EN Engineering Department

Electrical Distribution: How to Ensure Safe Powering and High Availability for LHC Machine Protection Systems?

Machine Protection Panel Workshop

March 2013

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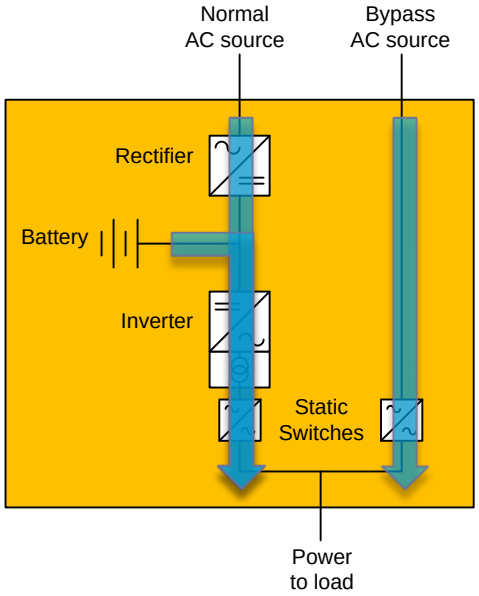
Outline

- How to power the Machine Protection systems?
- Review of the UPS distribution networks for the LHC
- Existing situation and failures statistics
- LHC UPS replacement project during LS1
- Improvements
- Quality of the power distribution network
- Conclusion

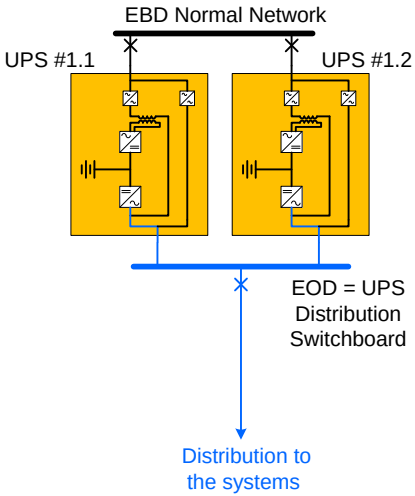
How to Power your MP Systems?

- Critical equipment powered by Uninterruptible Power Supply (UPS) systems
- UPS principle → Continues to provide power to critical loads whenever the input power fails for the time given by the backup battery
  - Normal mode of functioning: load powered via the double conversion path
  - In case of normal a.c. source failure: the load remains supplied by the inverter using the battery stored energy
  - Switch to battery mode with no break
  - Load automatically transferred to the bypass in the following conditions:
    - End of autonomy (if bypass a.c. source present)
    - Overload after a certain time (thermal image activated)
    - Short-circuit on the downstream load
- Priority given to the safe powering of the load!



Initial UPS Network for the LHC Machine Systems (Before 2009)

- 64 UPS systems for powering the LHC machine systems, spread out over the whole LHC tunnel in 32 zones:
  - RE alcoves, LHC even points (US and UA zones), LHC odd points
- 2 UPS systems in parallel-redundant configuration for each zone
- Single downstream distribution



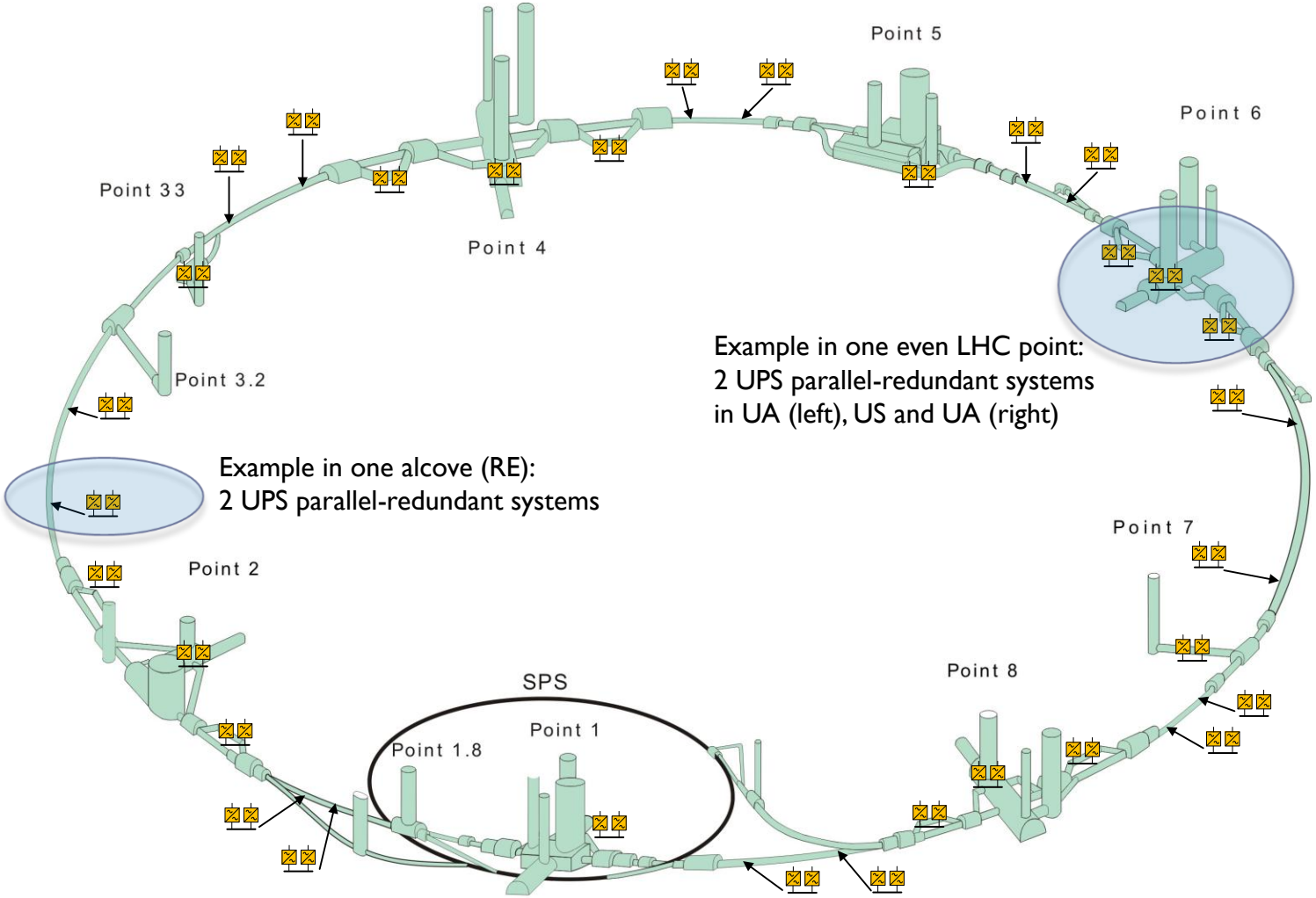
- UPS network for all users requesting safe powering!
  - QPS (quench protection systems)
  - Beam interlock systems
  - Beam Loss Monitors
  - Cryogenics control systems
  - Vacuum control systems
  - WorldFip
  - Star-points
  - ...

Machine protection: Safe powering

Reduce LHC downtime: High availability

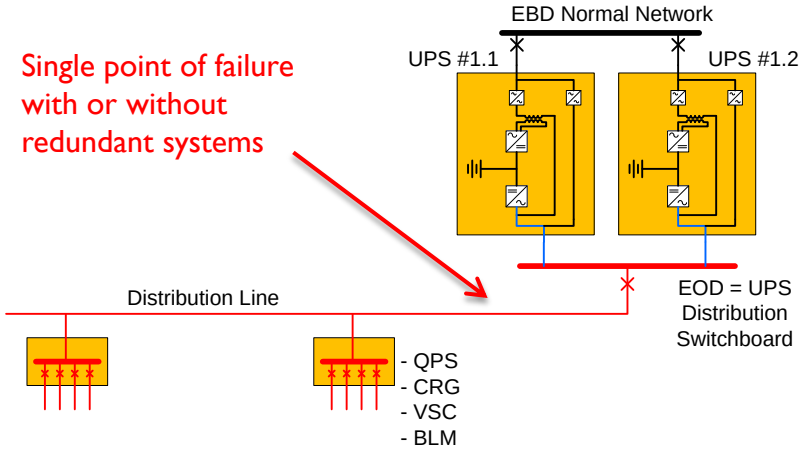
- Backup time defined by the QPS systems: 10 min, strict minimum for continuing protecting the magnets after a power abort (energy extraction time constant)

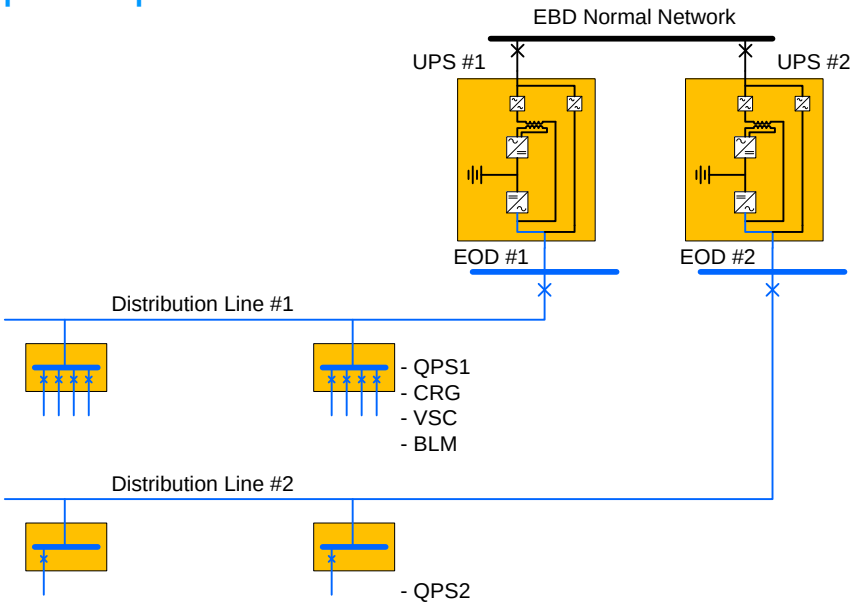
Overview of the UPS Network for the LHC



Requirement in 2009: Redundant Powering for the MP Systems

- After the incident in September 2008: needs for redundant QPS systems
- Other MP systems followed (mainly beam and power interlock systems)
- How to ensure safe powering for these MP systems?
- Only 1 solution: 2 independent and redundant power paths (protected by UPS systems)

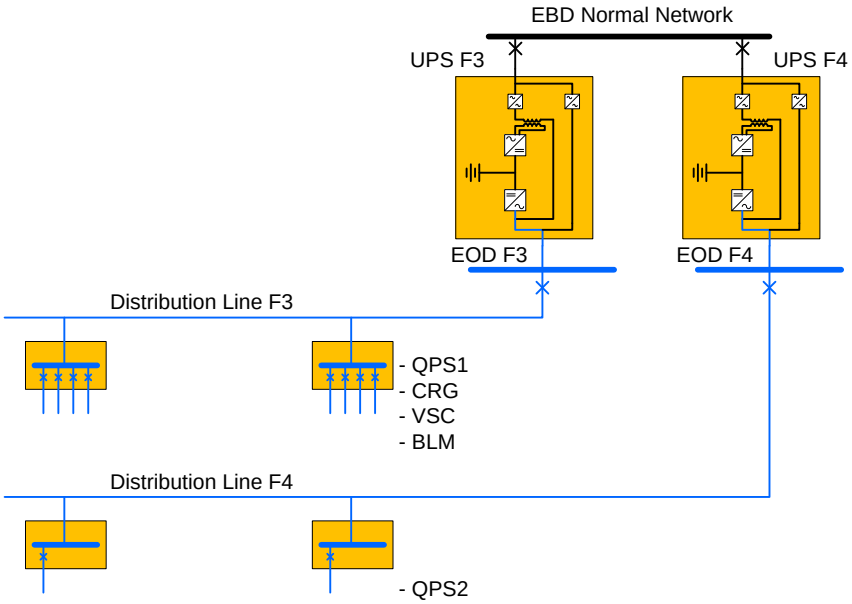




- Impact on the UPS network and for the users

Major Changes in the Alcoves (REs) and Odd Points

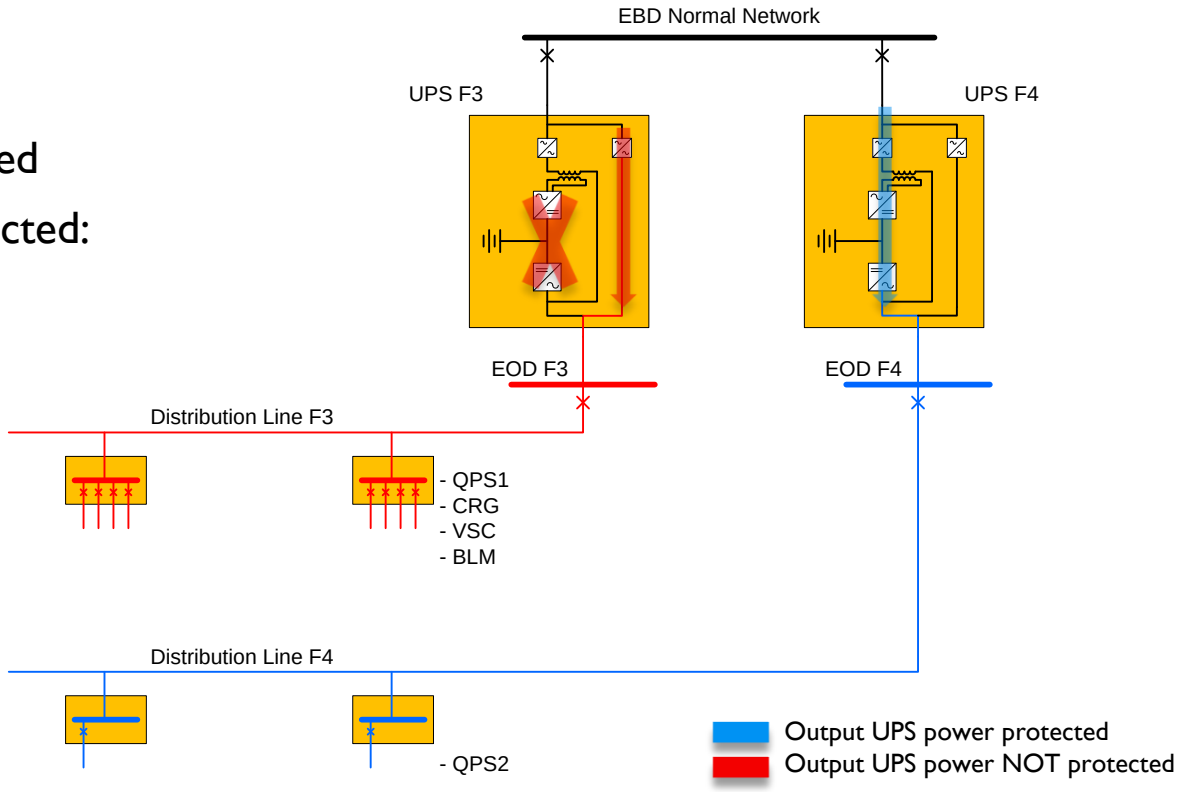
- New distribution line (so-called F4 line) for the nQPS (new and redundant QPS)
- UPS parallel-redundant configuration broken in each zone in order to obtain 2 independent and redundant power paths



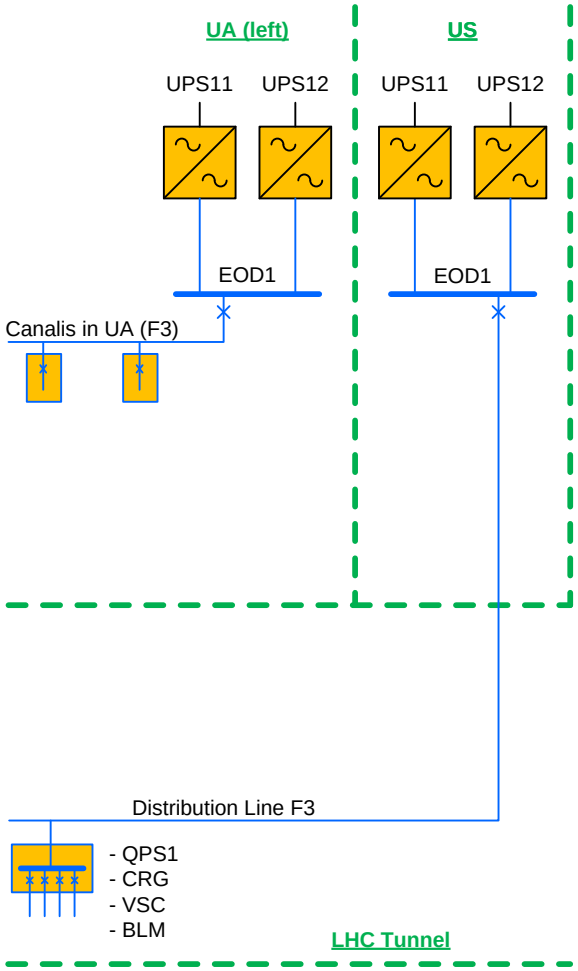
- Gain: safe powering
  - 2 independent power paths
  - Selectivity is no longer an issue!
- Inconvenience: availability reduced!
  - For all the other users left on one single distribution line
  - For the EN-EL Group who operates the UPS network

UPS Failure in the Existing Configuration

- Adaptation of the Power Interlock Chain (PIC)
- Failure of one UPS system = transfer of the load to bypass (with no break)
- PIC triggered
- Magnet powering STOP
- One power path not protected
- One power path STILL protected: minimum requirement for protecting the magnets!
- Condition to re-start: Both UPS systems OK!

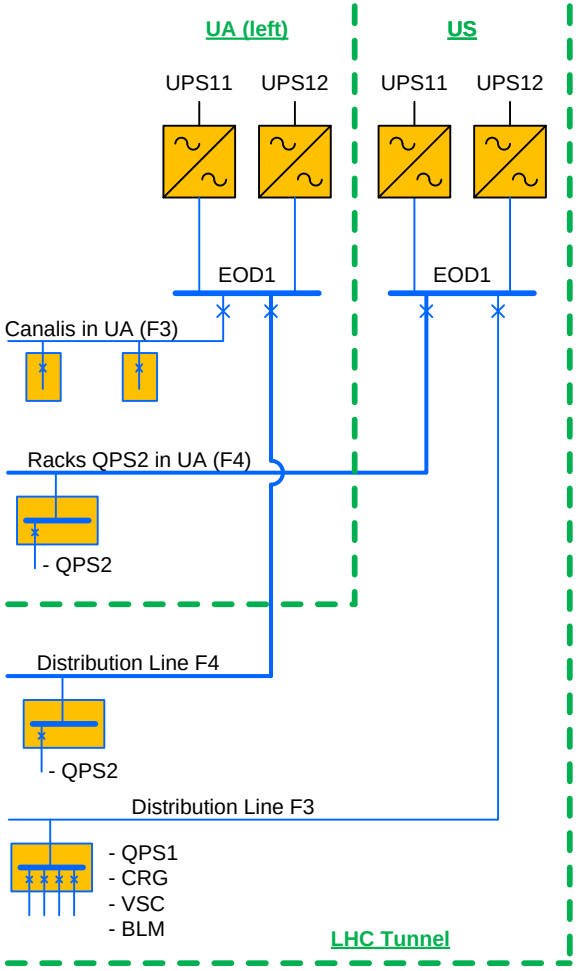


UPS Configuration and Distribution in UA and US zones (Before 2009)



- Same configuration for the LHC points 2, 4, 6 and 8
- 2 parallel-redundant UPS systems in:
  - UA (left side of the IP)
  - US
  - UA (right side of the IP)

Improvement of the UPS Distribution in UA and US zones



- New F4 distribution lines for the redundant MP systems
- F3 and F4 lines always powered from 2 different redundant UPS configurations (one in US, one in UA)
- Allows to preserve 2 parallel-redundant UPS systems in each zone
- In case of one single UPS system failure:
  - PIC not triggered
  - Automatic transfer of the full load to the remaining UPS system
  - F3 and F4 distribution lines fully protected
- Not applicable for the UPS distribution network in the ARC (due to distances)

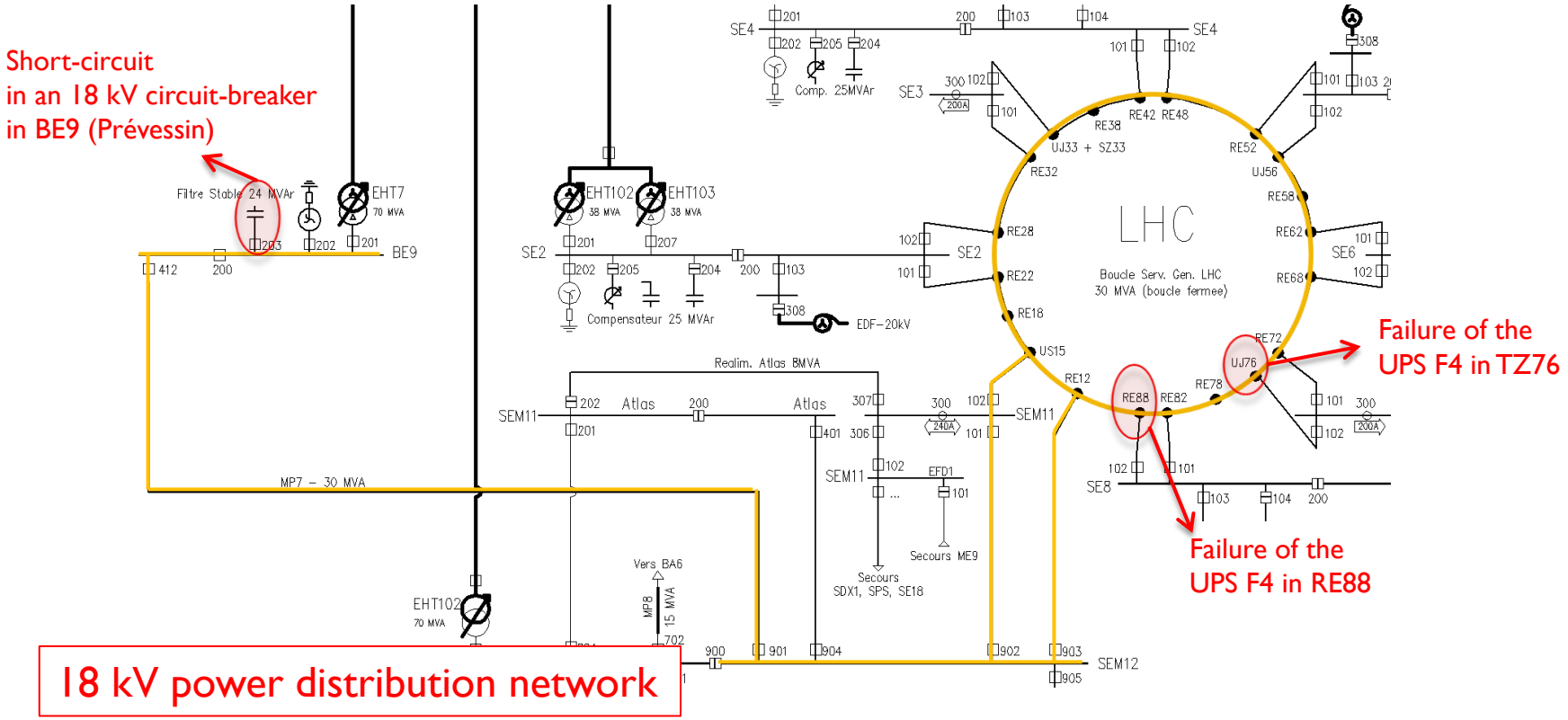
Failures in the LHC UPS Network

Date	UPS System	Failure	LHC Downtime [h]	LHC Beam to Beam [h]	Comments
12-Jan-13	EBS21/76 EBS21/88	IGBT module failure	**26.5**	**26.5**	Double UPS failure: surge on the 18 kV network
29-Sep-12	ESS11/85	IGBT module failure	**9**	**10**	Single Event Upset
1-Oct-11	EBS11/56	Output UPS out of tolerance	**8.5**	**14.5**	Single Event Upset
29-Sep-11	EBS11/56	IGBT module failure	**8.5**	**9.5**	Single Event Upset
3-May-11	EBS11/56	IGBT module failure	**26**	**28.5**	Single Event Upset
2-Sep-10	EBS11/76	Internal communication card failure	**4.5**	**n.a.**	UPS design issue
27-Aug-10	EBS21/28	Failure in the measure of the battery current	**8**	**n.a.**	UPS design issue
23-Apr-10	EBS21/78	Failure in the measure of the battery current	**5**	**12**	UPS design issue
18-Feb-10	EBS11/72	UPS output out of tolerance	**30**	**n.a.**	UPS design issue

- Cumulated LHC downtime = 126 h
- Figures over 2010-2013

Last UPS Failure in January 2013: What Happened?

- Simultaneous failure of 2 LHC UPS systems at the time with a short-circuit on an 18 kV cable termination in BE9 substation (Prévessin)



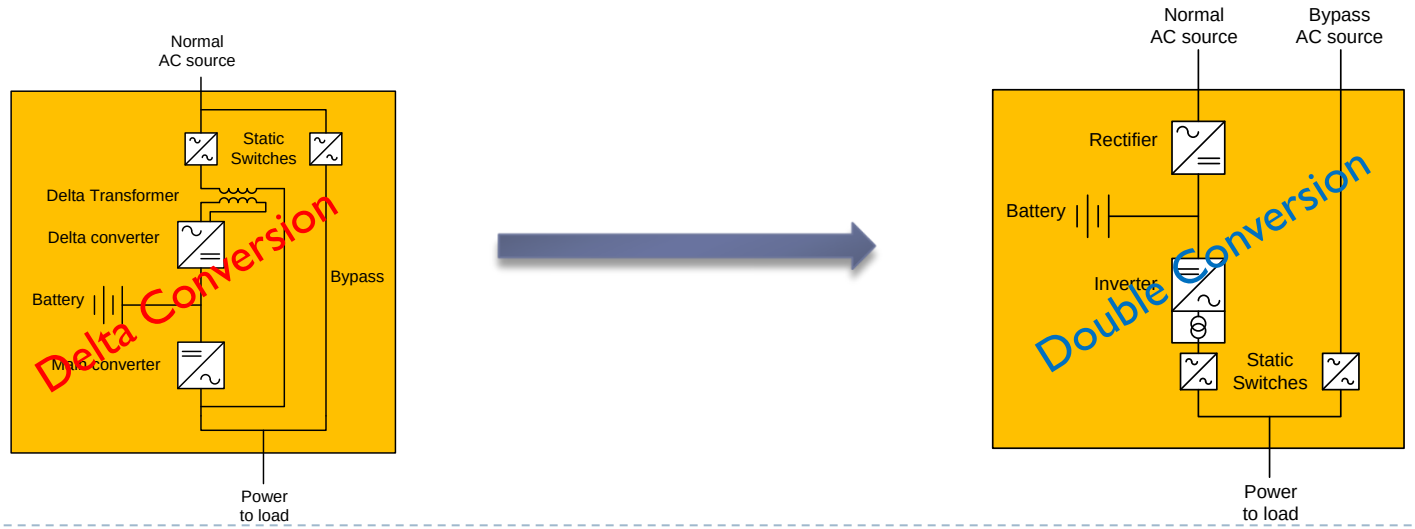
Double UPS Failure: Analysis

- Strictly identical failure on 2 UPS systems located at 4 km apart
- Cause = surge coming from the upstream 18 kV distribution network
- 18 kV circuit-breaker opening on a huge capacitive load (21 MVAR filter)
  → cause transients on the 18 kV network!
- Perturbation of 140 ms = time for the 18 kV circuit-breaker to open and isolate the fault
- No perturbation seen by the loads powered by these 2 UPS systems (QPS systems)
- However we may think the corresponding UPS power path was lost during the 140 ms power cut

- New UPS systems fully compliant with IEC norms with respect to surge transients
- Tests to be performed in collaboration with TE-EPC to confirm and determine the maximum immunity levels
- → New UPS systems topology should be more robust against surges (higher safety margins on the power components, i.e. IGBT modules)

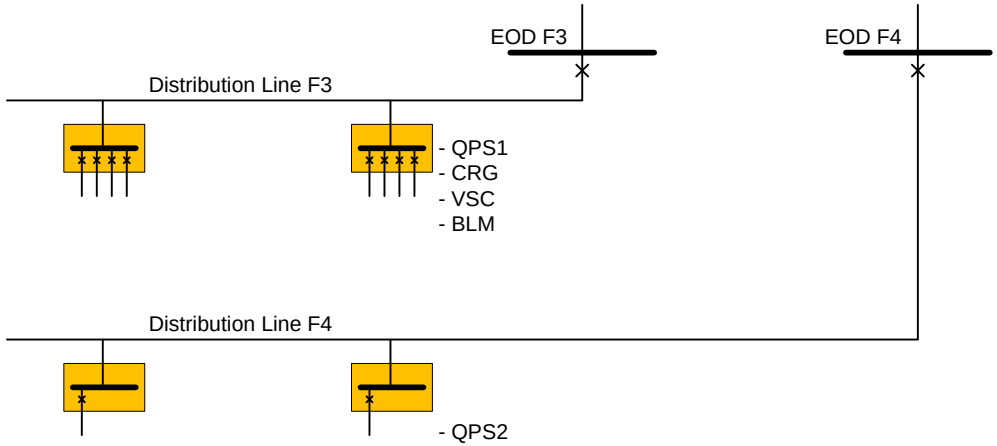
LHC UPS Systems Replacement Project

- Replacement of the existing APC Silcon UPS systems during LS1 (see EDMS 1151991)
- Project motivations:
  - Improve the reliability
  - Decrease the failure rate
  - Minimize LHC run time losses
- Change of UPS system topology: come back to the conventional double conversion UPS topology (with output isolation transformer)



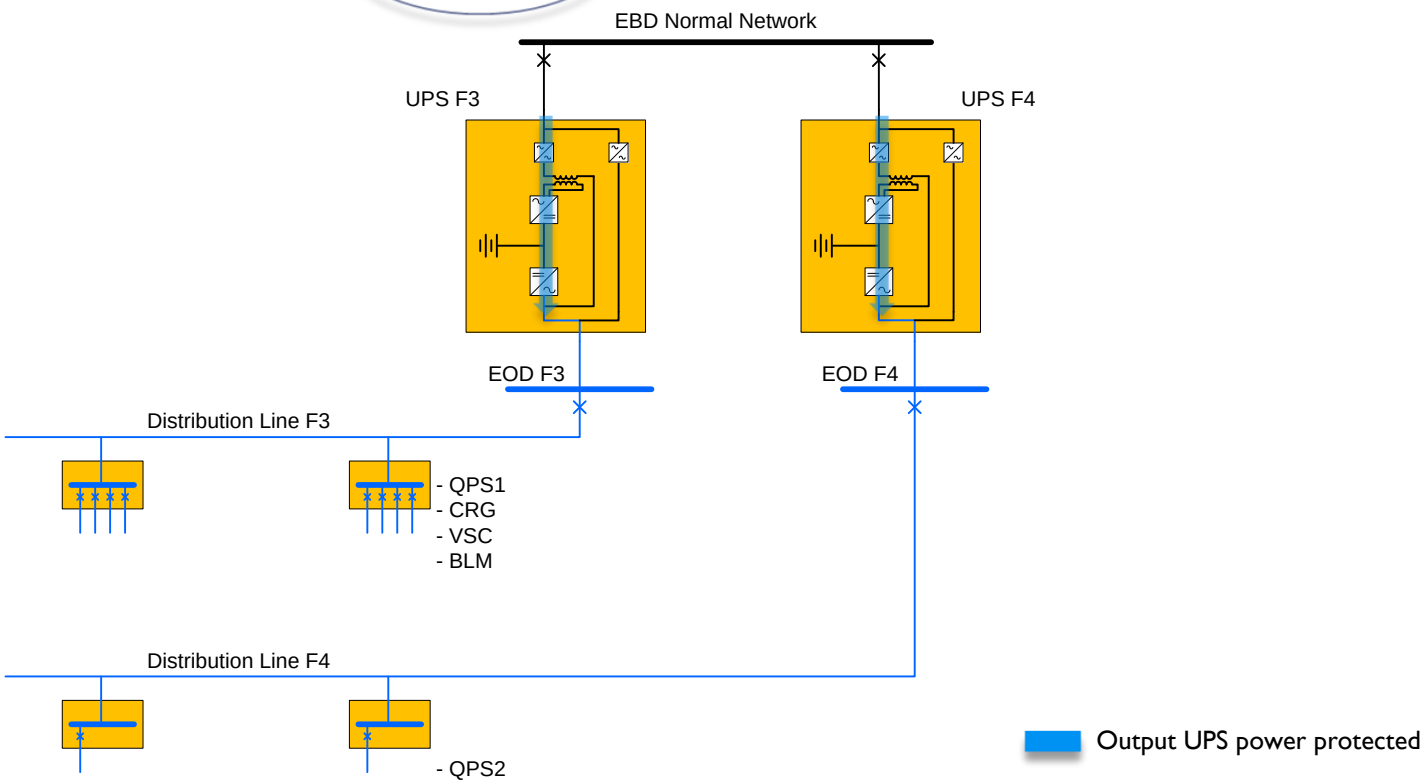
Basic Requirement for the MP Systems

- Basic requirement for a safe powering:
  2 independent power paths and protected by upstream UPS systems



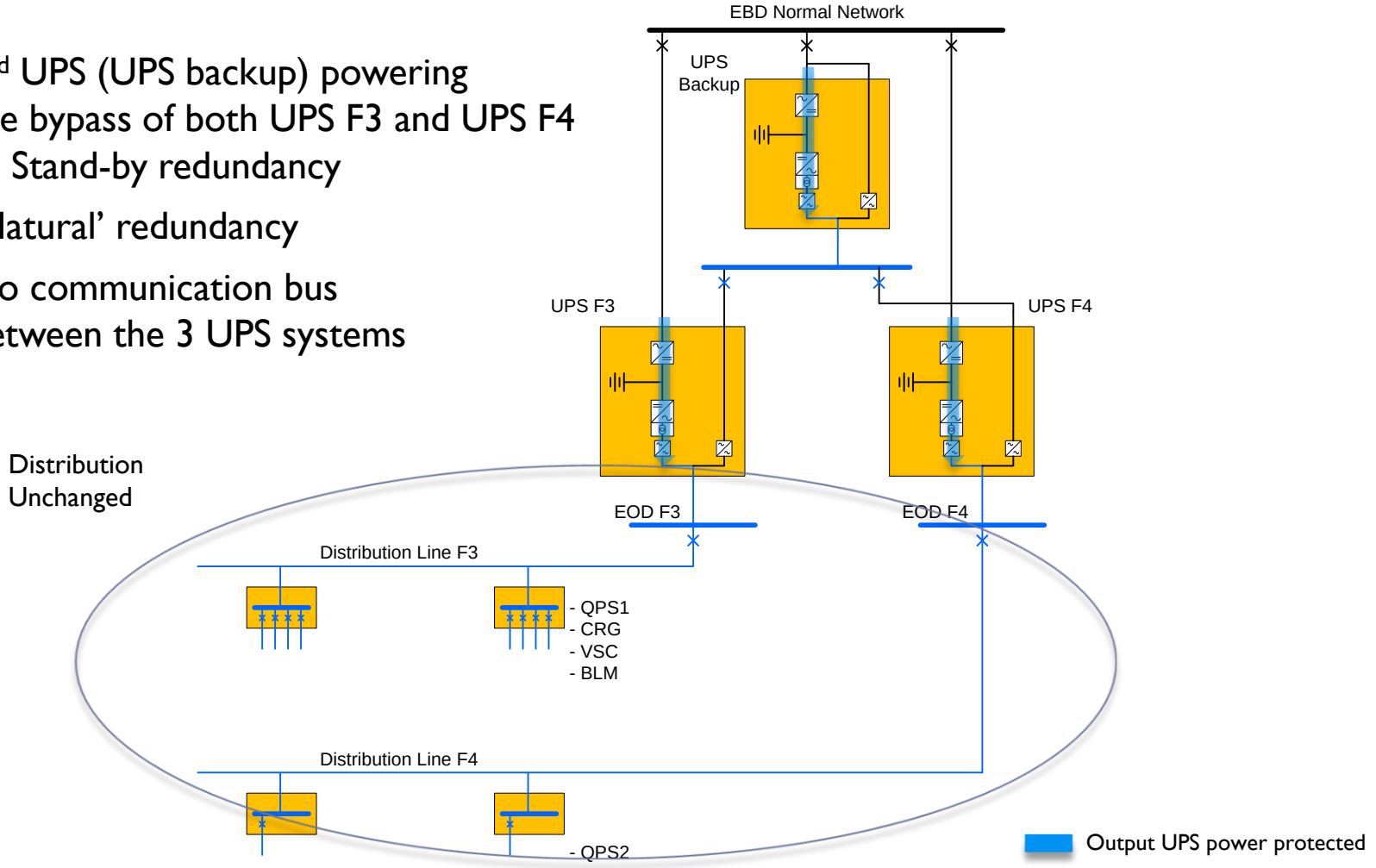
Existing UPS Configuration in the RE Zones

- Basic requirement:
  2 independent power paths and protected by upstream UPS systems



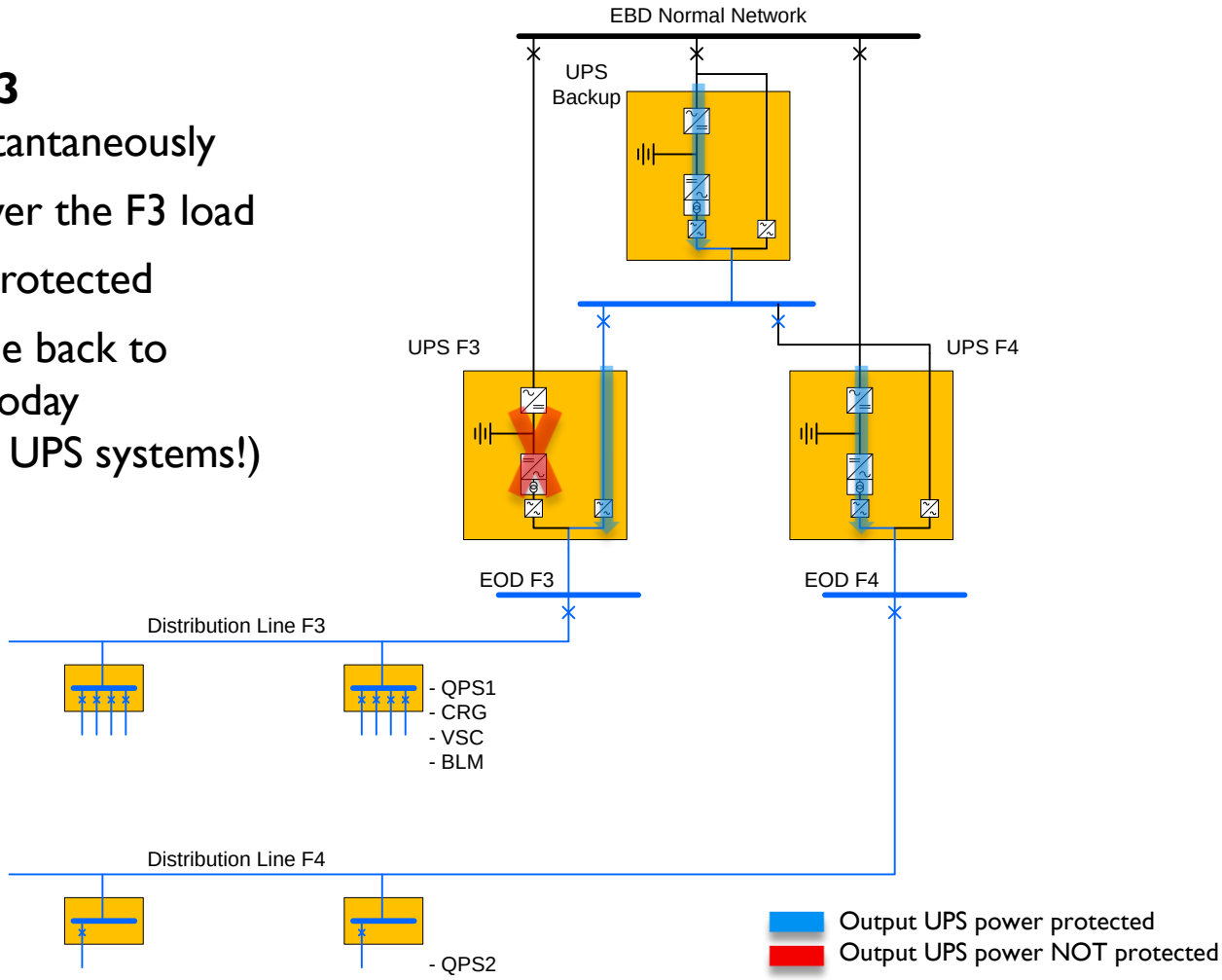
New UPS Configuration in the Alcoves (RE) and Odd Points

- 3rd UPS (UPS backup) powering the bypass of both UPS F3 and UPS F4 = Stand-by redundancy
- 'Natural' redundancy
- No communication bus between the 3 UPS systems

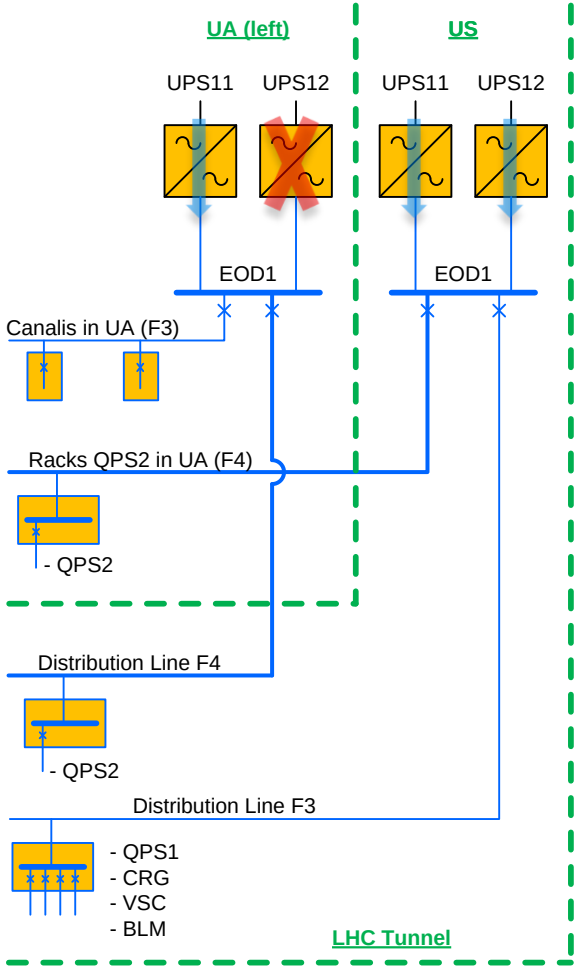


Tolerance to the First Failure

- Upon a failure, **UPS F3** transfers to bypass instantaneously
- **UPS backup** takes over the F3 load
- 2 power paths STILL protected
- After a failure, we come back to the same situation as today (but with conventional UPS systems!)



UPS Configuration in UA and US zones



- UPS configuration not changed
- UPS system replacement one-to-one

- In case of failure of one UPS system in a redundant UPS configuration:
  - Stop of the faulty UPS system
  - Automatic transfer of the full load to the remaining UPS system
  - F3 and F4 distribution lines fully protected

Output UPS power protected

New PIC Logic

- One single UPS failure = 2 power paths still protected = No PIC triggered
- Benefits of this new PIC logic:
  - Magnet powering can continue upon one single UPS failure
  - Machine can start with 2 UPS systems out of 3 in the RE zones and LHC odd points
  - Machine can start with one UPS system out of 2 in the UA and US zones
- This UPS distribution allows to wait for the next stop for repairing an UPS failure
- This gives time for preparing and optimizing the intervention!
- UPS redundancy restored (and improved)
- Increase availability for all users including MP and EN-EL group for fault repairs

How to Test the Safe Powering of MP Systems?

- Allows:
  - To check that the redundant systems are powered from the correct power path
  - To check that the machine protection is still operational (including post-mortem analysis)
  - To check the full chain (including all the interlocks)
  - To find out interdependencies between systems!
- Always mentioned but never done!

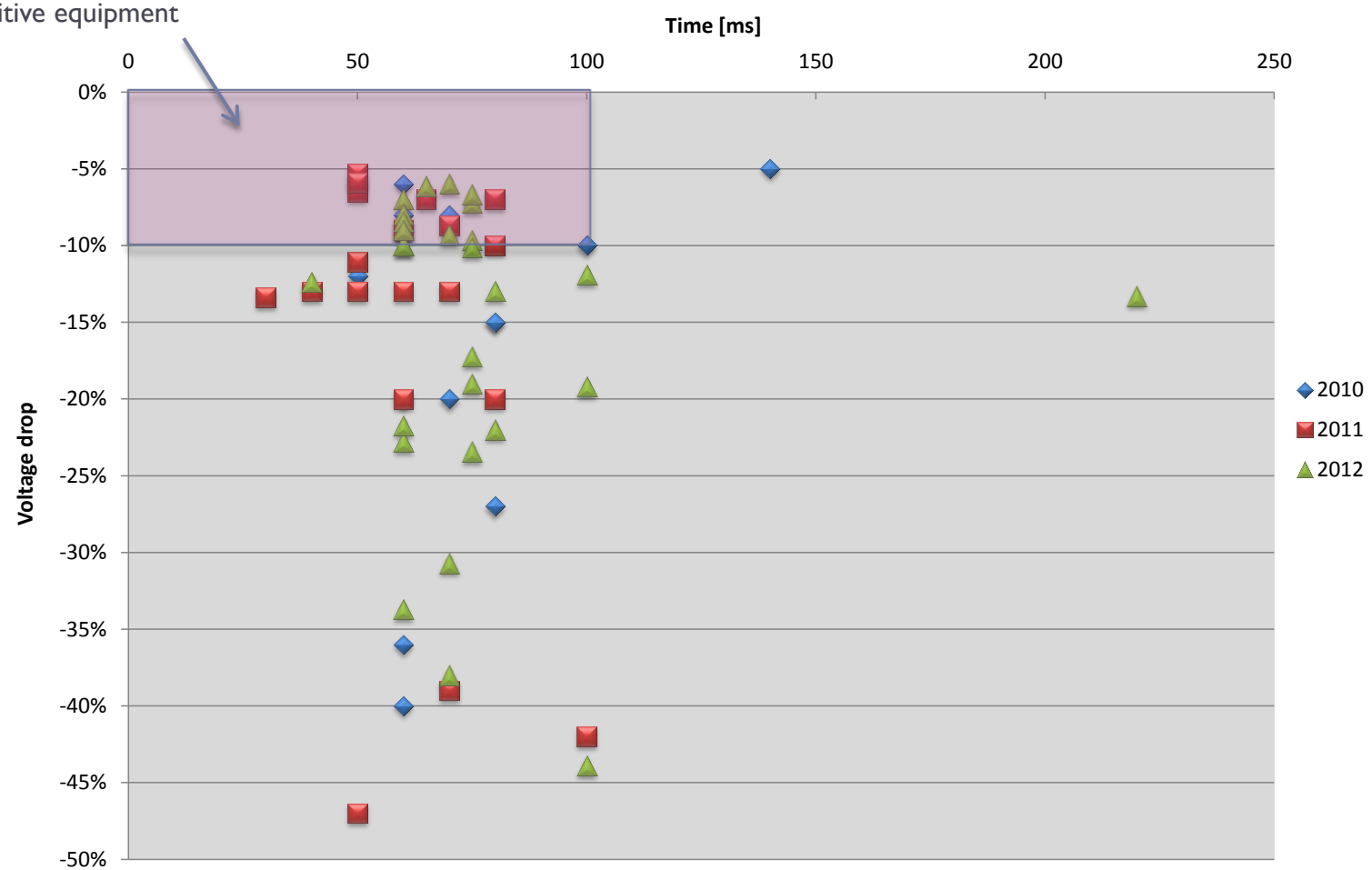
- Simple and fast! (only for EN-EL)
- Voluntary power cut on the downstream distribution powered by one UPS
  → all systems attached to the distribution of this UPS shut down!
- Test to be done one each power path (F4 then F3)
- Obviously when the systems are fully operational, to be assessed with LHC coordination team and all users
- Strong impact on all users (especially cryogenics, vacuum or star-point racks)

Quality of the Power Distribution Network

- CERN electrical network supplied by the French grid through a 400 kV line interconnected with the Swiss grid
  - Advantage for availability
  - Inconvenience: affected by all electrical perturbations
- LHC powering often impacted by outside perturbations occurring on the power distribution network
- Seems complicated to make the LHC powering more insensitive to outside perturbations when considering the powers involved:
  - Averaged power consumption (accelerator complex running) = 220 MW
  - Total installed power = 500 MW
- Document EDMS 113154 (September 2000):
  Main parameters for the LHC 400/230 V distribution system
- Recommendations for the users installing equipment at CERN:
  - Input voltage tolerance = -10% of the normal operating voltage
  - Hold-up time = 100 ms

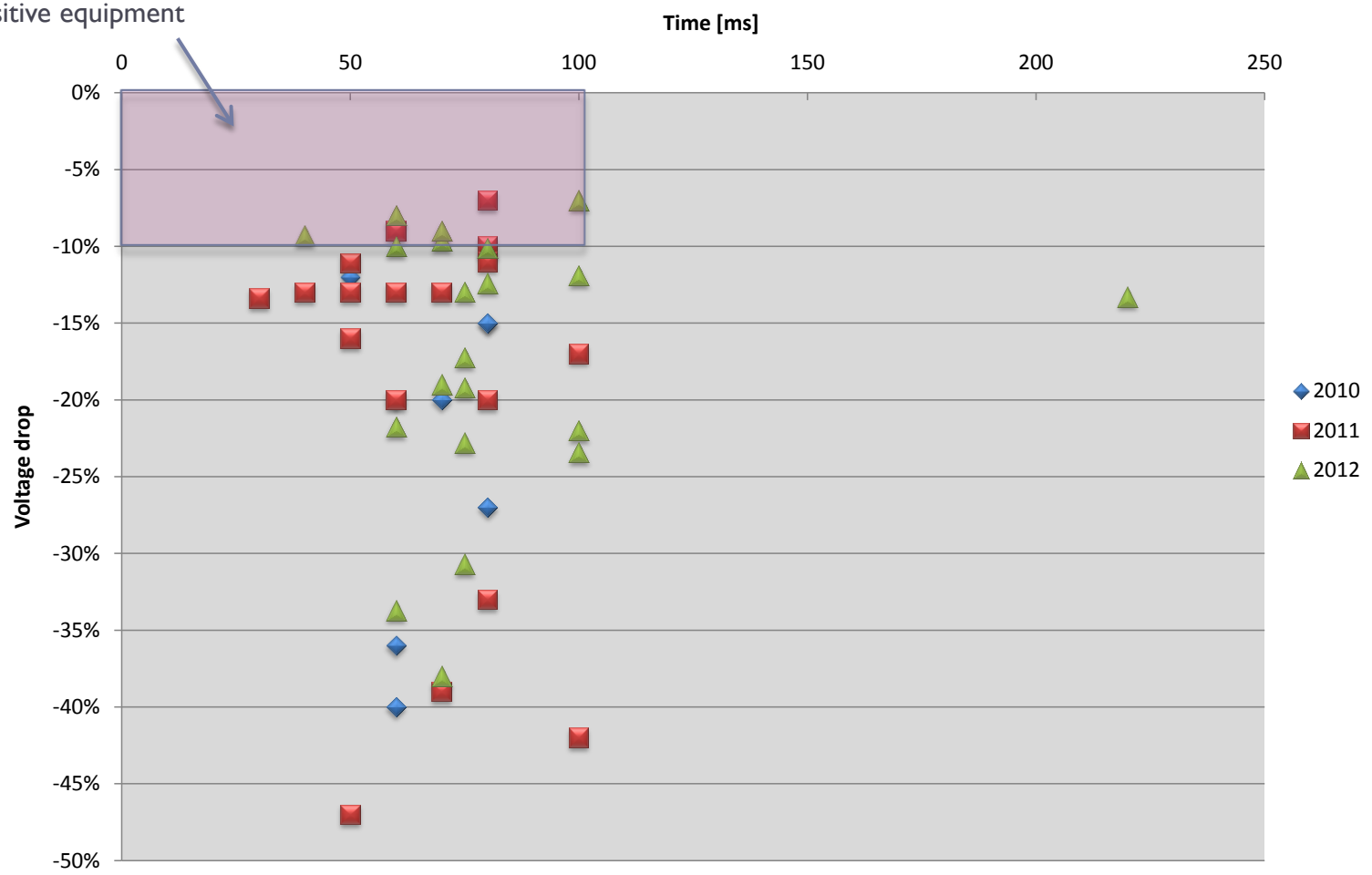
LHC Affected by Outside Perturbations

Recommendations for good insensitive equipment



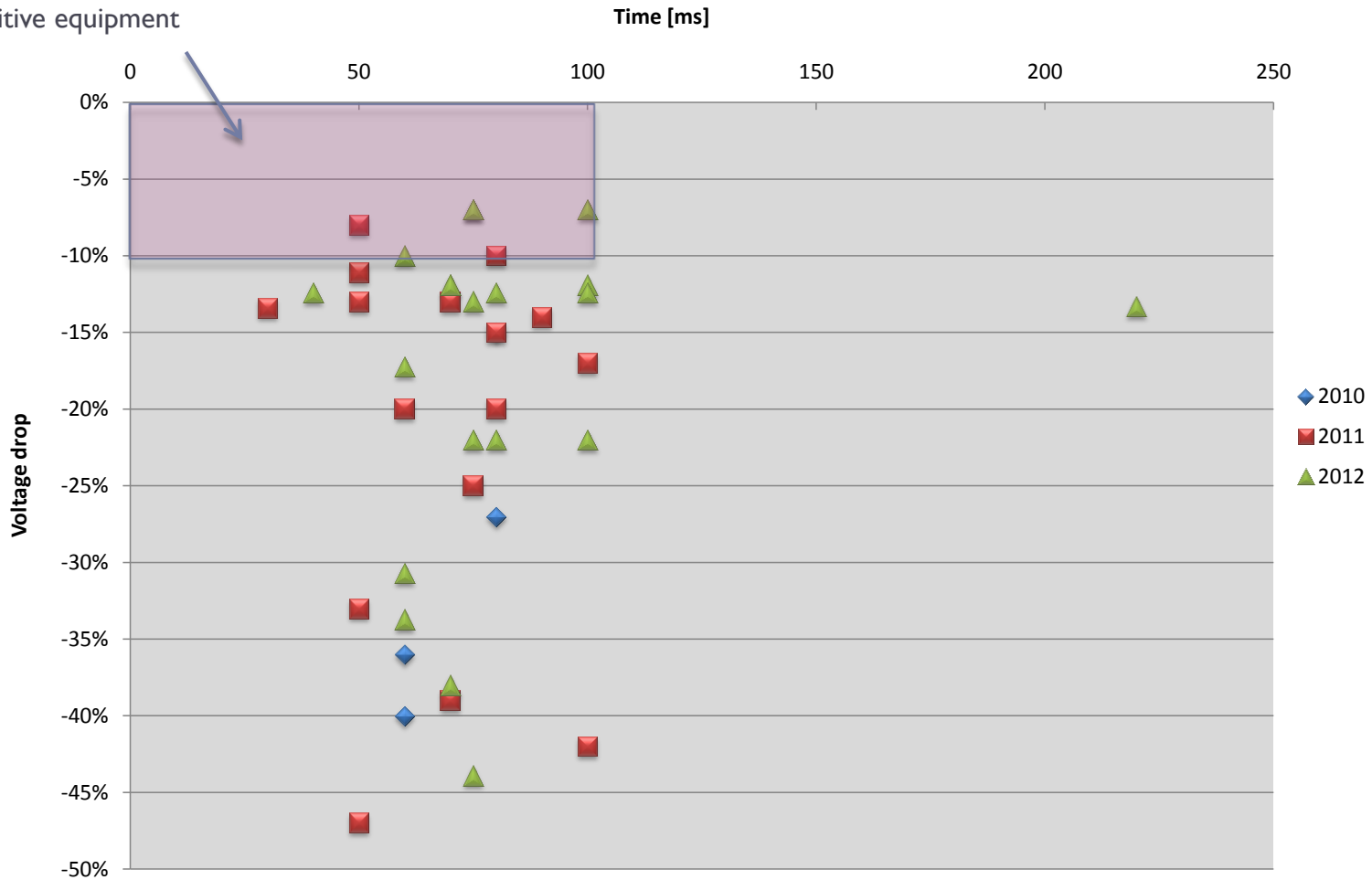
SPS Affected by Outside Perturbations

Recommendations for good insensitive equipment



PS Affected by Outside Perturbations

Recommendations for good insensitive equipment

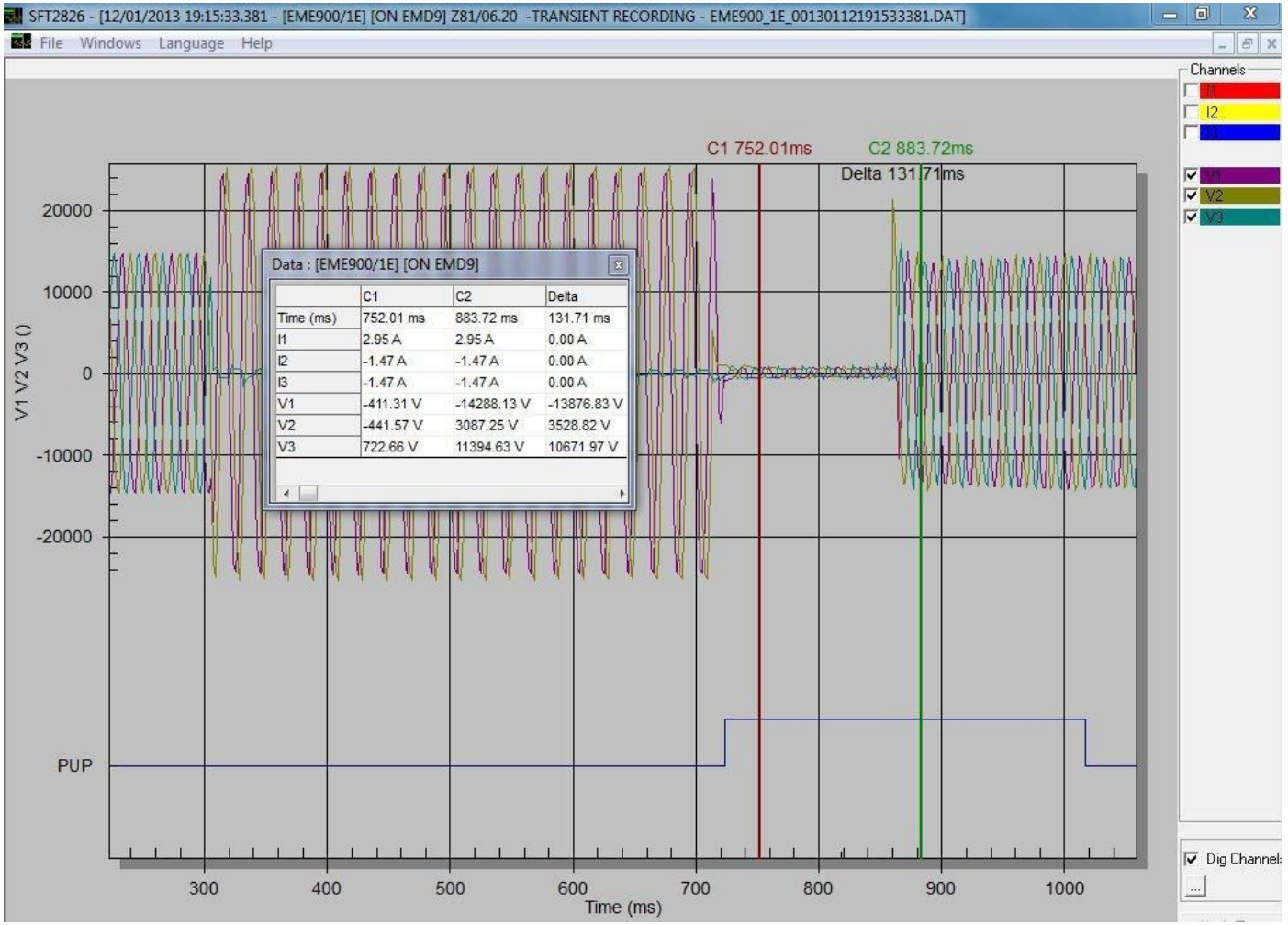


Conclusions

- Change of UPS system topology:
  - Conventional double conversion topology much more reliable
- New UPS system network configuration
  - Delocalization in point 5, 7 and 8 (R2E project)
- UPS network majorly improved during LS1:
  - Safe powering of the MP systems with independent and redundant paths
  - Availability increased for all users
  - Tolerance to the first UPS system failure in each zone

- Testing the redundant powering of all users systems can be very instructive!
- Should we allow other users to be powered from the F4 lines (initially reserved for QPS and now MP redundant systems)?
- How to be more insensitive to electrical perturbations?
  - Act on the users' systems and equipment (increasing the input voltage tolerance and the hold-up time)
- Do we accept to stop if availability is not impacted?
  - Implement solutions to restart as fast as possible

Annex I


SFT2826 - [12/01/2013 19:15:33.381 - [EME900/1E] [ON EMD9] Z81/06.20 -TRANSIENT RECORDING - EME900_1E_00130112191533381.DAT]
File Windows Language Help
C1 752.01ms
C2 883.72ms
Delta 131.71ms
Data : [EME900/1E] [ON EMD9]
C1 C2 Delta
Time (ms) 752.01 ms 883.72 ms 131.71 ms
I1 2.95 A 2.95 A 0.00 A
I2 -1.47 A -1.47 A 0.00 A
I3 -1.47 A -1.47 A 0.00 A
V1 -411.31 V -14288.13 V -13876.83 V
V2 -441.57 V 3087.25 V 3528.82 V
V3 722.66 V 11394.63 V 10671.97 V
V1 V2 V3 ()
20000
10000
0
-10000
-20000
PUP
300
400
500
600
700
800
900
1000
Time (ms)
Channels
I1
I2
I3
V1
V2
V3
Dig Channels

Annex 2:
Can We Lose the Redundancy or the Full UPS Network?

- Lose redundancy of powering: YES!
  - Major failure one UPS system (load not transferred to bypass and so to backup UPS)
  - Major failure in the UPS distribution switchboard or on power cables
  - Probability = very small!
- One power path STILL protected: minimum requirement for the redundant MP systems!

- Lose the full UPS distribution network in one zone: YES!
  - Fire in one alcove (RE) for instance
  - Probability = very small!
- By considering the time required to stop the magnet powering and extract energy, the MP systems should protect the machine before loosing the full UPS network!