Fast Magnet Current Change Monitors (FMCM) for additional protection against mains disturbances

…follow up of discussion in the LTC

Acknowledgements: V.Montabonnet, K.Kahle, V.Kain, P.Orlandi

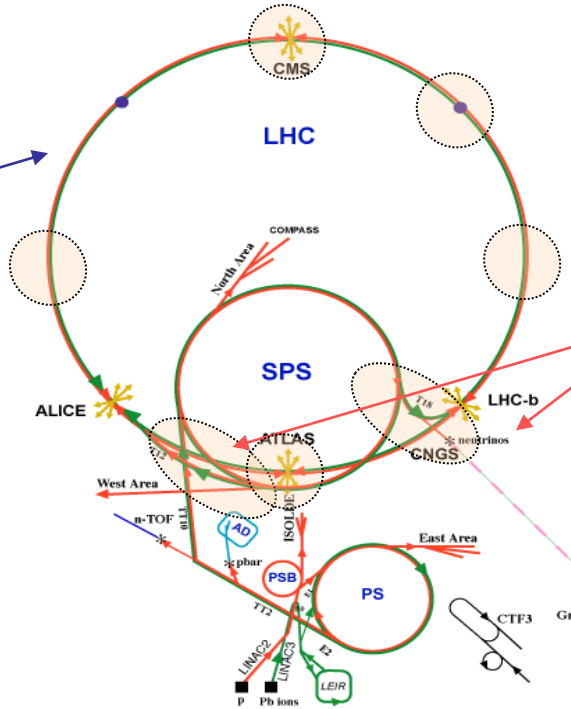
Outline

- Questions we try to answer
- Main Parameters of the CERN electrical network
- Architecture of the electrical network
- Failure propagation & some failure statistics
- Susceptibility of power converters
- Results and conclusions
- Future work

System Layout & Protection aims

LHC

- D1 in IR1 and IR5
- Dump septa in IR6
- Maybe IR3, IR7 for combined failures

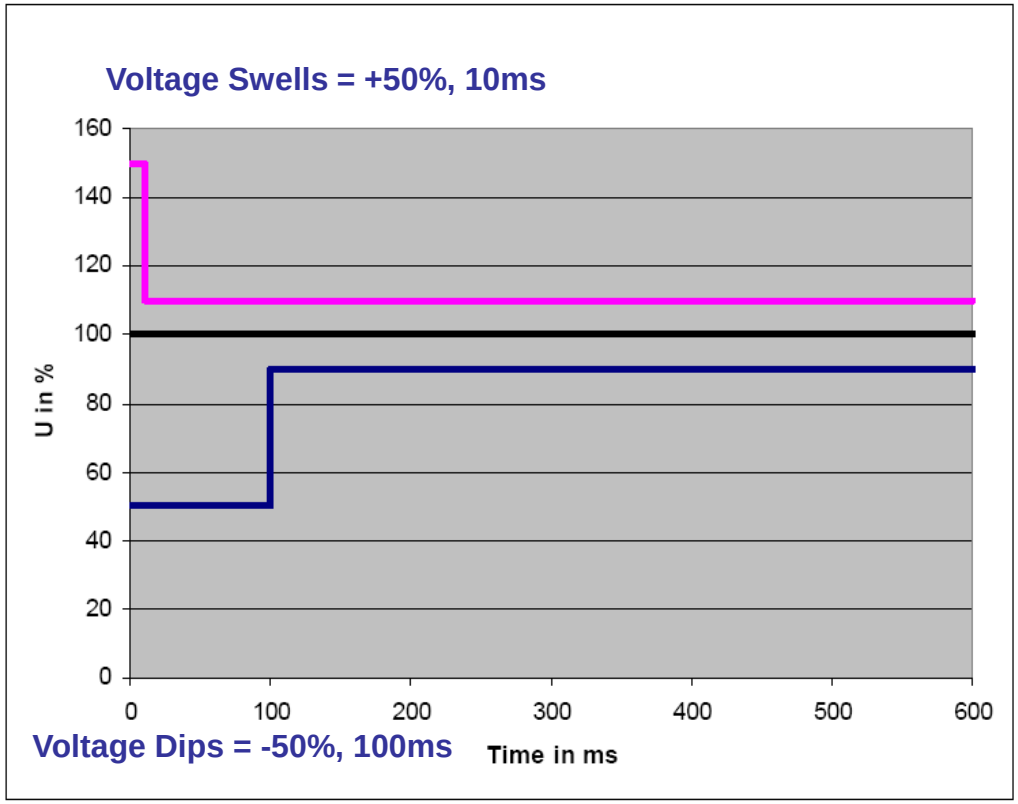


TI2, TI8, CNGS, TT41

- Septas (MSE, MSI, MST)
- MBB, MBG
- MBI, MBHC
- MBIBH

- 25 FMCM units will be deployed for protection against fast DC current changes in the normal conducting magnets of the SPS-LHC transfer lines and the LHC
- Quickest system to capture powering failures before significant beam effect (e.g. ΔI of $2*10^{-3}$ in 50µs for the MSE)
- Can we hope to achieve additional active protection against mains disturbances (AC side monitoring)
- Is this valid beyond the directly protected circuits?

- Based on the statistic of past network disturbances, a minimum immunity for equipment has been defined in an LHC ES 'Main Parameters of LHC 400/230V Distribution System'



U nom= 400 / 230V ± 10 %

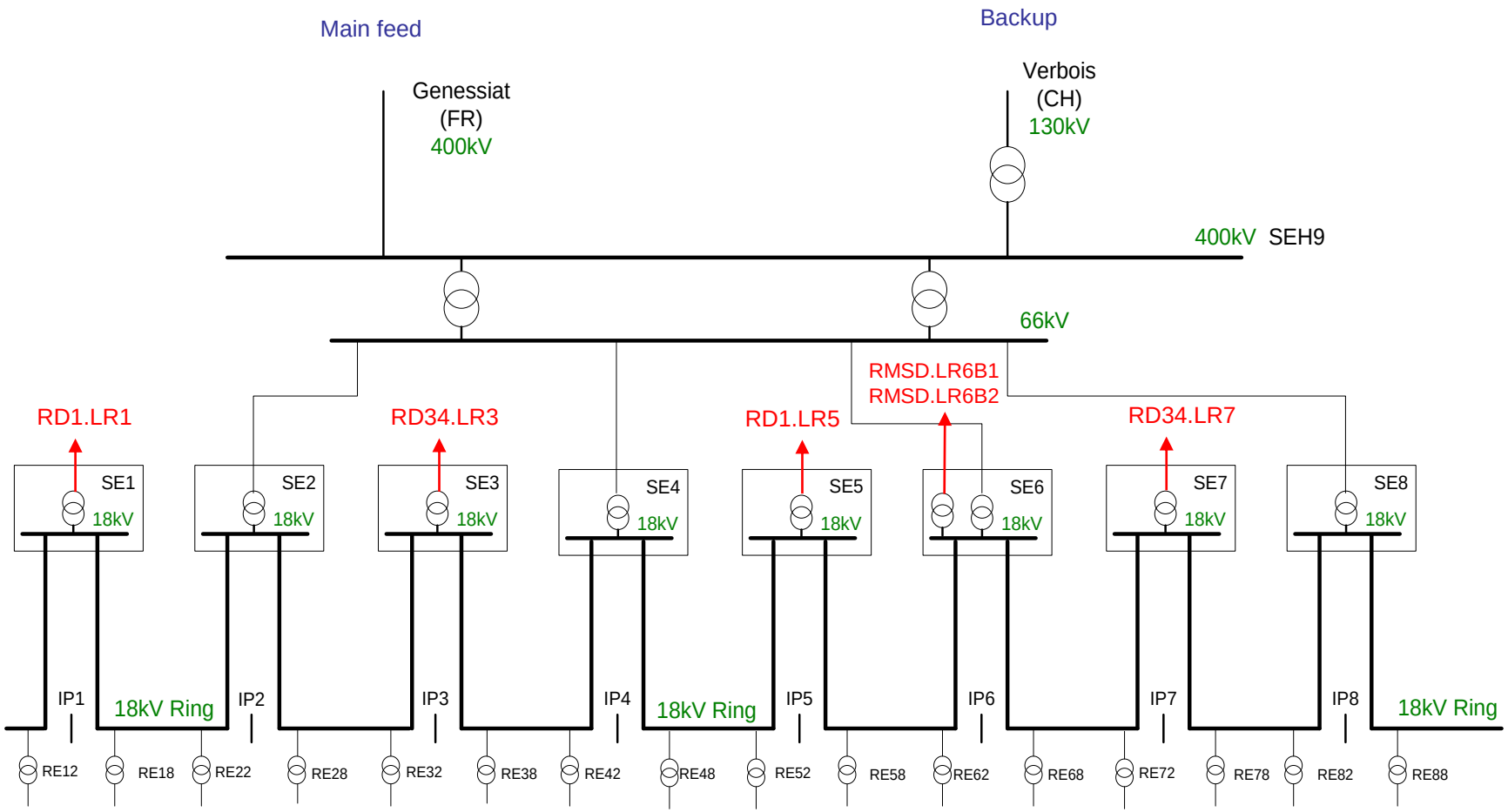
Typ. Variations = ± 5 %

Transients= 1200V for 0.2ms

THD = 5%

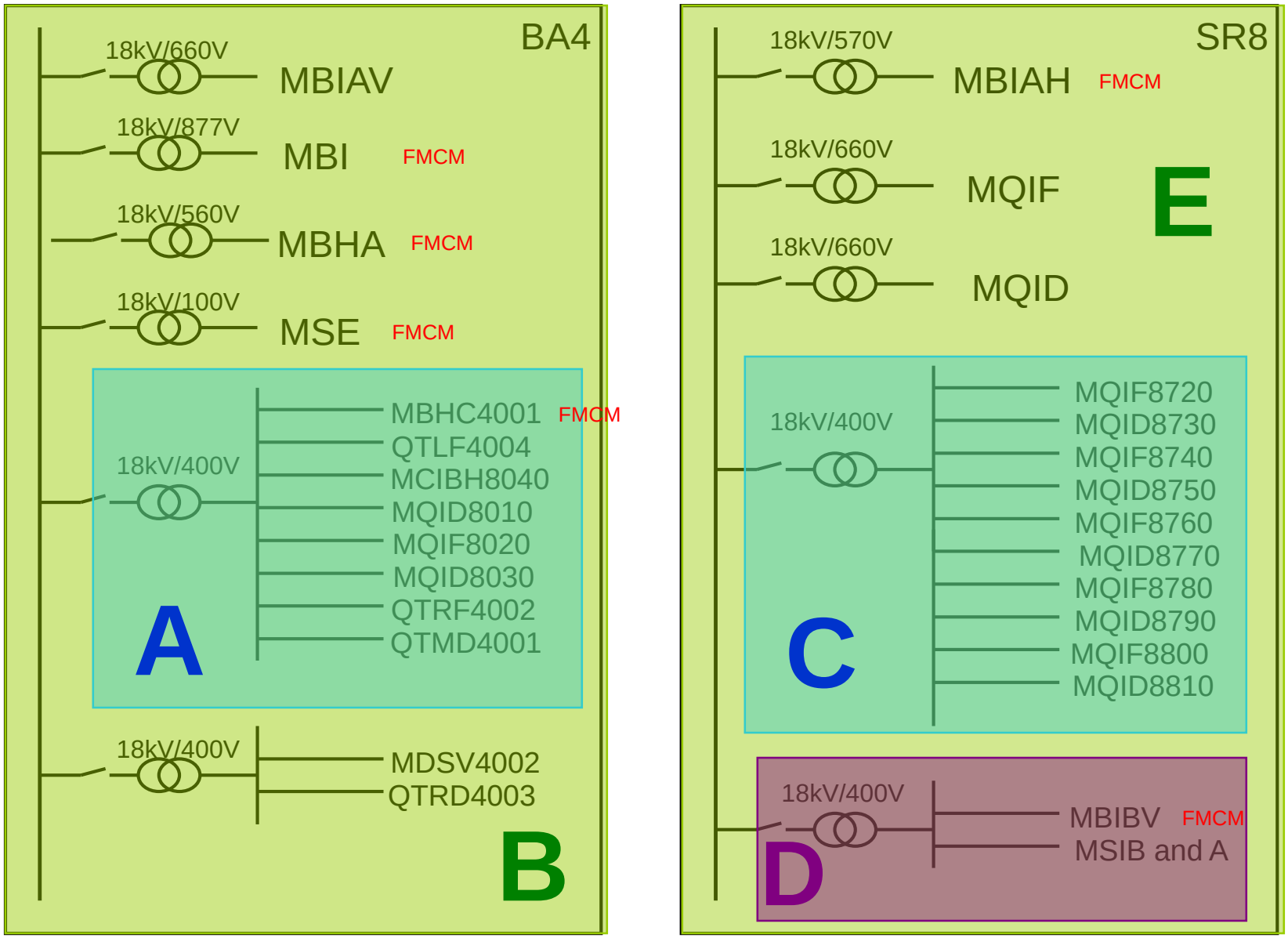
- Equipment racks with local power supplies for electronics supply can normally withstand
- Today's thyristor converters are amongst the first to suffer from disturbances due to their high power throughput and low storing capacity

Mains distribution to the LHC (schematic architecture)

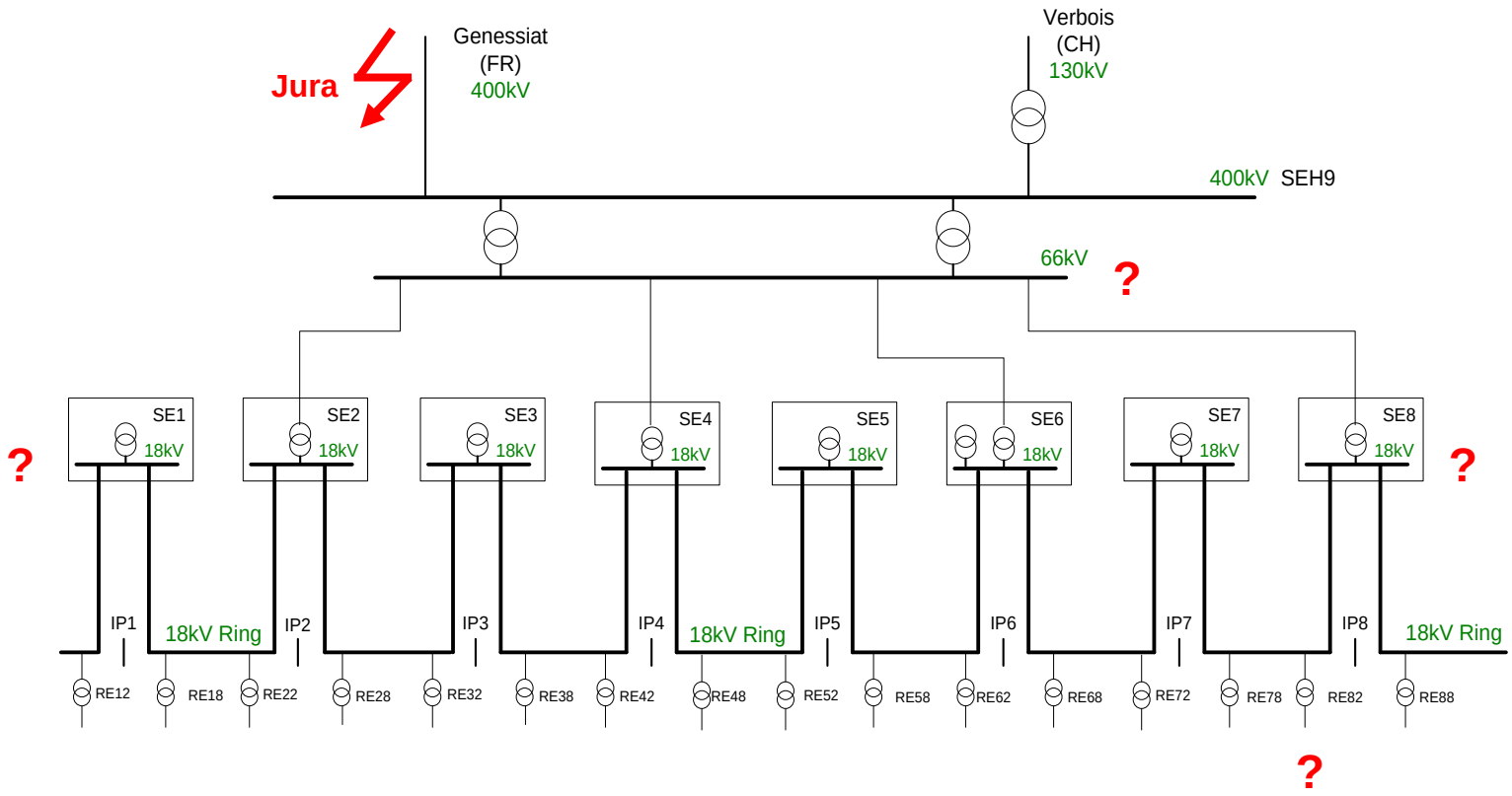


LHC Power Converters equipped with an FMCM

Grouping of converters on transformers in BA4 and SR8



Failure Propagation through the Network



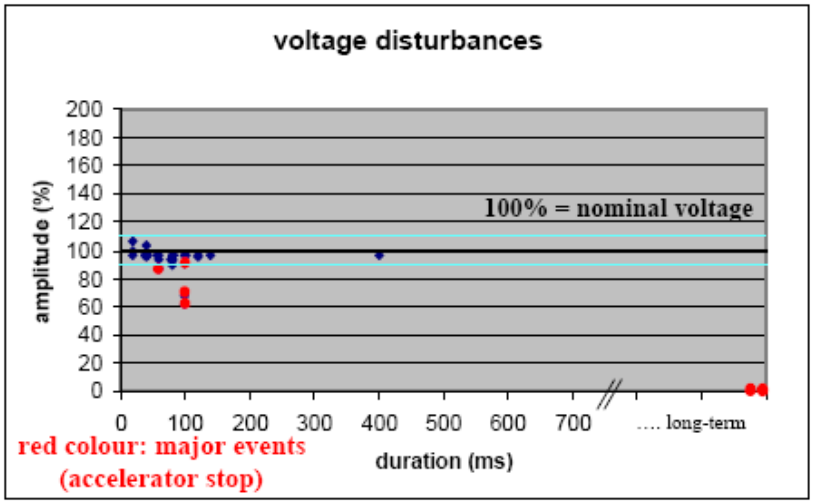
Example: Propagation of a 50% dip in Phase R of the 400kV network

		R	S	T	R-S	S-T	R-T
400 kV		50 %	100 %	100 %	75 %	100 %	75 %
66 kV		58 %	97 %	96 %	78 %	100 %	77 %
18 kV		77 %	100 %	77 %	95 %	96 %	65 %
18/0.4	0.4 kV	94 %	94 %	66 %	100 %	77 %	77 %
18/3.3/0.4	3.3 kV	94 %	94 %	66 %	100 %	75 %	78 %
	0.4 kV	94 %	94 %	66 %	100 %	76 %	76 %

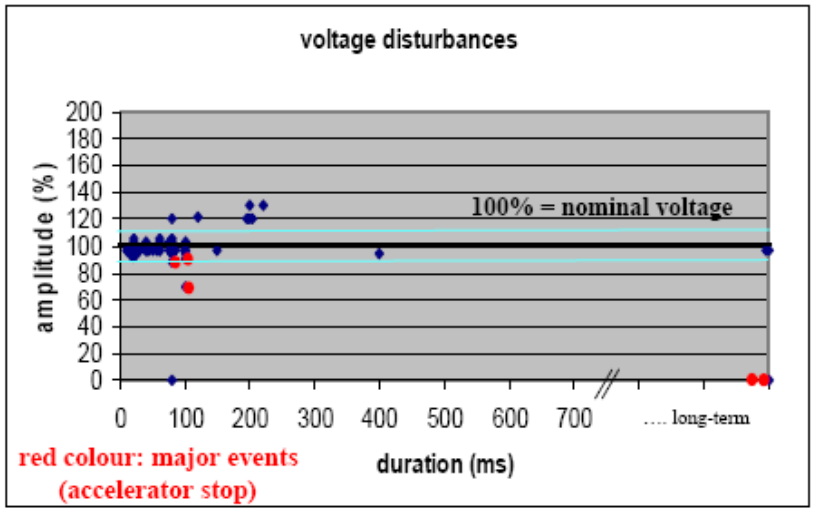
Courtesy of K.Kahle

Failure Propagation through the Network

- Failures propagate to lower voltage levels with >100%, while almost no upwards propagation is observed in the CERN network
  - Cause of this are the transformer vector groups and the reduction of zero sequence voltage components during 400/66/18kV transformation
- Average number of voltage variations observed
  - 400kV: 8/month, 18kV: 20/month, 0.4kV: 35/month
  - 60% dips, 10% swells, 30% transients, 0.4% mains failures (20% thunderstorms)



400kV network



18kV network

Courtesy of K.Kahle

Susceptibility of power converters

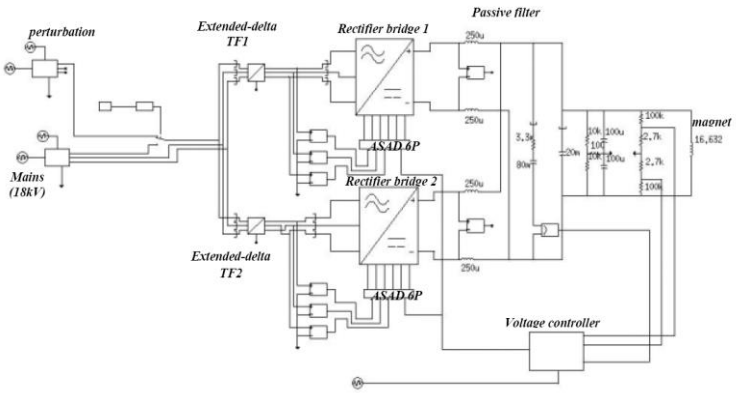
- In order to quickly capture disturbances, we have to search the 'weakest' element
- Power converters are particular dependent on the mains supply conditions
- Three main converter types are used in the CERN accelerators
  - Switched mode converters (60A-8kA)
  - Main Dipole Thyristor converters (Main Dipoles 13kA)
  - Thyristor converters for e.g. dump septas (n.c. mangnets)

- Converters are supplied by 3-phase 400V AC for the switched mode converters or 18kV and 400V AC for the Thyristor converters.
  - Function Generator Controller (3 phase 400V AC or UPS for Inom>4kA)
  - DCCT electronics (3 phase 400V AC or UPS for Inom>4kA)
  - Power part (400V for switched mode or 18kV and 400V for Thyristor)

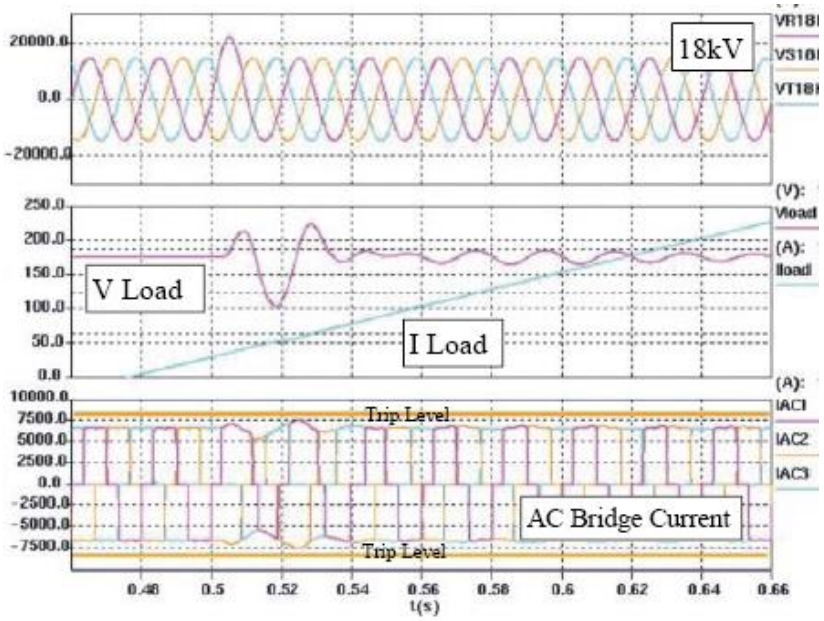
Susceptibility of power part

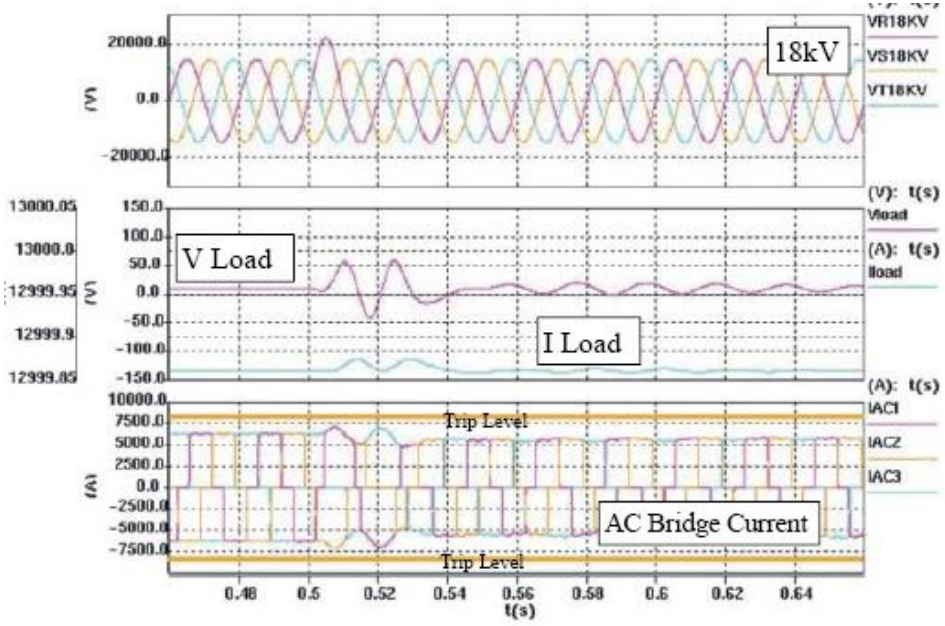
➔ Modeling of Power Converters in SABER

- During voltage surge of 1200V, 200us
- Over-voltage of 50% during 10ms
- Voltage drop of 50% during 100ms
- According to ES



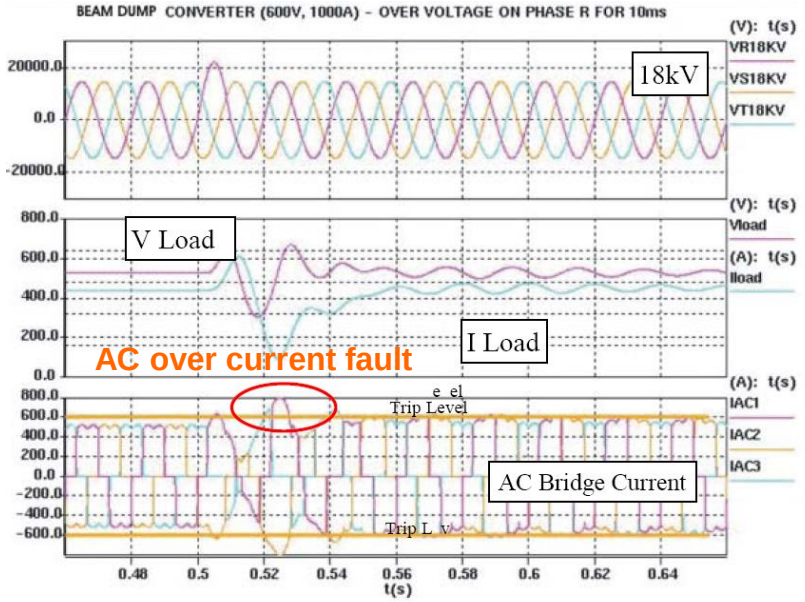
➔ Simulation results for 50% over-voltage on phase R during ramp and flat top



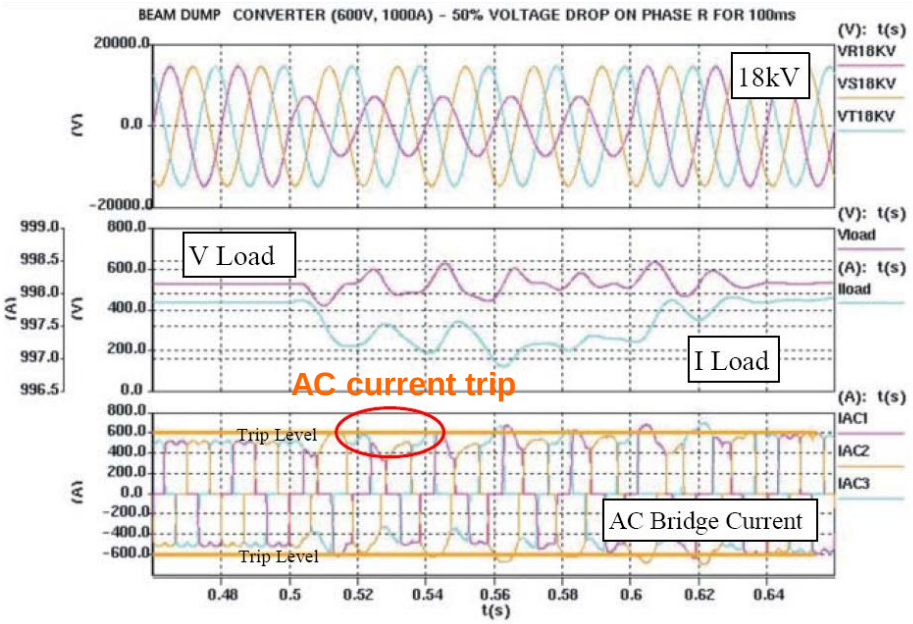


Courtesy of V.Montabonnet

➔ Simulation results for LHC Warm Dump Septa Converter



Simulation results for 50% over-voltage on phase R during 10ms



Simulation results for 50% under-voltage on phase R during 100ms

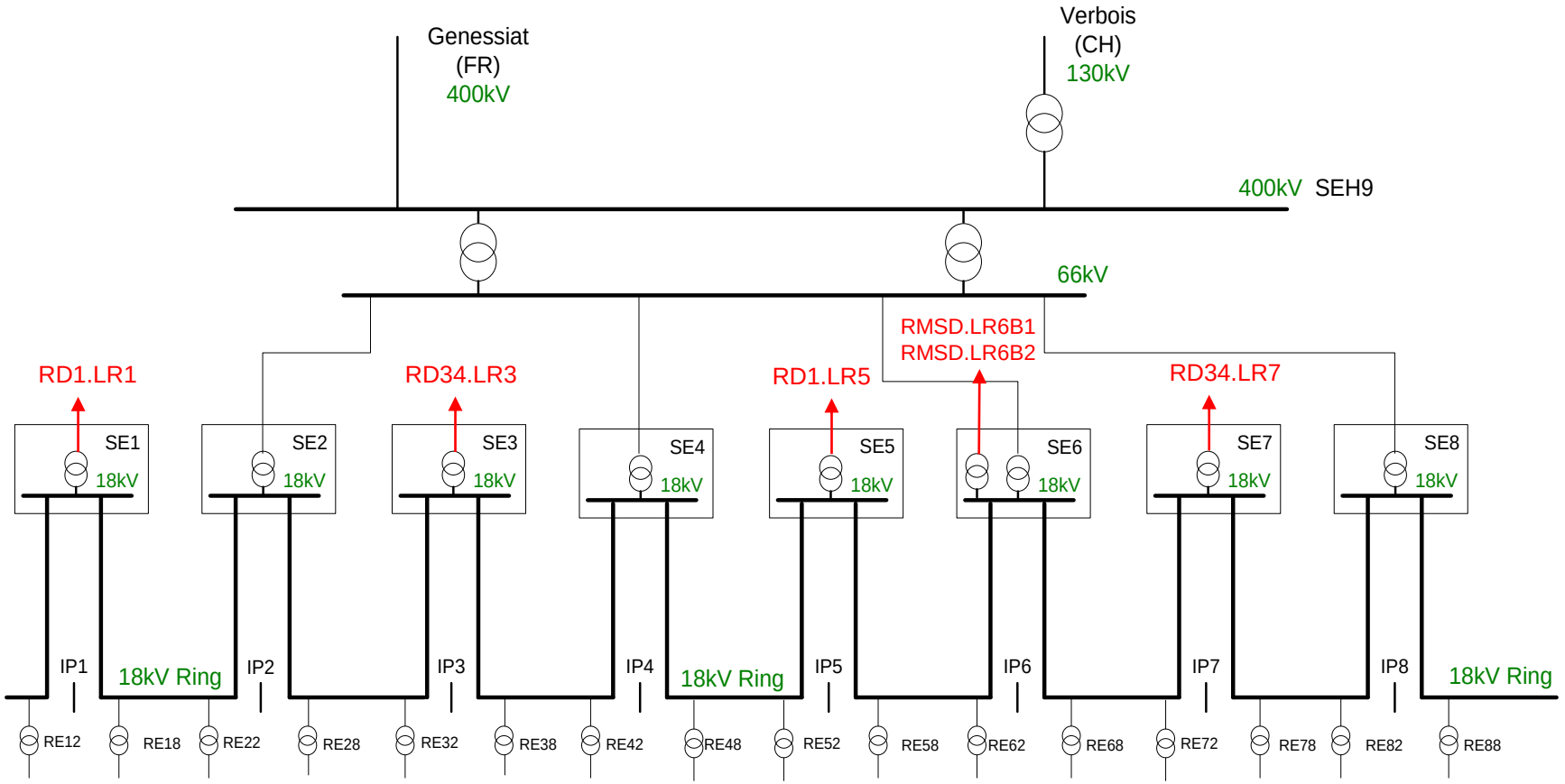
Courtesy of V.Montabonnet

Results (Chamonix XII, V.Montabonnet)

	Switch-mode converters	Main Dipole Thyristor Converter	Warm Dump Septa Thyristor converter
Voltage surge **1200V, 1 phase, 200us**	>1600V	<1ppm during ramp <1ppm during flat-top	negligible
Over-Voltage **50%, 1 phase, 10ms**	Saturation of choke, internal interlock	<1ppm during ramp <2ppm during flat-top	AC over-current <0.2% after 10ms
Voltage Drop **50%, 1 phase, 100ms**	Ripple >, U out drop	<1ppm during ramp <3ppm during flat-top	AC current trip 0.2% after 10ms

➔ Electronics will withstand voltage drops of 100% on three phases during 100ms for all converter types

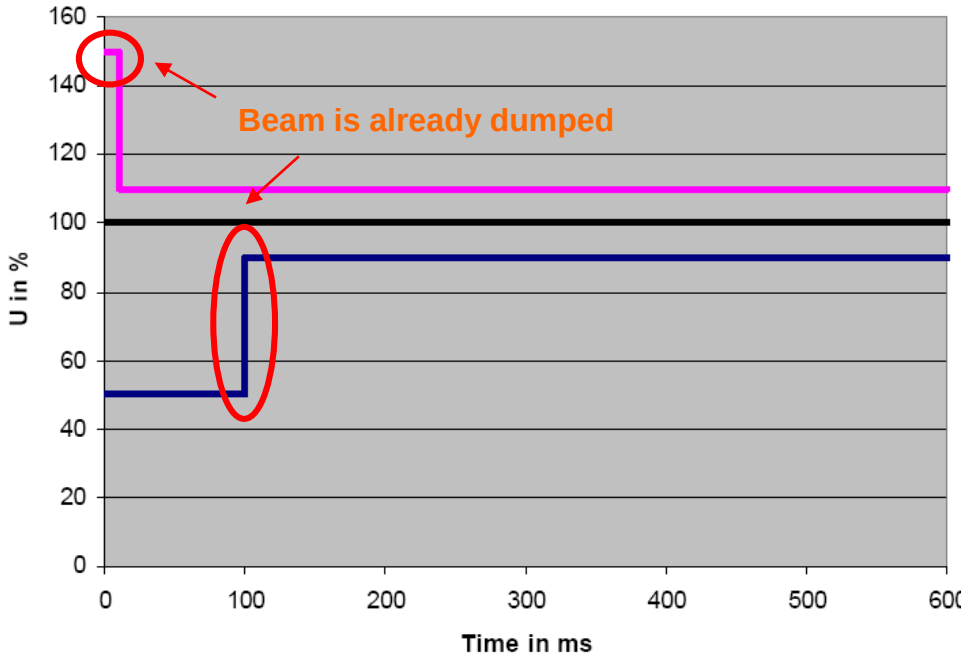
Comparison with maximum FMCM detection levels



RD1	RD34	RD1	RMSD	RD34
0.035%	>0.035%	0.035%	0.05%	>0.035%
0.9ms	1ms	0.9ms	1ms	1ms

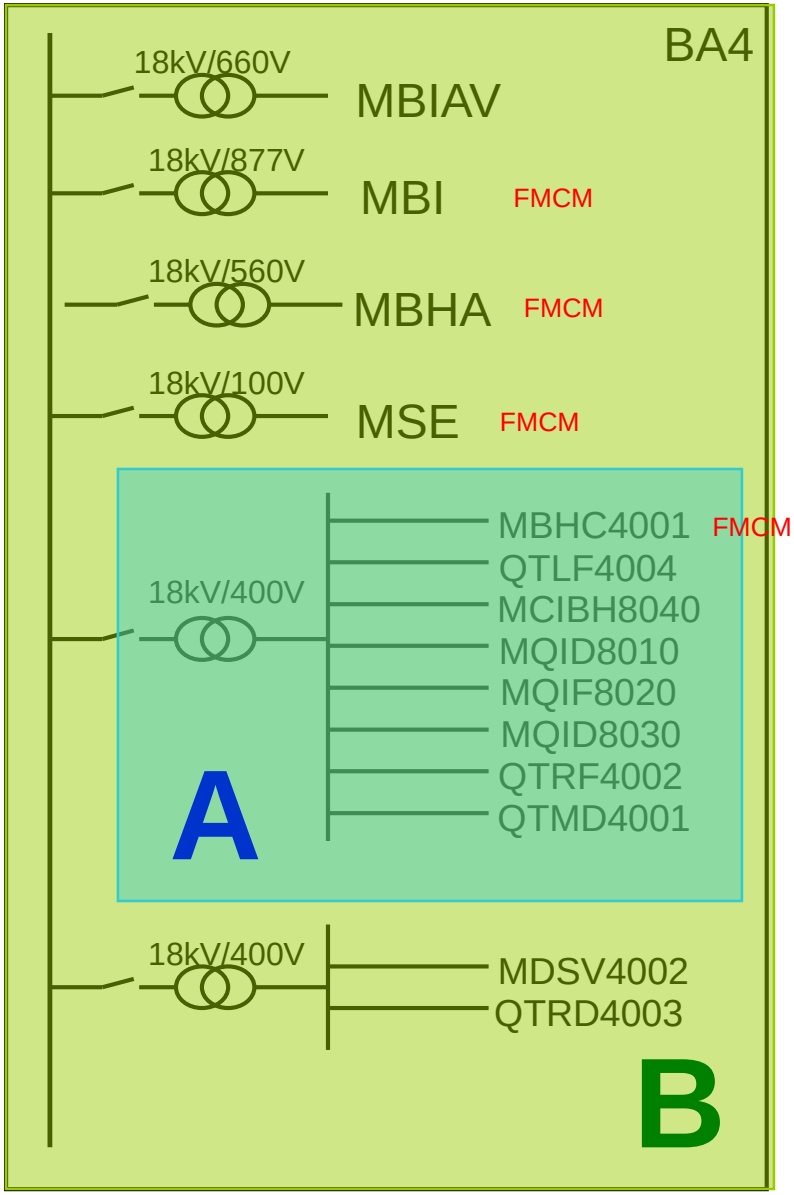
Conclusions

- Thyristor Power converters for n.c. magnets are particularly affected by mains disturbances, seem to be weakest element
  - Favorable, as FMCMs are connected to most of these converters



- Max. detection levels of FMCMs are a factor of 4 smaller (and a factor of 10 faster than) than current deviations that can occur after typical disturbances

Conclusions continued…



- Failures on the same or higher voltage levels (≥ 18kV) are seen by all underlying FMCMs
- Beams are dumped BEFORE the area defined as minimum immunity is left (and the power converter trips)
- Disturbances on transformers without an FMCM cannot be detected, rely on PC surveillance
- Still to be continued….
  - Correlation of FMCM triggers and major mains disturbances to be observed and further studied during commissioning and initial operation periods
  - Correlated failures
  - Other critical equipment ? (RF,…)

Major Events – Examples 2002

Major Events
(complete list)

Nr.	Datum	Uhrzeit	Ort	Art	Phase	Ursache	Dauer
1	24.06.2002	23:55	EDF 400 kV	dreiphasig	R S T	Sturm	90ms
2	06.09.2002	5:15	EDF 400 kV → Autotransfer 130 kV	dreiphasig	R S T	Powercut	
3	02.11.2003	7:16:26:640	EDF 400kV Bois Tollot-Genissiat	einphasig		Unbekannt	50ms
4	21.04.2003	13:45:58:050	EDF 400kV Bois Tollot-Verbois	einphasig		Unbekannt	60ms
5	22.04.2003	14:57 – 16:40	UPS bât. 513				1h43min
6	29.04.2003	21:50	BE (Trafo EHT1 + Compensator SVC1)	zweiphasig		Kurzschluss	150ms
7	16.05.2003		BEQ1	zweiphasig		Kurzschluss	
8	28.05.2003	19:57:22:820	EDF 400kV Chamosson-Bois Tollot	einphasig		Blitzeinschlag	70ms
9	13.06.2003	9:46	BB3			Not Aus	
10	13.06.2003	9:50 – 12:10	Pompes eau + AU BB3 (Wasserpumpen)				2h20min
11	03.07.2003	15:00	SD 18 (SE 18)				
12	14.07.2003	12:30 oder 12:48	Compensator BEQ1			Batterie in SPS zu alt → Ausfall	
13	15.07.2003 oder 16.07.2003	18:10 – 19:15	]o BA4 + BB4	einphasig		Fehler auf NS-Seite Trafo	1h05min
14	21.07.2003	5:50	EDF 400 kV	einphasig		Sturm	60ms
15	21.07.2003	5:51 – 6:15	EDF 400kV			Sturm	0h24min
16	21.07.2003	15:09 – 19:30	EDF 400kV			CERN Power cut	4h21min
17	23.07.2003	15:00 – 15:05	Onduleurs SD18 (Wechselrichter)				0h05min
18	27.07.2003	8:42	400kV Station Bois Tollot	einphasig		Erdfehler Fehlauslösung durch	