DC System Sizing Principles

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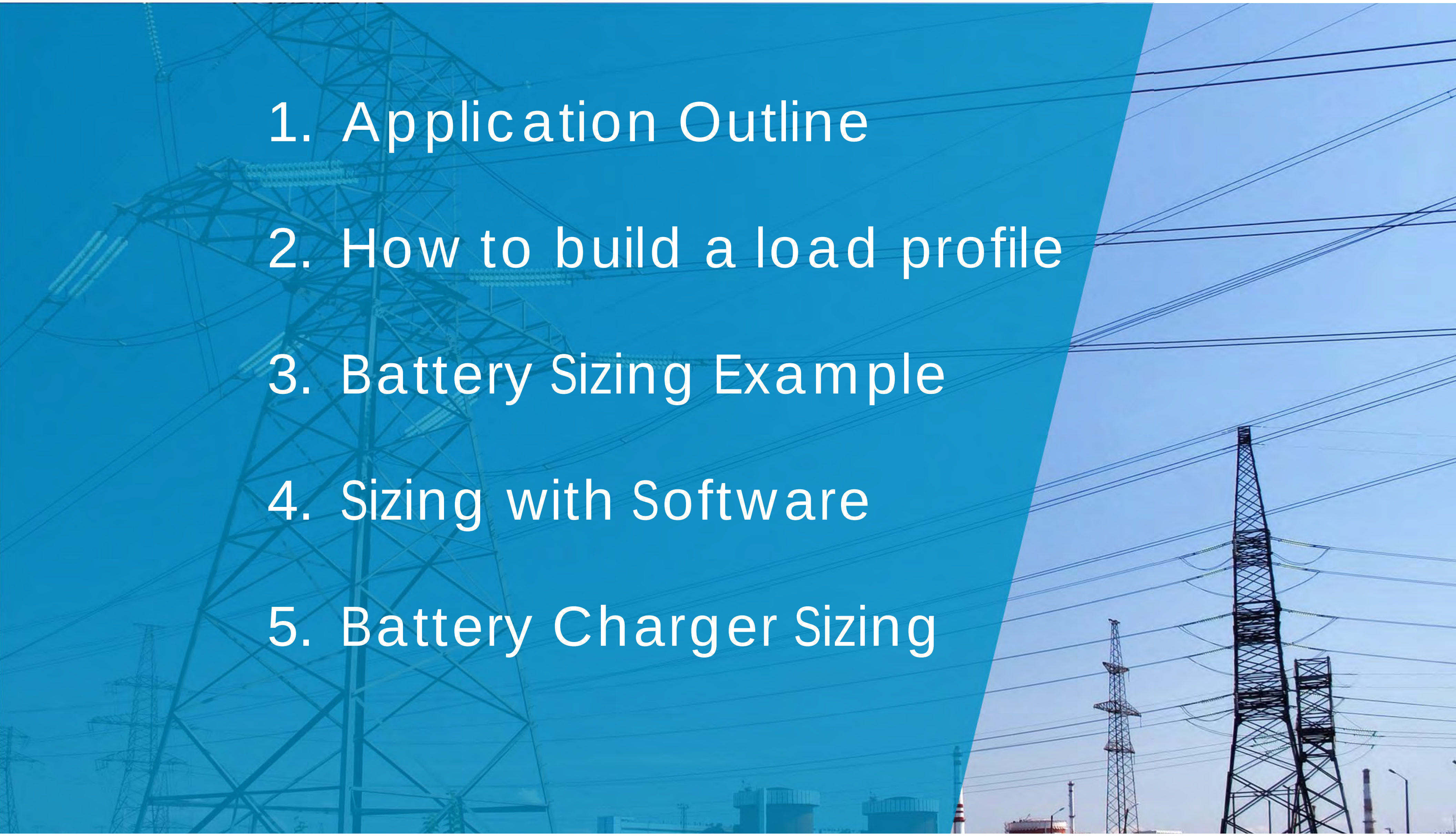
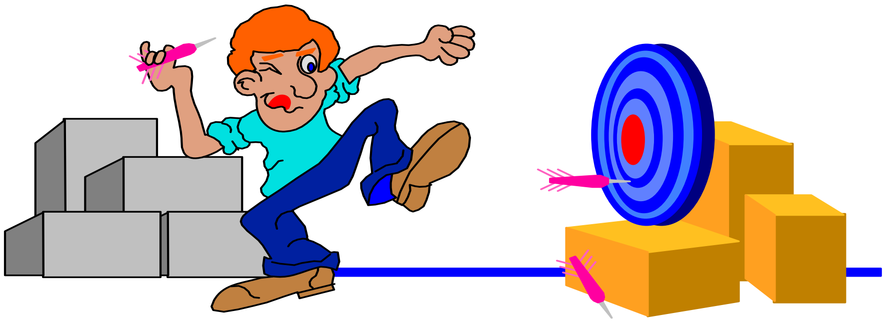
a company of TOTAL

Agenda



1. Application Outline
2. How to build a load profile
3. Battery Sizing Example
4. Sizing with Software
5. Battery Charger Sizing

The Art and Science of Battery Sizing



– Battery Sizing is a Science

– Building the load profile is an Art.

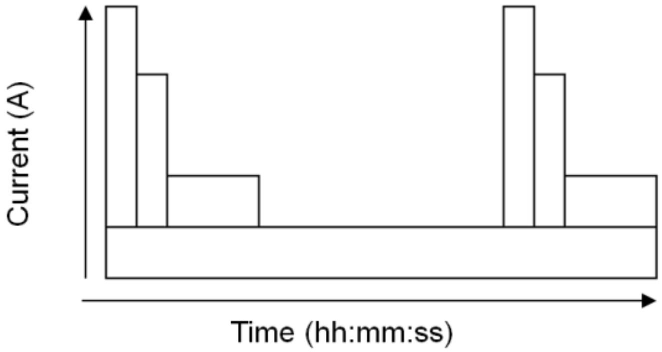
– Different electro-chemistries vary greatly

– You have more control over your battery selection than you think

APPLICATION OUTLINE

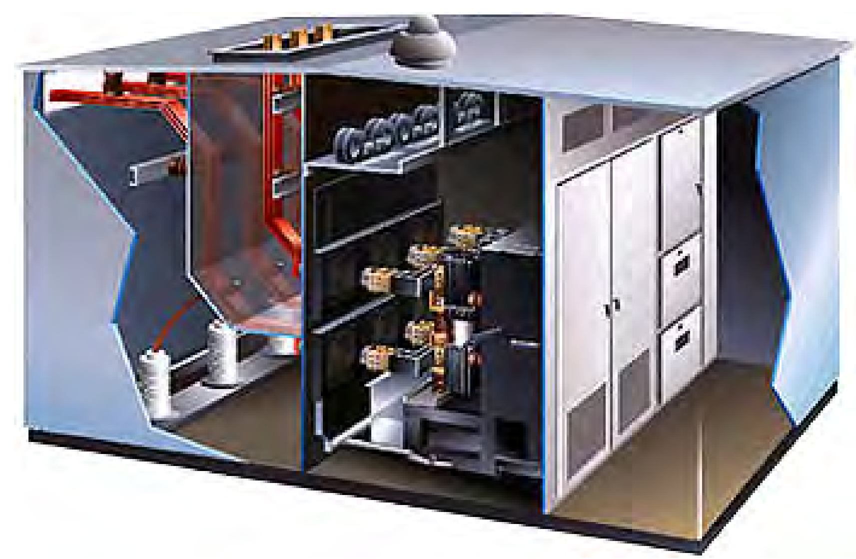
Introduction to Switchgear

- What is Switchgear?
  - The combination of electrical disconnect switches, relays, lighting, controls, fuses or circuit breakers used to control, protect and isolate electrical equipment
  - Large Panels of electrical distribution circuit breakers distribute power to a facility or grid
- Why is Switchgear used?
  - To de-energize equipment to allow work to be done and clear faults down stream
  - Fix power lines
  - Breakers are too big to flip by hand



Application Outline - Switchgear

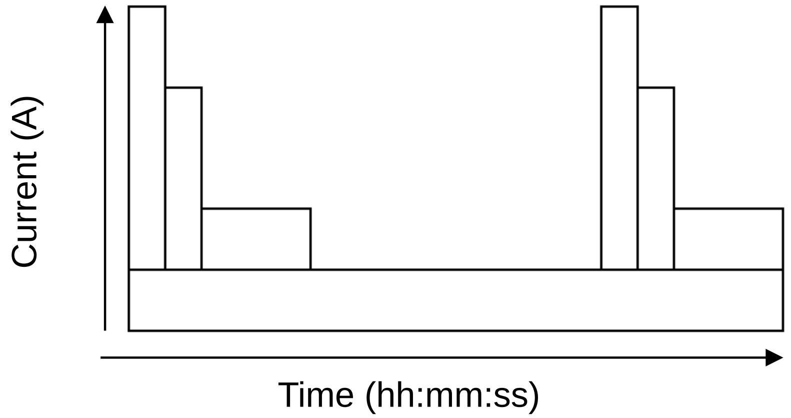
- Three main types of switchgear applications
  - MV (medium voltage)
    - Utility level protection
    - Typically 8 hr. load profile
  - LV (low voltage)
    - Building level protection
  - Paralleling
    - Two or more gensets
    - Typically 2-8 hr. load profiles
- Switchgear protects against
  - faults upstream and protects
  - equipment downstream



LV/MV Switchgear

480V to 38kV (typical)

- DC bus = 125Vdc (normal)
- 48Vdc is also popular
- Load profile is mixed
  - High peak currents (transient)
  - Continuous loads (steady state)
  - 2-8 hr. battery backup normal



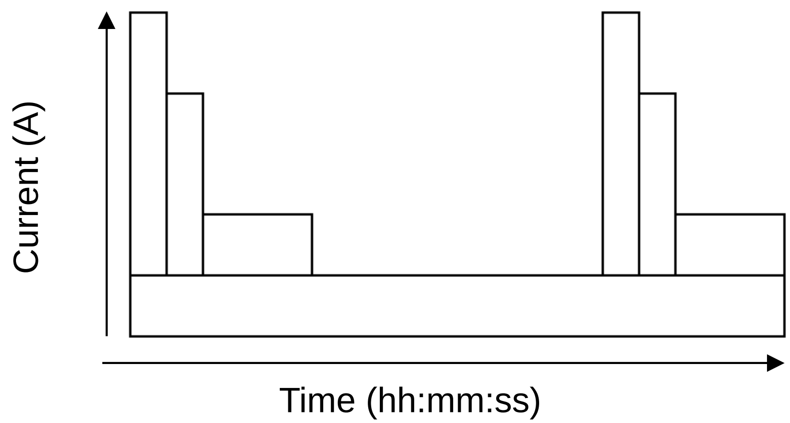
Paralleling Switchgear

120V to 600V (typical)

- DC bus = 24, 48 or 125Vdc
- Load profile is mixed
  - High peak currents (transient)
  - Continuous loads (steady state)
  - 20 min. - 4 hr. battery backup normal

The Battery's Purpose

- Batteries provide DC power to the switchgear equipment during an outage.
- Best practice is to have individual batteries for each load/application.
- Duration of backup is dependent on the battery Ah capacity
- Battery loads include:
  - Trip Current
  - Close Current
  - Spring Motor Rewind/Charge Current
  - Continuous Loads: Relays, Meters, Control Circuits, PLCs, Lighting, Etc.



IEEE Standards

- IEEE 1115
  - Recommended Practice for Sizing Nickel Cadmium Batteries
- IEEE 485
  - Recommended Practice for Sizing Large Lead Acid Batteries
- IEEE 1189
  - Recommended Practice for Selection of Valve Regulated Lead Acid Batteries
  - For Sizing, it refers to IEEE 485 practices

BUILDING LOAD PROFILES

Building Load Profiles - Switchgear

- Switchgear load profiles normally comprise of four components
  - Trip
    - Can be simultaneous, sequential or mixed
    - 1s (Ni-Cd) and 1min (Pb-acid)*
  - Close
    - Can be sequential, simultaneous or mixed
    - 1s (Ni-Cd) and 1min (Pb-acid)*
  - Spring motor rewind/charge
    - Usually sequential, but can be simultaneous
    - 6s (Ni-Cd) and 1min (Pb-acid)* minimum
  - Continuous loads
    - 20mins to 24hrs (8hr most common)

- *Lead-Acid has a minimum sizing duration of 1min. Why???

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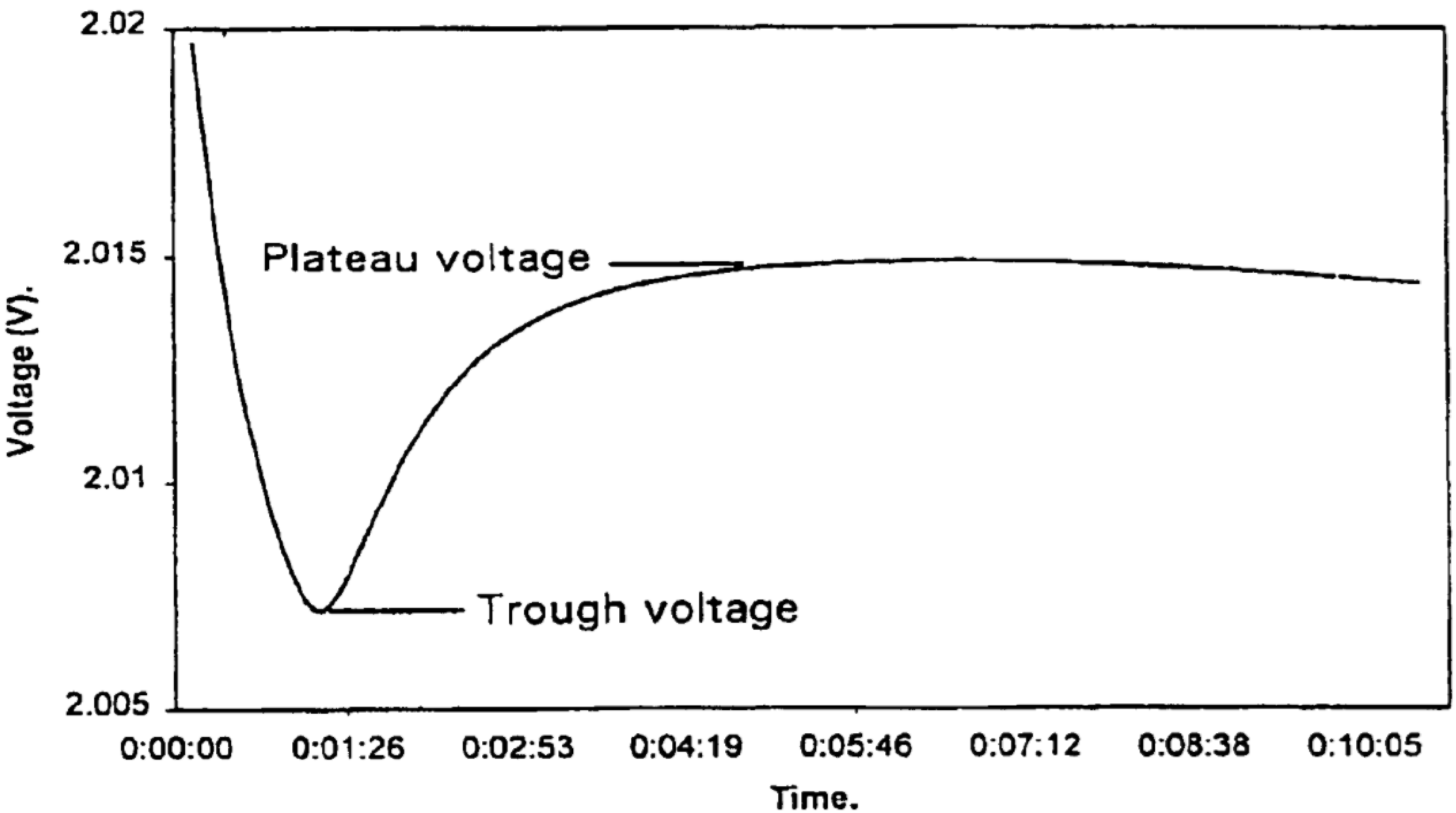
Coup De Fouet



Trip / Close / Spring Charge

– Simultaneous loads = (# breakers x current) for one device operation time
  - 1 second minimum duration for Ni-Cd
  - 1 minute minimum duration for Pb-acid
– Sequential loads = One device current for (# breakers x time)
  - 1s minimum duration for Ni-Cd
  - 1minute minimum duration for Pb-acid
– Mixed loads = # breakers x current + # breakers x time
  - e.g. 51 breakers

    17 x trip current (simultaneous)

    3 x time period (sequential)

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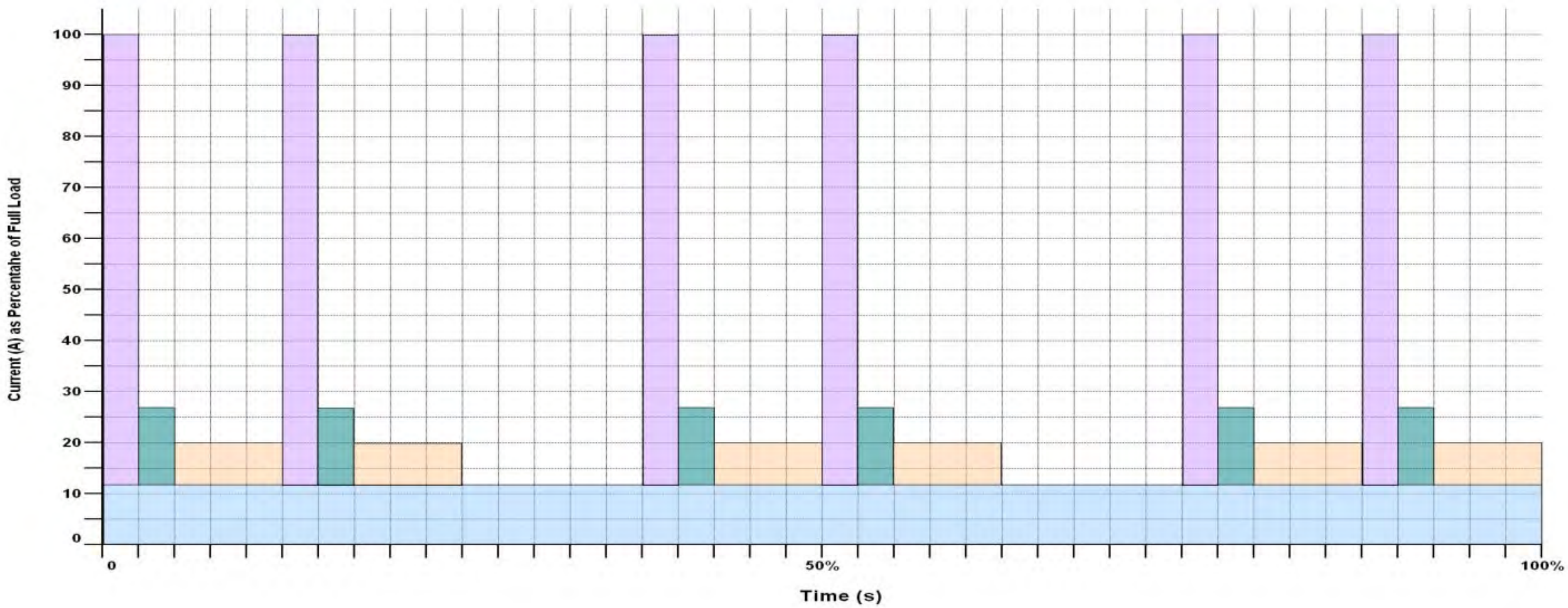
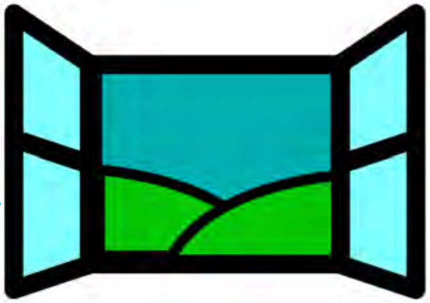
Load Sequencing

- Load sequencing defines the total number of operations and where they occur during the outage / backup period
- The number of operations and where they occur during the backup period can have a dramatic impact on battery capacity
- We will look at a load profile example and examine how sequencing impacts battery selection

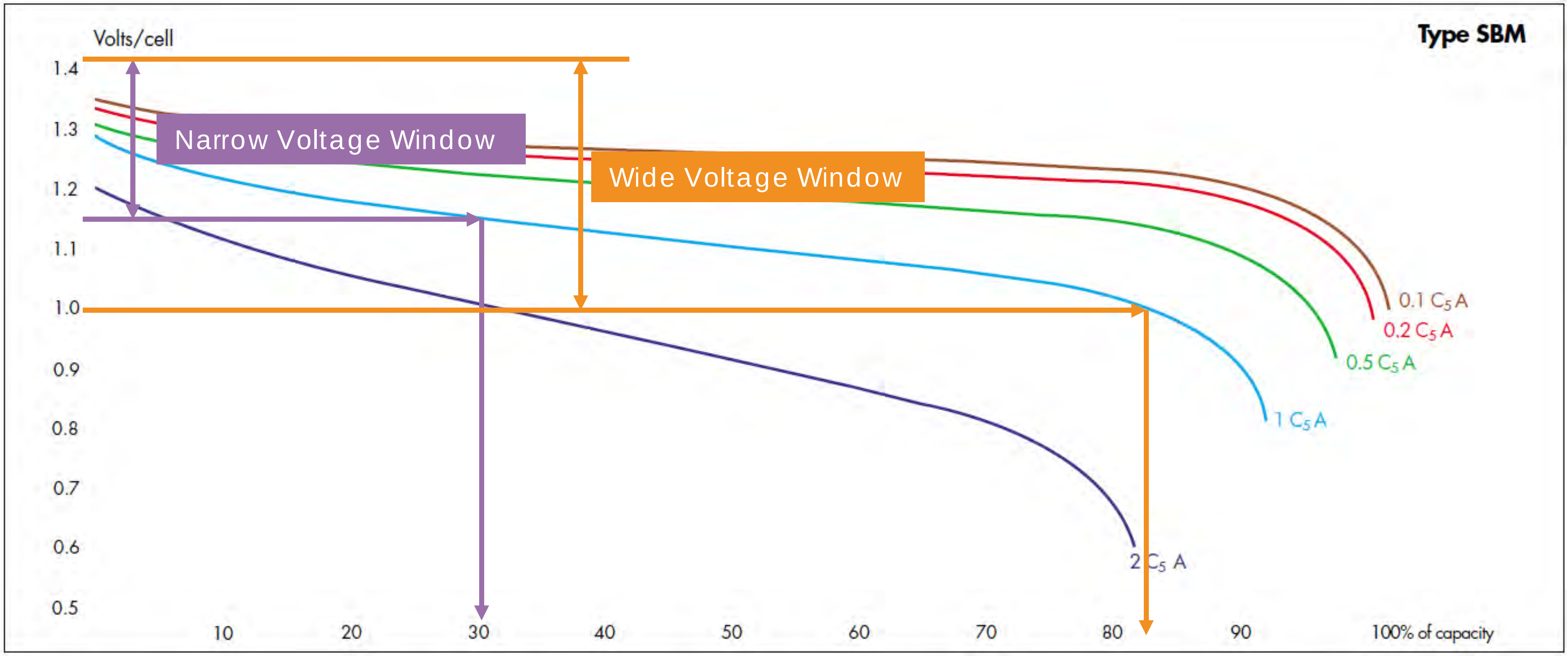


The Voltage Window



– Batteries Operate within a designed Voltage Window
  - The upper limit should allow for battery equalize/boost charging
  - The lower limit should allow for maximum usage during discharge.

12 Volt Lead Acid Battery State of Charge (SOC) vs. Voltage



- The narrower the voltage window, the larger the battery capacity has to be.

The Voltage Window (cont.)

– Lead Acid usually operates between 1.75vpc and 2.33vpc depending on construction

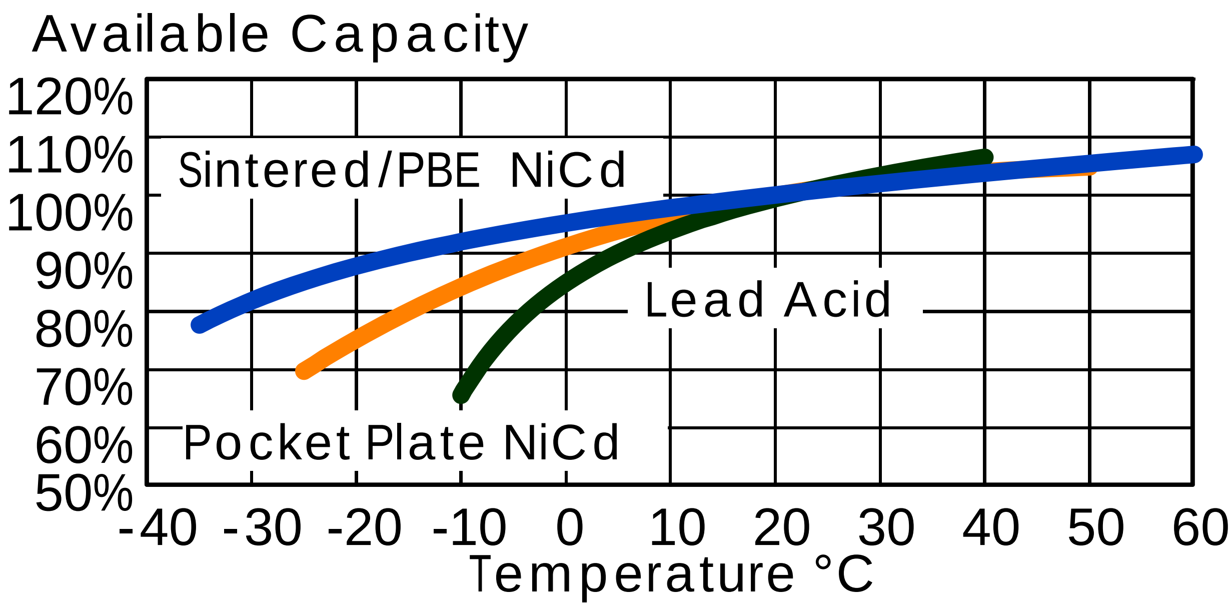
– NiCad batteries typically operate between 1.00vpc and up to 1.65vpc depending on load voltage tolerance.

– Typical voltage windows for standard nominal voltages
  - 24Vdc: 21Vdc to 30Vdc
  - 48Vdc: 42Vdc to 58Vdc
  - 125Vdc: 105Vdct to 140Vdc

*Should be based on equipment connected to the battery.

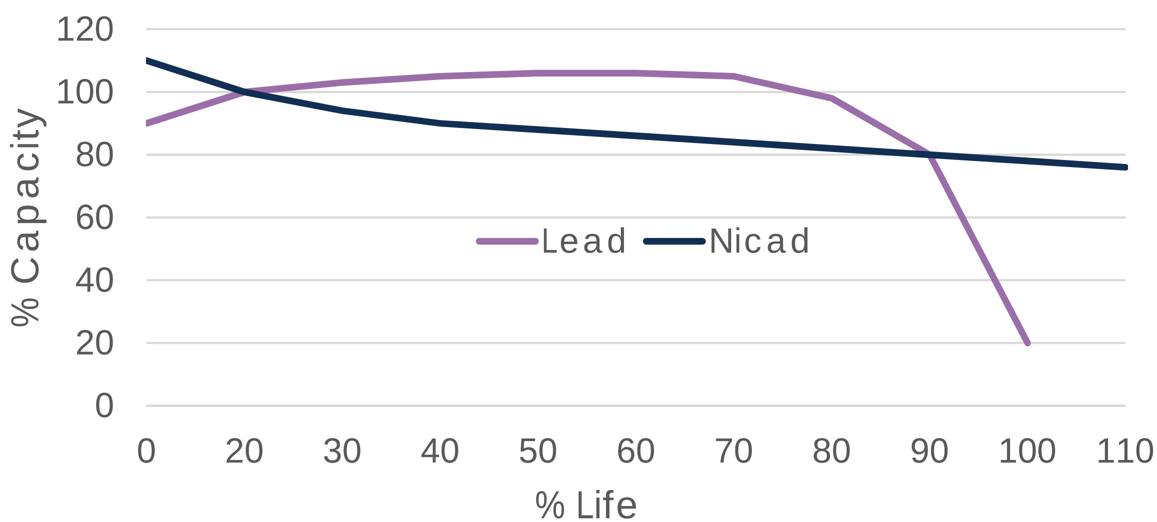
Temperature Factor

- Battery capacities and discharge ratings are published based on a certain temperature, usually between 68ºF & 77ºF.
- Battery performance decreases at lower temperatures and must be accounted for with correction factors.
- Lead Acid – Temperature correction factor applied at the end of the calculation.
- NiCad – Temperature correction factor applied at each step in the calculation.



Other Factors to Consider

– Design Margin
  - Used to allow for future load growth or unknowns in the load list.
  - Typically 1.1 - 1.15
– Aging Factor
  - Used when the requirement is for the battery to be able to perform the same duty cycle at the end of its life as when it is new.
  - Typically 1.25 based on the IEEE recommendation to replace a battery after its capacity has fallen to 80%.



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SIZING EXAMPLES

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125 Vdc MV Switchgear Example

– From Customer:

Rated Control Voltage	Spring Charging Motor			Close or Trip Amperes
	Inrush Amperes	Run Amperes	Average Run Time, Sec.	
48 Vdc	36.0	9	6	16
125 Vdc	16.0	4	6	7
250 Vdc	9.2	2	6	4
120 Vac	16.0	4	6	6
240 Vac	9.2	2	6	3

– 20 breakers:

- Breaker Trip/Close (T/C) = 7A for <1s
- Spring charge motor inrush (SI) = 16A for <1s
- Spring charge motor run (SR) = 4A for 6.0s
- Continuous loads = 5A for 8h
- Trip Sequence = Simultaneous @ t=0 and t=8hr
- Close Sequence = Simultaneous after trip
- Temperature = Temperature Controlled (room temp. 68ºF)
- Normal Aging (AF) = 1.25 AF
- Design Margin (DM) = 1.10 DM

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Written Load Profile

– *Trip* = (20 brkrs x 7A = 140A) + cont. load (5)= 145 Amps for .1s

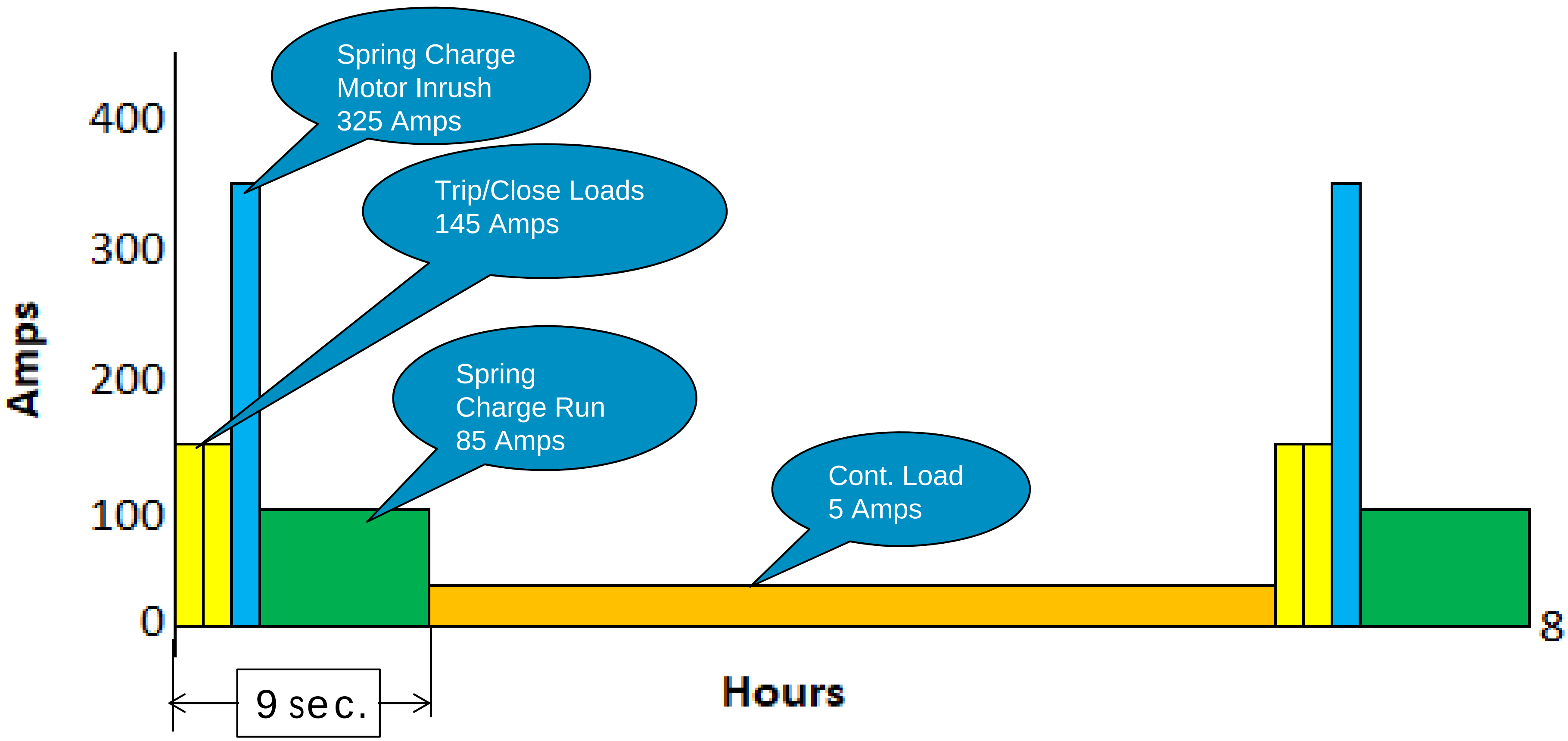
– *Close* = (20 brkrs x 7A = 140A) + cont. load (5)= 145 Amps for .2s

– *Spring SI* = (20 brkrs x 16A = 320A) + cont. load = 325 Amps for .25s

– *Spring SR* = (20 brkrs x 4A = 80A) + cont. load = 85 Amps for 6s

– *Cont. load* = 5A for 8h

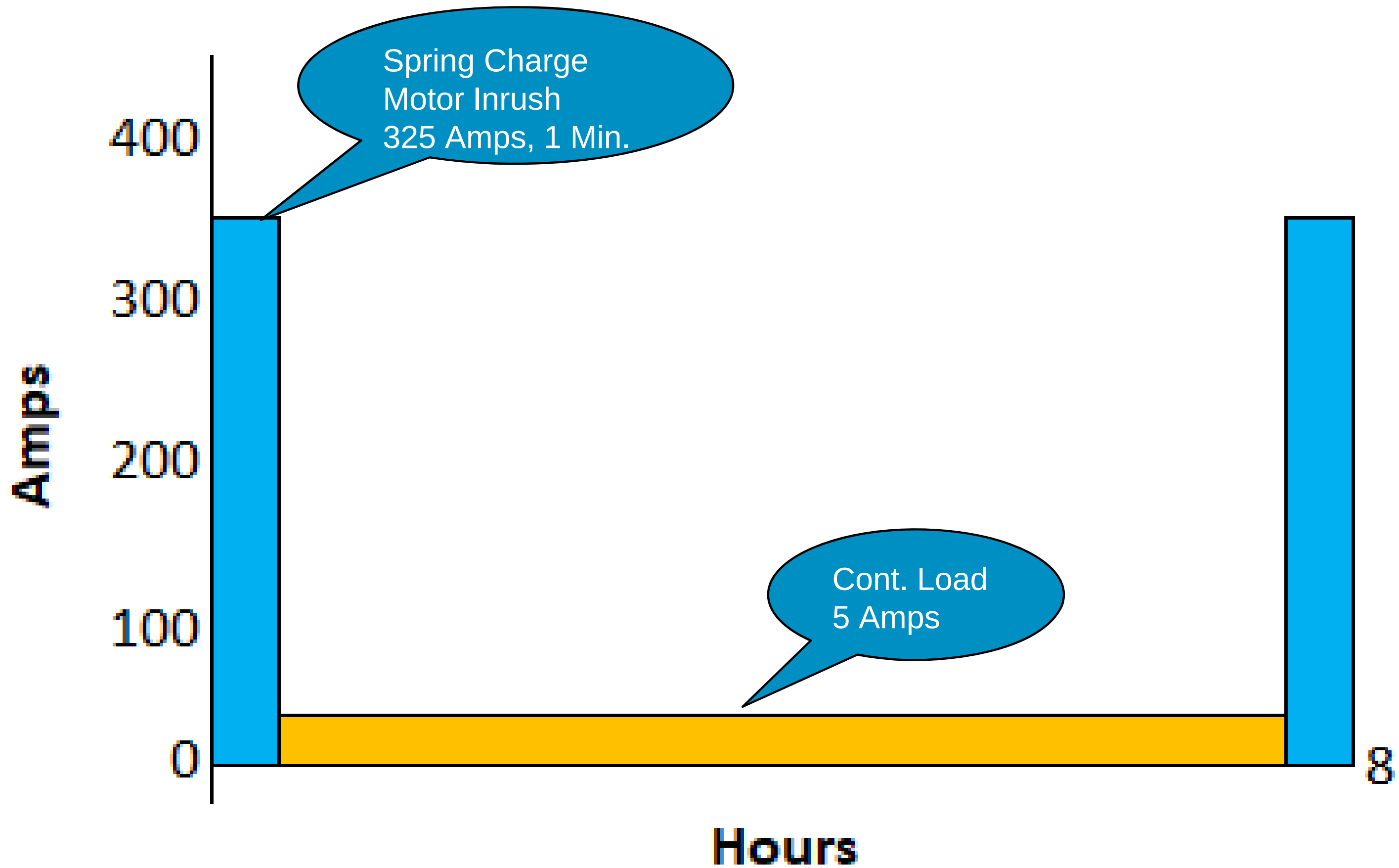
Load Profile – Graphical Form (NiCad)



Load Profile – Step Form (NiCad)

- Step 1 = 145A for 1sec (trip + cont.) followed by:
- Step 2 = 145A for 1sec (close + cont.)
- Step 3 = 325A for 1sec (Spring Charge Inrush + cont.)
- Step 4 = 85A for 6sec
- Step 5 = 5A for 7hr, 59min, 42 sec
- Repeat Steps 1 – 4:
- Step 6 = 145A for 1sec (trip + cont.)
- Step 7 = 145A for 1sec (close + cont.)
- Step 8 = 325A for 1sec (Spring Charge Inrush + cont.)
- Step 9 = 85A for 6sec

Load Profile – Graphical Form (Lead Acid)



Load Profile – Step Form (Lead Acid)

- Step 1 = 325A for 1min (Spring Charge Inrush + cont.)
- Step 2 = 5A for 7hr, 58min
- Step 3 = 325A for 1min (Spring Charge Inrush + cont.)

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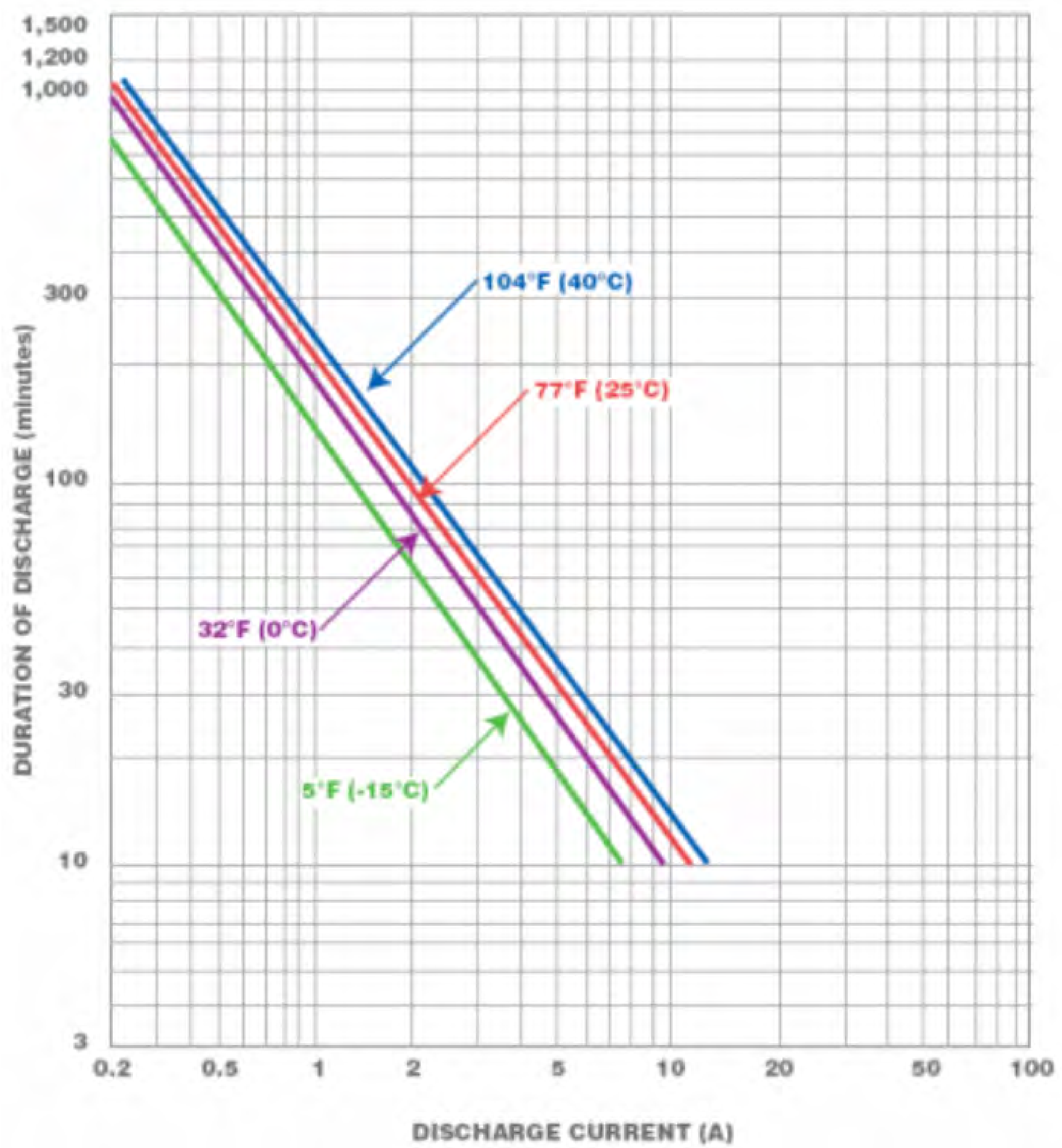
Sizing The Old Way (Fan Curves)



Sizing the “New” Way

These days we use custom software!!

- Drastically speeds up the battery selection process.
- Eliminates calculation errors.
- Ensures standards compliance by providing results in IEEE worksheet format.
- Many offer additional features:
  - Battery rack selection
  - Gassing/ventilation calculations
  - Product data sheets

IEEE 485 sizing worksheet from custom software

IEEE

SIZING LEAD-ACID BATTERIES FOR STATIONARY APPLICATIONS Std 485-1997

Project: **Battery Tag:** **Date:** 3/27/2018

Lowest Expected Electrolyte Temp: 77°F Minimum Cell Voltage: 1.75 Cell Type: LSe Sized By: David Hood

(1) Period	(2) Load (amperes)	(3) Change in Load (amperes)	(4) Duration of Period (minutes)	(5) Time to End of Section (minutes)	(6) Capacity at T Min Rate (6A) Amps/Pos (Rt) or (6B) K Factor (Kt)	(7) Required Section Size (3) ÷ (6A) = Positive Plates or (3) x (6B) = Rated Amp Hrs values
Section 1 - If A2 is greater than A1, go to Section 2						
1	A1=67.41	A1-0= 67.41	M1= 1	T=M1= 1	0.5586	37.656
					Section 1 Total	37.656
Section 2 - If A3 is greater than A2, go to Section 3						
Section 3 - If A4 is greater than A3, go to Section 4						
1	A1=67.41	A1-0= 67.41	M1= 1	T=M1+M2+M3= 480	8.004	539.55
2	A2=5.62	A2-A1= -61.79	M2= 478	T=M2+M3= 479	7.992	-493.82
3	A3=67.41	A3-A2= 61.79	M3= 1	T=M3= 1	0.5586	34.516
					Section 3 Total	80.246

Maximum Section Size: **80.246** + Random Section Size: **0** = Uncorrected Size (US): **80.246**
(US): **80.246** x Temp Corr: **1.00** x Design Marg: **1.10** x Aging Factor: **1.25** = **110.3**
When the cell size is greater than a standard cell size, the next larger cell is required.
Required cell size: **110.3** Amp Hours. Therefore cell part number **LSe150** is required.

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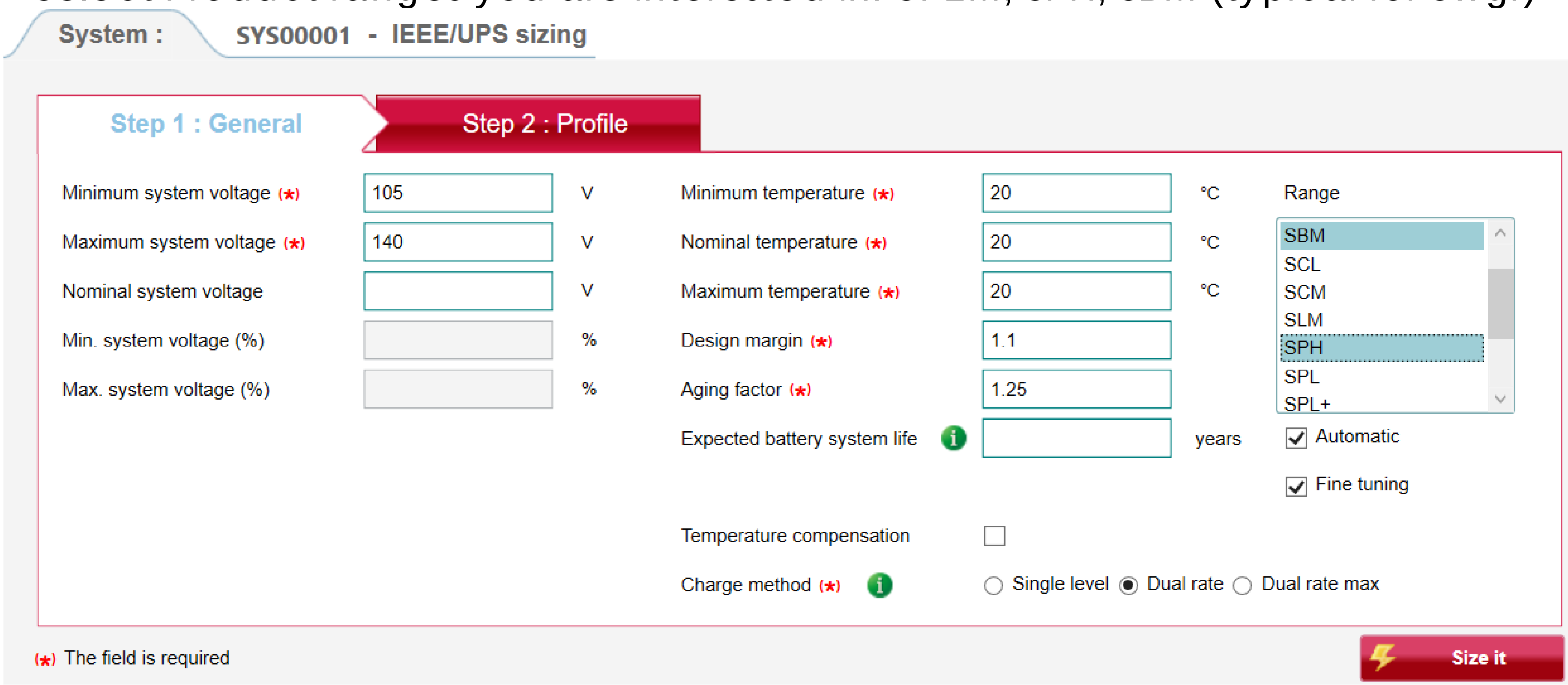
BaSiCS Sizing Software (NiCad)

– Step 1: Input General Information:
  - Voltage Window: 105 – 140 for 125Vdc
  - Temperature: 20ºC
  - Aging Factor: 1.25
  - Select Product ranges you are interested in: UP1M, SPH, SBM (typical for Swgr)



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BaSiCS (Cont.)

– Step 2: Input Load Profile:

- Input Current and Time, click Validate. Move to next step

Number	Current (A)	Hour	Minute	Second	Action
1	145	0	0	1	Insert Modify Duplicate Delete
2	145	0	0	1	Insert Modify Duplicate Delete
3	325	0	0	1	Insert Modify Duplicate Delete
4	80	0	0	6	Insert Modify Duplicate Delete
5	5	7	59	42	Insert Modify Duplicate Delete
6	145	0	0	1	Insert Modify Duplicate Delete
7	145	0	0	1	Insert Modify Duplicate Delete
8	325	0	0	1	Insert Modify Duplicate Delete
9	80	0	0	6	Insert Modify Duplicate Delete
		0	0	0	Validate Cancel

– Step 3: CLICK: **Size it**

Stationary Ni-Cd battery sizing

Folder name	New Folder 1
Folder reference	P_19Mar18_David_a
System name	SYS_00001 - IEEE/UPS
System reference	SYS_00001
Customer	
Customer reference	

Battery proposal

Proposed battery	**1 x 96 x SPH 130**	
Electrical data	Rated capacity	130 Ah
	Fast charge voltage	139.2 V
	Floating charge voltage	134.4 V
	Final voltage/cell	1.094 V
	Short-circuit current	4,697 A
	Topping-up interval	13.1 years
Physical data	Battery weight	1,481.5 lb

Technical specifications

Sizing method	IEEE	I
Voltage window	Minimum system voltage	105.00 V
	Maximum system voltage	140.00 V
Charge method	Dual rate	
Load profile		

Stationary Ni-Cd battery sizing

Battery calculation worksheet IEEE 1115-2014

Range	SPH
No. of cells	96
Final voltage/cell	1.094 V
Nominal temperature	20 °C
Minimum temperature	20 °C
Maximum temperature	20 °C

(1) Period	(2) Load (Amperes)	(3) Changes in Load (Amperes)	(4) Duration of Period (minutes)	(5) End of Section (minutes)	(6) Kt Factor * **	(7) Temp Derating Factor **	(8) Required Section Size (3)x(6)x(7) =Rated Ah

Section 1 - First 1 Periods Only - If A2>A1, go to Section 2-Yes

Section 2 - First 2 Periods Only - If A3>A2, go to Section 3-Yes

Section 3 - First 3 Periods Only - If A4>A3, go to Section 4-No

1	A1=145.00	A1-0= 145.00	M1=0.02	t=M1+... +M3=0.05	0.1699	1.0000	24.64
2	A2=145.00	A2-A1= 0.00	M2=0.02	t=M2+M3=0.03	0.1667	1.0000	0.00
3	A3=325.00	A3-A2= 180.00	M3=0.02	t=M3=0.02	0.1635	1.0000	29.43
Total							54.07

Section 4 - First 4 Periods Only - If A5>A4, go to Section 5-No

1	A1=145.00	A1-0= 145.00	M1=0.02	t=M1+... +M4=0.15	0.1826	1.0000	26.48
2	A2=145.00	A2-A1= 0.00	M2=0.02	t=M2+... +M4=0.13	0.1811	1.0000	0.00
3	A3=325.00	A3-A2= 180.00	M3=0.02	t=M3+M4=0.12	0.1795	1.0000	32.31
4	A4=80.00	A4-A3= -245.00	M4=0.10	t=M4=0.10	0.1779	1.0000	-43.59
Total							15.20

Section 5 - First 5 Periods Only - If A6>A5, go to Section 6-Yes

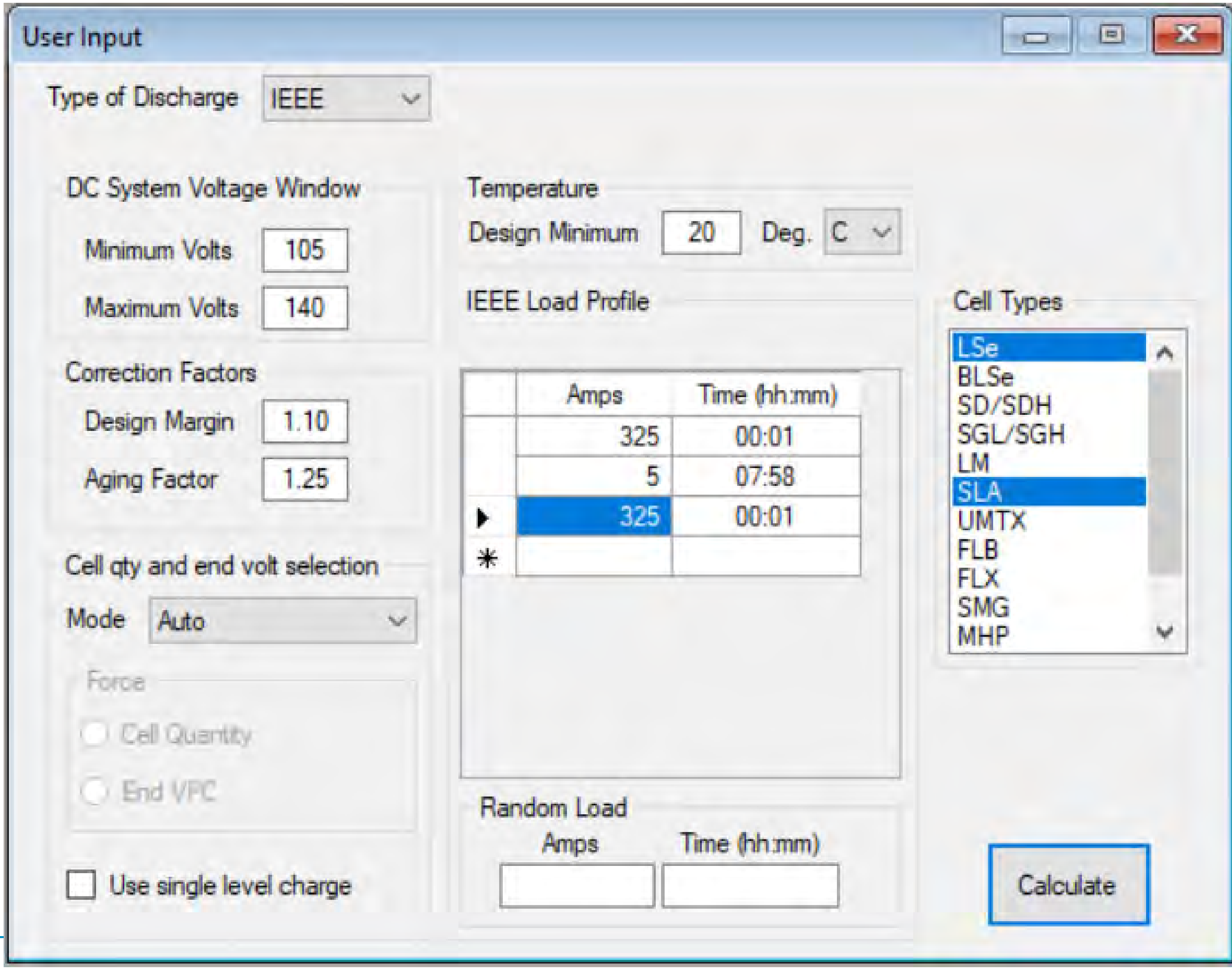
Section 6 - First 6 Periods Only - If A7>A6, go to Section 7-Yes

Section 7 - First 7 Periods Only - If A8>A7, go to Section 8-Yes

SAFT confidential and proprietary. The data herein given are for information purposes only and are not binding on SAFT. They may be modified without prior notice. Please contact a SAFT representative in order to obtain confirmation of the above data.

Visit our website at www.saftbatteries.com

Lead-Acid sizing



SIZING LEAD-ACID BATTERIES FOR STATIONARY APPLICATIONS Std 485-1997

Project: **Battery Tag:** **Date:** 3/19/2018

Lowest Expected Electrolyte Temp: 20°C Minimum Cell Voltage: 1.75 Cell Type: LSe Sized By: David Hood

(1) Period	(2) Load (amperes)	(3) Change in Load (amperes)	(4) Duration of Period (minutes)	(5) Time to End of Section (minutes)	(6) Capacity at T Min Rate (6A) Amps/Pos (Rt) or (6B) K Factor (Kt)	(7) Required Section Size (3) ÷ (6A) = Positive Plates or (3) x (6B) = Rated Amp Hrs values
Section 1 - If A2 is greater than A1, go to Section 2						
1	A1=325	A1-0= 325	M1= 1	T=M1= 1	0.5589	181.65
					Section 1 Total	181.65
Section 2 - If A3 is greater than A2, go to Section 3						
Section 3 - If A4 is greater than A3, go to Section 4						
1	A1=325	A1-0= 325	M1= 1	T=M1+M2+M3= 480	8.009	2603
2	A2=5	A2-A1= -320	M2= 478	T=M2+M3= 479	7.997	-2559
3	A3=325	A3-A2= 320	M3= 1	T=M3= 1	0.5589	178.85
					Section 3 Total	222.85

Maximum Section Size: **222.85** + Random Section Size: **0** = Uncorrected Size (US): **222.85**
(US): **222.85** x Temp Corr: **1.06** x Design Marg: **1.10** x Aging Factor: **1.25** = **324.8**
When the cell size is greater than a standard cell size, the next larger cell is required.
Required cell size: **324.8** Amp Hours. Therefore cell part number **LSe350** is required.

Switchgear Sizing Conclusion

- Proper load profile generation is critical to the outcome.
- Don’t forget to consider temperature, design margin and aging factors.
- The NiCad size will often be smaller than the Lead-Acid
  - Lead-Acid Size: 350AH
  - NiCad size: 130AH !!

Application Outline - UPS

- Uninterruptible Power Supply
  - Constant Power
  - Battery Selection Depends on:
    - UPS rating
    - Power Factor
    - Efficiency
    - Run Time
    - Environmental Conditions (Temperature)

$$Battery\ Load\ [kW_{batt}] = \frac{UPS\ rating\ [kVA] x\ P.F.}{Efficiency}$$

- Backing Up Critical Loads:
  - IT / Commercial Loads: 5 – 15 Minutes
  - Industrial UPS: 30 min +
- Design Life: 20 Years
- DC Bus Voltage depends on UPS manufacture
  - 480 Vdc common for Commercial
  - 125 Vdc common for Industrial

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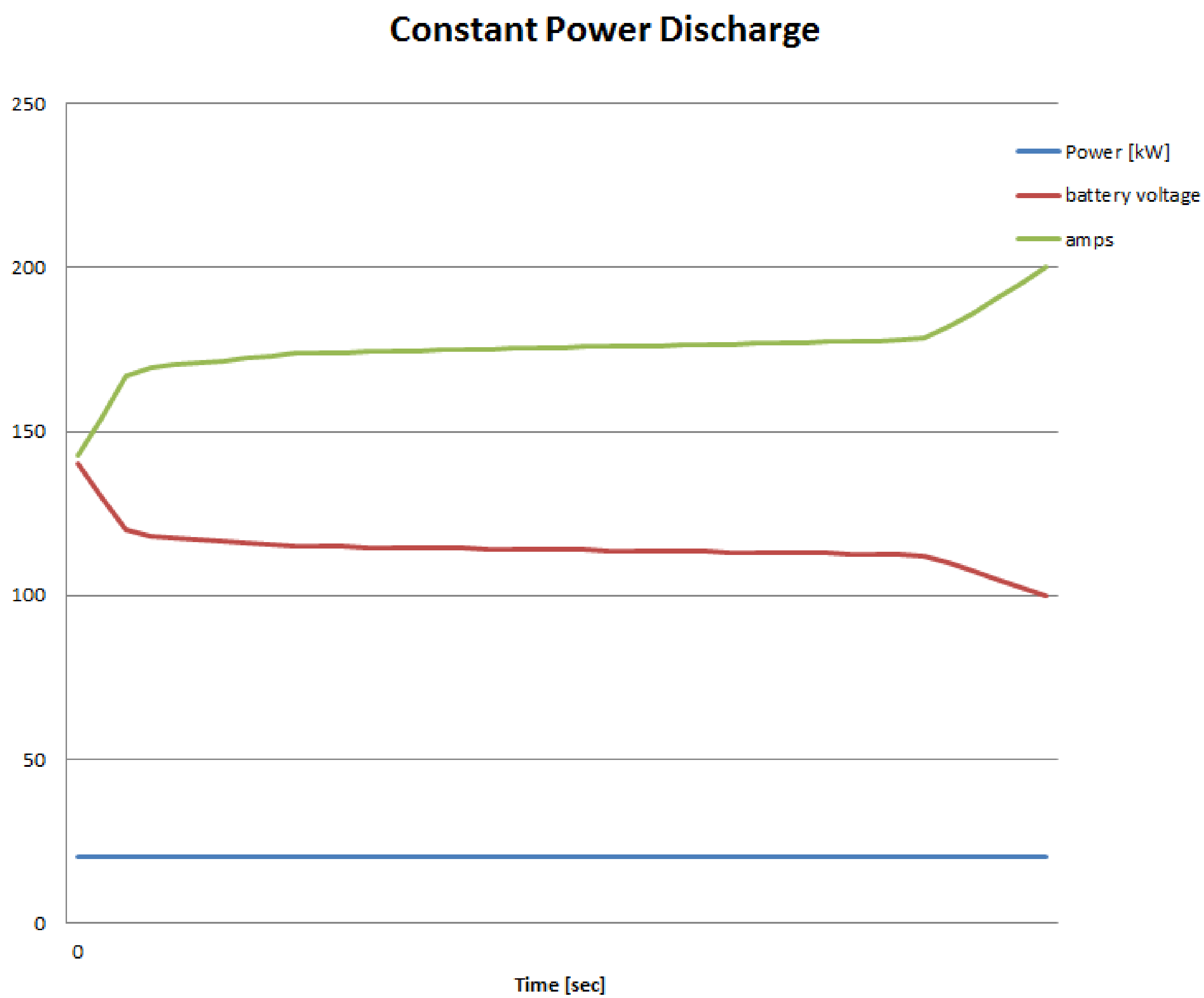
UPS Sizing

– From Customer:

- 25kVA
- 0.85 PF
- 92% Efficiency
- 30min backup
- 50F
- Normal Aging acceptable
- DC Bus = 125Vdc (105-140)



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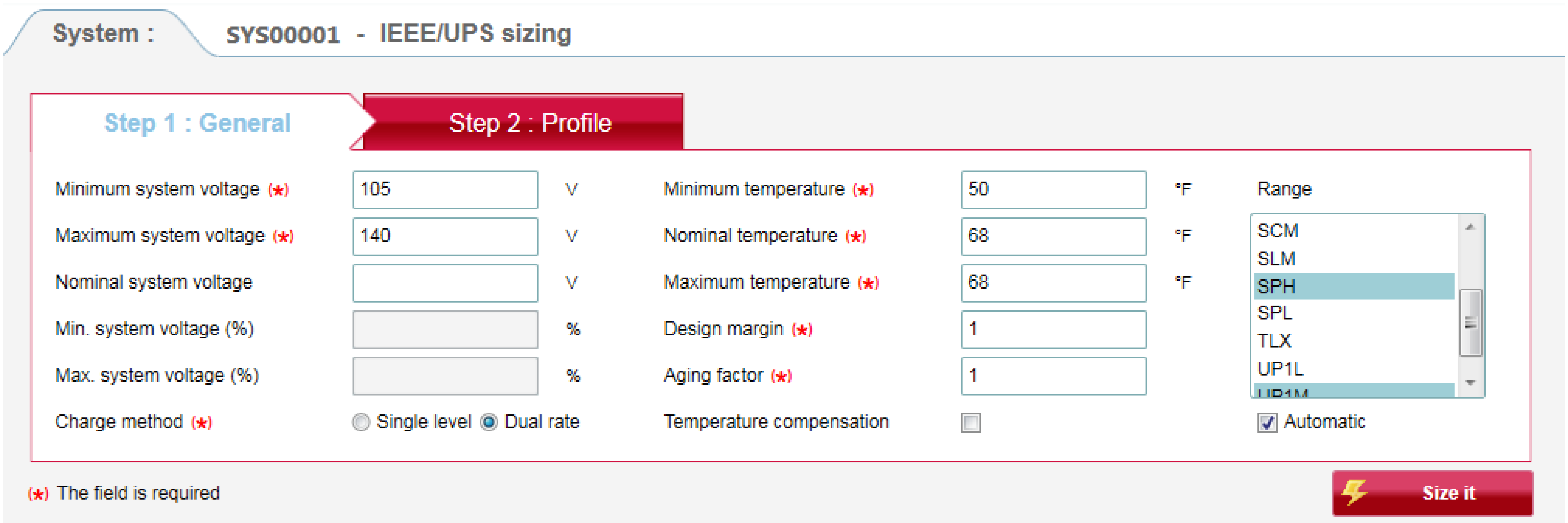
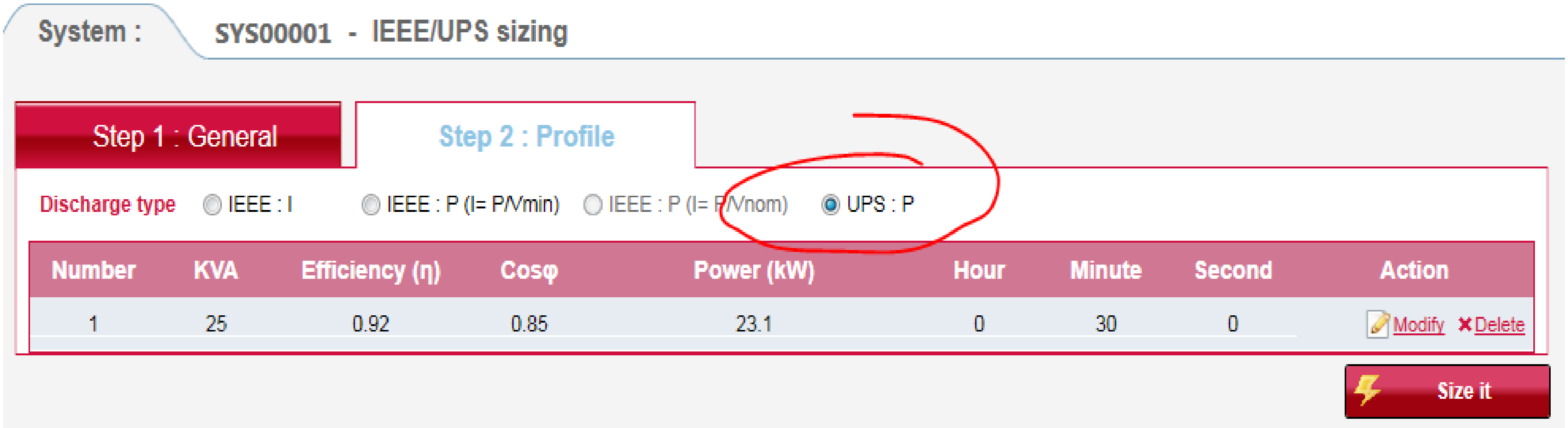
UPS BaSiCs Sizing

– Step 1: Same as Switchgear (input General Information)



UPS sizing with Basics

– Step 2: **Click UPS:P** sizing button (shown below)
– Step 3: Enter UPS information and backup time



– Step 4: Click: **Size it**
– Selection will be based on runtime.
- Less than 30min = H-rate
- 30min to 1hr = M-rate
- Greater than 1hr = L-rate

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Friday, January 12, 2018

Stationary Ni-Cd battery sizing

Folder name	New Folder 1
Folder reference	P_12Jan18_David_a
System name	SYS_00001 - IEEE/UPS
System reference	SYS_00001
Customer	
Customer reference	

Battery proposal

Proposed battery	**1 x 95 x SPH 170**	
Electrical data	Rated capacity	170 Ah
	Fast charge voltage	137.75 V
	Floating charge voltage	133 V
	Final voltage/cell	1.105 V
	Short-circuit current	6,143 A
	Topping-up interval	13.9 years
Physical data	Battery weight	2,031.6 lb

Technical specifications

Sizing method	UPS	P		
Voltage window	Minimum system voltage	105.00 V		
	Maximum system voltage	140.00 V		
Charge method	Dual rate			
Load profile	Number	Power	KVA / η / Cosφ	Time (hh:mm:ss)
	1	23.098 kW	25 / 0.92 / 0.85	00:30:00
Options	Nominal temperature	68 °F		
	Minimum temperature	50 °F		
	Maximum temperature	68 °F		
	Design margin	1		
	Aging factor	1		

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Friday, January 12, 2018

Stationary Ni-Cd battery sizing

Battery calculation worksheet IEEE 1115-2014

Range	SPH
No. of cells	95
Final voltage/cell	1.105 V
Nominal temperature	68 °F
Minimum temperature	50 °F
Maximum temperature	68 °F

(1) Period	(2) Load (Watt/Cell)	(3) Changes in Load (Watt/Cell)	(4) Duration of Period (minutes)	(5) End of Section (minutes)	(6) Kt Factor * **	(7) Temp Derating Factor **	(8) Required Section Size (3)x(6)x(7) =Rated Ah
Section 1 - First 1 Periods Only - If A2>A1, go to Section 2-No							
1	A1=243.14	A1-0= 243.14	M1=30.00	t=M1=30.00	0.6510	1.0342	163.70
Total							163.70

(*) In this calculation, constant potential charging effects are included in our Kt factors
(**) The factors is interpolated when needed and rounded down to 4 decimals in the calculation

Maximum Section size 163.70 + Random size 0.00 = Uncorrected Size 163.70.
Uncorrected Size 163.70 x Design margin 1 x Aging factor 1 = 163.70.
When the cell size is greater than a standard cell size, the next larger cell is required.
The Required cell size is 163.70 Amperes-hours. Therefore cell SPH 170 is required.

The Kt factor is a way to present the performance of a cell.
Kt=Nominal capacity (Ah)/Performance (A)
It is valid for a specific cell type, discharge time and final voltage.

Temperature compensated charge voltage
Not mandatory. If used the value to apply is -2 mV/°C (-1,1 mV/°F) starting from +20°C to +25°C (+68°F to +77°F).

Storage
Store the cells indoors in a dry, clean, cool location 0°C and +30°C (+32°F and +86°F).
Do not store in unopened packing crates. The lid and the packing material on top of the cells must be removed.
Make sure that the transport seals remain in place during storage.
Do not store in direct sunlight or expose to excessive heat.

Cells delivered discharged and filled may be stored for many years before installation.
Cells delivered exceptionally 80% charged (for starting application) must not be stored more than 3 months (including transport).

Sizing Software

Saft Basics Software for NiCad

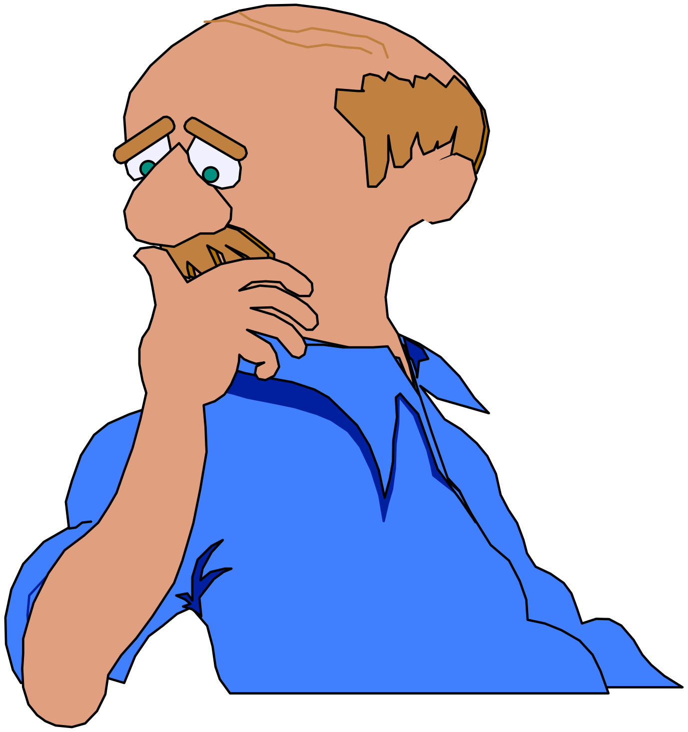
https://www.saftbatteries.com/basics2013/install/SaftBasics.zip

BATTERY CHARGER SIZING

Battery Charger Sizing

Important Things to Consider!!

- Continuous Load
- Battery Type
- Battery AH Capacity
- Altitude
- Design Margin



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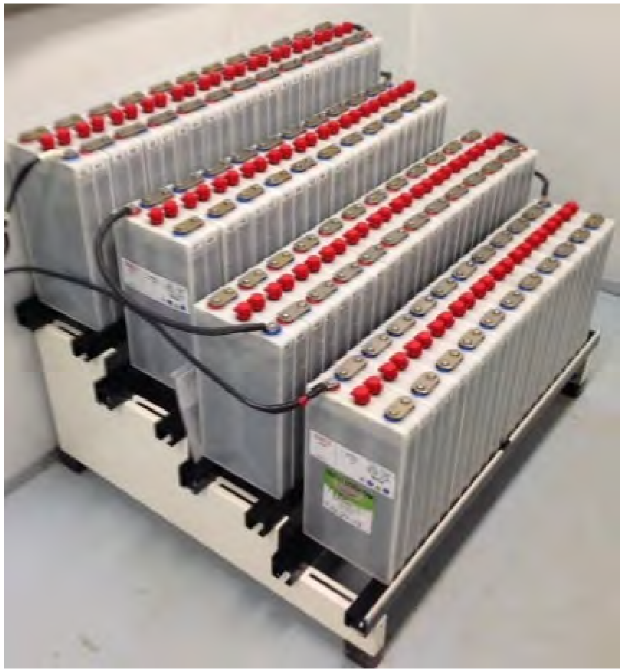
Battery Charger Sizing

– For Example…

- 100 AH Pocket Plate NiCad Battery
- Needs to recharge in 8 hours
- Continuous DC Load is 12 amps
- Design Margin is 10%
- Altitude is less than 3000 ft.



First we need to get all the factors…

Battery Charger Sizing

– Recharge Factor

- Per the table below, the recharge factor for Pocket Plate NiCad batteries is 1.40

Battery Type	Recharge Factor
Pocket Plate Nicad	1.40
Sintered/PBE Nicad	1.20
Lead Acid	1.15

– Altitude Derating

- Installation < 3000 ft. = no derating
- Installation > 3000 ft. = 6.7% derating per 3000 ft.
- Our example is less than 3000 feet so we have no derating factor.

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Battery Charger Sizing

– The Formula

$$C = \left(\frac{AH \text{ x } RF}{RT} + CL \right) \text{x } DM \text{ x } AD$$

Where:

- C = Charger Current
- AH = Battery Amp Hours
- RF = Recharge Efficiency Factor
- RT = Required Recharge Time
- CL = Continuous Load
- DM = Design Margin
- AD = Altitude Derating

Battery Charger Sizing

– The Calculation

$$C = \left(\frac{100 \times 1.4}{8} + 12\right) \times 1.10 \times 1.0$$

C = 32.45

Therefore the charger should be sized at 30 amps*

*a 30 amp charger will deliver 33 amps in current limit

Thank You!!

– Questions???