Predictive maintenance for wind-hydrogen plant using diagnostics and prognostics of PEM electrolysers

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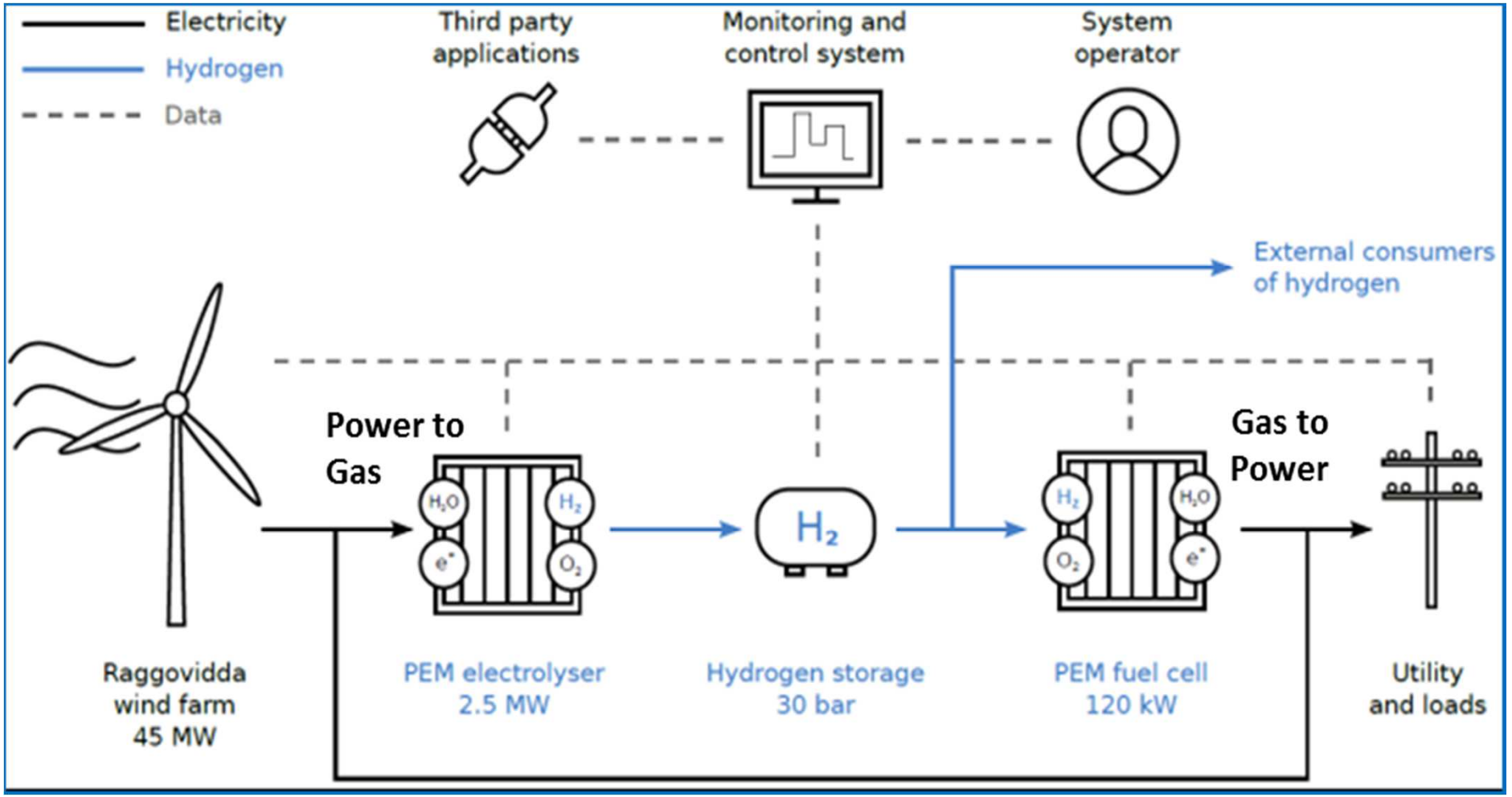
Haeolus Project

Integrate a fully functioning 2.5 MW electrolyser in a 45 MW wind farm

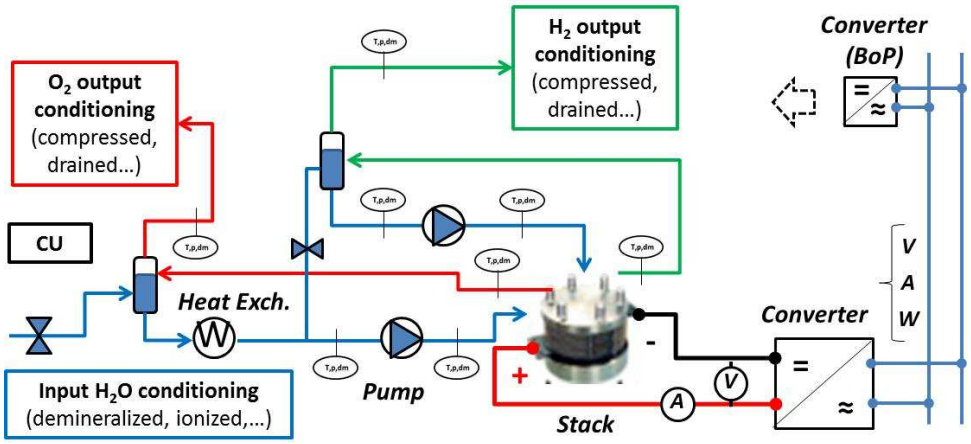


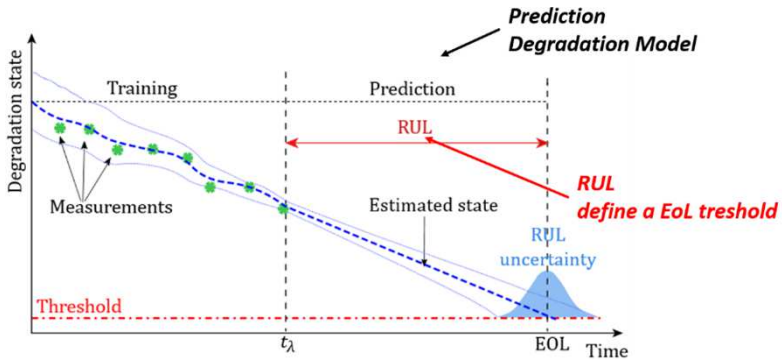
http://www.haeolus.eu/

Objectives

Enable remote system operation with anticipative maintenance

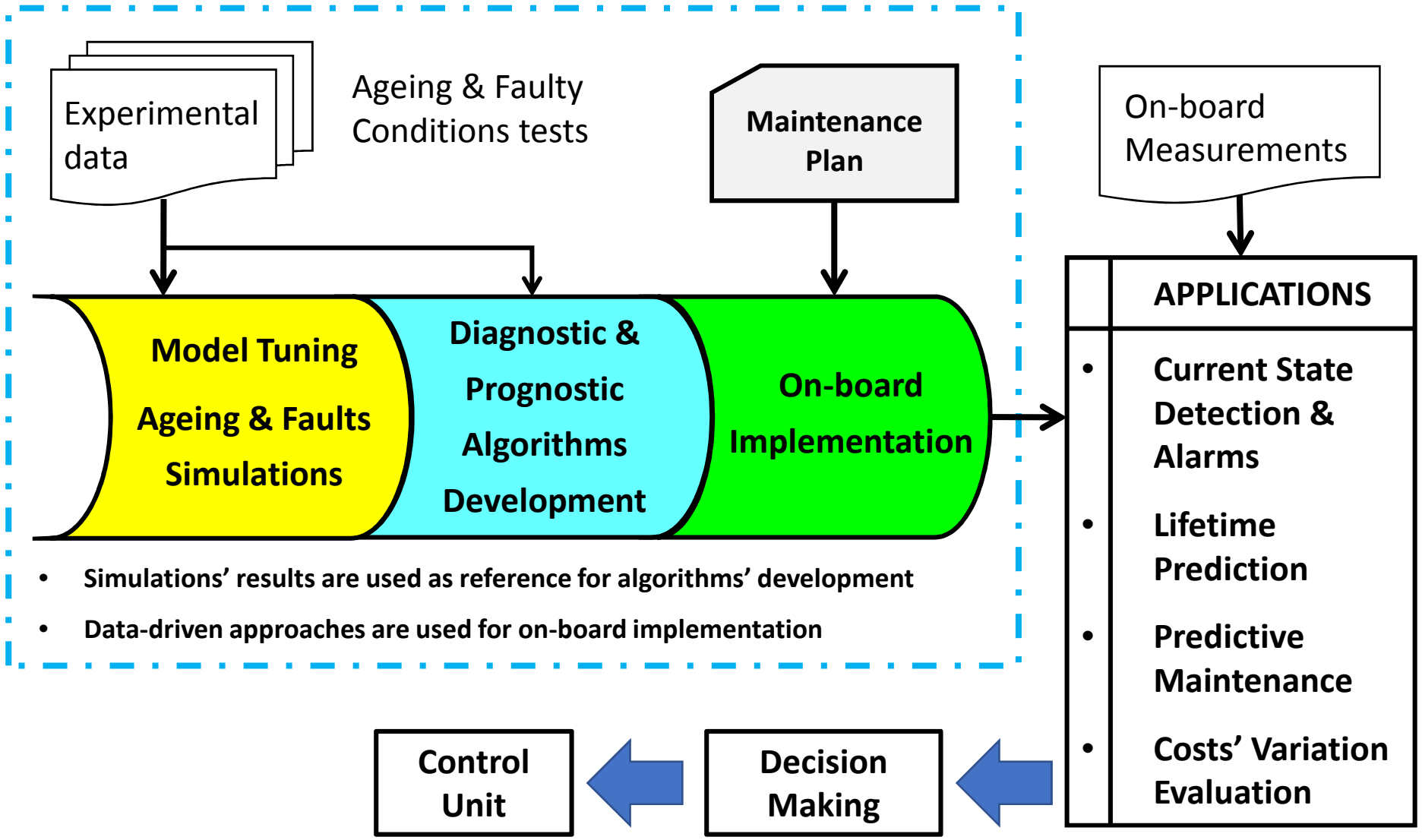
1. Assess the current state of critical components → **Diagnostics**
2. Anticipate maintenance requirements → **Prognostics**
3. Feed the controller with these inputs



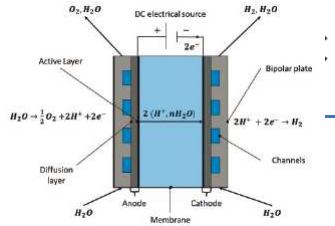


Maintenance Plan

The approach



PEM Electrolyzer Simulator

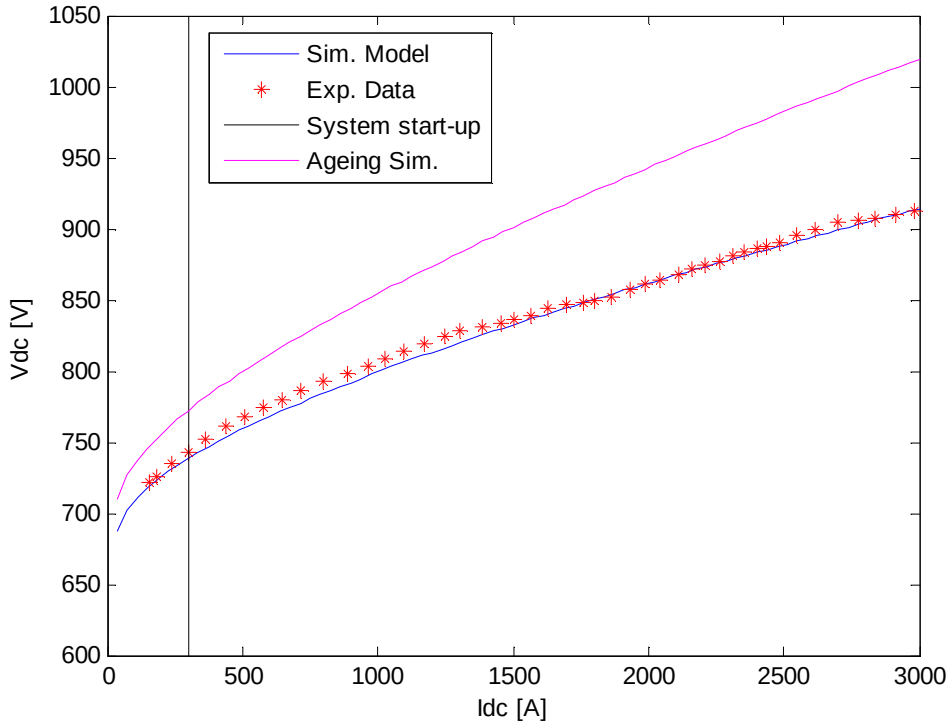


- Physical Model adapted for PEM EL stack ageing simulation
- BoP is also considered

Operating variables

- **Current**
  - **Current density**
  - **Area**
- **Anode Pressure**
- **Cathode Pressure**
- **Temperature**

Stack Overpotential

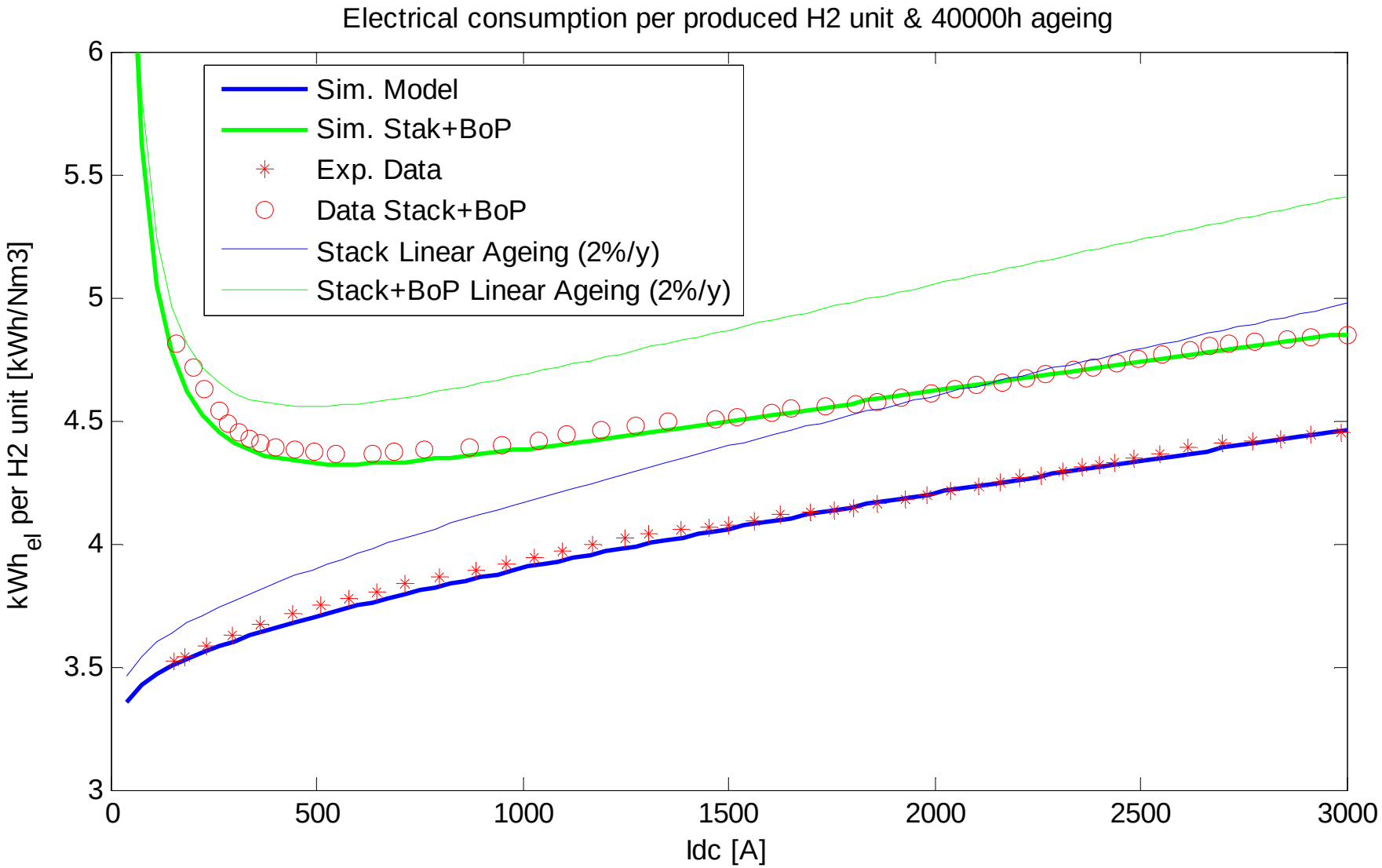


Cell Voltage *:

$$V_{Cell}(I, p_i, T, t) = V_{OCV}(p_i, T) + k_1(t) * V_{Act}(I, T) + k_2(t) * V_{\Omega}(I) + V_{Diff}(I, p_i, T)$$

k_i: ageing factors ; t : operational time

Simulation Results



Diagnostic Algorithms' Solutions

… for on-board applications

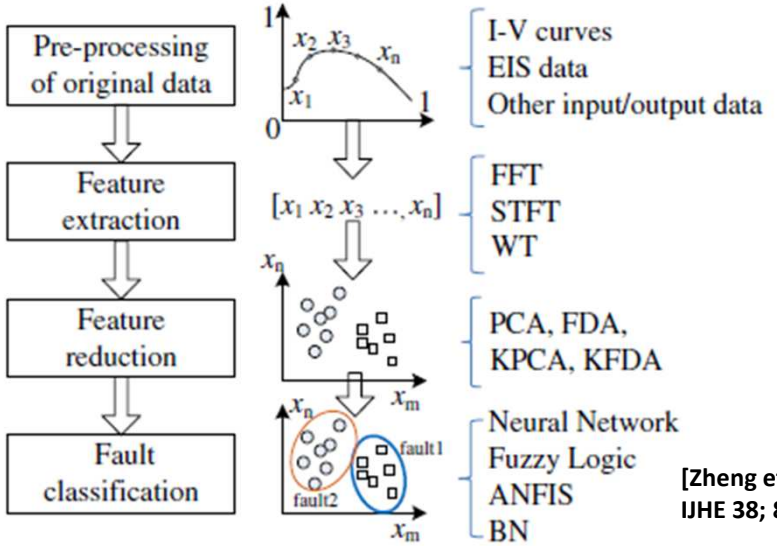
Sliding Windows

System Monitoring & Incipient Fault occurrence detection

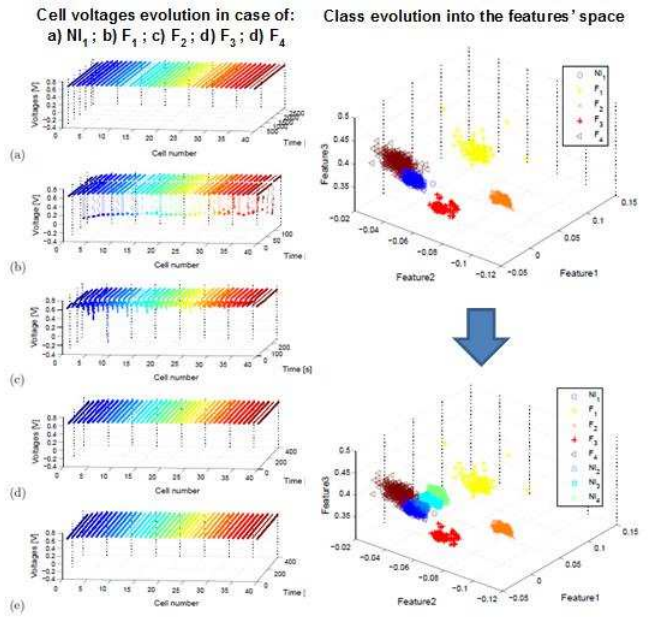
Fault Classification

Timeline (scale) **[s]**

DATA-DRIVEN

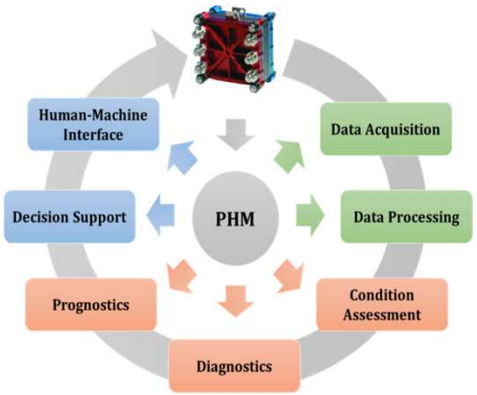


[Zheng et al. (2013) IJHE 38; 8914-26]



[LI et al. (2015) Industrial Electronics, IEEE transaction 62(8); 5164-74]

Prognostic Algorithms' Solutions



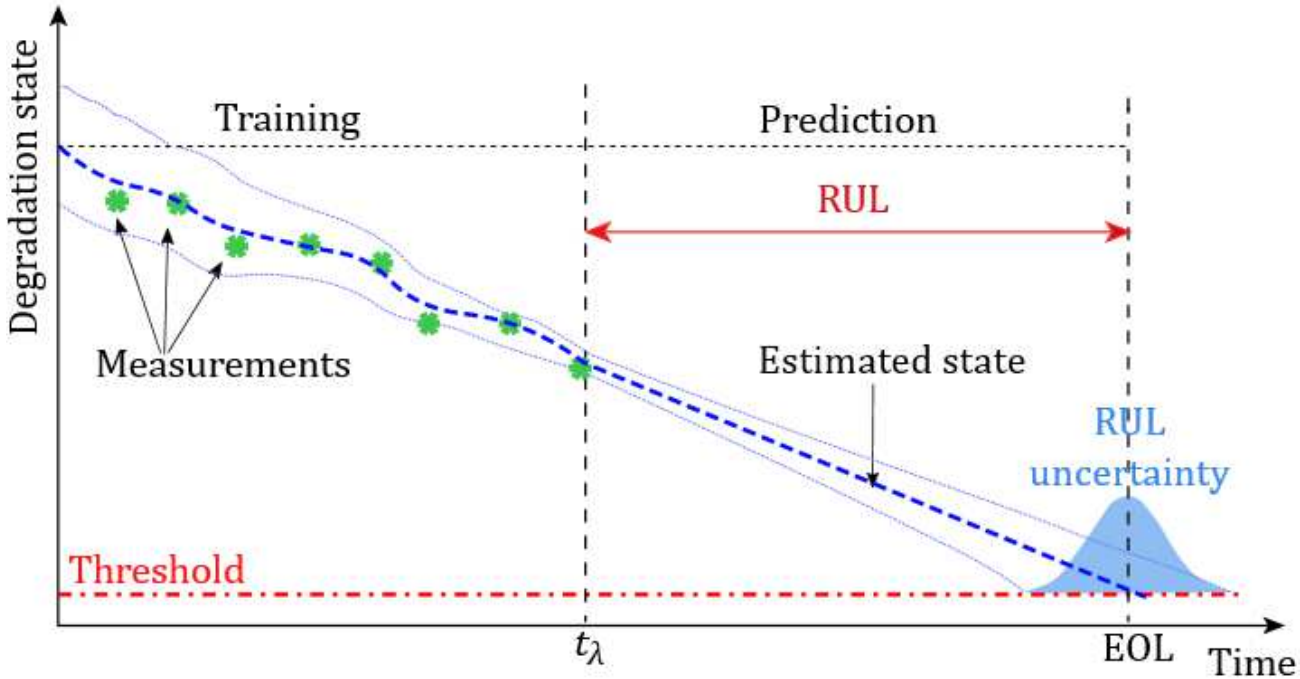
… for on-board applications

System State of Health & performance degradation (ageing)

Remaining Useful Life (RUL) prediction *Timeline (scale)* **[h]**

Data-based Approach

- ***Filters:*** *Kalman Filter, Particle Filter…*
- ***Deep learning:*** *Neural Network (NN)*
- ***Hybrid solutions:*** *Adaptive Neuro-Fuzzy Inference Systems (ANFIS)*



Performance Indicators

Available measurable variables able to characterize the system performance variations

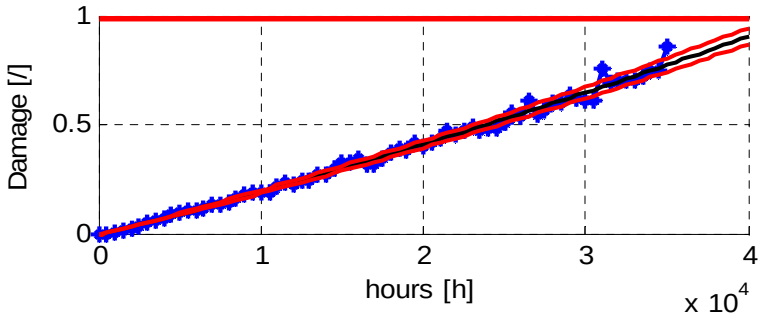
- Performance factor for PEM EL: ***Measured Stack Voltage***
- Limitations:
  - **Max Stack *Voltage*** = ***1kV***
  - ***Max System Power*** = ***3MW***

Defining

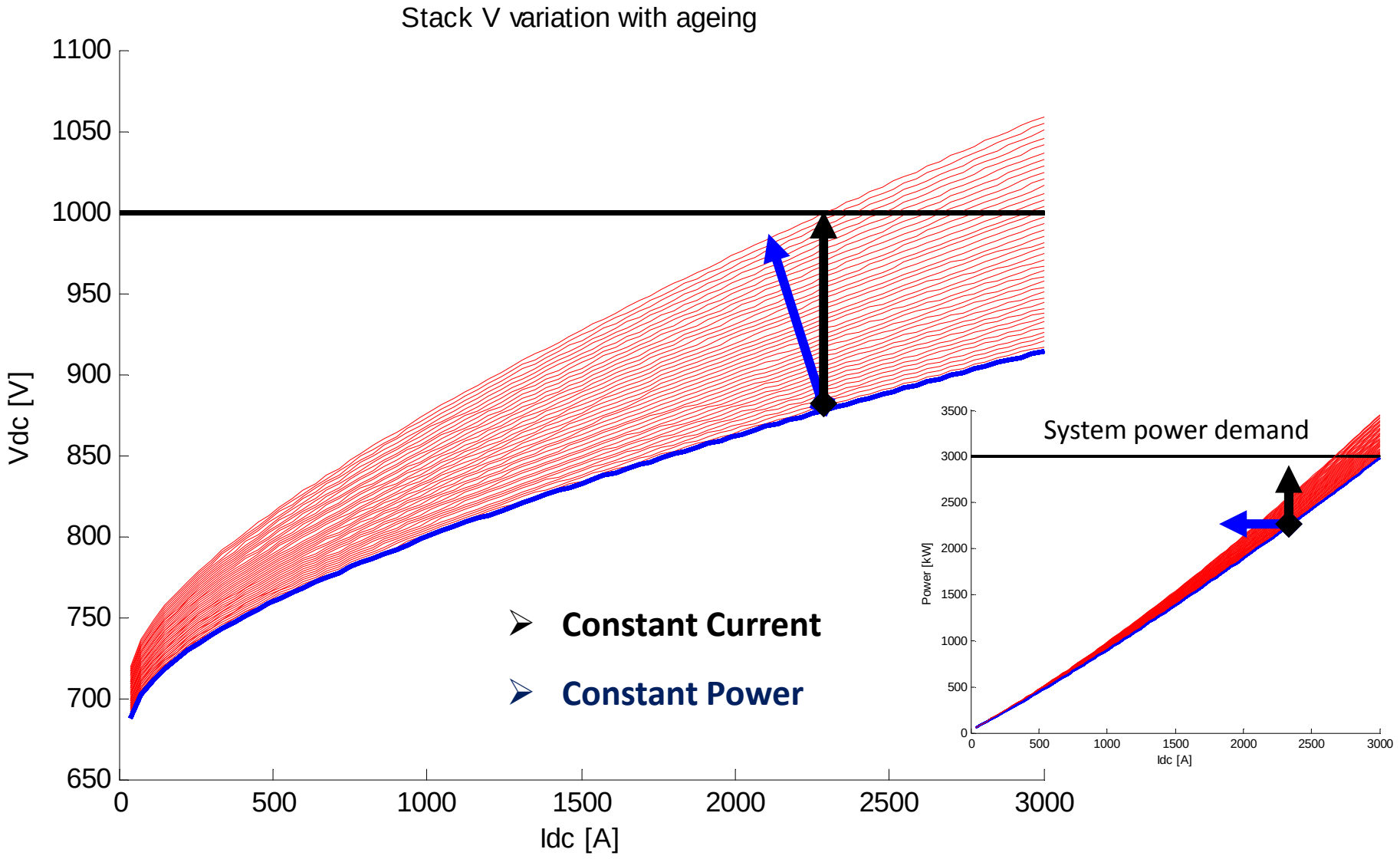
- V^N : Stack Voltage at nominal operations at the BoL
- V^C : Stack Voltage at critical operations (EoL) => **V = 1kV || Pw = 3MW**

- **Damage function**: $D(t) = \frac{V^N - V(t)}{V^N - V^c}$

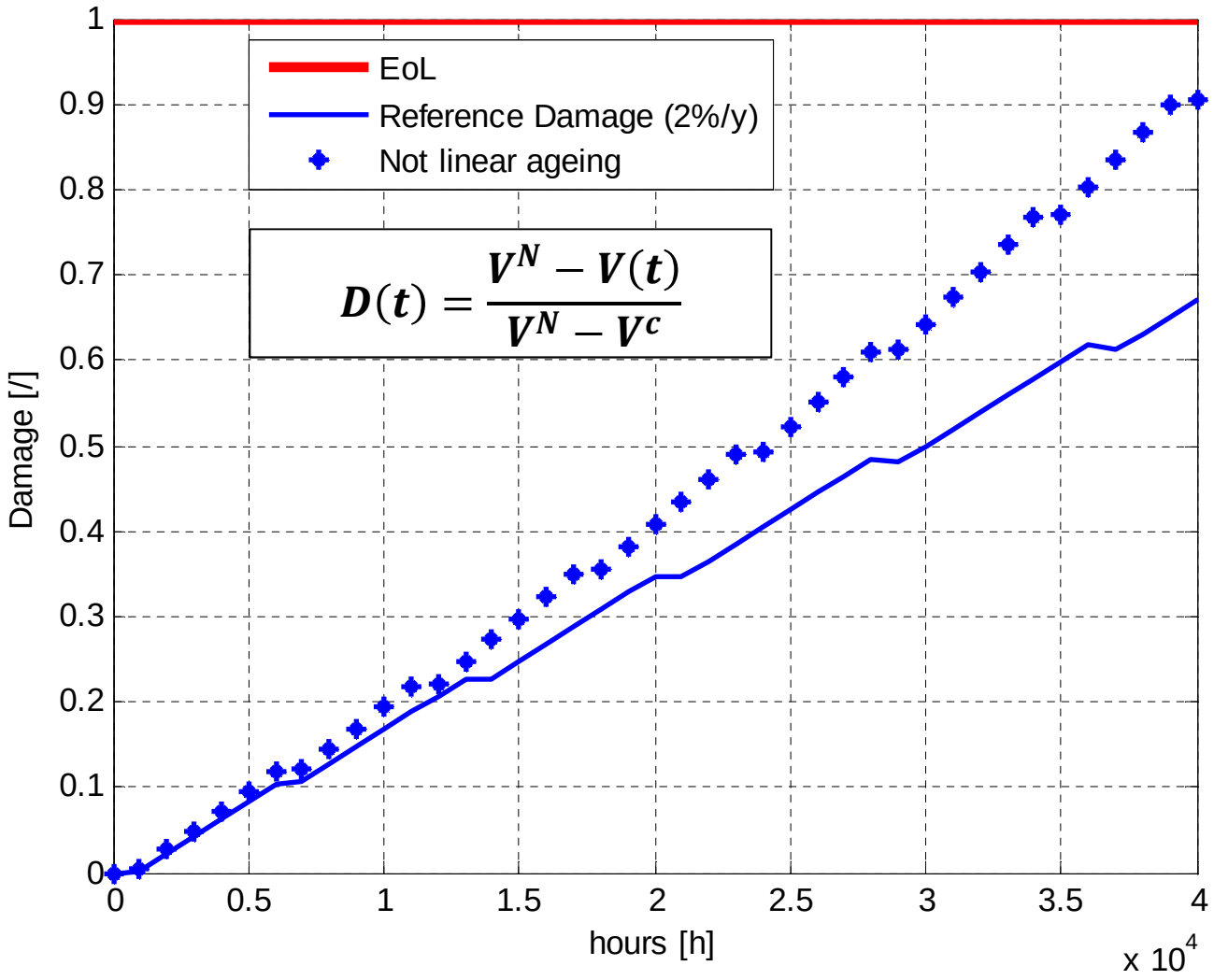
$$D(t_{BoL} = 0) = 0 \;\; ; \;\; D(t_{EoL}) = 1$$



Ageing impact in system operations



Off-line Damage Evaluation



Reference Damage

Reference linear ageing

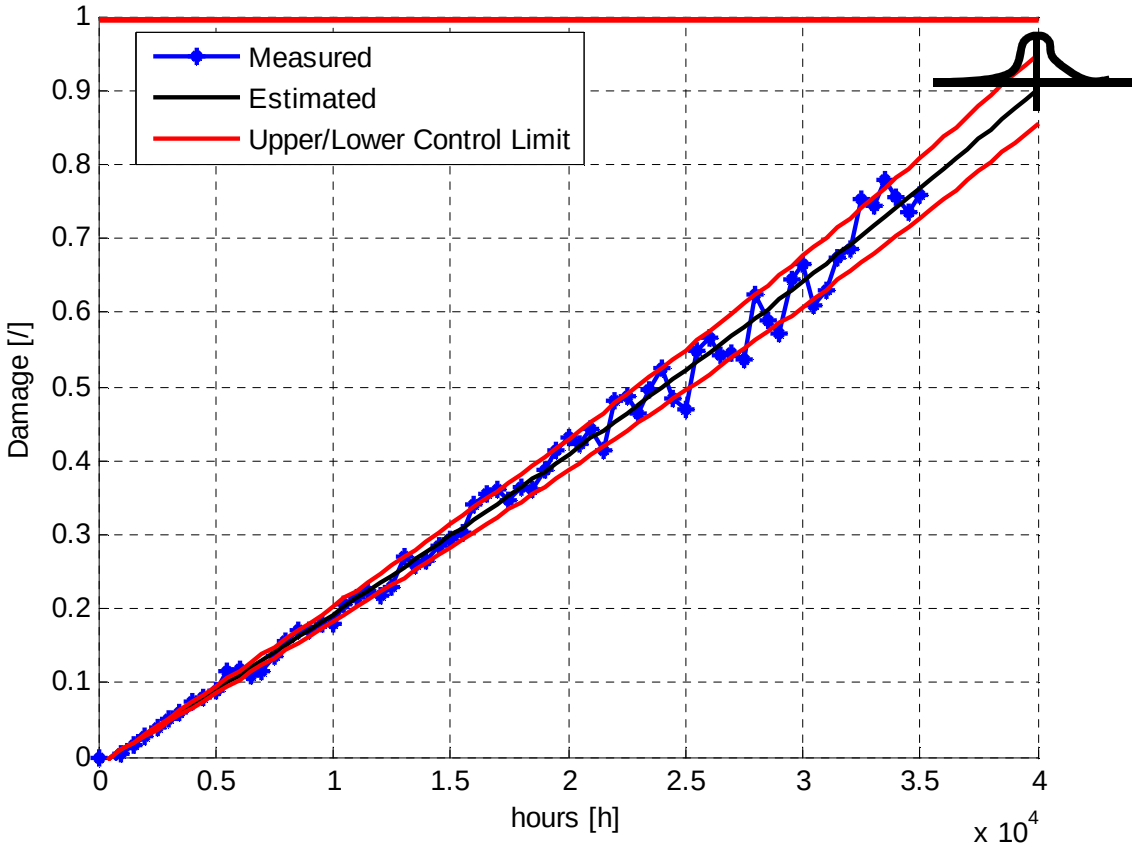
(2% / year)

Not Linear Ageing

(Real ageing)

Currently simulated will be replaced with the on-board measurements

On-board implementation

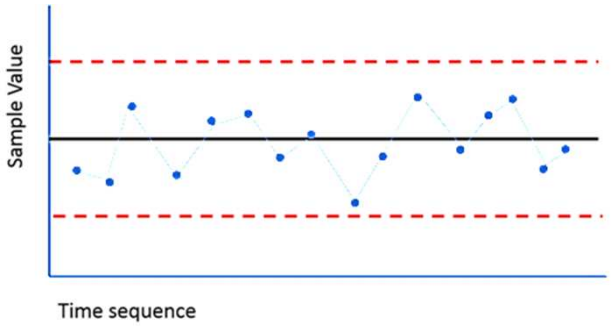


Control Chart (Shewhart chart)

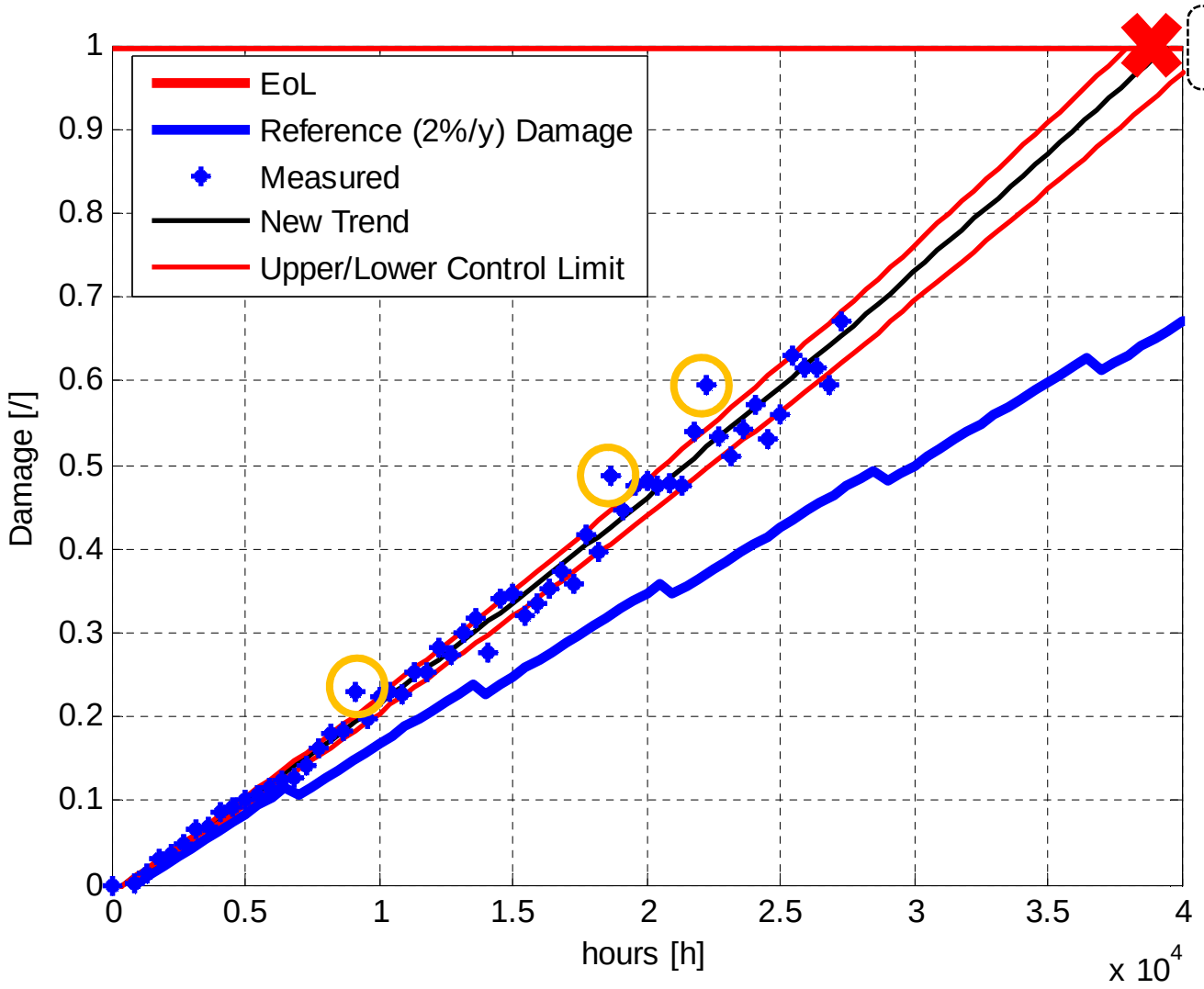
for alarms' generation

Data fitting & statistical inference

- ***Filters:*** *Kalman, Particle Filters*
- ***Deep learning:*** *Neural Network (NN)*
- ***Hybrid solutions:*** *Adaptive Neuro-Fuzzy Inference Systems (ANFIS)*

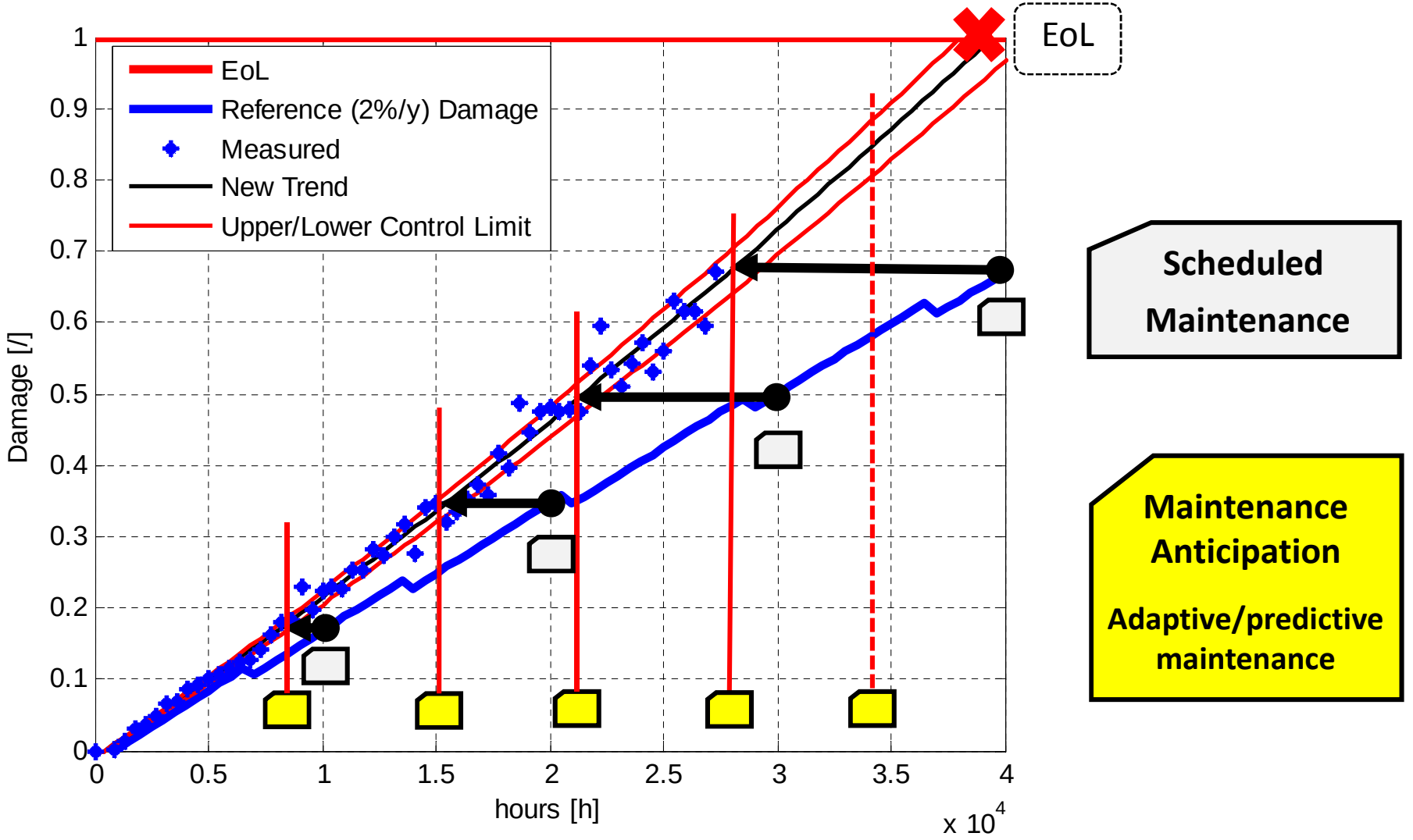


Applications 1

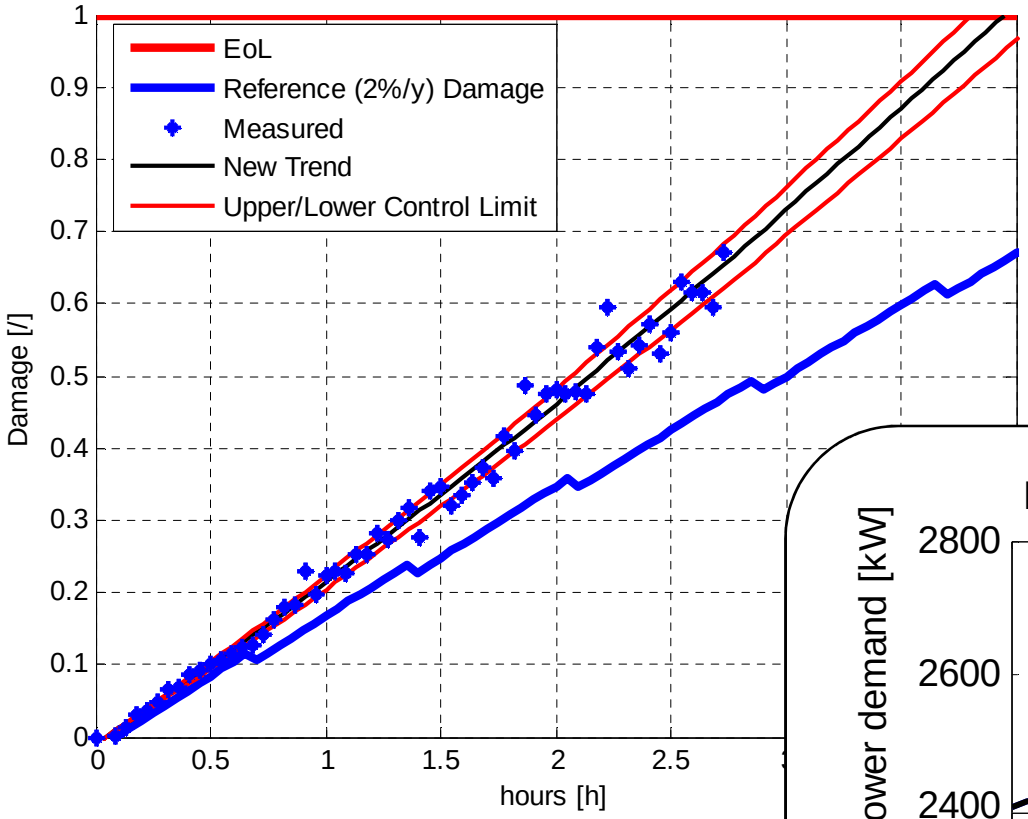


- **On-board Lifetime Prediction**
- **Current State Detection**
- **Alarms**

Applications 2



Applications 3

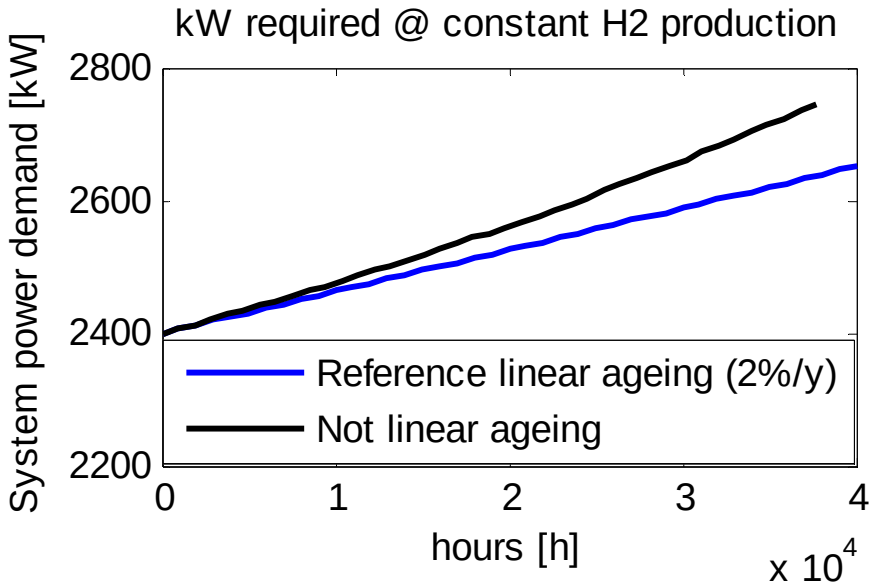


- **Evaluation of the H_2 Production Costs' Variation with ageing**

for decision making process integration

@ Constant H_2 production [kg/h]

➢ **Power demand** (→ Energy) growths with ageing



Key findings & Conclusions

Off-line preliminary study

- ***A PEMECs' simulator*** *for reference power consumptions, ageing and faulty conditions' simulation is developed*

Algorithms' development & On-board implementation

- *The* ***prognostic algorithm*** *is proposed; relevant results:*
  - ***Current state detection & EoL prediction***
  - ***Alarms & Maintenance anticipation***
  - ***Evaluation of the operational costs' variation with ageing***
- *The* ***diagnostic algorithm*** *based on data-driven is under development for*
  - ***System monitoring & Incipient faults' occurrence detection***

Thank you for your attention!!!

Any Questions???

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