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Content

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1. Introduction

The document outlines the procedure to be followed when designing DC systems for telecommunications purposes. The process will be explained by way of an example.

2. Supporting clauses

2.1 Scope

The document only covers the sizing for the battery, battery charger and interconnecting cables.

2.1.1 Purpose

To give a clear guideline of the steps to be followed when designing DC systems for telecommunications.

2.1.2 Applicability

This document shall apply throughout Eskom Telecommunications.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] 240-91244886, Battery Settings Standard

[2] ISO 9001 Quality Management Systems.

[3] Handbook of Electric Power Calculations, Third Edition, H. Wayne Beaty, McGRAW-HILL, ISBN: 9780071362986

[4] IEEE 946-2004, *IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Systems*

[5] IEEE Std 485 – 2010, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.

[6] SANS 10142-1:2017, The wiring of premises: Part 1: Low-voltage installations

2.2.2 Informative

[7] http://batteryuniversity.com/learn/article/charging_the_lead_acid_battery

2.3 Definitions

2.3.1 General

None

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
DC	Direct Current

2.5 Roles and responsibilities

It is the responsibility of Eskom Telecommunications to ensure that this guideline is followed and implemented where applicable.

2.6 Process for monitoring

The DC & Auxiliary Supplies Study Committee shall ensure that any future updates to this document are made.

2.7 Related/supporting documents

Not applicable.

3. Design guide

3.1 Required information / data

In order to design an effective DC System it is critical that the following information / data are available:

a) Load profile of the load equipment

b) Input voltage windows of the different load equipment

c) The number of cells in the battery bank

d) Datasheets of the different battery technologies that you intend to use

e) Allowable voltage drops along cable routes. This requirement is linked to item b).

f) Environmental conditions under which you expect the system to operate

g) Maintenance requirements

h) Reliability and availability requirements

Each of these different aspects will be discussed in greater detail in the following sections.

3.2 Load profile

The load profile is a visual aid used to analyse the duty cycle that the battery is supposed to support. Essentially it shows the different loads and their expected inception – and end times. Telecommunication load profiles generally have transmission –, receive – and idle periods that occur randomly. The relative durations of these different periods are indicated by the utilisation ratio which indicates the average time that the equipment spends in the different modes. The utilisation ratio is dependent on the amount of traffic experienced on the communications channels / links.

The load profile that should be used is shown in 1. It indicates the load profile segments as random loads, because the exact start time, end time and sequence of occurrence of these segments are unknown. This also represents the worst case scenario. The continuous loads are on for the entire standby time duration and should be indicated as such on the load profile.

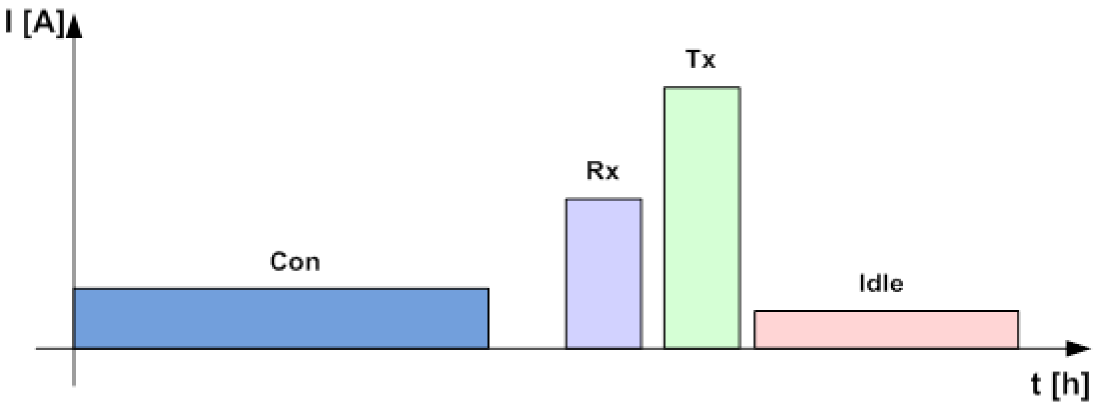

Figure 1: Load profile with random loads

The average current drain is calculated using the following equation:

$$I_{avg} = \frac{(I_{Tx} \times T_{Tx}) + (I_{Rx} \times T_{Rx}) + (I_{Idle} \times T_{Idle})}{T} \qquad \text{Equation 1}$$

$$I_{avg} = \frac{(I_{Tx} \times F_{Tx} \times T) + (I_{Rx} \times F_{Rx} \times T) + (I_{Idle} \times F_{Idle} \times T)}{T} \qquad \text{Equation 2}$$

$$I_{avg} = (I_{Tx} \times F_{Tx}) + (I_{Rx} \times F_{Rx}) + (I_{Idle} \times F_{Idle}) \qquad \text{Equation 3}$$

Where:

I_{Tx} – Transmit current

I_{Rx} – Receive current

I_{Idle} – Idle current

T – Total period (required standby time)

F_{Tx} – Transmit utilisation ratio

F_{Rx} – Receive utilisation ratio

F_{Idle} – Idle utilisation ratio

1 shows the different equipment, their load currents and utilisation ratios for a fictitious system.

Table 1: Load profile currents

Equipment	Utilisation Ratio [%] F_{Tx}:F_{Rx}:F_{Idle}	Current [A]					Time [h]			
		Tx	Rx	Idle	Con	Avg	Tx	Rx	Idle	Con
Ericsson Minilink TN (1+1)	N/A	---	---	---	2.5	2.5	---	---	---	12
Ericsson Minilink TN (1+1)	N/A	---	---	---	2.5	2.5	---	---	---	12
Motorola ACE 3600	N/A	---	---	---	0.4	0.4	---	---	---	12
Tait 800 VHF Repeater 25W	40:40:20	4.20	0.44	0.20	---	1.88	4.8	4.8	2.4	---
Tait TB8100 UHF Repeater 5W	20:20:60	2.60	0.72	0.15	---	0.75	2.4	2.4	7.2	---
Aprisa SE	N/A	---	---	---	1	1	---	---	---	12
	Totals	**6.8**	**1.16**	**0.35**	**6.4**					

Equipment	**Utilisation Ratio [%] F_{Tx}:F_{Rx}:F_{Idle}**	**Current [A]**					**Time [h]**			
		Tx	**Rx**	**Idle**	**Con**	**Avg**	**Tx**	**Rx**	**Idle**	**Con**

Legend:

Tx – when the equipment is transmission state

Rx – when the equipment is in the receiving state

Idle – when the equipment is in the idle state

Con – Continuous current drain

Avg – Average current drain

3.3 Input voltage windows

The input voltage window of the load equipment indicates the minimum – and maximum input voltages under which the load will operate. The different load equipment will have different input voltage windows. In order to ensure that all load equipment are operational for the required standby time, it is important to select the highest minimum voltage of the different loads as the minimum load voltage that needs to be maintained for the entire standby period.

For the load equipment listed in 2, the highest minimum voltage to design for is 42V. This will ensure that all load equipment is powered for the entire standby period.

Table 2: Equipment Input Voltage Windows

Equipment	**V_{min} [V]**	**V_{max} [V]**
Ericsson Minilink TN (1+1)	40	60
Ericsson Minilink TN (1+1)	40	60
Motorola ACE 3600	40	60
Tait 800 VHF Repeater 25W	42	60
Tait TB8100 UHF Repeater 5W	42	60
Aprisa SE	42	60

3.4 Number of cells in battery bank

The maximum number of cells that can be connected to the DC bus is limited by the maximum input voltage of the load equipment plus the maximum voltage drop expected along the connecting cables between the battery charger output terminals. The use of a load voltage regulator (LVR) circuit (dropping diode) increases the upper voltage limit of the connected load equipment. This means that the DC bus voltage (battery charging voltage) can be higher which means that more cells can be connected in series. The upside of more cells in series is that the resultant capacity required for a specific standby time can be marginally reduced (depending on the cell technology used), because the end-of-discharge voltage (V_{eod}) is lower which means that more of the cell's available energy can be used during the discharge.

The LVR is part of the battery charger and in cases where it is fitted; the battery charger output terminals will be after the LVR. The LVR has various voltage dropping stages which are switched in-circuit or out-of-circuit to maintain the output voltage to the load equipment within the input voltage window of the load.

The maximum input voltage of the load equipment is used to calculate the number of cells in the battery bank. It is calculated using the equation below:

$$N_{cells} = \frac{V_{\max load}}{V_{max\ cell}} \qquad \text{Equation 4}$$

where:

N_{cells} is the number of cells;

$V_{max\ load}$ is the maximum load input voltage [V];

$V_{max\ cell}$ is the maximum cell voltage to charge the cells adequately [V].

In cases where an LVR is used the equation changes to:

$$N_{cells} = \frac{V_{\max LVR}}{V_{max\ cell}}$$ Equation 5

where:

N_{cells} is the number of cells;

$V_{max\ LVR}$ is the maximum load input voltage [V] of the LVR;

$V_{max\ cell}$ is the maximum cell voltage to charge the cells adequately [V].

The maximum charging cell voltage is dependent on the type of battery technology and cell chemistry as indicated in 240-91244886, *Battery Settings Standard.*

Note: If the battery bank should be equalised, then the load is isolated from the battery with a transfer switch or dropping diodes are used.

Note: In cases where dropping diodes (load voltage regulating equipment) are used, the battery charge voltage can be much higher than the maximum load input voltage.

Examples:

$$N_{cells} = \frac{V_{\max load}}{V_{\max cell}} = \frac{60}{2.40} = 25$$

This implies that a maximum of 25 cells can be used in the battery bank. The actual voltage at the load terminals will be lower than this value due to the cable voltage drop.

For an LVR that has a maximum voltage drop of 7.5V, the maximum input voltage would be

$$V_{\max LVR} = V_{\max load} + \Delta V_{LVR} = 60 + 7.5 = 67.5V$$

This means that the number of cells is now:

$$N_{cells} = \frac{V_{\max LVR}}{V_{max\ cell}} = \frac{67.5}{2.40} = 28$$

3.5 Cable voltage drop

The minimum load input voltage and the expected voltage drop along the supply cables affect the end-of-discharge voltage to be used for the battery sizing exercise.

SANS 10142 specifies a maximum voltage drop of 5% of the nominal battery bank voltage. The design engineer can decide if the maximum voltage drop should be less than 5% and ensure that the cable sizes are correctly rated to accommodate this requirement.

Table 3: Allowed voltage drop

V_{nom}	V_{drop} (5%)
50	2.5
110	5.5
220	11

When a voltage drop analysis is performed, the maximum current that the equipment will be drawing at the end of the duty cycle should be used.

ET Configurations

1) Single system

2) Dual system – one DB with Diode combiner

3) 2 x Dual System – Essential sites – 2 DBs

Usually there will be not more than 2 distribution boards between the power supply and the loads. The cable sizes should be selected in order to get the least voltage drops on the main current paths because these will be usually the shortest cable runs.

The single line diagram of a telecommunications site DC distribution system is shown in 2.

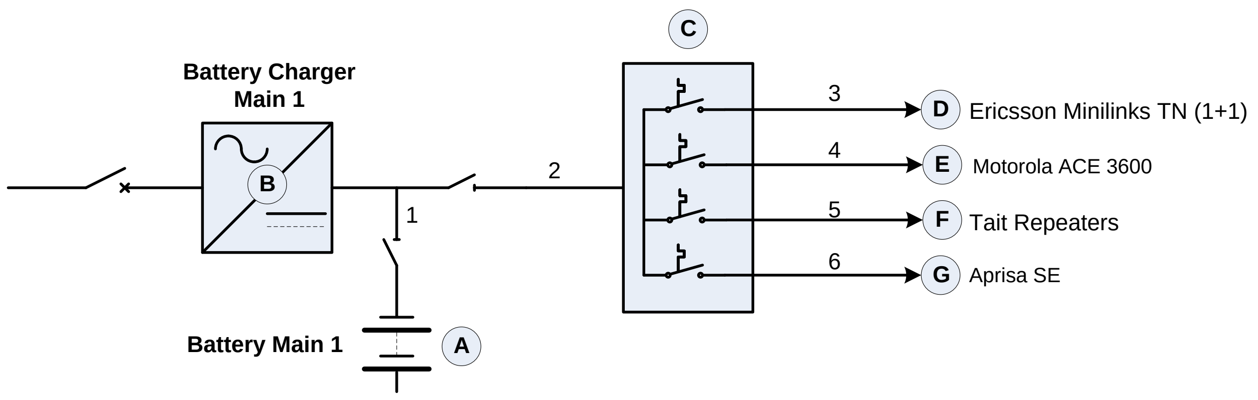

Figure 2: System single line diagram

In order to perform a voltage drop analysis we need to know the different impedance elements and the minimum operating voltages of the connected loads.

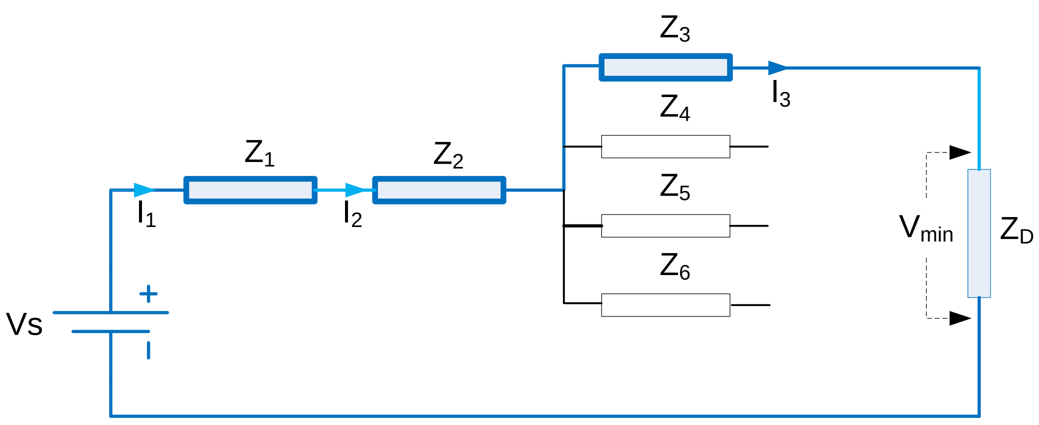

Figure 3: Circuit diagram of the distribution system

Applying Kirchoff's Voltage Law leads (indicated by blue highlighted circuit path in 3) to Equation 6 with the voltage drops across the cable sections indicated by Equation 7. The formula used to calculate the voltage drop across each cable section is indicated by Equation 8.

$$V_S = V_{min} + V_{drop} \quad \text{Equation 6}$$

$$V_{drop} = \Delta V_{Z1} + \Delta V_{Z2} + \Delta V_{Z3} \quad \text{Equation 7}$$

$$\Delta V_{Zn} = \frac{2\mathrm{L} \cdot \mathrm{Z} \cdot \mathrm{I_n}}{1000\mathrm{N}} \quad \text{Equation 8}$$

Where

- ΔV_{Zn}: Voltage drop across cable section
- L: Cable section length in metres (one way)
- Z: Per unit cable impedance in kilometres
- I_n: Cable section current
- N: Number of cables in parallel

The objective is to select cable sizes that will maintain the cumulative voltage drops within the allowed values.

The data of the cables used in the system are indicated in 4.

Table 4: System cable data

Cable #	Start	End	Location / Cable	CSA	Qty	L1	L	d	Z/km	Ztotal
	A	A	Battery Terminals							
1	A	B	Battery Charger	16	1	10	10	10	1.38	0.03
2	B	C	DC Distribution Board	16	1	5	5	15	1.38	0.01
3	C	D	Ericsson Minilinks	4	1	10	10	25	5.52	0.11
3-1	D	D1	Ericsson Minilink TN (1+1)	2.5	1	2	2	27	8.87	0.04
3-2	D	D2	Ericsson Minilink TN (1+1)	2.5	1	2	2	27	8.87	0.04
4	**C**	**E**	**Motorola ACE 3600**	**4**	**1**	**10**	**10**	**25**	**5.52**	**0.11**
5	**C**	**F**	**Tait Repeaters**	**4**	**1**	**10**	**10**	**25**	**5.52**	**0.11**
5-1	F	F1	Tait 800 VHF Repeater 25W	2.5	1	2	2	27	8.87	0.04
5-2	F	F2	Tait TB8100 UHF Repeater 5W	2.5	1	2	2	27	8.87	0.04
6	**C**	**G**	**Aprisa SE**	**4**	**1**	**10**	**10**	**25**	**5.52**	**0.11**

Legend:
CSA – Cross sectional area
L1, L – Cable section length
D – Cumulative cable path length
Z/km – Cable impedance per kilometre
Ztotal – Total cable impedance per section

The voltage drop information along the different cable paths are indicated in 5. The same data is displayed in graphical format in 4. It is clear that the load terminal voltages are maintained well above the minimum voltage of 42V.

Table 5: System voltage drop information

Cable #	Start	End	Location / Cable	Ztotal	I [A]	V	Vdrop [V]	Vdrop [%]	Vcum [%]	Vmin [V]
	A	**A**	**Battery Terminals**		**13.20**	**44.40**		**0.00%**		
1	**A**	**B**	Battery Charger	0.03	13.20	44.04	0.36	0.73%	0.73%	
2	B	C	DC Distribution Board	0.01	13.20	43.85	0.18	0.36%	1.09%	
3	**C**	**D**	**Ericsson Minilinks**	**0.11**	**5.00**	**43.30**	**0.55**	**1.10%**	**2.20%**	
3-1	D	D1	Ericsson Minilink TN (1+1)	0.04	2.50	43.21	0.09	0.18%	2.37%	40.00
3-2	D	D2	Ericsson Minilink TN (1+1)	0.04	2.50	43.21	0.09	0.18%	2.37%	40.00
4	**C**	**E**	**Motorola ACE 3600**	**0.11**	**0.40**	**43.81**	**0.04**	**0.09%**	**1.18%**	**42.00**
5	**C**	**F**	**Tait Repeaters**	**0.11**	**6.80**	**43.10**	**0.75**	**1.50%**	**2.59%**	**42.00**
5-1	F	F1	Tait 800 VHF Repeater 25W	0.04	4.20	42.95	0.15	0.30%	2.89%	42.00
5-2	F	F2	Tait TB8100 UHF Repeater 5W	0.04	2.60	43.01	0.09	0.18%	2.78%	42.00
6	**C**	**G**	**Aprisa SE**	**0.11**	**1.00**	**43.74**	**0.11**	**0.22%**	**1.31%**	**42.00**

Legend:

I – load DC current

V – Voltage at End point of cable section

V_{drop} – Voltage drop over cable section

V_{cum} – Cumulative percentage voltage drop

V_{min} – Load minimum input voltage

Z_{total} – Total cable impedance per section

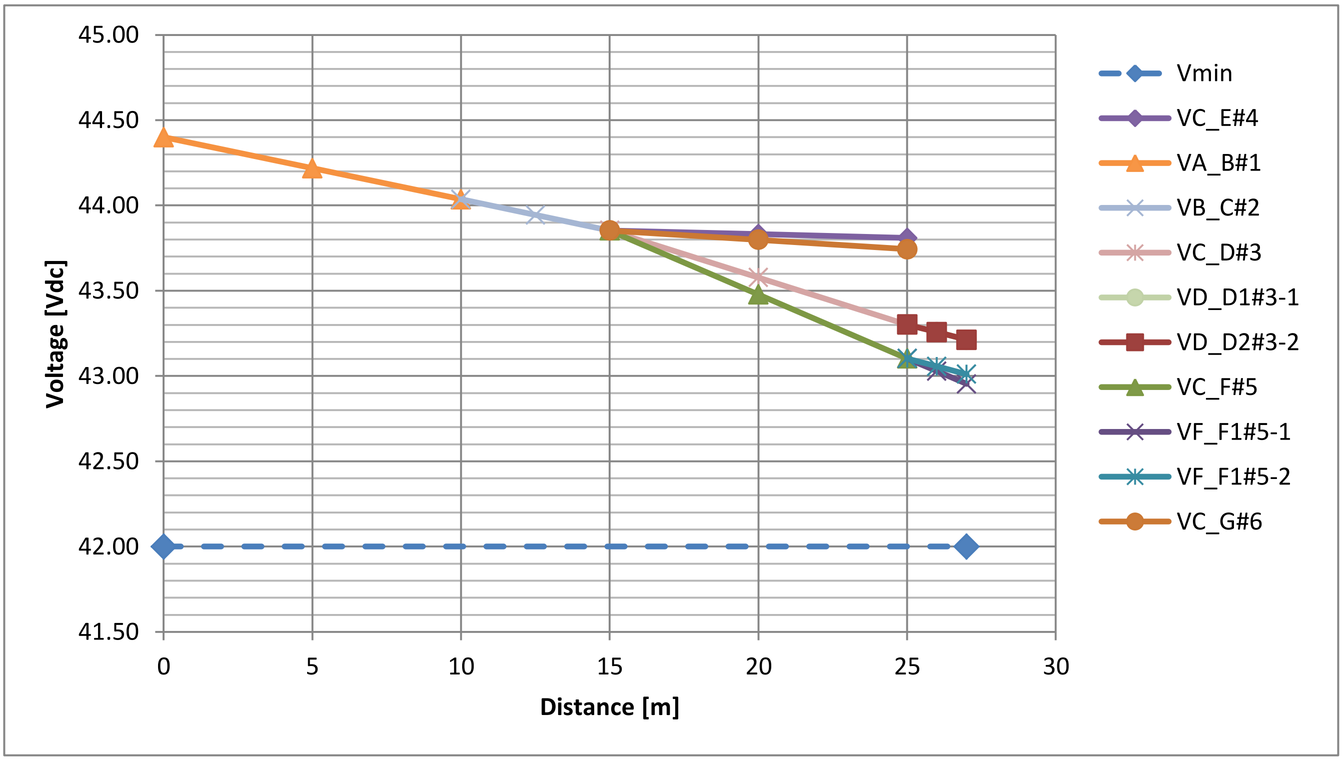

Figure 4: System voltage drop analysis graph

3.6 System short circuit analysis

The battery will deliver a substantial amount of current when it is short circuited. If the battery charger is also powered as this point in time the current limit of the battery charger also needs to be taken into consideration. The short circuit analysis is important to determine the fault levels at different locations in the system and to select the correct protection equipment.

The cell open-circuit voltage for vented lead acid cells can be approximated by using Equation 9 [3].

$$E_{oc} = 0.84 + SG \qquad \text{Equation 9}$$

The cell short circuit current at the terminals can be calculated by using Equation 10 [3].

$$I_{sc} = \frac{E_{oc}}{R_c} \qquad \text{Equation 10}$$

Where

- E_{oc}: cell open-circuit voltage
- R_c: ell internal resistance
- SG: Specific gravity of the electrolyte

In cases where the cell internal resistance is not available, the cell short circuit current may be approximated as 10 times the 1 minute discharge rate to an end-of-discharge voltage of 1.75V/cell for a lead acid cell [4].

In order to calculate the short circuit fault level at different points in the system, Equation 10 may be used with the total cable resistance between the battery and the fault location added to R_c.

3.7 End-of-discharge voltage

The end-of-discharge voltage (V_{eod}) is the minimum voltage that will be maintained at the battery terminals for the required standby time. It takes into account the minimum load input voltage and the expected voltage drop along the supply cables.

The end-of-discharge voltage at the battery terminals can be calculated as follows:

$$V_{batt} = V_{\min load} + V_{drop} \qquad \text{Equation 11}$$

Therefore, the end-of-discharge voltage (V_{eod}) per cell can be calculated as follows:

$$V_{eod} = \frac{V_{batt}}{N_{cells}} \qquad \text{Equation 12}$$

Examples:

In our example, the end-of-discharge voltage at the battery terminals can be calculated as follows:

$$\begin{aligned} V_{batt} &= V_{\min load} + V_{drop} \\ &= 42 + 2.5 \\ &= 44.5V \end{aligned}$$

The end-of-discharge voltage (V_{eod}) per cell:

$$\begin{aligned} V_{eod} &= \frac{V_{batt}}{N_{cells}} \\ &= \frac{44.5}{25} \\ &= 1.78V/cell \end{aligned}$$

This means that we need to use the Kt factors from the discharge table where V_{eod} is 1.80V/cell (or the closest V_{eod} value equal to or greater than 1.78V/cell) if we are going to use lead acid cells. The V_{eod} for the battery bank is then 45V.

In the case where the LVR is installed, the end-of-discharge voltage (V_{eod}) per cell:

$$V_{eod} = \frac{V_{batt}}{N_{cells}}$$

$$= \frac{44.5}{28}$$

$$= 1.58V/cell$$

This means that we need to use the Kt factors from the discharge table where V_{eod} is 1.60V/cell (or the closest V_{eod} value equal to or greater than 1.58V/cell) if we are going to use lead acid cells.

3.8 Required battery capacity

The required battery capacity is determined by going through the following additional steps:

a) Calculating the uncorrected battery capacity based on the load profile and the Kt (cell performance) factors.

b) Applying a compensation factor for temperature variations – this ensures that the battery can still deliver the required capacity under expected low temperature conditions.

c) Applying a compensation factor for aging / capacity loss – this ensures that the battery can still deliver the required capacity over the expected life.

d) Applying a compensation factor for expected load growth – this ensures that the battery capacity is big enough to cater for expected load growth at the site in the foreseeable future.

e) After all these factors have being applied, the corrected capacity is obtained.

f) This corrected capacity is then used to select a suitable cell from the list of available cells in the range with a rated capacity equal to or greater than the required capacity.

3.8.1 Cell performance data

The next step would be to calculate the required battery capacity using the Kt factors for an end-of-discharge voltage equal to the value calculated in the previous section (1.85V/cell). Kt is the ratio of rated ampere-hour capacity [at a standard time rate, at the standard temperature and to a standard minimum cell voltage] of a cell, to the amperes that can be supplied by that cell for t minutes at the standard temperature and to a given minimum cell voltage – see Equation 13. The standard temperature is usually 25 °C (77 °F).

$$K_t = \frac{C_{rated}}{I_t} \qquad \text{Equation 13}$$

Interpolation or extrapolation is used to calculate the Kt values for time periods not indicated on the standard discharge tables – see Annex B.

3.8.2 Uncorrected capacity

The uncorrected capacity takes only the load profile and corresponding Kt factors into consideration. The methodology followed is as indicated in IEEE Std 485 – 2010, *IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.*

The defined loads of the load profile / duty cycle are divided into periods (P_1 – P_N). Cumulative periods form the different sections (S_1 – S_N). To determine the required cell size, it is necessary to calculate, from an analysis of each section of the duty cycle, the maximum capacity required by the combined load demands (current versus time) of the various sections. The first section analysed is the first period of the duty cycle.

Using the Kt factor for the given cell type, a cell size is calculated that will supply the required current for the duration of the first period. For the second section, the capacity is calculated assuming that the current A1, required for the first period, continued through the second period; this capacity is then adjusted for the change in current (A2–A1) during the second period. In the same manner, the capacity is calculated for each subsequent section of the duty cycle. This iterative process is continued until all sections of the duty cycle have been considered. The calculation of the capacity C_{SN} required by each section S, where S can be any integer from 1 to N, is expressed mathematically in Equation 14.

$$C_{SN} = \sum_{P=1}^{P=N} [A_P - A_{P-1}] \times K_t|_{SN-S(P-1)} \qquad \text{Equation 14}$$

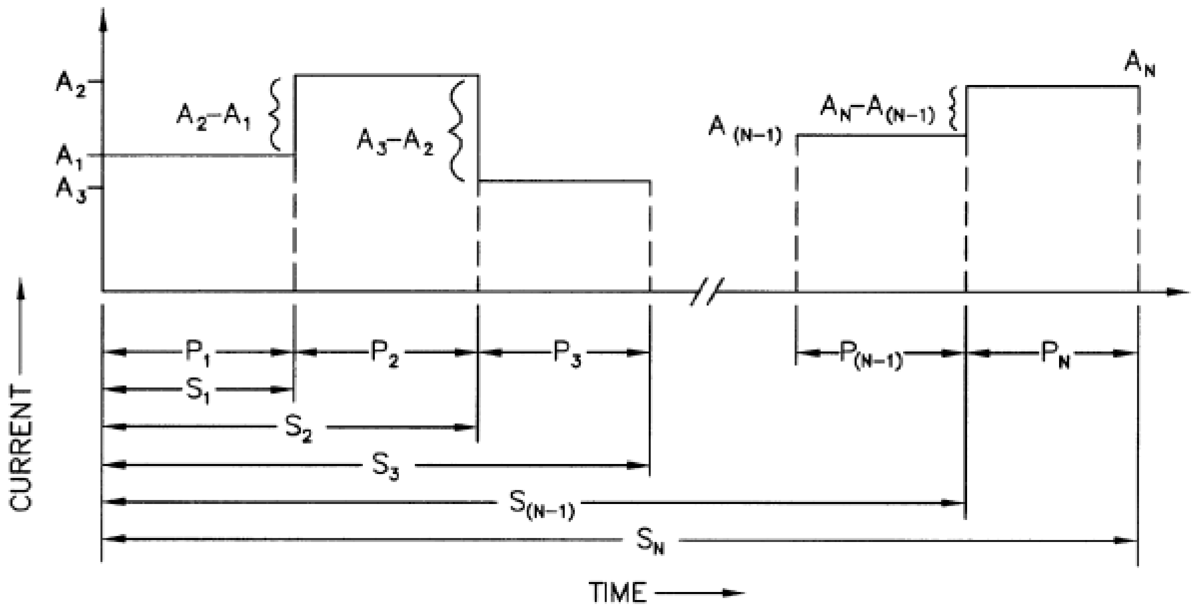

Figure 5: Generalised duty cycle [5]

The section with the maximum required capacity is then selected and the random section capacities added to get to the total required uncorrected capacity.

3.8.3 Temperature factors

The operating (electrolyte) temperature of a cell affects its available capacity. The standard temperatures for stating cell capacity is 25°C and 20°C. If the lowest expected electrolyte temperature is below the standard, it is necessary to select a cell large enough to have the required capacity available at the lowest expected temperature. For electrolyte temperatures higher than the standard temperature, there is a small increase in available capacity. Although the capacity of a cell slightly increases for electrolyte temperatures higher than the standard temperature, it is normal practice to select a cell size to match the required capacity at the standard temperature. The resulting increase in available capacity as a result of the higher electrolyte temperature is regarded as being part of the design margin. The temperature derating factor is also influenced by the discharge rate.

3.8.4 Design margin

To allow for unforeseen circumstances, like growth in load, less-than-optimum operating conditions, etc. a design margin (also referred to as the growth factor) is included in the sizing calculations. A method to provide for the design margin is to add a certain percentage to the calculated cell size. The recharge efficiency of the battery may also be included in the design margin, because in order to ensure that a battery are recharged within a specified recharge time you need to ensure that the selected battery type complies, otherwise you need to make provision in the design margin.

The calculated cell size is seldom equal to commercially (off-the-shelf) available cell capacities. In such cases the next higher capacity cell is selected. The additional capacity obtained can be considered as part of the design margin.

3.8.5 Aging factor

The capacities of both lead acid and nickel cadmium batteries decrease gradually over the life of the battery due to various factors, including operating temperature, electrolyte specific gravity, depth and frequency of discharge, amongst others.

An aging factor of 1.25 is used, meaning that the battery is sized to carry the loads until its capacity has reached 80% of its rated capacity. 6 shows the different aging factors to be applied for different plate types.

Table 6: Aging factors for different lead acid cell types

Plate type	Aging factor
Flat plate	1.25
Tubular plate	1.25
Planté plate	1.00

3.8.6 Corrected capacity

The corrected capacity is calculated by taking the design margin, effects of temperature and aging into consideration. The following formula can be used to calculate the corrected capacity (C_C):

$$C_C = C_{UC} \times T_F \times D_F \times A_F \qquad \text{Equation 15}$$

Where:

C_C is the corrected capacity [Ah]

C_{UC} is the uncorrected capacity [Ah]

T_F is the temperature factor

D_F is the design margin

A_F is the aging factor

The selected cell would then be the one from the range of available cells with a rated capacity of at least the corrected capacity (C_C).

Examples:

7 below shows the applied Kt factors (see Annex E) and resulting uncorrected capacities for the different loads in the example. It is clear that V_{eod} had a marginal impact on the calculated capacities. Kt factors for other cells shall be available from the manufacturer or on the DC Technology website.

Table 7: Kt factors and uncorrected capacities

	(1)		**(2)**	**(3)**					
Loads	**I [A]**	**T [min]**	**T [h]**	**Q [Ah]**	**V_{eod} = 1.60V/cell**		**V_{eod} = 1.80V/cell**		**ΔC_{uc}**
					Kt	**C_{uc}**	**Kt**	**C_{uc}**	
A1	6.4	720	12	76.8	12	76.80	12	76.80	0
R1	4.2	288	4.8	20.16	5.80	24.36	5.80	24.36	0
R2	0.44	288	4.8	2.11	5.80	2.55	5.80	2.55	0
R3	0.2	144	2.4	0.48	3.57	0.71	3.72	0.74	0.03
R4	2.6	144	2.4	6.24	3.57	9.28	3.57	9.28	0
R5	0.72	144	2.4	1.73	3.57	2.57	3.57	2.57	0
R6	0.15	432	7.2	1.08	7.83	1.17	7.83	1.17	0
				108.60		**117**		**117.03**	**0.03**

Legend:
A1: 2 x Ericsson Minilink TN (1+1), Motorola ACE 3600 and Aprisa SE (Continuous loads)
R1 – R3: Tait 800 VHF Repeater 25W
R4 – R6: Tait TB8100 UHF Repeater 5W
C_{uc}: Uncorrected capacity [Ah]
Q: Capacity removed from battery during duty cycle – (3) = (1) x (2)

8 below shows the applied factors to compensate for temperature (0°C), aging, a design margin and the resultant corrected capacities for the example.

Table 8: Applied factors and results

Description	**Abbr.**	**Value**
Uncorrected Capacity [Ah]	C_{UC}	117
Aging Factor	A_F	1.25
Temperature Factor	T_F	1.40
Design Margin	D_F	1.00
Corrected Capacity [Ah]	C_C	205
Rated Capacity	Cr	224
Cell Model Number (Cr)	Model #	FCP 15
Min Rated Capacity in Range	Cr (Min)	64
Max Rated Capacity in Range	Cr (Max)	672

3.9 Battery charger sizing

The main function of the battery charger is to ensure that the connected load is powered and that the battery remains fully charged or is recharged as quickly as possible after a discharge event (due to a battery charger failure). 6 shows that under normal conditions when the battery charger is functional, the battery charger charges the battery and supplies the load; and that under abnormal conditions when the battery charger is not available, the battery supports the load for the required standby time.

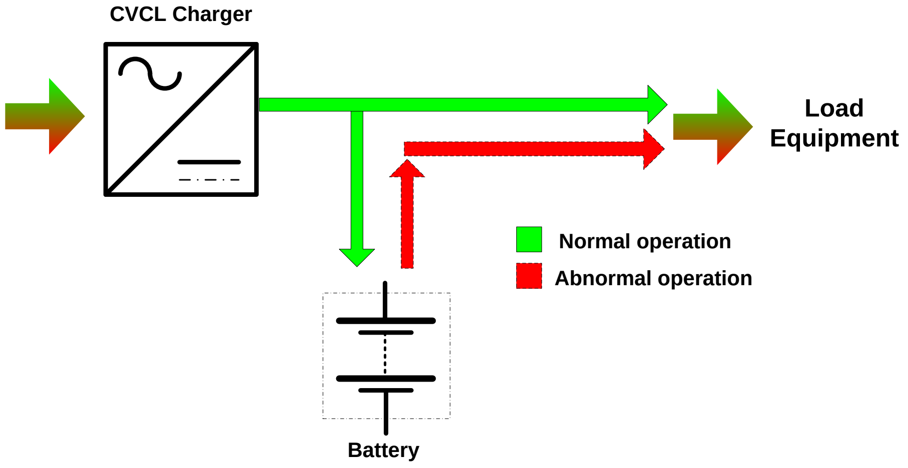

Figure 6: Block diagram of single DC system

Constant voltage, current limited battery chargers are used in Eskom which means that the battery charger is able to maintain the required charge voltage profile whilst at the same time controlling the output current not to exceed the maximum charging current as specified by the battery manufacturer. After a prolonged discharge event, the battery charger enters the boost mode which aims to recharge the battery as quickly as possible by subjecting the battery to a higher voltage than in float mode. During the initial stages of the recharge process, the battery charger acts as a current source and delivers a charging current up to the set current limit. As the battery charges the battery terminal voltage rises, reducing the difference between the charger voltage and battery terminal voltage until the desired charger output voltage is achieved. At this point the battery charging current tapers until only a trickle (float) current is maintained. When all the boost mode requirements have been met, the battery charger switches to the float charge mode. This is illustrated in 7.

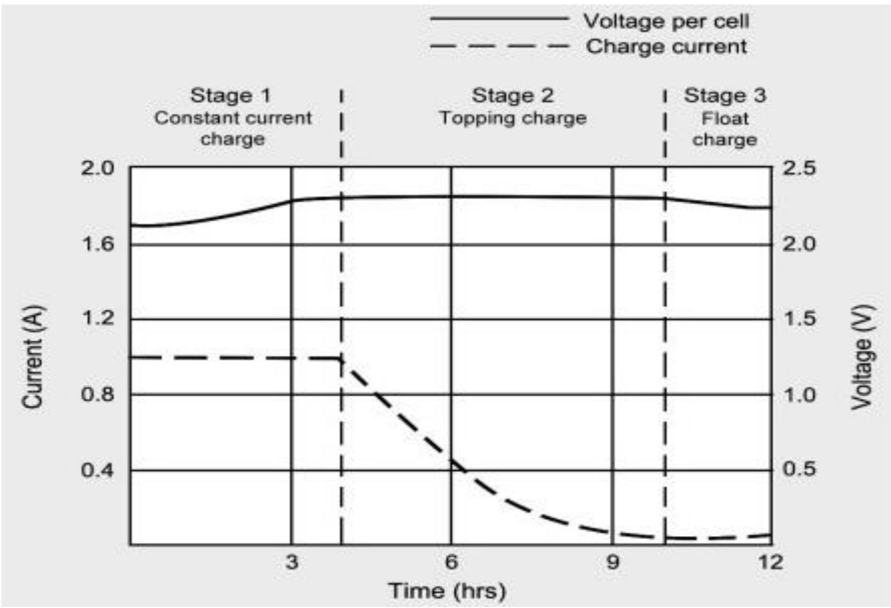

Figure 7: Recharge characteristics of a lead acid battery

The aim of the recharge function is basically to replenish the removed charge as quickly as possible. The battery has been sized to deliver the required load duty cycle which means that for all practical reasons the battery will be discharged when this energy have been removed and therefore under the worst case scenario this is the energy that need to be restored, taking recharge efficiency into consideration.

$$I_1 = I_{batt} + I_{LC}$$

$$I_{batt}|_{min} = \frac{k_1 \cdot Q}{T}$$

$$I_{batt}|_{max} = k_2 \cdot C_r$$

$$I_2 = I_{LC} + I_{LN}$$

Where:

I_{ch} : The minimum battery charger output current

I_{batt} : Battery charging current

I_{LC} : DC load current

k_1 : Battery recharge efficiency factor

k_2 : Battery current limit factor

Q : Ampere-hours drained from the battery during the substation duty-cycle.

T : Battery recharge period. Usually selected as 10h.

The greater value between I_1 and I_2 is selected.

Examples:

In the example the DC load current (I_{LC}) is calculated as follows:

$$\begin{aligned} I_{LC} &= I_{con} + I_{Tx} \\ &= 6.4 + (4.20 + 2.60) \\ &= 13.2A \end{aligned}$$

Note: The repeater cannot transmit, receive and be idle at the same time, therefore the maximum value was used which is the transmit current.

The minimum battery recharge recharge current is (value for Q obtained from 7):

$$\begin{aligned} I_{batt}|_{min} &= \frac{k_1 \cdot Q}{T} \\ &= \frac{1.10 \times 108.6}{10} \\ &= 11.95A \end{aligned}$$

The maximum battery recharge recharge current is:

$$\begin{aligned} I_{batt}|_{max} &= k_2 \cdot C_r \\ &= 0.14 \times 224 \\ &= 31.36A \end{aligned}$$

The battery charger output current, I_{ch}, is calculated as follows:

$$\begin{aligned} I_{ch} &= I_{batt} + I_{LC} \\ &= 11.95 + 13.2 \\ &= 25.15A \end{aligned}$$

The available charger with a rating equal to or higher than 25.15A is selected.

3.10 System Configuration

In order to avoid single points of failure and achieve the highest system reliability and availability, it is important to note the following with 8 as reference when designing a dual redundant DC system:

Load equipment with dual power supplies shall be fed separately from the Main 1 and Main 2 Distribution Boards. Separate supply cables following different routes shall be used.

Load equipment with single power supplies shall be fed via the Diode Combiner Distribution Board as indicated.

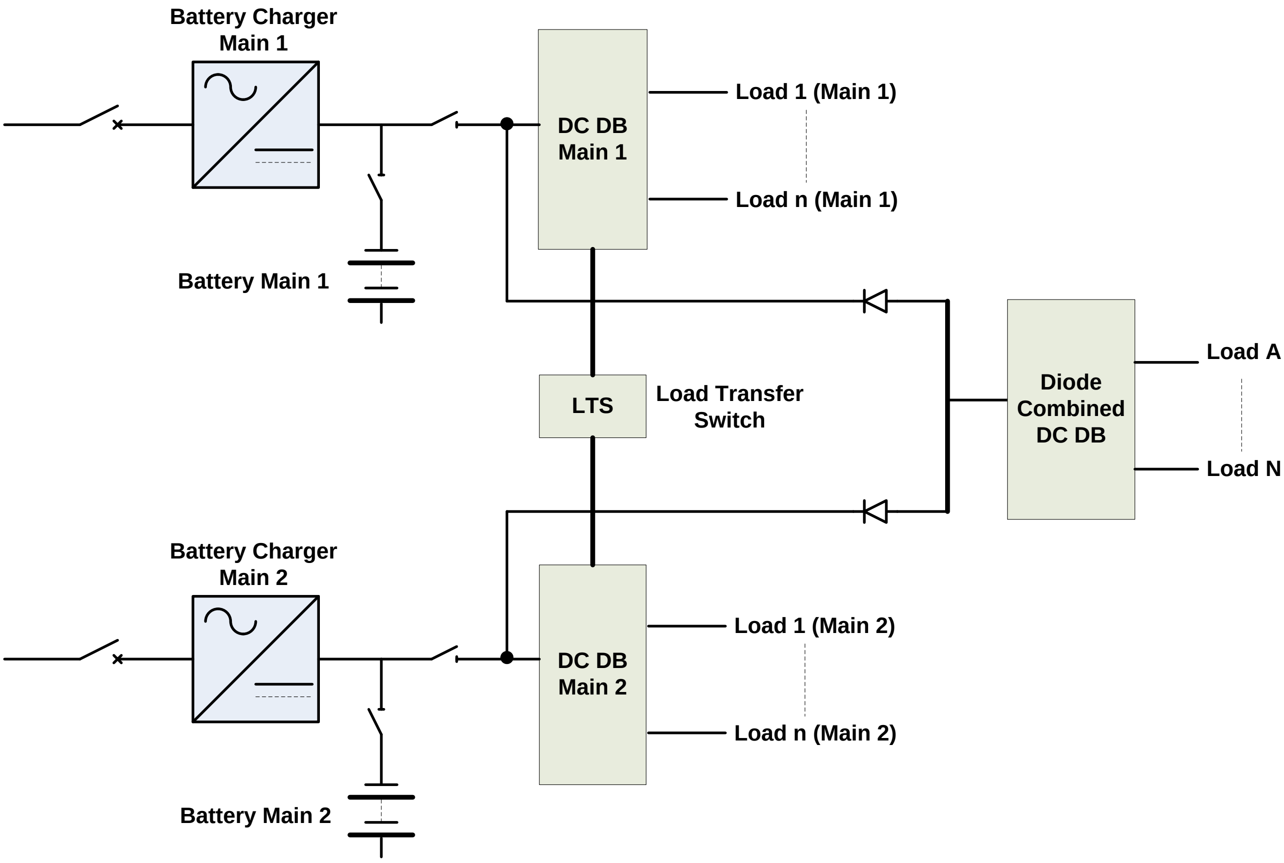

Figure 8: Single line diagram for a dual redundant DC system

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
Richard McCurrach	PTM&C Senior Manager
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Isabel Fick	Senior Manager – Eskom Telecommunications

5. Revisions

Date	Rev	Compiler	Remarks
March 2020	2	T Jacobs	Updated, DST_34-366, *DC Systems Settings Standard,* to the latest reference document. Removed “Table 3: Maximum battery charging voltages” and referenced 240-91244886, *Battery Settings Standard.* Added SANS 10142-1:2017, The wiring of premises: Part 1: Low-voltage installations, under Normative references.
Dec 2014	1	T Jacobs	Original document.

6. Development team

- Thomas Jacobs

7. Acknowledgements

Not applicable.

Annex A – Procedure for calculating Kt Factors

In order to calculate the Kt factors for a range of cells you will need the discharge tables for the different end-of-discharge voltages as recommended by the manufacturer. It is useful to also know the rated capacity and corresponding end-of-discharge voltage of the cells as indicated on the cell casing or as stated by the manufacturer.

A.1 shows the discharge table information for some cells. The C10 capacities were calculated by multiplying the column 7 time (10 hours) with the corresponding current value of the applicable row e.g. 10h (column 7) x 16.4A (row 7) = 164Ah. This means that the BATT12-170 cell has a 10 hour rated capacity of 164Ah at the standard electrolyte temperature and that it will be able to deliver 16.4A for 10 hours whilst maintaining its terminal voltage above or equal to 1.80V/cell. In this example we have selected the C10 to Veod = 1.80V/cell as the reference capacities to calculate the Kt factors.

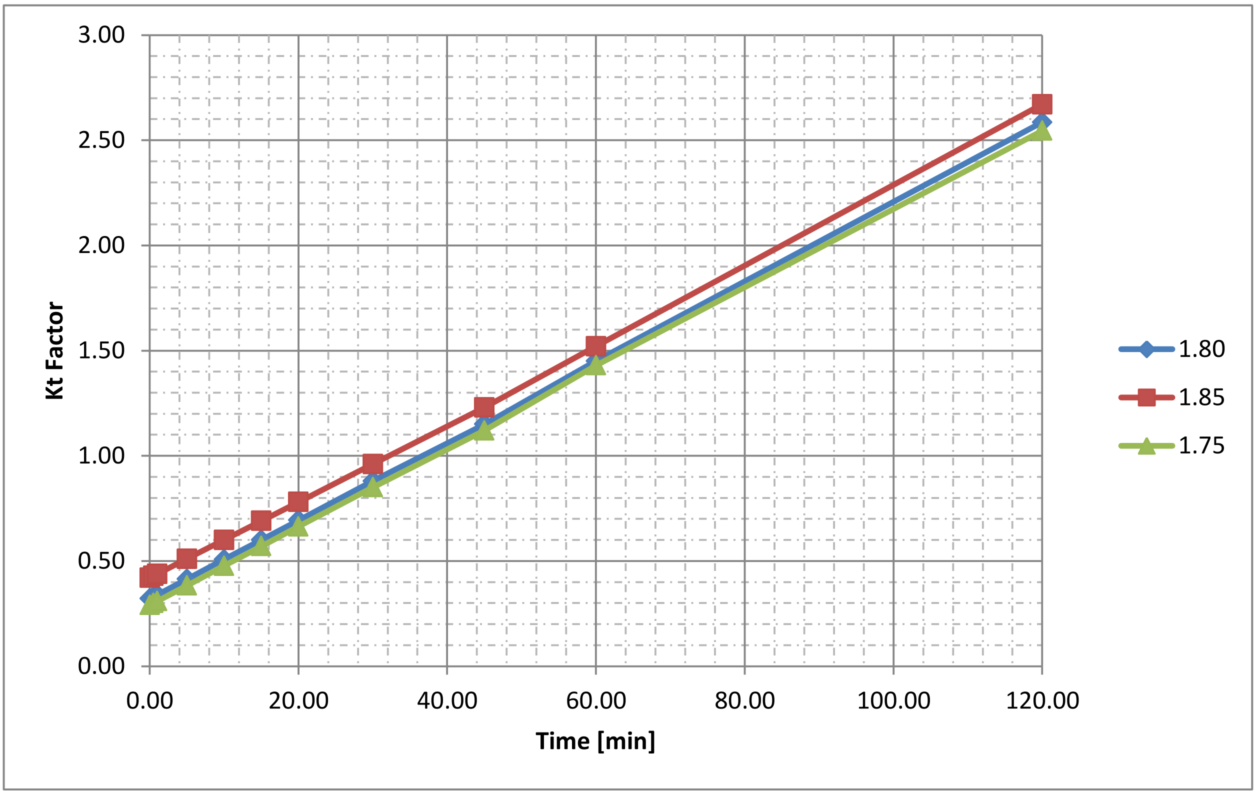
Table A.1: Example of discharge tables

	Column #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Row #		**Time [hours] - Amps to 1.85 VPC**								
1	**Battery Model**	**0.25**	**0.50**	**0.75**	**1.0**	**3.0**	**6.0**	**10.0**	**20.0**	**C10**
2	**BATT12-50**	81.3	57.9	44.0	34.8	13.4	7.6	4.9	2.7	49.4
3	**BATT12-100**	141.0	105.0	82.4	65.5	25.4	14.6	9.6	5.3	96
4	**BATT12-170**	217.0	151.0	121.0	101.0	42.6	24.4	16.0	8.5	160
		Time [hours] - Amps to 1.80 VPC								
	Battery Model	**0.25**	**0.50**	**0.75**	**1.0**	**3.0**	**6.0**	**10.0**	**20.0**	**C10**
5	**BATT12-50**	88.1	60.5	45.4	35.8	13.6	7.8	5.0	2.7	50.4
6	**BATT12-100**	170.0	114.0	87.1	68.4	26.3	15.0	9.8	5.4	98.1
7	**BATT12-170**	253.0	175.0	135.0	108.0	44.1	25.0	16.4	8.7	164
		Time [hours] - Amps to 1.75 VPC								
	Battery Model	**0.25**	**0.50**	**0.75**	**0.02**	**0.05**	**6**	**10**	**20**	**C10**
8	**BATT12-50**	91.4	62.1	46.1	36.1	13.8	7.8	5.1	2.8	51
9	**BATT12-100**	178.0	118.0	88.5	69.2	26.5	15.1	10.0	5.5	100
10	**BATT12-170**	269.0	183.0	141.0	112.0	45.2	25.4	16.7	8.9	167

In the corresponding Kt Factors are indicated for the discharge table data of A.1. The average Kt values for the cells in the range are calculated – these are the values that will be used in the sizing calculations.

Table A.2: Corresponding Kt Factor tables

	Column #	1	2	3	4	5	6	7	8
Row #		**Time [hours] - Kt to 1.85 VPC**							
1	**Battery Model**	**0.25**	**0.50**	**0.75**	**1.0**	**3.0**	**6.0**	**10.0**	**20.0**
2	**BATT12-50**	0.6	0.9	1.1	1.4	3.8	6.7	10.2	18.9
3	**BATT12-100**	0.7	0.9	1.2	1.5	3.9	6.7	10.2	18.6
4	**BATT12-170**	0.8	1.1	1.4	1.6	3.8	6.7	10.3	19.3
5	**Avg Kt**	0.69	0.96	1.23	1.52	3.82	6.71	10.22	18.93
		Time [hours] - Kt to 1.80 VPC							
	Battery Model	**0.25**	**0.50**	**0.75**	**1.0**	**3.0**	**6.0**	**10.0**	**20.0**
6	**BATT12-50**	0.6	0.8	1.1	1.4	3.7	6.5	10.0	18.5
7	**BATT12-100**	0.6	0.9	1.1	1.4	3.7	6.5	10.0	18.2
8	**BATT12-170**	0.6	0.9	1.2	1.5	3.7	6.6	10.0	18.8
9	**Avg Kt**	0.60	0.88	1.15	1.45	3.72	6.53	10.00	18.51
		Time [hours]- Kt to 1.75 VPC							
	Battery Model	**0.25**	**0.50**	**0.75**	**1.00**	**3.00**	**6.00**	**10.00**	**20.00**
10	**BATT12-50**	0.6	0.8	1.1	1.4	3.7	6.5	9.9	18.3
11	**BATT12-100**	0.6	0.8	1.1	1.4	3.7	6.5	9.8	18.0
12	**BATT12-170**	0.6	0.9	1.2	1.5	3.6	6.5	9.8	18.5
13	**Avg Kt**	0.57	0.85	1.12	1.43	3.66	6.47	9.84	18.24



Annex B – Interpolation and Extrapolation

In order to calculate the Kt factors for intermediate – or out of bound points interpolation and extrapolation may be used.

If we know the coordinates of point 1 and point 3 on a straight line and would like to calculate y_2 whilst knowing x_2, interpolation using Equation B 1 may be used.

$$y_2 = y_3 - \frac{(x_3 - x_2) \cdot (y_3 - y_1)}{(x_3 - x_1)}$$ **Equation B 1**

If we know the coordinates of point 1 and point 2 on a straight line and would like to calculate y_3 whilst knowing x_3, extrapolation using Equation B 2 may be used.

$$y_3 = y_1 + \frac{(x_3 - x_1) \cdot (y_2 - y_1)}{(x_2 - x_1)}$$ **Equation B 2**

If we know the coordinates of point 2 and point 3 on a straight line and would like to calculate y_1 whilst knowing x_1, extrapolation using Equation B 3 may be used.

$$y_1 = y_3 - \frac{(x_3 - x_1) \cdot (y_3 - y_2)}{(x_3 - x_2)}$$ **Equation B 3**

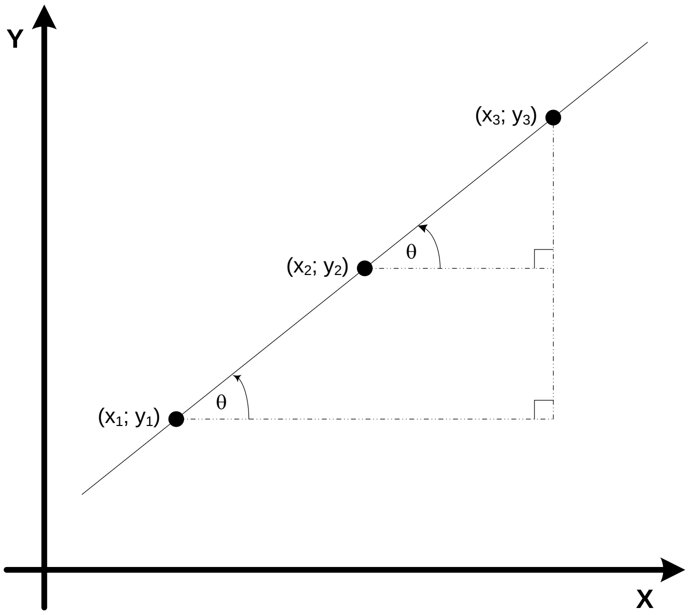


Figure B.1: Interpolation and Extrapolation graph

Annex C – Aging Factor

C.1 shows a graph in aid of explaining how the aging factor (capacity loss) factor is determined. C_s and C_r represent the start capacity and the required capacity, respectively. The required capacity is that which needs to be available over the expected life of the battery and takes the effect of temperature and growth into consideration. If the available battery capacity at any point during the expected life reaches this point, then it needs to be replaced because it will not be able to support the connected load in line with the load profile anymore.

The user can decide the percentage of allowable sacrificed capacity. Generally a capacity loss of 20% is allowed for a design which means that at 80% capacity the design limit is reached.

C_r is calculated and by taking the above criteria into consideration, C_s can be calculated as follow:

$$C_r = kC_s$$

$$C_r = 80\% \times C_s$$

$$\therefore C_s = \frac{C_r}{80\%} = \frac{C_r}{0.8} = 1.25 \times C_r$$

Where:

C_s – Start capacity

C_r – Required capacity

k – Percentage capacity at which the design limit is reached which means that 1/k is the aging factor.

Note: For cells that are considered not to experience any capacity loss, k=100% like in the case of planté cells.

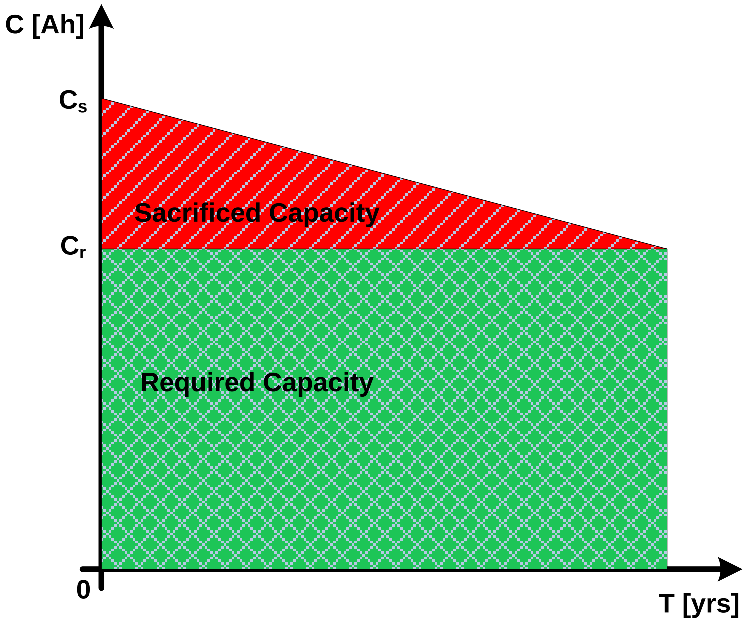


Figure C.1: Capacity loss graph

Annex D – IEEE Sizing Method

This Annex attempts to explain the IEEE sizing method. D.1 shows the load profile of a system consisting of some defined loads and a random load.

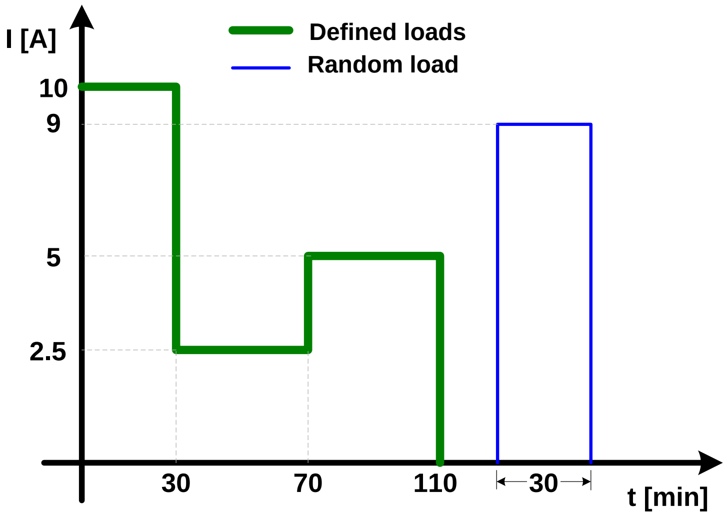


Figure D.1: Load profile

The load profile is divided into periods and sections as indicated in D.2.

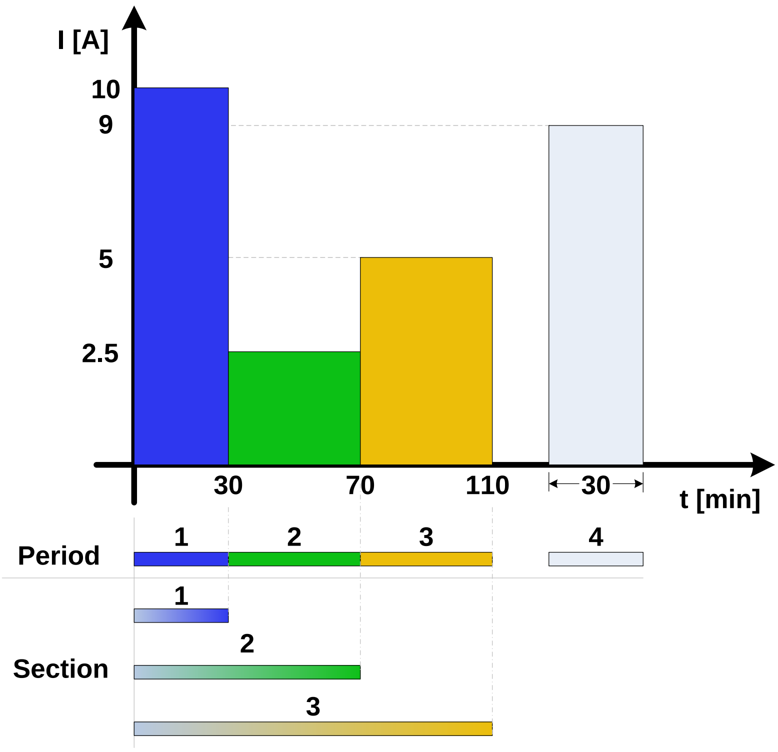


Figure D.2: Load profile periods and sections

The next step is to calculate the required capacities for the different sections and to select the maximum section capacity and add to it the required capacity for the random load/s.

Table D.1: Kt factors for the BATT cells in Annex A to Veod = 1.80V/cell

t [h]	t [min]	Kt
0.08	5	0.41 1)
0.17	10	0.51 1)
0.25	15	0.60
0.33	20	0.69 2)
0.5	30	0.88
0.67	40	1.06 2)
0.75	45	1.15
1	60	1.45
1.17	70	1.64 2)
1.33	80	1.83 2)
1.83	110	2.40 2)
2	120	2.59 2)
3	180	3.72
Notes: 1) Extrapolated values 2) Interpolated values		

The calculations for the respective Sections are shown below and the applicable Kt factors are indicated in D.1.

Section 1 = Period 1

$$C_{S1}|_{N=1} = \sum_{P=1}^{P=1} [A_1 - A_{1-1}] \times K_t|_{S1-S(1-1)}$$

$$C_{S1}|_{N=1} = [A_1] \times K_t|_{S1}$$

$$= 10 \times 0.88$$
$$= 8.8\ Ah$$

Section 2 = Periods 1 & 2

$$C_{S2}|_{N=2} = \sum_{P=1}^{P=2} [A_P - A_{P-1}] \times K_t|_{SN-S(P-1)}$$

$$C_{S2}|_{N=2} = [A_1 - A_{1-1}] \times K_t|_{S2-S(1-1)} + [A_2 - A_{2-1}] \times K_t|_{S2-S(2-1)}$$

$$= [A_1 - A_0] \times K_t|_{S2-S0} + [A_2 - A_1] \times K_t|_{S2-S1}$$

$$= [10 - 0] \times 1.64 + [2.5 - 10] \times 1.06$$

$$= (10 \times 1.64) + (-7.5 \times 1.06)$$

$$= 16.4 - 7.95$$
$$= 8.45\ Ah$$

Section 3 = Periods 1 & 2 & 3

$$C_{S3}|_{N=3} = \sum_{P=1}^{P=3} [A_P - A_{P-1}] \times K_t|_{SN-S(P-1)}$$

$$\begin{aligned} C_{S3}|_{N=3} &= [A_1 - A_{1-1}] \times K_t|_{S3-S(1-1)} + [A_2 - A_{2-1}] \times K_t|_{S3-S(2-1)} + [A_3 - A_{3-1}] \times K_t|_{S3-S(3-1)} \\ &= [A_1 - A_0] \times K_t|_{S3-S0} + [A_2 - A_1] \times K_t|_{S3-S1} + [A_3 - A_2] \times K_t|_{S3-S2} \\ &= [10 - 0] \times 2.40 + [2.5 - 10] \times 1.83 + [5 - 2.5] \times 1.06 \\ &= (10 \times 2.40) + (-7.5 \times 1.83) + (2.5 \times 1.06) \\ &= 24 - 13.73 + 2.65 \\ &= 12.92\ Ah \end{aligned}$$

Period 4

$$\begin{aligned} C_{P4} &= A_4 \times K_t|_{P4} \\ &= 9 \times 0.88 \\ &= 7.92\ Ah \end{aligned}$$

The maximum section capacity is that of Section 3 which means that the Total Uncorrected Capacity is calculated as follows:

$$\begin{aligned} C_{UC} &= C_{S3} + C_{P4} \\ &= 12.92 + 7.92 \\ &= 20.84\ Ah \end{aligned}$$

A graphical representation of the Section 2 and Section 3 calculations are shown in D.3 and D.4, respectively.

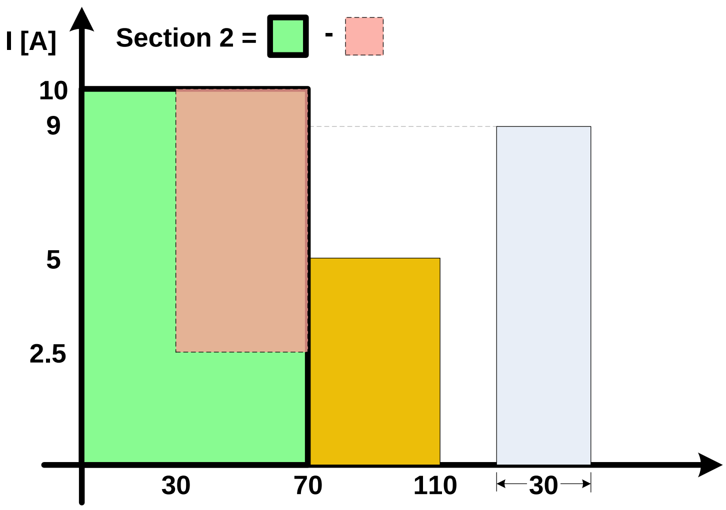


Figure D.3: Required capacity for Section 2

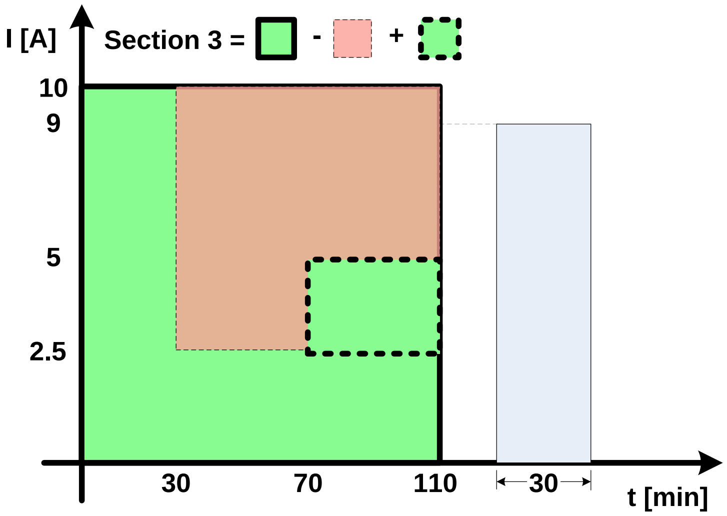


Figure D.4: Required capacity for Section 3

Annex E – Kt Factors for FCP Cells

This Annex shows the calculated Kt factors using the method described in this document for the flat plate cells (FCP – range) from First National Battery for different end-of-discharge voltages.

Time	Time [min]	End-of-discharge voltage (V_{eod})					
		1.6	**1.65**	**1.7**	**1.75**	**1.8**	**1.85**
1 Sec	0.02	0.60	0.65	0.77	0.96	1.15	1.53
30 Sec	0.5	0.61	0.66	0.78	0.97	1.16	1.53
60 Sec	1	0.62	0.67	0.79	0.97	1.17	1.54
5 Min	5	0.71	0.77	0.88	1.03	1.24	1.60
10 Min	10	0.83	0.88	0.99	1.09	1.34	1.67
15 Min	15	0.88	0.97	1.06	1.19	1.42	1.77
20 Min	20	0.99	1.04	1.15	1.33	1.50	1.91
30 Min	30	1.32	1.32	1.32	1.49	1.73	2.10
45 Min	45	1.59	1.59	1.59	1.72	2.02	2.59
1 Hr	60	2.00	2.00	2.00	2.00	2.35	2.86
2 Hr	120	3.15	3.15	3.15	3.15	3.40	3.68
3 Hr	180	4.18	4.18	4.18	4.18	4.18	4.50
5 Hr	300	5.98	5.98	5.98	5.98	5.98	6.15
6 Hr	360	6.82	6.82	6.82	6.82	6.82	7.05
8 Hr	480	8.50	8.50	8.50	8.50	8.50	8.50
10 Hr	600	10.00	10.00	10.00	10.00	10.00	10.00
12 Hr	720	12.00	12.00	12.00	12.00	12.00	12.00
18 Hr	1080	18.00	18.00	18.00	18.00	18.00	18.00
20 Hr	1200	20.00	20.00	20.00	20.00	20.00	20.00
24 Hr	1440	24.00	24.00	24.00	24.00	24.00	24.00
30 Hr	1800	30.00	30.00	30.00	30.00	30.00	30.00
50 Hr	3000	50.00	50.00	50.00	50.00	50.00	50.00
100 Hr	6000	100.00	100.00	100.00	100.00	100.00	100.00