

tinyML[®] Foundation

Enabling Ultra-low Power Machine Learning at the Edge

tinyML Summit April 22 - 24, 2024



www.tinyML.org

HPE GROUP

Real-World Success Stories

Intelligent monitoring of
IPMSM with
Stellar E MCU

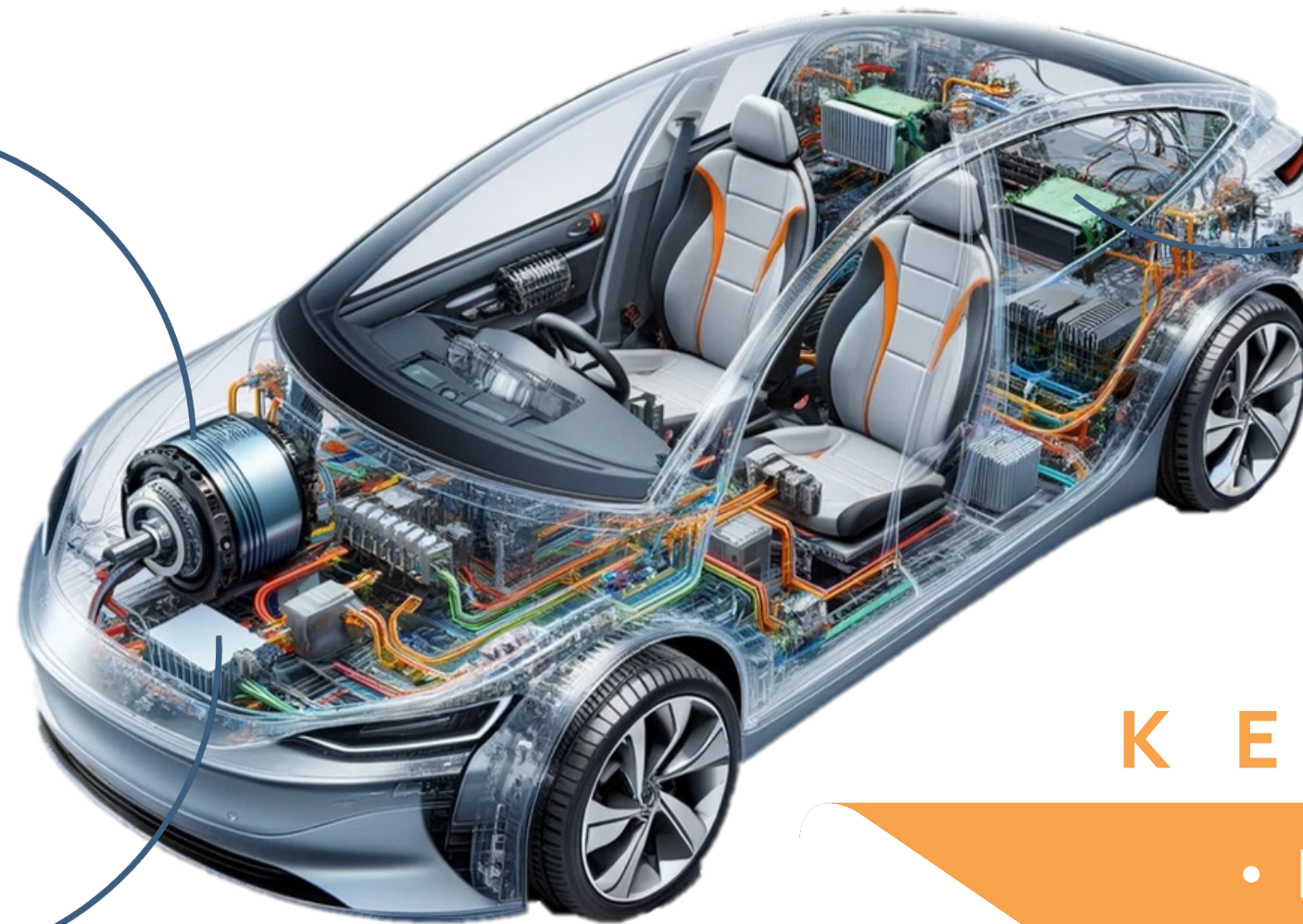


Speaker: Andrea Zanellini
Machine Learning Engineer

WHY WE ARE INTERESTED IN Tiny ML

1. **High frequency data**
generated by sensors
(e.g. vibrations, currents)

2. **Local & energy efficient**
edge processing and
information usage with
minimal latency

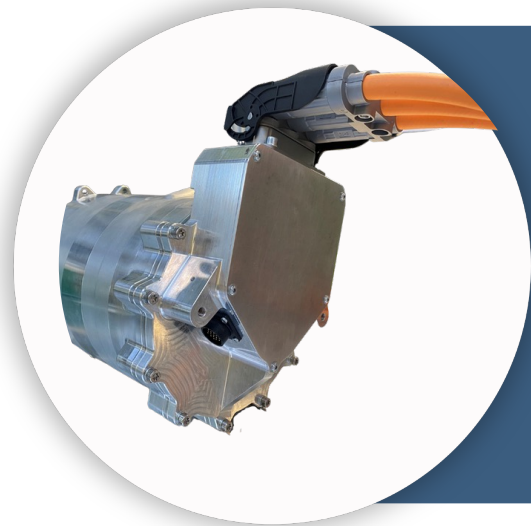


3. Low frequency/high
semantic level data
**stream towards central
CPU and cloud**

K E Y B E N E F I T S

- Process and use high frequency data at the edge
- Minimum latency
- Energy efficiency

Tiny ML APPLICATIONS Overview



E-MOTOR HPE P140

- IPMSM
- Max speed: 16000 RPM
- Max torque: 240 Nm
- Max power: 200 kW
- Weight: 40 kg



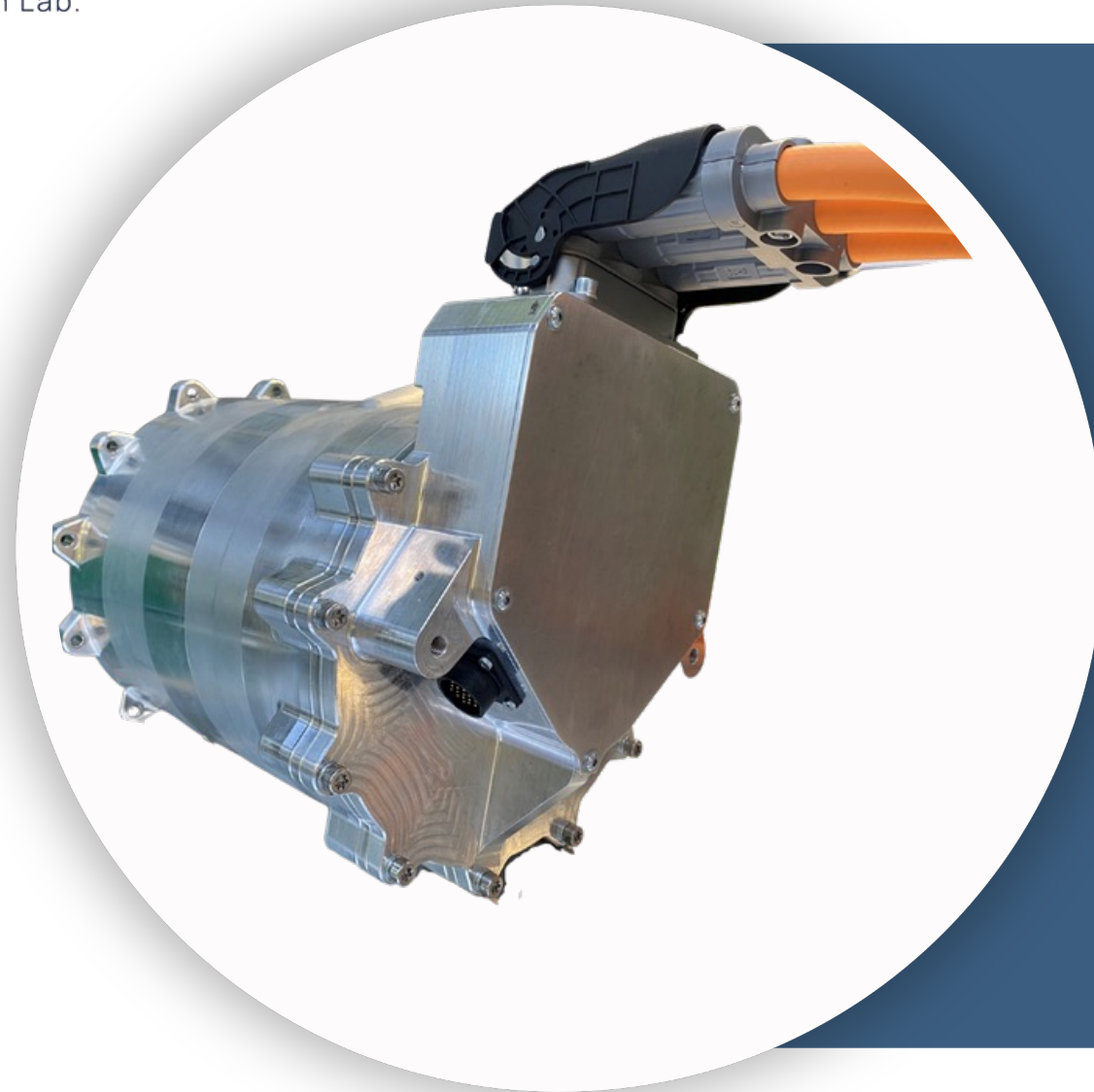
INVERTER ST

- SiC MOSFET 3rd generation
- Automotive grade
- 1200 V

Predictive
maintenance

Efficient
control

Tiny ML APPLIED TO HPE's E-Motors

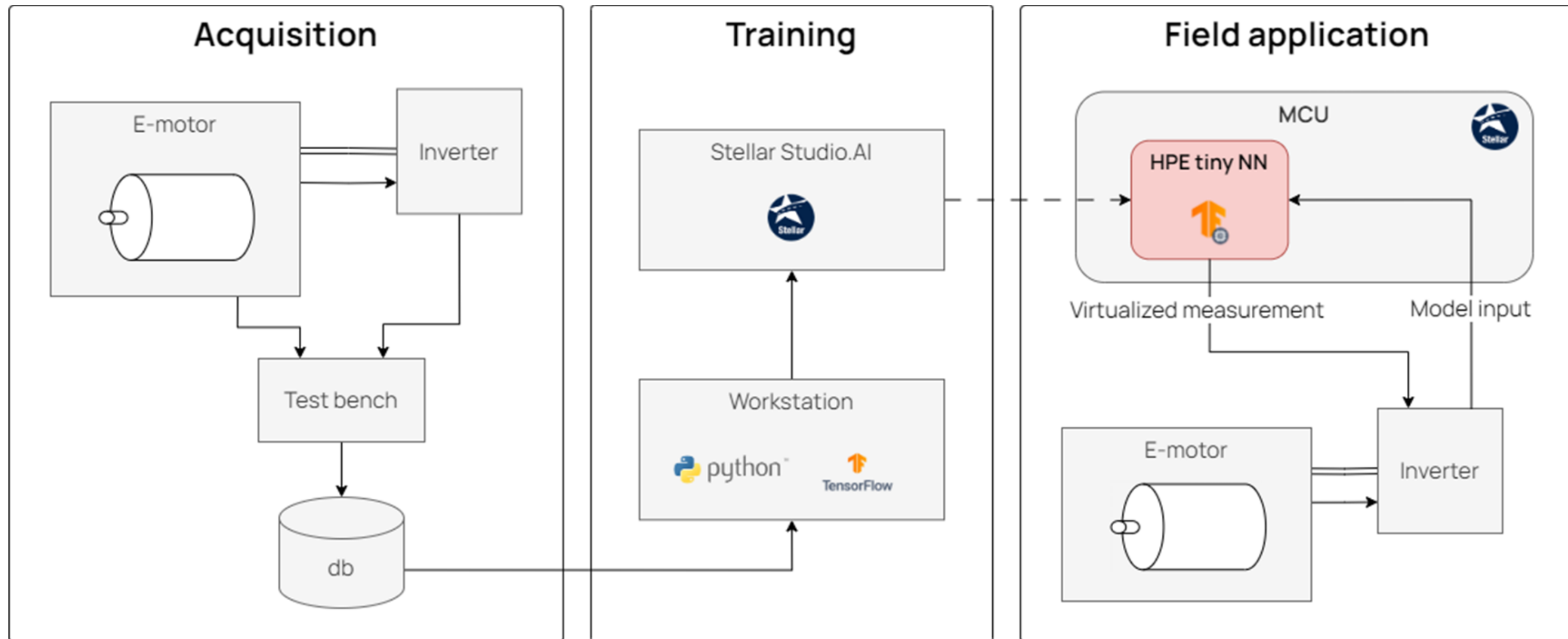


During the 2023 HPE and ST developed two Tiny ML applications on e-motor:

1. Temperature sensor virtualization
2. Predictive maintenance

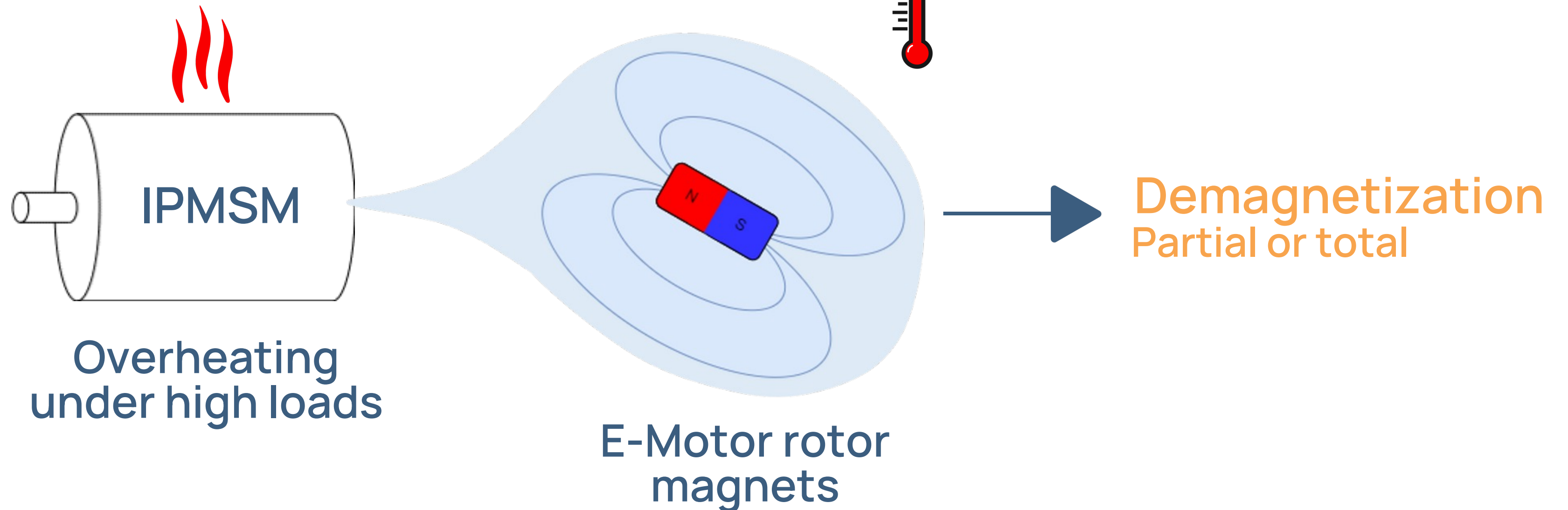
Methodology

From test bench to the field



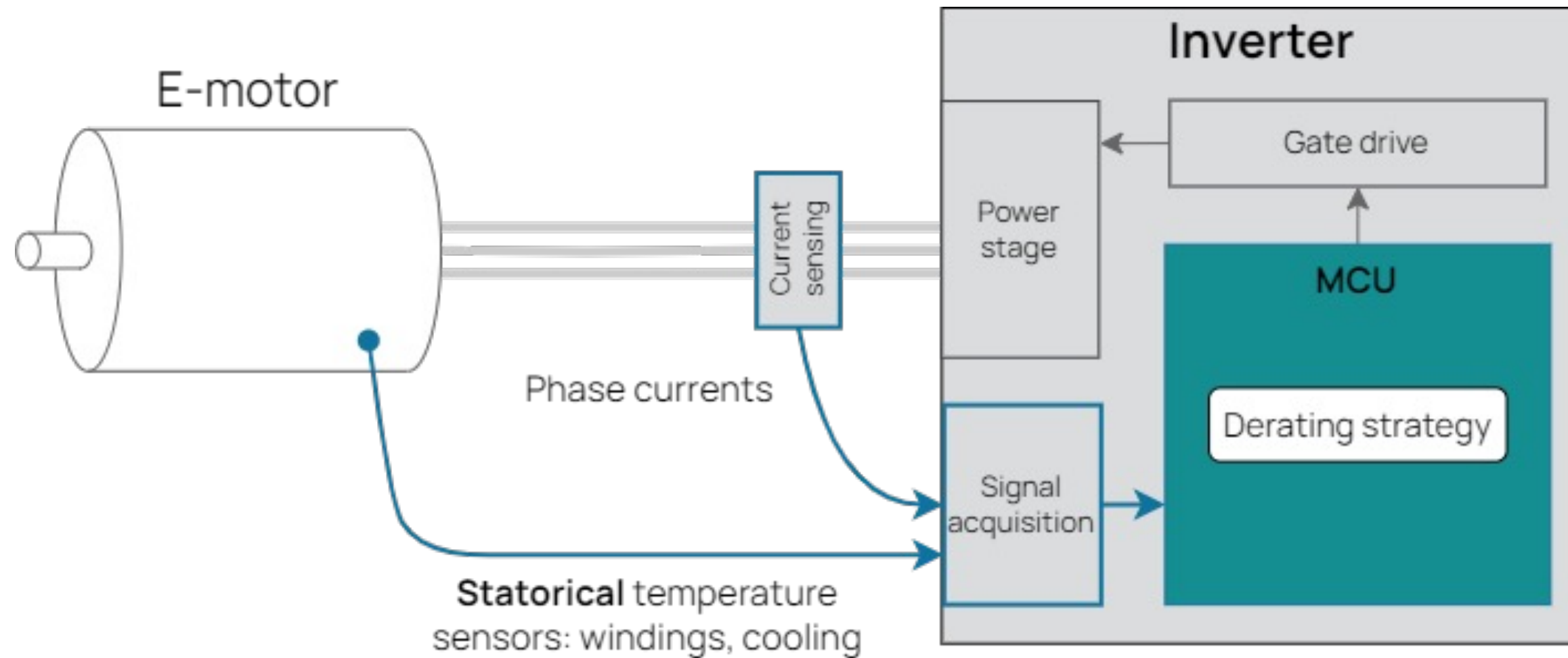
1. E-MOTOR TEMPERATURE SENSORS VIRTUALIZATION

PROBLEM
TO SOLVE



E-MOTOR TEMPERATURE SENSORS VIRTUALIZATION

PROBLEM TO SOLVE

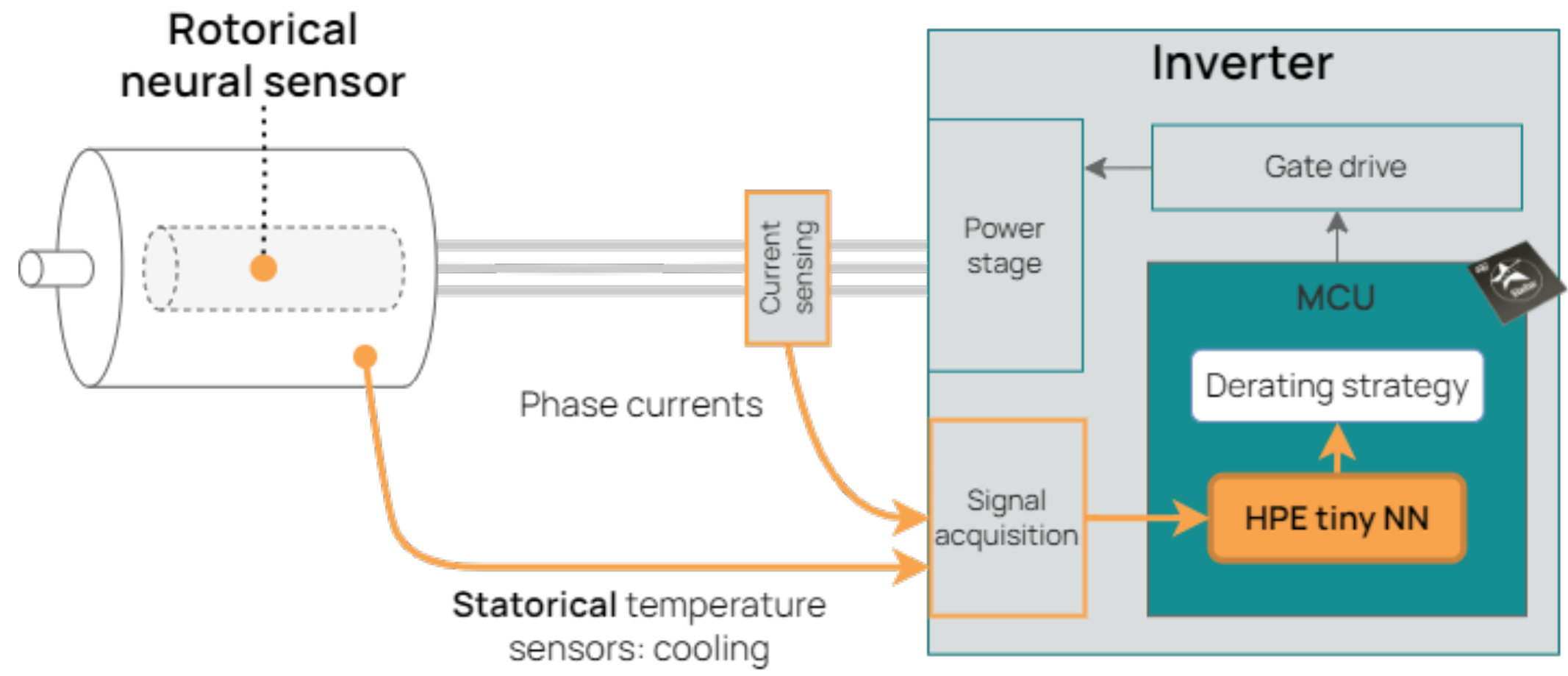


The motor control applies a **derating strategy** based on windings temperature

The derating strategy has **conservative safety margins** based on worst case operating conditions

E-MOTOR TEMPERATURE SENSORS VIRTUALIZATION

SOLUTION



- phase currents
- phase voltages
- cooling temperatures

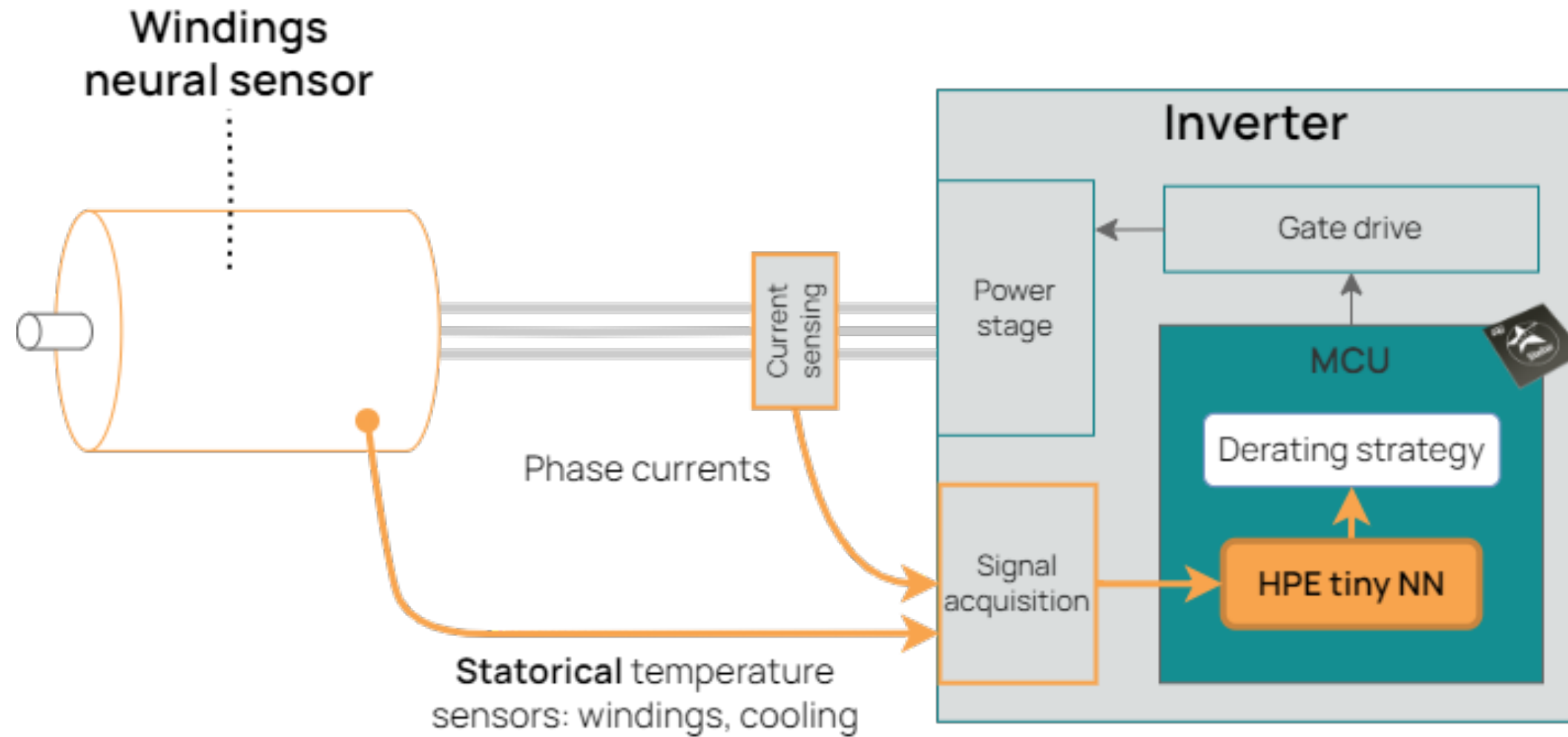


The HPE tiny NN virtualizes the magnets temperature sensor

Knowing magnets temperature, the safety margins can be reduced, incrementing the performance

E-MOTOR TEMPERATURE SENSORS VIRTUALIZATION

SOLUTION



- phase currents
- phase voltages
- cooling temperatures



The HPE tiny NN also estimates windings temperatures to ensure continuous operations in case of real sensor failure

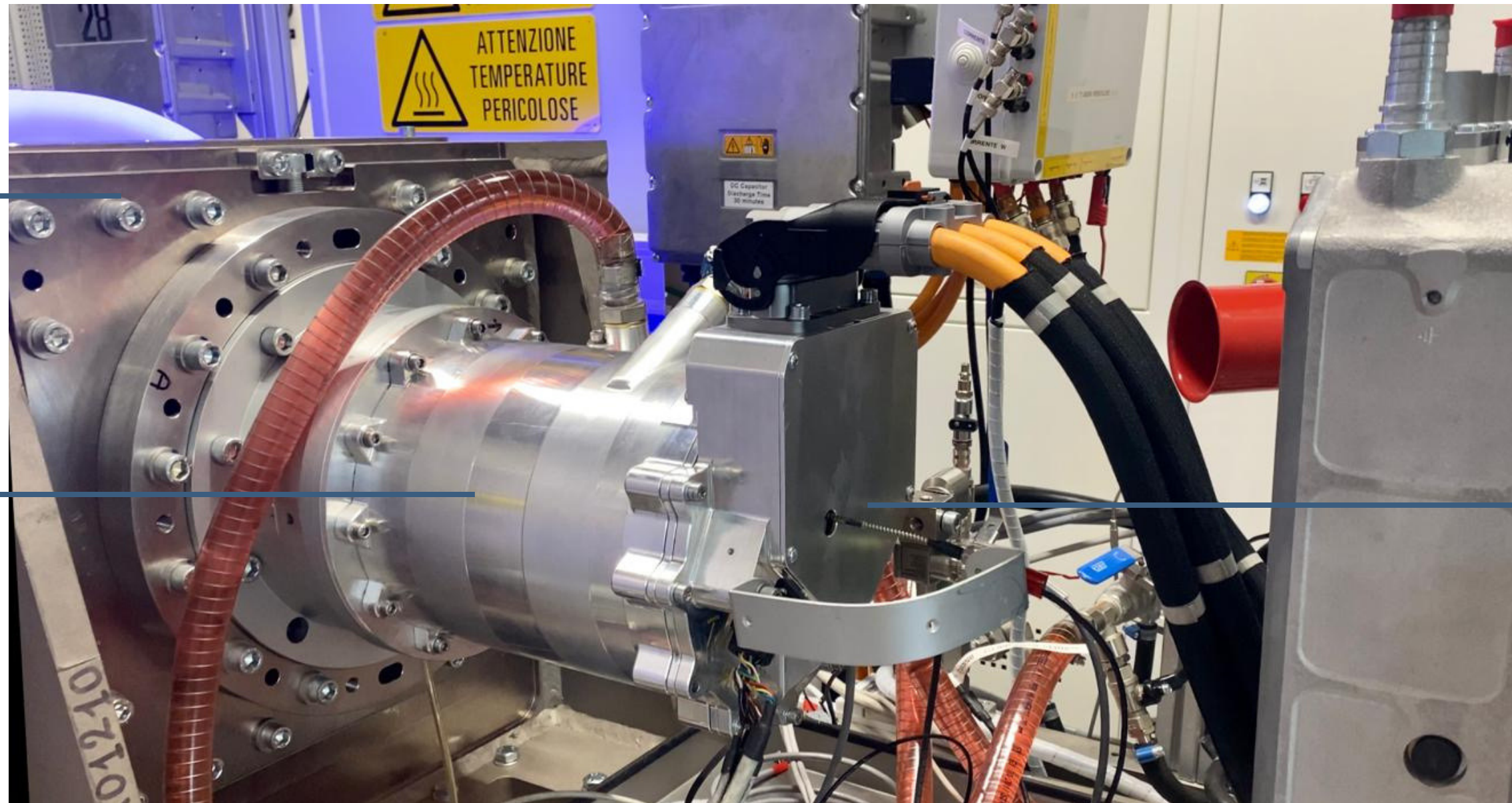
The HPE tiny NN prediction is also used to monitor the temperature sensor degradation

Data acquisition

We acquired data from our e-motors in our test facilities

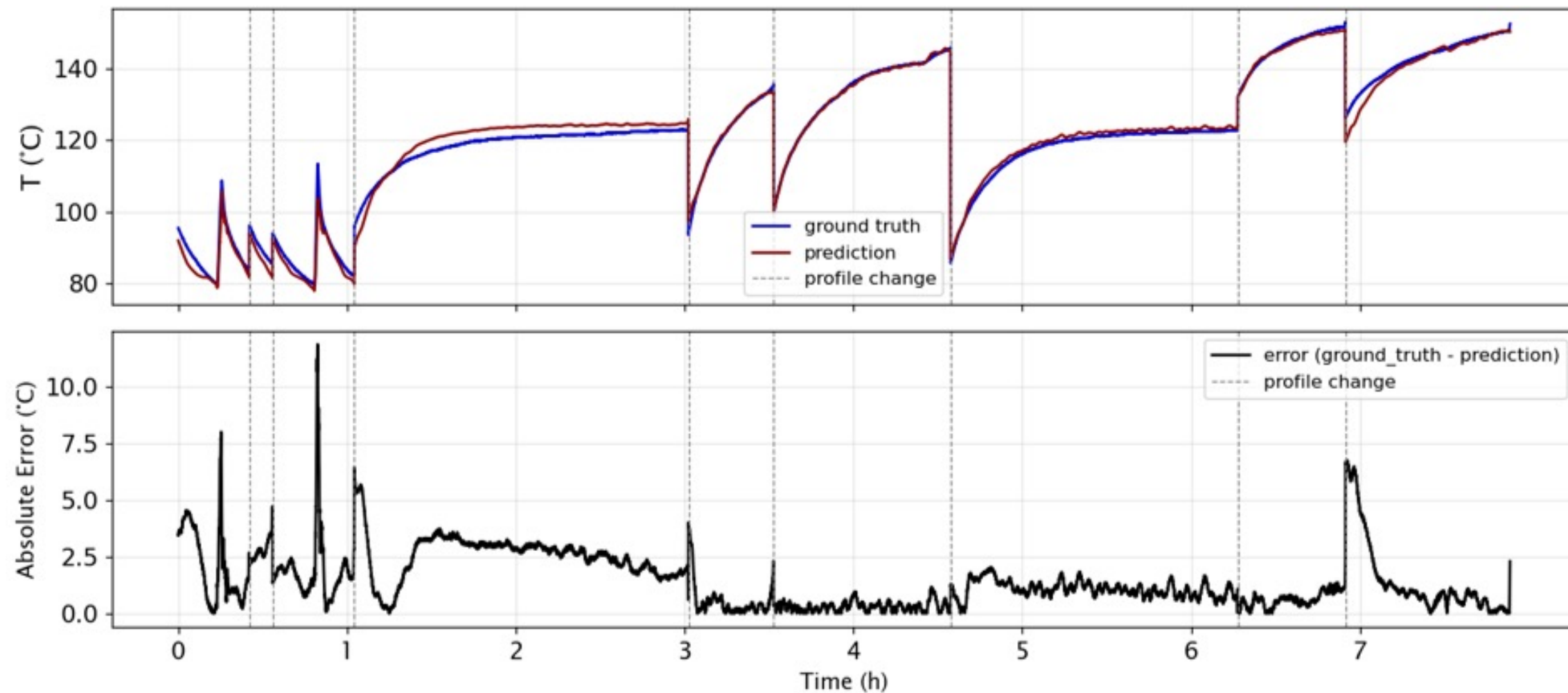
Test bench

DUT
HPE P140



Rotor
temperature
sensor
Infrared

Magnets temperature predictions



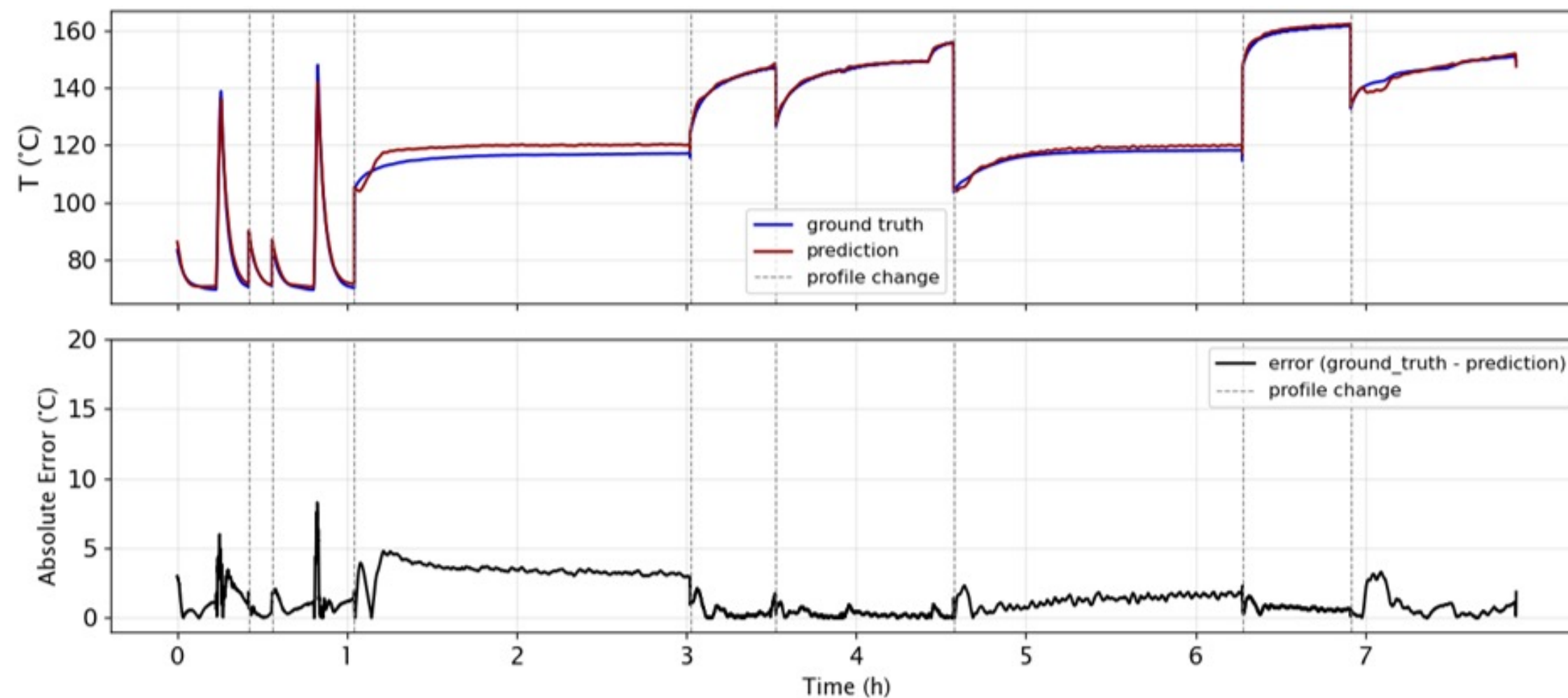
- **Maximum error**
11,89 °C (5,9 %)

- **Mean absolute error**
1,45 °C (0,7 %)

- **Model size**
71,2 kB

Ability to reduce de-rating time and safety margins enables
increment of performance

Windings temperature predictions



- **Maximum error**
8,28 °C (4,2 %)

- **Mean absolute error**
1,52 °C (0,76 %)

- **Model size**
114 kB

Ability to monitor thermocouple behavior
increment of reliability

E-MOTOR TEMPERATURE SENSORS VIRTUALIZATION

VIDEO

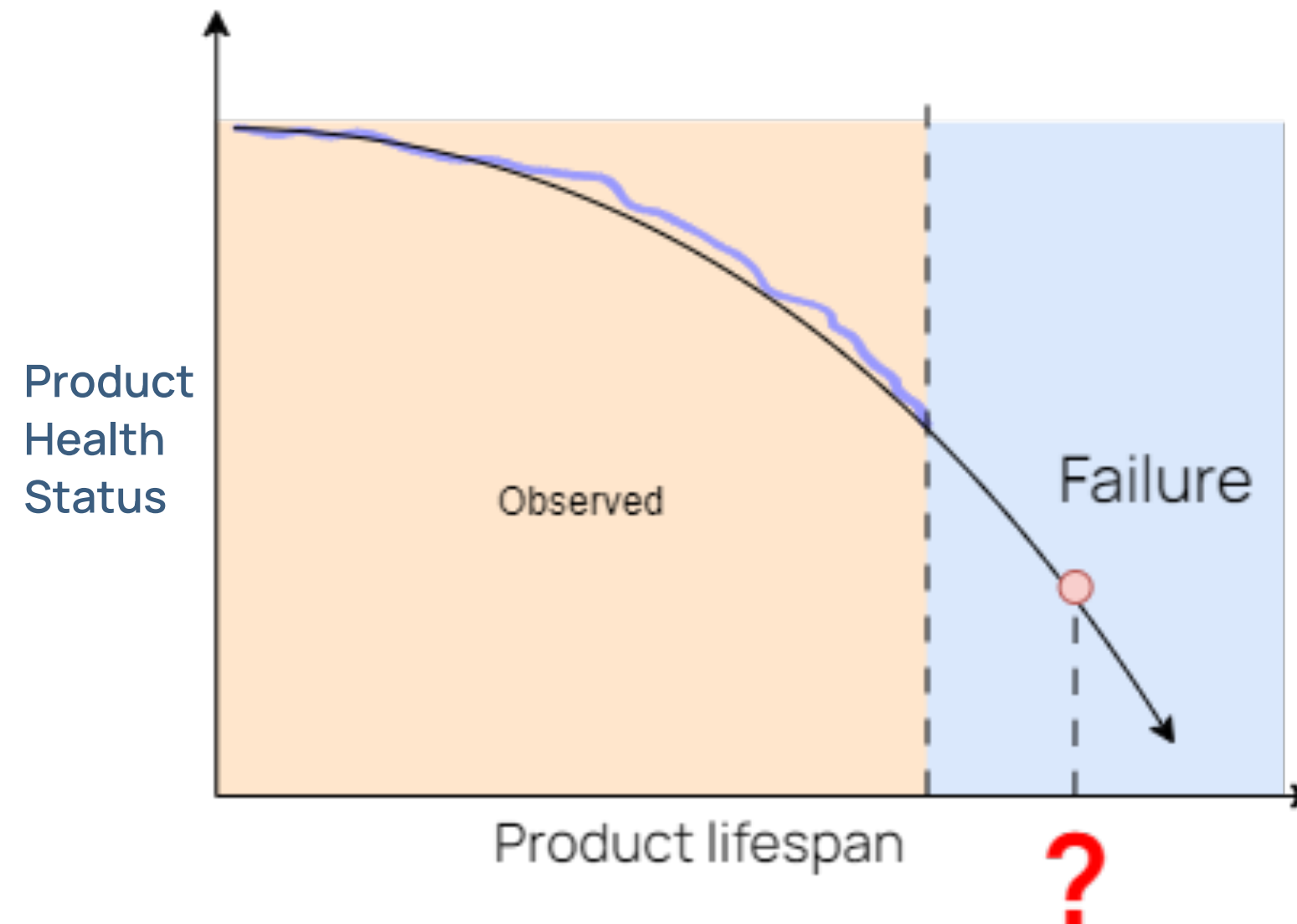
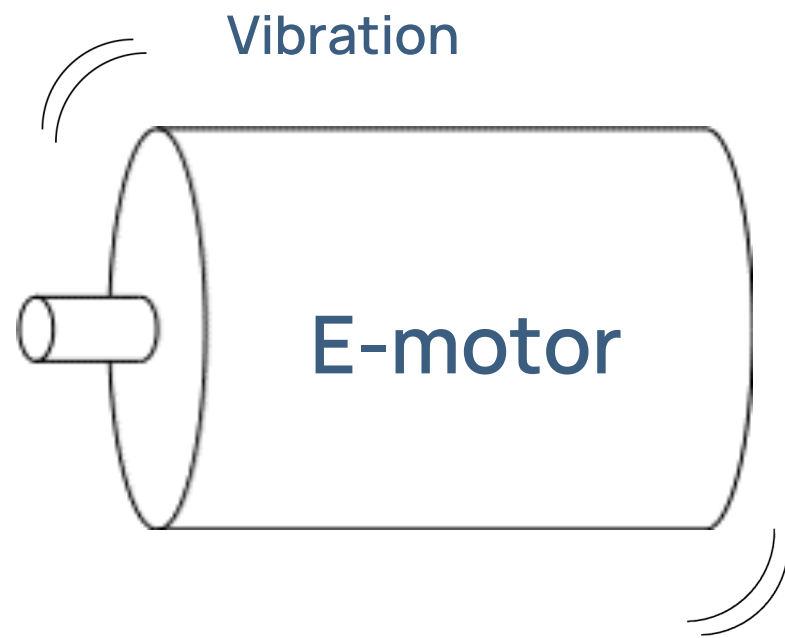
Our exhibition during the CES in Las Vegas. See our demo!!!



<https://www.youtube.com/watch?v=ippdbkSf1os>

2. E-MOTOR PREDICTIVE MAINTENANCE

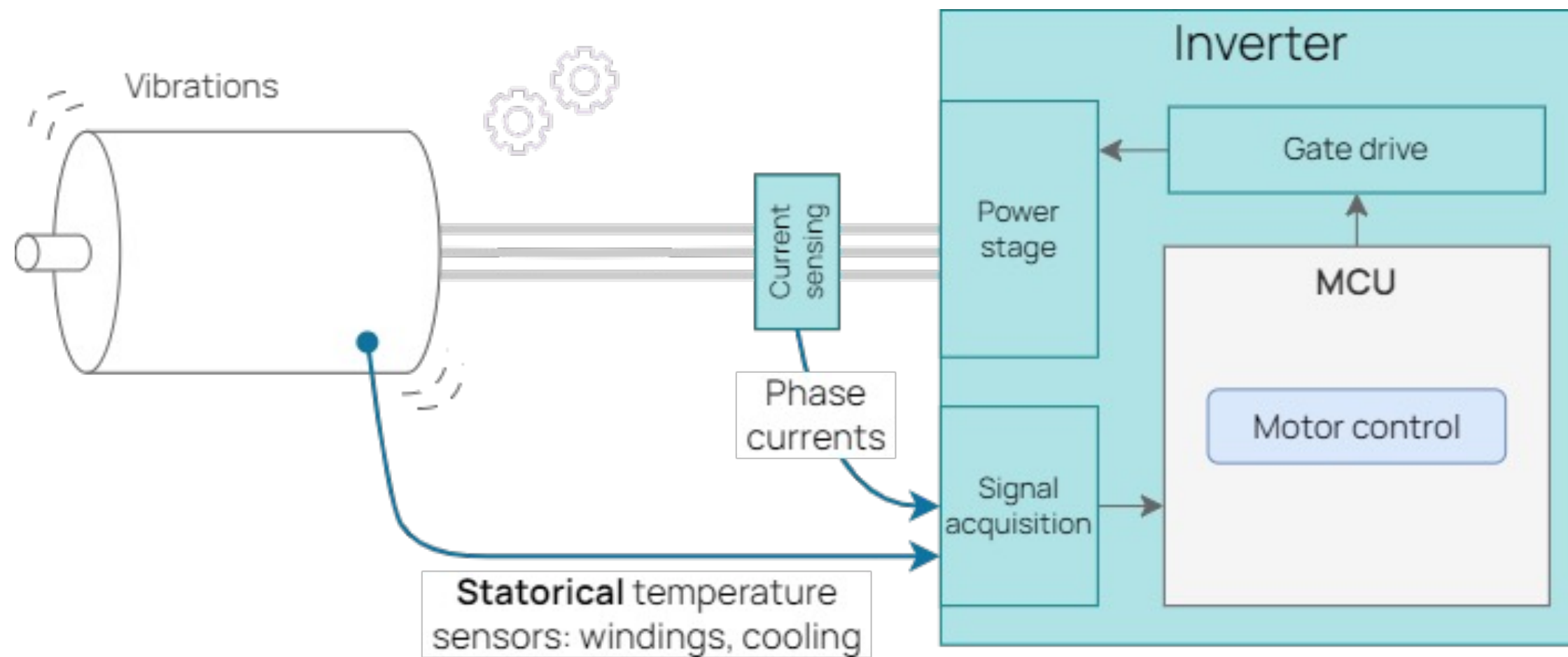
PROBLEM
TO SOLVE



How long will
the motor run?

E-MOTOR TEMPERATURE SENSORS VIRTUALIZATION

PROBLEM TO SOLVE

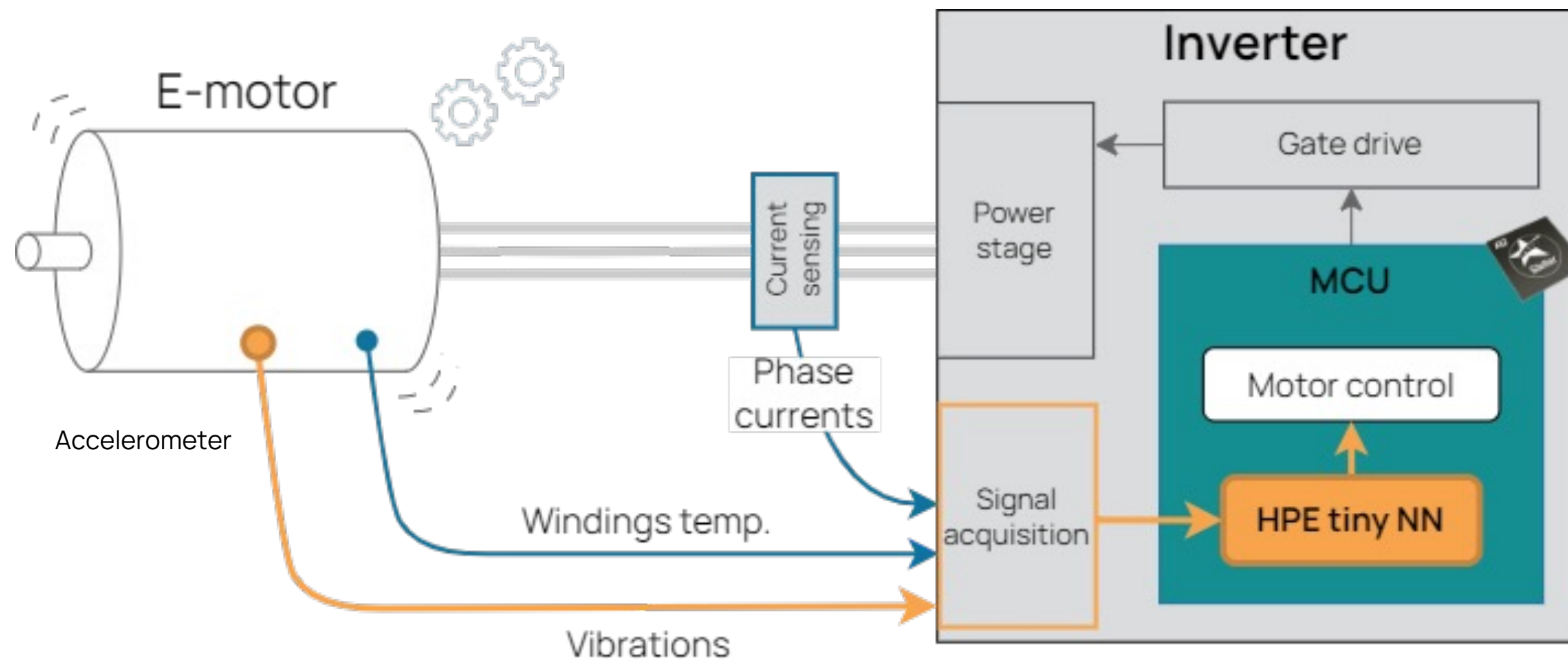


The standard practice is to implement over-current and over-temperature protection mechanism to address mechanical failures

Currently, it's not possible to prevent anomalies

E-MOTOR PREDICTIVE MAINTENANCE

SOLUTION

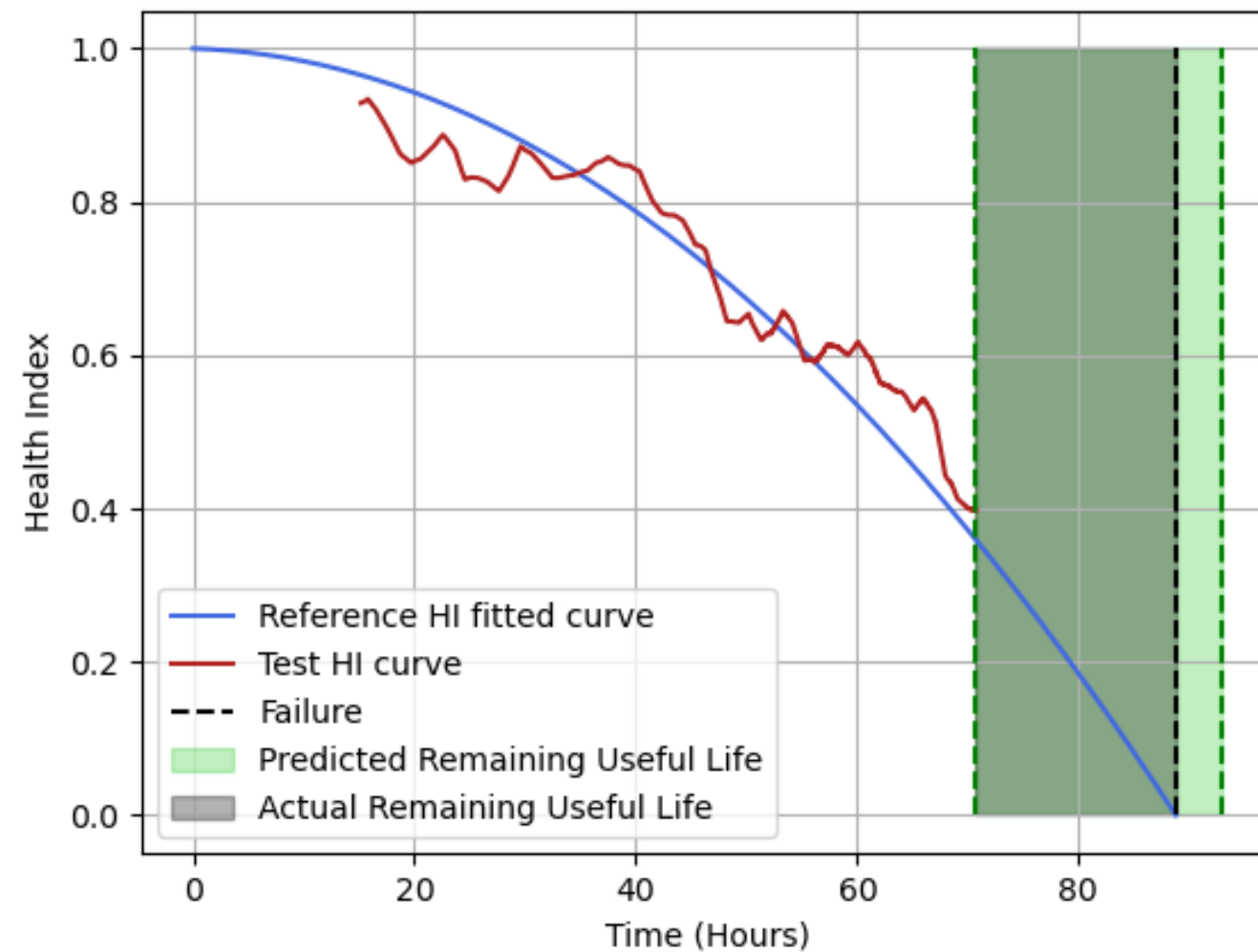


The HPE tiny NN process the high frequency vibration signal and provides a health index to the motor control

In case of incipient failure, the motor control limits the performance to avoid downtime

• Raw vibrations → **HPE tiny NN** → HEALTH INDEX

Remaining Useful Life prediction



- **Maximum error**
23 Hours (20 %)

- **Model size**
5,01 kB

Ability to anticipate failure **increment of reliability**

Our exhibition during the CES in Las Vegas. See our demo!!!



<https://www.youtube.com/watch?v=ippdbkSf1os>

Key takeaways

Two applications of
Tiny ML in the
automotive field

Two Tiny neural networks
that satisfy your needs

Proprietary data acquired
from our facility

Deployment of neural
networks on the
Inverter's Stellar E MCU



Future developments

Use case latency critical which requires HW acceleration for neural network execution at the inverter switching frequency, to improve the inverter efficiency.

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