Battery Cloud: Data-Powered Intelligent Battery Management for Mobile and Stationary Battery Systems

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Chair for Electrochemical Energy Conversion and Storage Systems
Motivation

Performance  Safety  Longevity

Smart BMS + Big data based algorithms
Digital Twin for Battery Systems

- Computation capability
- Data storage capability
- System reliability

### Agenda

| 1 | Digital Twin: Cloud Battery Management System |
| 2 | Digital Twin: Monitoring and Diagnostics       |
| 3 | Field Validation of Cloud BMS Functionalities |
| 4 | Experimental Validation of Diagnostic Algorithms |
| 5 | Conclusion and Future Work                   |
Agenda

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Digital Twin: Cloud Battery Management System

- Battery Systems
  - Data Generation
- BMS-Slave
  - Data Sensing
- IoT Component
  - Data Collection
- Cloud
  - Data Storage
- API
  - Data Analytics
- UI
  - Data Visualization

Data Generation → Data Sensing → Data Collection → Data Storage → Data Analytics → Data Visualization
Digital Twin: Life cycle monitoring and optimization

Monitoring and Diagnostics

Fault Diagnostic and Prediction

Lifetime Prediction

Evaluation and Optimization
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Digital Twin: Monitoring and Diagnostic

- Seamlessly monitoring of the battery cells.

- By bridging the physical and the virtual world, data is transmitted seamlessly allowing the virtual entity to exist simultaneously with the battery systems.
Digital Twin: Monitoring and Diagnostic

- Continuous updating of the cell parameters.
- Identification of various system parameters
  - Cell remaining capacity (SoC)
  - Cell impedance (SoH-R)
  - Cell capacity (SoH-C)
  - Pack impedance
  - Pack capacity
- Algorithms based on physical, electrochemical, and machine learning models
Model-Based State of Charge Estimation

- Model-based state estimation
  - High robustness and accuracy

- Equivalent circuit model
  - Extended Thevenin model with two RC pairs

- State observer
  - Adaptive extended H-infinity filter
  - Covariance machine technique
Artificial Intelligence for State of Health Estimation

- **Particle Swarm Optimization**
  - Population-based and gradient-free global optimization method.
  - The optimal solution is searched by improving the candidate solutions based on the measure of quality.

- **Time-domain parameter identification**
  - PSO algorithm tuning ECM parameters based on the real-world driving data.
  - Both SoH-R and SoH-C are estimated.

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Field Validation of the Cloud BMS Functionalities

- Voltage measurement
- Temperature measurement
- Current measurement
- BMS-Slave
Field Validation of the Cloud BMS Functionalities

- Real-time remote monitoring
  - Voltage
  - Current
  - Temperature

- Verification
  - Data sensing
  - Data collection
  - Data storage
  - Data visualization
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   4.1 Multi-use Stationary Battery System
   4.2 Automotive Battery System
5. Conclusion and Future Work
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Experimental Validation of the Diagnostic Algorithms

Battery tester

Battery system

Slave-BMS

Sensors

CAN

MQTT

Raspberry Pi

Cloud

MQTT

Battery tester

Battery system

Slave-BMS

Sensors

CAN

MQTT

Raspberry Pi

Cloud

MQTT
Experimental Validation of SoC Algorithm with Lead-acid Batteries

- A dynamic current profile with pulses
  - Multi-use stationary battery system

- Voltage estimation
  - Mean absolute error: 0.01 V

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Experimental Validation of SoC Algorithm with Lead-acid Batteries

- SoC estimation
  - Mean absolute error: 0.06%.

- Self-regulation ability
  - Both voltage and SoC converges fast to real values
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Experimental Validation of SoC Algorithm with Lithium-ion Batteries

- High dynamic real-world driving data
  - Samsung 35e, NCA+Graphite/Si

- Voltage estimation
  - Mean absolute error: 0.01 V
Experimental Validation of SoC Algorithm with Lithium-ion Batteries

- **SoC estimation**
  - Mean absolute error: 0.49%

- **Self-regulation ability**
  - Both voltage and SoC converges fast to real values
Experimental Validation of SoH Algorithm with Lithium-ion Batteries

- Convergence performance of the fitness value
  - Fitting error of the voltage data

- Convergence performance of the cell parameters
  - Parameters converge after 600 iterations
Experimental Validation of SoH Algorithm with Lithium-ion Batteries

- **SoH-C estimation**
  - Compared with capacity test with C/3
  - Mean absolute error is 0.74%

- **SoH-R estimation**
  - Compared with Ohmic resistance @ 1C, 80%SoC
  - Mean absolute error is 1.70%
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Conclusion and Future Work

- Cloud BMS for digital twin of battery systems
- Model-based SoC estimation algorithm for both lead-acid and lithium-ion batteries
- Particle swarm optimization-based SoH estimation algorithm for both capacity fade and power fade
- Field and experimental validation of the monitoring and diagnostics for digital twin
- In the future work, other functionalities will be developed for cloud BMS
  - Lifetime prediction
  - Fault diagnostic
  - Evaluation and optimization
- For more information please refer to:
Thank you for your attention

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