# Online Economic Control of Co-Located Wind Turbine and Battery by Balancing Damage and Generation

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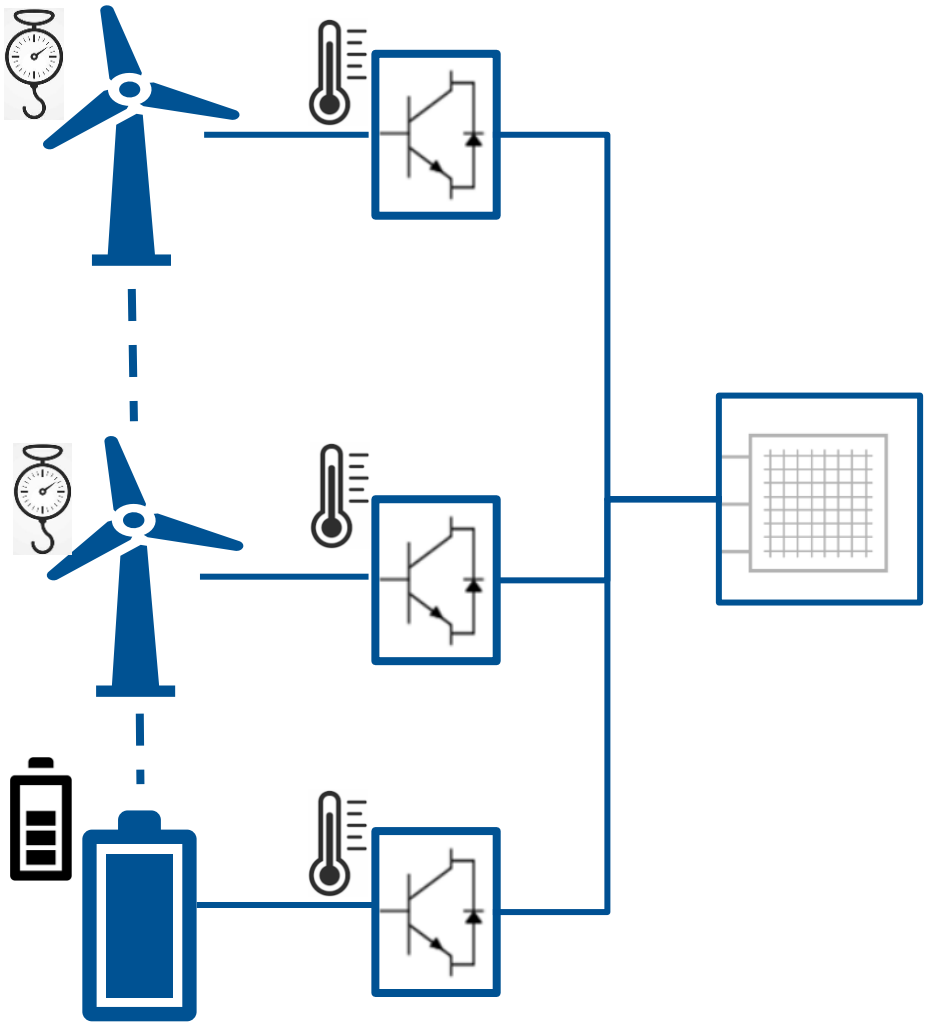
# Motivation: Fatigue estimation and control

**Fatigue is a crucial cost factors for economic operation of Hybrid power plant**

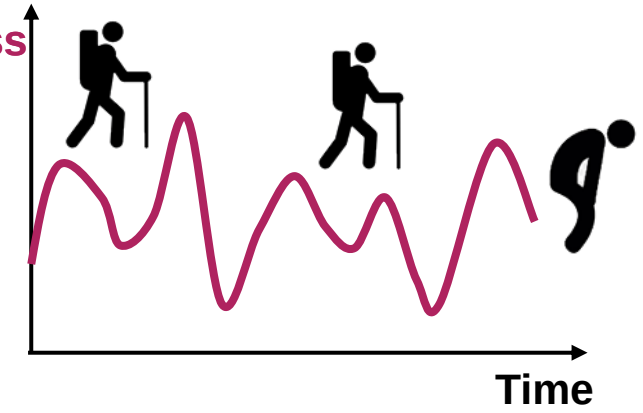


Fatigue refers to the damage due to cyclic application of **stress**:

**Mechanical stress**

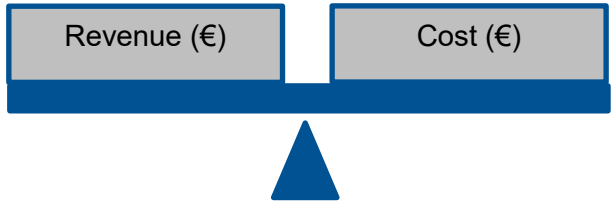
**State of charge**

**Temperature**




**Economic operation** of hybrid power plant may leads to:

- Reduction of fatigue → Extension of lifetime
- Lower LCOE values
- Higher generator profit



1. Motivation

2. Online estimation of fatigue

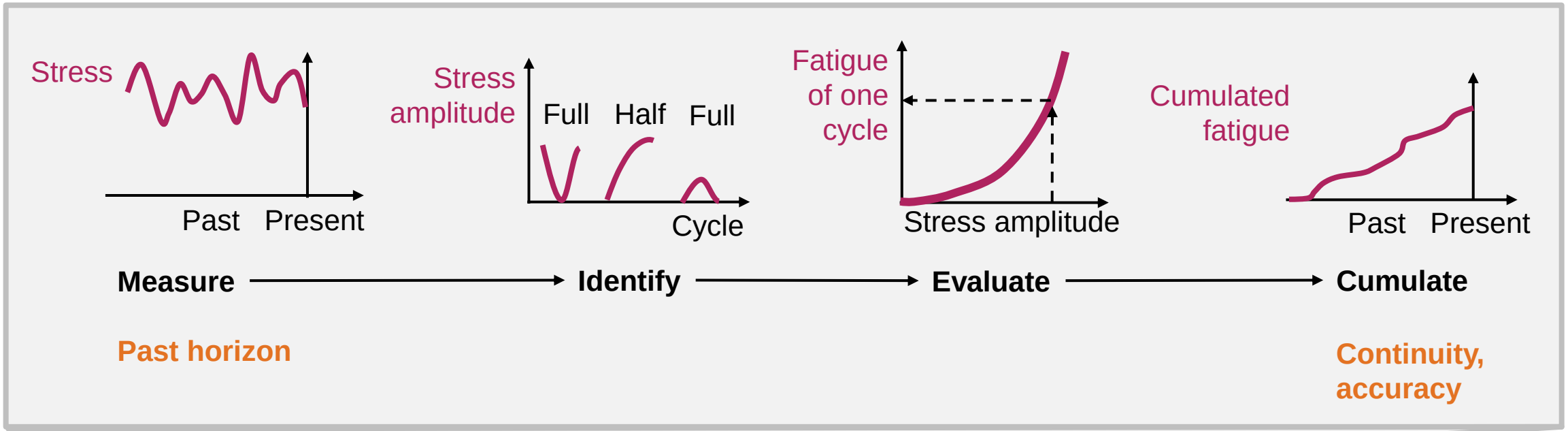
3. Model predictive control of fatigue

4. Application: WT & Battery based hybrid plant

5. Conclusion & Outlook

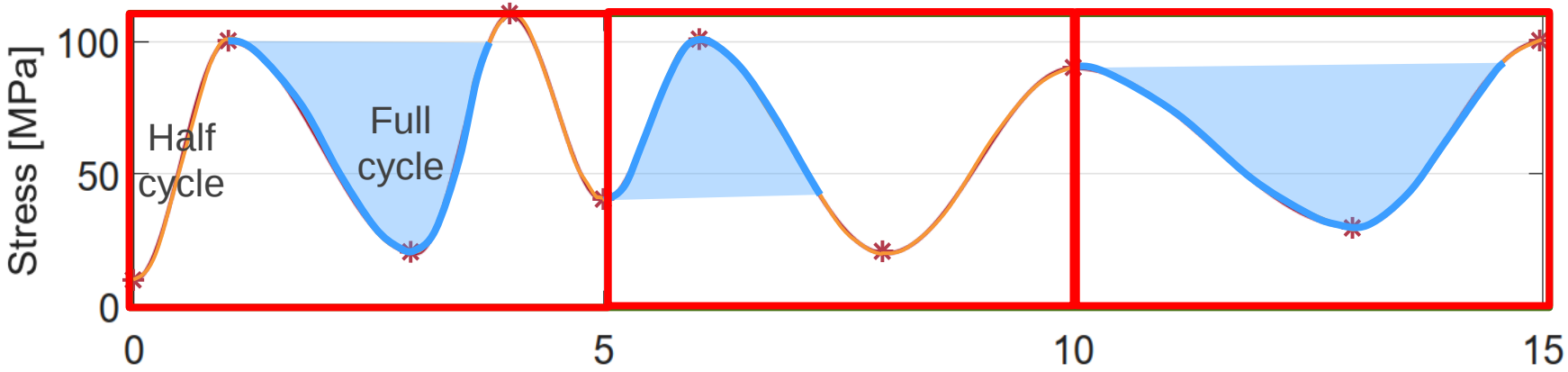
# Online estimation of fatigue

## Simplified schematic and challenges



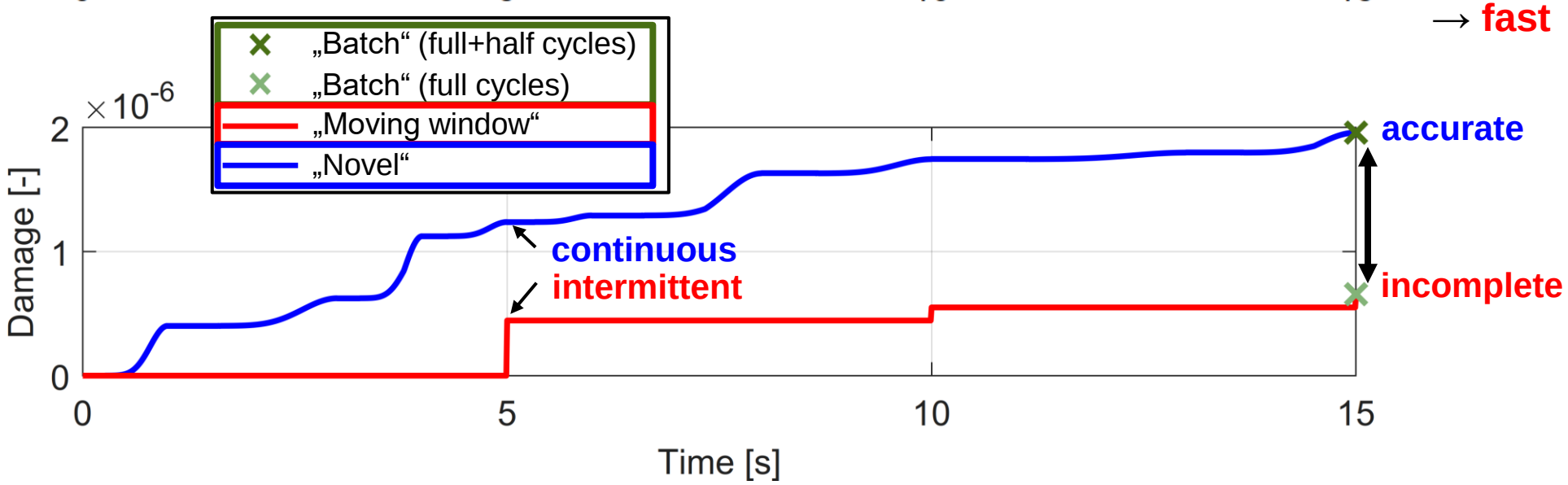

# Online estimation of fatigue

**Past horizon, continuity, accuracy – Condensed memory enables fast & accurate fatigue estimation**




**Memory:**

- **All** past extrema *
  → **computationally heavy**
- **Condensed set** of past extrema *
  → **fast** **fast**



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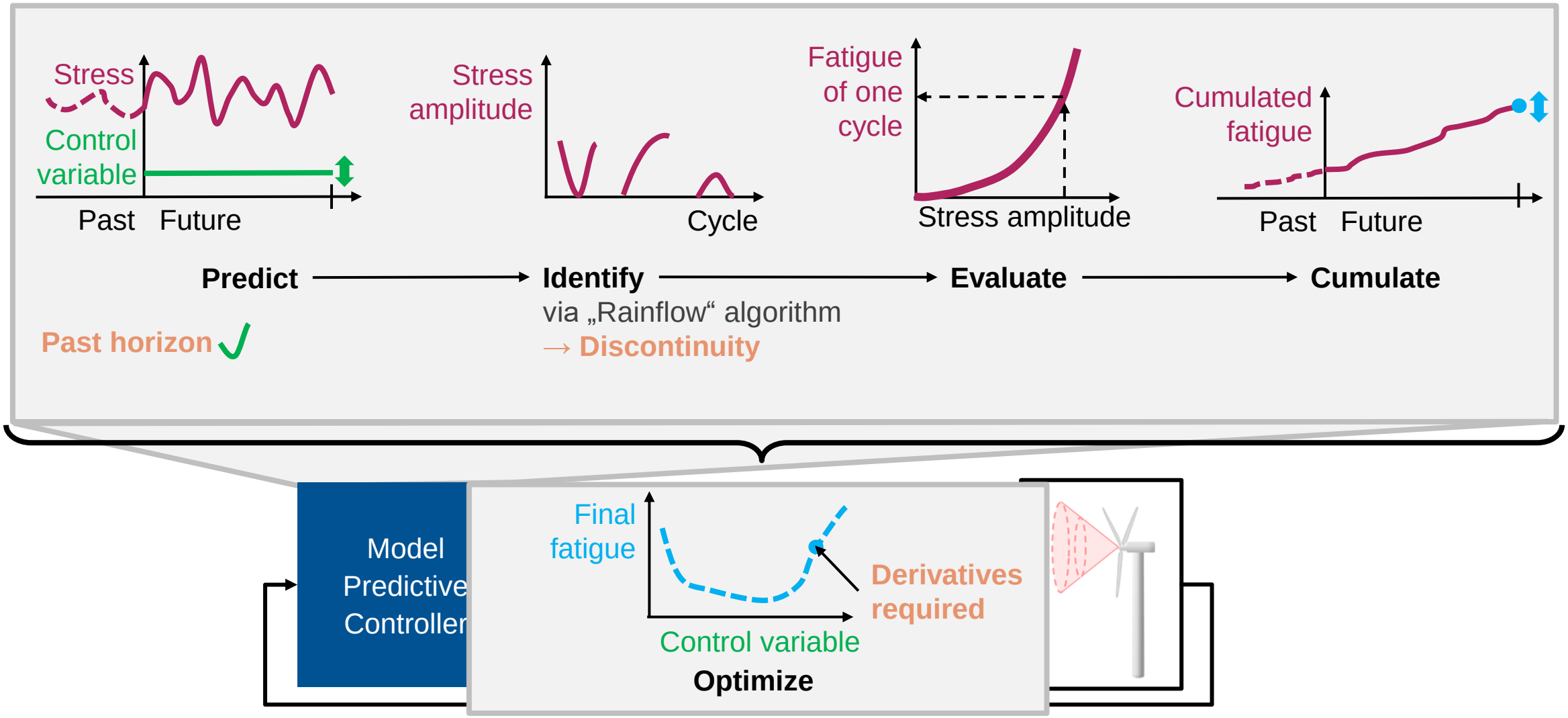
# Model Predictive Control of fatigue

## Simplified schematic & challenges

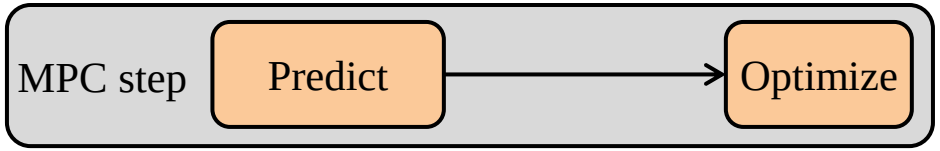


# Model Predictive Control of Fatigue

**Discontinuity – Fix discontinuous decisions and only optimize continuous variables**

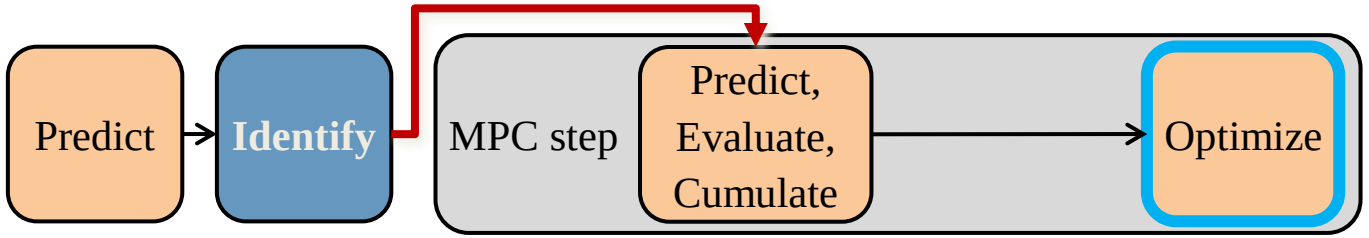
## Standard MPC

**Limitation:** Prediction by **continuous** model

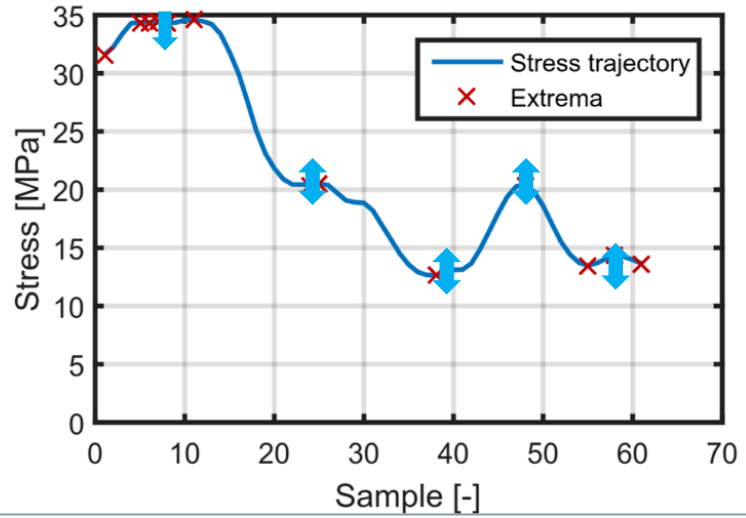



## Externalization from MPC

**Key:** Time-varying **parameters**

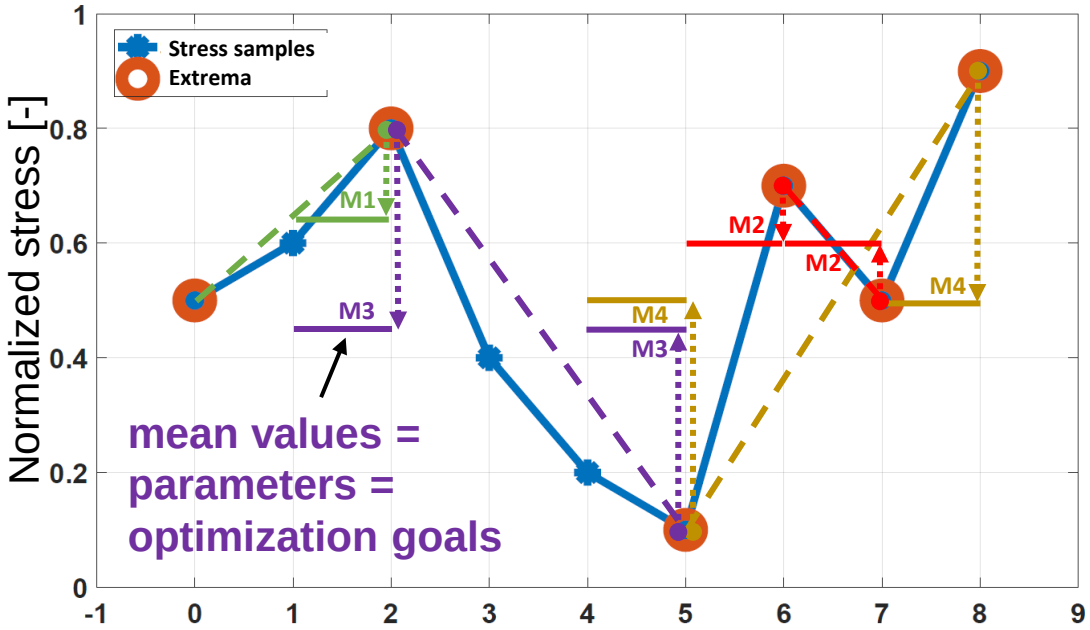


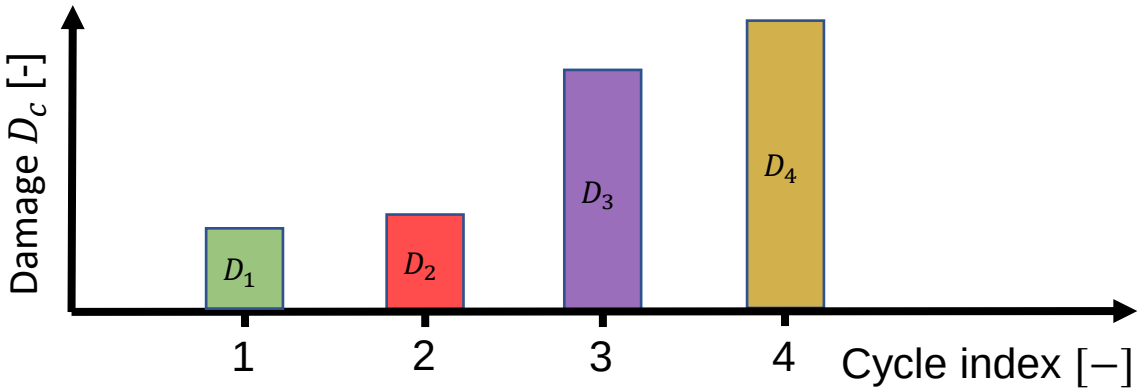

- Fixed **cycle** pattern → **time-varying parameters**
- **Continuous optimization** of variable **stress values**



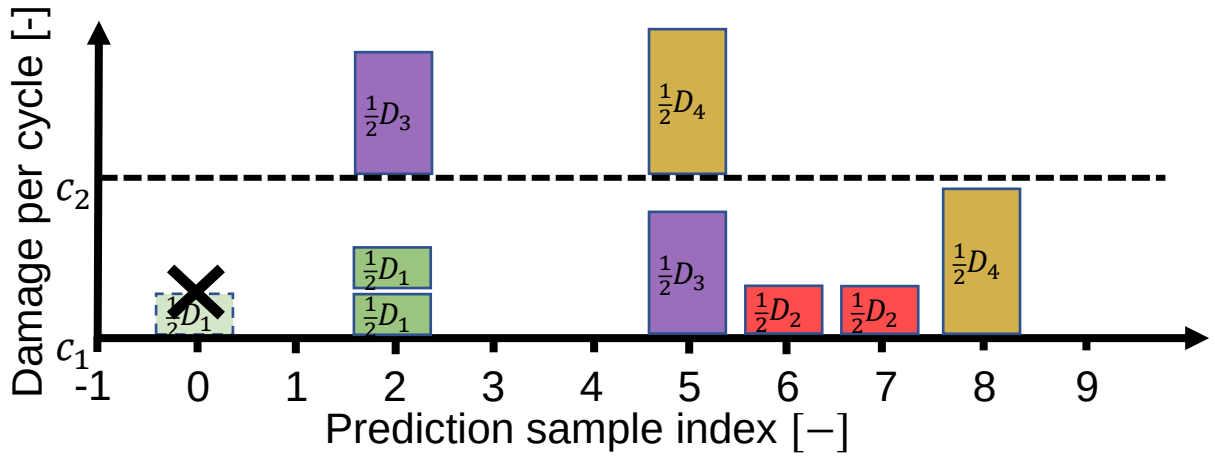
# Model Predictive Control of Fatigue

## Externalization – Split damage of each cycle & distribute over time




heuristics: split & distribute



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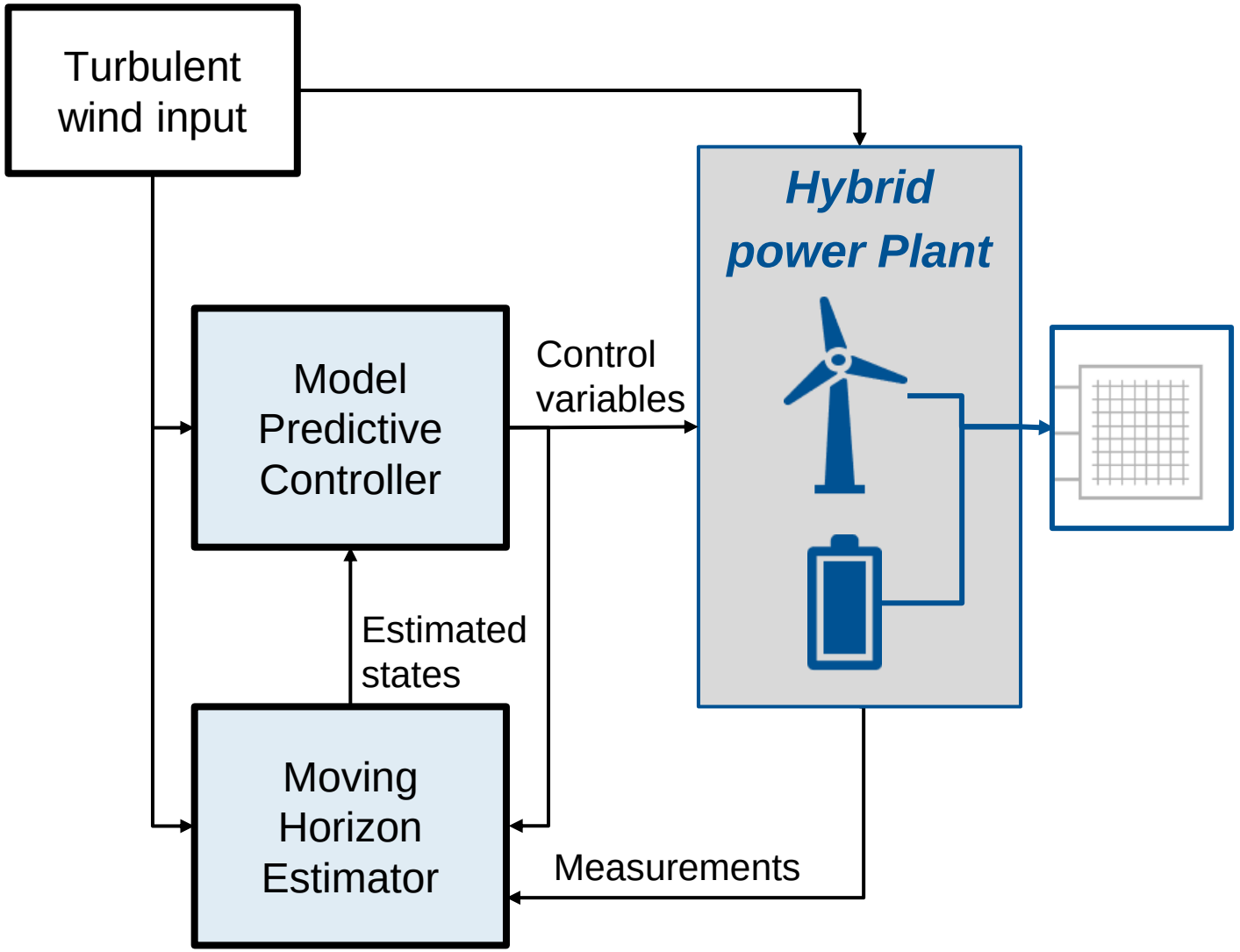
# Application

## Closed loop control of Wind and Battery based Hybrid generation system




### Controller hybrid power plant model

**Plant model**:

- NREL 5MW High fidelity OpenFAST WT
- 1MW/1MWh Li-ion integrated battery

**Controller internal model**:

- Reduced order model with 10 states ($x$) and 3 control variables ($u$)

**External inputs**

- Wind speed (DLC1.2 turbulent wind)
- Power demand signal

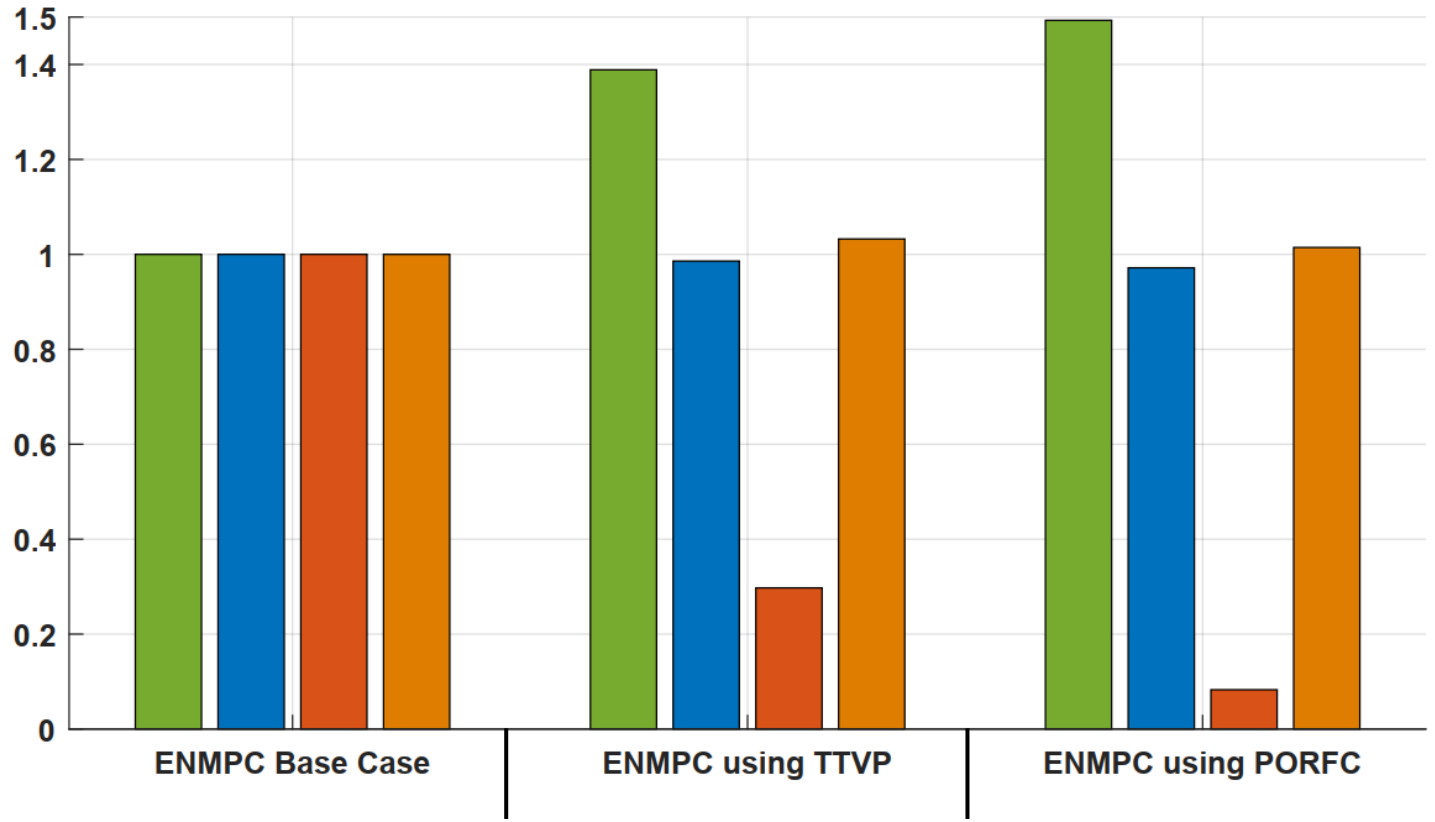
### Control objective

$$\min_{u} \; \begin{matrix} -\text{Revenue\_Hybrid}(x) + \\ \text{Fatigue}_{\text{Tower}}(x) \;\; + \text{Fatigue}_{Battery}(x) \end{matrix} \quad [€]$$

# Application

**Novel MPC results in 5% more profit than power maximization base case and 1.5% higher profit than standard economic controller**

€ **Profit = Revenue – Tower fatigue cost – Battery fatigue cost**



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# Conclusion & Future work

## Summary

- Economic optimal control is imperative for wind based hybrid generation system
- Using formulated novel approach, cyclic damage can be evaluated and minimized online directly inside the optimization step without approximations
- The formulated MPC controller performs economically better than a realistic base-case MPC controller
- All closed loop controller formulations manage to track a realistic power reference and satisfy input and state constraints

## Outlook

- Extension to a complex system with a holistic economic optimization objective
- Numerical setup of optimization approach to improve performance
- Considering energy markets and grid simulations

# Thank you very much!

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