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Arc Flash in DC Systems – example from project

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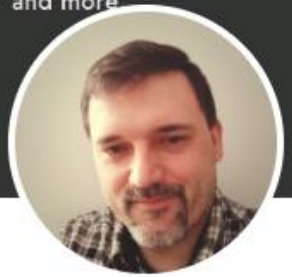
Jan 2023

About me

- Arc Flash Studies AC/DC
- Short Circuit Calculations AC/DC
- Protection Coordination
- Power Flow Analysis
- and more



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Talks about #safety, #arcflash, #mrpowertech, #electricalsafety, and #electricalengineering

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Arc Flash Studies || Request

12,148 followers · 500+ connections

MR Power Systems

Politechnika Krakowska im. Tadeusza Kościuszki

1 DC Arc Flash

2 Examples & Solutions

3 Q&A

1 DC arc flash?

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Common DC systems use

Typically :

- PV Systems
- Battery Energy Storage Systems (BESS)
- UPS - battery side of UPS
  - Data Centers
  - Marine
  - Industrial
- EV cars, trucks, machines, ships, boats, buses ect (goes above 800V DC already)

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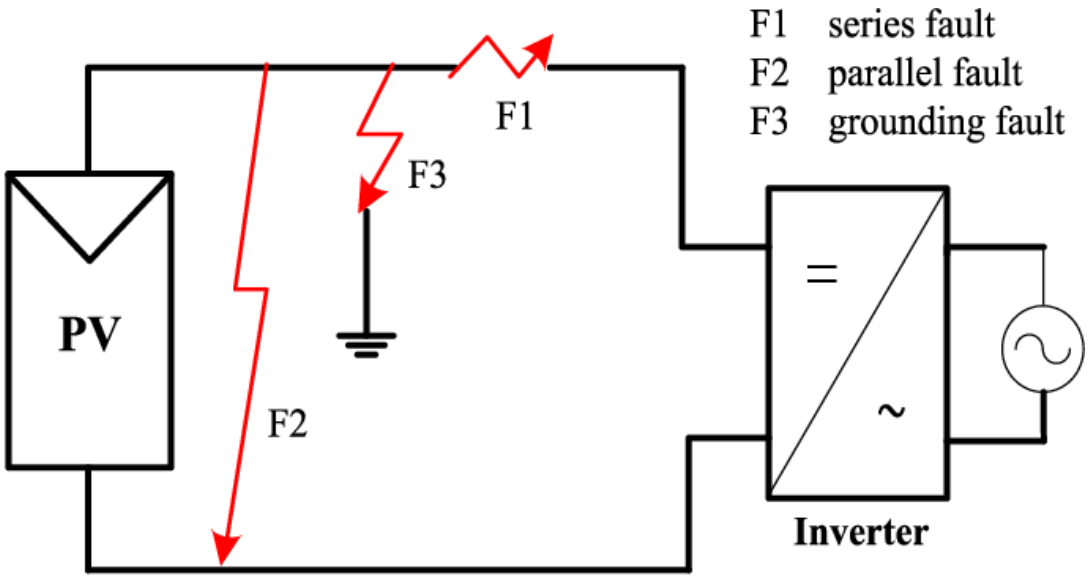
PV - DC arc flash

DC arc flash in PV:

Type:
- Series arcs
- Parallel arcs (phase and ground)

Locations:
- Panel side
- String cable
- Combiner box side
- Inverter DC side
- Inverter AC side (AC fault)



Source: „The Detection of Parallel Arc Fault in Photovoltaic Systems Based on a Mixed Criterion” Chuxuan He, Longhua Mu, Yijian Wang

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Accidents and fires

PV central inverter fire

One out of three plants was damaged October 2020

- Ullum I (25 MW),
- Ullum II (25 MW)
- Ullum III (32 MW),

Source : Government of Ullum

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PV - accidents

DC arc flash in PV:

- Arc flash can occur in multiple areas
- Closer to source is worse condition but it depends on system topology (multi-inverters or central inverter)

Source: YouTube

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BESS/UPS- DC arc flash

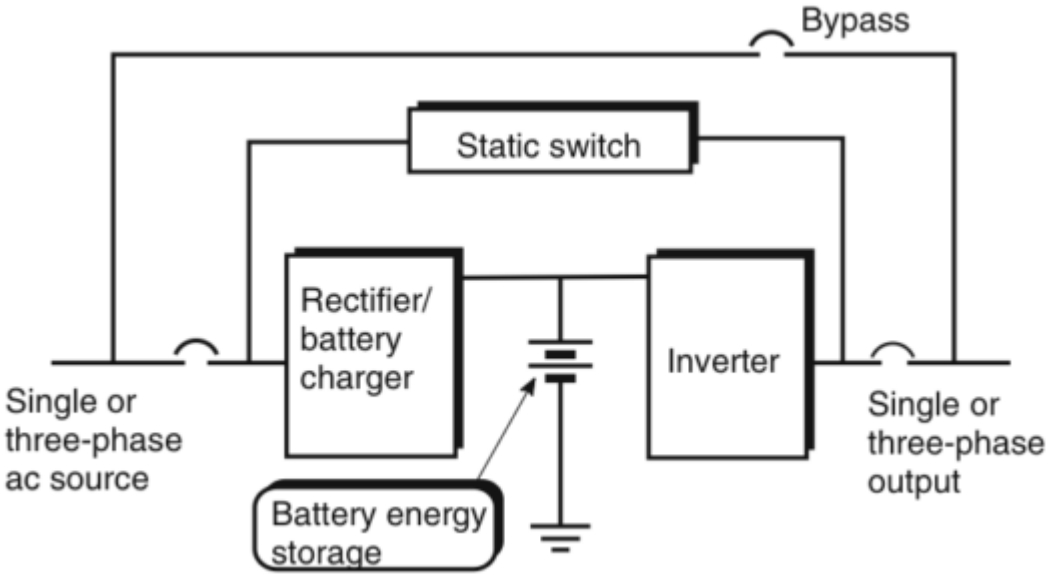
DC arc flash in UPS/BESS:

Place of fault:

- Battery
- Cable to DC panel
- DC panel (protection side)
- DC main bus
- DC main panel (few BESS panel)
- Inverter DC side
- Inverter AC side

Mode of operations:

- SoC 100%
- SoC low (0%)
- Charging (higher voltage)



Surce: https://electricalacademia.com/electric-power/uninterruptible-power-supply-ups-works-uninterruptible-power-supply-types/

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BESS- accidents

DC arc flash in BESS:

- Battery faults leads to fires
- Protection is limited – if fault is on battery side protection will open but fault will not stop

Recent fire in OVH SBG1 data center probable cause was increased humidity (water ?) in battery rooms that most llikely caused arc flash and fire as consequence.

, départ de feu dans l'ASI2 de la vidéosurveillance OVH)

Photographie 6 : 0h35, départ de feu dans le local à batteries (source : image extraite de la vidéosurveillance OVH)

Source OVH report https://www.cgedd.developpement-durable.gouv.fr

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BESS- accidents

BESS Korea

Not specified but looks like thermal runaway fault type

Source : channel 8 SBS News / Korea

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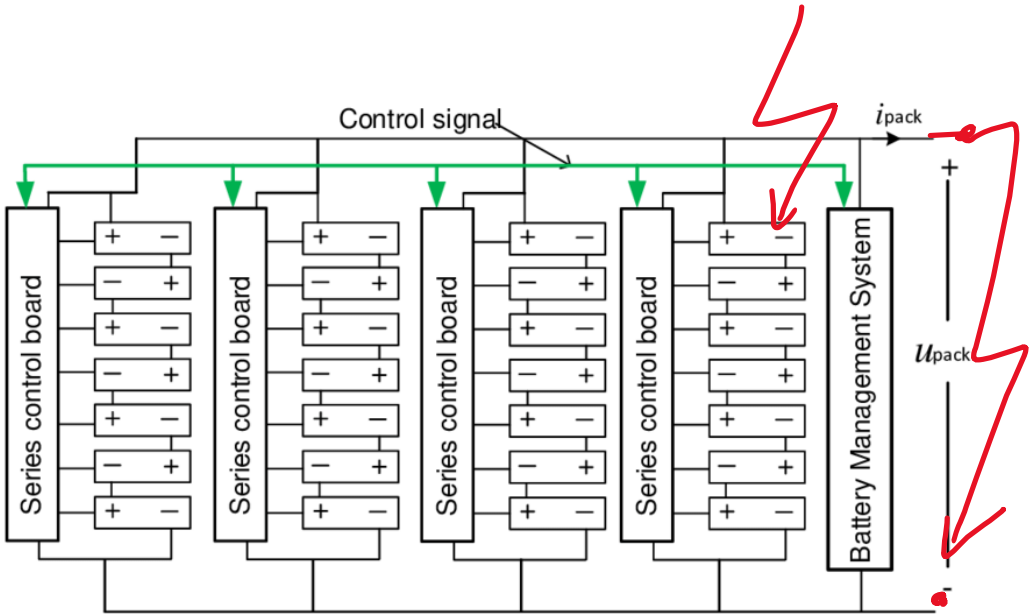
EV DC arc flash

DC arc flash in BESS:

Place of fault:
- Battery internal
- Battery external
- DC Cable/BusBars

Mode of operations:
- Normal
- Charging
- Discharging
- Damage (overheat)



Surce: „*GA-based approach to optimize an equivalent electric circuit model of a Li-ion battery-pack* „Victor Pizarro-Carmonaa,d,*, Sandra Castano-Solísb, M arcelo Cortés-Carmonaa, Jesus Fraile-Ardanuyc, David Jimenez-Bermejo

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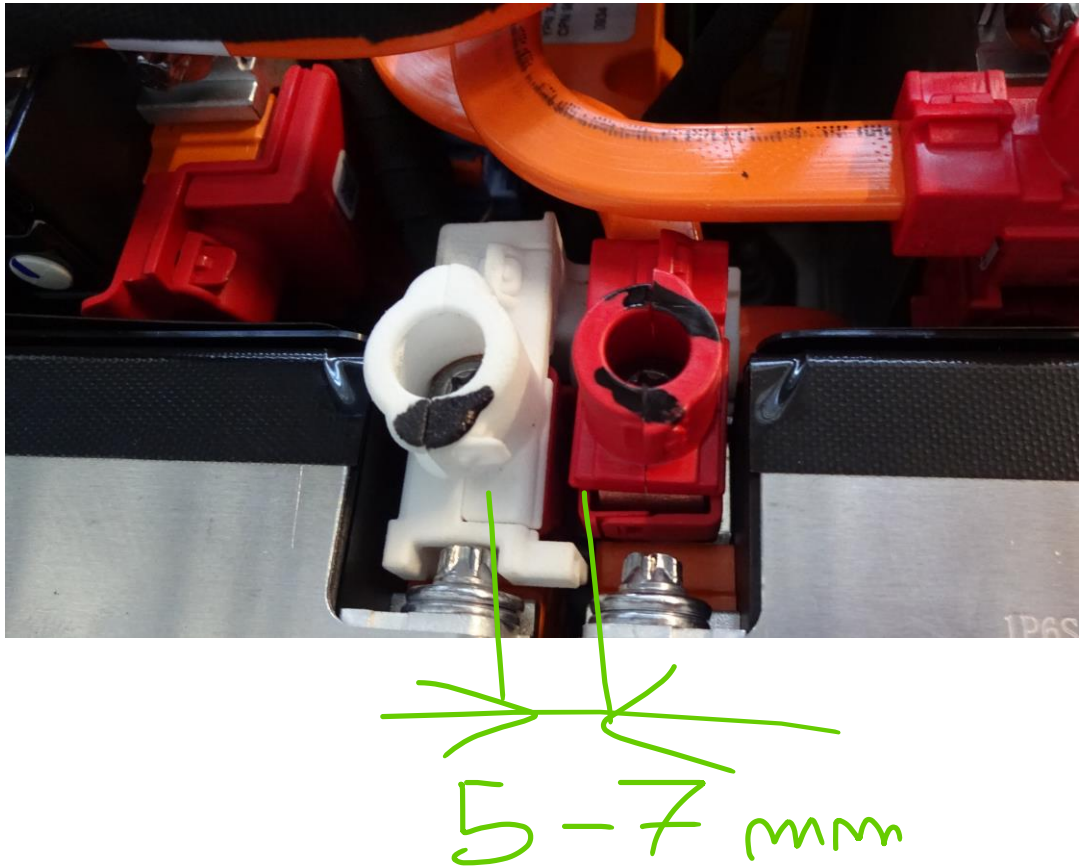
EV DC arc flash

DC arc flash in EV:

Fault time:
- During assembly (factory line)
- During service (workshop)
- During normal use/charging

Location in EV battery depends on proces, configuration and SoC:
- Worst connection location
- Full voltage (all modules connected together)
- One battery module itself



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EV - DC arc flash

DC arc flash in EV:

- Battery faults leads to fires during accidents and thermal run away
- Protection is limited
- EV cars operate now up to 900V DC which is increased shock hazard as well

NASA -Robot Li-Ion Battery Fire

Probably 120-140VDC 15-30Ah Li-ion

Source YouTube

2 Examples & solutions

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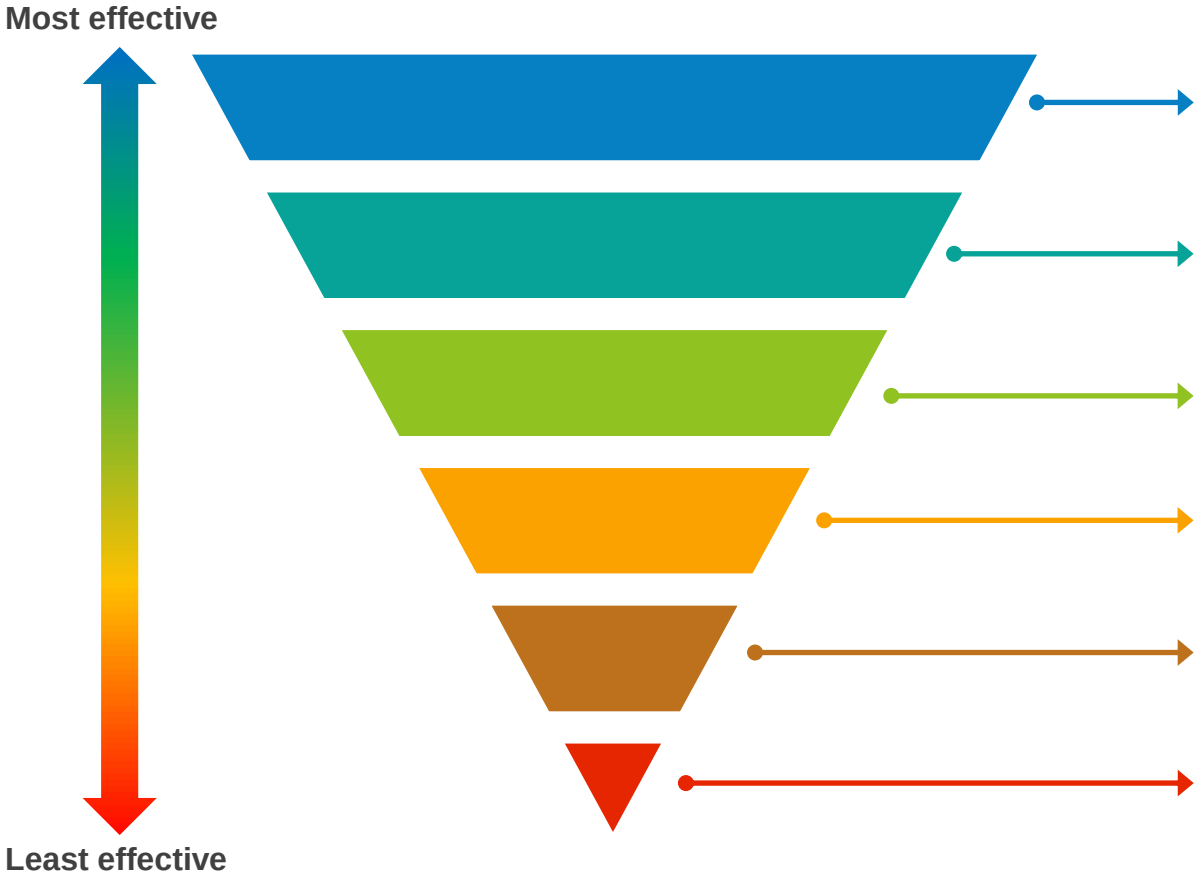
Hierarchy of controls



Elimination

LOTO, no live work *(it is almost always live work in BESS EV and PV)*

Substitution

Voltage<50VAC and 100VDC *(not anymore in DC with systems U>400VDC)*

Engineering controls

Barriers, remote controls *(remote control is good option in BESS, less in EV)*

Awareness

Training, arc flash labelling

Administrative controls

Electrical Safety Plan, operating procedures

PPE

Properly selected arc and shock PPE

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Project – model SLD

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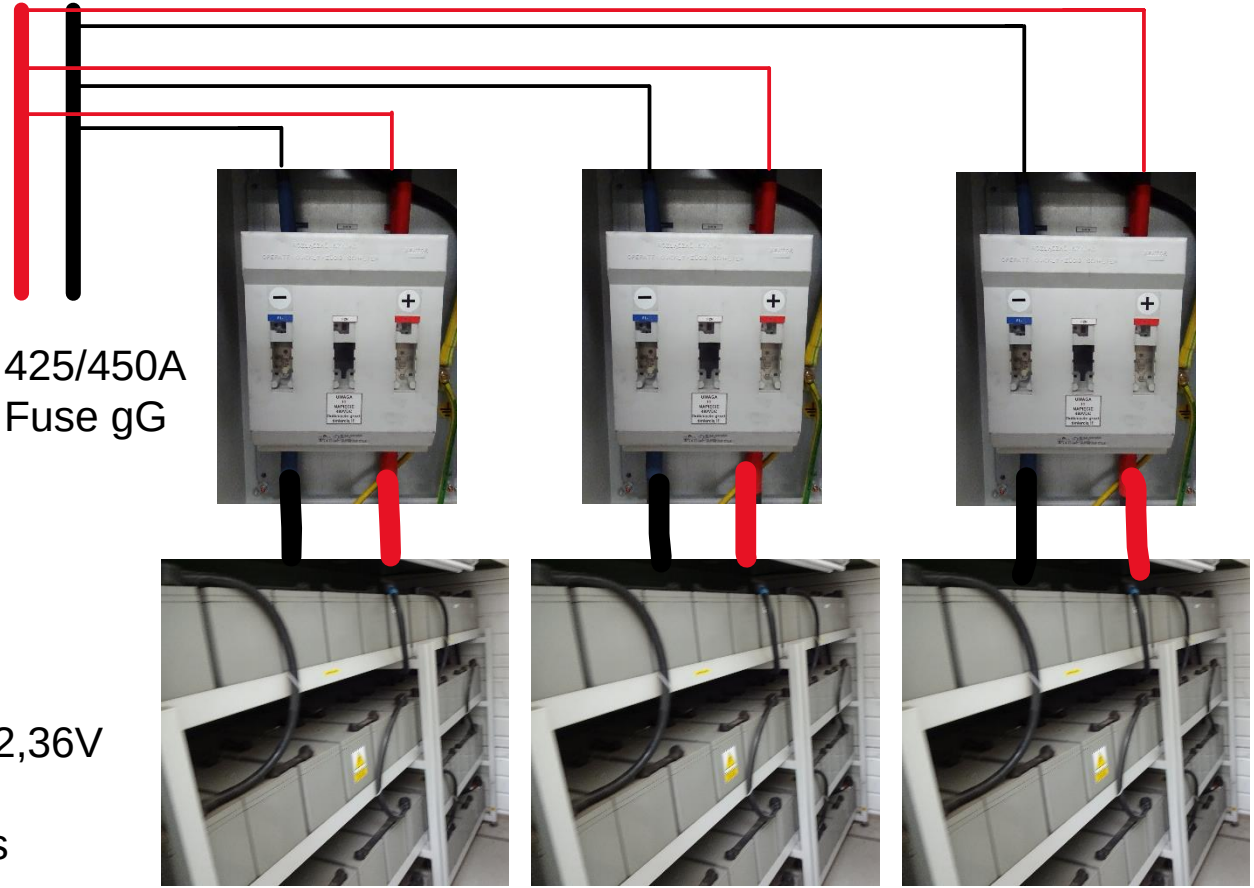
UPS –ETAP model DC Arc Flash

UPS 400kVA with ByPass

425/450A
Fuse gG



VRLA 48 x 12,36V
140Ah
3 paralel sets

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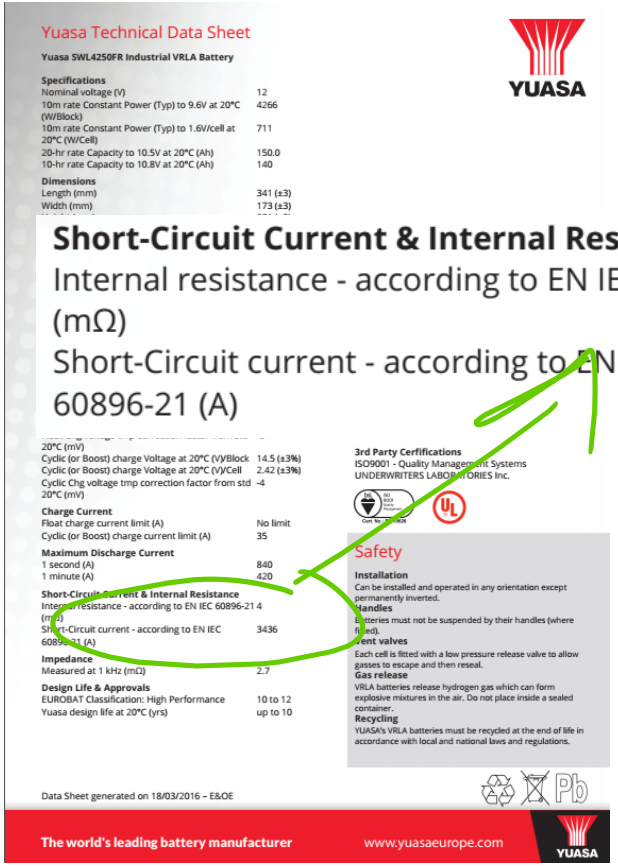
UPS –ETAP model DC Arc Flash

Fuse 425A gG AC 500V/ 250VDC ETI NH3

48x12V 576 VDC nominal

48x14,5V 696 VDC cyclic loading



Yuasa Technical Data Sheet

Yuasa SWL4250FR Industrial VRLA Battery

Specifications	
Nominal voltage (V)	12
10m rate Constant Power (Typ) to 9.6V at 20°C (W/Block)	4266
10m rate Constant Power (Typ) to 1.6V/cell at 20°C (W/Cell)	711
20-hr rate Capacity to 10.5V at 20°C (Ah)	150.0
10-hr rate Capacity to 10.8V at 20°C (Ah)	140
Dimensions	
Length (mm)	341 (±3)
Width (mm)	173 (±3)

Short-Circuit Current & Internal Resistance

Internal resistance - according to EN IEC 60896-21 4 (mΩ)

Short-Circuit current - according to EN IEC 60896-21 (A) 3436

20°C (mV)	
Cyclic (or Boost) charge Voltage at 20°C (V)/Block	14.5 (±3%)
Cyclic (or Boost) charge Voltage at 20°C (V)/Cell	2.42 (±3%)
Cyclic Chg voltage tmp correction factor from std 20°C (mV)	-4
Charge Current	
Float charge current limit (A)	No limit
Cyclic (or Boost) charge current limit (A)	35
Maximum Discharge Current	
1 second (A)	840
1 minute (A)	420
Short-Circuit Current & Internal Resistance	
Internal resistance - according to EN IEC 60896-21 4 (mΩ)	
Short-Circuit current - according to EN IEC 60896-21 (A)	3436
Impedance	
Measured at 1 kHz (mΩ)	2.7
Design Life & Approvals	
EUROBAT Classification: High Performance	10 to 12
Yuasa design life at 20°C (yrs)	up to 10

3rd Party Certifications

ISO9001 - Quality Management Systems

UNDERWRITERS LABORATORIES Inc.

Safety

Installation
Can be installed and operated in any orientation except permanently inverted.

Handles
Batteries must not be suspended by their handles (where fitted).

Vent valves
Each cell is fitted with a low pressure release valve to allow gasses to escape and then reseal.

Gas release
VRLA batteries release hydrogen gas which can form explosive mixtures in the air. Do not place inside a sealed container.

Recycling
YUASA's VRLA batteries must be recycled at the end of life in accordance with local and national laws and regulations.

Data Sheet generated on 18/03/2016 – E&OE

The world's leading battery manufacturer www.yuasaeurope.com YUASA

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DC Arc Flash models for use

Preferred Modelling

- Stokes-Oppenlander for DC arc flash
- IEEE 946 and IEC 61660 for DC short circuit

1) NFPA70E D.5.1 Maximum Power Method

2) "DC-Arc Models and Incident-Energy Calculations," Ammerman, R.F.; et al.; IEEE Transactions on Industry Applications, Vol. 46, No.5.

3) "Arc Flash Calculations for Exposures to DC Systems," Doan, D.R., IEEE Transactions on Industry Applications, Vol. 46, No.6

4) A. D. Stokes, W. T. Oppenlander, "Electric Arcs in open air," Journal of Physics D: Applied Physics, vol. 24, pp. 26-35,1991

5) J. C. Das, "Arc-Flash Hazard Calculations in LV and MV DC Systems Part I: Short-Circuit Calculations," IEEE Trans. On Industry Applications, vol. 50, pp. 1687-1697, 2014.

6) DGUV-I 203-077 Arc Energy Analysis – AC&DC arc flash

7) IEEE 946-2020 IEEE Recommended Practice for the Design of DC Power Systems for Stationary Applications

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DC Arc Flash models for use

Modelling steps

- Cable impedance
- Short connections between batteries (good to include eg.48x0,3=14,4m
- 0,156 mΩ/m*14,4=2,24 mΩ vs battery internal R~=4mΩ
- SoC – for arc flash max value but for specific application it might be few scenarios
- DC protection – and precise location as it makes difference

Used software for DC arc flash – ETAP v21 (possible CYME and SKM)

Scenarios: maximum SoC + limited time up to 2, 60 sec (if human sfety oriented)

Main standard : NFPA70E-2021 for PPE and remaining procedures

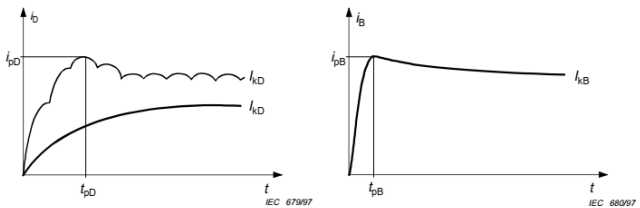

Figure 1a – Rectifier without and with smoothing reactor

Figure 1b – Battery

Figure 1c – Capacitor

Figure 1d

Figure 1 – Diagrams of typical short-circuit currents

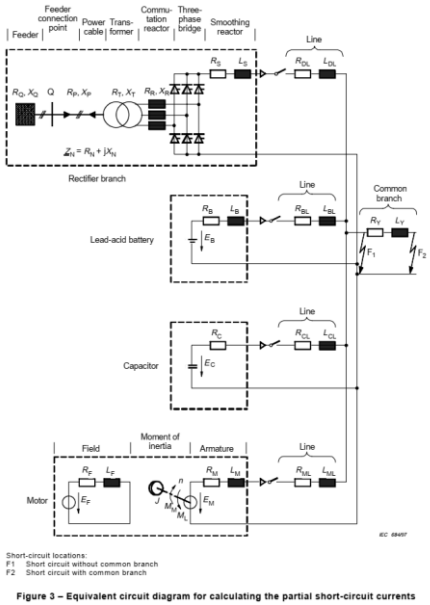

Figure 3 – Equivalent circuit diagram for calculating the partial short-circuit currents

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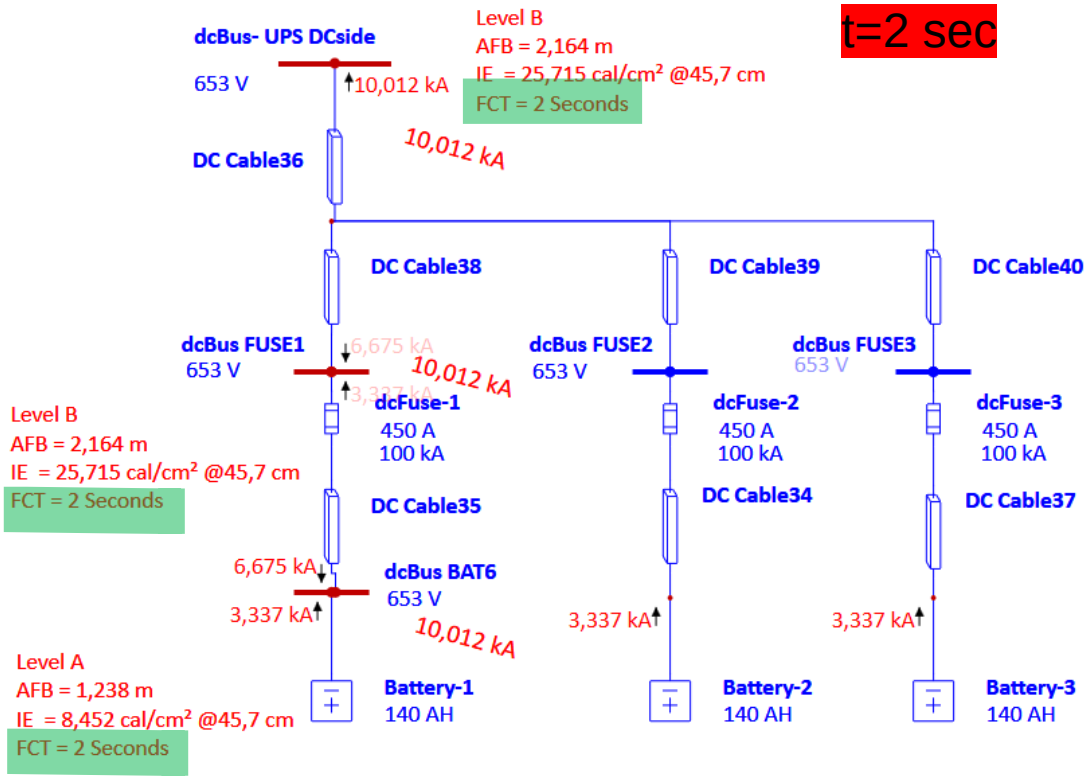
UPS –ETAP model DC Arc Flash

ETAP model

- DC side of UPS system 400kVA Vertiv
- 3 battery banks 140Ah
- Fuse (AC type 450A/500V) !
- Cable 2x120mm2/phase 6m

- Max time t=2sec by NFPA70E



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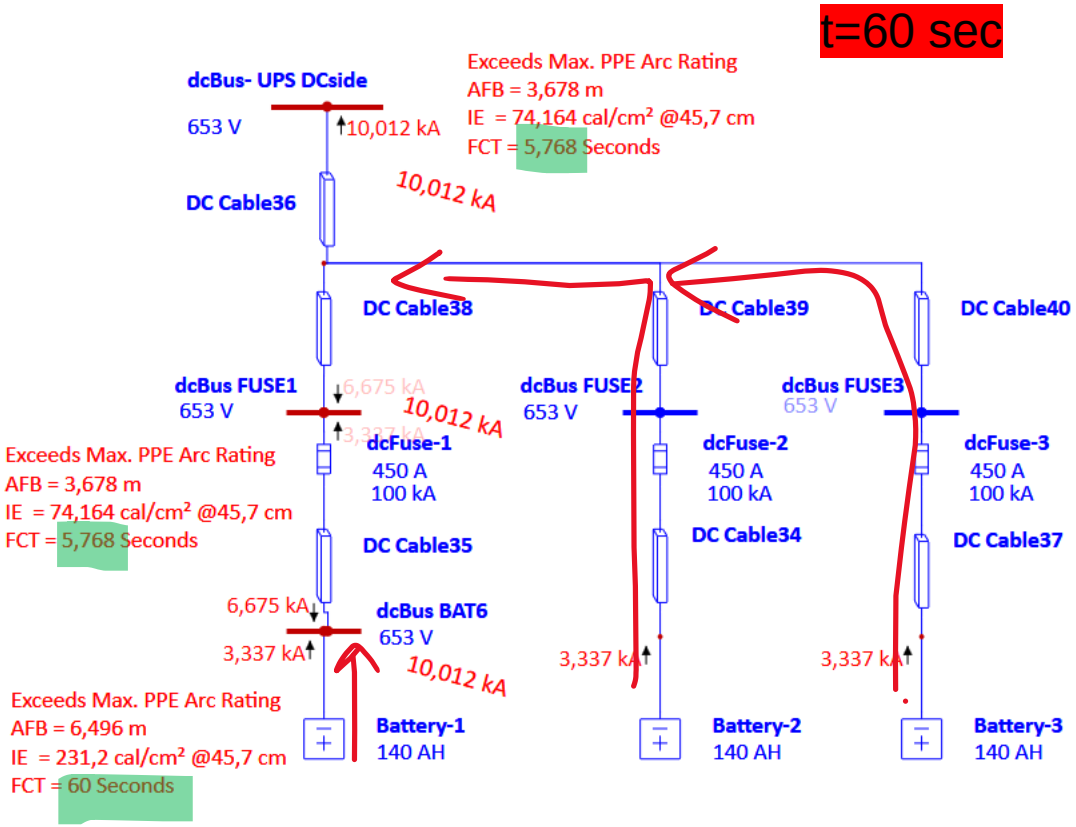
UPS –ETAP model DC Arc Flash

ETAP model

- DC side of UPS system 400kVA Vertiv
- 3 battery banks 140Ah
- Fuse (AC type 450A/500V) !
- Cable 2x120mm2/phase 6m

- Max time t=60sec (1min rating)



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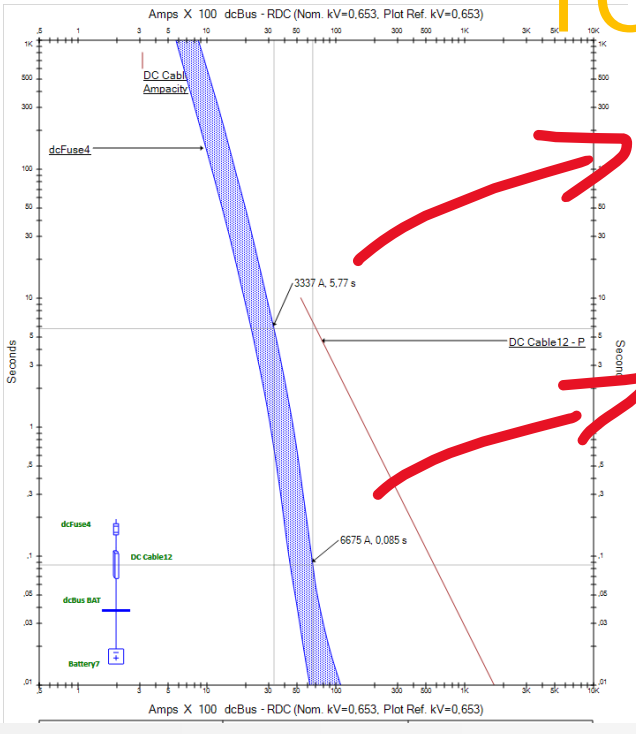
TCC + fuse tripping



Fault current 3,37 kA
Trip time 5,76 sec

Fault current 6,675 kA
Trip time 85 msec

Fault current 3,4 kA
Trip time 60 sec

No protection on battery side (source)

	Code	ID	Totalla	Ei	Et	PDID	PDIarc	TripTime	OpenTime	Condition
1										
2	A	dcBus - RDC	10012,1377	74,1637039	74,1637039	dcFuse5+	10012,1377	0	5,76821232	5,768
3	A	dcBus BAT	10012,1377	1,098389	1,098389	dcFuse4	6674,7583	0	0,08542913	0,085
4	A	dcBus BAT	3404,393	230,132	231,2304		0	0	60	Arc fault de-energized
5	A	dcBus- UPS side	10012,1377	74,1637039	74,1637039	dcFuse5+	9355,977	0	5,76821232	5,768

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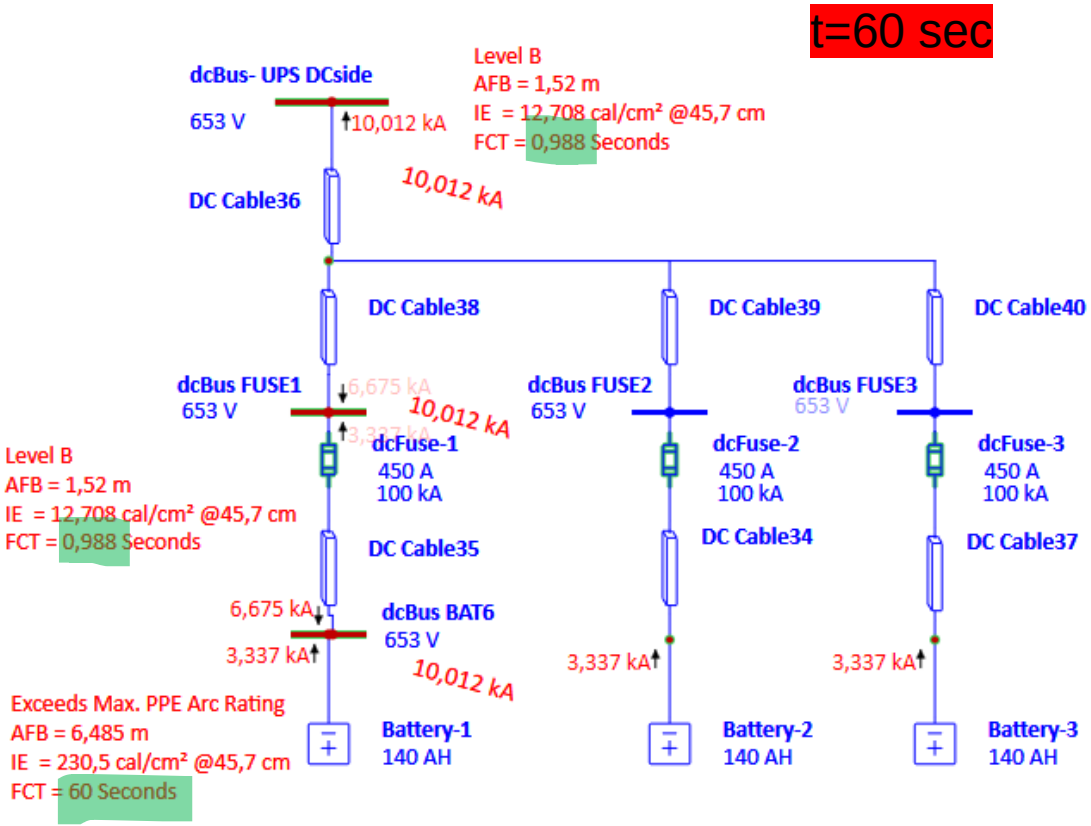
Solutions 1 –fuse aR

ETAP model

- No change to model
- Fuse 450A aR type

- Max time t=60sec (1min rating)

Difference ?
- Time from 5.76 to 0,98 sec
- No change to battery itself
- IE from 74 to 12,7 cal/cm2



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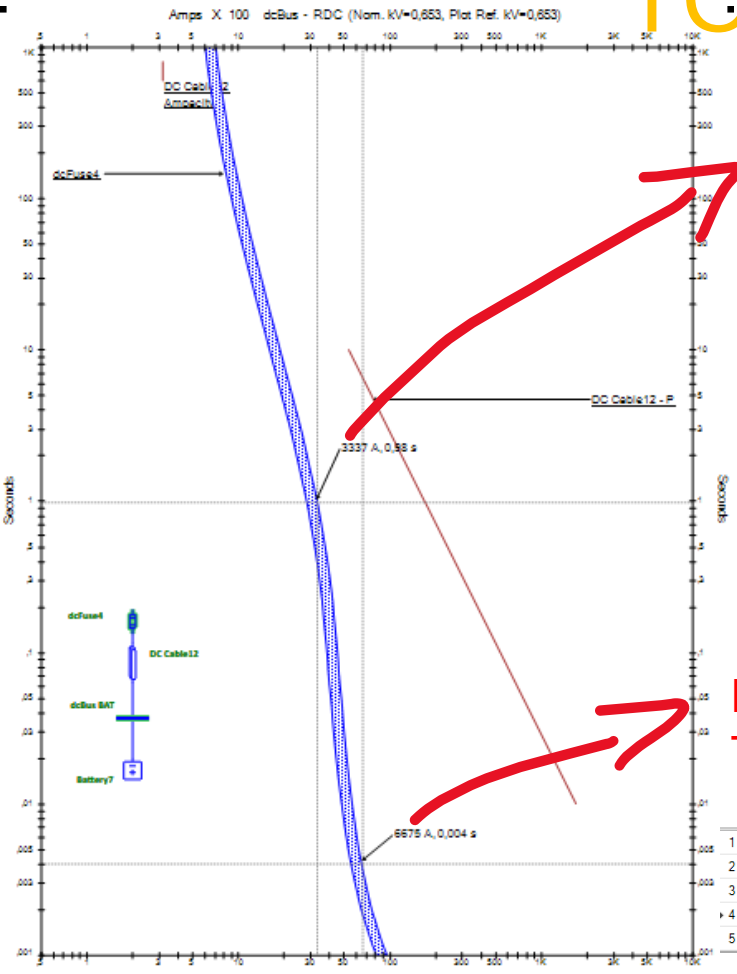
TCC + 450A aR



Fault current 3,37 kA
Trip time 0,98 sec

Fault current 3,4 kA
Trip time 60 sec

No protection on battery side (source)

Fault current 6,675 kA
Trip time 4 msec

	Code	ID	Totalla	Ei	Et	PDID	PDIarc	TripTime	OpenTime	Condition
1										
2	A	dcBus - RDC	10012,1377	12,7079811	12,7079811	dcFuse5	10012,1377	0	0,988385558	0,988
3	A	dcBus BAT	10012,1377	0,04654673	0,04654673	dcFuse4	6674,7583	0	0,00362025388	0,004
4	A	dcBus BAT	3404,393	230,446243	230,492783		0	0	60	Arc fault de-energized
5	A	dcBus- UPS side	10012,1377	12,7079811	12,7079811	dcFuse5	10012,1377	0	0,988385558	0,988

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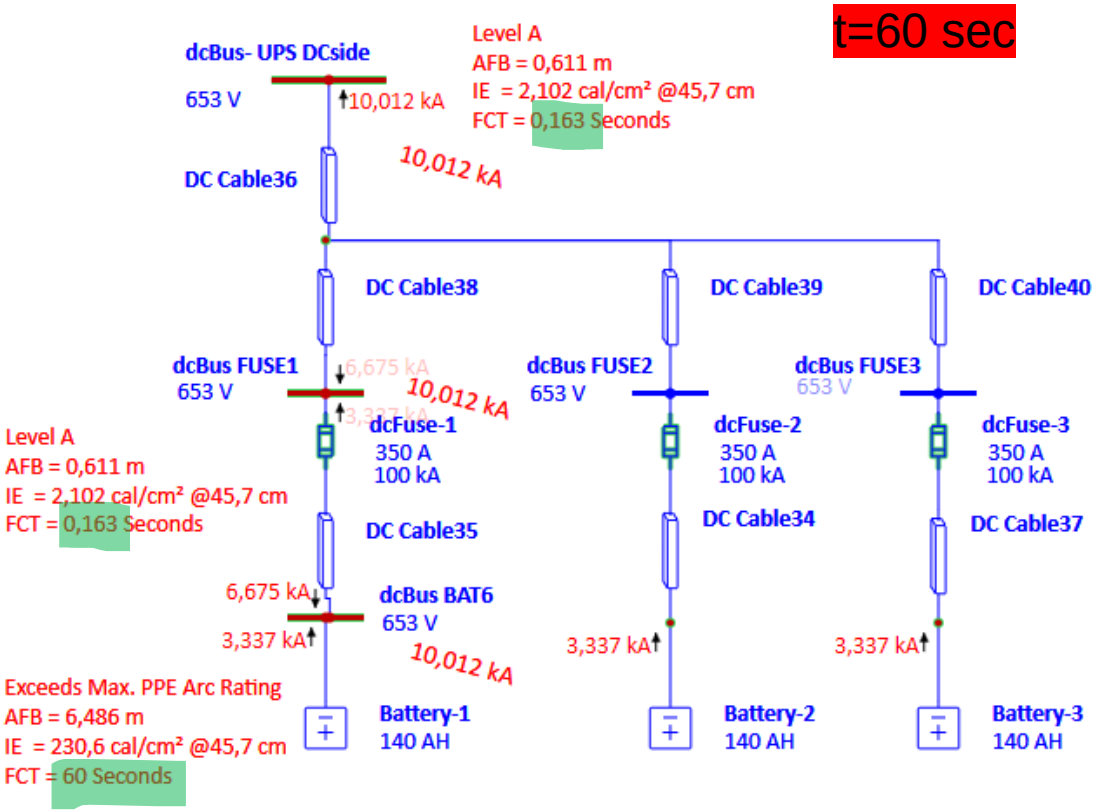
Solution 2 –350A fuse aR

ETAP model

- No change to model
- Fuse 350A aR type

- Max time t=60sec (1min rating)

Difference ?
- Time from 5.76 to 0,163 sec
- No change to battery itself
- IE from 74 to 2,1 cal/cm2



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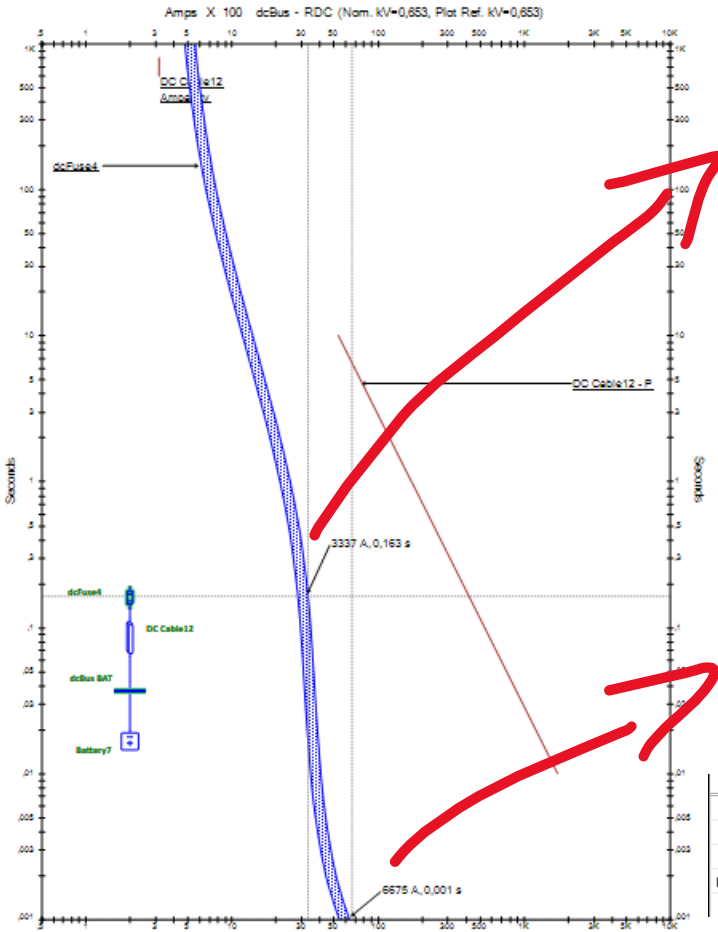
TCC + 350A aR



Fault current 3,37 kA
Trip time 0,163 sec

Fault current 3,4 kA
Trip time 60 sec

No protection on battery side (source)

Fault current 6,675 kA
Trip time 2-4 ms

	Code	ID	Totalla	Ei	Et	PDID	PDIarc	TripTime	OpenTime	Condition
1										
2	A	dcBus - RDC	10012,1377	2,1018362	2,1018362	dcFuse5	10012,1377	0	0,163474008	0,163
3	A	dcBus BAT	10012,1377	0,1285731	0,1285731	dcFuse4	6674,7583	0	0,01	0,010
▶ 4	A	dcBus BAT	3404,393	230,421738	230,550308		0	0	60	Arc fault de-energized
5	A	dcBus- UPS side	10012,1377	2,1018362	2,1018362	dcFuse5	10012,1377	0	0,163474008	0,163

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What else we can do?

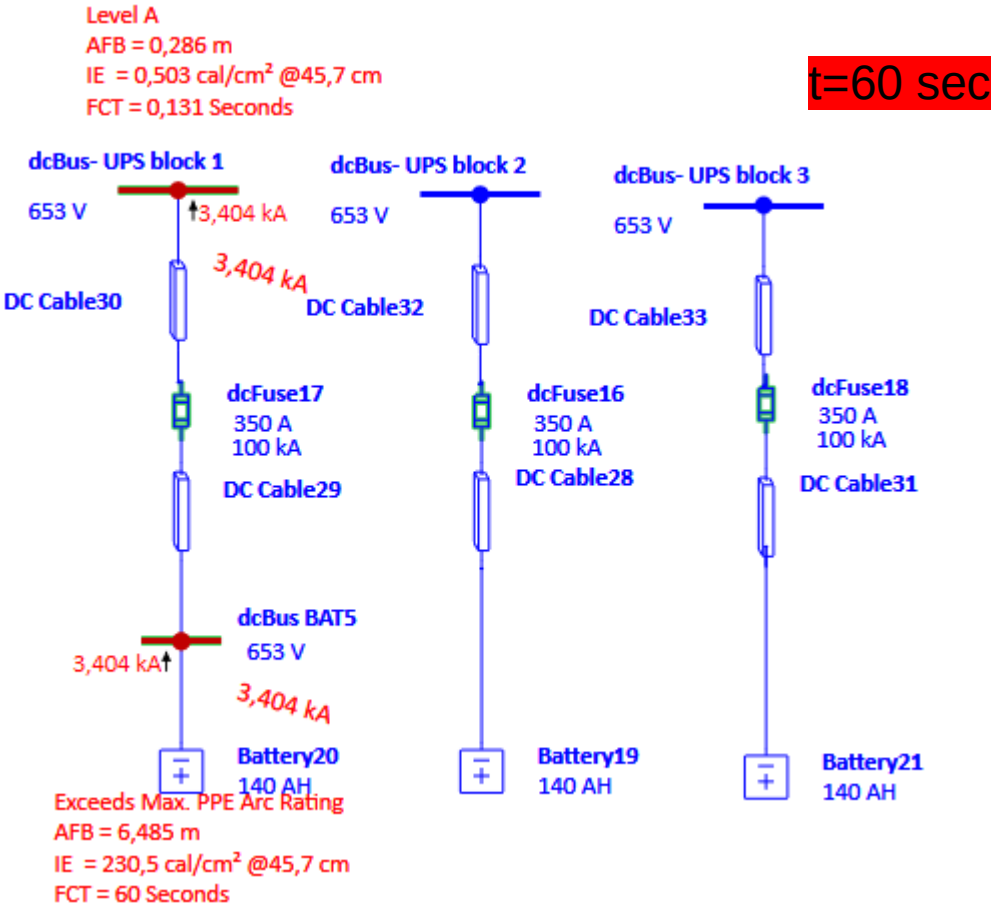
ETAP model

- Change connection to UPS
- Fuse 350A aR type

- Max time t=60sec (1min rating)

Difference ?

- Time from 5.76 to 0,131 sec
- No change to battery itself
- IE from 74 to 0,5 cal/cm2



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Q&A

Q&A

- Li-Ion batteries and fire fighting
- EV and Shock & Arc flash
- BESS DC arc flash SoC
- General Arc Flash issues in EU
- Topic knowledge across different countries and regions
- Clear working procedures vs associated risk /hazard
- How to select PPE
- Modelling and practical solutions for improvements

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Thank You for attention