**Hierarchy of Control & PHM functions**

1. **Basic Regulatory Control in Fuel Cell Control Unit (FCCU)**
2. **Performance monitoring and prediction**
3. **On-line vs off-line functions**

**Basic regulatory control – Realised in BEG’s FCCU**

Process interface, sequencing and basic control functions by BEG:
- Process measurements, manipulative outputs, communication
- Establishment and maintenance of operating conditions and handling of transients in presence of real-world disturbances and uncertainties – Power, Temperature, Pressure, Flow rates
- Process monitoring, constraint and emergency handling
- Sequencing and operational mode management
- Charging protocol
- Optimised scheduling based on FC performance test data
- Data logging to storage unit for off-line analysis
- Prepared for on-line PHM functions & interface

**PHM functions suited for on-line implementation**

- **Poor Man’s Prognostics:**
  Fit equivalent model of polarisation with linear regression. Direct degradation & EOL estimated based on trend data.
- **Stack Regeneration/Rejuvenation:**
  Regeneration effects after stop/start have been observed in long term tests. Performance after start can be recorded.
- **Poor Man’s EIS (see example*)**:
  Estimate of resistance in resonant element of EIS model. Log value for mapping against cell degradation.
- **Polarisation curve:**
  Procedure for recording the polarisation curve points can be executed periodically (e.g. each month).
- **Humidity (Flooding/Drying):**
  Measure voltage noise and pressure drop over cathode. Increased measurement values are correlated with flooding.
- **Advanced Diagnosis and Prognostics for Stack and BoP:**
  Data logging / communication for off-line analysis.

*) Prognostic Function example: Poor man’s EIS

- Identify the FC resistance at the low frequency intercept on the EIS-curve
- Establish cyclic perturbation that automatically converges to the frequency of interest by relay feedback excitation of sol current
- Estimate Low Frequency Resistance on-line

**Testing on a full stack**

Tests have been carried out at a set of fixed frequencies and with the relay excitation.

The key parameters can be estimated from data.

- **Even simple PHM monitoring functions gives enhanced insight in FC performance development.**
- **PHM functions may require active excitations that can be included in normal operation procedures.**
- **Some advanced PHM function may require large amount of data and is limited by available storage and/or remote communication.**
  - Developments in mobile communication opens for higher amounts of data gathering for more advanced PHM in near future.
  - Do the right things, and avoid damaging incidents during operation.

**SINTEF Digital, Trondheim, Norway**

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700101. This Joint Undertaking receives support from the European Union’s Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.