DESIGN FOR SAFE AND RELIABLE ELECTRICAL PROTECTION OF BATTERY SYSTEM

These guidelines are specifically designed for electrical systems in EMEA, Asia and Latin America (non UL).

Summary

1 Introduction

The UPS is supplied by AC and DC sources.
Unlike the short circuit current generated by the AC sources, generally predictable, the short circuit current generated by the battery is variable and not easily predictable. With an unpredictable fault current the selection of the rating of the protection is quite challenging. The purpose of this document is to go more in depth in the analysis of the current delivered by the battery and the selection of the proper protection.

Steps to choose the right protection device are the following:

A. Refer to the battery short circuit current value found in the battery data sheet

B. Apply a derating factor of 0.6 multiplier on the short circuit current value (found in point A) to take into account the fault current reduction from the battery, due to connections and battery ageing or undercharge

C. Select the proper protection device with the following rules:

1. It must not trip during the normal function. Need to consider the case also of parallel battery strings and the case when one battery string is damaged or not available. The nominal current of the remaining battery strings in the parallel system will increase and the protection system must not trip due to this.
2. The selected protection device must trip in case of a fault in less than 100 ms.

D. In case the fault current provided by the battery does not allow for the finding of protection devices, such as a Circuit Breaker or fuse, that meets the derating criteria stated in point B, it is hence possible to increase the multiplier up to 0.7. This increase will reduce the effectiveness of the overcurrent protection especially in case of weak/aged battery or a high impedance of the fault. However, this will still cover most of the fault conditions.

E. In case the 0.6 and extended 0.7 multipliers are not applicable, a Circuit Breaker controlled by an undervoltage trip protection device must be used.

The steps are also included at the end of the document.

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Background

2. Parameters that influence the Fault current

2.1 Battery

The battery is an electrochemical voltage generator characterized by the following parameters:

- The Open Circuit Voltage (OCV).
- Internal impedance, resistance and inductance (R_batt, L_batt)

The internal battery parameters are strongly dependent by the state of charge and the aging of the battery.

The OCV decreases and the internal impedance of the battery increases as the battery is discharged or as it gets older.

IMPORTANT: The reduction of OCV and/or the increase of R_batt cause the reduction of the fault current provided by the battery.

Example: For the VRLA type battery close to the End of Discharge (EOD) and End of Life (EOL), due the OCV reduction and resistance increase, the short circuit current can be around 60% of the nominal short circuit current.

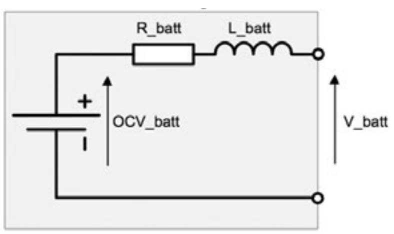


Fig. 1

Battery manufacturers provide a value of short circuit current which needs to be used for validation of proper protection device. Duration of this short circuit current can be of few seconds before a battery failure occurs. The characteristic current and duration changes depending on the battery type.
A protection device must be sized properly so that the energy flowing from the batteries during the failure will not cause damage to the batteries or other components along the short circuit path. The protection must clear the fault in less than 100 milliseconds.

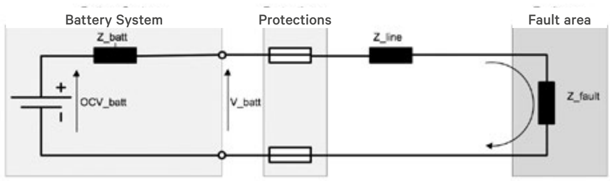
2.2 External circuit

The impedance of the line is mainly resistance and inductance. The inductance present on the circuit limits the rise rate of the fault current while the resistances reduce the value of the fault current.
The fault itself have its own impedance that it is difficult to predict, the bolted short circuit has a very low impedance, but it is an ideal condition, the breakdown of a component or a loss of isolation between two conductive parts add a not negligible impedance to the fault-path.

2.3 Whole system

The combination of the unpredictable fault current generated by the battery in conjunction with the current limiting effect of the line and fault impedances make very difficult the selection of the proper protection devices.

Fig. 2



2.4 Type of faults considered

The faults considered in this document are related to the DC path (positive and negative connections) between the battery cabinet/rack and the UPS. The type of battery used, e.g. lithium or VRLA battery does not change the considerations in this document.
The guidelines in this document are not intended to cover faults that are located inside the battery cabinet/rack. Similarly, DC ground faults, i.e. faults between positive/negative and ground connections are not covered by these guidelines.

3. Protection devices

3.1 Fast acting fuses

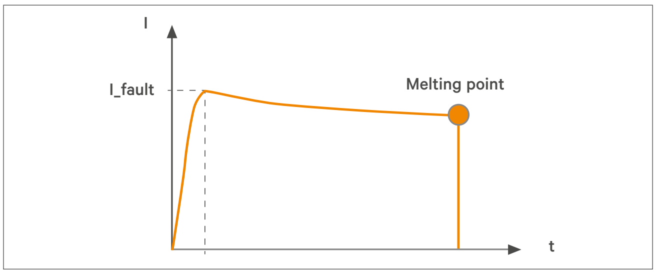
The fast-acting fuses are the fastest protection providing that the coordination with the fault current is correctly done on all operating conditions including current and voltage. First of all, verification must be done if voltage rating of fuse is compatible with battery voltage level:

198 cells ▶ 2.27 V / cell ▶ 450 Vdc ▶ Fuse rating >= 500 Vdc

240 cells ▶ 2.27 V / cell ▶ 545 Vdc ▶ Fuse rating >= 600 Vdc

300 cells ▶ 2.27 V / cell ▶ 680 Vdc ▶ Fuse rating >= 700 Vdc

Fig. 3 - Short-circuit current with DC fuses.



The wide spread of the battery fault current ends into a wide range of the melting time.
The following example is related to a 400kW application with a battery nominal voltage of 480 Vdc. A 550A, DC rated fast acting fuse has been selected as an overcurrent protection. The battery used in the application have a nominal fault current of 4000A that in the worst-case scenario it becomes 2400A by applying a derating factor of 0.6 as described in chapter 2.1 (i.e. at the End of Life and the End of Discharge).

The melting point goes from a minimum of 2 ms in case of nominal fault current to a max of 20 ms in case of minimum fault current.
These fuses have relatively low intervention time for current higher than the rated current. These can be equipped with a monitoring device connected to the UPS or BMS to warn if a fuse has tripped or is disconnecting the battery from the UPS.

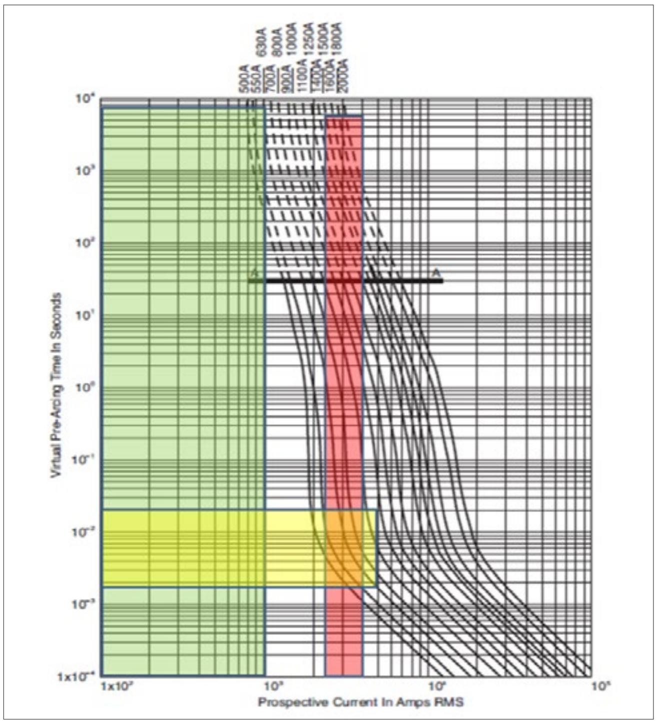


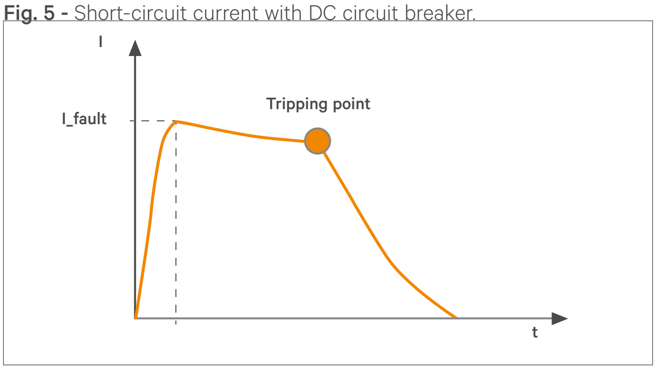
Fig. 4

3.2 DC rated Battery Circuit breaker

The DC rated Battery Circuit Breaker (BCB) provides still overcurrent protection, if correctly coordinated, even though it is not as fast as the fuses. These breakers must be set at a safe intervention value based on the battery short circuit current. The concerned "setting" is the magnetic or instantaneous level, that is usually given adjustable in % of the nominal current. Battery circuit breakers can be equipped with a monitoring device connected to the UPS or BMS to warn if the breaker tripped. The selected breaker has to be DC rated with the DC voltage value coordinate with the battery voltage (e.g. 240 cells battery, 480Vdc nominal, CB rated at least 500Vdc). In case the selected breaker is AC rated, it must be applied the derating factors specified by the manufacturer documentation for DC application of this AC rated CB (e.g. voltage derating, poles in series).

Usually, when a breaker operated to interrupt a battery terminal short circuit fault, it is recommended to replace the breaker.

Fig. 5 - Short-circuit current with DC circuit breaker.



Applying the same example as the one used for the fuses: 400kW application with a battery nominal voltage of 480 Vdc. The battery used in the application have a nominal fault current of 4000A that in the worst-case scenario it becomes 2400A. Two DC rated CB have been selected: CB-1 1000A rated; CB-2 800A rated CB. Setting on both CB the tripping threshold at the minimum admissible value: 2500A for CB-1 and 2000A for CB-2, the tripping time for CB-1 goes from a minimum of 30 ms in case of nominal fault current to a max of 100 sec in case of minimum fault current. For CB-2 the tripping time is always below 40 ms.

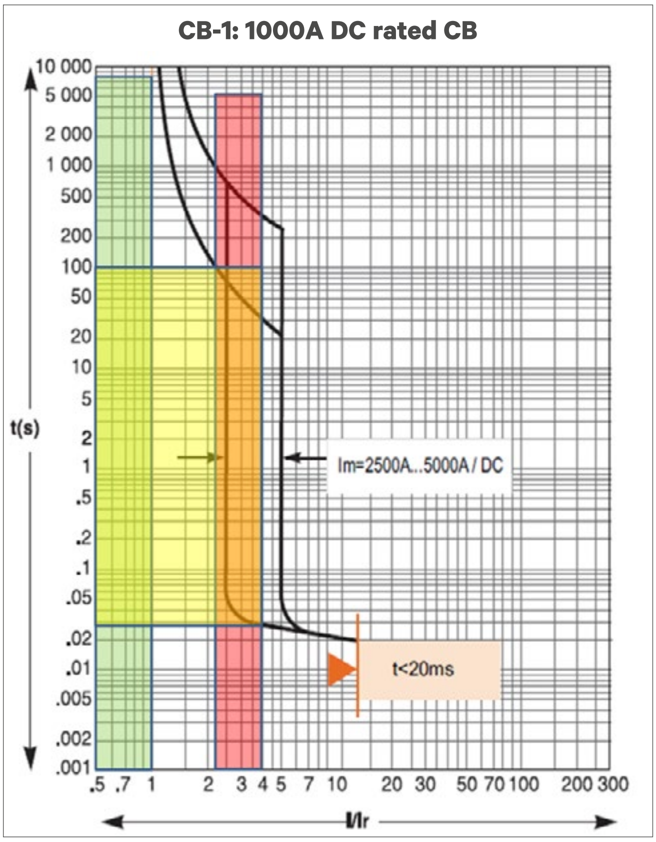


Fig. 6

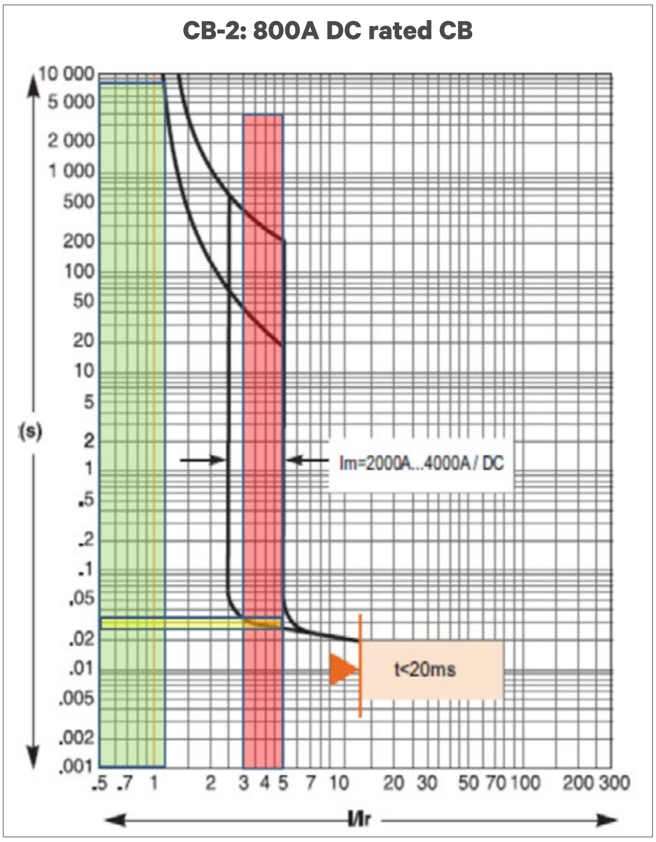


Fig. 7

Verification must be done if voltage rating of the breaker is compatible with battery voltage level

198 cells ▶ 2 V / cell ▶ 396 Vdc ▶ Breaker rating >= 500 Vdc

240 cells ▶ 2 V / cell ▶ 480 Vdc ▶ Breaker rating >= 500 Vdc

300 cells ▶ 2 V / cell ▶ 600 Vdc ▶ Breaker rating >= 600 Vdc

3.2.1 Under Voltage tripping on the Battery Circuit Breaker

The DC rated Circuit Breaker still provides overcurrent protection, if correctly coordinated, even though its intervention time can be not enough to avoid extensive damages on the equipment and on the battery.

A dedicated device, integrated into the UPS itself or an auxiliary of the battery installation (i.e. on BMS), can be used to quickly detect conditions associated to a battery fault. These conditions can vary from a sudden battery under voltage to a trigger of specific alarms inside the UPS (i.e. a desaturation of a semiconductor device).

These devices, thru a proper interface circuit, command the tripping unit of the BCB to disconnect the battery. The setting is upon the application, not strictly related to the fault current.

All the components exposed to the battery voltage must be compatible with the actual battery voltage level. Same approach as for the Battery Circuit Breaker.

3.2.2 Current UPS offering solutions for Under Voltage tripping

A possible solution to provide remote battery tripping controlled by the UPS is shown in the picture below.

The UPS is interfaced to the Battery Circuit Breaker (BCB) control board using input contacts to retrieve the status of the external switches/breakers and an output contact used to send the trip signal to remotely open the battery circuit breaker. There are several events controlled by the UPS control that can activate the remote battery trip signal:

1. Battery undervoltage below a specific threshold
2. Battery End Of Discharge (EOD). Once the battery reaches the EOD voltage and the inverter is turned off, after a specific time delay the booster is turned off. Then the battery breaker is tripped to avoid further battery discharge
3. Any fault condition related to booster/charger converter, e.g. desaturation, overtemperature, over current, DC bus overvoltage, charger voltage out of control, fuse blown.
4. Emergency Power OFF (EPO)

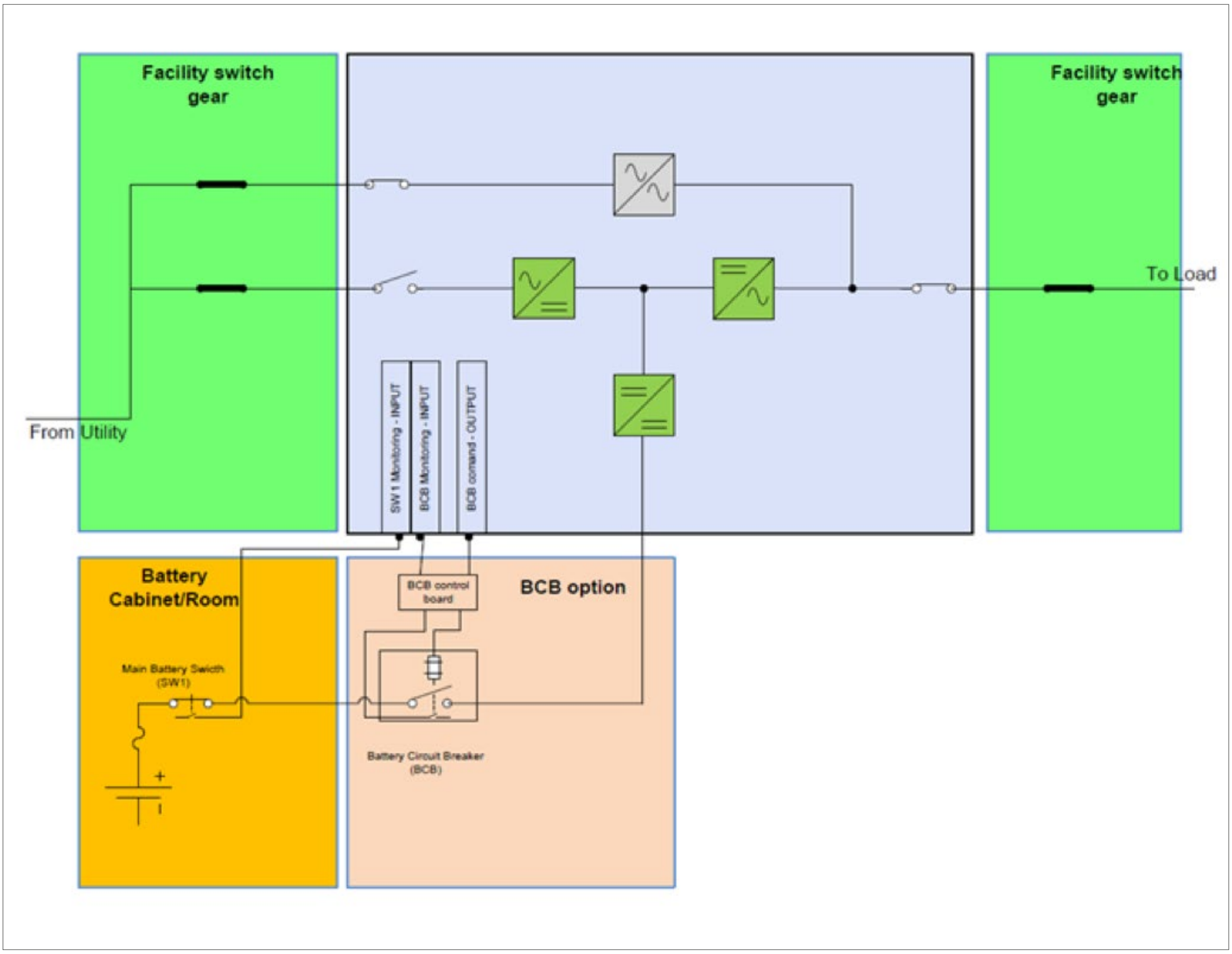


Fig. 8 - **Important note:** The solution depicted above may slightly differ depending on the product line and the BCB option, always refer to your regional presales and offering teams for more detailed information.

4. Steps to evaluate the effectiveness of a protection device for the site and application

A. Refer to the battery short circuit current value found in the battery data sheet

B. Apply a derating factor of 0,6 (multiplier on the short circuit current value (found in point A) to take into account the fault current reduction from the battery, due to connections and battery ageing or undercharge

C. Select the proper protection device with the following rules:

1. It must not trip during the normal function.
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