Alexandre Oudalov, ABB Switzerland Ltd., 10th Microgrid Symposium, Beijing, November 13-14, 2014

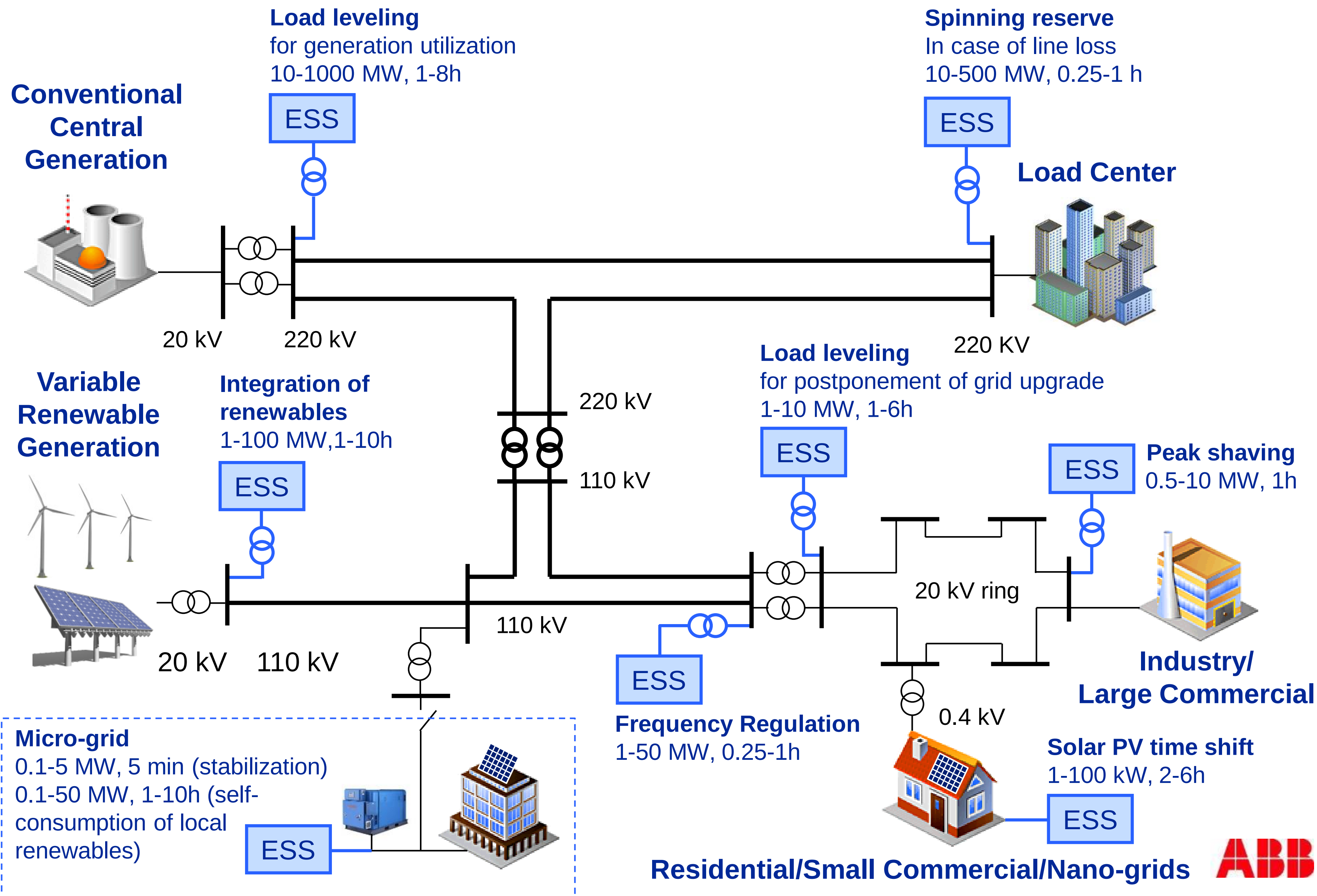
Microgrid Storage Integration
Battery modeling and advanced control

Microgrid Storage Integration
Outline

- **Introduction**
  - Energy storage technologies and applications
- **LIB aging model**
  - Semi-empirical model overview
- **Advanced BESS control strategies**
  - Application and SoC control
- **Conclusions**

LIB	Lithium Ion Battery
BESS	Battery Energy Storage System
SOC	State of Charge

Energy Storage Applications



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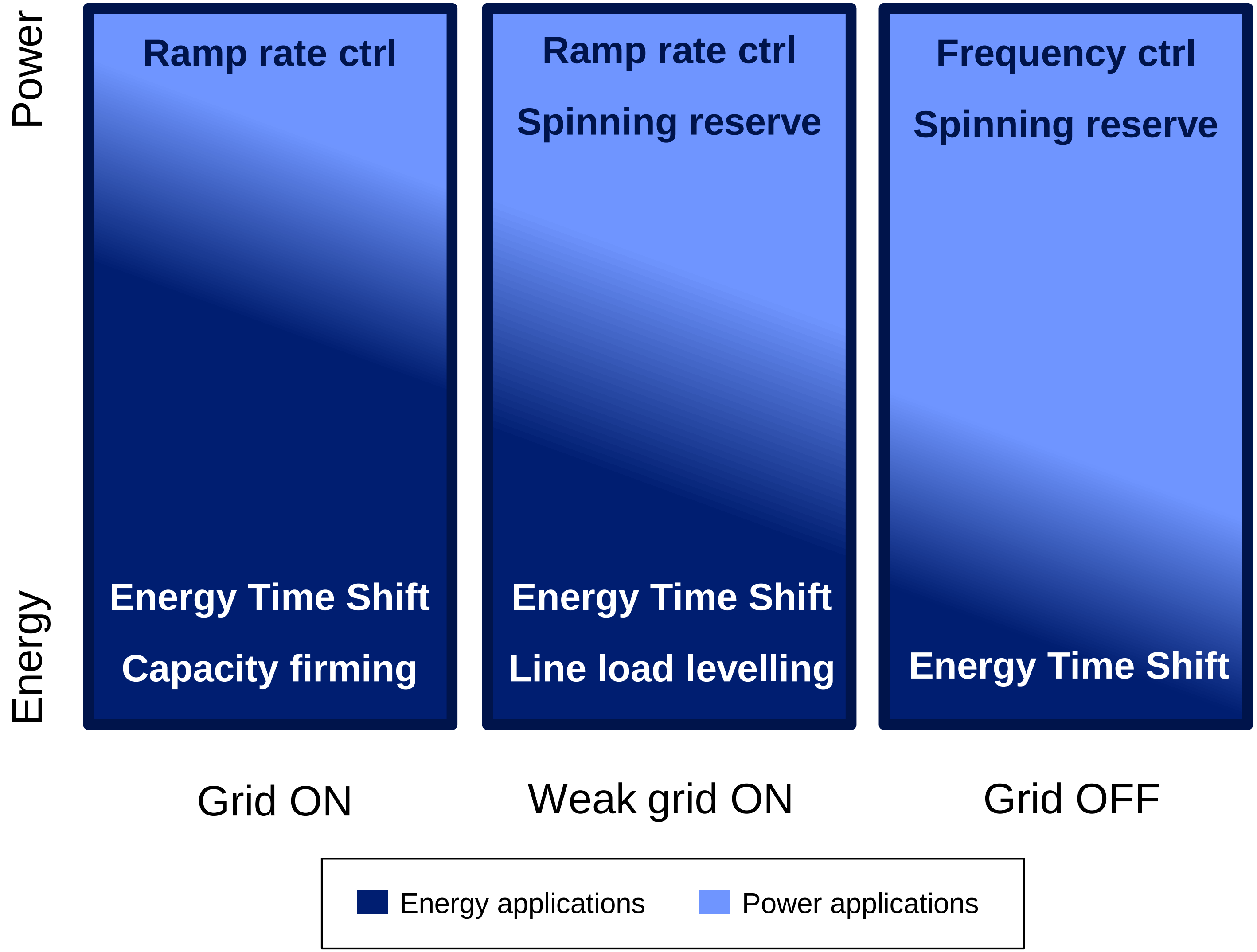
Microgrid Storage Integration
Energy vs Power Applications in Microgrids



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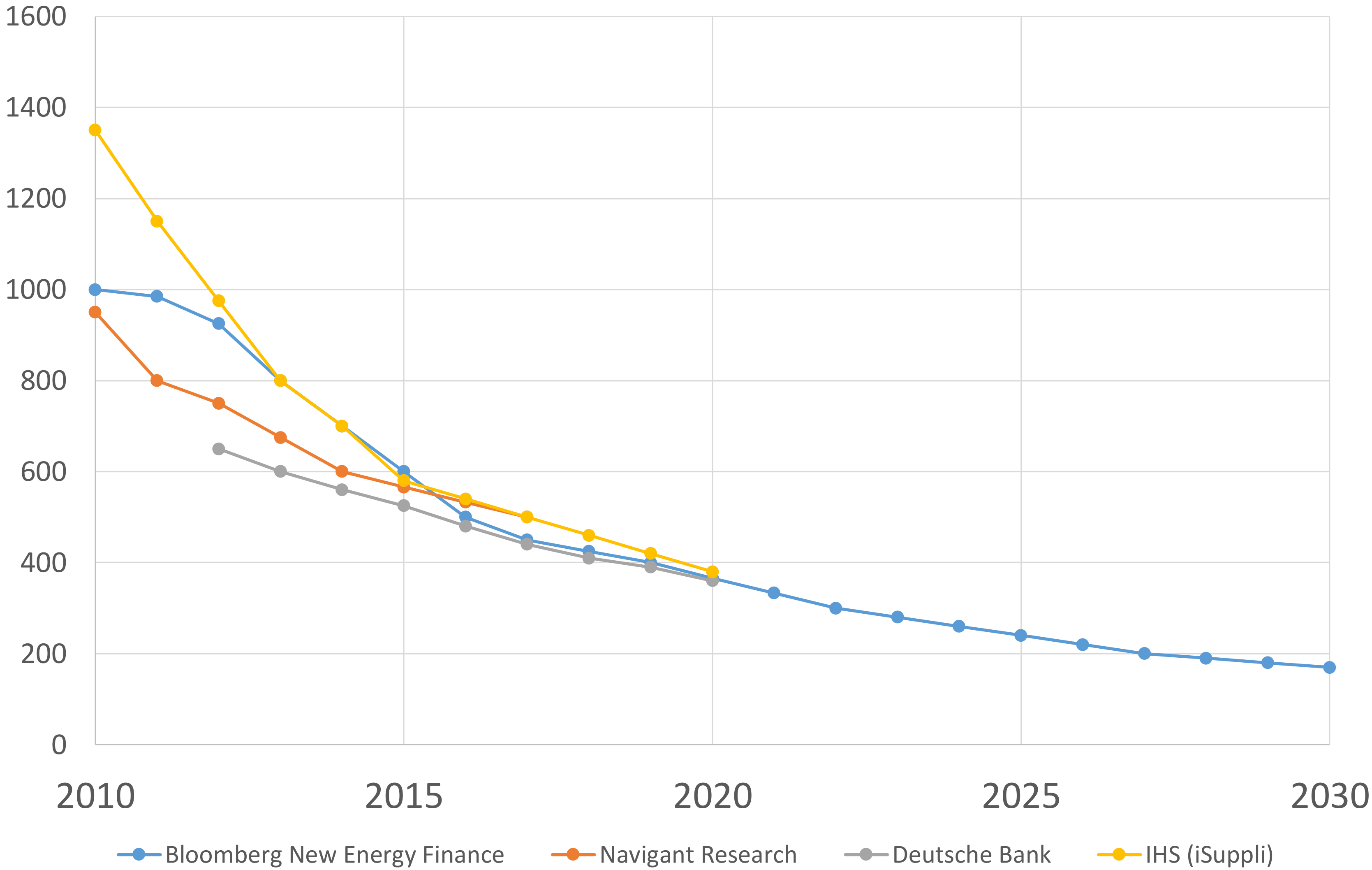
Microgrid Storage Integration
Key Technologies

- **Mechanical**
  - Kinetic
    - Flywheel
  - Gravitation
    - Pumped hydro
- **Thermo-dynamic**
  - Heat
    - Thermo electric
  - Pressure
    - Compr. Air (CAES)
  - Pressure Heat
    - Adiabatic CAES
- **Electrochemical**
  - Batteries
    - Lead acid
    - NiCd
    - NaS
    - **Lithium**
    - Ni-MH
  - Flow cells
    - Vanadium
    - ZnBr
    - PSBr
  - Hydrogen
    - Electro-lyser & Fuel Cell
- **Electro-magnetic**
  - Electric
    - Capacitors
    - Supercaps
  - Magnetic
    - Super-conducting (SMES)

Projected Cost Reductions of LIB ($/kWh)

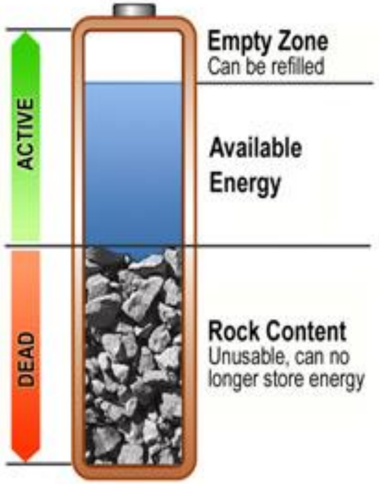


*) final prices include margins most probably in the range of 30-40%

Battery Aging Model
Overview

- Battery capacity fading is a limiting factor for BESS performance
- Customers usually expect a certain battery life in years or number of cycles for a given application
- Battery manufacturers usually over-dimension the battery to reduce the risk of earlier system depletion
- We recommend to include battery aging models in the **design** of and **operation** strategies for BESS

Source: skywriting-net



Source:batteryuniversity.com

Battery Aging Model
LIB Model

- We propose a semi-empirical model

$$l_{remain} = p_{SEI} e^{-r_{SEI} l_{faded}} + (1 - p_{SEI}) e^{-l_{faded}}$$

- Capacity fades due to battery cycling and time elapsed

$$l_{faded} = l_{cycling} + l_{calendar}$$

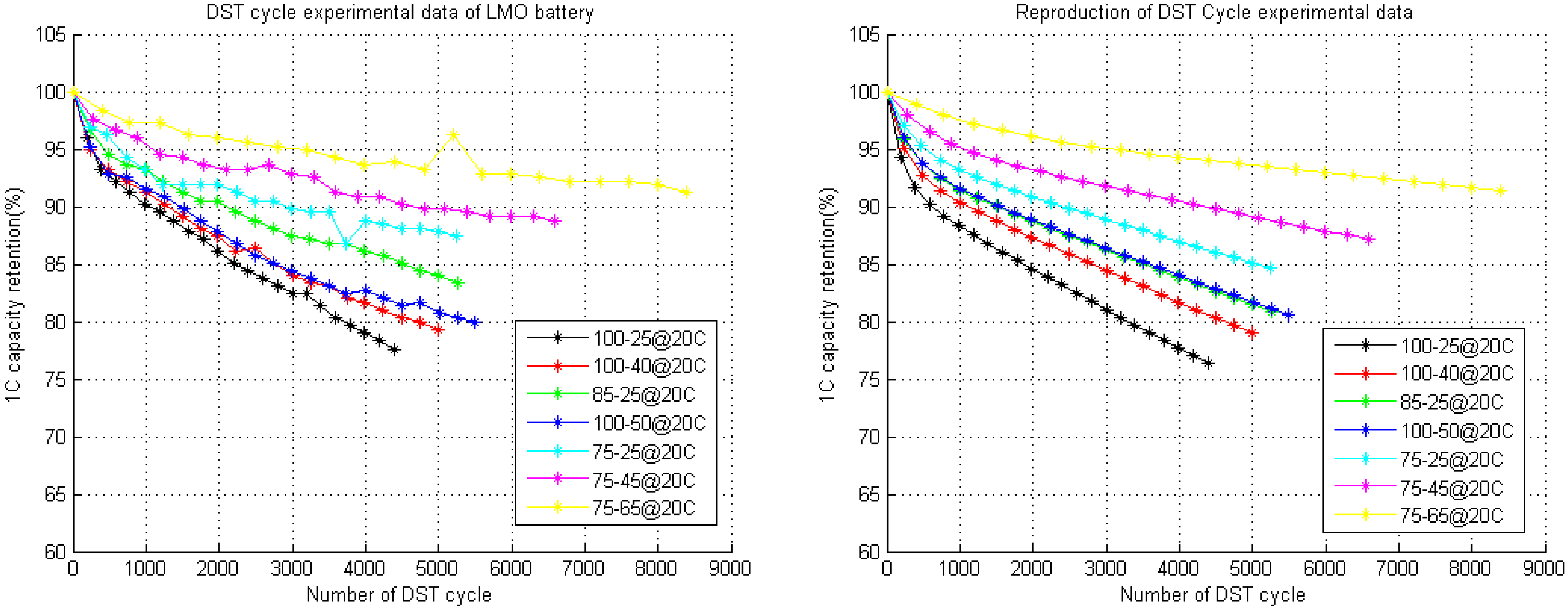
- Cycling aging is fully dependent on battery usage and is modeled as a sum of aging during each cycle

$$l_{cycling} = \sum_{i=1}^{N} \sigma_{DoD}(DoD_i)\ \sigma_{SoC}(SoC_i)\ \sigma_I(I_i)\ \sigma_T(T_i)$$

- Calendar aging is independent of battery usage and is modeled as a linear function of time, average SoC and temperature

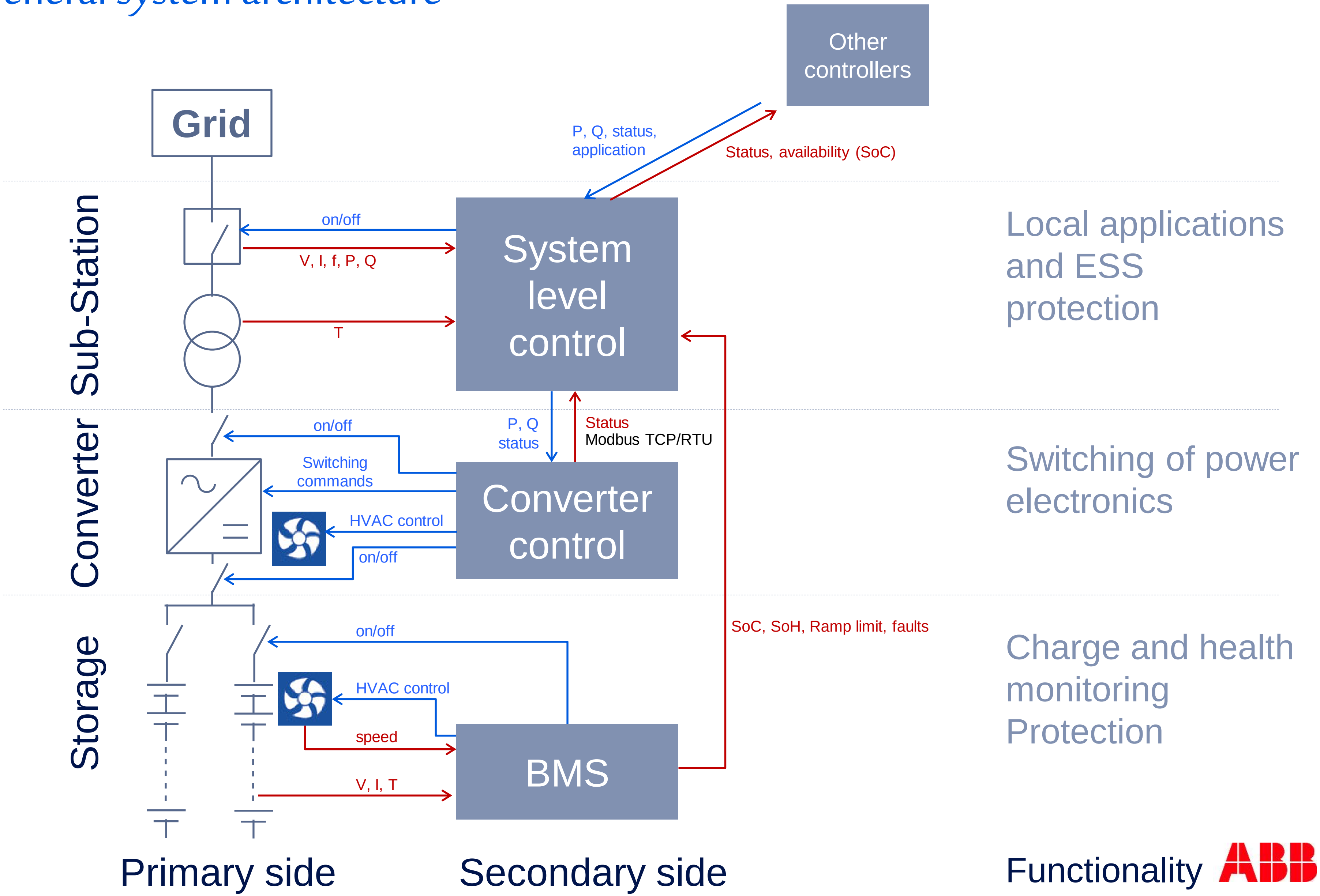
$$l_{calendar} = k_{calendar}\ \sigma_{SoC}\left(\sum_{i=1}^{N} \frac{SoC_i}{N}\right) \sigma_T\left(\sum_{i=1}^{N} \frac{T_i}{N}_i\right) t$$

Battery Aging Model
LIB Test Data vs. Model Reconstruction

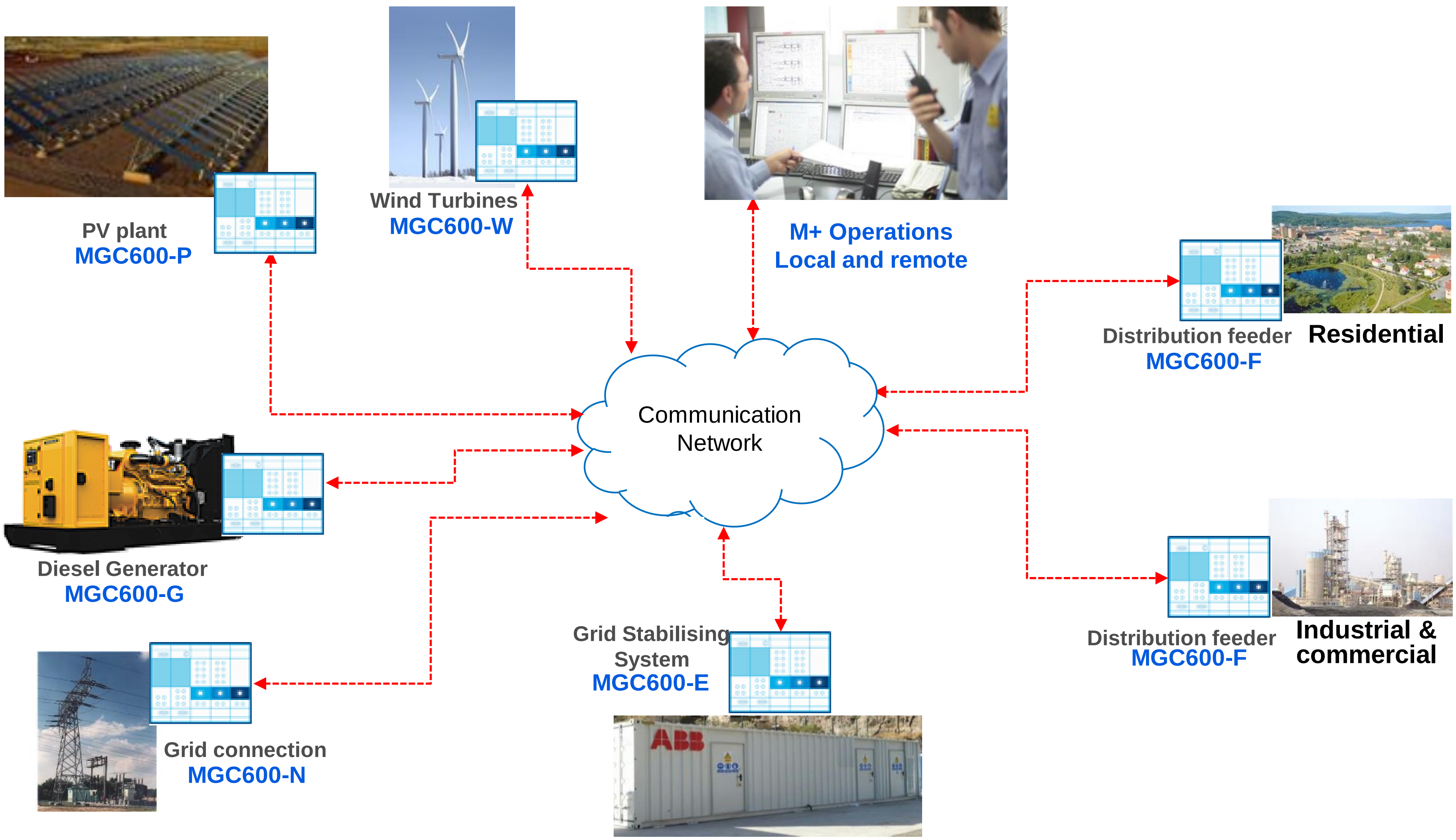


BESS

General system architecture



Microgrid Plus System
Efficient and reliable power flow management



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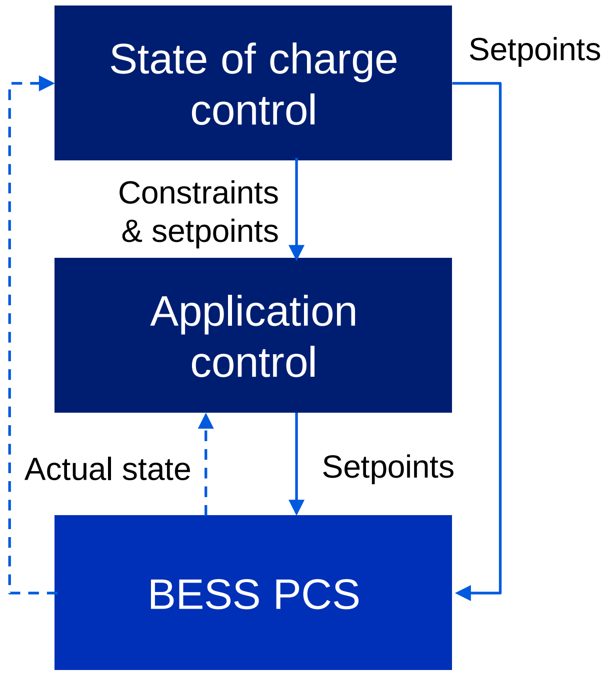
Advanced Battery Control Strategies
Combination of application and SoC control

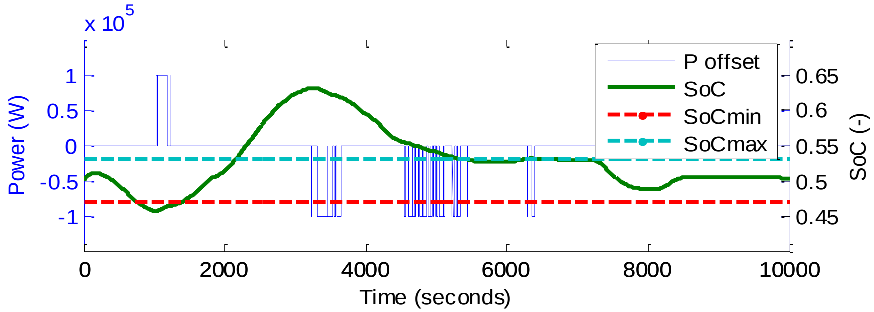
- Due to a battery inefficiency and in some applications due to a none zero mean control signal, the BESS can be totally discharged or charged in a short time interval
- It limits a use of BESS until its SoC will be back into an acceptable range
- An optimal BESS control strategy must cover both:
  - Application control
  - State of charge control
- Consideration of a battery aging model can provide additional information in order to take pro-active measures to fulfill the lifetime targets

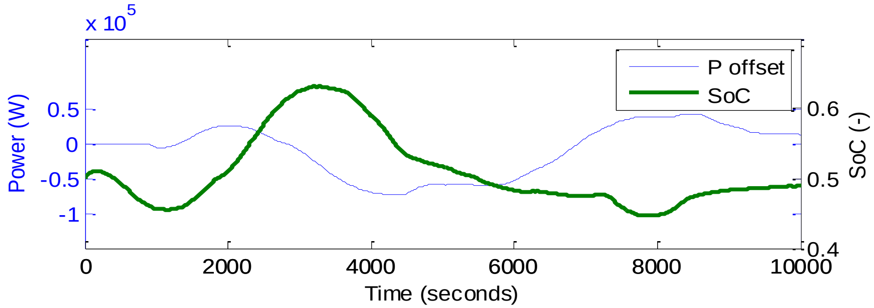


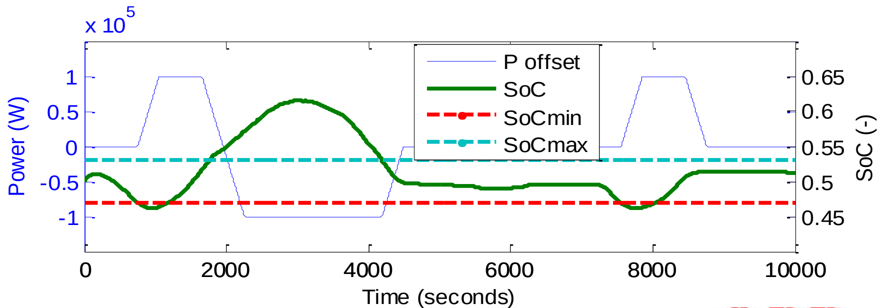
Advanced Battery Control Strategies
Frequency Control in Microgrids

State of charge (SoC) control according to one of the following strategies

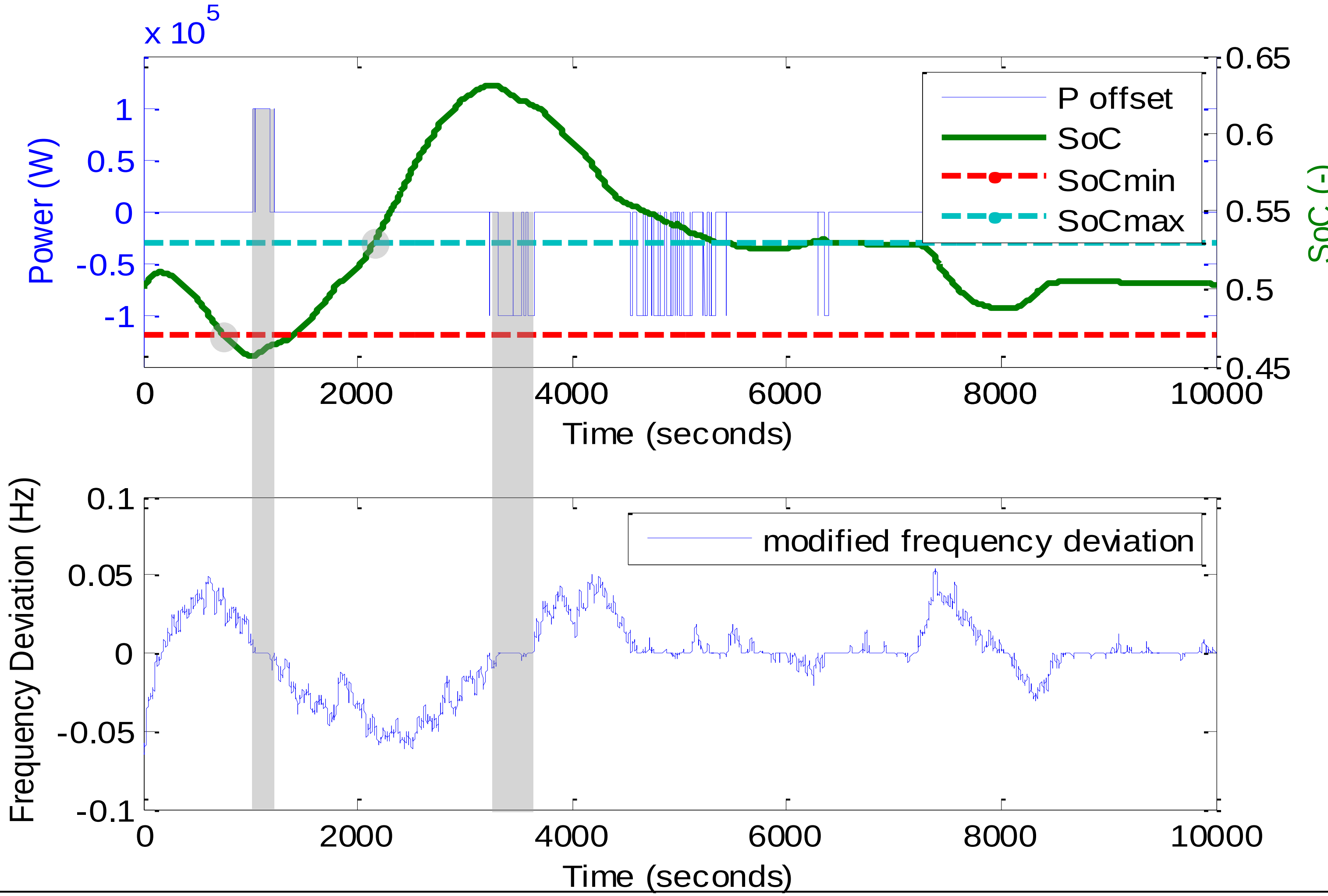
- **Strategy 1:**
  - Active when SoC exceeds adjustable thresholds and frequency is within a regulation dead-band
  - Off-set value is 0-100% $*P_{nom}$ at any time step (preferably small values)
- **Strategy 2:**
  - Is continuously activated and adjusts a power set-point using an average over the previous usage, i.e. ctrl signal is zero-mean
  - Variable off-set value is taken from a secondary reserve
- **Strategy 3:**
  - Active when SoC exceeds adjustable thresholds
  - Fixed off-set value is taken via a ramp of fixed slope for a fixed duration from a secondary reserve or an intraday market







SoC control strategy 1
Offset and SoC variations



- For P_{offset} = 5% of rated power, the annual capacity fading ≈ 6%
- For P_{offset} = 10% of rated power, the annual capacity fading ≈ 3.7%

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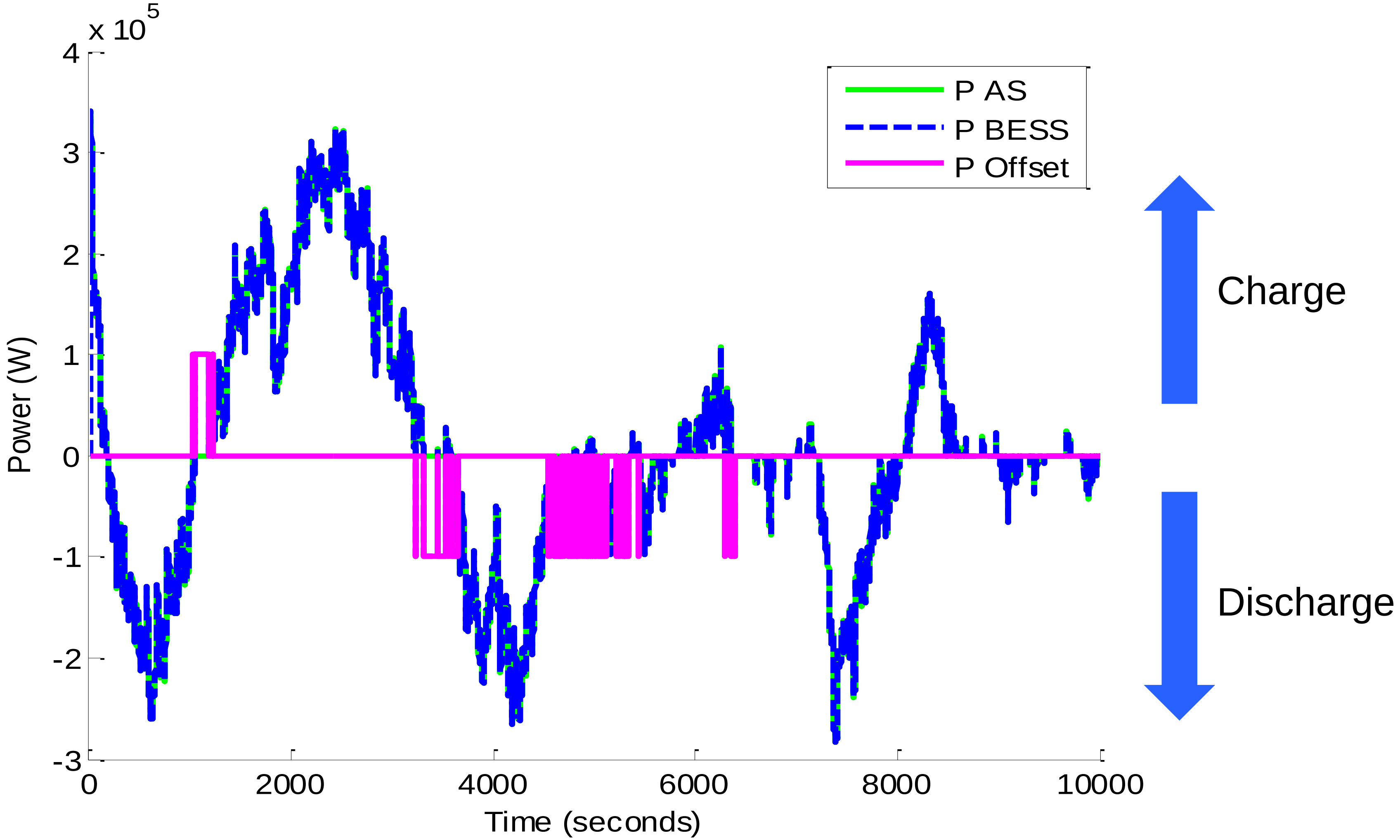
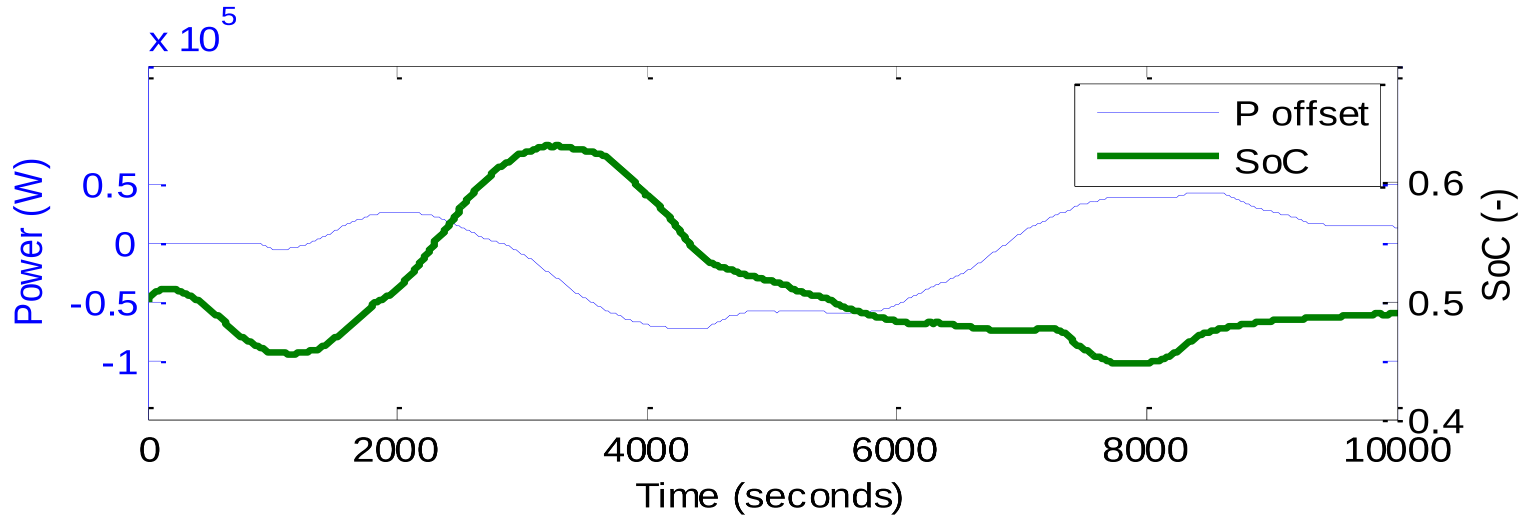
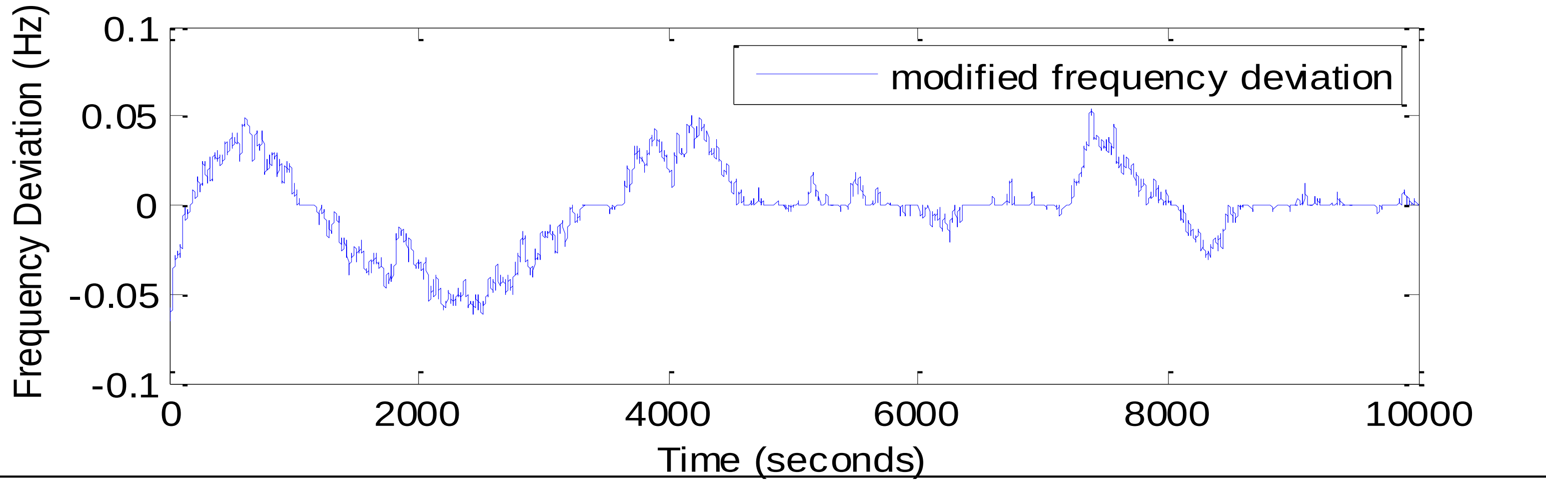
SoC control strategy 1
Variations of different power signals



- Offset is active when system frequency is within a deadband
- BESS follows exactly the requested ancillary service power when Δf≠0

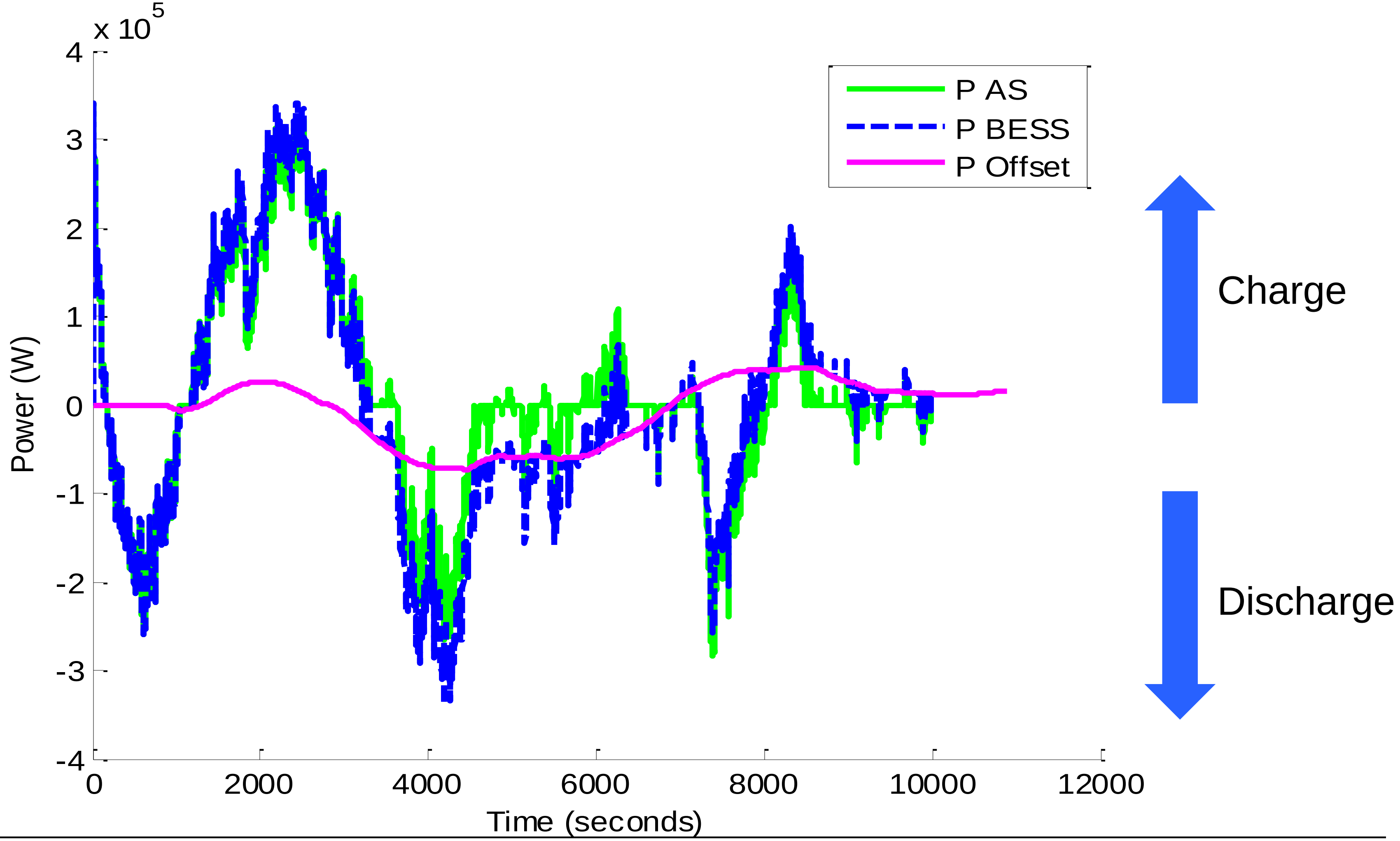
SoC control strategy 2
Offset and SoC variations





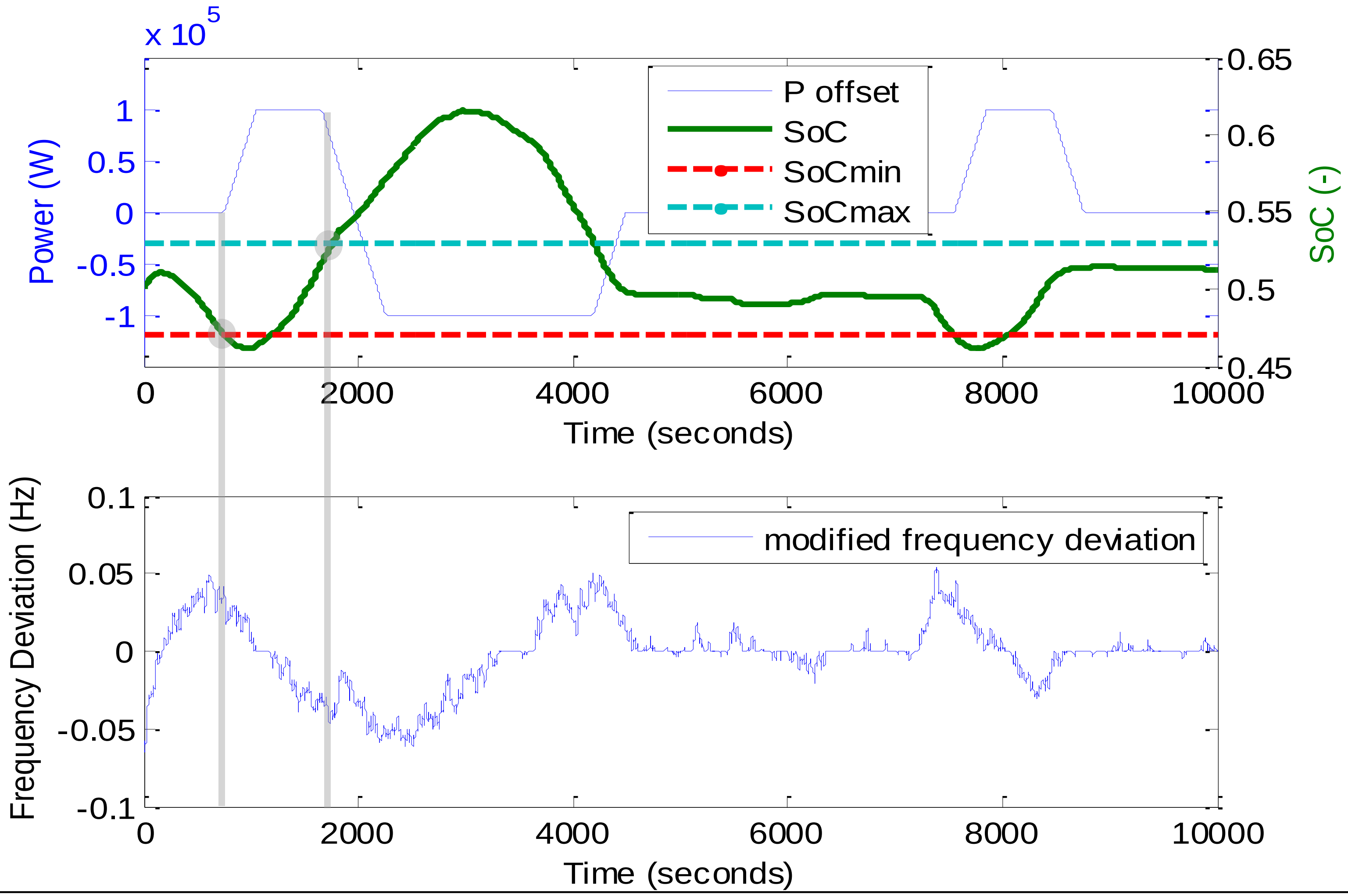
- For an averaging period of 1 hour and a dispatch delay of 15 min, the annual capacity fading ≈ 3.2%

SoC control strategy 2
Variations of different power signals



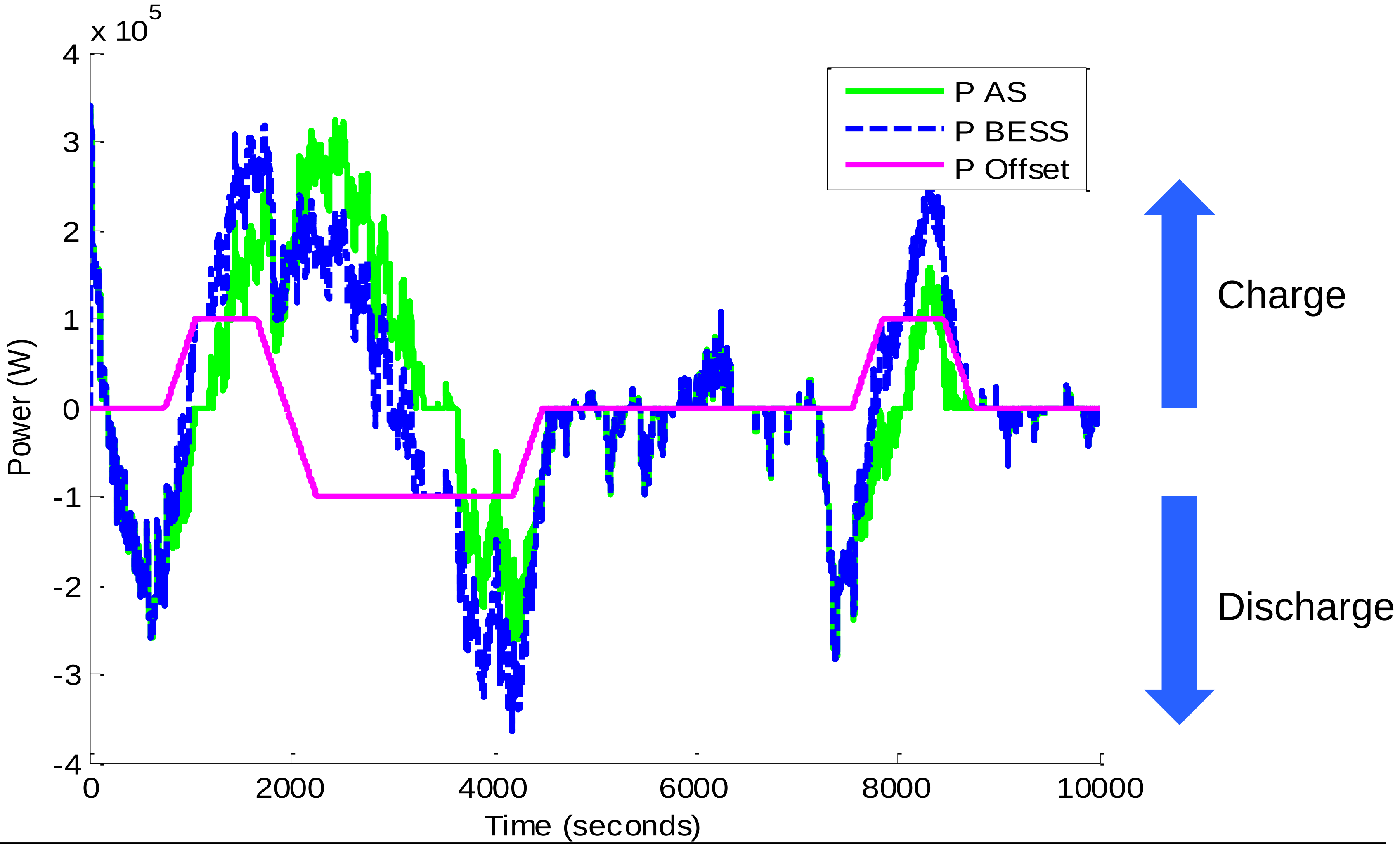
- Offset mechanism ‘forces’ the BESS power signal to be zero-mean
- Deviations between P_{AS} and P_{BESS}

SoC control strategy 3
Offset and SoC variations



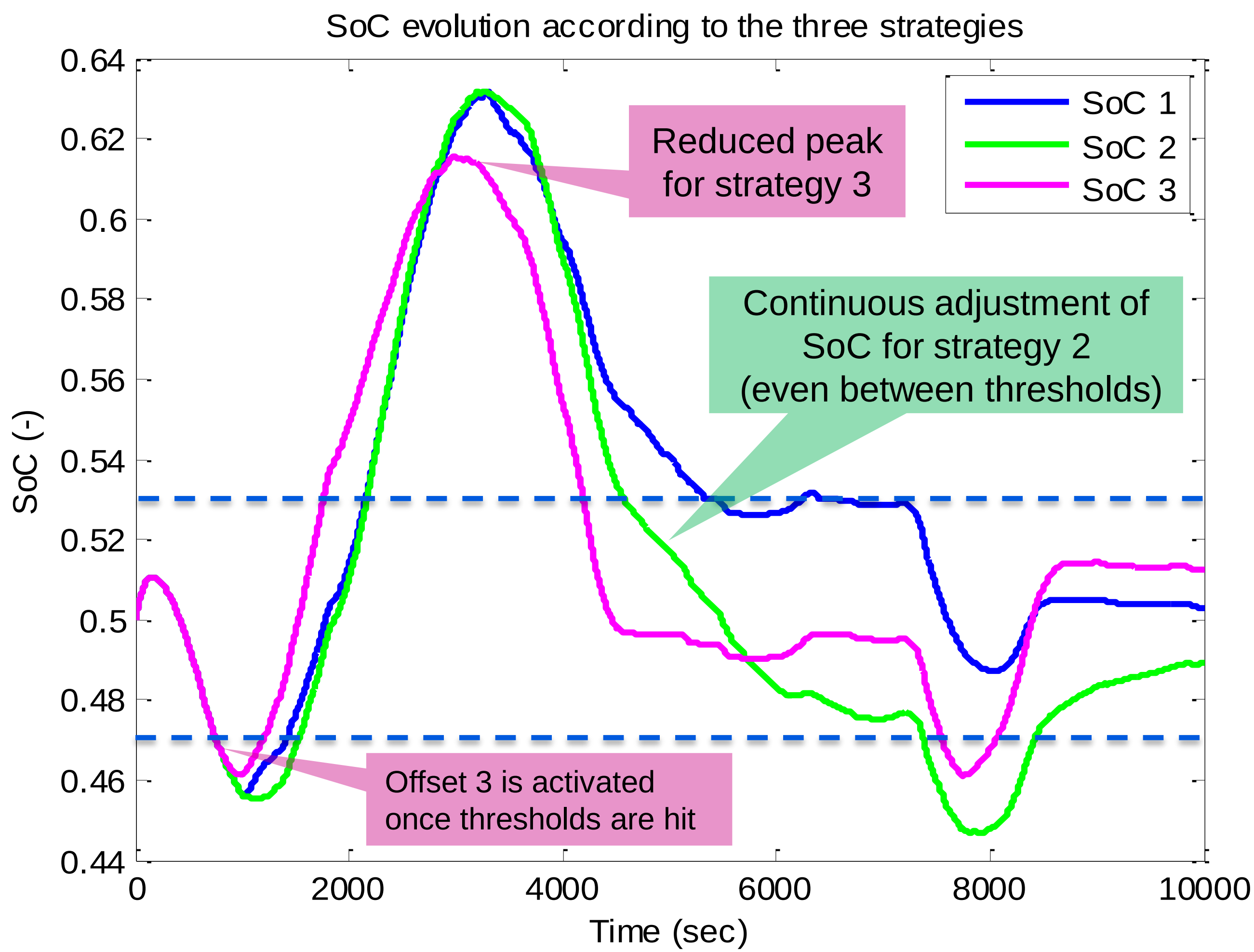
- For SoC upper threshold = 53%, SoC lower threshold = 47%, off-set level = 10% of rated power, ramp up/down in 5 min and min offset duration = 15 min, the annual capacity fading ≈ 3%

SoC control strategy 3
Variations of different power signal



- Offset active when SoC hits the thresholds
- Deviations between P_{AS} and P_{BESS}

Comparison of three SoC control strategies



Offset 1 depends on Δf → frequent threshold violations with limited control

Offset 2 depends on past values of P_{AS} → forces BESS to reach SoC_{nom}

Offset 3 is activated once thresholds are hit → less sensitive to SoC variation ➡ Less degradation for strategy 3

Preferred SoC Control Strategies
Need for an adaptive approach

Operation mode	Reference	Advantages
Off-grid	Strategy 1	• The offset does not directly cancel the control signal
Grid-tied	Strategy 3	• Less energy is cycled through the offset than in strategy 2 • Less battery capacity fading

- Depending on the operation mode grid-tied or off-grid we switch between strategies
- Based on the actual generation mix we can tune the parameters of each strategy

Conclusions

- Battery based energy storage plays an important role in microgrids with a large amount of RES
- A battery model allows to quantify capacity fading and to take corrective measures in case of deviations from the initially planned lifetime trajectory
- There are several strategies to control SoC and a preferred strategy depends on:
  - status of the microgrid (grid-tied vs isolated)
  - available options for the off-setting part (available generation mix, accessibility to power markets, etc.)
- Availability of forecast information (RES, load, scheduled islanding operation, etc.) can help to predict future SoC and parameterize the control system accordingly

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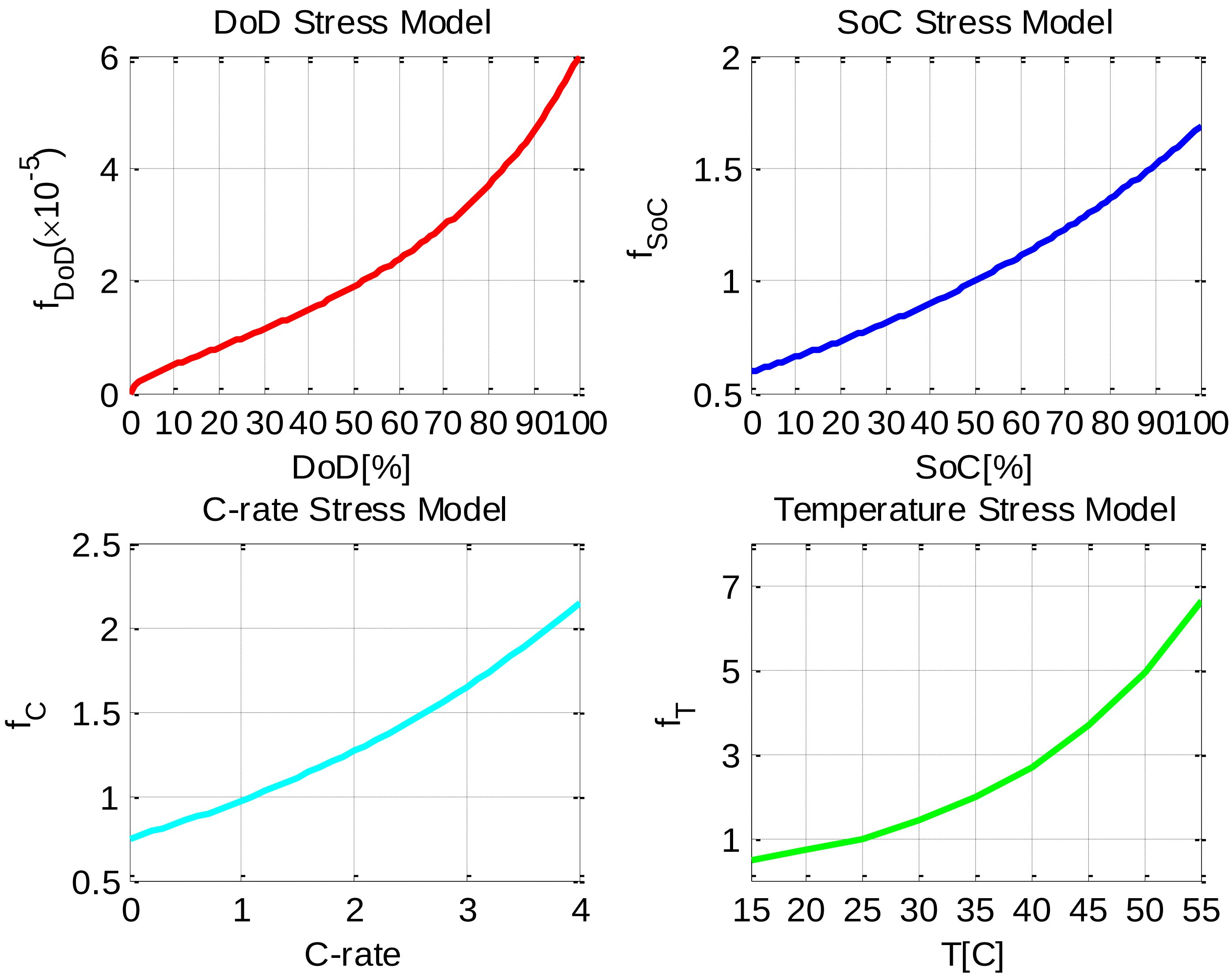
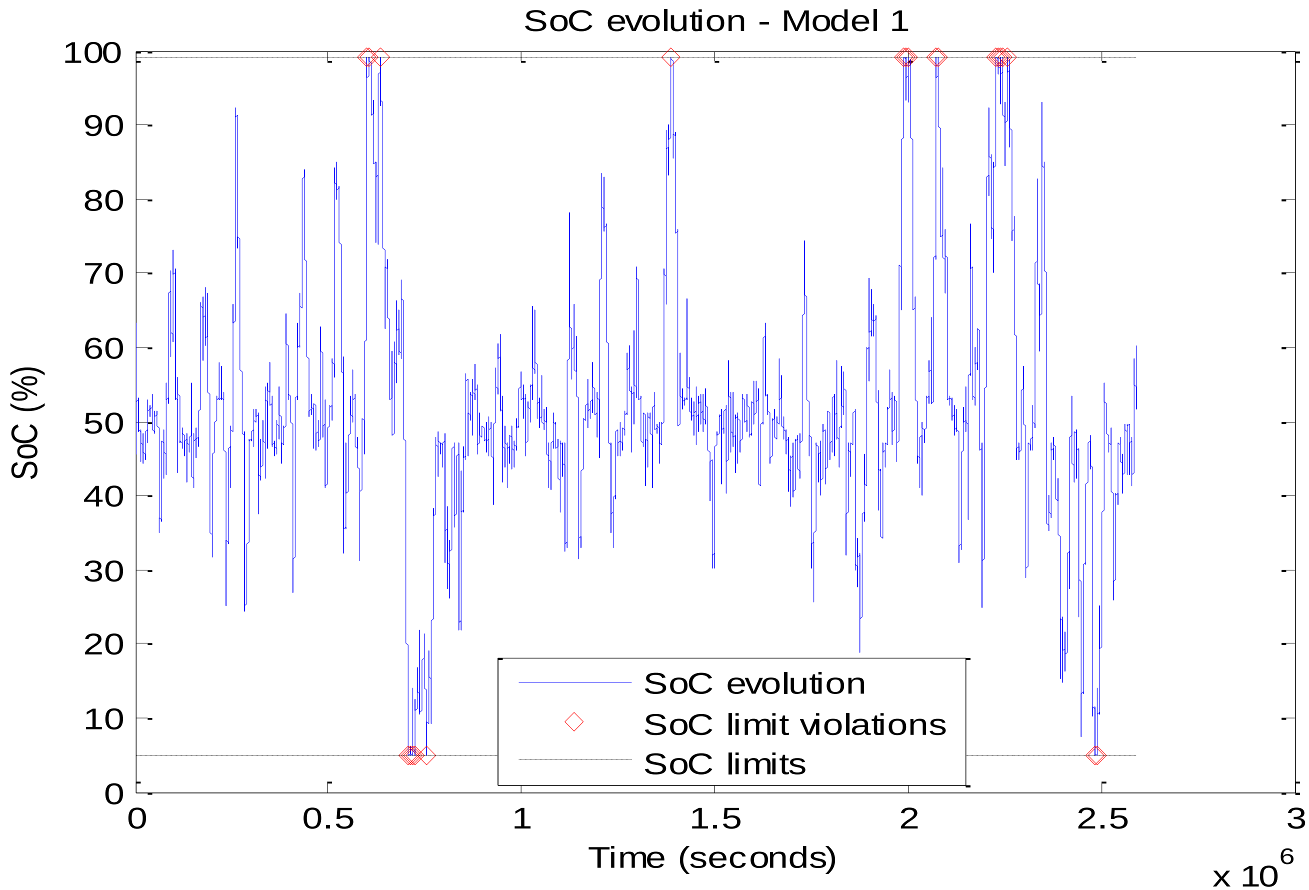
Battery Aging Model
Stress Factors



SoC Control Strategies
Model 1 – SoC evolution for one month

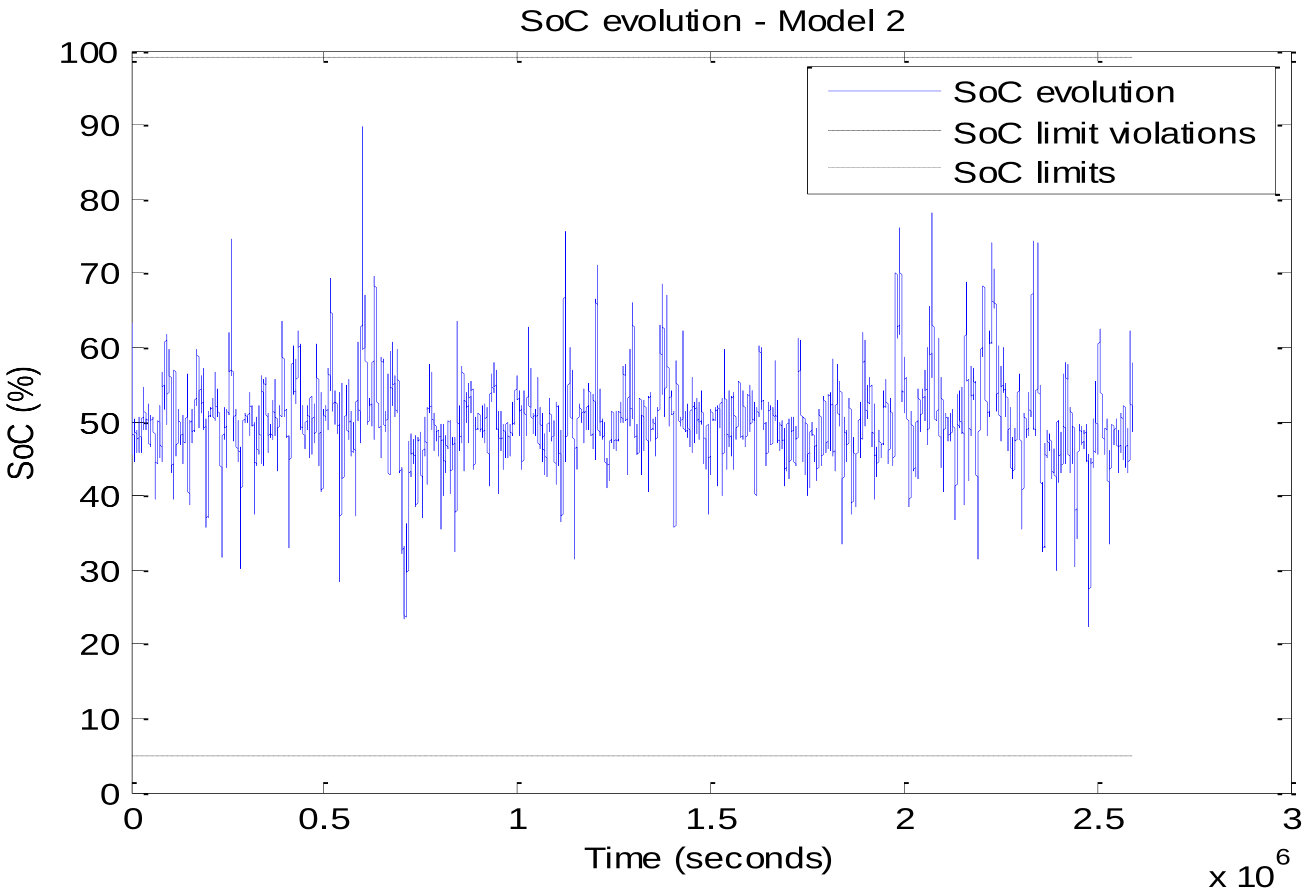
BESS degradation after 1 year: **= 3.67 %**



$$P_{offset} = 10\ \%\ P_{nom}$$

SoC Control Strategies
Model 2 – SoC evolution for one month

BESS degradation after 1 year: **= 3.22 %**

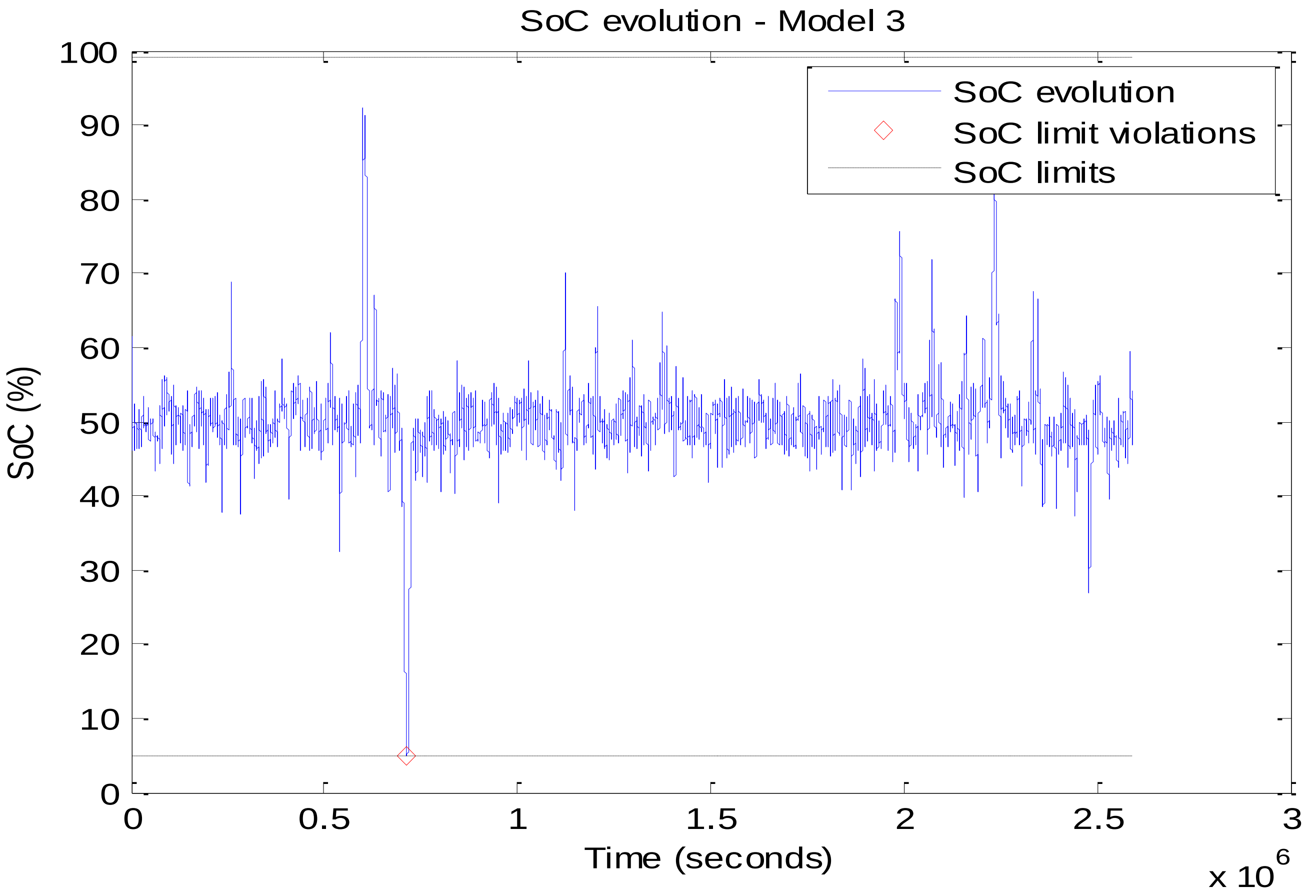


Averaging period:
1 hour

Dispatch delay:
15 min

SoC Control Strategies
Model 3 – SoC evolution for one month

BESS degradation after 1 year: **= 3.02 %**



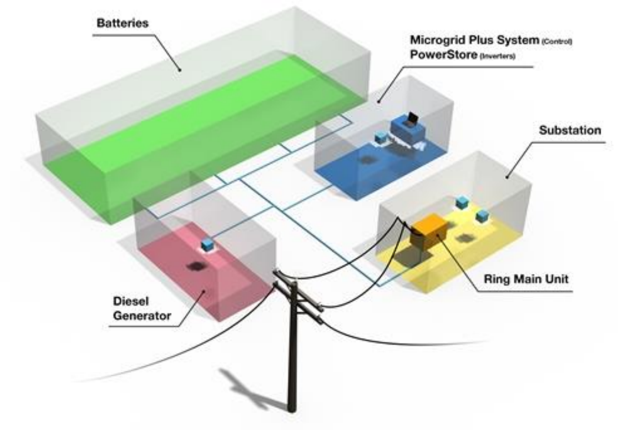
SoC upper threshold:
53 %

SoC lower threshold:
47 %

Ramp duration:
5 min

Min offset time:
15 min

References – Ancillary power system services
SP AusNet Grid Energy Storage System



Project name
SP AusNet GESS
Country
Victoria, Australia
Customer
SP AusNet
Completion date
Due to be completed in 2014

ABB solution

- Design, engineering, installation and testing of PowerStore-Battery, transformer and diesel generator
- Microgrid Plus System for overall system management
- Based on transportable containerized solution

Customer benefits

- Active and reactive power support during high demand periods
- Transition into isolated/Off-grid operation on command or in emergency cases without supply interruption
- Delay of power line investments

About the project

First grid-tied microgrid with Battery Energy Storage for distribution network support in Australia