Keep the evaluation of a battery state of energy updated

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INTRODUCTION

- Storage System
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Storage system

Power applications:

- **Power Quality**
- **Primary reserve**

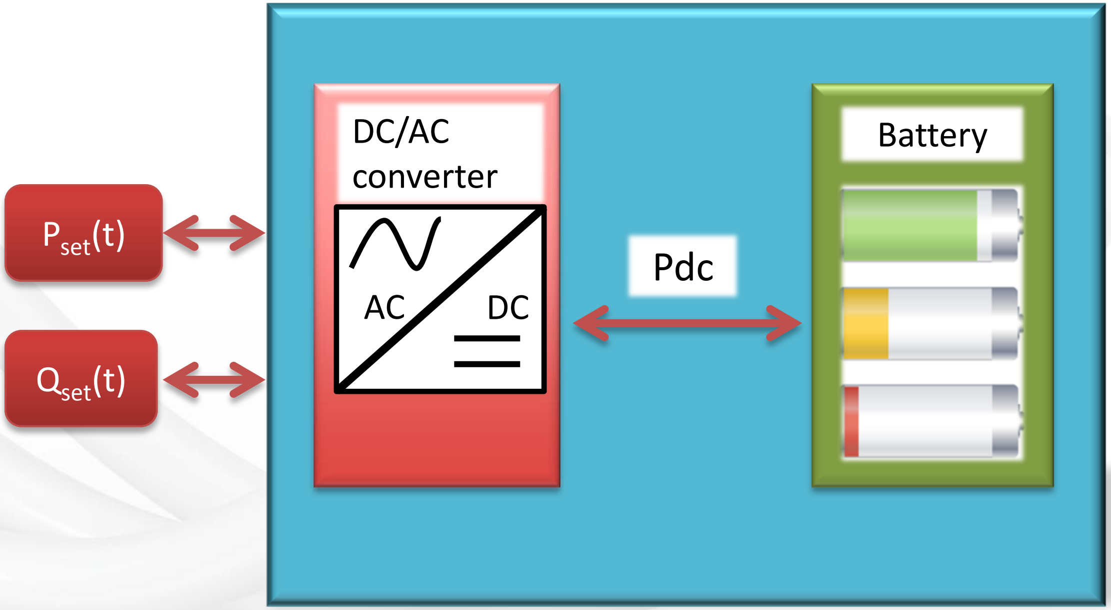
Energy applications:

- **Time shift**
- **Peak shaving**
- **Back-up**
- **Secondary reserve**

Storage system

An electrochemical storage system is composed of a battery and a DC/AC converter for connecting the battery (DC source) to the AC grid.

Diagnostic tool should not consider only the battery but all the devices in the storage system (at least the DC/AC converter).



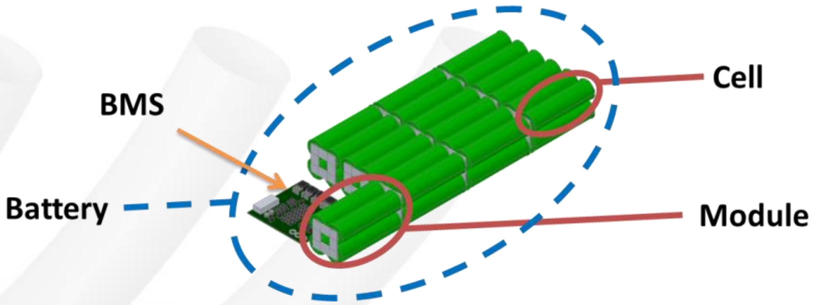
Battery

All the electrochemical storage system are composed of cells connected in series and parallel in order to have the nominal voltage and current.

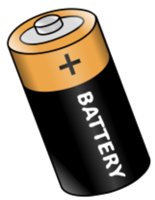
In general a Battery Management System monitors and controls the main battery variables for safety reason.

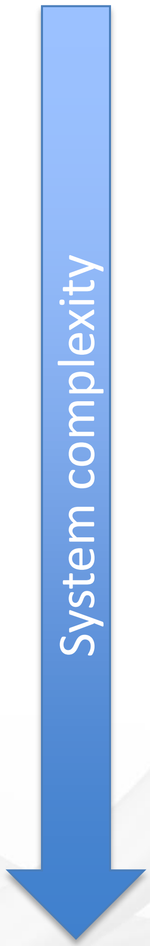
The battery operating limits depends on:

- Battery voltage
- Modules or cell voltage
- Temperature
- *State of charge estimation*
- ...

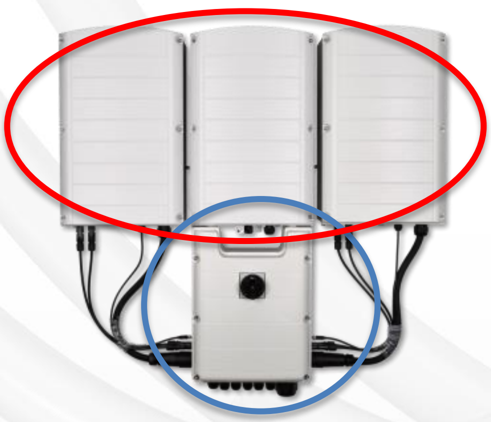


State Estimators





Battery



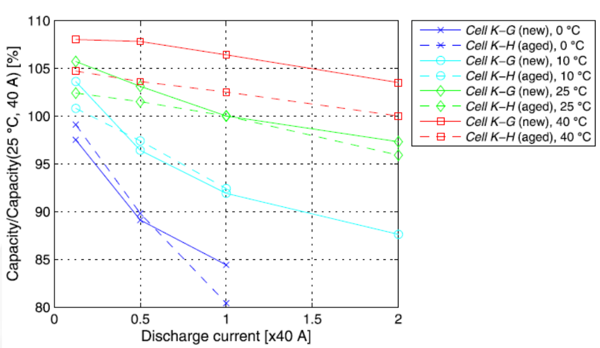
Inverter

State of Charge (SoC):

$$SoC(t) = SoC(0) + \frac{\int_{t_0}^{t} I_{DC}\, dt}{C}$$

???

A. Farmann et al. / Journal of Power Sources 281 (2015) 114–130

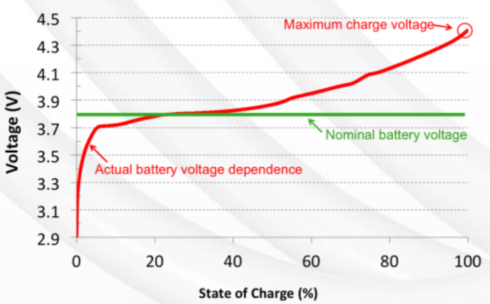


State of Energy (SoE):

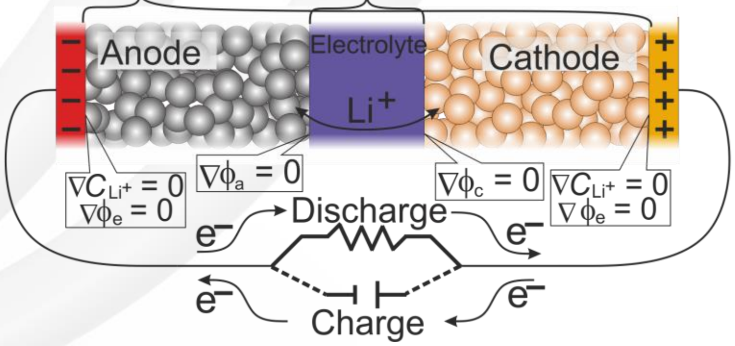
$$SoE(t) = SoE(0) + \int_{t_0}^{t} P_{AC}\, dt$$

Battery State Estimators

- On-board capacity estimation methods
  - Current based estimation
  - Voltage based estimation
    - Off-line
    - On-line
      - Kalman filter or other filters
      - Least squares estimation-based
  - Electrochemical model-based
  - Incremental capacity analysis and differential voltage analysis



$$i_{a/c} = i^0_{a/c}\left(\exp\left(\frac{\alpha_{a/c}F}{RT}\eta\right) - \exp\left(-\frac{(1-\alpha_{a/c})F}{RT}\eta\right)\right) \qquad \frac{\partial C_{Li^+}}{\partial t} = D_{Li^+}\frac{\partial^2 C_{Li^+}}{\partial x^2} + \frac{FD_{Li^+}}{RT}\frac{\partial}{\partial x}\left(C_{Li^+}\frac{\partial \phi}{\partial x}\right)$$



STATE OF ENERGY

- Input/Output
- Algorithm
- Parameters

STATE OF ENERGY

Input/Output

$P_{ac}(t)$

$Q_{ac}(t)$

Sistema di accumulo

SoE

Energia disponibile

Batteria (DC)

Stadio di conversione DC/AC

$V_{dc}(t)$

$I_{dc}(t)$

STATE OF ENERGY

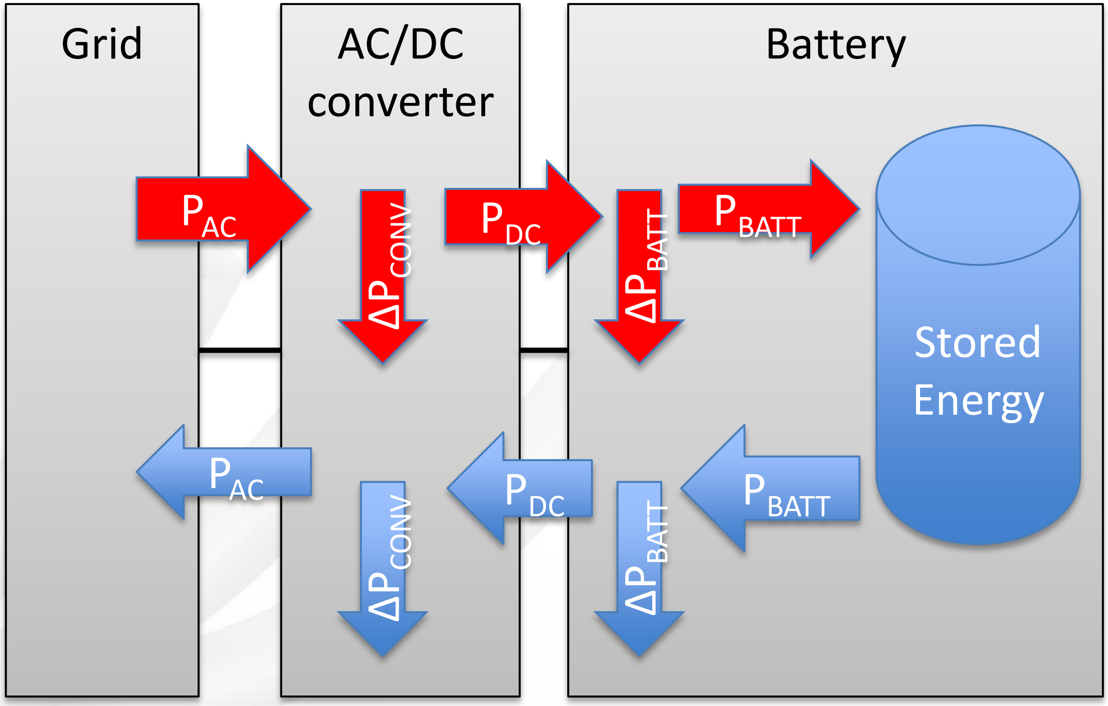
Algorithm

$$SoE(P_{ac}, Q_{ac}, V_{oc}(t_0)) = \int_{t_0}^{t_{end}} P_{ac} dt$$

$E_{charged} > E_{stored}$

$E_{discharged} < E_{stored}$

Due to converter and battery losses



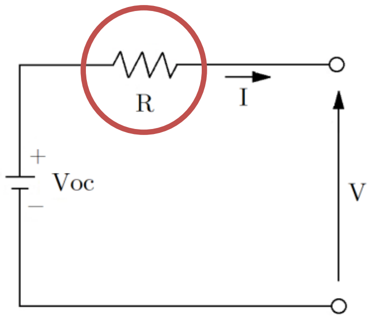
STATE OF ENERGY

Algorithm

$t \rightarrow V_{OC}$

$P_{AC} \rightarrow P_{DC}$

$$SoE = \int_{V_{oc}(t_0)}^{V_{oc}(t_{end})} \frac{P_{dc}}{\eta} \cdot \left[\frac{dV_{oc}}{dt} \right]^{-1} dV_{oc}$$



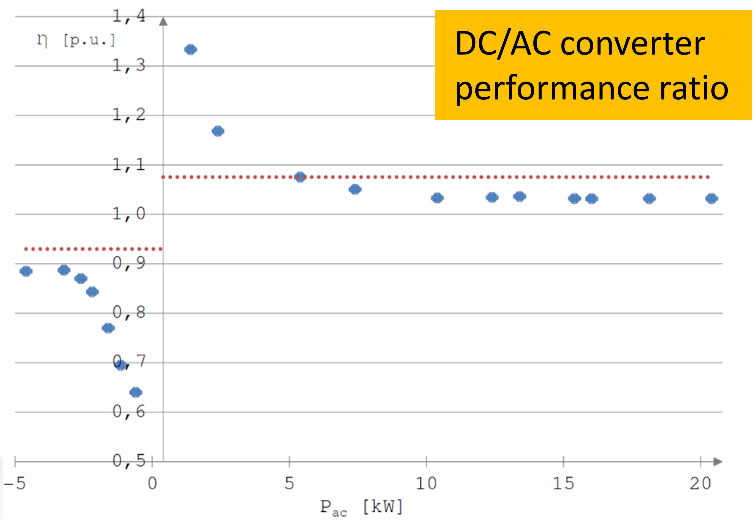
Energy discharged as function of the open circuit voltage variation

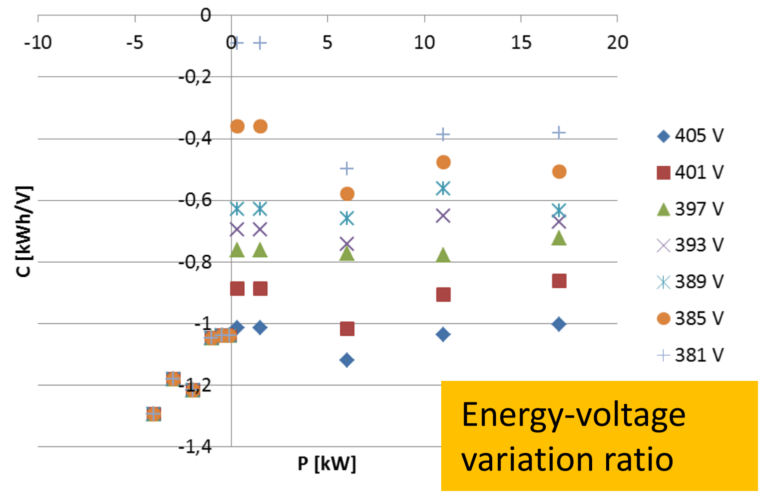
$$C(P_{dc}, V_{oc-uc}) = \frac{\Delta E_{dc}(\Delta t)}{\Delta V_{oc}(\Delta t)}$$

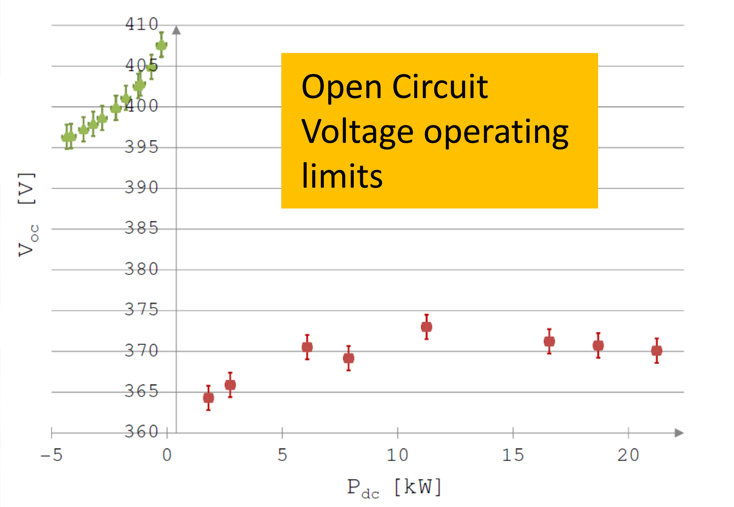
- **Less parameters** to use
- Updating parameters value **online**
- Higher estimation accuracy

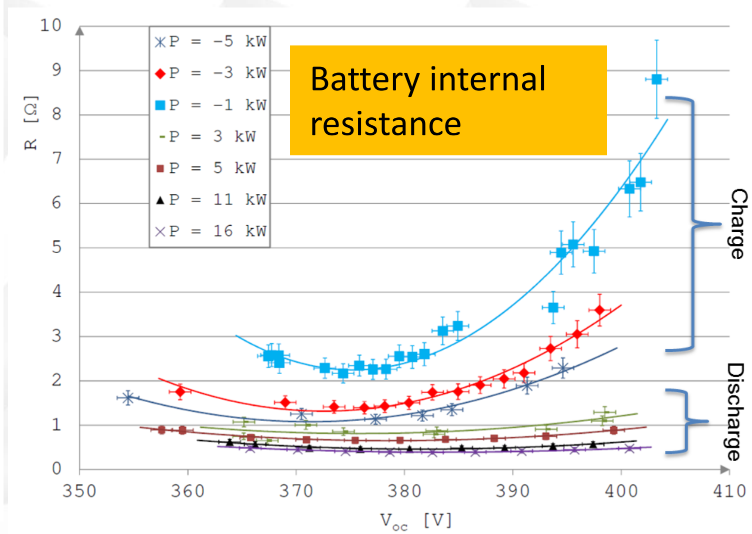
STATE OF ENERGY

Parameters









TESTING

- System under test
- Procedure
- Results

TESTING

System under test

Specification	
Number of modules	31
Battery Rated voltage	372 V
Nominal capacity	150 Ah
Maximum voltage	298 V
Minimum voltage	446 V
Active Power	-5 ÷ 20 kW
Reactive Power	-15 ÷ 15 kVar

Battery	**Nominal value**	**Sperimental value**
Energy	58,8 kWh	31 kWh

AGING EFFECT!

Procedure

Repeat the following points starting every time from different state of charge:

1. Make the estimation of the available energy using the SoE estimator
2. Leave the battery in stand-by
3. Measure the open circuit voltage
4. Make the estimation of the available energy using the **state of the art method**
5. Discharge the battery at constant power until it reaches one of the operating limit
6. Measure the discharged Energy

Charge

$$E_{nom} = \underset{\text{31 kWh}}{\underbrace{E_{max}}} \cdot \underbrace{\frac{V_{oc}(0) - max[V_{oc}]}{\Delta V_{oc}}}_{\sim \text{DoD}}$$

Discharge

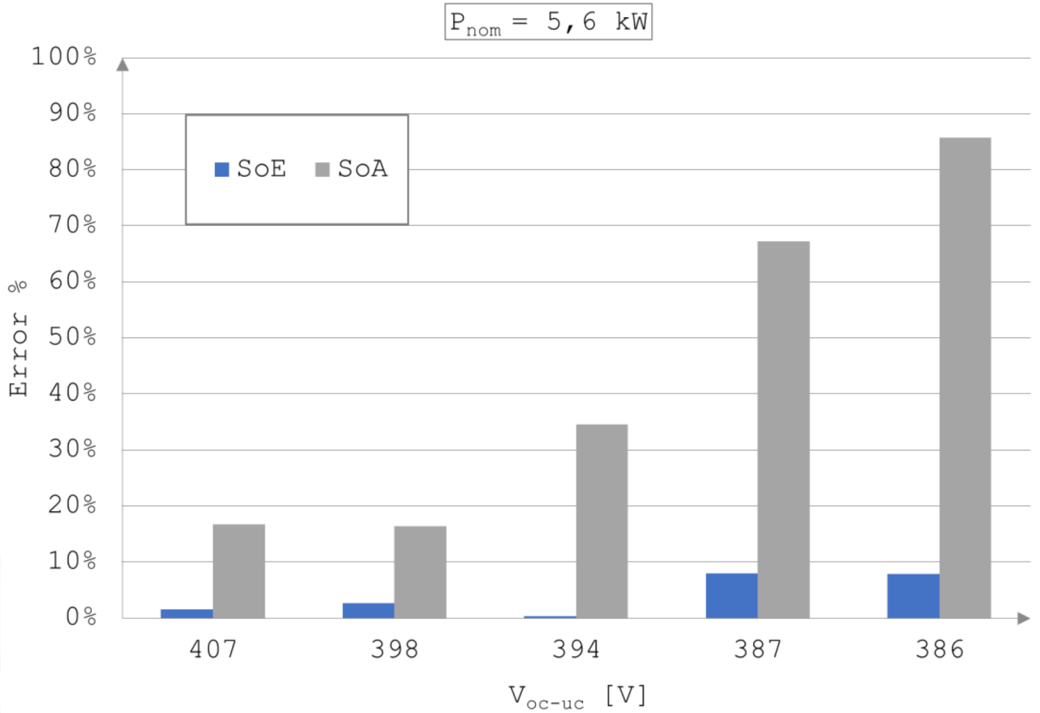
$$E_{nom} = E_{max} \cdot \underbrace{\frac{V_{oc}(0) - min[V_{oc}]}{\Delta V_{oc}}}_{\sim \text{SoC}}$$

TESTING

Results

Average error with SoE estimator ~ 6%

Average error of SoA much higher than the SoE estimator



SoA does not take into account the DC/AC converter and the memory effect

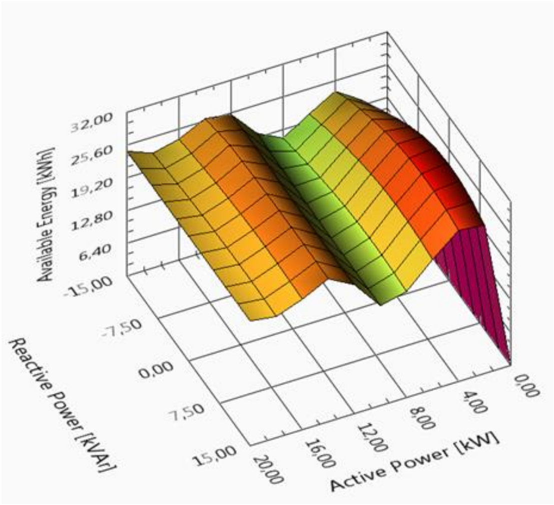
Conclusion

Tool for evaluating the available energy of a storage system:

- Higher accuracy than the SoA
- Low computational complexity
- Easy parameters updating

Using this tool recursively, the net capacity of a storage system can be evaluated as function active and reactive power

Improvement of the optimization tools used to manage smart grids or to aggregate storage systems



Thank you for your attention!

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