Stationary Battery Sizing

IEEE IAS Atlanta Chapter

Presented by:
Lesley Varga, P.E.
Quality Standby Services, LLC
1649 Sands Place, SE, Suite C
Marietta, GA 30067
(770) 916-1747
lesley@qualitystandbyservices.com
www.qualitystandbyservices.com
Safety First!

Basic PPE

- **Personal Protective Equipment** – example:
  - Goggles and face shields, eye protection
  - Acid-resistance gloves
  - Protective aprons
  - Emergency eye-wash and safety showers
  - Bicarbonate soda and water for neutralization (mixed to the ratio of 1 lb. to 1 gallon)
  - Insulated tools
  - Class C fire extinguisher
Personal Protective Equipment
WARNING !!!

GAS PRODUCED BY THIS BATTERY CAN BE EXPLOSIVE. PROTECT EYES WHEN AROUND BATTERY. PROVIDE ADEQUATE VENTILATION SO HYDROGEN GAS ACCUMULATION IN THE BATTERY AREA DOES NOT EXCEED ONE PERCENT BY VOLUME. DO NOT SMOKE, USE OPEN FLAME OR CREATE SPARKS NEAR THE BATTERY.
WARNING !!!

THE BATTERY CONTAINS SULFURIC ACID WHICH CAN CAUSE SEVERE BURNS. IN CASE OF SKIN CONTACT WITH ELECTROLYTE, REMOVE CONTAMINATED CLOTHING AND FLUSH AFFECTED AREAS THOROUGHLY WITH WATER. IF EYE CONTACT HAS OCCURRED, FLUSH FOR A MINIMUM OF 15 MINUTES WITH LARGE AMOUNTS OF RUNNING WATER AND SEEK IMMEDIATE MEDICAL ATTENTION.
WARNING !!!

SHOCK HAZARD – DO NOT TOUCH UNINSULATED BATTERY CONNECTORS OR TERMINALS. BE SURE TO DISCHARGE STATIC ELECTRICITY FROM TOOLS AND TECHNICIAN BY TOUCHING A GROUNDED SURFACE IN THE VICINITY OF THE BATTERIES BUT AWAY FROM THE CELLS AND FLAME ARRESTERS.
Switchgear and Control DC system

“125VDC” Bus: 133.8 VDC
Typical Float Voltage

Charger/Rectifier

AC→DC
24, 48, 125 or 240 VDC

Battery

DC Loads

Lamps
Relays
Breaker
Coils

Motors
Pumps
Valves

Inverter
DC→AC

Switchgear
Controls
System One Line - AC Input Lost

VAC
1Φ or 3Φ

Charger/Rectifier

AC→DC
24, 48, 125 or 240 VDC

Battery

≥ DC Loads

DC→AC

Inverter

Motors
Pumps
Valves

Lamps
Relays
Breaker
Coils

Switchgear
Controls
**Telecom DC System**

“48 VDC” Bus: 54.2 VDC
Typical Float Voltage
Telecom DC System - AC Input Lost

“48 VDC”: 54.2 VDC
Typical Float Voltage
Telecom DC System – AC Lost, Generator On Line

Utility AC Input

Transfer Sw

Generator

AC→DC Rect. #1

AC→DC Rect. #n

AC→DC Rect. #n+1

Battery

Bus Work Power Board

Distribution to Loads
Typical UPS System

“480 VDC Bus”: 540 VDC Float
UPS System – Utility Lost Before Generator

- Utility AC Input
- Transfer Switch
- Generator
- Rectifier AC→DC
- Battery
- Inverter DC→AC
- UPS
- Loads
Batteries in Mission Critical Applications

Utility AC

- Substation Battery 125 volt

Switchgear

- Switchgear Battery 125 V/48 V

Emergency Lighting

- Telecom Equip 48 VDC

- Telecom Battery 48 V/24 cells

Fire Pump Battery

- Emergency Lighting Battery

Fire Pump

Generator

- Engine Starting Battery 24 volt

Transfer Switch

UTPS

- Rectifier

- UPS Battery 480 Volt 240 cells

Inverter

LOADS
**Definition of a Cell**

- **Cell**: A unit part consisting of two dissimilar electrodes immersed in an electrolyte;
  - One lead acid cell is 2 volts nominal
  - One nickel cadmium cell is 1.2 volts nominal
Definition of a String

**String**: An energy storage system consisting of two or more series connected cells up to the required system voltage

**Lead Acid**

“125 Vdc” = 58-60 cells
Typical Float = 130-134Vdc
Definition of a String

Nickel Cadmium

“125 Vdc” = 90-96 cells
Typical Float = 130 - 134 Vdc
Battery Basics

Within the cell the plates are connected in parallel. If each positive plate is 100 Amp Hours in capacity, the cell is 300 Amp Hour.
Battery Basics

Series connection of Cells

- Start with Cell # 1 Positive, connecting from a negative terminal on cell #1 to a positive terminal on adjacent cell (typical connection within a battery string)
- Add up the cell voltage, but the Amp-hour stays the same
- Example: Two 6V-25Ahr units connected in series = 12 Volt, 25 Amp-hour
Battery Basics

- **Parallel connection**
  - Connecting from a positive terminal on one battery to a positive terminal on another battery
  - Sum the Capacity of each string (Watts or Amp Hours); the voltage remains the same
  - Example: Two 6V-25 Amp hour units connected in parallel = System: 6 Volts, 50 Amp-hours
Lead Acid Battery

- Lead dioxide Positive plate, PbO₂
- Metallic sponge lead Negative plate, Pb
- Immersed into an electrolyte of Water & Sulfuric Acid, H₂SO₄
Types of Lead Acid Battery

- **Vented Lead Acid ("VLA")**
  - Also called Flooded or Wet
  - *Lead-Calcium (most common)*, Lead-Antimony, Low Antimony ("lead selenium") and Pure Lead

- **Valve Regulated Lead Acid ("VRLA")**
  - Also called Sealed *not maintenance free*
  - Lead Calcium
  - Pure Lead
  - AGM design
    - (Absorbed Glass Mat)
  - Gel design
Lead Acid Cell Components

Post
Vent
Cover
Strap
Separator
Plate
Container

VLA (Flooded)

2 Volt VRLA
Lead Acid Grids and Plates

Grid

Positive Plate

Negative Plate
**Separators**

**Separator:** prevents electrical contact between the positive and negative plates while maintaining sufficient electrolyte to sustain capacity

- **Flooded:** micro porous separator
  - Grooved design to allow free liquid and gas movement within cell
  - Provides prevention from shorts
  - Glass mat may be used

- **VRLA:** “absorbent glass mat” wraps positive and negative plates
  - AGM
  - Gel
# Lead Acid Battery Design Differences

<table>
<thead>
<tr>
<th>Telecom Battery</th>
<th>UPS Battery</th>
<th>Switchgear Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Rate/Long Duration</td>
<td>High Rate/Short Duration</td>
<td>General Purpose Step Loads</td>
</tr>
<tr>
<td>Nominal 8 hr discharge rate</td>
<td>Nominal 15 min. discharge rate</td>
<td>Combination of long &amp; short duration rates</td>
</tr>
<tr>
<td>Thicker pos plates</td>
<td>Thinner pos plates</td>
<td>Moderately thick plates</td>
</tr>
<tr>
<td>Plates farther apart</td>
<td>Plates very close</td>
<td>Moderate plate center</td>
</tr>
<tr>
<td>High electrolyte to plate ratio</td>
<td>Low electrolyte to plate ratio</td>
<td>Moderate electrolyte to plate ratio</td>
</tr>
<tr>
<td>Minimal cycling</td>
<td>Improved cycling</td>
<td>Moderate cycling</td>
</tr>
<tr>
<td>Poor high rates</td>
<td>Very good high rates</td>
<td>Reliable high rates</td>
</tr>
<tr>
<td>Good long rates</td>
<td>Poor long rates</td>
<td>Reliable long rates</td>
</tr>
</tbody>
</table>
Nickel Cadmium Battery

- Nickel positive plate
- Cadmium negative plate
- Immersed into an electrolyte of Potassium Hydroxide (alkaline)
# Nickel Cadmium Design Differences

<table>
<thead>
<tr>
<th>Cell type</th>
<th>L (Low rate of discharge)</th>
<th>M (Medium rate of discharge)</th>
<th>H (High rate of discharge)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Emergency lightning</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telecommunication</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel start</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>UPS</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Utility Equipment</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Emergency supply</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Alarm equipment</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Nickel Cadmium - Internal Construction

L
Low Rate of Discharge

M
Medium Rate of Discharge

H
High Rate of Discharge
IEEE Standards, Guides, Practices

- IEEE Std 485-2010: Sizing, Stationary Lead Acid
- IEEE Std 1184-2006: Batteries for UPS Systems
- IEEE Std 1189-2007: Selection & Sizing VRLA
- IEEE Std 1115-2014: Sizing Nickel Cadmium

Additional System Considerations:

1375 – Protection of Battery Systems
1578 – Spill Containment
1491 – Monitoring Systems
1635 – Guide to Ventilation design
1657 – Personnel Qualifications for Install & Maint
946 – Design of DC Auxiliary Power Systems for Generating Stations (charger sizing)
General Sizing Considerations

The battery must supply the DC power when:

1. The load on the dc system exceeds the maximum output of the charger
2. The output of the charger is interrupted
3. The AC power is lost (may result in greater dc power demand than item 2.)
Define the System Loads

- **Continuous** – energized throughout the duty cycle
- **Noncontinuous** - energized only during a portion of the duty cycle, defined duration
- **Momentary** - short duration loads not exceeding 1 minute at any occurrence.
  - Lead Acid: considered a full minute, 1 minute
  - Nickel Cadmium: for loads < 1 sec, consider 1 second
Define Load & Application

**Steady Loads** – typically Telecom, “long duration” 8 hour backups

**KVA/KW Loads** – typically UPS, “high rate, short duration” 15 minutes, KVA/KW ratings

**Step Loads** – Switchgear & Control – Utility Applications – “step loads” - combination of high rates and long duration
The loads applied to the battery are either:

- **Constant power** (inverters, dc/dc power supplies)
- **Constant resistance** (dc motor starting, relays, contactors, lights)
- **Constant current** (running dc motors)

*For Sizing purposes, loads are treated as Constant Power or Constant Current*
Selection Factors to be Considered

- Physical characteristics of the cells
- Planned life of the installation
- Frequency and depth of discharge
- Charging characteristics
- Maintenance requirements
- Cell orientation requirements
- Ventilation requirements
- Seismic characteristics
- Spill management
Battery Size – Nominal Rating

**Ampere-hour**: 8 hour capacity of a lead acid storage battery (in the US)

- The quantity of electricity that the battery can deliver in amp-hours at the 8 hour rate.
- Example: a “2000 Ampere Hour” battery will provide 250 amps for 8 hours to 1.75 volts per cell
  
  \[ \frac{2000}{8} = 250 \text{ amps continuously for 8 hours} \]

- Nickel Cadmium: 5 hour or 10 hour or 20 hour rate
Battery Size – Constant Power Rating

- UPS batteries are rated in Watts or kW:
  \[ \text{kW/cell} \times \text{number of cells} = \text{kWb} \]

- For a specified time period to a specified end voltage, e.g., 15 minutes to 1.67 volts per cell.

- Battery is typically sized for full load of the UPS system.
Important Sizing Considerations

Operating Temperature
- Affects the available capacity
- Size for the lowest expected temperature
- At high temperatures use the rated capacity for 77° F
- High temperature affects battery life
- Cold temperature affects battery capacity
- For Nickel Cadmium - see manufacturer
## Temperature Correction Factors

From IEEE Std 485-2010

<table>
<thead>
<tr>
<th>Electrolyte temperature (°C)</th>
<th>Electrolyte temperature (°F)</th>
<th>Temperature correction factor</th>
<th>Electrolyte temperature (°C)</th>
<th>Electrolyte temperature (°F)</th>
<th>Temperature correction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>40</td>
<td>1.300</td>
<td>26.1</td>
<td>79</td>
<td>0.987</td>
</tr>
<tr>
<td>7.2</td>
<td>45</td>
<td>1.250</td>
<td>26.7</td>
<td>80</td>
<td>0.980</td>
</tr>
<tr>
<td>10.0</td>
<td>50</td>
<td>1.190</td>
<td>27.2</td>
<td>81</td>
<td>0.976</td>
</tr>
<tr>
<td>12.8</td>
<td>55</td>
<td>1.150</td>
<td>27.8</td>
<td>82</td>
<td>0.972</td>
</tr>
<tr>
<td>15.6</td>
<td>60</td>
<td>1.110</td>
<td>28.3</td>
<td>83</td>
<td>0.968</td>
</tr>
<tr>
<td>18.3</td>
<td>65</td>
<td>1.080</td>
<td>28.9</td>
<td>84</td>
<td>0.964</td>
</tr>
<tr>
<td>18.9</td>
<td>66</td>
<td>1.072</td>
<td>29.4</td>
<td>85</td>
<td>0.960</td>
</tr>
<tr>
<td>19.4</td>
<td>67</td>
<td>1.064</td>
<td>30.0</td>
<td>86</td>
<td>0.956</td>
</tr>
<tr>
<td>20.0</td>
<td>68</td>
<td>1.056</td>
<td>30.6</td>
<td>87</td>
<td>0.952</td>
</tr>
<tr>
<td>20.6</td>
<td>69</td>
<td>1.048</td>
<td>31.1</td>
<td>88</td>
<td>0.948</td>
</tr>
<tr>
<td>21.1</td>
<td>70</td>
<td>1.040</td>
<td>31.6</td>
<td>89</td>
<td>0.944</td>
</tr>
<tr>
<td>21.7</td>
<td>71</td>
<td>1.034</td>
<td>32.2</td>
<td>90</td>
<td>0.940</td>
</tr>
<tr>
<td>22.2</td>
<td>72</td>
<td>1.029</td>
<td>32.9</td>
<td>95</td>
<td>0.930</td>
</tr>
<tr>
<td>22.8</td>
<td>73</td>
<td>1.023</td>
<td>33.8</td>
<td>99</td>
<td>0.910</td>
</tr>
<tr>
<td>23.4</td>
<td>74</td>
<td>1.017</td>
<td>34.6</td>
<td>101</td>
<td>0.890</td>
</tr>
<tr>
<td>23.9</td>
<td>75</td>
<td>1.011</td>
<td>35.3</td>
<td>103</td>
<td>0.880</td>
</tr>
<tr>
<td>24.5</td>
<td>76</td>
<td>1.006</td>
<td>36.1</td>
<td>106</td>
<td>0.870</td>
</tr>
<tr>
<td>25.0</td>
<td>77</td>
<td>1.000</td>
<td>36.9</td>
<td>110</td>
<td>0.860</td>
</tr>
<tr>
<td>25.6</td>
<td>78</td>
<td>0.994</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE**—This table is based on lead-acid nominal 1.215 specific gravity cells. For cells with other specific gravities, refer to the manufacturer.
Important Sizing Considerations

**Aging Margin – LEAD ACID:**
- Replacement criteria = 80% of rated capacity.
- Battery is defined at end of life at 80% capacity.
- The initial rated capacity of the battery should be at least 125 percent (1.25 aging factor) of the load expected at the end of its service life.
Important Sizing Considerations

- **Aging – NICKEL CADMIUM:**
  - No defined end of life point
  - Capacity gradually decreases (linear)
  - 1.25 margin is typically used
  - Aging margins of 1.10 – 1.40 may apply

*Figure E.1—Typical nickel-cadmium aging at 20 °C to 25 °C*
Important Sizing Considerations

- **Initial Capacity**
  - Batteries may have less than rated capacity when delivered. Unless 100% capacity upon delivery is specified, the initial capacity can be as low as 90% of rated capacity (per IEEE-485)
  - Typical UPS and Switchgear batteries ship at 100%; Telecom at 90%
Important Sizing Considerations

**Nickel Cadmium**

- For the float application (telecom, switchgear, UPS), make sure to use the data based on Constant Potential Float Charging.
Important Sizing Considerations

**Design margin**

- It is prudent to provide a capacity margin to the battery sizing for unforeseen additions to the dc system and less than optimum operating conditions.
- Typical design margins are 10-15%.
Battery Size

Factors governing battery size:
- Maximum system voltage
- Minimum system voltage
- Correction factors (e.g. aging, temperature)
- Duty cycle

If cells of sufficiently large capacity are not available, then two or more strings may be connected in parallel. The capacity of such a battery is the sum of the capacities of the strings.
The maximum and minimum allowable system voltage ("voltage window") determines the number of cells in the battery.

When the battery voltage is not allowed to exceed a given maximum system voltage the number of cells will be limited by the cell voltage required for satisfactory charging.
Maximum Voltage
48 Volt Telecom Example

Number of cells =
\[
\frac{\text{Maximum system voltage}}{\text{Max cell voltage required for charging}}
\]

Given: 2.33 volts per cell required for equalize charging
Maximum allowable system voltage = 56 V and 54 V

\[
\frac{56 \text{ V}}{2.33 \text{ Vpc}} = 24 \text{ cells}
\]

\[
\frac{54 \text{ V}}{2.33 \text{ Vpc}} = 23 \text{ cells}
\]
Minimum Voltage
Telecom Example

Minimum battery voltage equals the minimum system voltage plus the cable voltage drop

Minimum system voltage at the equipment: 42 VDC
Allowable voltage drop from battery to load: 2 VDC
Minimum battery voltage: \((42 + 2) = 44\) VDC

\[
\frac{\text{Minimum battery voltage}}{\text{Number of cells}} = \text{minimum cell voltage}
\]

Given: the minimum allowable battery voltage is 44 Volts and the maximum number of cells is 24 or 23:

- \(44V \div 24\) cells = 1.83 volts per cell
- \(44V \div 23\) cells = 1.91 volts per cell
Maximum Voltage
Switchgear Example

Number of cells = 
\[
\frac{\text{Maximum system voltage}}{\text{cell voltage required for charging}}
\]

Given: 2.33 volts per cell required for equalize charging
Maximum allowable system voltage either 140 V or 135 V

\[
\frac{140 \text{ V}}{2.33 \text{ Vpc}} = 60.08 \text{ cells: use 60 cells}
\]

\[
\frac{135 \text{ V}}{2.33 \text{ Vpc}} = 57.94 \text{ cells: use 58 cells}
\]
Minimum Voltage
Switchgear Example

Minimum battery voltage equals the minimum system voltage plus the cable voltage drop

Minimum system voltage at the equipment: 103 VDC
Allowable voltage drop from battery to load: 2 VDC
Minimum battery voltage: \((103 + 2) = 105\) VDC

\[
\text{Minimum battery voltage = minimum cell voltage} \\
\text{Number of cells}
\]

Given: the minimum allowable battery voltage is 105 Volts and the maximum number of cells is 60 or 58:

\[
105V = 1.75 \text{ volts per cell} \\
60 \text{ cells}
\]

\[
105V = 1.81 \text{ volts per cell} \\
58 \text{ cells}
\]
Maximum Voltage
UPS Example

Number of cells =

\[
\frac{\text{Maximum system voltage}}{\text{cell voltage required for charging}}
\]

Given:  2.38 volts per cell (1.250 sp. gr.) and 2.33 vpc (1.215 sp.gr.) required for equalize charging

Maximum allowable system voltage: 576 VDC

\[
\frac{576 \text{ V}}{2.38 \text{ Vpc}} = 240 \text{ cells}
\]

\[
\frac{576 \text{ V}}{2.33 \text{ Vpc}} = 247 \text{ cells: (typical 240-244 cells)}
\]
Minimum Voltage UPS Example

Minimum battery voltage equals the minimum system voltage plus the cable voltage drop

Minimum system voltage at the UPS equipment: 396 VDC
Allowable voltage drop from battery to UPS: 4 VDC
Minimum battery voltage: \((396 + 4) = 400\) VDC

\[
\frac{\text{Minimum battery voltage}}{\text{Number of cells}} = \text{minimum cell voltage}
\]

Given: the minimum allowable battery voltage is 400 Volts and the maximum number of cells is 244

\[
\frac{400V}{240 \text{ cells}} = 1.67 \text{ volts per cell}
\]

\[
\frac{400V}{244 \text{ cells}} = 1.64 \text{ volts per cell}
\]
Sizing Example: Telecom

Constant Current loads

Sizing for:
- Load = 400 Amps for 8 hours
- 24 cells, battery end voltage 1.75 vpc
- Aging margin: 1.25
- Design margin: 1.10
- Temperature factor at 77°F: 1.00

\[
400 \times 1.25 \times 1.10 \times 1.0 = 550 \text{ Amps continuously for 8 hours to 1.75 vpc:}
\]

4,400 Ampere hour battery
Sizing Example: UPS Battery

UPS Specifications require a 300 kW Battery (kWb) for 15 minutes, 240 cells, 400 Vdc end voltage (1.67 vpc):

- The lowest ambient temperature: 65°F
- Battery must be sized for 300 kW at end of life

- 300 kWb x 1.080 (temp correction) x 1.25 (aging margin for 300 kW at end of life)

  \[= 300 \times 1.080 \times 1.25 \times = 405 \text{ kWb}\]

- Select a battery that will provide 405 kW
1.250 Specific Gravity
Discharge Rates in kW per Cell to 1.67Vpc at 25°C (77°F)

<table>
<thead>
<tr>
<th>Type</th>
<th>5</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>DXC-5B</td>
<td>0.908</td>
<td>0.758</td>
<td>0.735</td>
<td>0.713</td>
<td>0.693</td>
<td>0.673</td>
<td>0.653</td>
<td>0.634</td>
<td>0.616</td>
<td>0.599</td>
<td>0.582</td>
<td>0.567</td>
</tr>
<tr>
<td>DXC-7B</td>
<td>1.350</td>
<td>1.124</td>
<td>1.091</td>
<td>1.059</td>
<td>1.029</td>
<td>1.000</td>
<td>0.971</td>
<td>0.943</td>
<td>0.917</td>
<td>0.891</td>
<td>0.866</td>
<td>0.843</td>
</tr>
<tr>
<td>DXC-13B</td>
<td>2.585</td>
<td>2.239</td>
<td>2.166</td>
<td>2.096</td>
<td>2.028</td>
<td>1.964</td>
<td>1.903</td>
<td>1.845</td>
<td>1.791</td>
<td>1.740</td>
<td>1.691</td>
<td>1.645</td>
</tr>
<tr>
<td>DXC-15B</td>
<td>3.016</td>
<td>2.580</td>
<td>2.493</td>
<td>2.410</td>
<td>2.331</td>
<td>2.256</td>
<td>2.185</td>
<td>2.120</td>
<td>2.057</td>
<td>1.999</td>
<td>1.944</td>
<td>1.893</td>
</tr>
</tbody>
</table>

Example: UPS System requires a 405 kWb (300kWb EOL), 240 cells for 15 minutes to 400 VDC (400/240 cells = 1.67 volts per cell); 405/240 cells = 1.688 kW/cell
Select the DXC-13B at 1.903 kW/c x 240 cells = 456 kWb
When Battery kW ("kWb") is Unknown But UPS kVA is Known

Battery kWb = \( kVA \times p.f \)

efficiency of inverter

\( kVA = kVA \) is the Inverter output or load

p.f. = the power factor

Efficiency = the efficiency of the inverter

Battery kW = kW/cell \( \times 1.25 \) for EOL Sizing

# of Cells
Sizing Example: Switchgear & Control / Utility

- **Duty Cycle**
  - Combination of continuous, noncontinuous and momentary loads
  - All loads expressed in constant Current or constant Power
  - Time span of the duty cycle is determined by the requirements/design
Sizing Example: Switchgear & Control
### Table A.1—Sample cell sizing data

<table>
<thead>
<tr>
<th>Period</th>
<th>Loads</th>
<th>Total amperes</th>
<th>Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$L_1 + L_2$</td>
<td>320</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>$L_1 + L_3$</td>
<td>100</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>$L_1 + L_3 + L_4 + L_5$</td>
<td>280</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>$L_1 + L_3 + L_4$</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>$L_1$</td>
<td>40</td>
<td>59</td>
</tr>
<tr>
<td>6</td>
<td>$L_1 + L_6$</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>R</td>
<td>$L_7$</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>Period (minutes)</td>
<td>Change in Load (amps)</td>
<td>Duration of Period (minutes)</td>
<td>Time to End of Section (minutes)</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------------</td>
<td>-----------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Section 1: First Period Only - If A2 is greater than A1, go to Section 2.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 A1+320 A1-0+120 M1+ T-M1+ M2+ 5.77 246.4 ***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 2: First Two Periods Only - If A3 is greater than A2, go to Section 3.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 A1- A1-0+ M1+ T-M1+ M2+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 A1- A1-0+ M1+ T-M1+ M2+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sec Sub Tot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 3: First Three Periods Only - If A4 is greater than A3, go to Section 4.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 A1+320 A1-0+120 M1+ T-M1+ M2+ 5.77 246.4 ***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 A2+100 A2-0+50 M2+ T-M2+ M3+ 2.03 440.0 -440.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 A3+200 A3-0+100 M3+10 T-M3+10 1.44 199.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sec Sub Tot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 4: First Four Periods Only - If A5 is greater than A4, go to Section 5.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 A1+320 A1-0+120 M1+ T-M1+ M2+ 5.77 246.4 ***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 A2+100 A2-0+50 M2+ T-M2+ M3+ 2.03 440.0 -440.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 A3+200 A3-0+100 M3+10 T-M3+10 1.44 199.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 A4+200 A4-0+50 M4+10 T-M4+10 2.03 442.8 -40.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sec Sub Tot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 5: First Five Periods Only - If A6 is greater than A5, go to Section 6.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 A1- A1-0+ M1+ T-M1+ M2+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 A2- A2-0+ M2+ T-M2+ M3+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 A3- A3-0+ M3+ T-M3+ M4+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 A4- A4-0+ M4+ T-M4+ M5+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 A5- A5-0+ M5+ T-M5+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sec Sub Tot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 6: First Six Periods Only - If A7 is greater than A6, go to Section 7.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 A1+320 A1-0+120 M1+ T-M1+ M2+ 5.77 246.4 ***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 A2+100 A2-0+50 M2+ T-M2+ M3+ 2.03 440.0 -440.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 A3+200 A3-0+100 M3+10 T-M3+10 1.44 199.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 A4+200 A4-0+50 M4+10 T-M4+10 2.03 442.8 -40.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 A5+200 A5-0+50 M5+10 T-M5+10 2.03 442.8 -40.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 A6+100 A6-0+50 M6+10 T-M6+10 0.97 61.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sec Sub Tot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 7: First Seven Periods Only - If A8 is greater than A7, go to Section 8.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 A1- A1-0+ M1+ T-M1+ M2+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 A2- A2-0+ M2+ T-M2+ M3+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 A3- A3-0+ M3+ T-M3+ M4+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 A4- A4-0+ M4+ T-M4+ M5+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 A5- A5-0+ M5+ T-M5+ M6+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 A6- A6-0+ M6+ T-M6+ M7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 A7- A7-0+ M7+ T-M7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sec Sub Tot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Random Equipment Load Only (if needed): 5


Figure A.1—Sample worksheet using K_T capacity factors
Example: Substation Battery Duty Cycle

![Graph showing AMPS over time]

- AMPS: 100 at 1 min, 45 at 2 min, 2 at 1 hour, 2 at 239 hours
Sizing Report Using IEEE-485 Method

Customer Name: Substation Battery Sizing Example  |  Prepared by: Lesley Varga
Location: Unspecified  |  Phone: 770-916-1747
Project: Unspecified  |  Date: 2/16/15
Email: lesley@qualitystandbyservices.com

| Lowest Expected Electrolyte Temp. | 77.0 °F (25.0 °C) | Minimum Cell Voltage | 1.75 |

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---------------------------------|------------------|----------------------|------|
| PERIOD                          | LOAD (AMPERES)   | CHANGE IN LOAD       | DURATION OF PERIOD | TIME TO END OF SECTION | CAPACITY AT 1 MIN RATE | K FACTOR (K) | REQUIRED SECTION SIZE (3 * 6) = RATED AMP HOURS |
| SECTION 1 - FIRST PERIOD ONLY - IF A1 IS GREATER THAN A2 GO TO SECTION 2 | | | | | | |
| 1 | 100.00 | 100.00 | 00:01:00 | 00:01:00 | 0.706 | 70.637 | 0.000 |
| Sub Total | | | | | | 70.637 | 0.000 |
| Section 1 Total | | | | | | 70.637 | 0.000 |
| SECTION 2 - FIRST 2 PERIOD ONLY - IF A3 IS GREATER THAN A2 GO TO SECTION 3 | | | | | | |
| 1 | 100.00 | 100.00 | 00:01:00 | 00:35:00 | 4.788 | 478.754 | 0.000 |
| 2 | 2.00 | -98.00 | 03:58:00 | 03:58:00 | 4.772 | 0.000 | -467.703 |
| Sub Total | | | | | | 478.754 | -467.703 |
| Section 2 Total | | | | | | 11,051 | 
| SECTION 3 - FIRST 3 PERIOD ONLY - IF A4 IS GREATER THAN A3 GO TO SECTION 4 | | | | | | |
| 1 | 100.00 | 100.00 | 00:01:00 | 04:00:00 | 4.803 | 480.254 | 0.000 |
| 2 | 2.00 | -98.00 | 03:58:00 | 03:59:00 | 4.788 | 0.000 | -469.176 |
| 3 | 45.00 | 43.00 | 00:01:00 | 00:00:00 | 0.706 | 30.374 | 0.000 |
| Sub Total | | | | | | 510.627 | -469.176 |
| Section 3 Total | | | | | | 41,451 | 

MAXIMUM SECTION (8) 70.64 + RANDOM SECTION SIZE (9) 0.00 = UNCORRECTED SIZE - (US) (10) 70.64
(US) (11) 70.64 x TEMP CORR (12) 1.000 x DESIGN MARGIN (13) 1.10 x AGING FACTOR (14) 1.25 = (15) 97.13
WHEN THE CELL SIZE IS GREATER THAN A STANDARD CELL SIZE, THE NEXT LARGER CELL IS REQUIRED.
REQUIRED CELL SIZE (16) = 100 AH (PRODUCT RATING PER STRING IS 100 AH)

THEREFORE 1 STRING OF (20) CC-05M IS RECOMMENDED

Total AH Removed for System: 10  |  Number of Cells for System: 60
EnerSys Battery Sizing Program “BSP”

Register on-line at:

http://www.enersysreservepower.com/
Engineer, Furnish and Install

- Standby Power Products for the Utility, UPS and Telecom Applications
- Application and System Design
  - Registered Electrical PE
  - Technicians with Electrical Contractor Licenses
- Installation Services
- Start-up Service and Inspection
- Battery Load Testing
- Maintenance Contracts
- 24 Hour Emergency Service
- Battery Recycling/Disposal
EXPERIENCE & EXPERTISE = RELIABILITY & VALUE