TSDOS TRANSMISSION & SUBSTATION DESIGN & OPERATION SYMPOSIUM

THE UNIVERSITY OF TEXAS AT ARLINGTON

NERC Compliance and Battery Health Assessment Through Analysis of Impedance Measurements

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Agenda

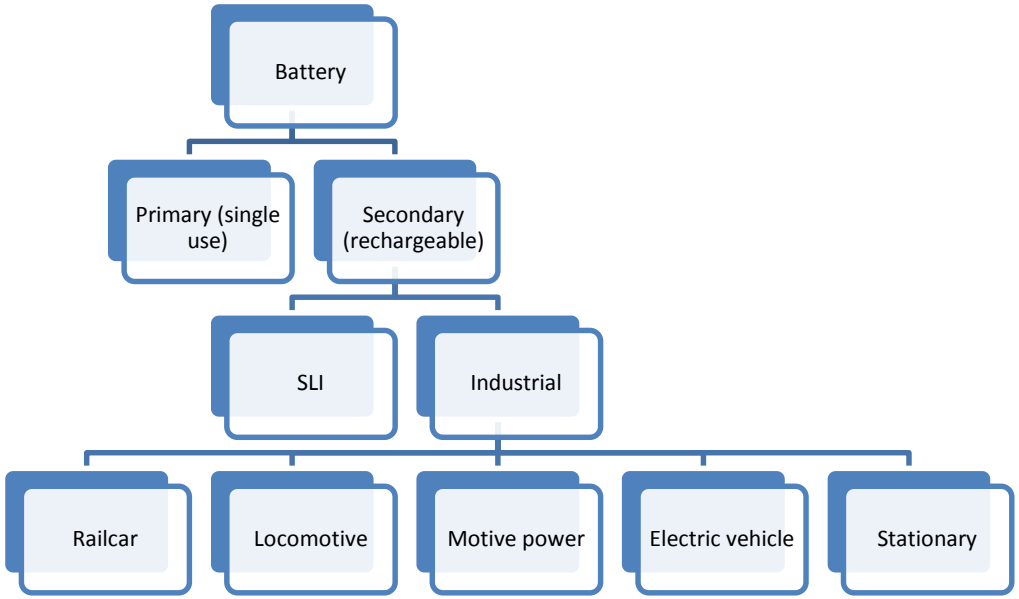
- Why is battery testing important?
- What is a battery?
- Lead-Acid Battery (VLA and VRLA)
- Nickel-Cadmium Battery
- Internal Ohmic Testing
- Battery Impedance Testing
- Pointers for a good measurement
- Data analysis
- NERC Compliance
- Case Studies

Why is battery testing important?

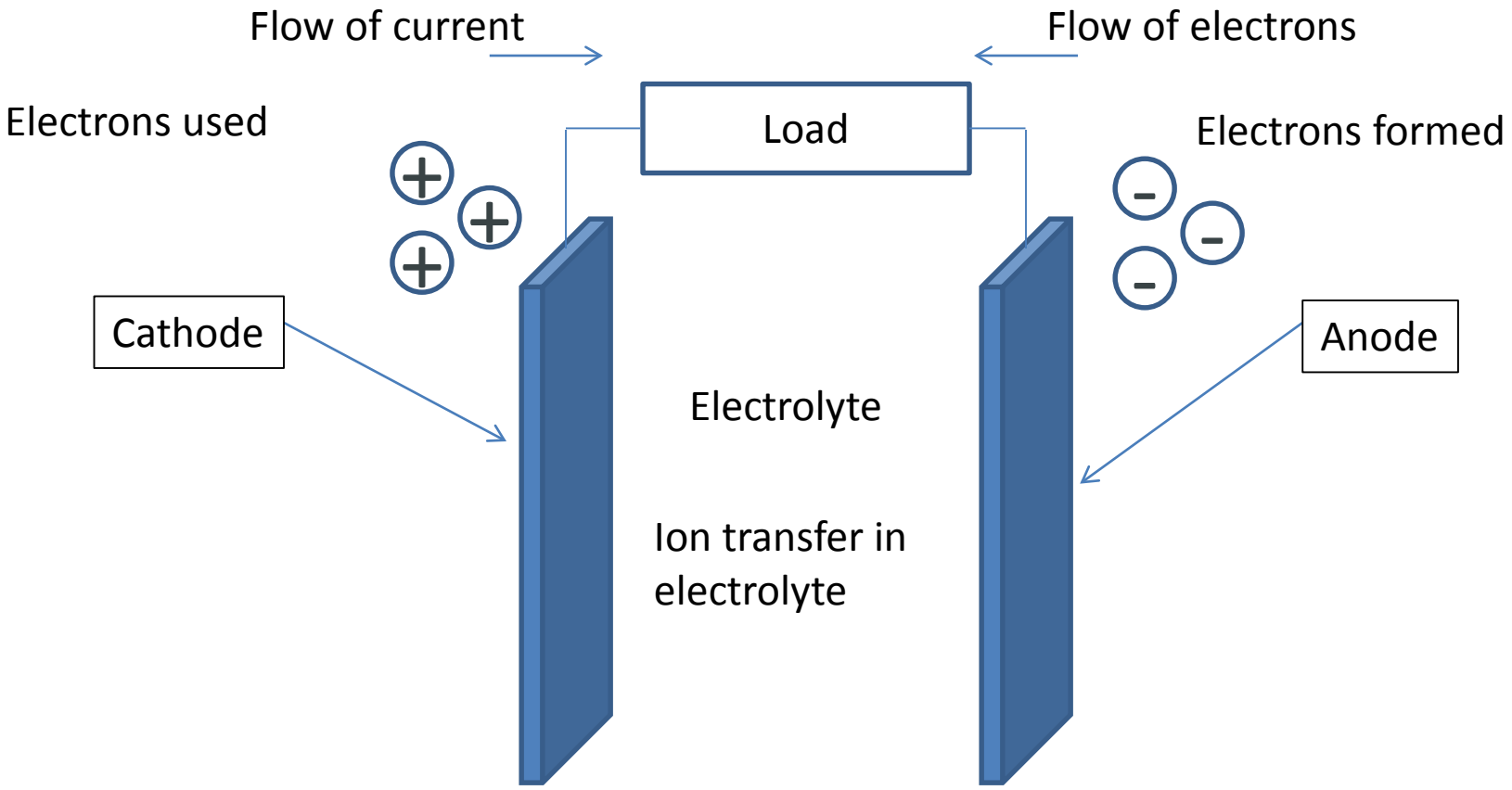
- When AC mains fails, batteries serve as the main source of power for the following in a substation
  - Relays
  - Circuit breaker control
  - Motor operators
  - SCADA
  - Indicator lamps
  - Event recorders
- Batteries have a limited service life
- Important to track the health so that
  - Measures can be taken to prolong the life
  - Timely replacement of bad batteries can be done

What is a battery?

- Battery is an electrochemical device
- Made of 1 cell or multiple cells
- Cell consists of positive plate and negative plate in an electrolyte
- Chemical energy is converted into electrical energy



Battery principle

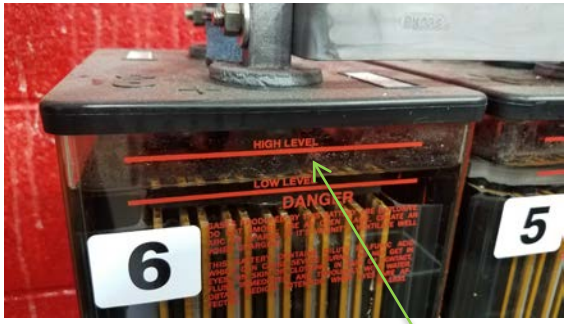


Lead-Acid battery

- Positive plate: Lead peroxide (PbO_2)
- Negative plate: Lead (Pb)
- Electrolyte: Diluted sulphuric acid (H_2SO_4)
- Equations:

Electrolyte:	$2H_2SO_4$	$\longleftrightarrow$	$4H^+ + 2SO_4^{--}$
Negative plate:	$Pb + SO_4^{--}$	$\longleftrightarrow$	$PbSO_4 + 2e^-$
Positive plate:	$PbO_2 + 4H^+ + SO_4^{--} + 2e^-$	$\longleftrightarrow$	$PbSO_4 + 2H_2 + O_2$
Overall:	$Pb + PbO_2 + 2H_2SO_4$	$\longleftrightarrow$	$2PbSO_4 + 2H_2 + O_2$

Vented lead-acid battery (VLA)



Electrolyte level

Separator

PbO_2

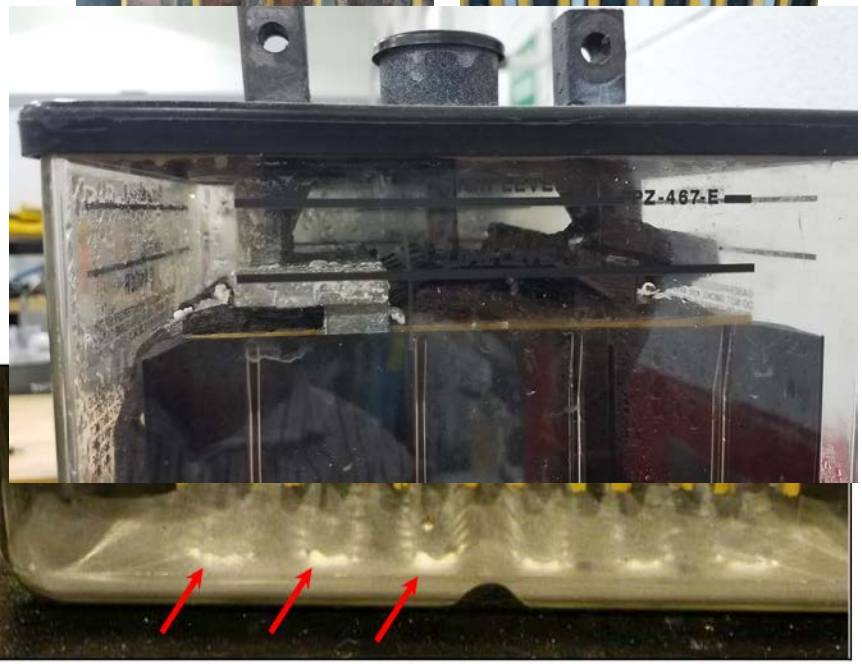
Pb

Valve Regulated lead-acid battery (VRLA)

- Electrolyte immobilized
- Sealed
- Maintenance free

Failure modes in lead acid battery

- Vented lead acid (VLA)
  - Plate sulphation
  - Sediment buildup (shedding)
  - Positive grid corrosion
  - Top lead corrosion
- Sealed lead acid (VRLA)
  - Dry-out
  - Soft and hard shorts
  - Thermal runaway



Nickel-Cadmium battery

- Positive plate: Nickel oxide hydroxide (NiO(OH))
- Negative plate: Cadmium (Cd)
- Electrolyte: Potassium hydroxide (KOH)
- Equations:

$2H_2O \longleftrightarrow 2H^+ + 2OH^{--}$

Negative plate: $Cd + 2OH^{--} \longleftrightarrow Cd(OH)_2 + 2e^-$

Positive plate: $2NiO(OH) + 2H^+ + 2e^- \longleftrightarrow 2Ni(OH)_2$

Overall: $Cd + 2NiO(OH) + 2H_2O \longleftrightarrow Cd(OH)_2 + 2Ni(OH)_2$

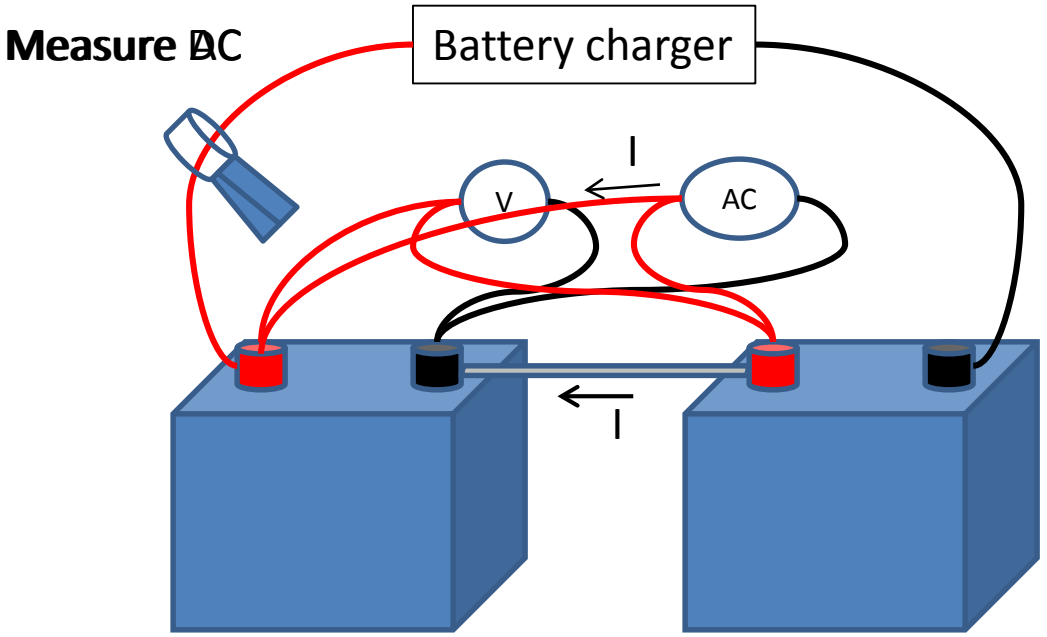
Picture taken from https://www.globaltechenvironmental.com

Internal ohmic testing

- Resistance testing with DC current
- Admittance / conductance testing with AC current
- Impedance testing with AC

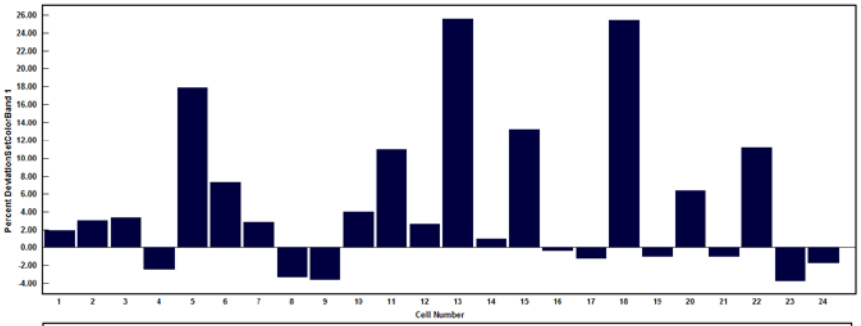
Battery impedance testing

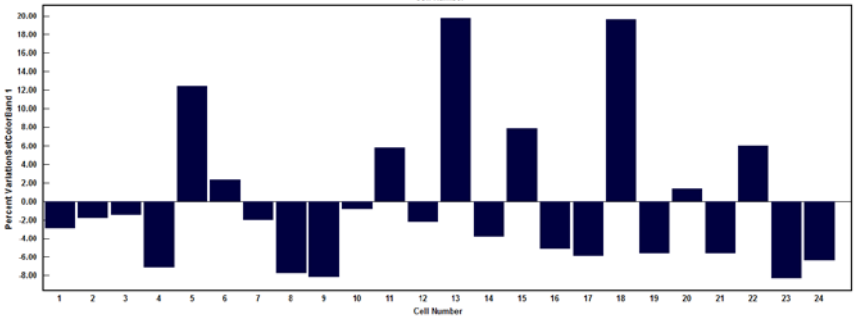
- Involves checking of the electrical path by injection of AC into the battery bank
- Ripple current
- Float current
- Float voltage
- Cell impedance
- Strap resistance

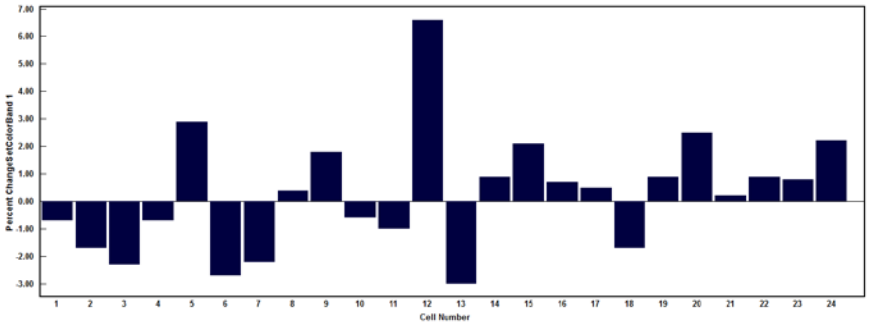


Impedance data analysis

- % deviation from baseline impedance
- % variation from average impedance
- % change in impedance







Determining baseline

- Baseline is determined in the first test.
- 24 cell bank impedance data
- Average was computed
- All cells highlighted in red were outside ±5% and were discarded for the next iteration
- Average recomputed in the next iteration
- Some cells discarded again for iteration#3
- Eventually, all cells are within ±5% of the average.

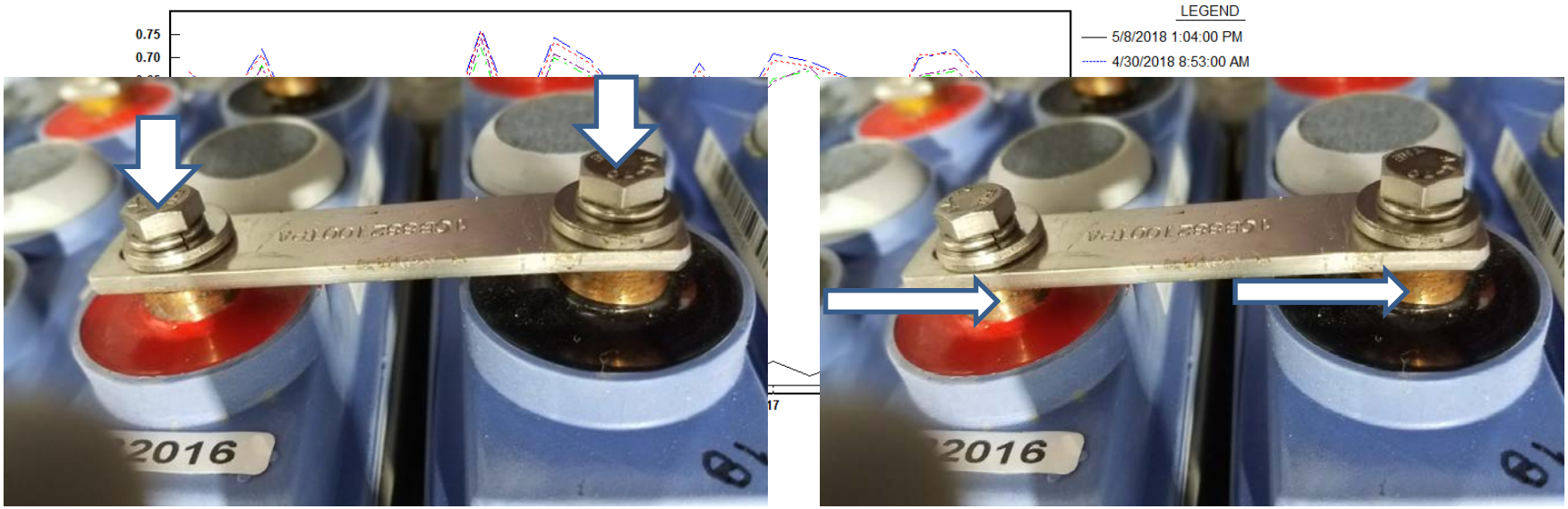
Cell#	Iter#1	Iter#2	Iter#3
1	0.879	0.879	0.879
2	0.880	0.880	0.88
3	0.877	0.877	0.877
4	0.841		
5	1.054		
6	0.907	0.907	0.907
7	0.873	0.873	0.873
8	0.843		
9	0.852		
10	0.898	0.898	0.898
11	0.954	0.954	
12	0.950	0.950	
13	1.058		
14	0.885	0.885	0.885
15	1.004		
16	0.871	0.871	0.871
17	0.862		
18	1.071		
19	0.868	0.868	0.868
20	0.947	0.947	
21	0.862		
22	0.975		
23	0.843		
24	0.872	0.872	0.872
Average	0.914	0.897	0.881

Pointers for a good measurement

- Probe positioning
- Saving the readings at the right time
- Consistency in multiple strap measurements

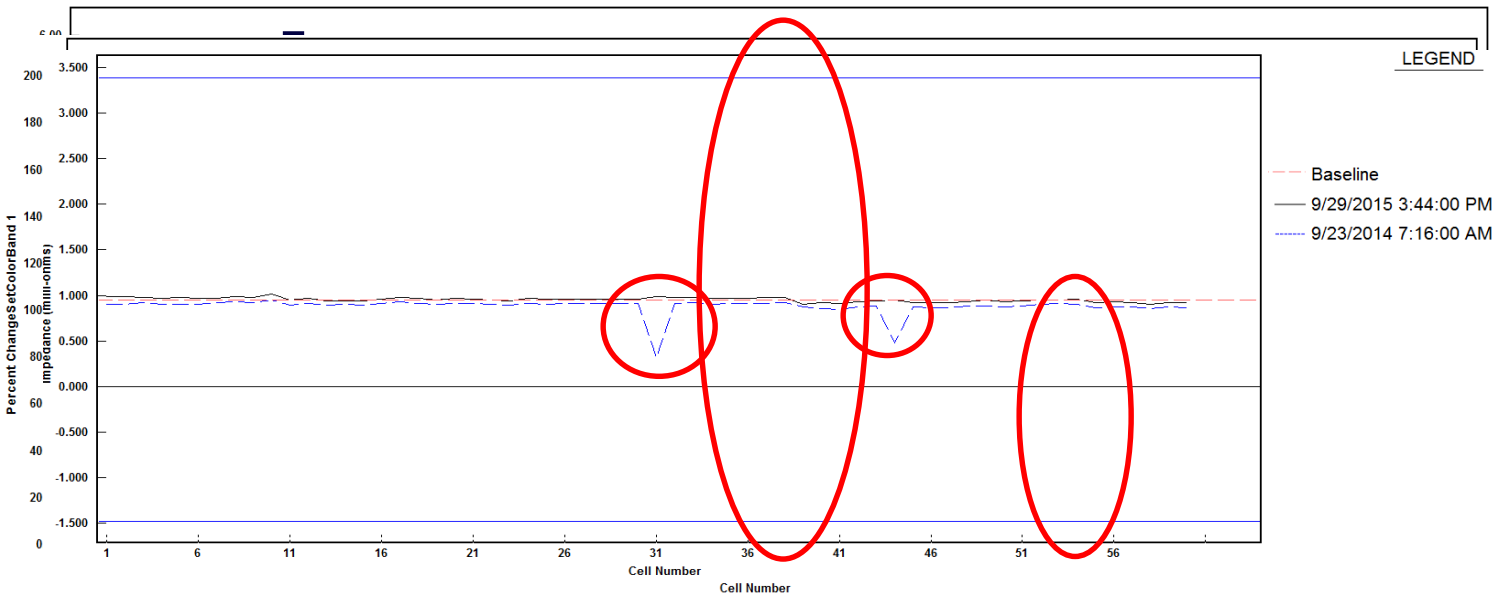
Probe positioning

- It is important to connect the probes on the posts.
- Connect on the straps if posts are inaccessible
- Avoid connecting on the terminal bolting



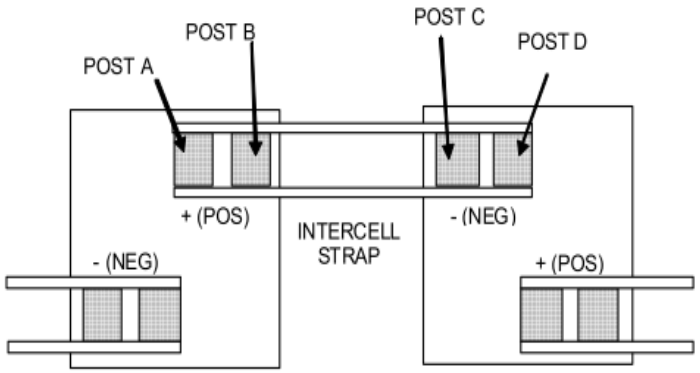
Saving the readings at the right time

- Readings should be logged at the right instant when they are stable

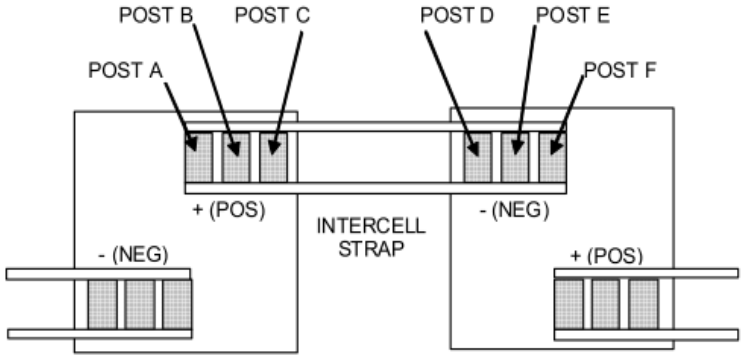


Recording multiple strap readings

- Consistency should be observed in recording multiple strap resistance measurements



Strap resistance #	Connection points
1A	A to C
1B	B to D



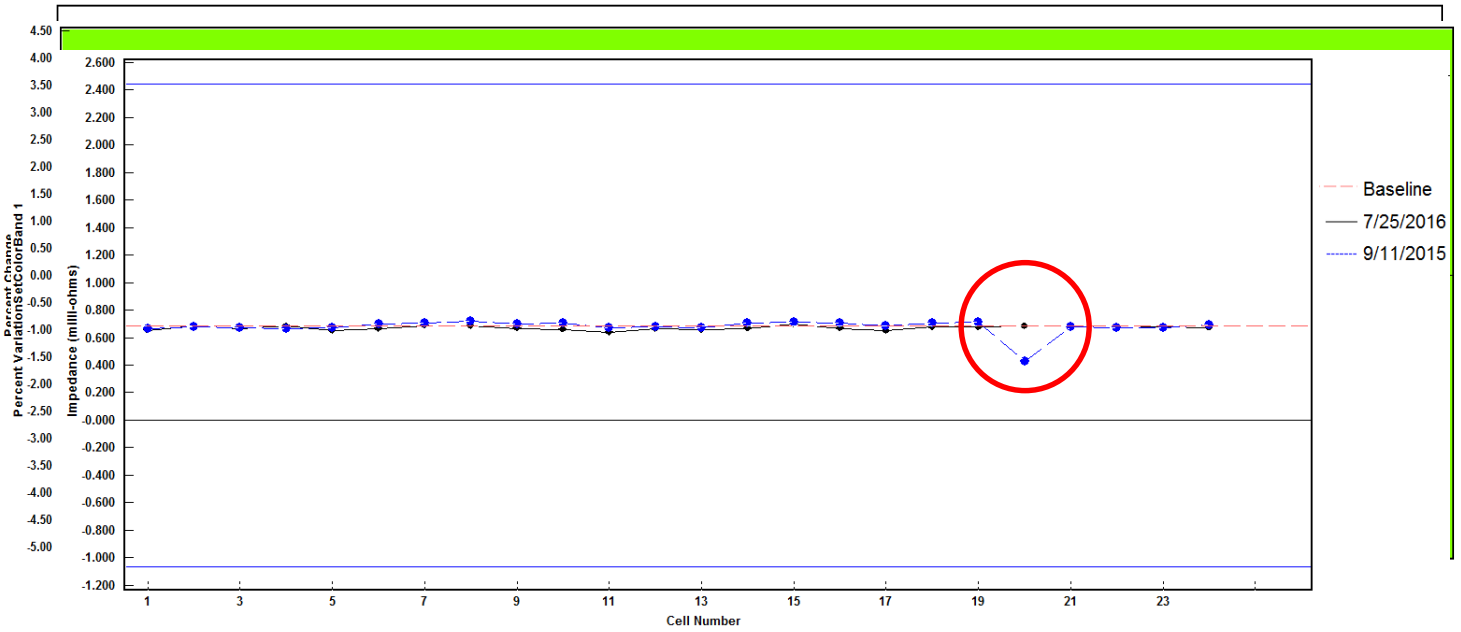
Strap resistance #	Connection points
1A	A to D
1B	B to E
1C	C to F

NERC Compliance

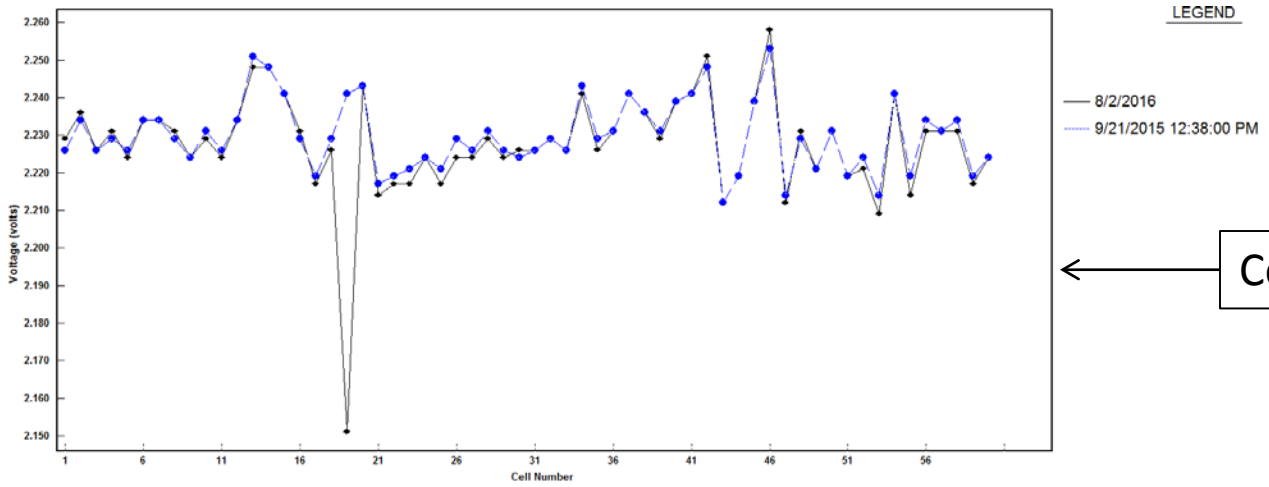
Battery type	Maximum interval	Maintenance activities
Vented Lead-Acid (VLA) battery	18 months	Strap resistance measurement, float voltage measurement, etc.
	18 months OR 6 years	Internal ohmic testing OR discharge testing
Valve Regulated Lead-Acid (VRLA) battery	6 months	Internal ohmic testing
	18 months	Strap resistance measurement, float voltage measurement, etc.
	6 months OR 3 years	Internal ohmic testing OR discharge testing
Nickel-cadmium (NiCd) battery	18 months	Strap resistance measurement, float voltage measurement, etc.
	6 years	Discharge testing

Case 1

% char	% vari	Impedance measurements

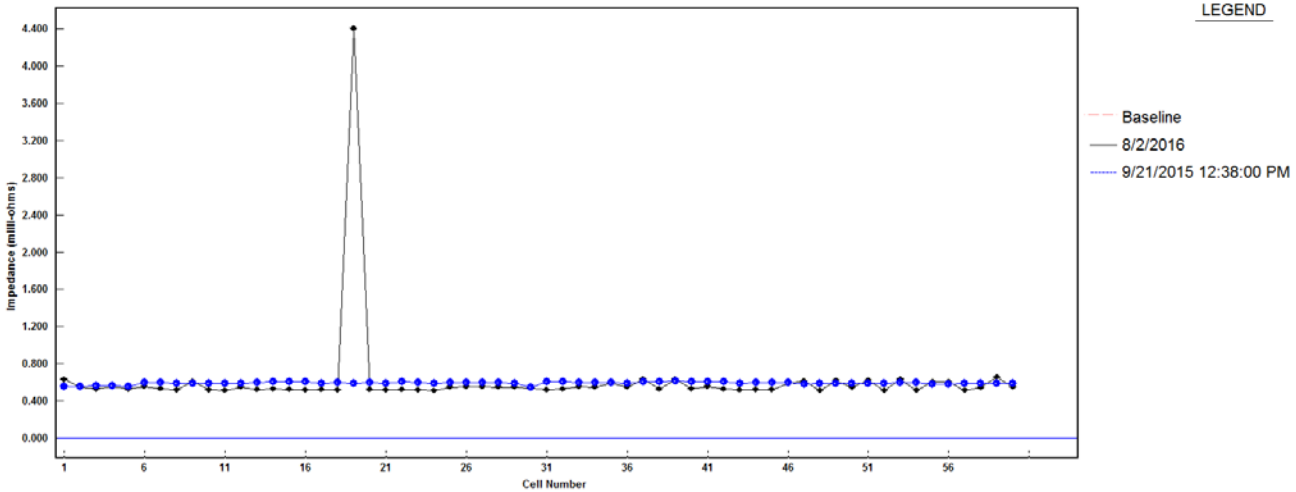


Case 2

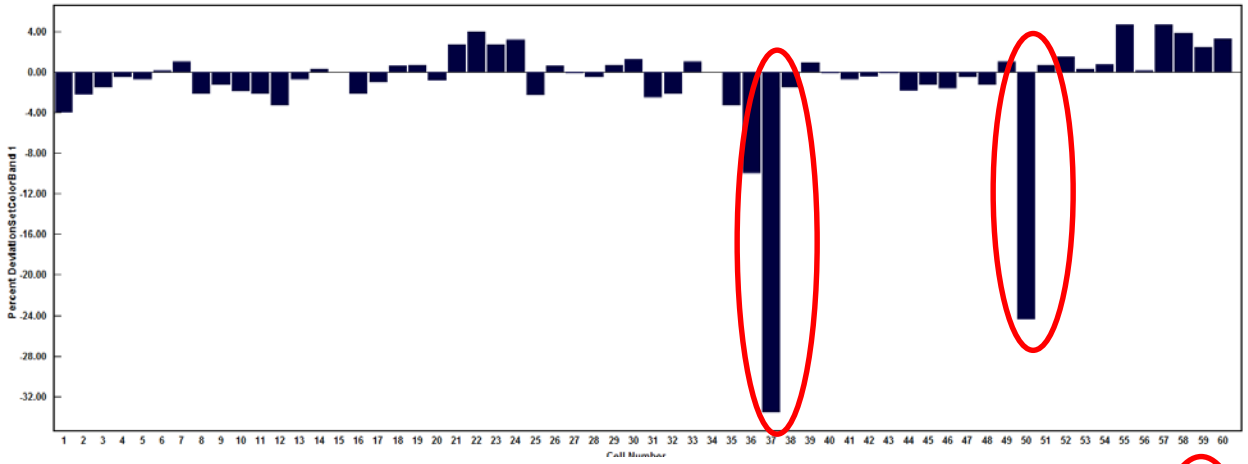


Cell voltages

Cell impedances

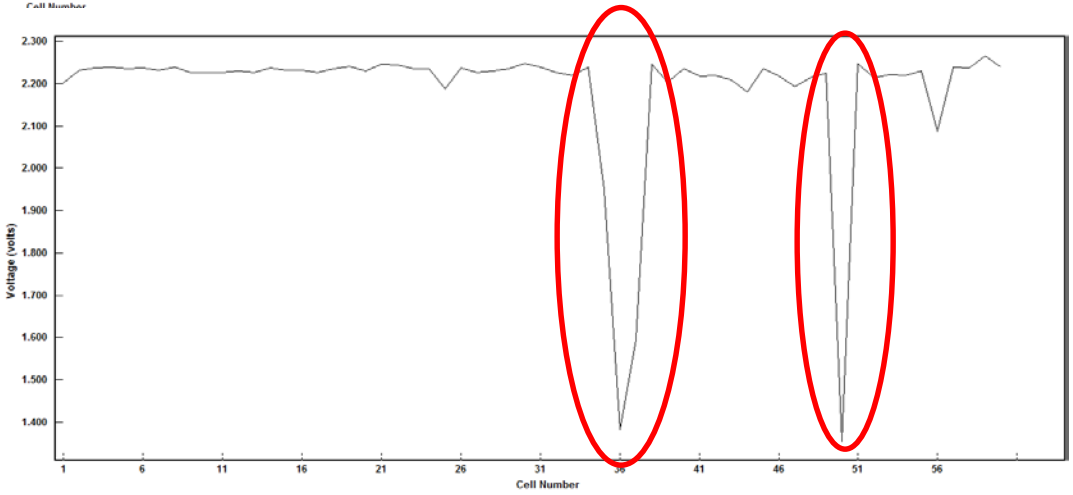


Case 3



% deviation

Cell voltages



References

- IEEE 450 – Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications
- IEEE1180 - Recommended Practice for Maintenance, Testing and Replacement of Valve Regulated Lead-Acid (VRLA) Batteries for Stationary Applications
- NERC PRC-005-6
- Megger Battery Testing Guide

Questions?

- Hope you slept comfortably ☺