POCPA Workshop

Trieste, May 2008

Reliability of Static Var Compensators

Karsten KAHLE

CERN, Electric Power Distribution Group

ATC Meeting

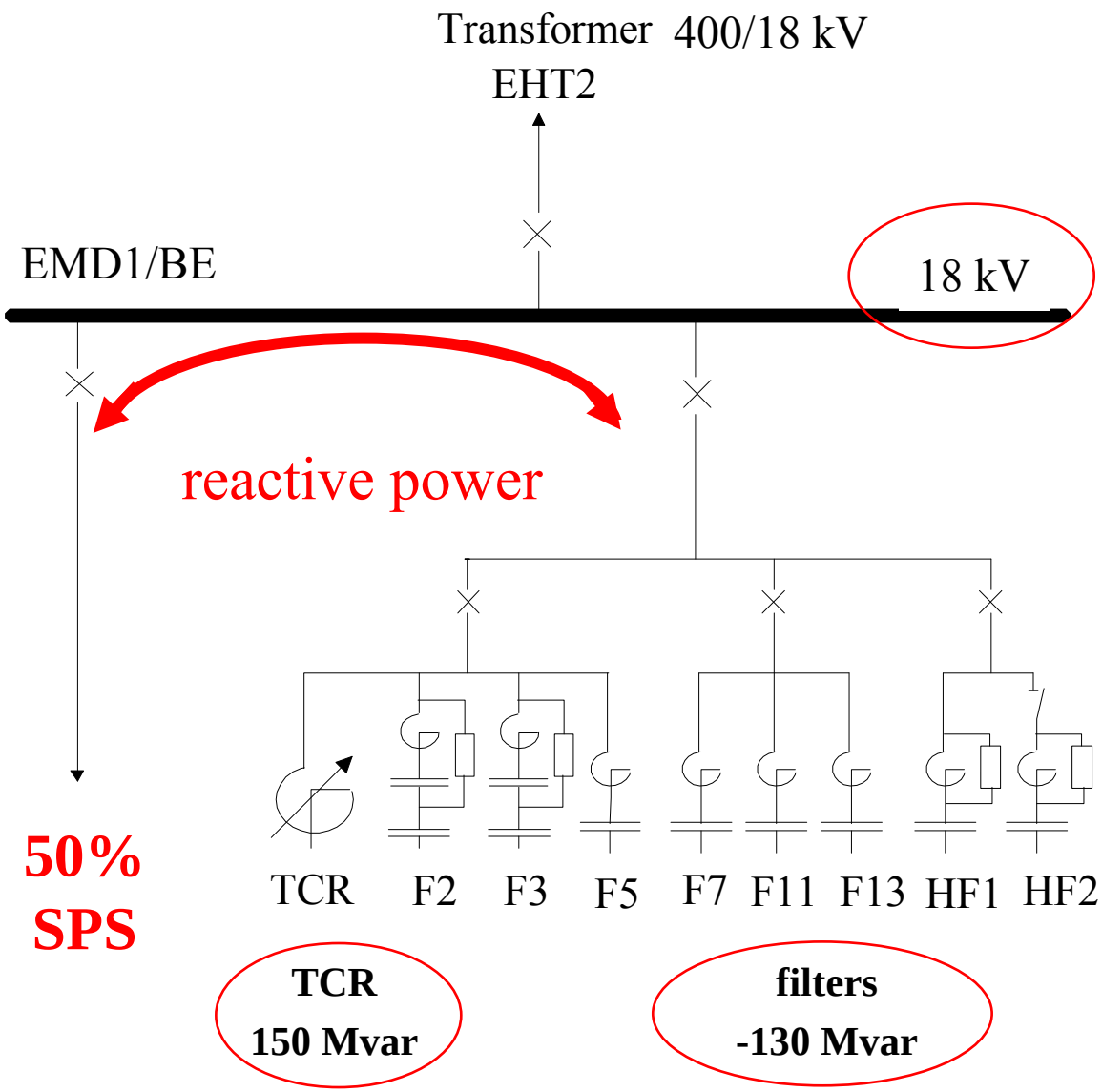
16 May 2008

The Static Var Compensators for SPS in 2008

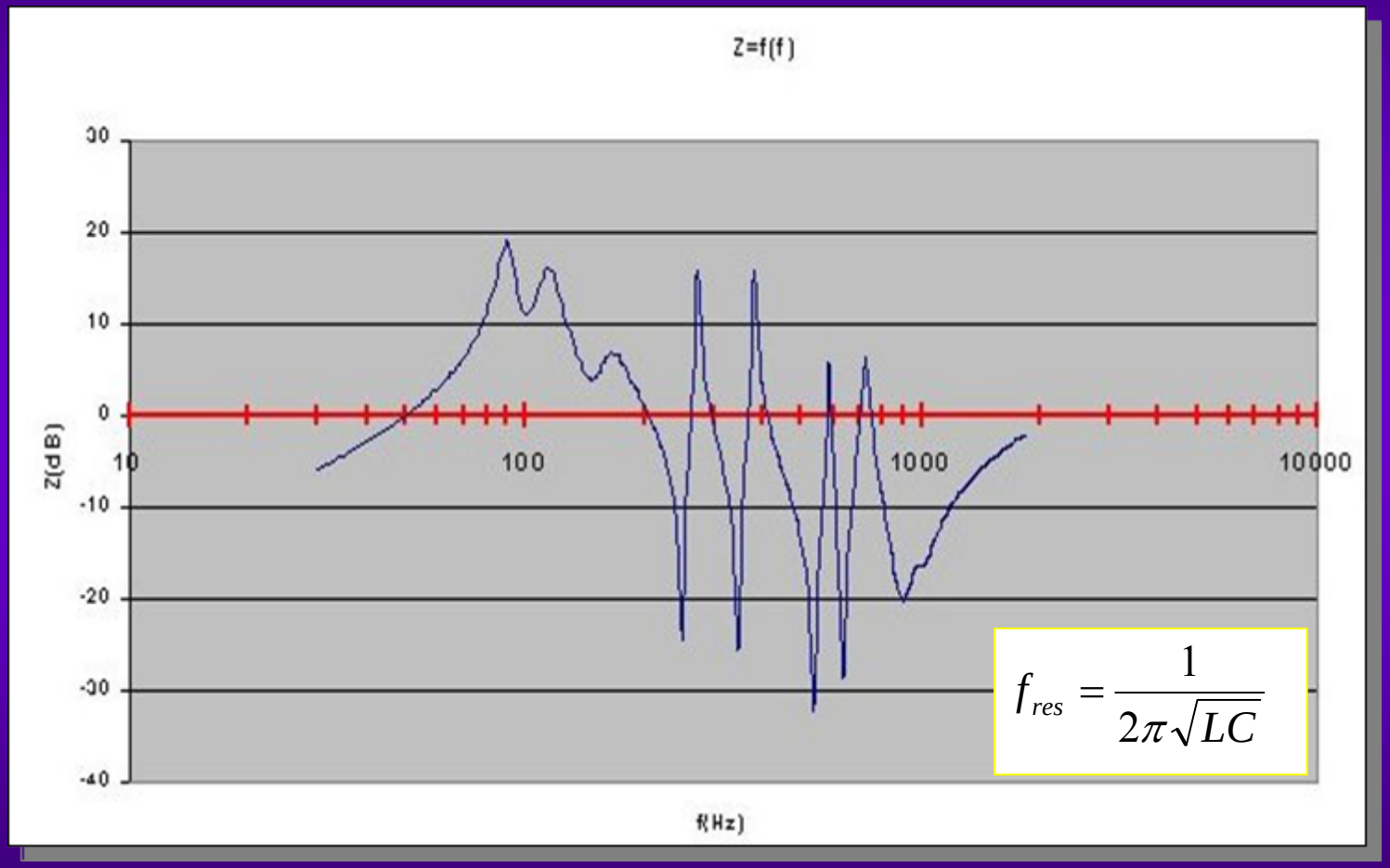
1. What is a Static Var Compensator (SVC)?
2. The electrical network for Super Proton Synchrontron (SPS)
3. Reliability studies for LHC electrical distribution network
4. Overview of SVC3 project
5. Reliable design and operation of Static Var Compensators
6. SVC3 performance measurements
7. Conclusions

What is a Static Var Compensator (SVC)?

Static Var Compensator SVC3 for SPS



Harmonic filter design



Impedance diagram Z = f (f)

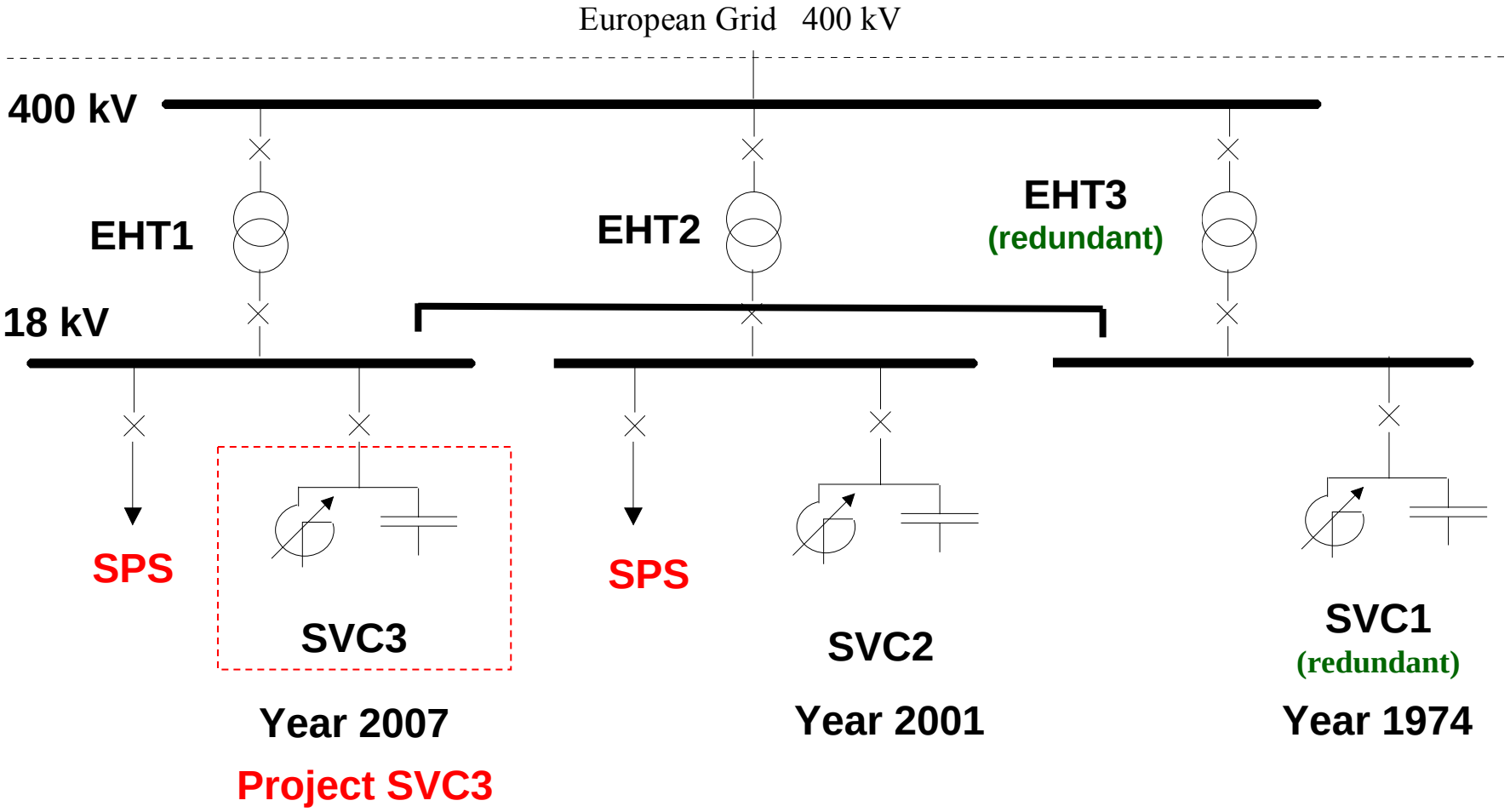
The performance of SPS Static Var Compensators

		without SVC	with SVC
reactive power compensat.	reactive power	70 Mvar	0…10 Mvar
harmonic filtering	THD(U) (18 kV)	20 %	0.75 %
voltage stabilization 18 kV	Δ U (18 kV)	- 14 %	± 0.5 % ± 1.5 % *1)

*1) for very fast transient changes (ramp-down)

The electrical network
for Super Proton Synchrontron (SPS)

Electrical Network for Super Proton Synchrotron (SPS)

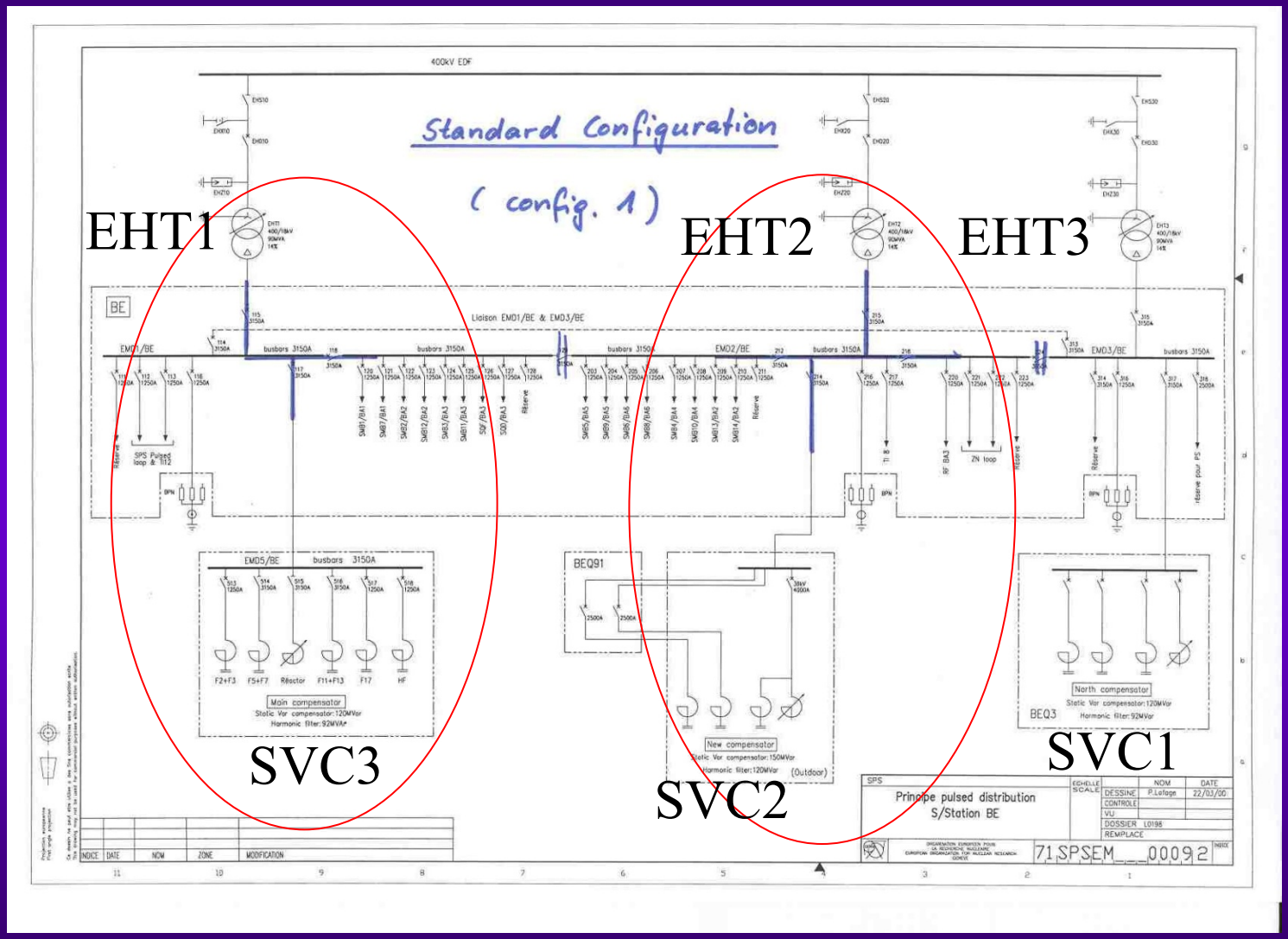


BE substation configurations (3 transformers, 3 SVC's)

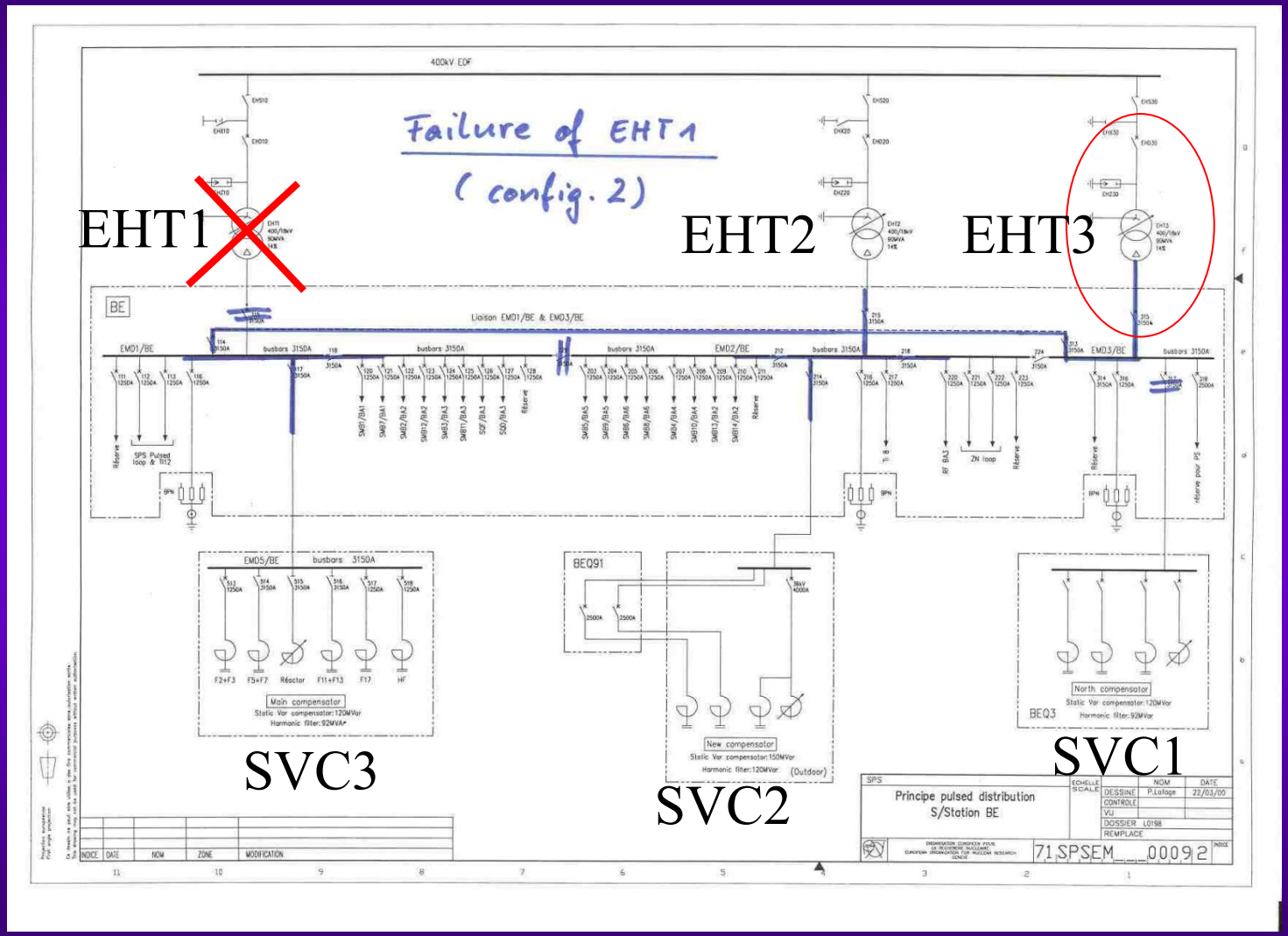
SPS continues operation in case of one failure:

Failure of transformer EHT1
or transformer EHT2
or SVC3
or SVC2

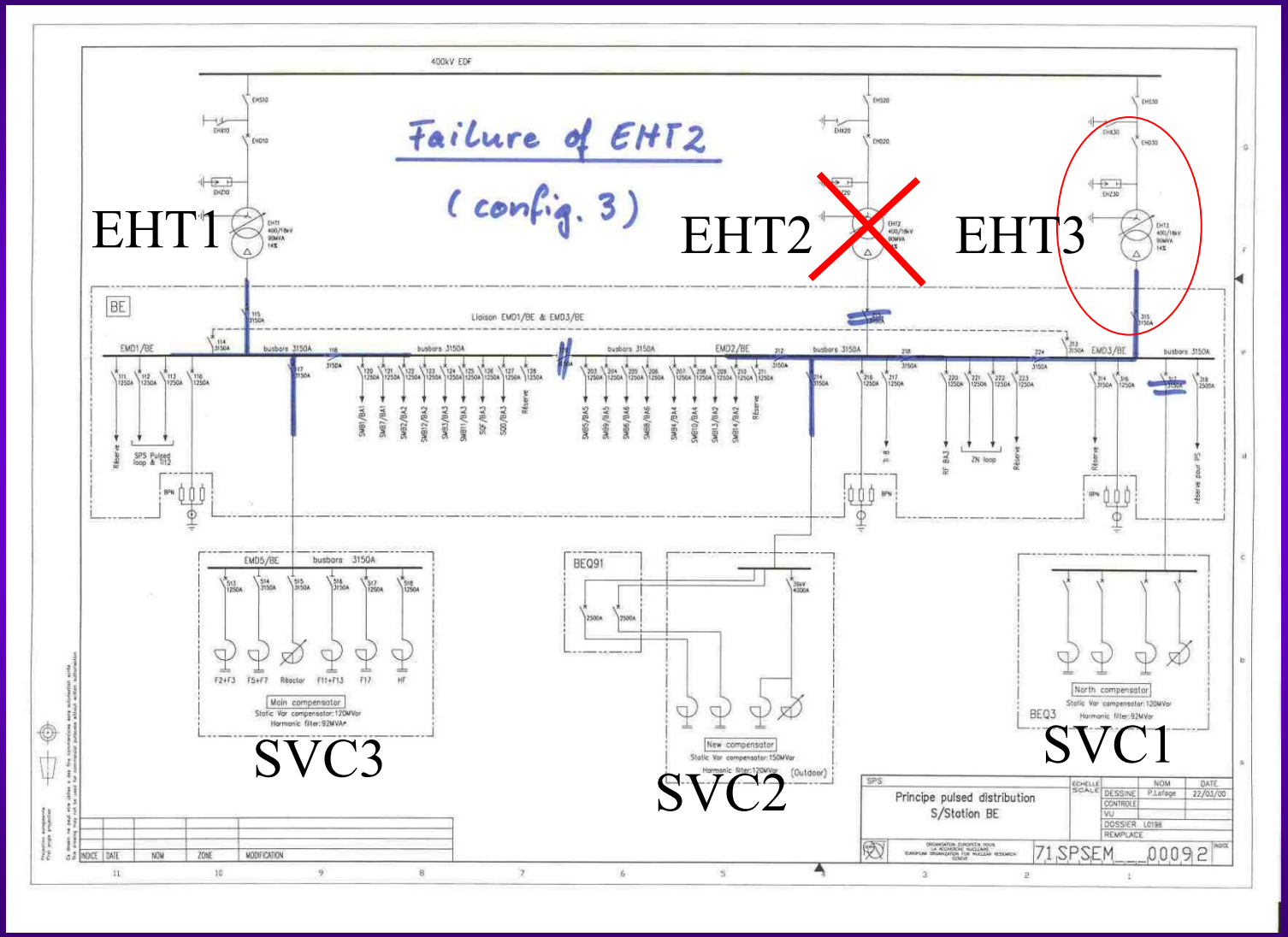
BE substation configurations



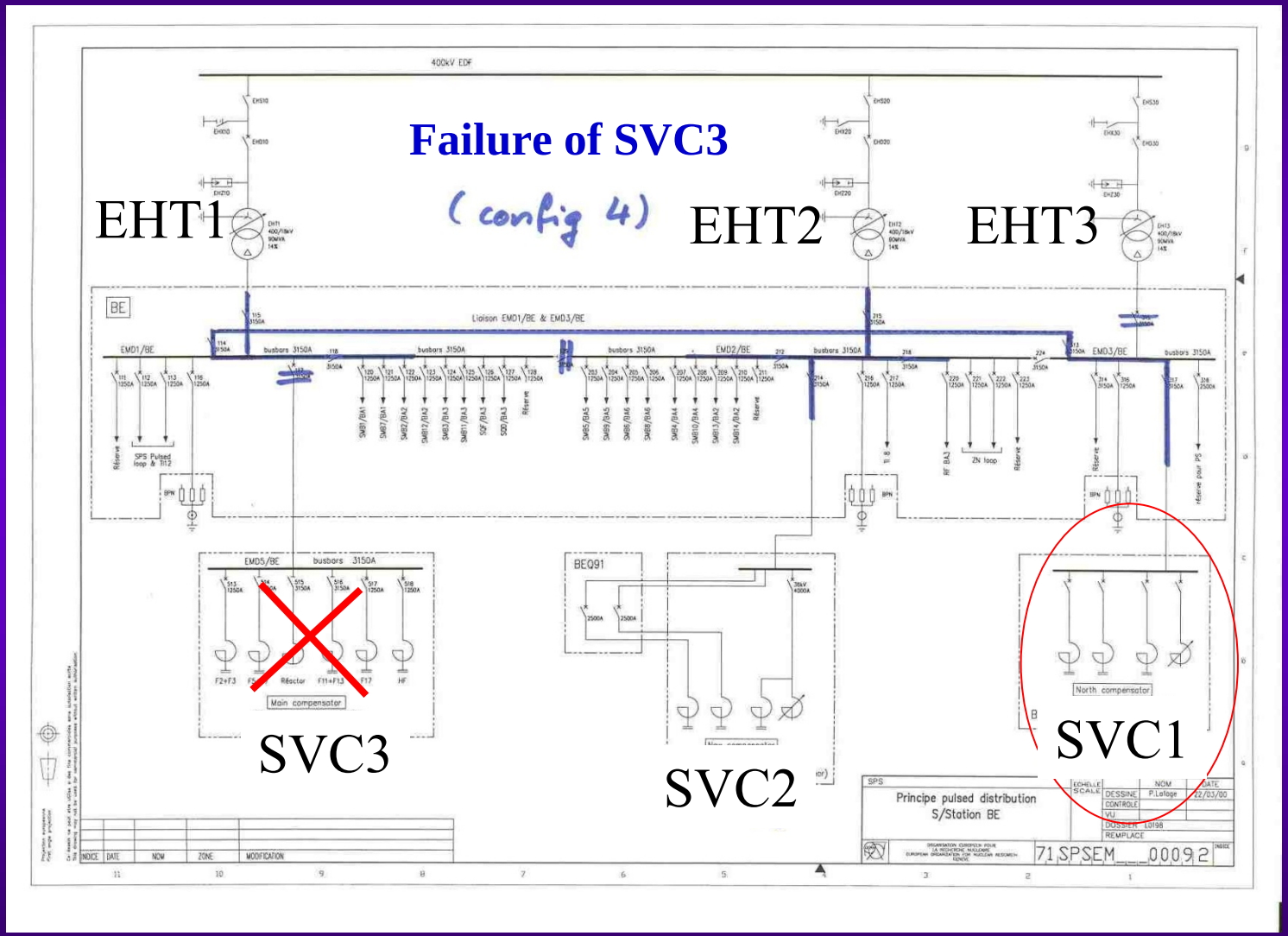
BE substation configurations



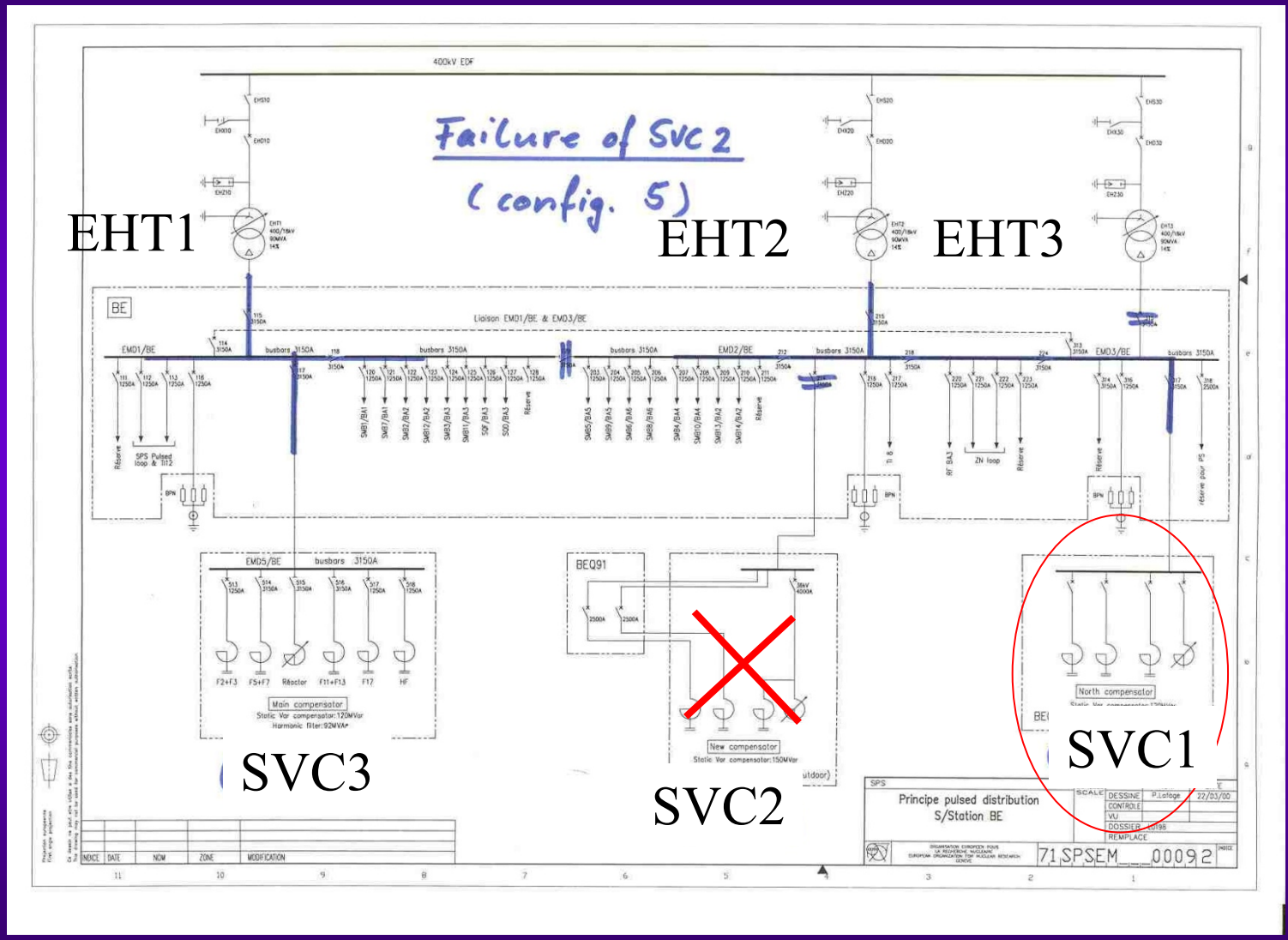
BE substation configurations



BE substation configurations



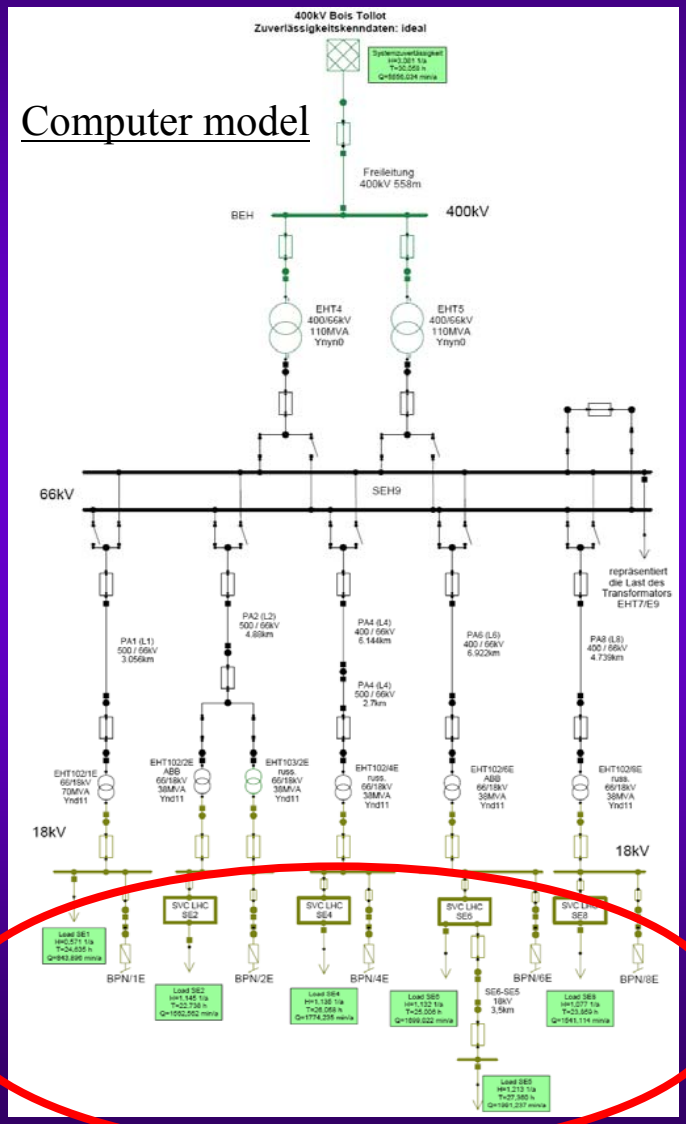
BE substation configurations

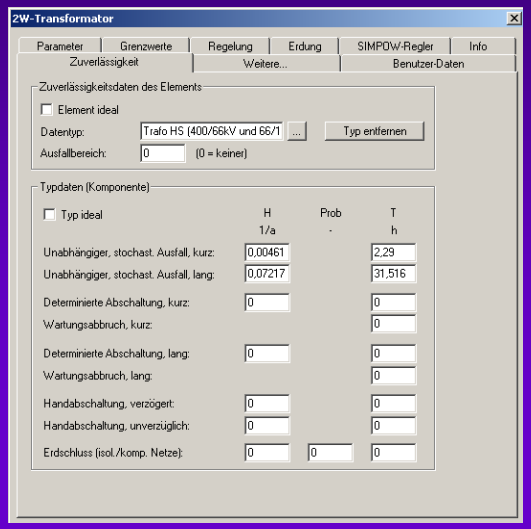


Reliability studies for electrical distribution system of Large Hadron Collider (LHC)

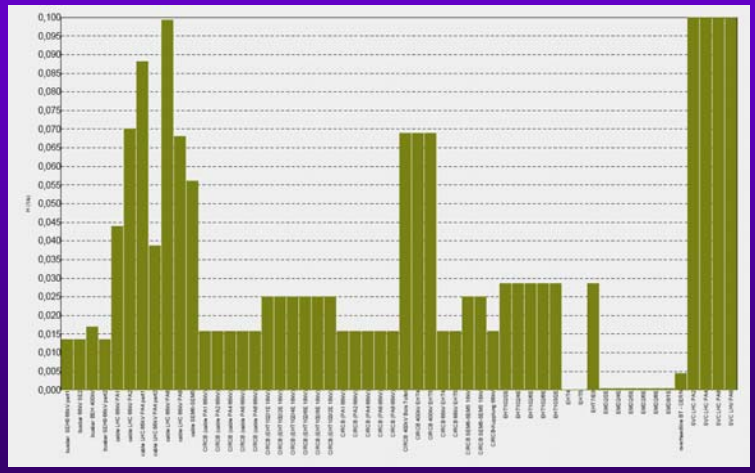
Reliability studies for LHC electrical distribution system

Computer model



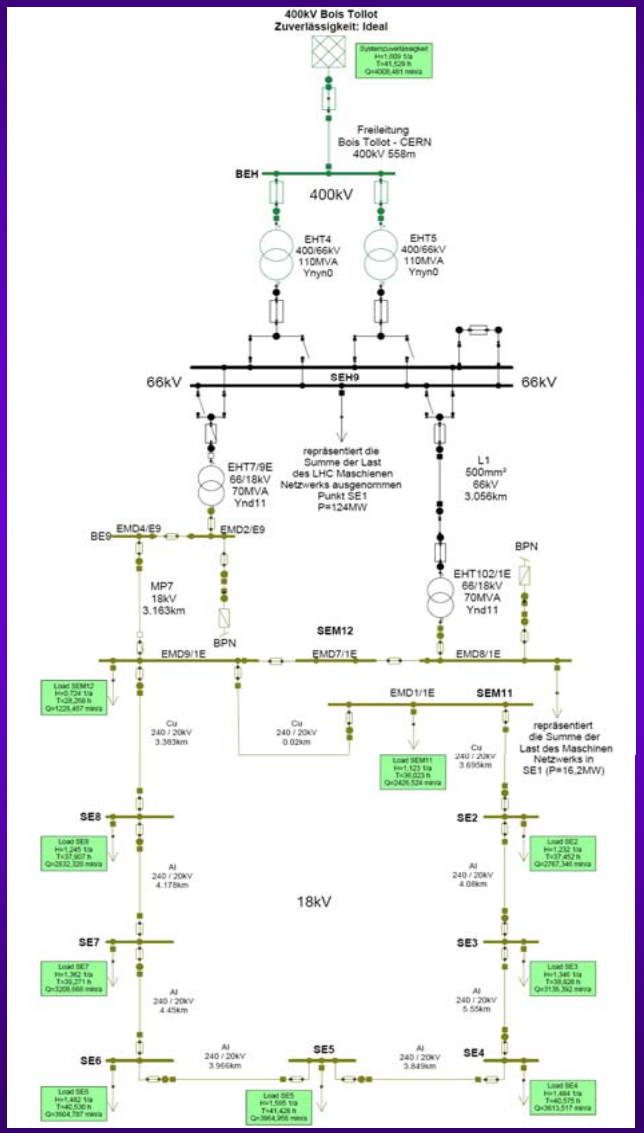


Input data for each component

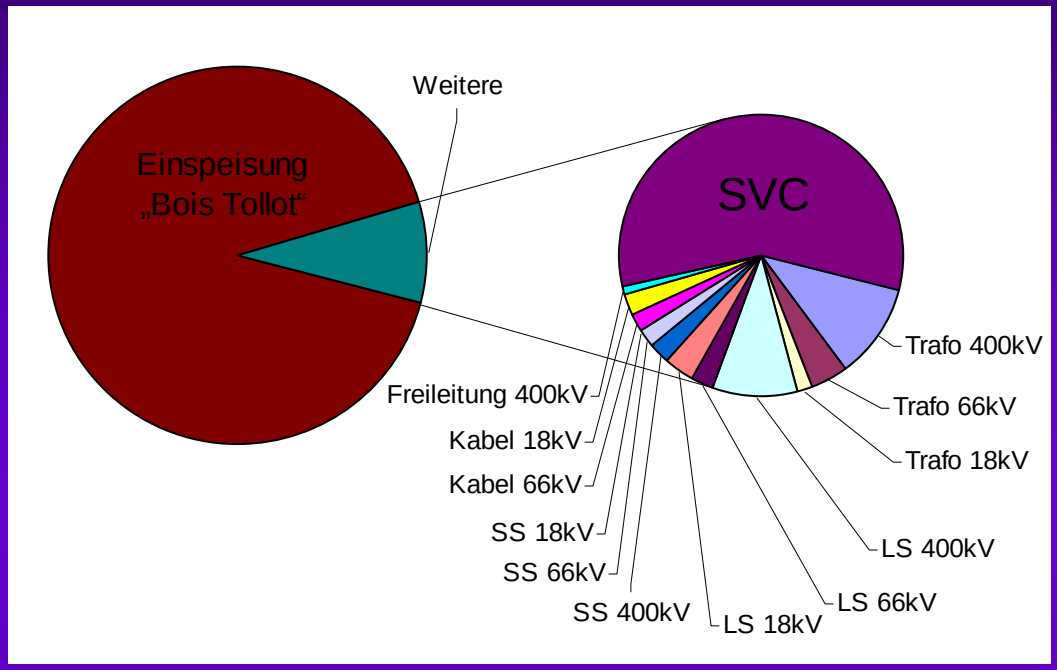


Quantification of reliability data (results)

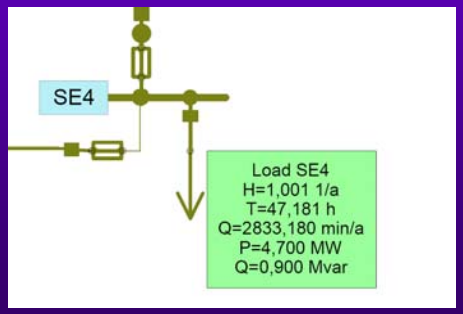
Reliability studies for LHC electrical distribution system



Computer model

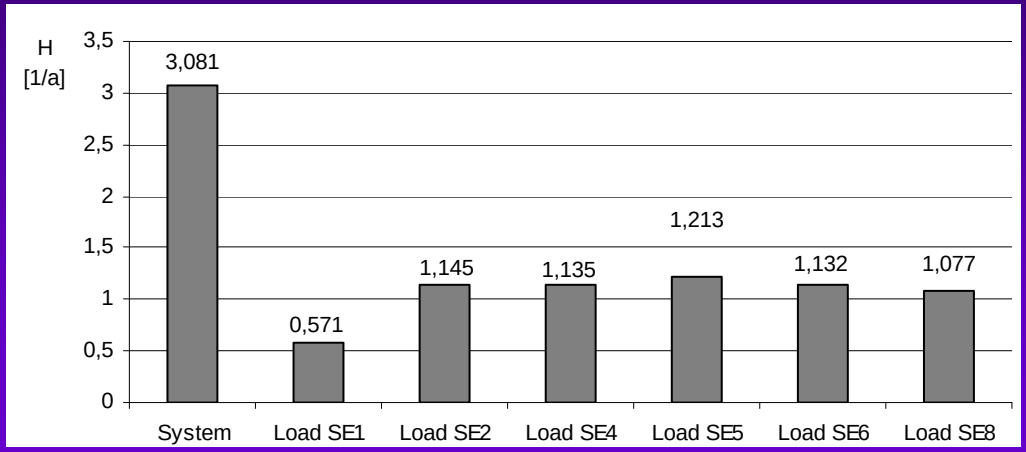


Calculated reliability data for each load

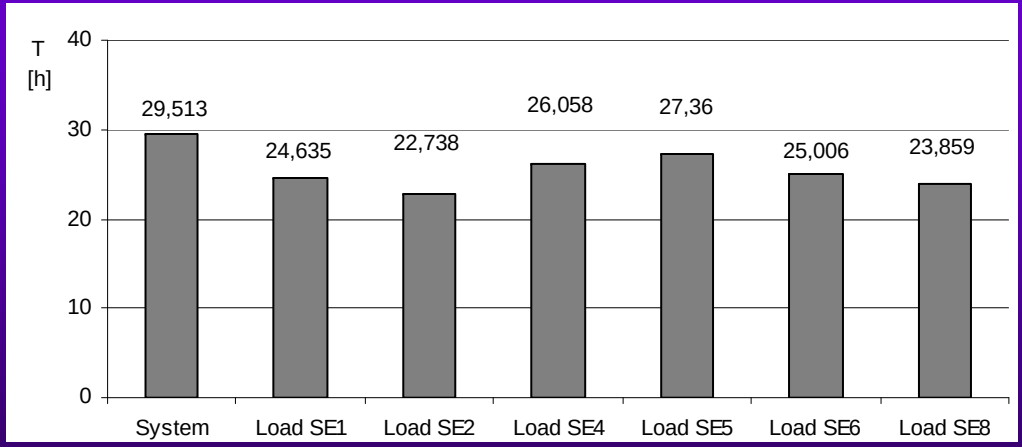


Calculated reliability data for each load

Reliability studies for LHC electrical distribution system



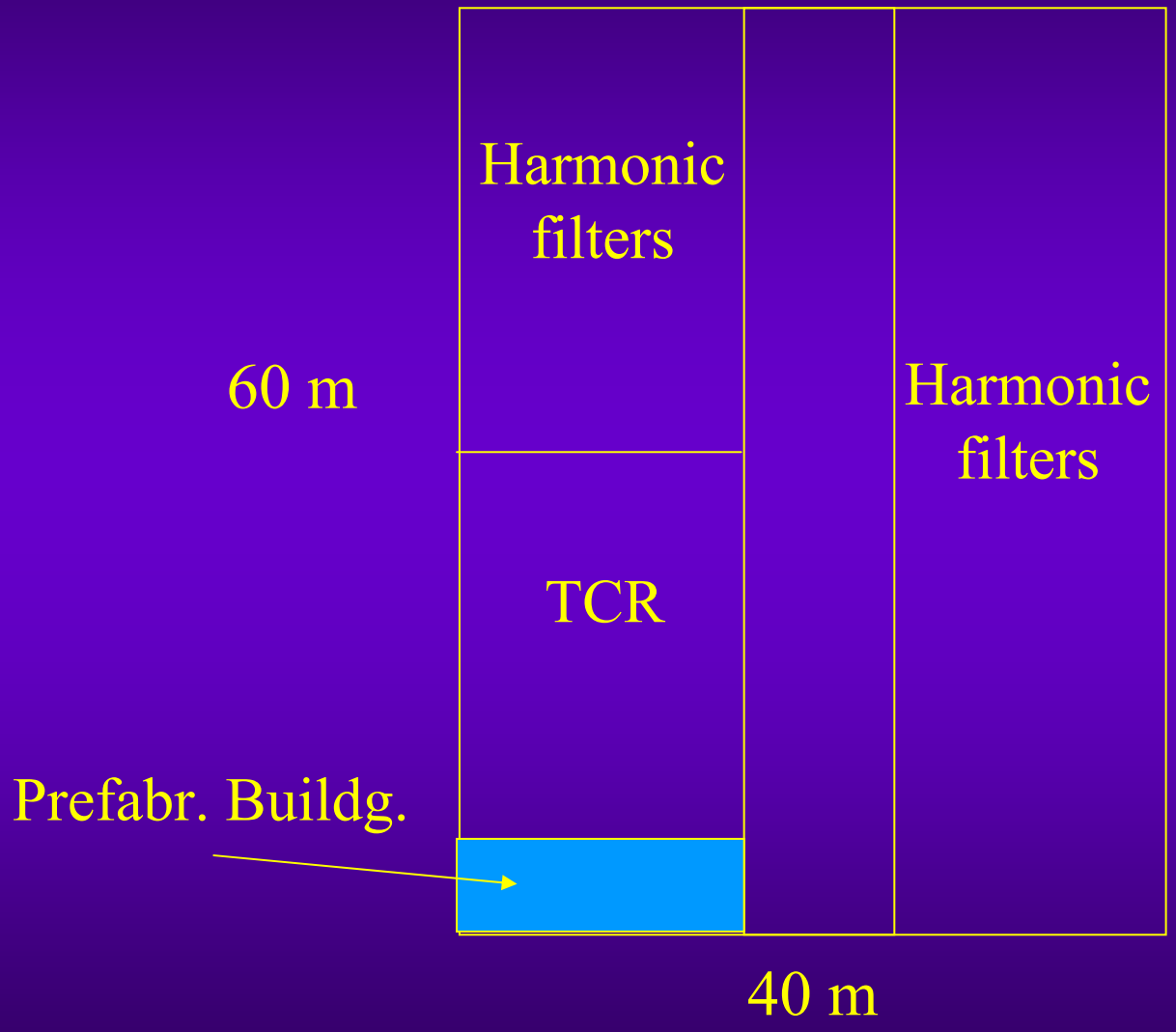
Probability of interrupted power



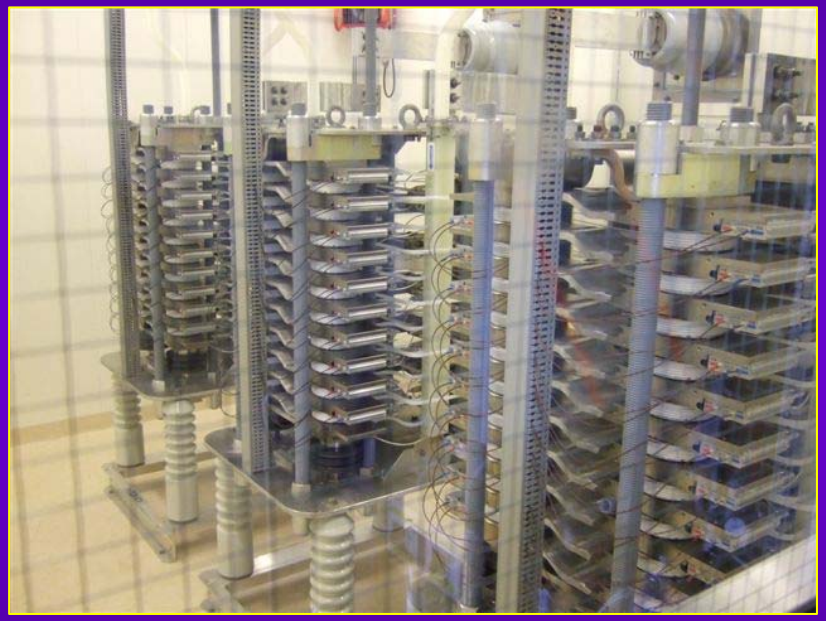
Statistical duration of each interruption

Overview of SVC3 project

Overview of SVC3 project



Overview of SVC3 project



Thyristor controlled reactors (TCR) and thyristor valve

Overview of SVC3 project

18 kV busbar system for TCR and 72 kV circuit breaker

Overview of SVC3 project

8 Harmonic filters in total

Overview of SVC3 project

18 kV outdoor installation
(attention to thermal expansion of bars!)

Reliable design and operation of Static Var Compensators

(example: SVC3 project)

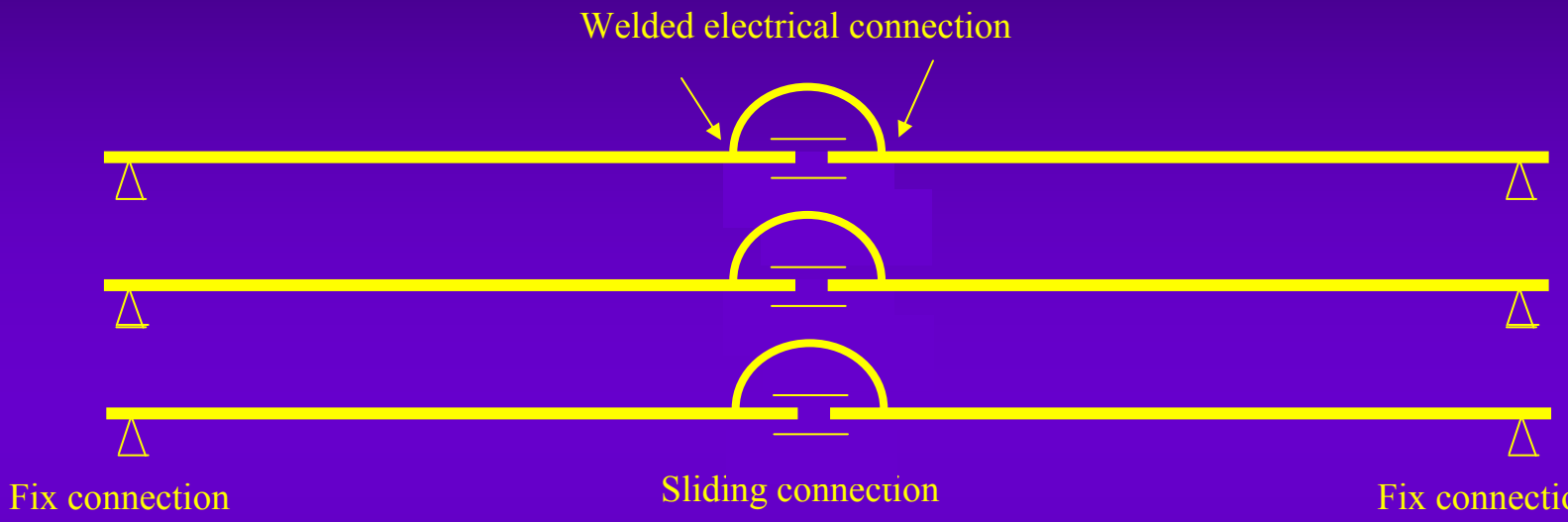
Reliability of auxiliary power

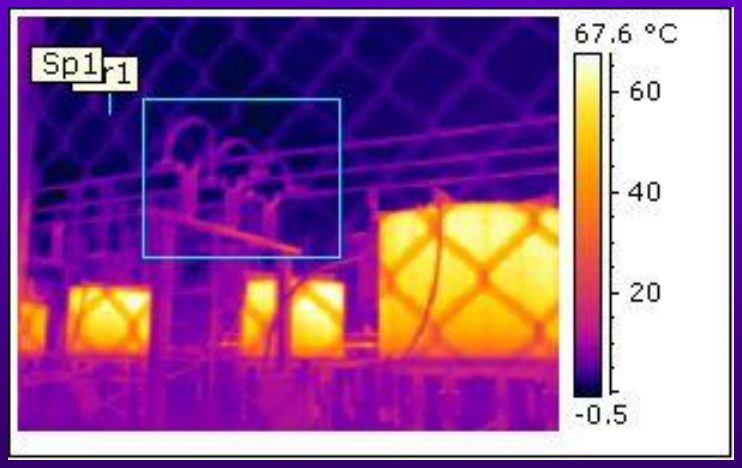
Auxiliary supply for 400kV station at CERN:
Two redundant systems with automatic coupling

Distribution chassis with two independent sources,
via diodes

For critical installations:
Two redundant sources of auxiliary power

Thermal expansion of busbars





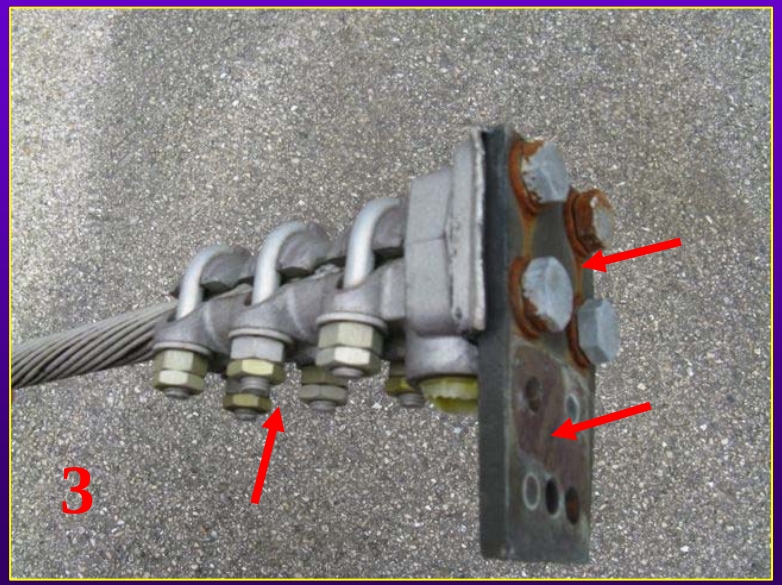
α coefficient (x 10^{-6}/K)

Copper:	17
Aluminium	23

Delta T: -25ºC -> +75ºC = 100 Kelvin
Length of busbar = 100 m
Thermal expansion of Al bars = 23 cm

Reliability of power connections (bad examples)

Connection of two conducting elements should ideally have only one connection point, max. two



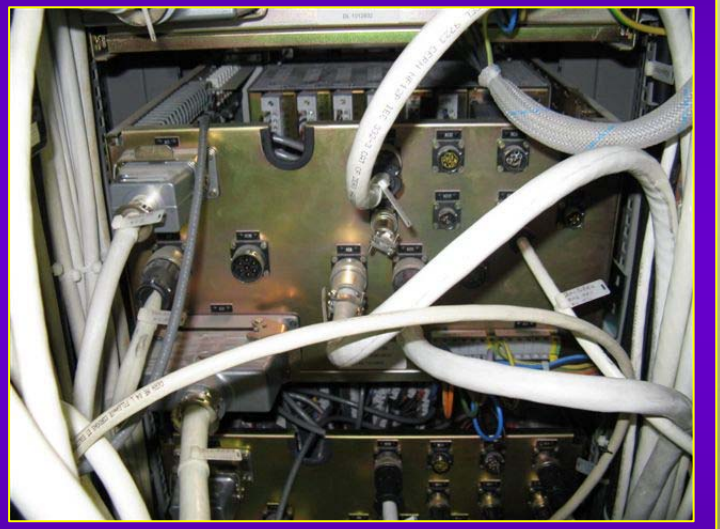
Reliability of power connections (good examples)

Redundancy and modular design for easy repair

- Two redundant computers (hot stand-by)
  * automatic switch-over without SVC trip

- One spare computer for each unit,
  * plug-in connections,
  * spare computers fully commissioned,
  * detailed instructions how to replace,
  * automatic start-up of new computers,
  * can be replaced by operator without computer knowledge (within 2 hours)

Reducing cabling errors by design



Example: protection relays:
- in factory: Chassis cabled and fully tested
- on site: standardised cabling connections via BURNDY connector
- time reduction for commissioning (time reduced by 50%)
- reduction of cabling errors (less than 1 error per 10 HV feeders found during commissioning

Auxiliary systems

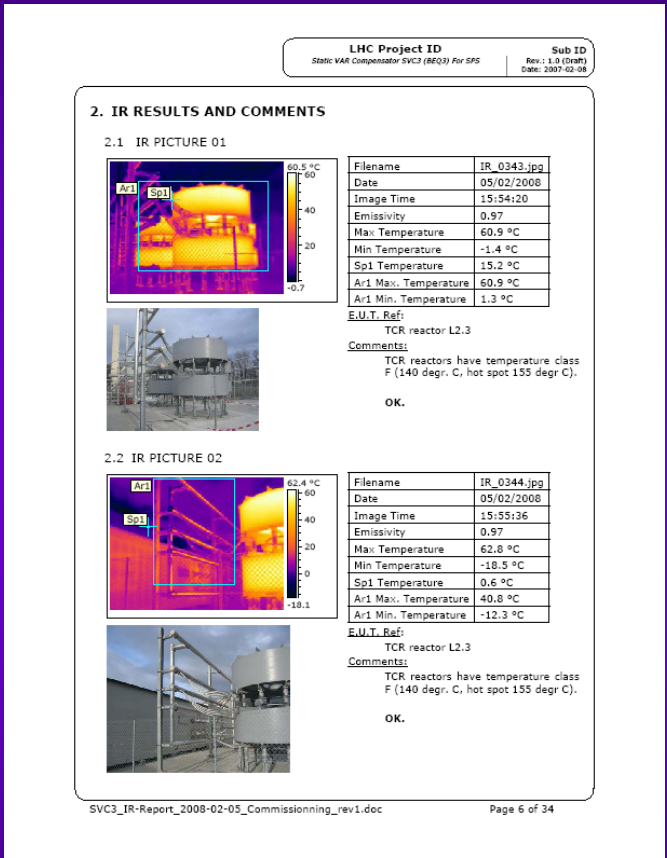
might strongly influence reliability

Example: Air-conditioning unit in SVC control room
(without A/C, temperature in control room rises above 40ºC and computers shut down)

Reliability of earthing connections

Example: earthing of fences
(attention to choice of materials!)

Infrared imaging and thermal optimisation



LHC Project ID
Static VAR Compensator SVC3 (BEQ3) For SPS
Sub ID
Rev.: 1.0 (Draft)
Date: 2007-02-08

2. IR RESULTS AND COMMENTS

2.1 IR PICTURE 01

Filename	IR_0343.jpg
Date	05/02/2008
Image Time	15:54:20
Emissivity	0.97
Max Temperature	60.9 °C
Min Temperature	-1.4 °C
Sp1 Temperature	15.2 °C
Ar1 Max. Temperature	60.9 °C
Ar1 Min. Temperature	1.3 °C

E.U.T. Ref:
TCR reactor L2.3
Comments:
TCR reactors have temperature class F (140 degr. C, hot spot 155 degr C).

OK.

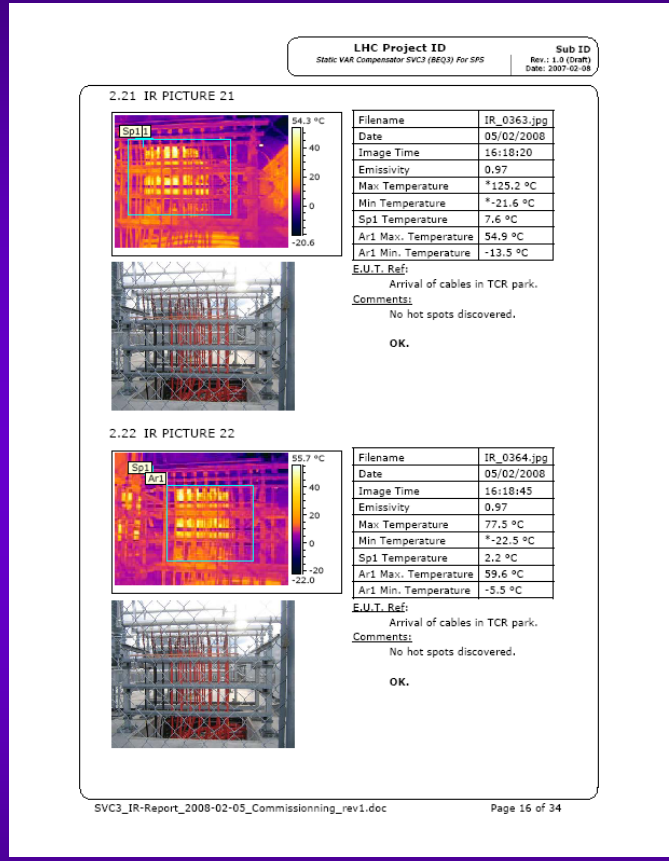
2.2 IR PICTURE 02

Filename	IR_0344.jpg
Date	05/02/2008
Image Time	15:55:36
Emissivity	0.97
Max Temperature	62.8 °C
Min Temperature	-18.5 °C
Sp1 Temperature	0.6 °C
Ar1 Max. Temperature	40.8 °C
Ar1 Min. Temperature	-12.3 °C

E.U.T. Ref:
TCR reactor L2.3
Comments:
TCR reactors have temperature class F (140 degr. C, hot spot 155 degr C).

OK.

SVC3_IR-Report_2008-02-05_Commissionning_rev1.doc Page 6 of 34



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Sub ID
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Date: 2007-02-08

2.21 IR PICTURE 21

Filename	IR_0363.jpg
Date	05/02/2008
Image Time	16:18:20
Emissivity	0.97
Max Temperature	*125.2 °C
Min Temperature	*-21.6 °C
Sp1 Temperature	7.6 °C
Ar1 Max. Temperature	54.9 °C
Ar1 Min. Temperature	-13.5 °C

E.U.T. Ref:
Arrival of cables in TCR park.
Comments:
No hot spots discovered.

OK.

2.22 IR PICTURE 22

Filename	IR_0364.jpg
Date	05/02/2008
Image Time	16:18:45
Emissivity	0.97
Max Temperature	77.5 °C
Min Temperature	*-22.5 °C
Sp1 Temperature	2.2 °C
Ar1 Max. Temperature	59.6 °C
Ar1 Min. Temperature	-5.5 °C

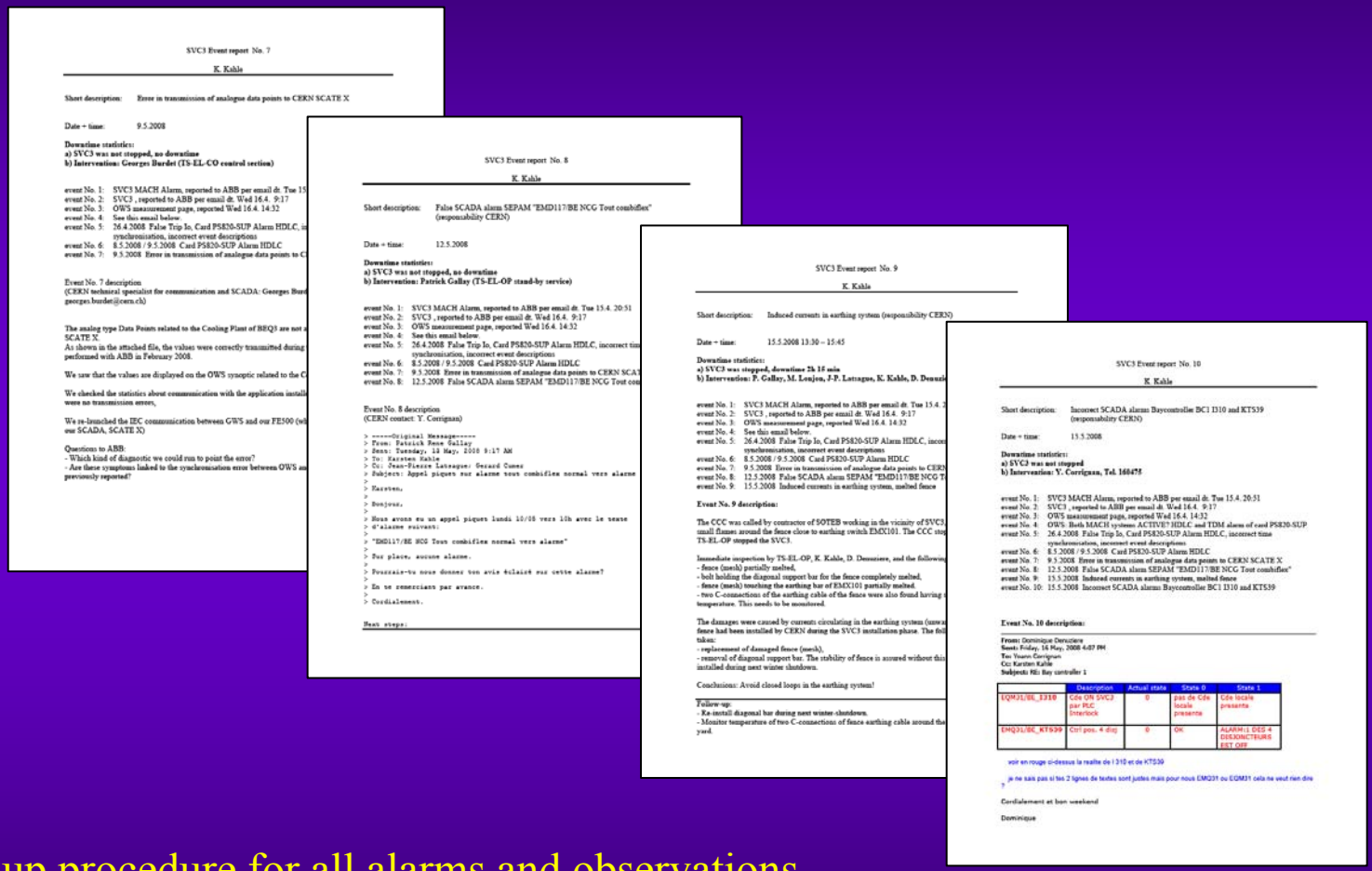
E.U.T. Ref:
Arrival of cables in TCR park.
Comments:
No hot spots discovered.

OK.

SVC3_IR-Report_2008-02-05_Commissionning_rev1.doc Page 16 of 34

IR imaging is part of the preventive maintenance programme

Reliability and operation of HV installations



SVC3 Event report No. 7

K. Kahle

Short description: Erreur in transmission of analogue data points to CERN SCATE X

Date + time: 9.5.2008

Downtime statistics:
a) SVC3 was not stopped, no downtime
b) Intervention: Georges Burdet (TS-EL-CO control section)

event No. 1: SVC3 MACH Alarm, reported to ABB per email dt. Tue 15
event No. 2: SVC3 , reported to ABB per email dt. Wed 16.4. 9:17
event No. 3: OWS measurement page, reported Wed 16.4. 14:32
event No. 4: See this email below.
event No. 5: 26.4.2008 False Trip Io, Card PS820-SUP Alarm HDLC, i
synchronisation, incorrect event descriptions
event No. 6: 8.5.2008 / 9.5.2008 Card PS820-SUP Alarm HDLC
event No. 7: 9.5.2008 Error in transmission of analogue data points to C

Event No. 7 description
(CERN technical specialist for communication and SCADA: Georges Burd
georges.burdet@cern.ch)

The analog type Data Points related to the Cooling Plant of BEQ3 are not
SCATE X.
As shown in the attached file, the values were correctly transmitted during
performed with ABB in February 2008.

We saw that the values are displayed on the OWS synoptic related to the C

We checked the statistics about communication with the application install
were no transmission errors,

We re-launched the IEC communication between GWS and our FE500 (wh
our SCADA, SCATE X)

Questions to ABB:
- Which kind of diagnostic we could run to point the error?
- Are these symptoms linked to the synchronisation error between OWS an
previously reported?

SVC3 Event report No. 8

K. Kahle

Short description: False SCADA alarm SEPAM "EMD117/BE NCG Tout combiflex" (responsability CERN)

Date + time: 12.5.2008

Downtime statistics:
a) SVC3 was not stopped, no downtime
b) Intervention: Patrick Gallay (TS-EL-OP stand-by service)

event No. 1: SVC3 MACH Alarm, reported to ABB per email dt. Tue 15.4. 20:51
event No. 2: SVC3 , reported to ABB per email dt. Wed 16.4. 9:17
event No. 3: OWS measurement page, reported Wed 16.4. 14:32
event No. 4: See this email below.
event No. 5: 26.4.2008 False Trip Io, Card PS820-SUP Alarm HDLC, incorrect tim
synchronisation, incorrect event descriptions
event No. 6: 8.5.2008 / 9.5.2008 Card PS820-SUP Alarm HDLC
event No. 7: 9.5.2008 Error in transmission of analogue data points to CERN SCAT
event No. 8: 12.5.2008 False SCADA alarm SEPAM "EMD117/BE NCG Tout com

Event No. 8 description
(CERN contact: Y. Corrignan)

> -----Original Message-----
> From: Patrick Rene Gallay
> Sent: Tuesday, 13 May, 2008 9:17 AM
> To: Karsten Kahle
> Cc: Jean-Pierre Latsague; Gerard Cuneo
> Subject: Appel piquet sur alarme tout combiflex normal vers alarme
>
> Karsten,
>
> Bonjour,
>
> Nous avons eu un appel piquet lundi 10/05 vers 10h avec le texte
> d'alarme suivant:
>
> "EMD117/BE NCG Tout combiflex normal vers alarme"
>
> Pas plaie, aucune alarme.
>
> Pourrais-tu nous donner ton avis éclairé sur cette alarme?
>
> En te remerciant par avance.
>
> Cordialement.

Next steps:

SVC3 Event report No. 9

K. Kahle

Short description: Induced currents in earthing system (responsibility CERN)

Date + time: 15.5.2008 13:30 – 15:45

Downtime statistics:
a) SVC3 was stopped, downtime 2h 15 min
b) Intervention: P. Gallay, M. Loujon, J-P. Latsague, K. Kahle, D. Deuzie

event No. 1: SVC3 MACH Alarm, reported to ABB per email dt. Tue 15.4. 2
event No. 2: SVC3 , reported to ABB per email dt. Wed 16.4. 9:17
event No. 3: OWS measurement page, reported Wed 16.4. 14:32
event No. 4: See this email below.
event No. 5: 26.4.2008 False Trip Io, Card PS820-SUP Alarm HDLC, incor
synchronisation, incorrect event descriptions
event No. 6: 8.5.2008 / 9.5.2008 Card PS820-SUP Alarm HDLC
event No. 7: 9.5.2008 Error in transmission of analogue data points to CERN
event No. 8: 12.5.2008 False SCADA alarm SEPAM "EMD117/BE NCG T
event No. 9: 15.5.2008 Induced currents in earthing system, melted fence

Event No. 9 description:

The CCC was called by contractor of SOTEB working in the vicinity of SVC3.
small flames around the fence close to earthing switch EMX101. The CCC sto
TS-EL-OP stopped the SVC3.

Immediate inspection by TS-EL-OP, K. Kahle, D. Deuzieve, and the followin
- fence (mesh) partially melted,
- bolt holding the diagonal support bar for the fence completely melted,
- fence (mesh) touching the earthing bar of EMX101 partially melted.
- two C-connections of the earthing cable of the fence were also found having
temperature. This needs to be monitored.

The damages were caused by currents circulating in the earthing system (unwa
fence had been installed by CERN during the SVC3 installation phase. The foll
taken:
- replacement of damaged fence (mesh),
- removal of diagonal support bar. The stability of fence is assured without this
installed during next winter shutdown.

Conclusions: Avoid closed loops in the earthing system!

Follow-up:
- Re-install diagonal bar during next winter-shutdown.
- Monitor temperature of two C-connections of fence earthing cable around the
yard.

SVC3 Event report No. 10

K. Kahle

Short description: Incorrect SCADA alarm Baycontroller BC1 I310 and KT539 (responsability CERN)

Date + time: 15.5.2008

Downtime statistics:
a) SVC3 was not stopped
b) Intervention: Y. Corrignan, Tel. 160475

event No. 1: SVC3 MACH Alarm, reported to ABB per email dt. Tue 15.4. 20:51
event No. 2: SVC3 , reported to ABB per email dt. Wed 16.4. 9:17
event No. 3: OWS measurement page, reported Wed 16.4. 14:32
event No. 4: OWS: Both MACH systems ACTIVE? HDLC and TDM alarm of card PS820-SUP
event No. 5: 26.4.2008 False Trip Io, Card PS820-SUP Alarm HDLC, incorrect time
synchronisation, incorrect event descriptions
event No. 6: 8.5.2008 / 9.5.2008 Card PS820-SUP Alarm HDLC
event No. 7: 9.5.2008 Error in transmission of analogue data points to CERN SCATE X
event No. 8: 12.5.2008 False SCADA alarm SEPAM "EMD117/BE NCG Tout combiflex"
event No. 9: 13.5.2008 Induced currents in earthing system, melted fence
event No. 10: 15.5.2008 Incorrect SCADA alarm Baycontroller BC1 I310 and KT539

Event No. 10 description:

From: Dominique Deruelere
Sent: Friday, 16 May, 2008 4:07 PM
To: Yoann Corrignan
Cc: Karsten Kahle
Subject: RE: Bay controller 1

	Description	Actual state	State 0	State 1
EQM31/BE_I310	Cde ON SVC3 par PLC Interlock	0	pas de Cde locale presente	Cde locale presente
EMQ31/BE_KT539	Ctrl pos. 4 disj	0	OK	ALARM:1 DES 4 DISJONCTEURS EST OFF

voir en rouge ci-dessus la realite de I 310 et de KT539

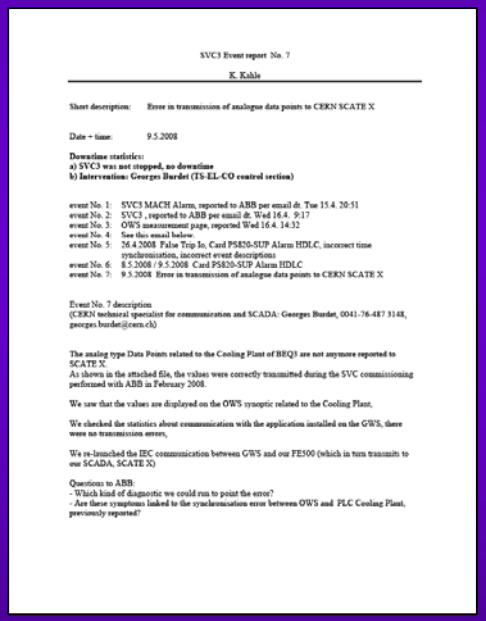
je ne sais pas si les 2 lignes de textes sont justes mais pour nous EMQ31 ou EQM31 cela ne veut rien dire ?

Cordialement et bon weekend

Dominique

Follow-up procedure for all alarms and observations

Reliability and operation of HV installations: The human factor



SVC3 Event report No. 7

K. Kahle

Short description: Error in transmission of analogue data points to CERN SCATE X

Date + time: 9.5.2008

Downtime statistics:
a) SVC3 was not stopped, no downtime
b) Intervention: Georges Burdet (TS-EL-CO control section)

event No. 1: SVC3 MACH Alarm, reported to ABB per email dt. Tue 15.4. 20:51
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event No. 6: 8.5.2008 / 9.5.2008 Card PS820-SUP Alarm HDLC
event No. 7: 9.5.2008 Error in transmission of analogue data points to CERN SCATE X

Event No. 7 description
(CERN technical specialist for communication and SCADA: Georges Burdet, 0041-76-487 3148, georges.burdet@cern.ch)

The analog type Data Points related to the Cooling Plant of BEQ3 are not anymore reported to SCATE X.
As shown in the attached file, the values were correctly transmitted during the SVC commissioning performed with ABB in February 2008.

We saw that the values are displayed on the OWS synoptic related to the Cooling Plant.

We checked the statistics about communication with the application installed on the GWS, there were no transmission errors.

We re-launched the IEC communication between GWS and our FE500 (which in turn transmits to our SCADA, SCATE X)

Questions to ABB:
- Which kind of diagnostic we could run to point the error?
- Are these symptoms linked to the synchronisation error between OWS and PLC Cooling Plant, previously reported?

Clear instructions for:
- operation,
- fault finding and corrective maintenance,
- preventive maintenance

Training of operators

Systematic follow-up of all alarms and observations

Keep detailed statistics of downtime and failure causes!

Spare parts management

- Define spare parts policy,
- example: spares management of CERN's Power Converter Group (F. Bordry),
- bar code identification for each item in stock and central data base,
- maintenance of spares in stock
- technical data sheets,
- re-test spares, if necessary,
- keep inventory up-to-date, replace spares when used.

Example of overheating

due to induced currents in a closed earthing circuit

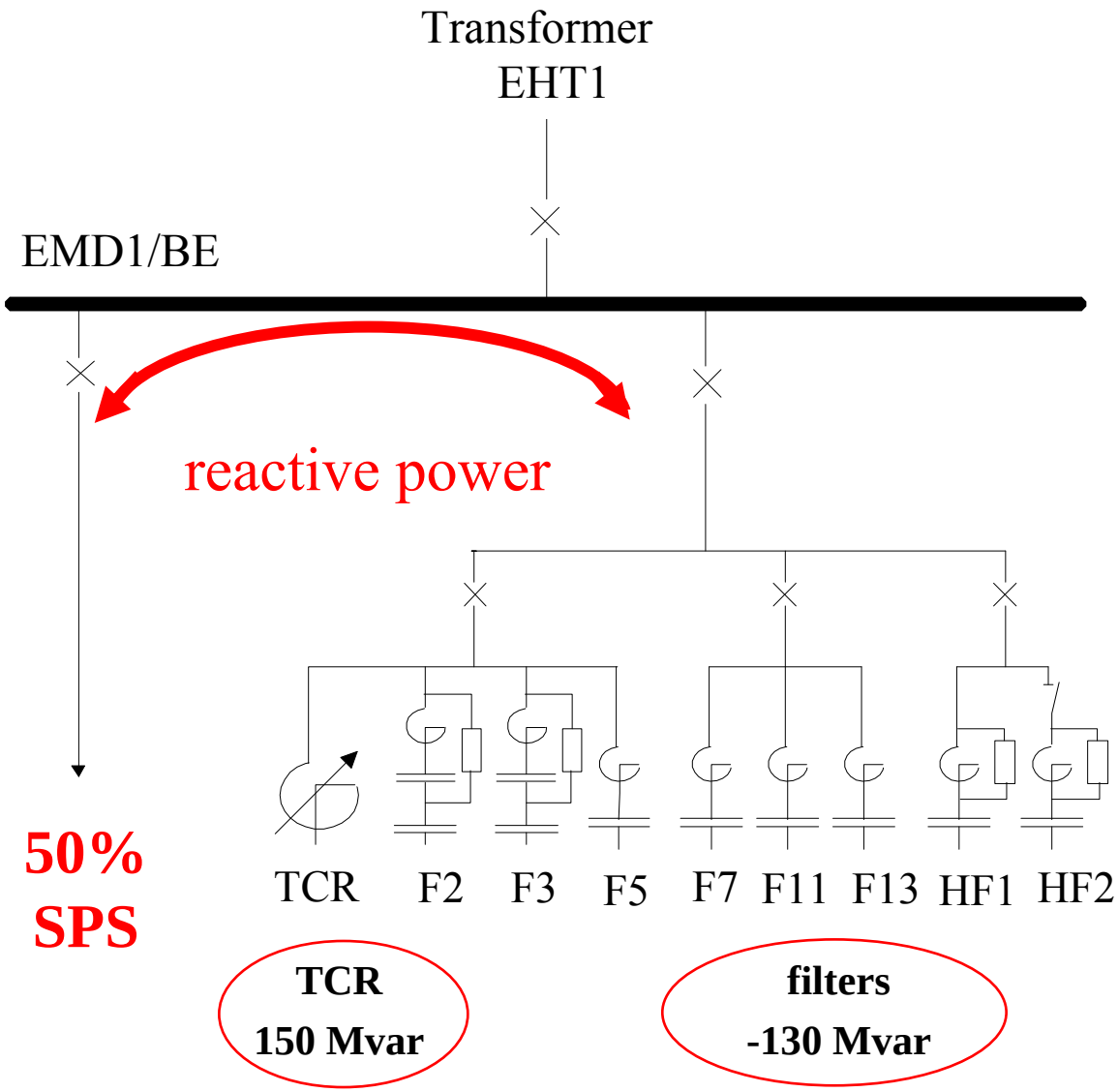
Burned fence

Melted bolt M10

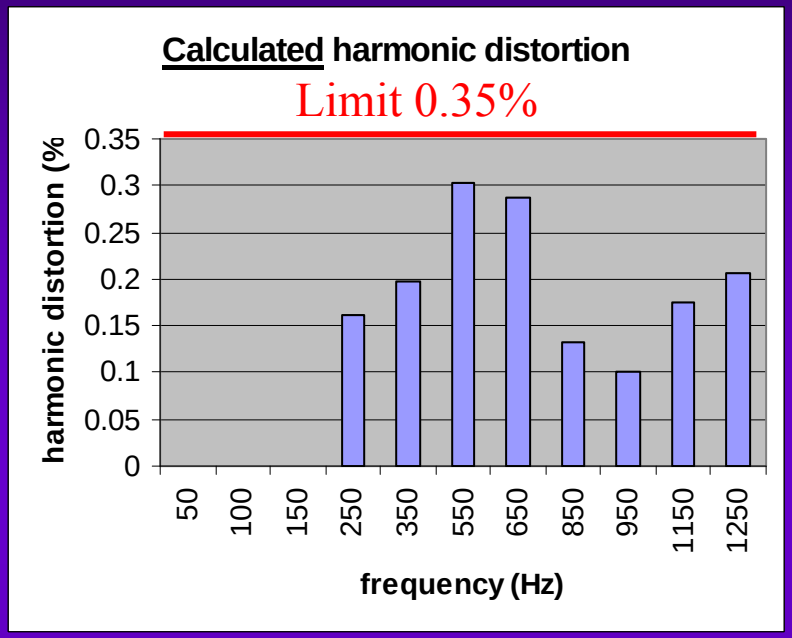
Cause:
unwanted interconnection
of two earthing circuits

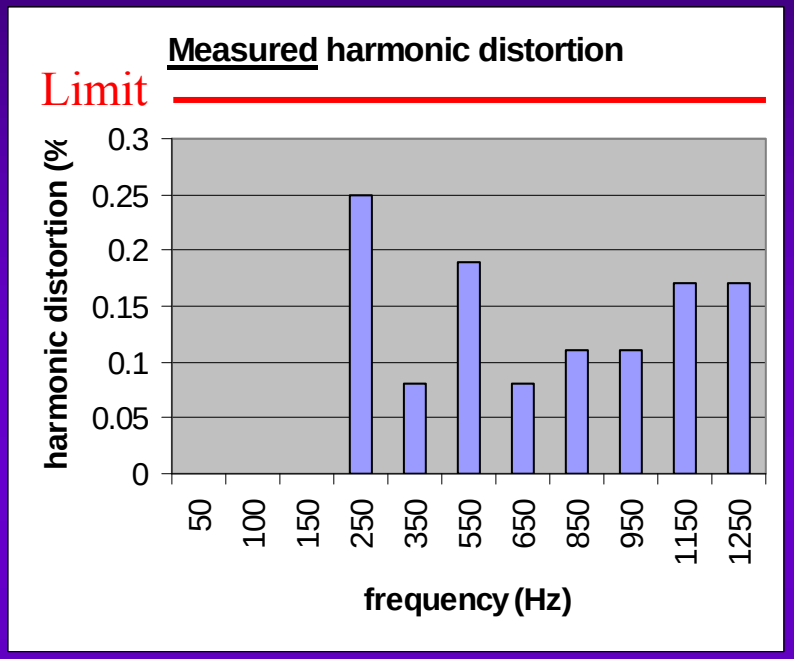
SVC3 performance measurements

Static Var Compensator SVC3



Harmonic filtering performance





Calculated THD (18kV)
0.58 %

Measured THD (18kV)
0.49 %

(e.g. for pulse 450 GeV FT 3s)

SVC3: Simulations of dynamic response

(University of Belfast UK, University of Aberdeen UK)

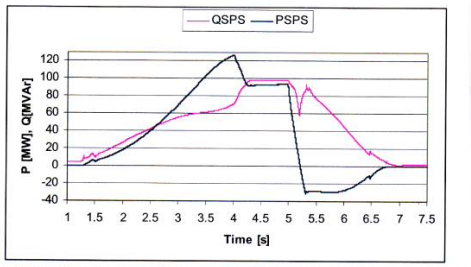
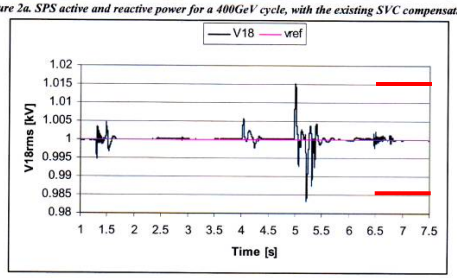


Figure 2a. SPS active and reactive power for a 400GeV cycle, with the existing SVC compensation.

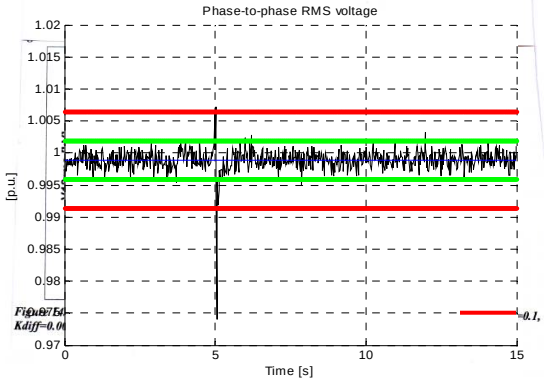


1.5%

-1.5%

Figure 2b). 18kV bus voltage for a 400GeV cycle, with the existing SVC compensation.

+/-



-2.5%

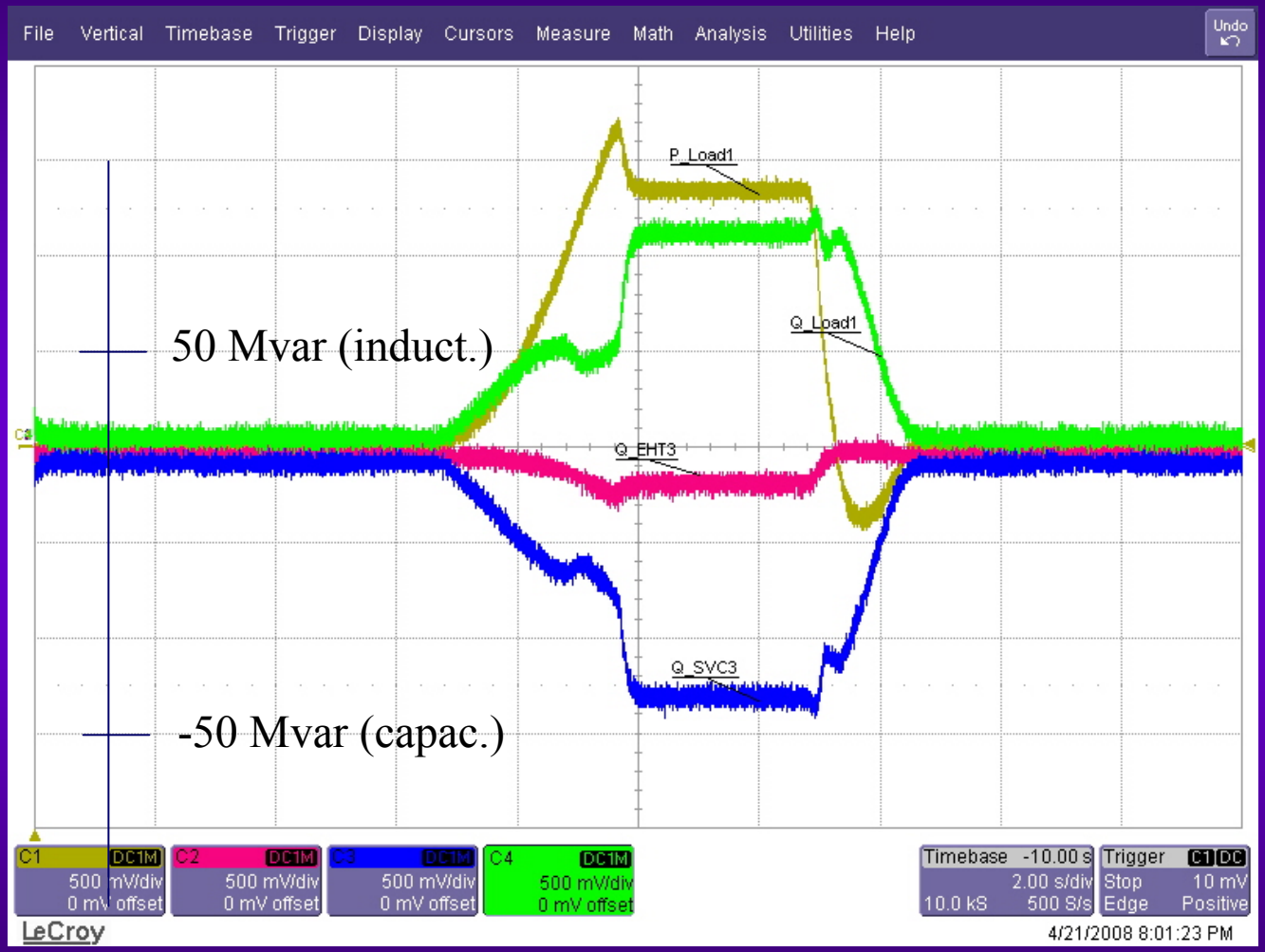
Active and reactive power
(pulse larger than 450 GeV FT 3s)

18 kV voltage response
(simulated)

18 kV voltage response
(measured)

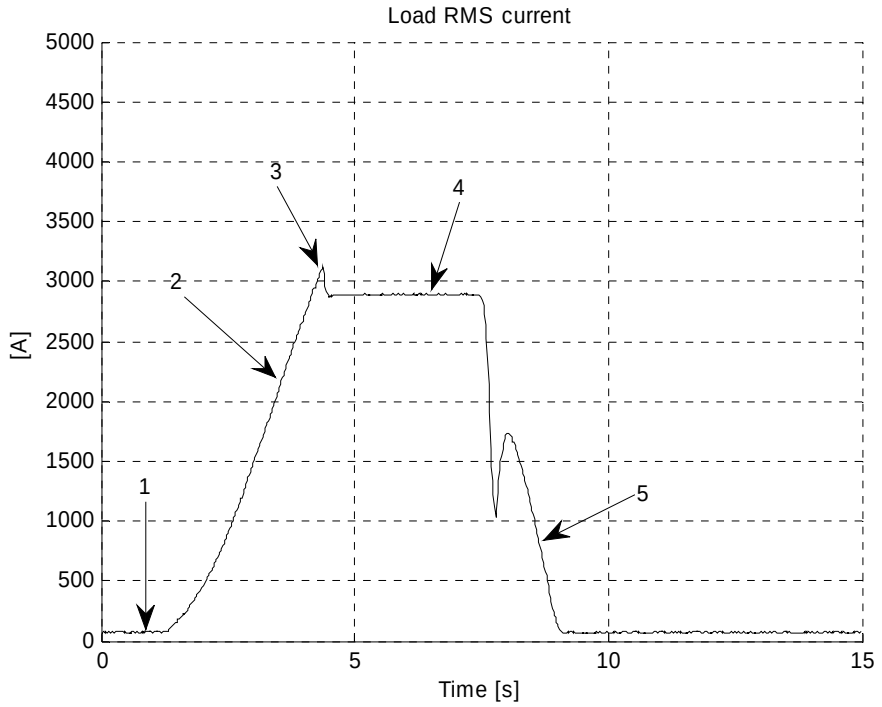
Close correspondence
Simulations - Measurements

SVC3 (450 GeV FT 3s)



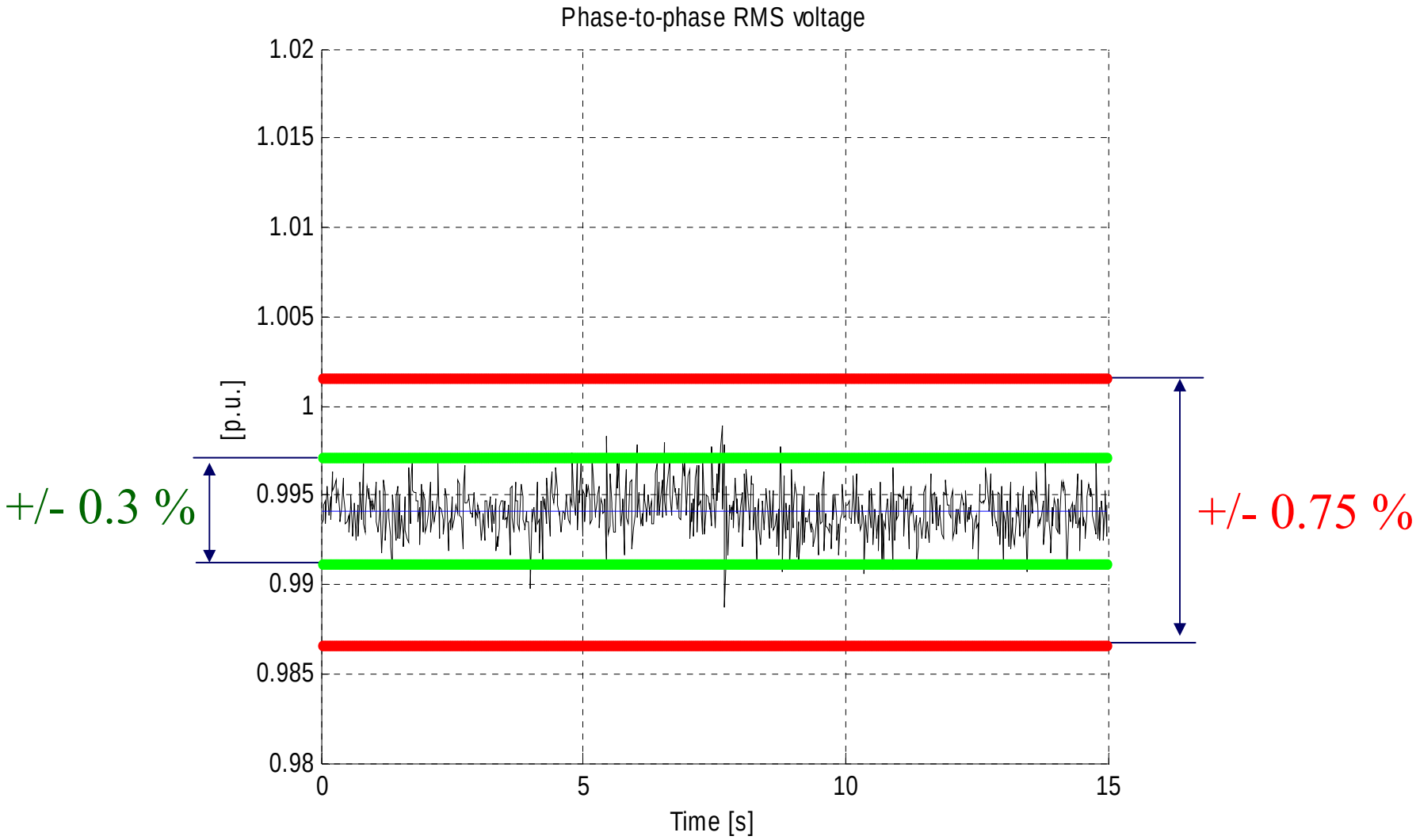
Active and reactive power

SVC3 (450 GeV FT 3s)



Current of SMD's (450 GeV FT 3s)

SVC3 (450 GeV FT 3s)



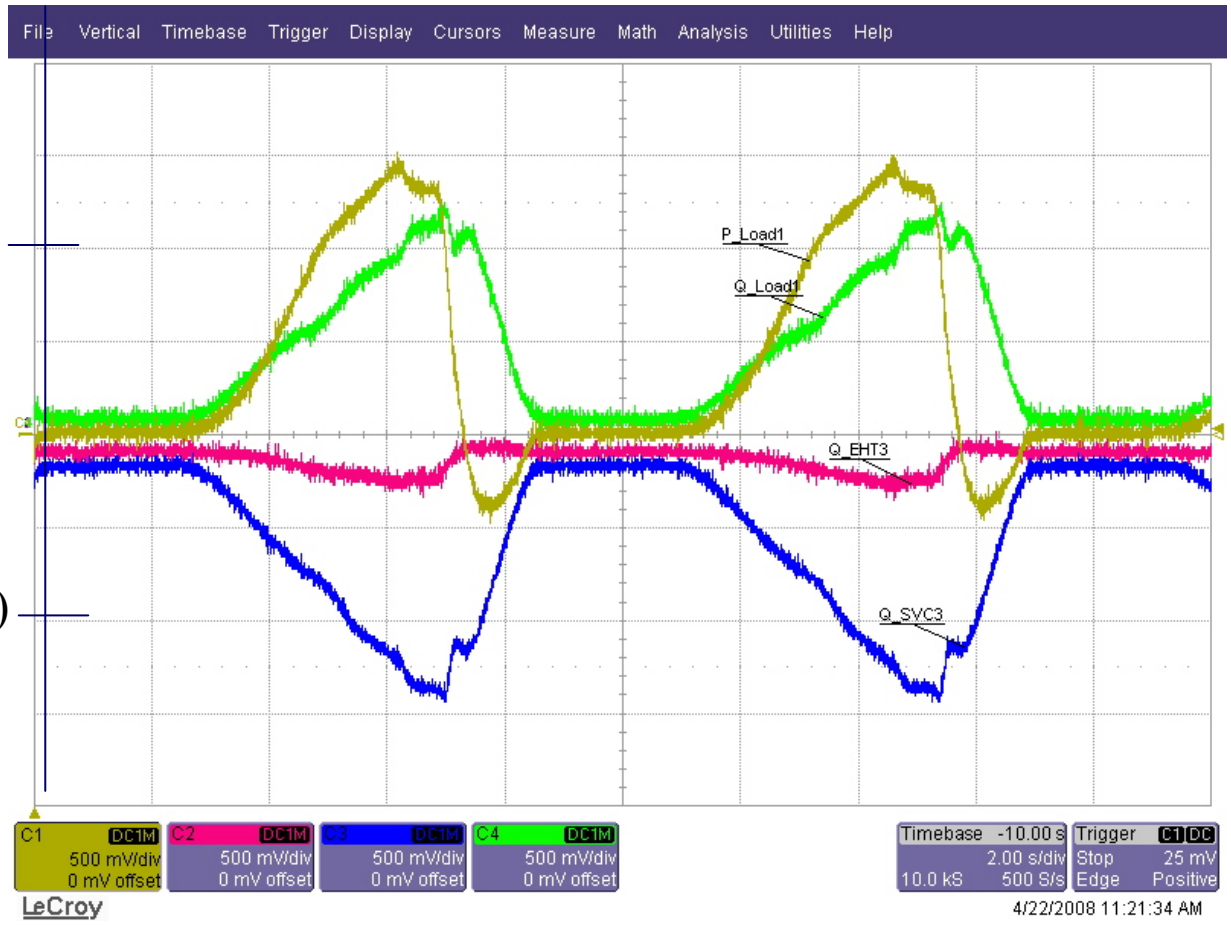
18 kV voltage response

SVC3 (450 GeV LHC pulse)

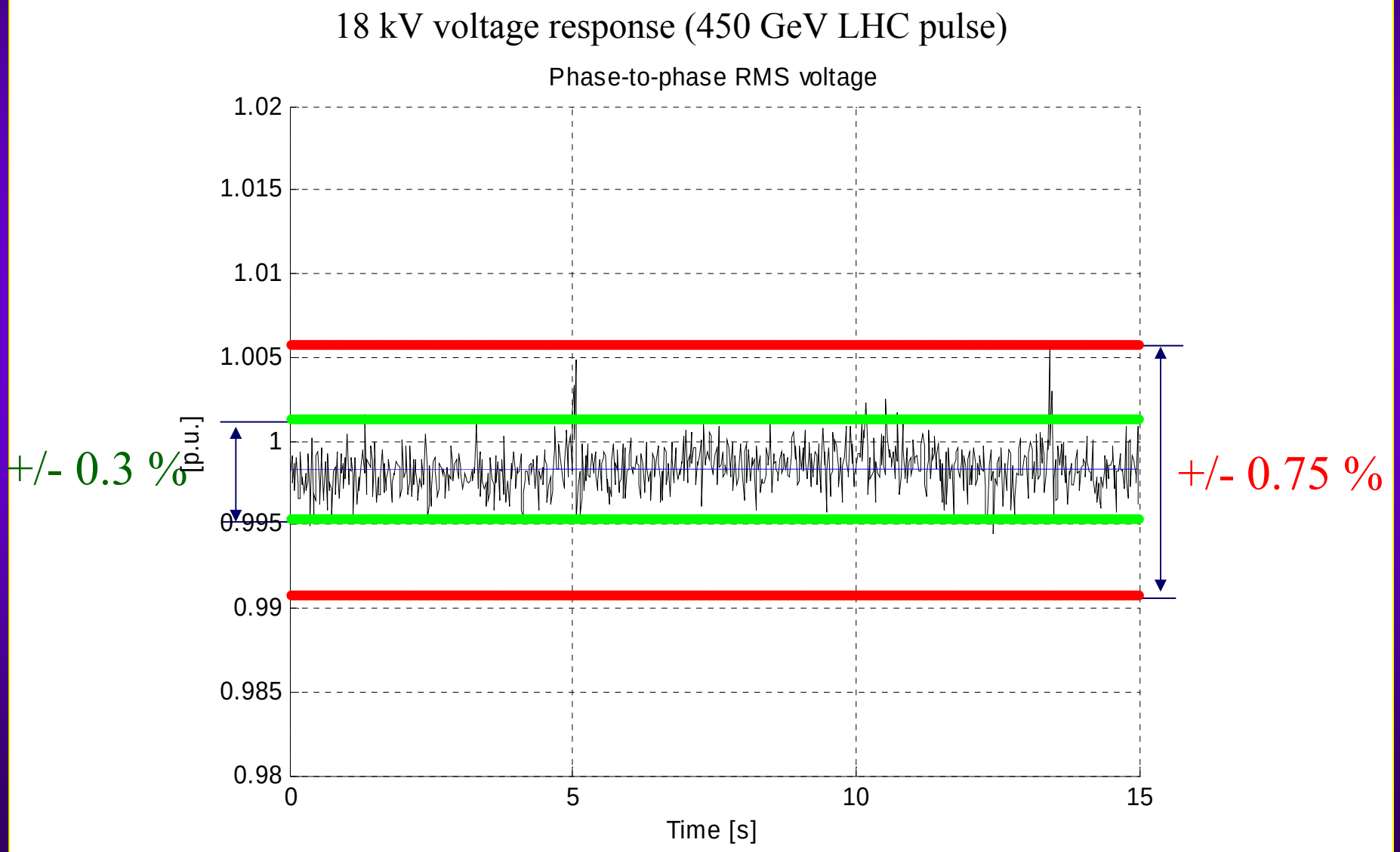
Active and reactive power

50 Mvar (induct.)

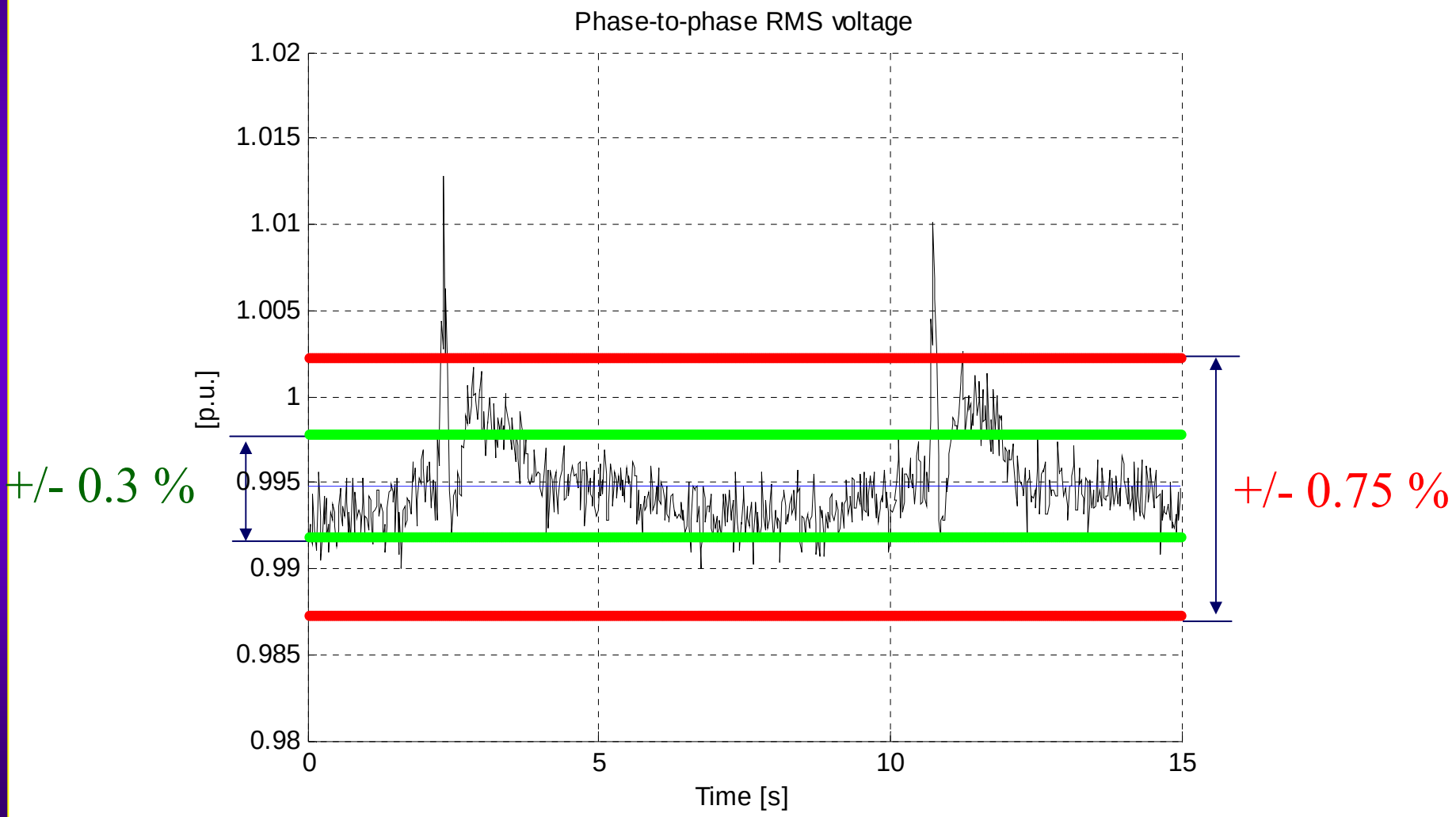
-50 Mvar (capac.)



SVC3 (450 GeV LHC pulse)

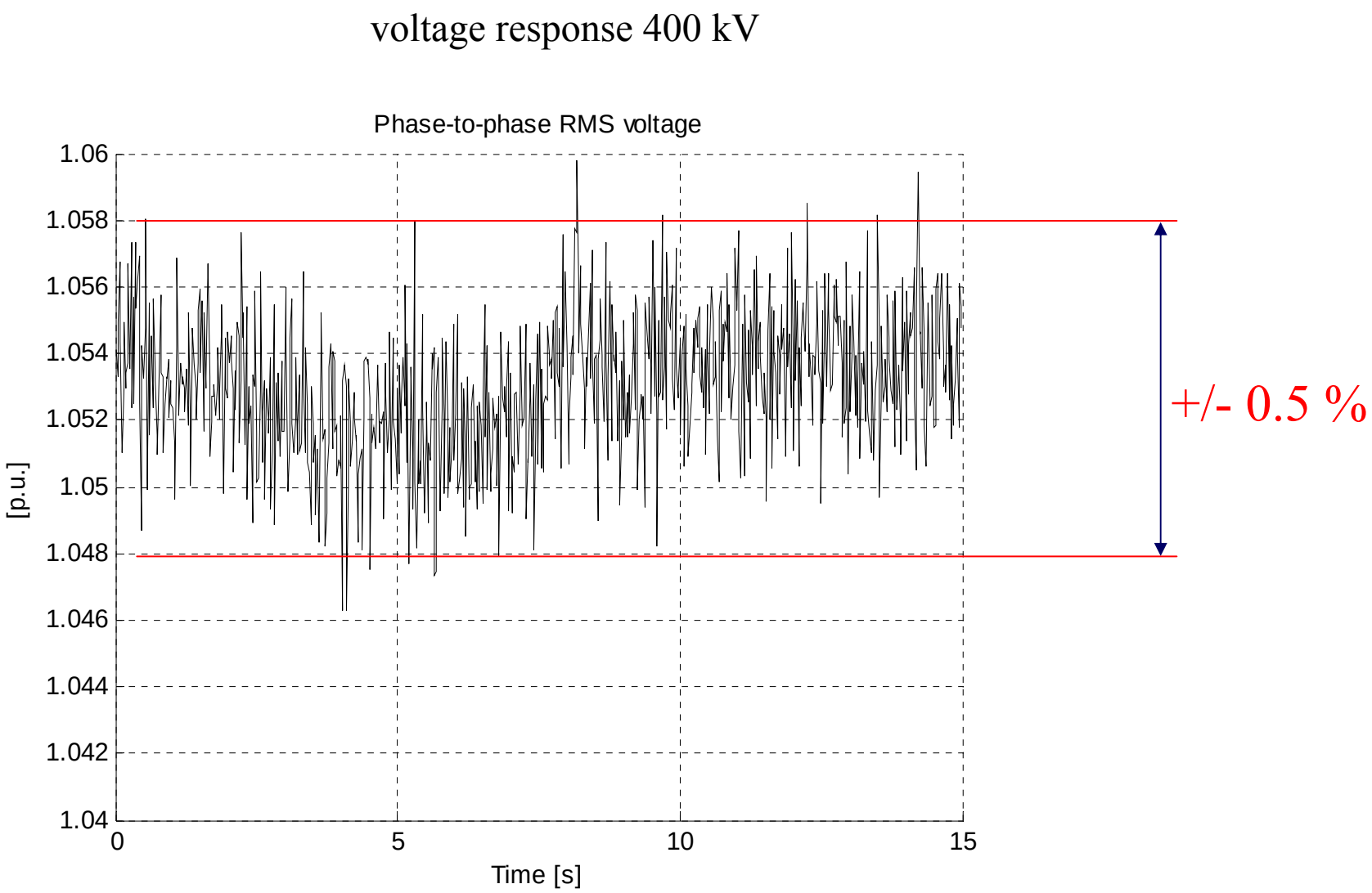


SVC3 (450 GeV LHC pulse) – with regulation error



SVC3 regulation error: 18 kV network voltage response (is now repaired)

European 400 kV network RTE during 450 GeV FT 3s pulse



Summary

Reliability covers all aspects of the life cycle of an electrical installation:

- design,
- specification of components (thermal rating, voltage rating),
- choice of materials,
- workmanship of installation,
- preventive and corrective maintenance,
- operation and follow-up of observations,
- operational procedures, documentation and instructions,
- spare parts management.

Questions ?

Thank you.