TEXAS INSTRUMENTS

TI POWER

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

DOMINIK HARTL

GAUGING TECHNIQUES FOR RARELY DISCHARGED BATTERIES

Agenda

- Rarely discharged systems
- New algorithms for rarely discharged applications
  - End-of-service (EoS) determination
  - Watt hour (WHr) charge termination
  - Accumulated charge measurement
- Compensated end-of-discharge voltage (CEDV) gas gauges for rarely discharged applications

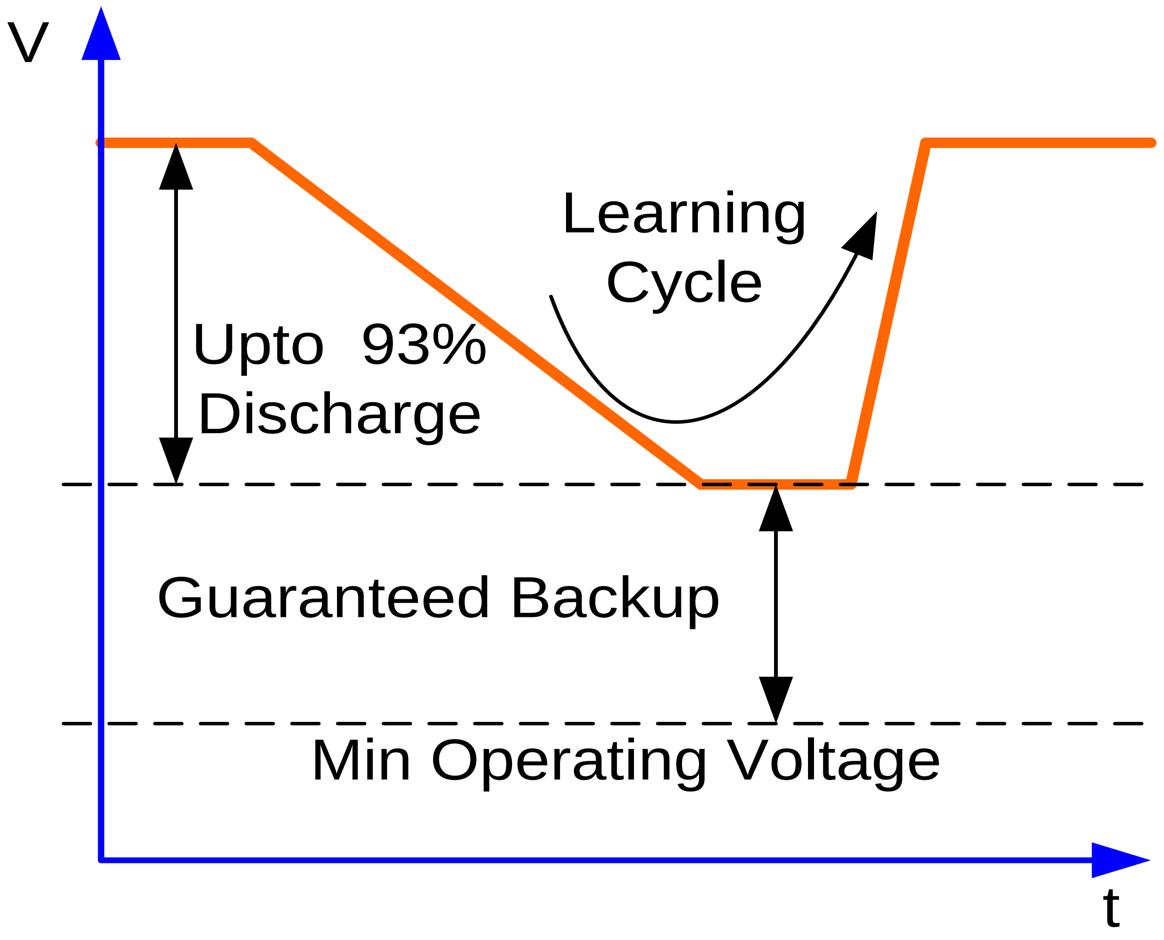
RARELY DISCHARGED SYSTEMS

Rarely discharged systems

- Battery is kept fully charged
- Require minimum guaranteed battery power
- Battery is rarely discharged
- Mostly used as backup systems
- Examples of rarely discharged systems:
  - UPS backup systems
  - Telematics backup systems
  - Energy storage systems
  - Server power systems
  - Emergency battery power modules

Traditional learning NOT optimal for rarely discharged systems

- Traditional learning:
  - The dreaded ‘maintenance cycle’
  - Alternatively, the energy system can be removed from service for maintenance
  - For maximum system stability, it’s oversized in every way:
    - Physically
    - Economically
    - Redundant energy



END-OF-SERVICE (EOS) DETERMINATION METHOD

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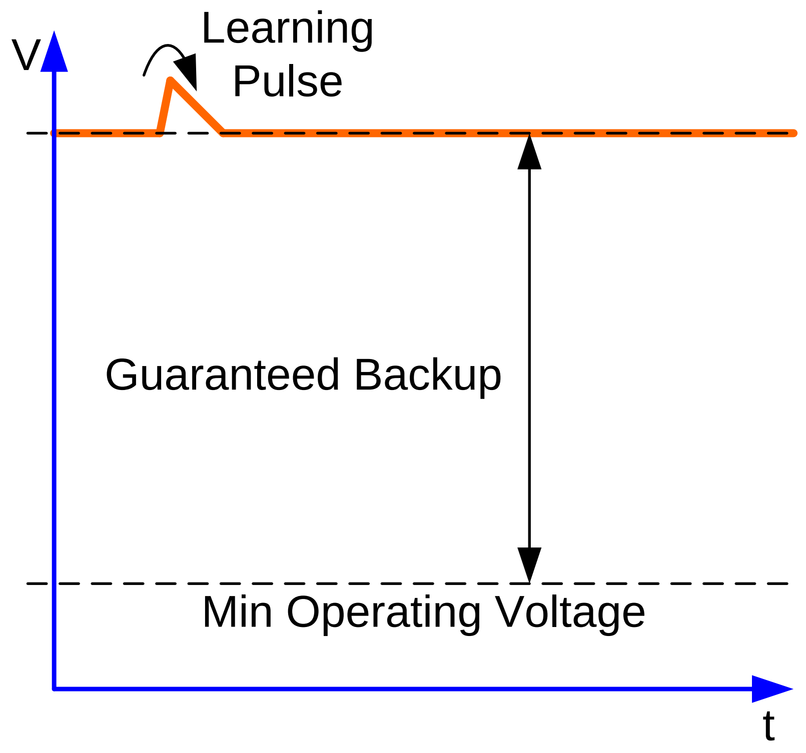
EoS determination

- Device uses learning phases to evaluate battery health and estimate when it is nearing the end of usable life.
- Learning phases consist of infrequent learning pulses.
- During the learning pulse, enough data is gathered to enable EoS determination through change of resistance d(dR/dt) detection.
- Learning phases may be configured to use either one of the two options:
  - Charge-before-discharge learning pulse
  - Discharge-before-charge learning pulse

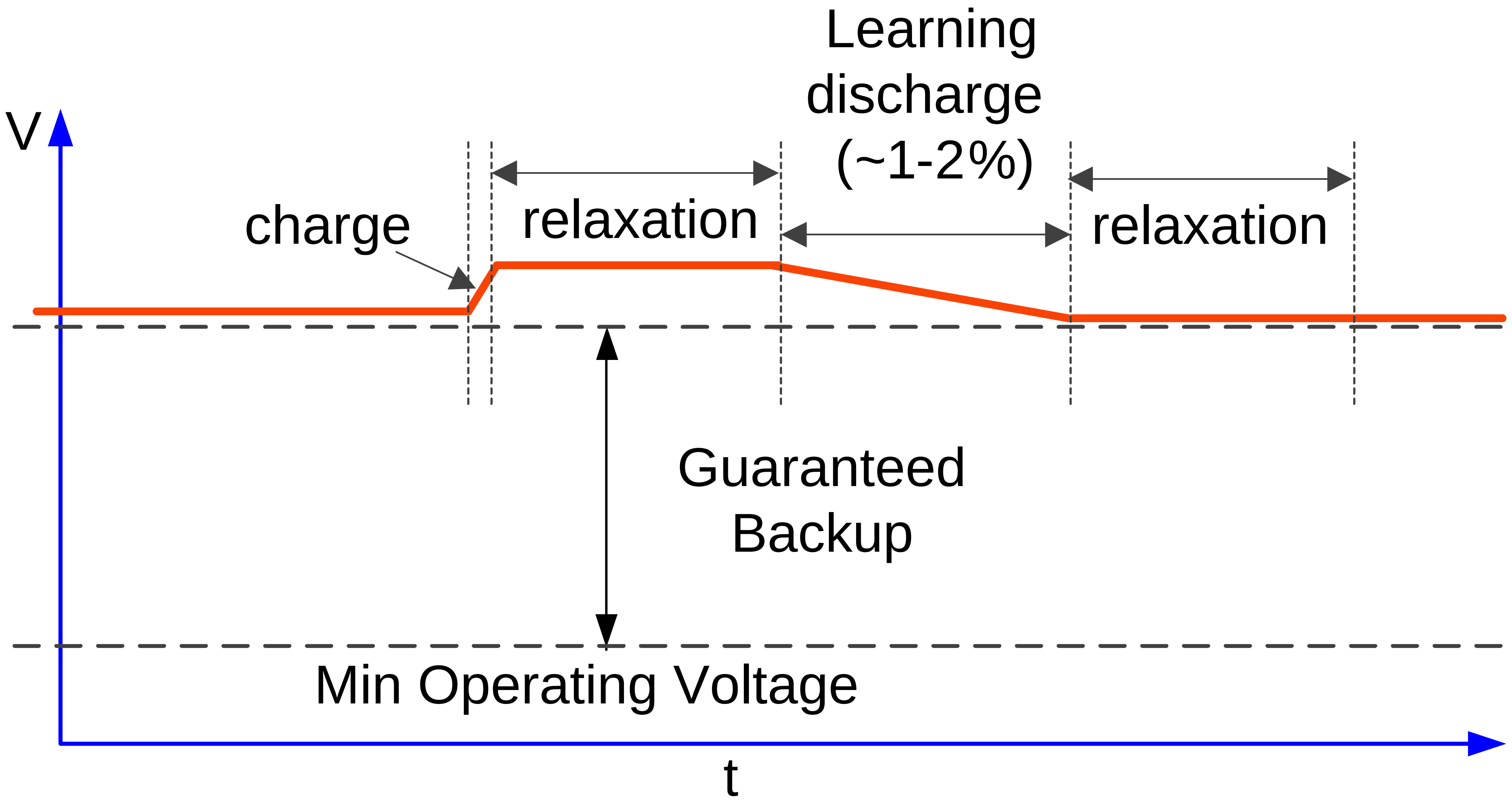


EoS determination

- Normal operation:
  - System under power with battery charged and maintained.
  - Normal compensated end-of-discharge voltage (CEDV) algorithm is used with slight change in configuration settings.
  - Normal charging with charging voltage optimized for longevity, e.g., 4.0V.
    - This FullChargeCapacity () is used for reporting.
- Learning pulses:
  - Controlled, limited discharge avoids impact to the guaranteed capacity available.
  - Timing between learning pulses is important for algorithm.
- Through multiple learning pulses, enough data is gathered to enable EoS determination.

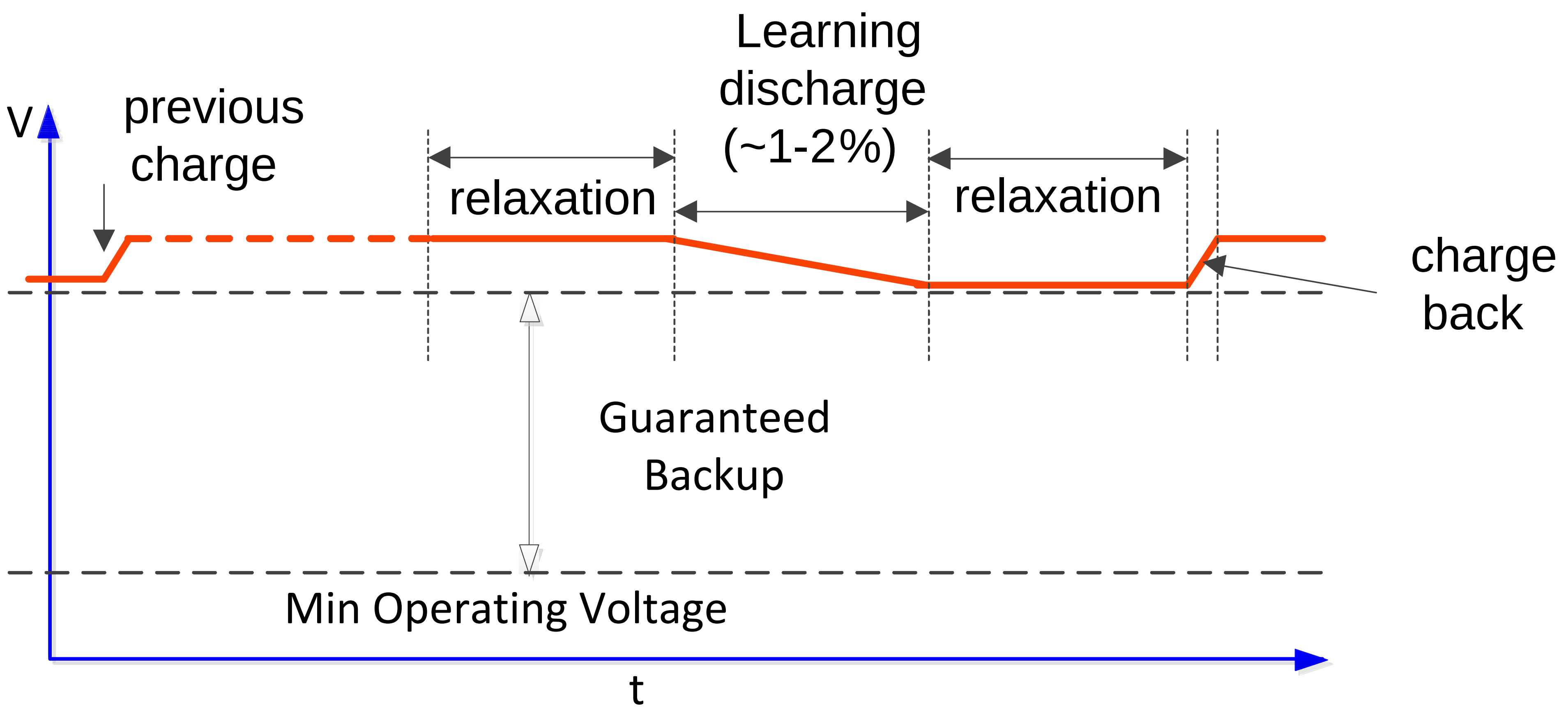
EoS determination

- Charge-before-discharge learning pulse:
  - ChargingVoltage() is increased slightly to charge battery higher than typical.
  - After relaxation, a learning discharge pulse is triggered, discharging ~1-2% of capacity over a fixed time period.



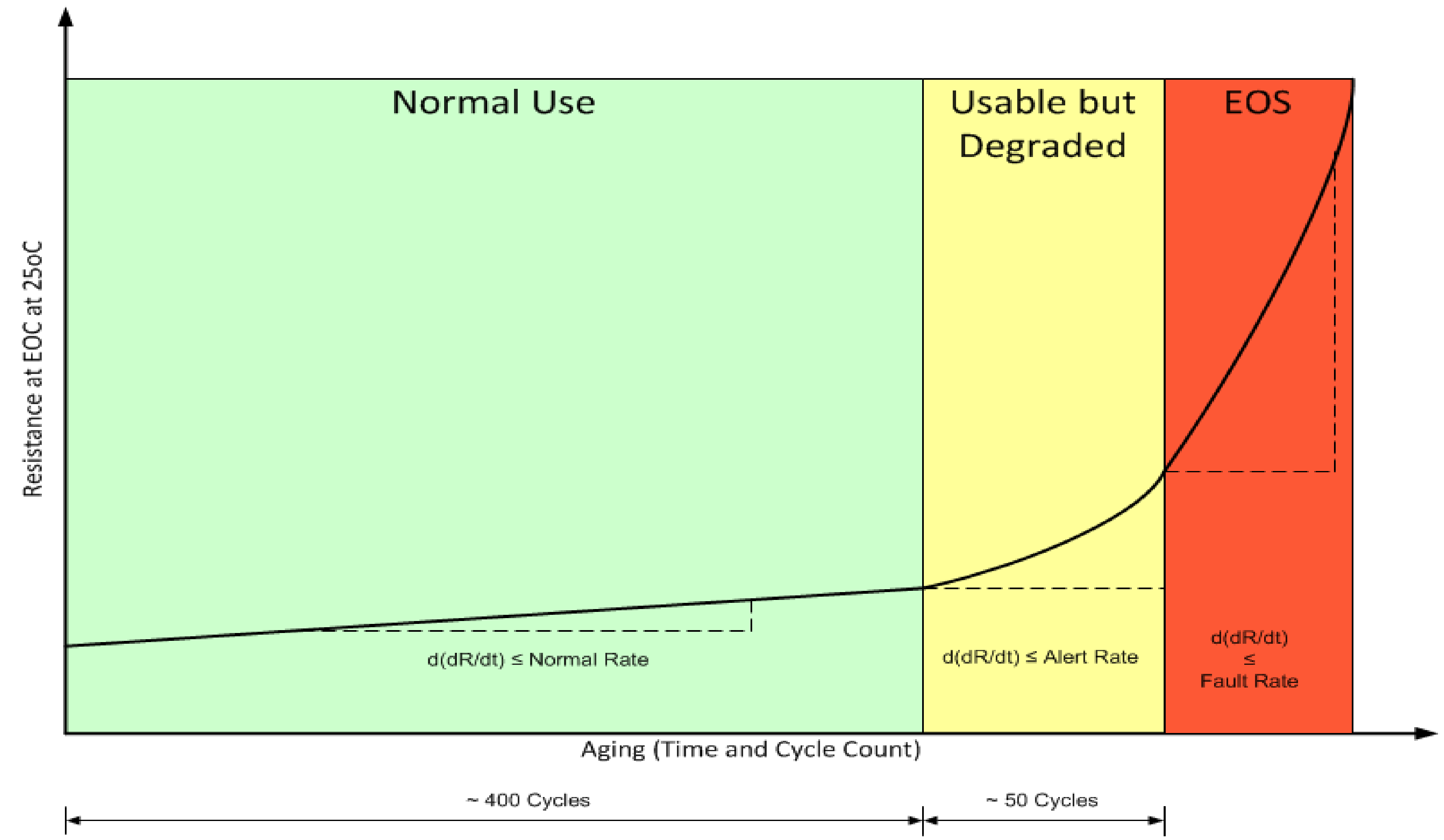
EoS determination

- Discharge-before-charge learning pulse:
  - Battery is charged to existing *ChargingVoltage()* level and allowed to relax.
  - A learning-discharge pulse is triggered, discharging ~1-2% of capacity over a fixed time period.
  - After pulse completes, battery can be recharged back to *ChargingVoltage()* level.



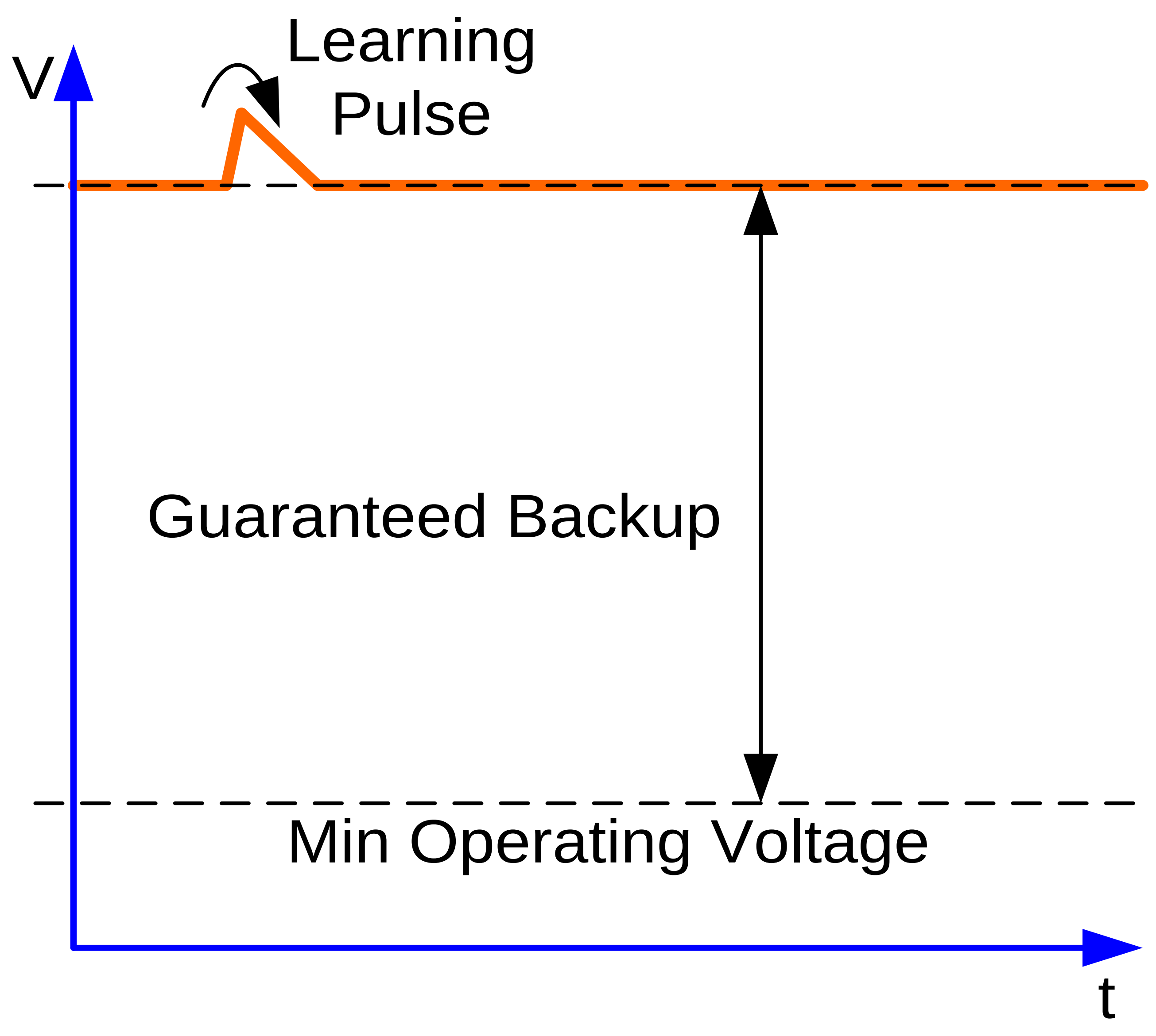
Change in resistance Vs age

- Nominal profile shown.
- There are cell, chemistry and temperature variations leading to a different resistance profile between regions.
- Relationship between R and aging is a function of cycle count AND time.



EoS determination

- Learning pulses:
  - Triggered discharge of ~C/10 for a fixed time duration (~1-2% of capacity).
  - Battery voltage measured at end of discharge and after battery is relaxed.
  - Pulses triggered at periodic intervals.
  - Effective **resistance of cell** calculated from each pulse capture using difference in battery voltages and pulse load current.
  - Two methods may be used to detect EOS:
    - Direct resistance monitoring called **Direct Resistance Decisioning (DRD).**
    - Cell resistance trend called **Resistance Slope Decisioning (RSD).**



EoS determination

- DRD:
  - Change in resistance is computed using multiple learning pulses over timed intervals (~days to weeks).
  - Increase in resistance versus baseline resistance provides indication of cell approaching end of usable service.
  - The degradation of resistance should be linear until SOH has degraded by 30 to 40%.
  - Provides additional information the system can leverage.

DRD: Cell resistance monitoring

- Cell resistance at beginning of service is measured and stored as ***initial Rcell\.***
- Programmable thresholds for system flags:
  - Rcell / ***initial Rcell*** ≤ ***DRD alert threshold***
    - → Normal operation
  - ***DRD alert threshold*** < Rcell / ***initial Rcell*** ≤ ***DRD warning threshold***
    - → Set ALERT Flag
  - ***DRD warning threshold*** < Rcell / ***initial Rcell***
    - → Set WARN flag
- Significant changes in Rcell may indicate cell replacement.
- EoS ALERT could be ~50 cycles or a few months prior to actual EoS.
  - Some filtering can be enabled before EoS alert or fault indicated.
    - eg: Condition must be detected 3 times in a row.

EoS determination

- RSD:
  - Resistance rate of change (dR/dt) computed using multiple learning pulses over timed intervals (~days to weeks).
  - Included as secondary EoS determination technique.
  - The degradation of R should be linear until SOH has degraded by 30 to 40%.
  - Increase in dR/dt versus baseline rate provides indication of cell approaching end-of-usable service.

RSD: d(dR/dt) – Rate of change of resistance

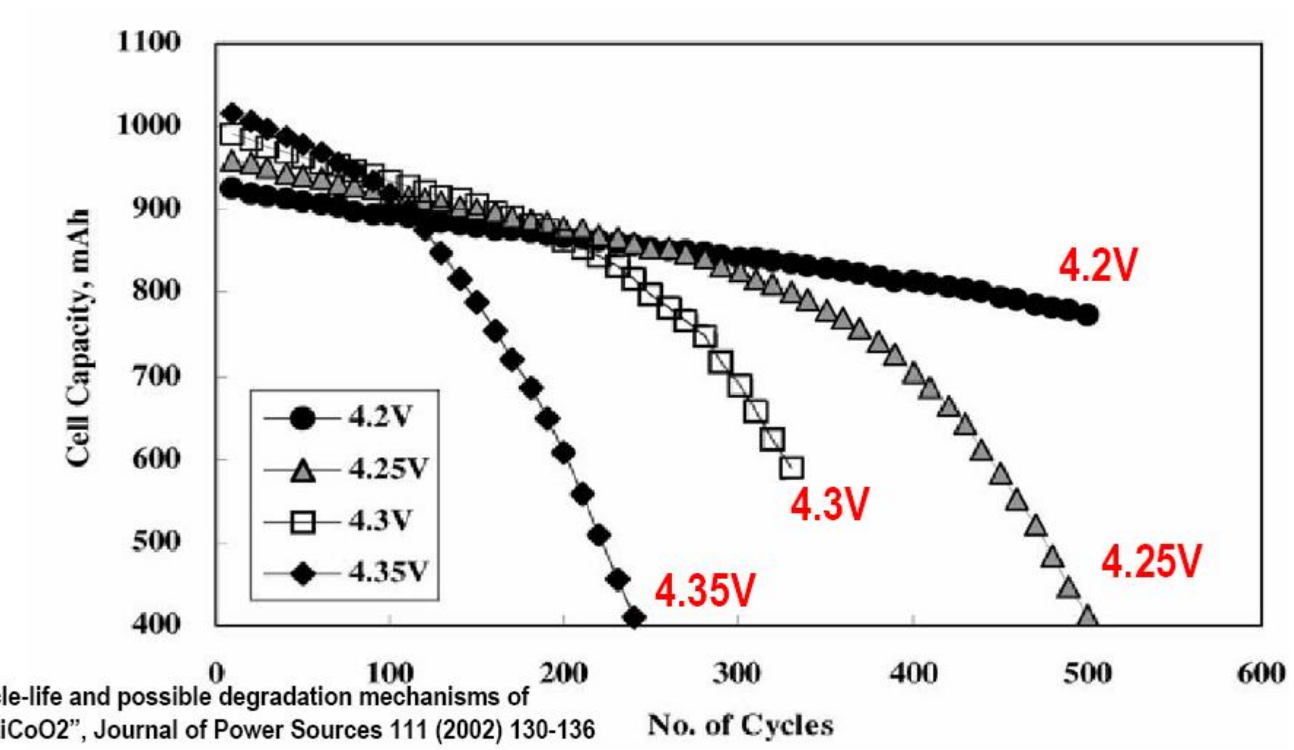
- Programmable thresholds for system flags:
  - dR/dt ≤ ***RSD alert threshold***
    - → Normal operation
  - ***RSD alert threshold*** < dR/dt ≤ ***RSD warning threshold***
    - → Set ALERT Flag
  - ***RSD warning threshold*** < dR/dt
    - → Set WARN Flag
- EoS ALERT could be ~50 cycles or a few months prior to actual EoS.
  - Some filtering can be enabled before EoS alert or fault indicated.
    - eg: Condition must be detected 3 times in a row.
- High level of configurability allows for greater system and battery adaptability.

EoS learning initiation and control

- Optional automatic initiation:
  - Programmable period between learning: Eg: 1 week
  - Programmable period between failed learning and initiate a new one: Eg: 1 day
- Host controlled initiation learn() command:
  - Read returns present learning cycle status:
    - Running, pass, fail, abort, complete
  - Write can control key states:
    - Start, abort
- Learning is bounded:
  - Temperature: Learn min temperature ≤ temperature ≤ learn max temperature
    - Learning is declared invalid if temperature is measured outside of this temperature at any time during the learning cycle.
    - The gauge will adjust cell resistance within the allowed temperature range using Rcell high and low temperature coefficients to calculate an expected value of resistance at the learn target temperature.

EoS determination benefits

- Increased battery longevity:
  - Majority of inactive time spent at lower voltage, thereby reducing battery degradation.



"Factors that affect cycle-life and possible degradation mechanisms of a Li-ion cell based on LiCoO2", Journal of Power Sources 111 (2002) 130-136

- Battery always online:
  - Learning occurs using the top ~1-2% of capacity that is only available if charged to the higher voltage.
  - Capacity available for operation is never used for learning.

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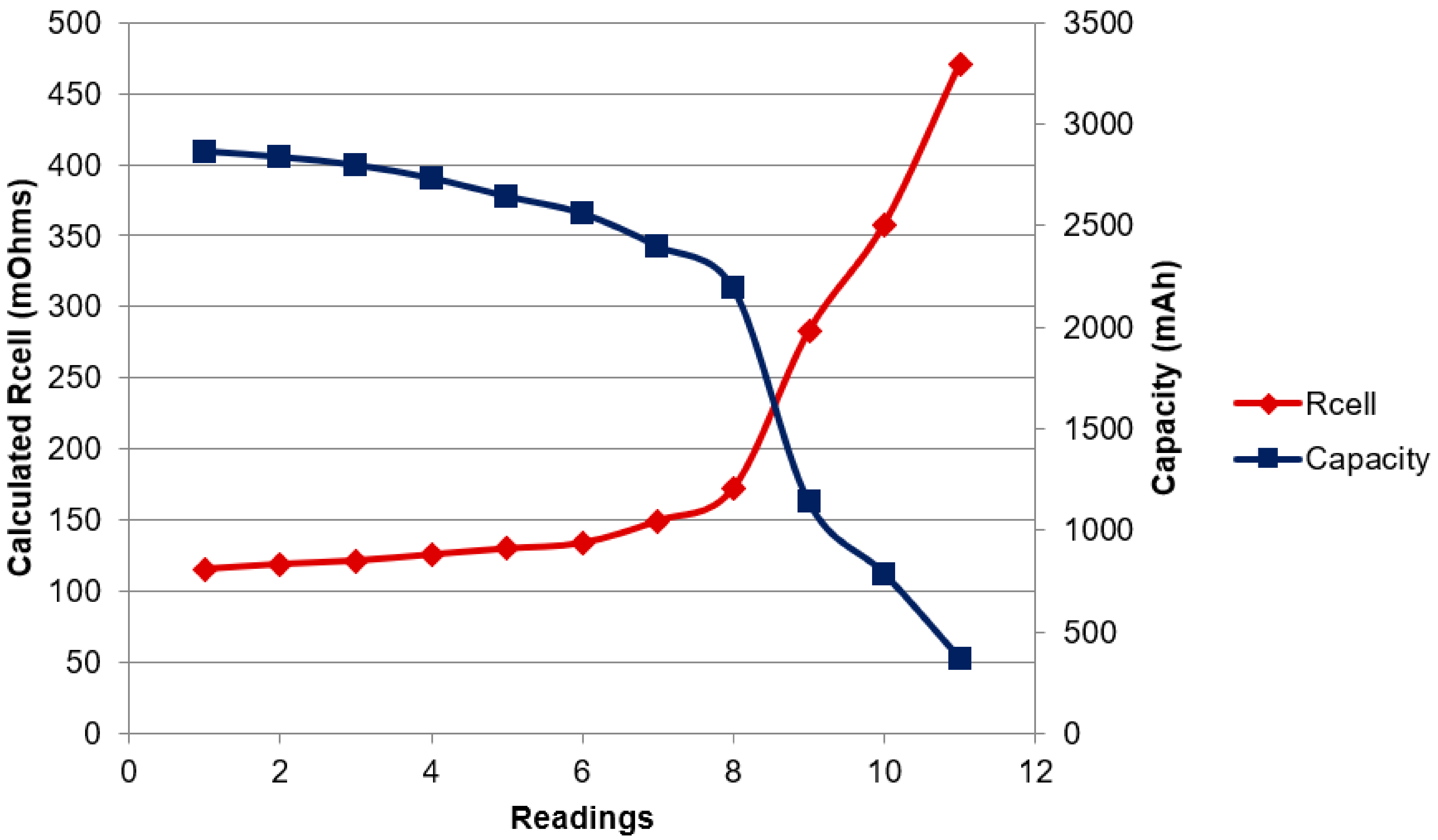
Experimental data



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WHR CHARGE TERMINATION

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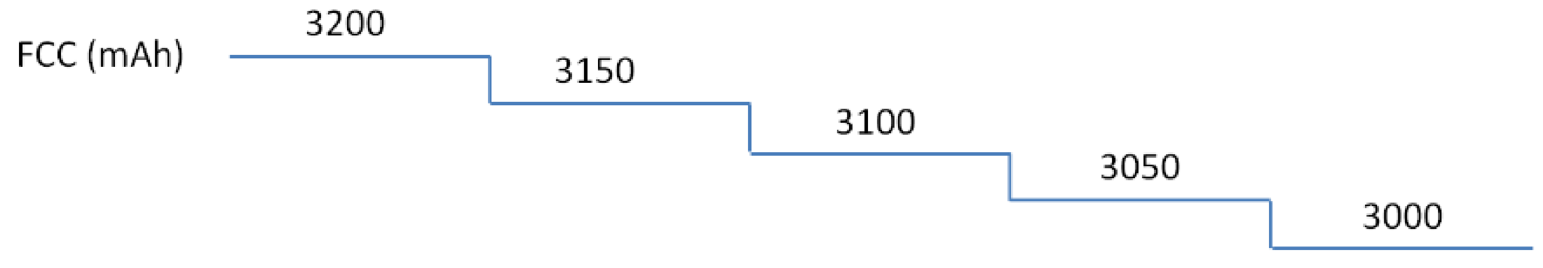
WHr charge termination

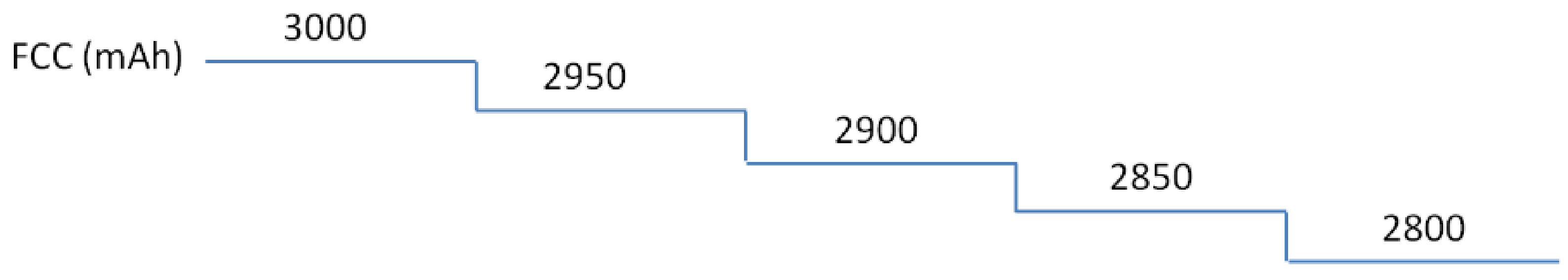
- Device monitors *RemainingCapacity()* and automatically increases *ChargingVoltage()* to achieve target capacity.
- Allows reduced *ChargingVoltage()* while battery is new for extended life operation.
- Increases *ChargingVoltage()* as needed to maintain required capacity as battery health degrades.
- Requires use of smart charger or other programmable charge control circuitry.

WHr charge termination

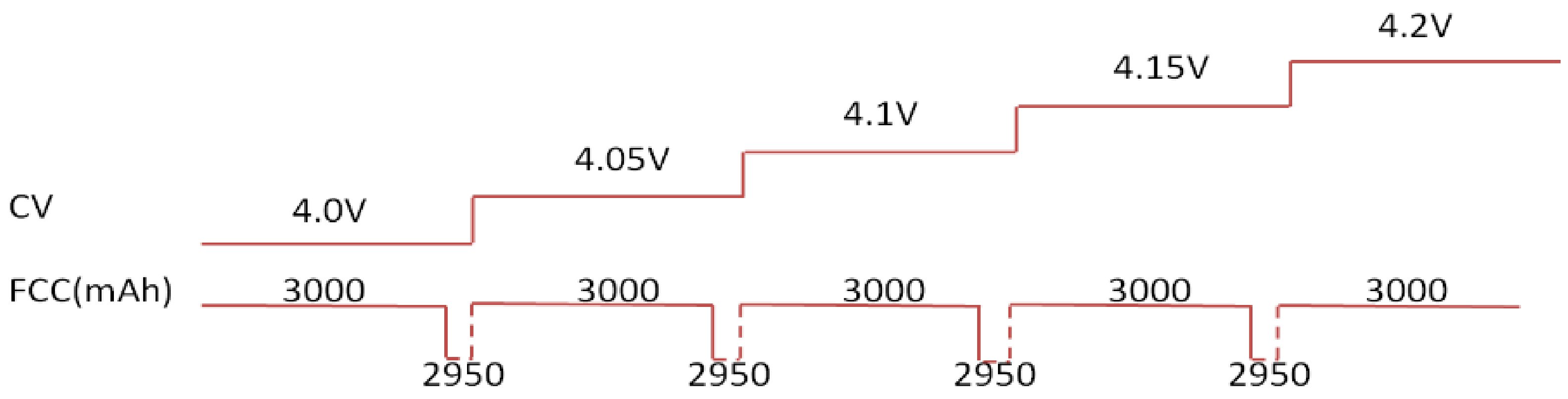
Conventional charging algorithm: 4.2 V



Conventional charging algorithm: 4.0 V



WHr charging algorithm



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Accumulated charge measurement

- Charge in/out of battery measured and accumulated using integrated coulomb counter.
- Charge integration can include:
  - Discharging current only.
  - Charging current only.
  - Both charging and discharging current.
- Configurable interrupt after programmed level of charge accumulated

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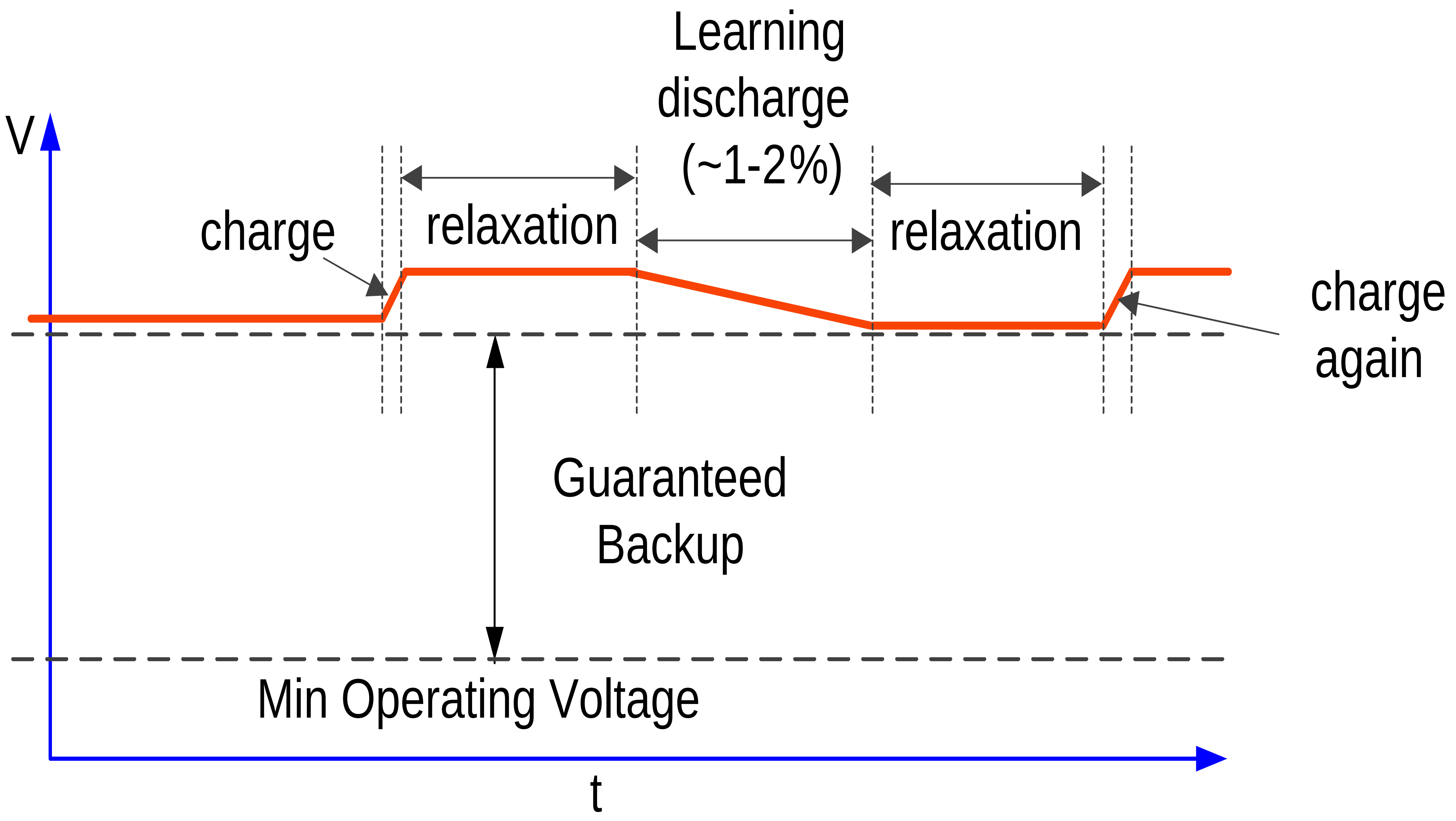
SUMMARY

Conclusion / summary

- The **new resistance learning pulse (EoS method)** in rarely discharged systems enables optimized power systems:
  - System power stability
  - Power system reliability
  - Energy predictability
  - Power system safety
  - Emergency power longevity



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