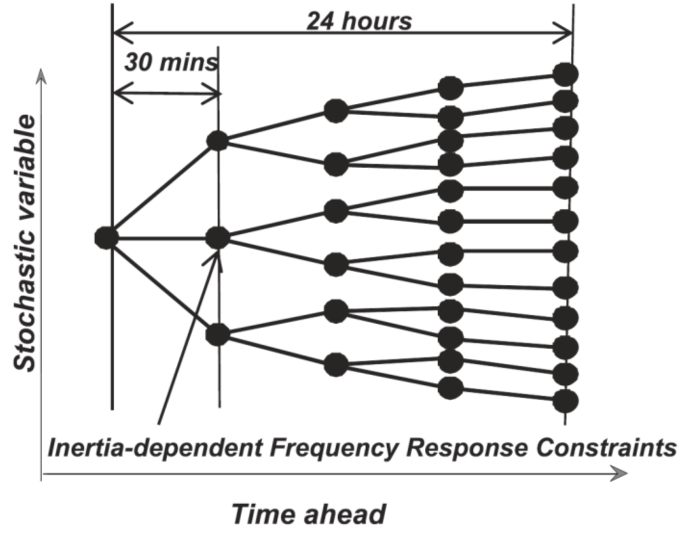

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$\Longrightarrow H_{SI}^{*}$

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Synthetic Inertia Allocation

SI of entire system $H_{SI}^{*} \overset{?}{\longrightarrow}$ SI of individual turbine H_{SI}^{i} with $i \in I$, set of WTs with SI provision

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Real time implementation:

$$\min_{\mathrm{H_{SI}^{i}}} \quad \sum_{i \in I} \alpha_i \cdot \left(\Delta\omega_{r,m}^{i}\right)^2$$

$$\text{s.t.} \quad 0 \leq H_{SI}^{i}(\omega_{r0}) \leq H_{SI}^{i,c}$$

$$\sum_{i \in I} H_{SI}^{i} = H_{SI}^{*}$$

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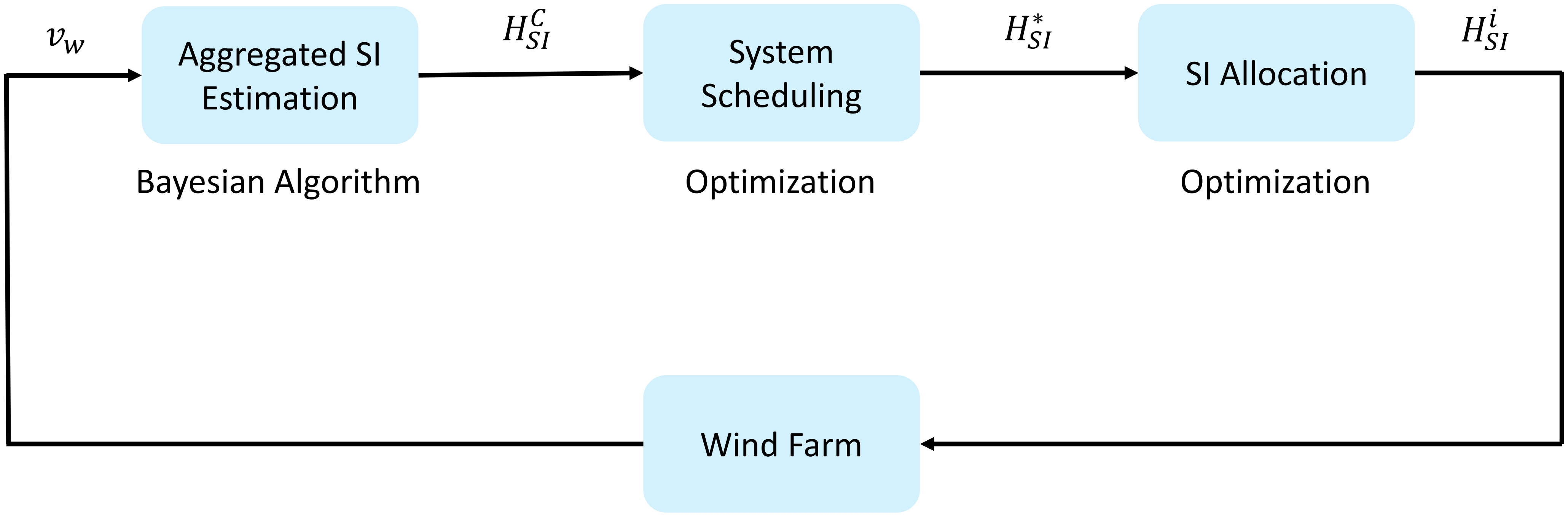
Summary



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Thank you for your attention!