GE Power: Transient Recovery Voltage (TRV)

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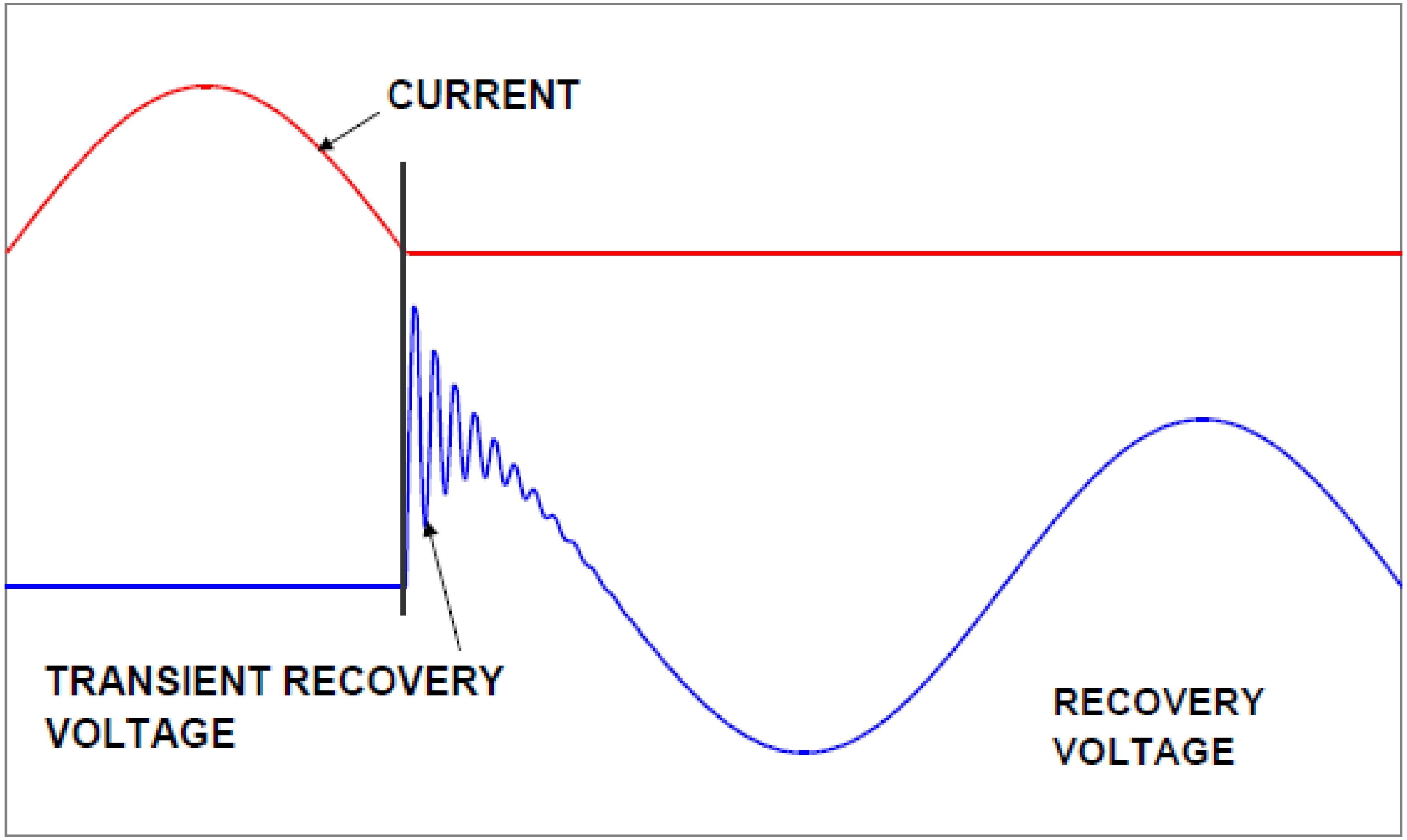
11/27/2017 – CIGRE CHILE

Agenda

1) **General considerations**
2) TRVs with higher values than the standard
3) Performances already demonstrated
4) Increase the performances
5) Future developments
6) Experiences and other markets

General considerations

The **Transient Recovery Voltage** (TRV) is the voltage which appears across the terminals of a pole of circuit breaker after current interruption

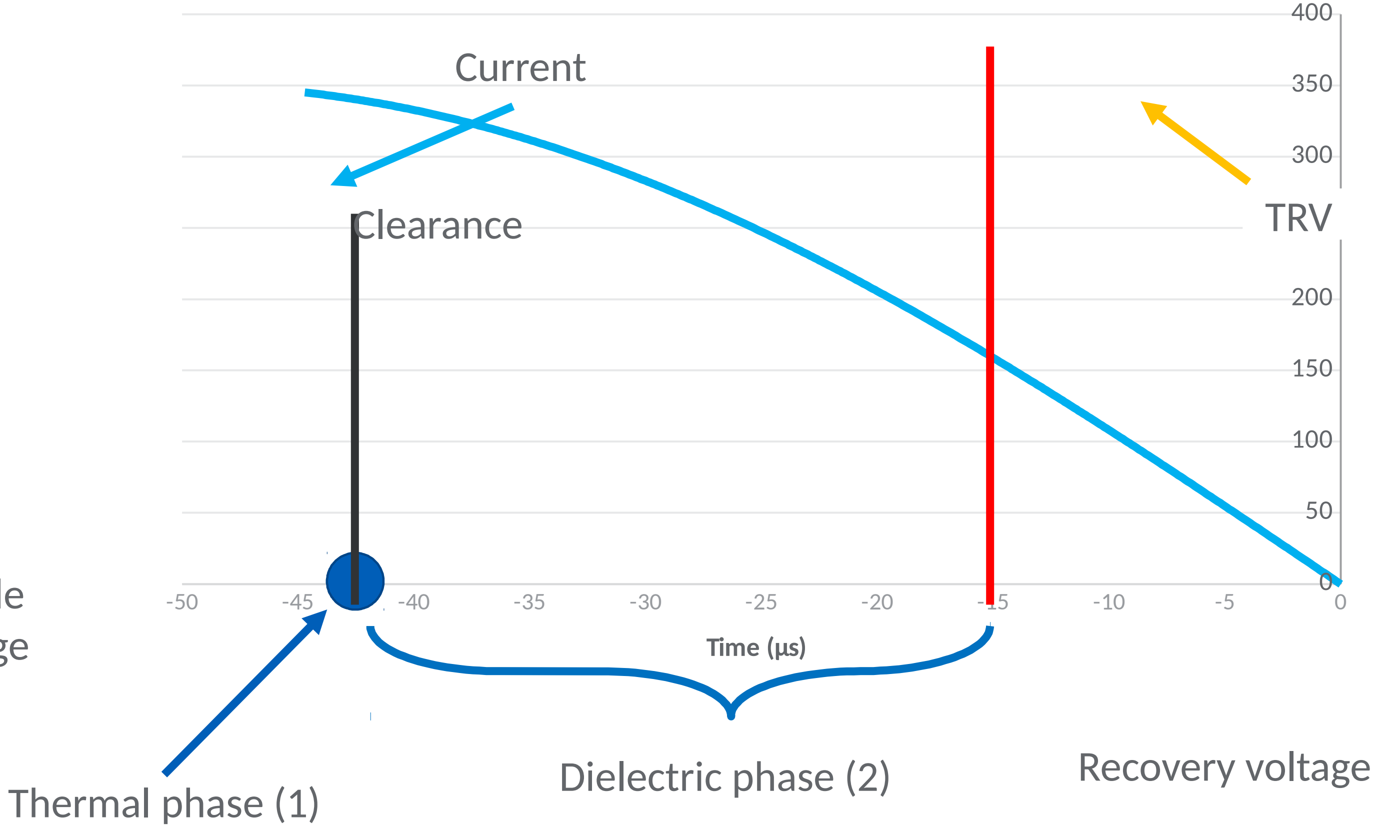


General considerations

During the first microseconds after current zero, the TRV withstand is function of the energy balance in the arc: it is the **thermal phase of interruption**

Later, the voltage withstand is function of the dielectric withstand between contacts: it is the **dielectric phase of interruption**

The breaking operation is successful if the circuit breaker is able to withstand the TRV and the power frequency recovery voltage

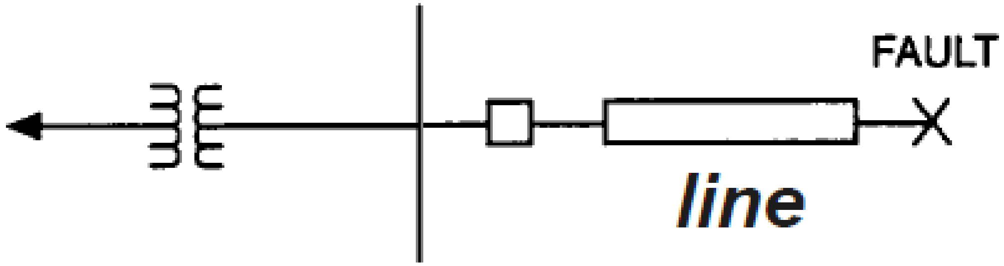


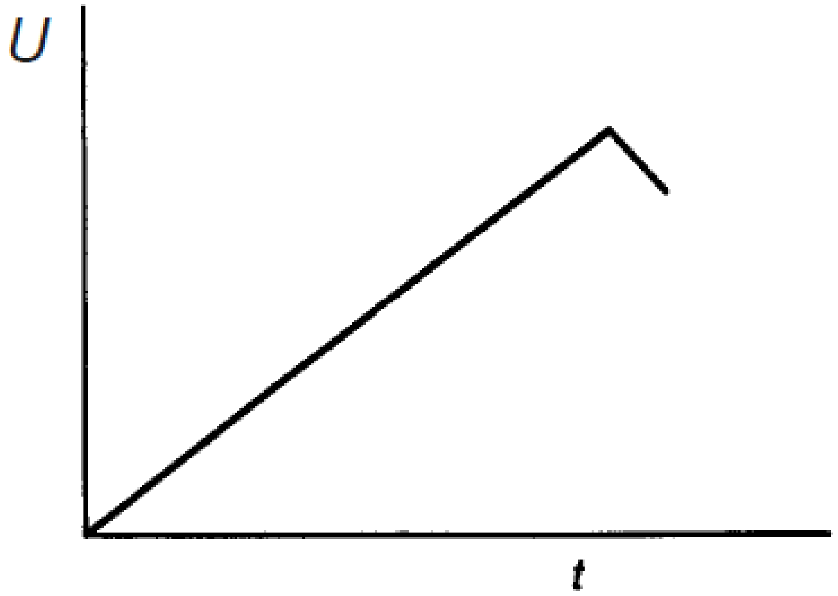
General considerations

Short line fault: Thermal capability

Short-line faults occur from a **few hundred** meters up to several **kilometers** down the line.

After current interruption, the line-side voltage exhibits a characteristic **triangular wave shape** in **addition** of the **voltage** on the **source side**



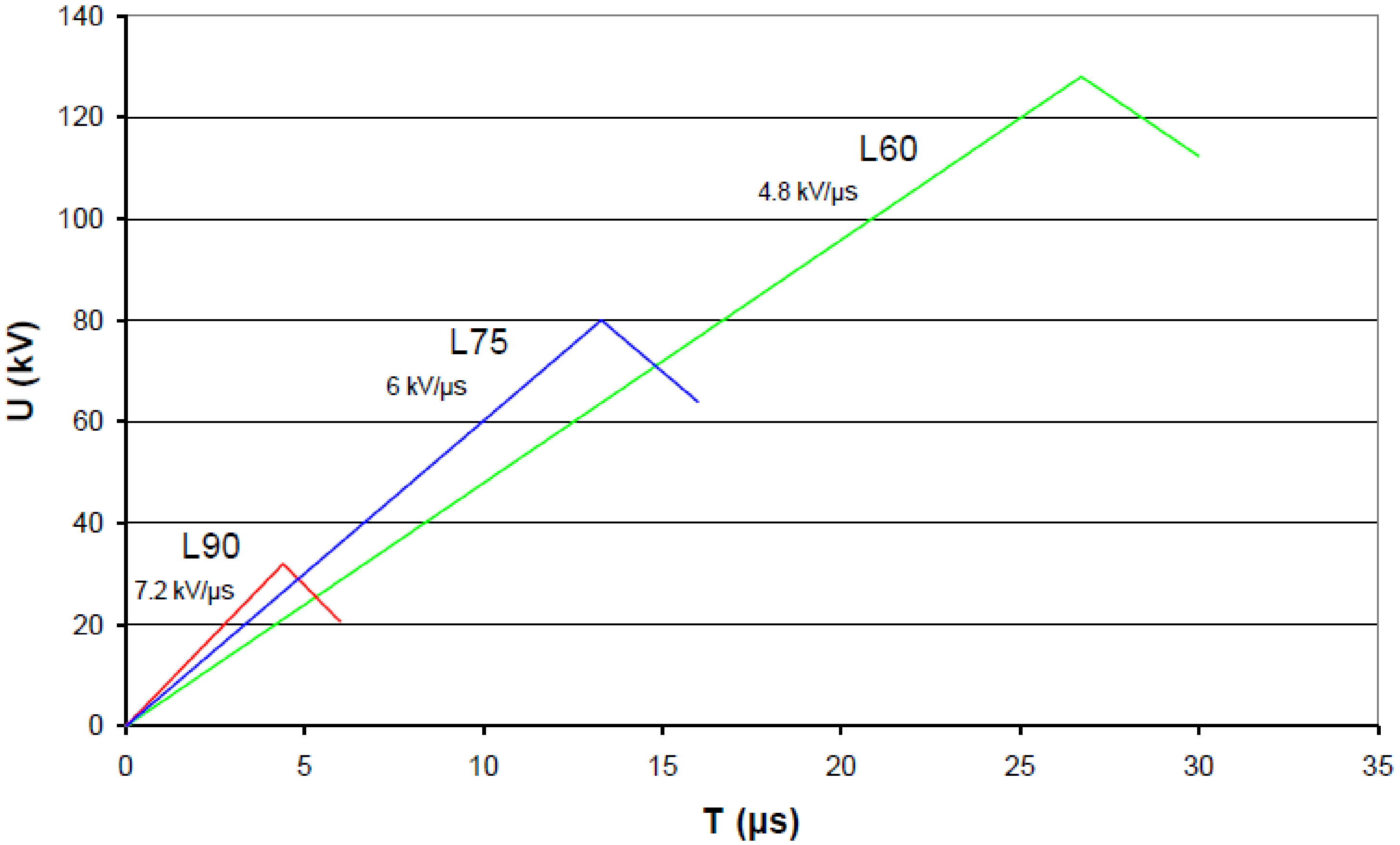


TRV, neglecting the contribution from the supply-side

General considerations

Short line fault: Thermal capability

Impact of the line



U_r = 245kV

I_{sc} = 40kA

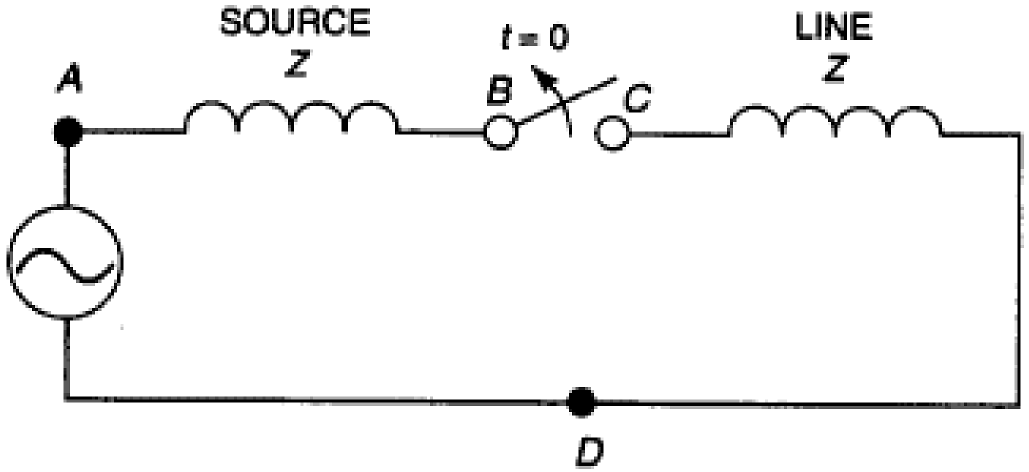
f_r = 50Hz

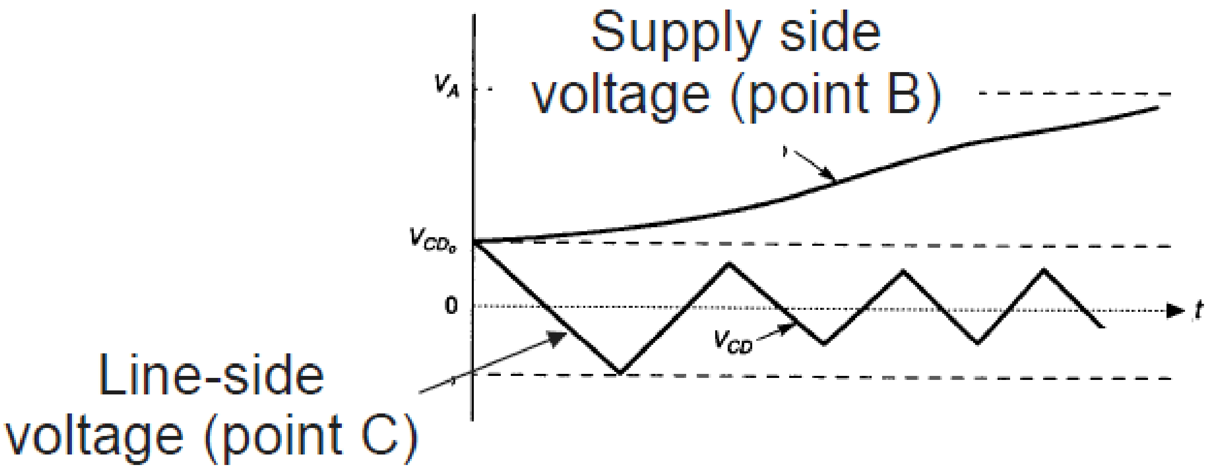
General considerations

Short line fault: Thermal capability

Due to the impedance of the line (Z), the **time delay** for the rise of the voltage on the **line side** is **<0.1µs** for AIS and **<0.5µs** for GIS

In comparison, for SLF, the **time delay** for the **source** side is **2µs**

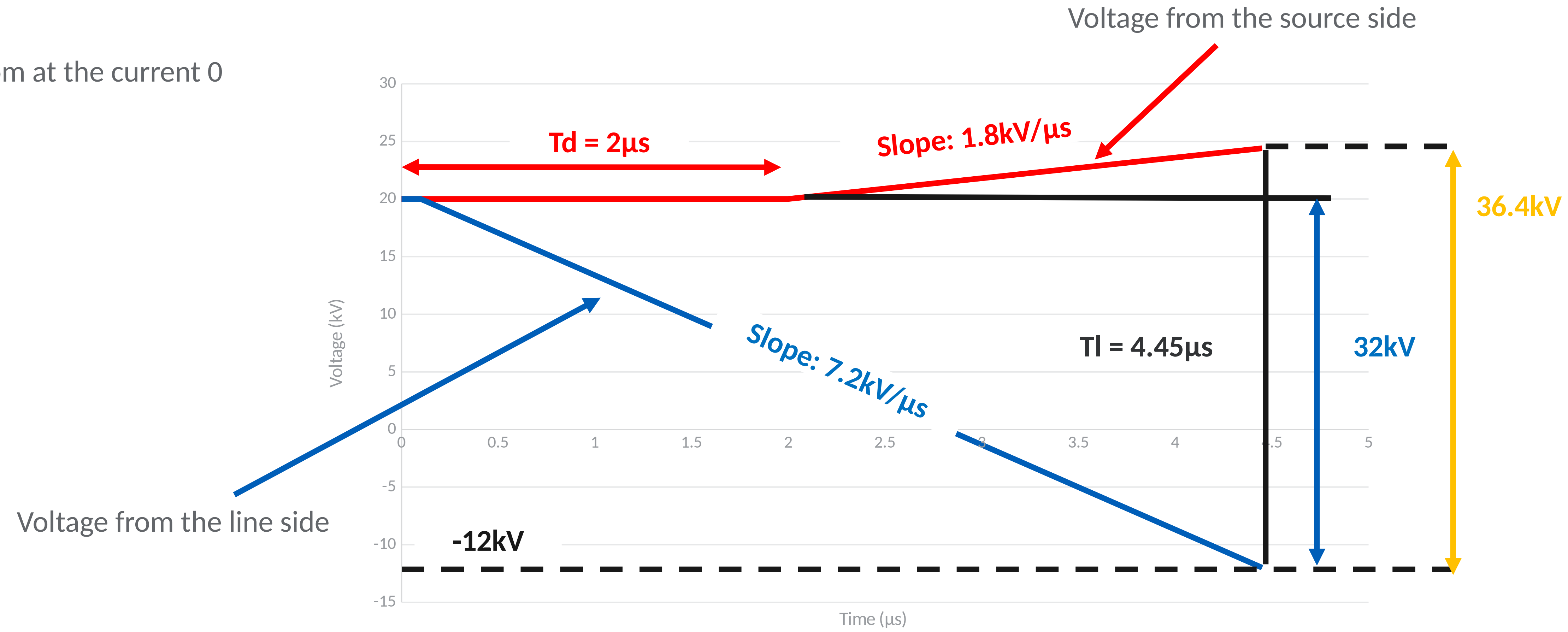




General considerations

Short line fault: Thermal capability

Zoom at the current 0



Ut = 36.4kV □ RRRV (slope) = 36.4/4.45 = 8.2kV/µs

General considerations

Short line fault: Thermal capability

Examples for 245kV, 40kA, AIS

Challenge for the CB

	Current (kA)	Tdl (µs)	RRRV (kV/µs)	Time for the first peak of the line (µs)	Voltage at the first peak of the TRV (kV)
L60 (60% of Icc)	24	<0.1	5.9	26.7	157.6
L75 (75% of Icc)	30	<0.1	7.3	13.3	97
L90 (90% of Icc)	36	<0.1	8.2	4.45	36.4

Main challenges

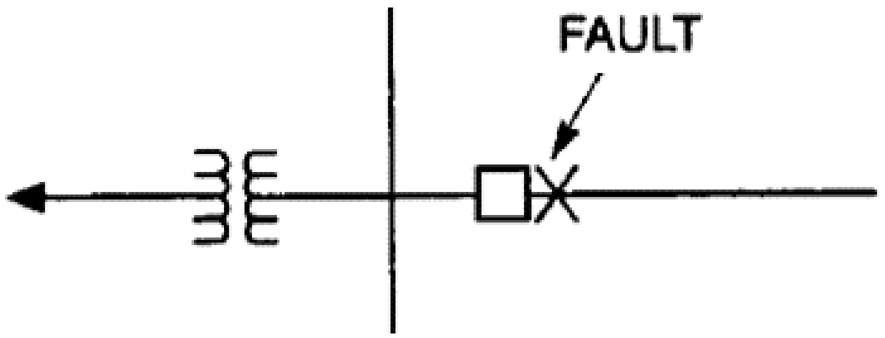
The **thermal capability** of the circuit-breaker is demonstrated during **short line fault** tests (L60 only needed with critical current)

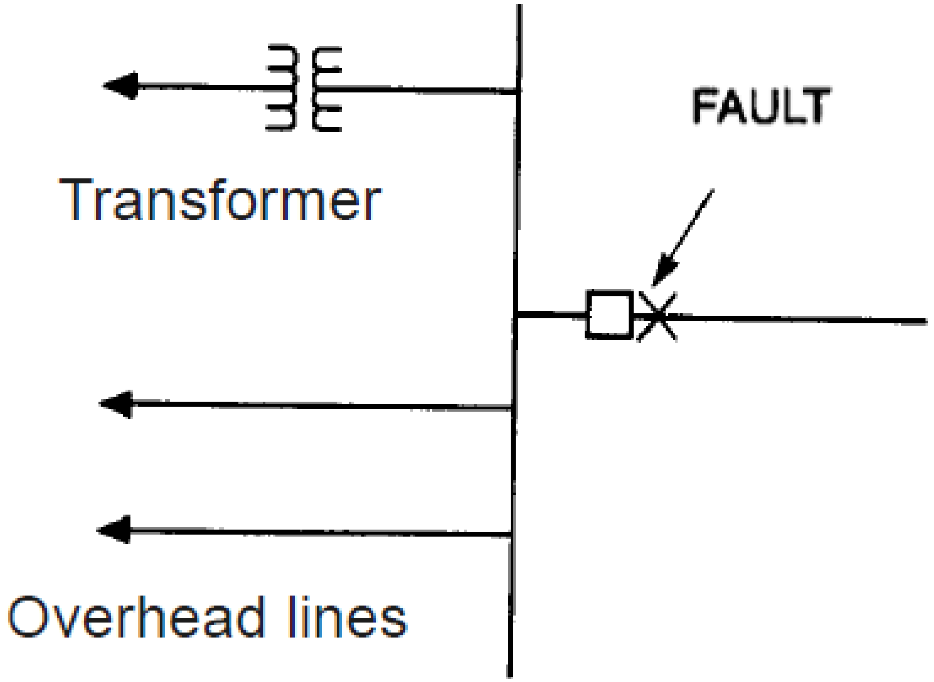
General considerations

Terminal fault: Dielectric capability

Terminal faults occur at the **terminals** of the circuit-breaker, **in the sub-station** .

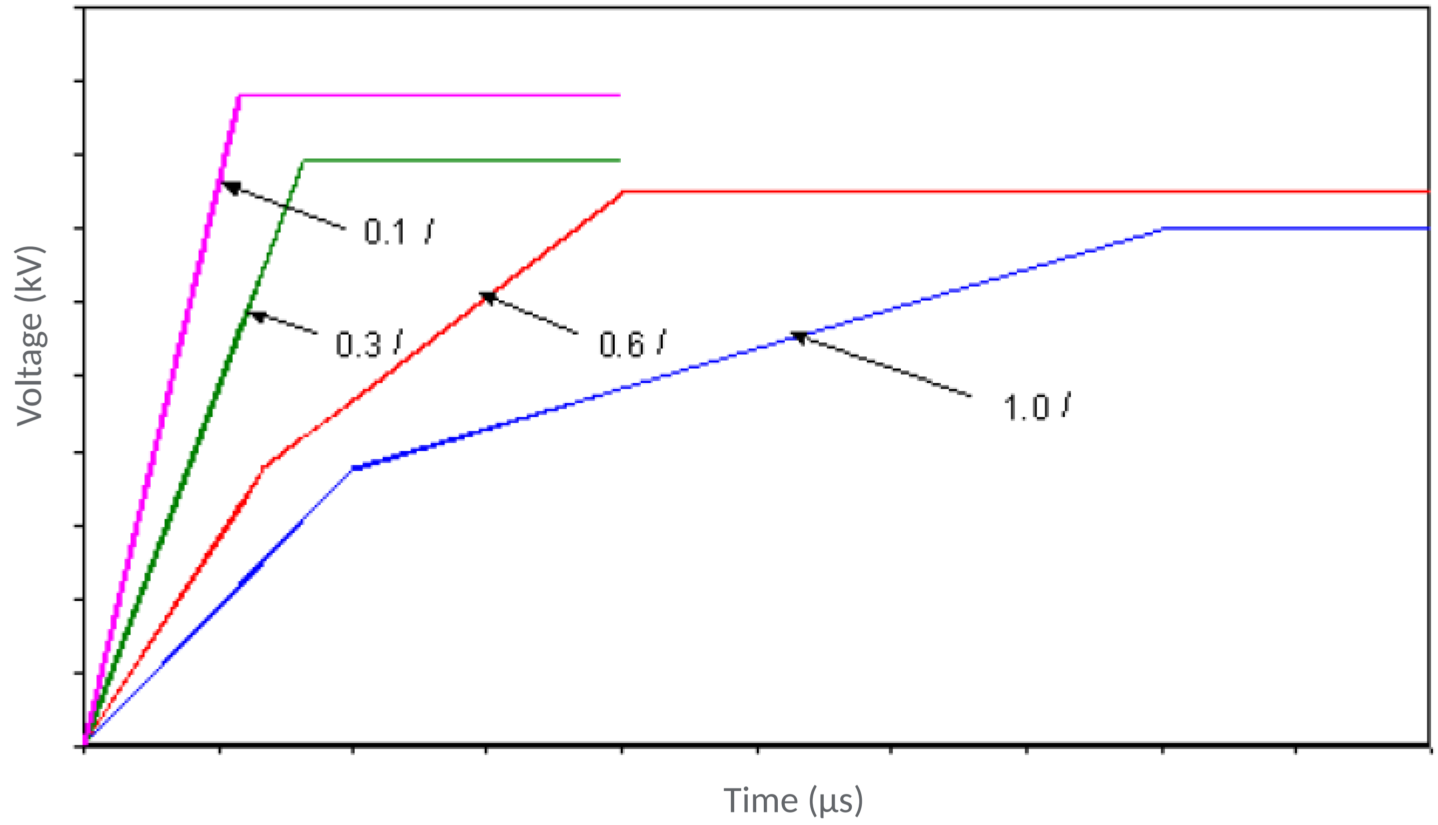
After current interruption, the standards considers a **three phases defaults** to the **ground**





General considerations

Terminal fault: Dielectric capability



Time delay	AIS	GIS
Short line fault	<0.1µs	<0.5µs
Terminal fault	≥2µs	

The **time delay** for the rise of the TRV is **longer** for the **terminal fault**

The needed shorts circuits current to test defined by the standard are 10%, 30%, 60% and 100% of the Icc with the TRV above

General considerations

Terminal fault: Dielectric capability

Examples for 245kV, Kpp=1.3

Challenge for the CB

	Current (kA)	Td (µs)	du/dt (kV/µs)	TRV peak (kV)
T10 (10% of Icc)	4	10	7	459
T30 (30% of Icc)	12	12	5	400
T60 (60% of Icc)	24	2-20	3	390
T100 (100% of Icc)	40	2	2	364

Main challenge

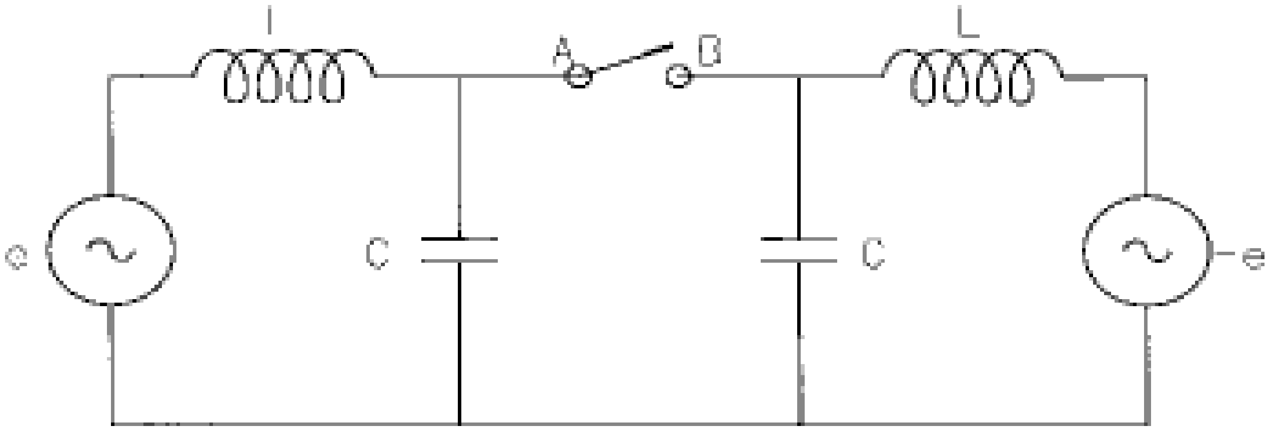
The **dielectric capability** of the circuit-breaker is demonstrated during **terminal fault** tests

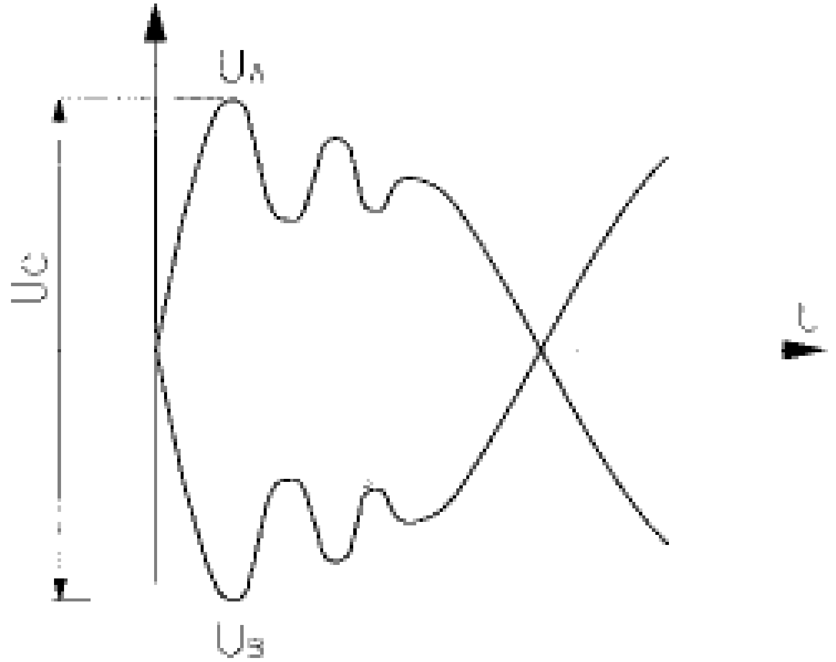
General considerations

Out of phase: Dielectric capability

Out-of-phase occur at the **terminals** of the circuit-breaker, **in the sub-station**

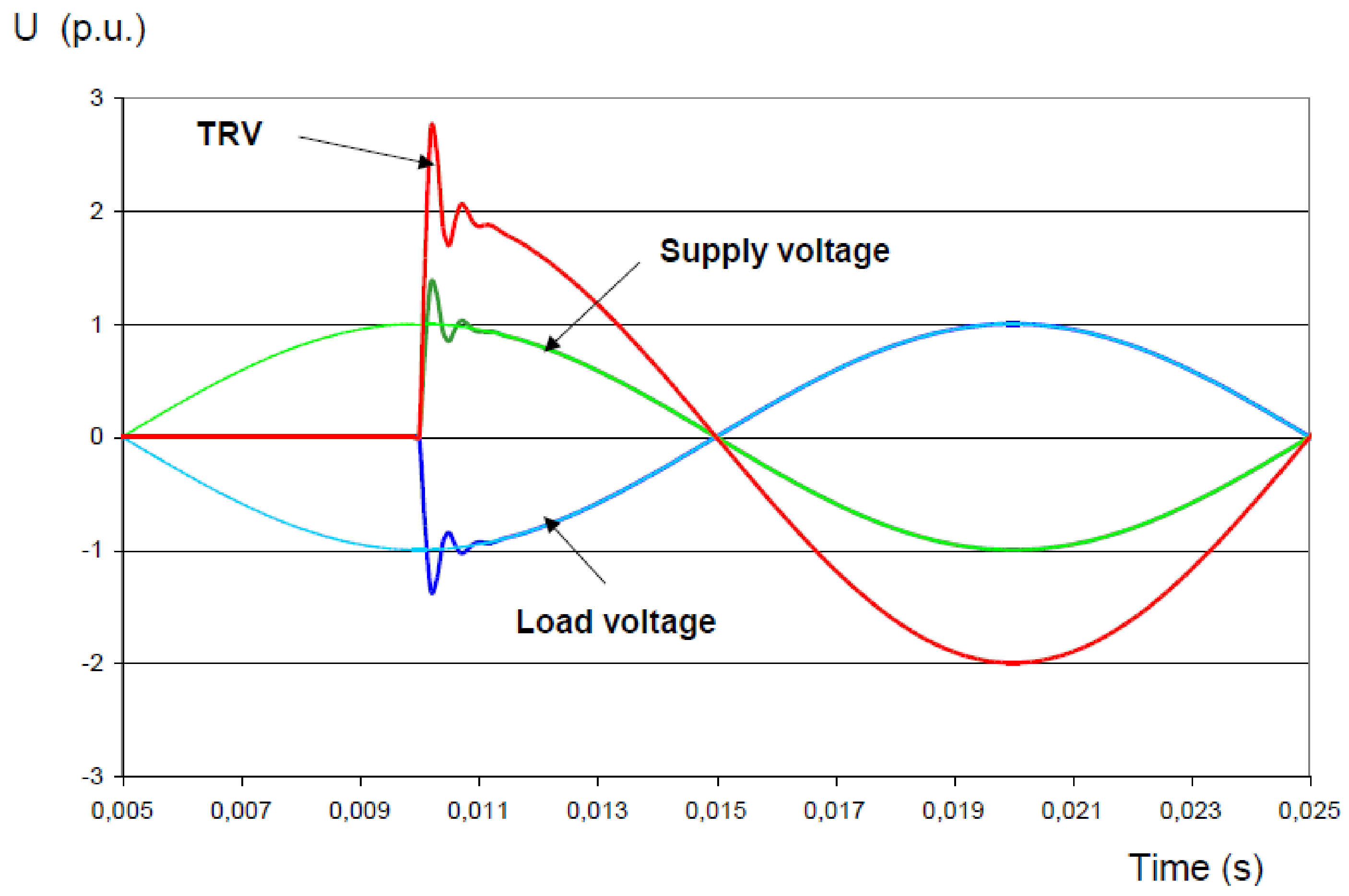
After current interruption, the **TRVs appeared** in **both terminals** and in reversed polarity each others





General considerations

Out of phase: Dielectric capability



General considerations

Out of phase: Dielectric capability

Challenge for the CB

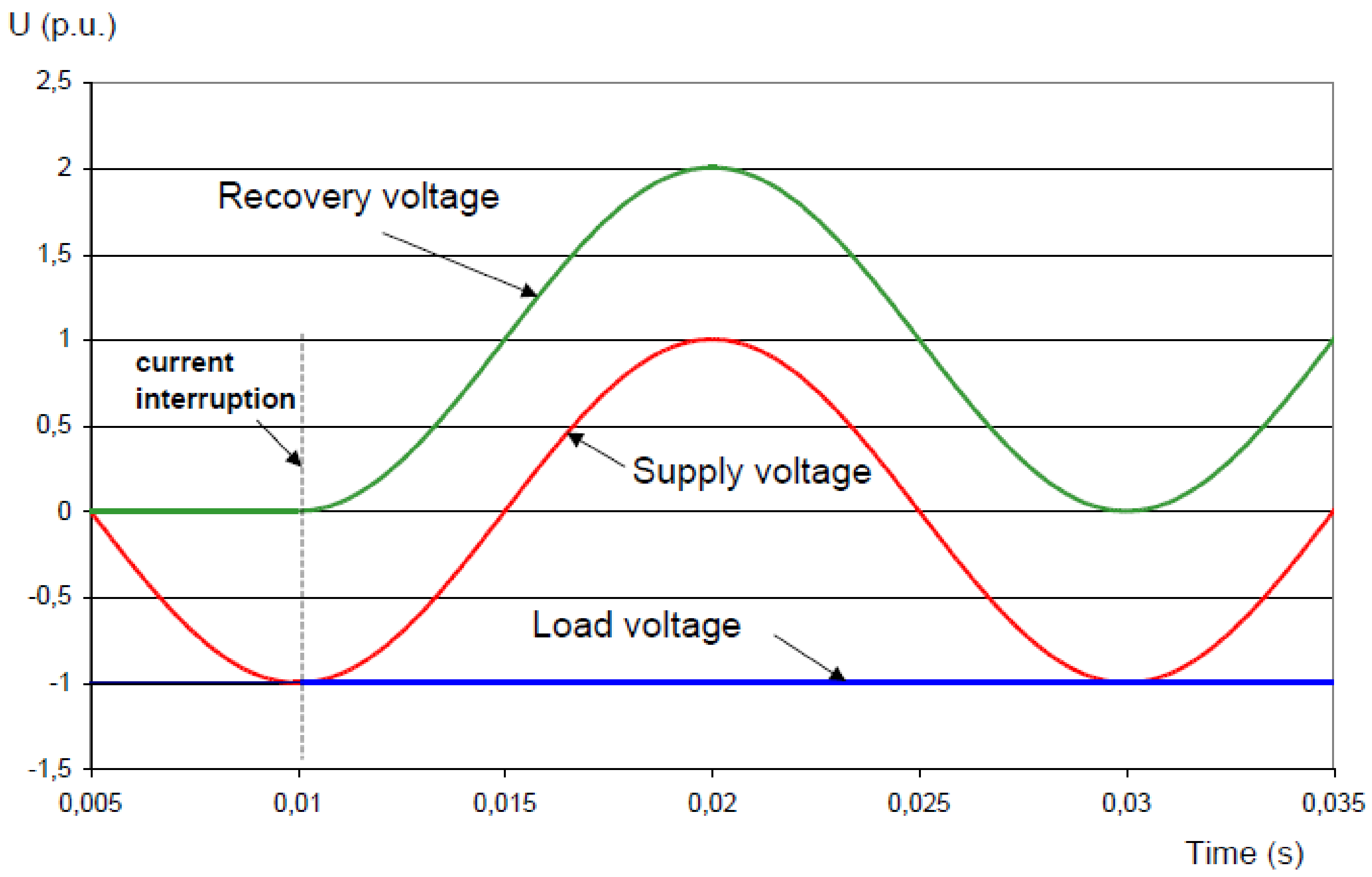
	Current (kA)	Td (µs)	du/dt (kV/µs)	TRV peak (kV)
OP2 (25% of the Icc)	10	2-20	1.54	500

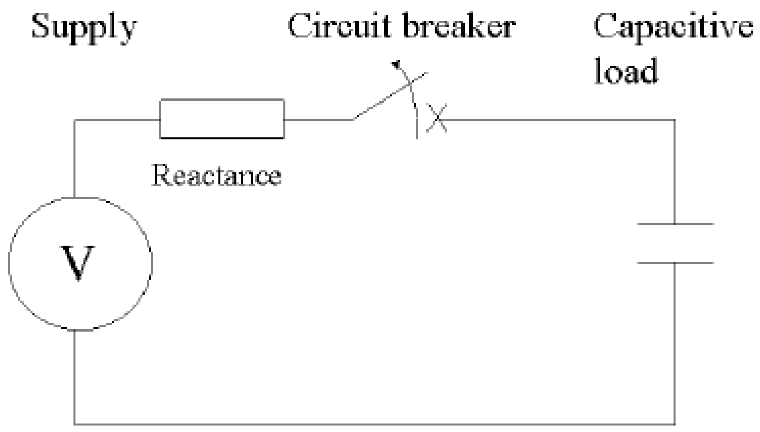
Main challenge

The **dielectric capability** of the circuit-breaker is demonstrated during **out of phase** tests

General considerations

Capacitor switching: Dielectric capability





General considerations

Capacitor switching: Dielectric capability

Challenge for the CB

	Current (A)	Time of the first peak (ms)	RV Peak (kV)
Cap-switching	Around 500	10	560

Due to the **very small current** compared to the Icc (500A), the **minimum arcing time** will be very **short** (smaller than 1ms)

The main difficulty is to **withstand** the rise of the **voltage** after the clearance despite a **small distance** between the contacts

An efficient **speed** and **insulating coordination** must be defined for this application

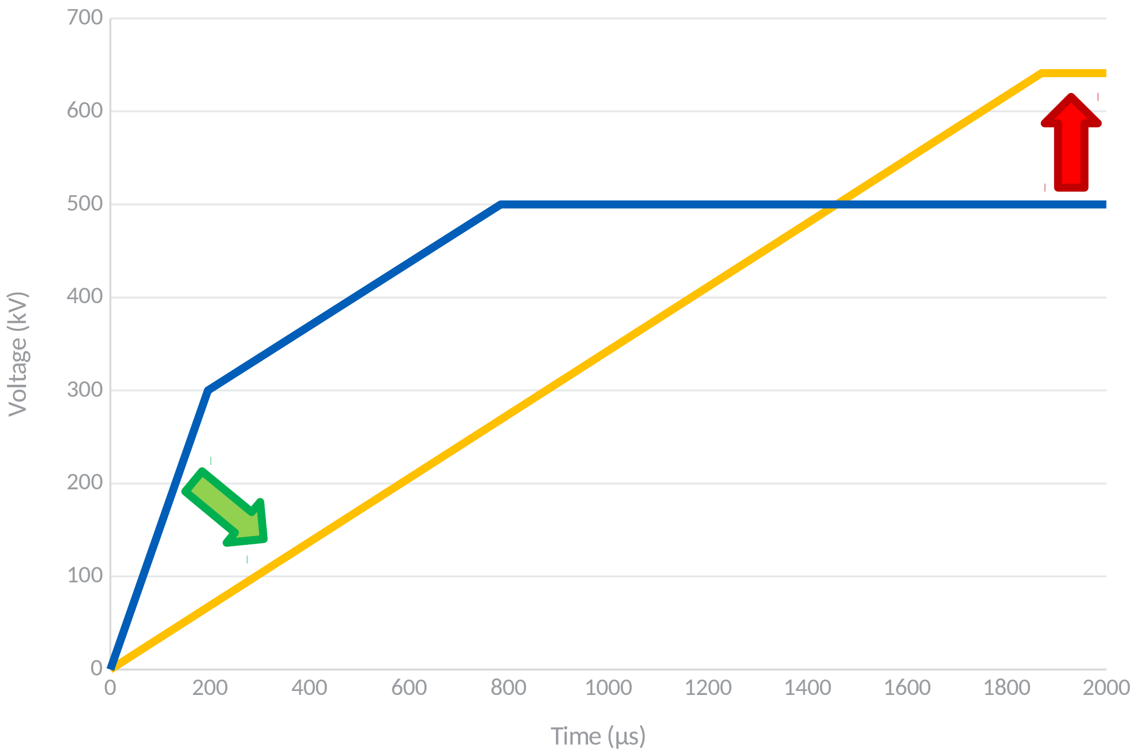
→ The **dielectric capability** of the circuit-breaker is demonstrated during **capacitor switching** tests

Agenda

1) General considerations
2) **TRVs with higher values than the standard**
3) Performances already demonstrated
4) Increase the performances
5) Future developments
6) Experiences and other markets

TRVs with higher values than the standard

Chilean request (example at 245kV)



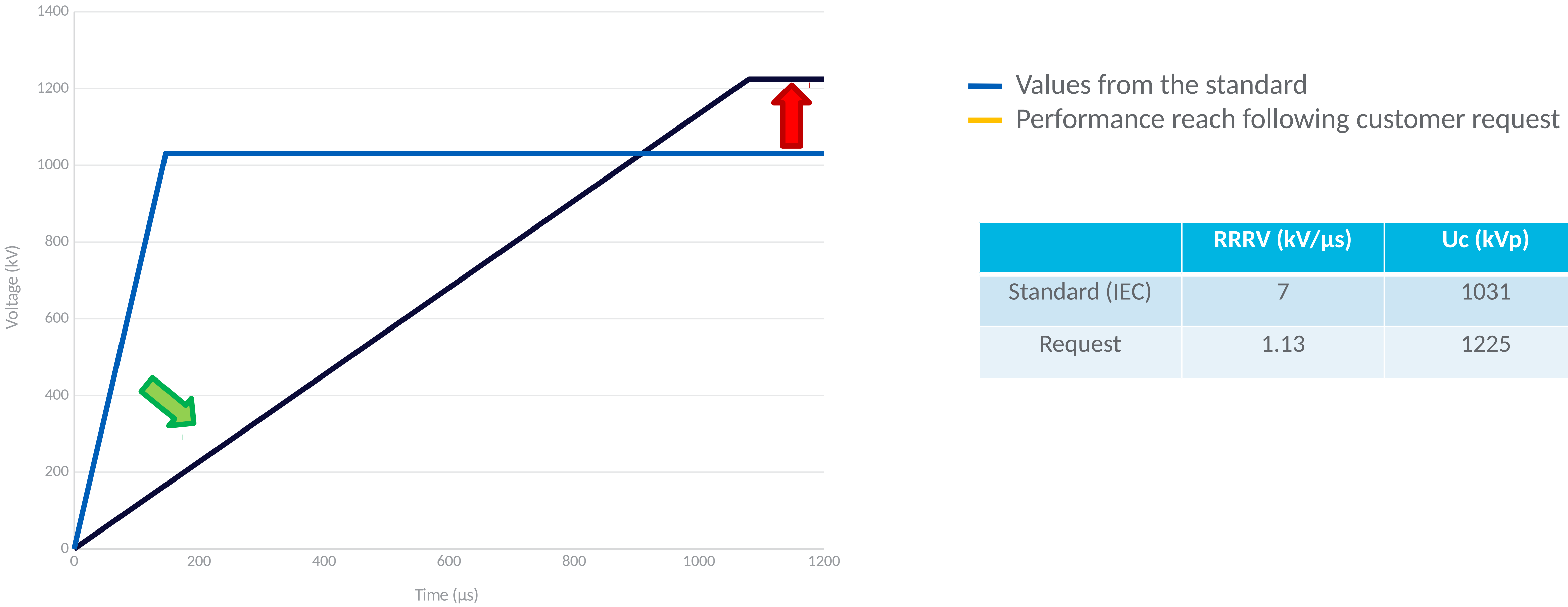
- Values from the standard
- Performance reach following customer request

	RRRV (kV/µs)	Uc (kVp)
Standard (IEC)	1.54	500
Request	0.36	641

TRV with **smaller** RRRV but **higher** peak of voltage

TRVs with higher values than the standard

Chilean request (example at 550kV)



	RRRV (kV/µs)	Uc (kVp)
Standard (IEC)	7	1031
Request	1.13	1225

Once again, a TRV with **smaller** RRRV but **higher** peak of voltage

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Performances already demonstrated

Today chambers

With the today circuit-breakers, **performances** up to **800kV** and **63kA** according the standard are reached

The **performances limitations** are **not necessarily** the values of the standards

Higher performances can in general be **reached** with the today design by performing **new tests** with specific requirements **beyond** the standards values

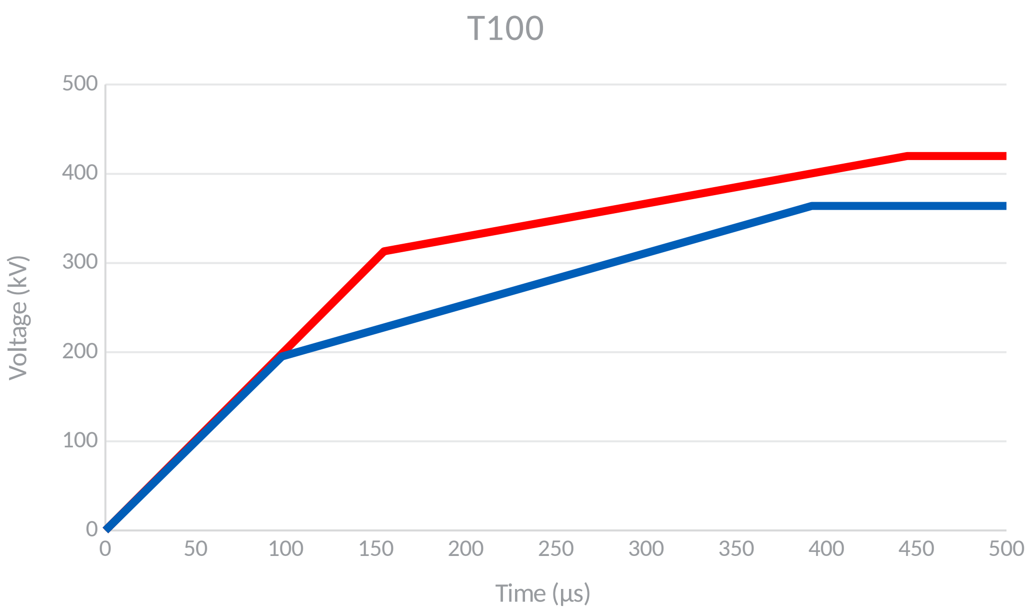
Live tank **245kV** circuit-breaker

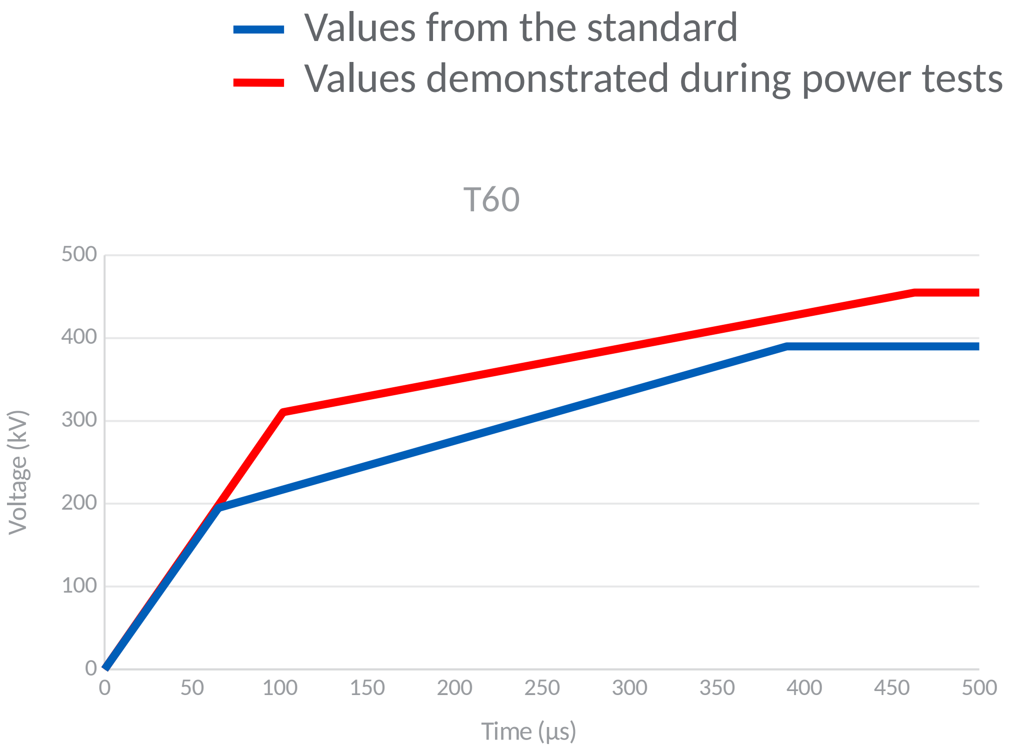
Live tank **550kV** circuit-breaker

Performances already demonstrated

Values from the standard and performances

Example: 245kV, 40kA, 50Hz





Some « extra » **performances** are **already demonstrated**

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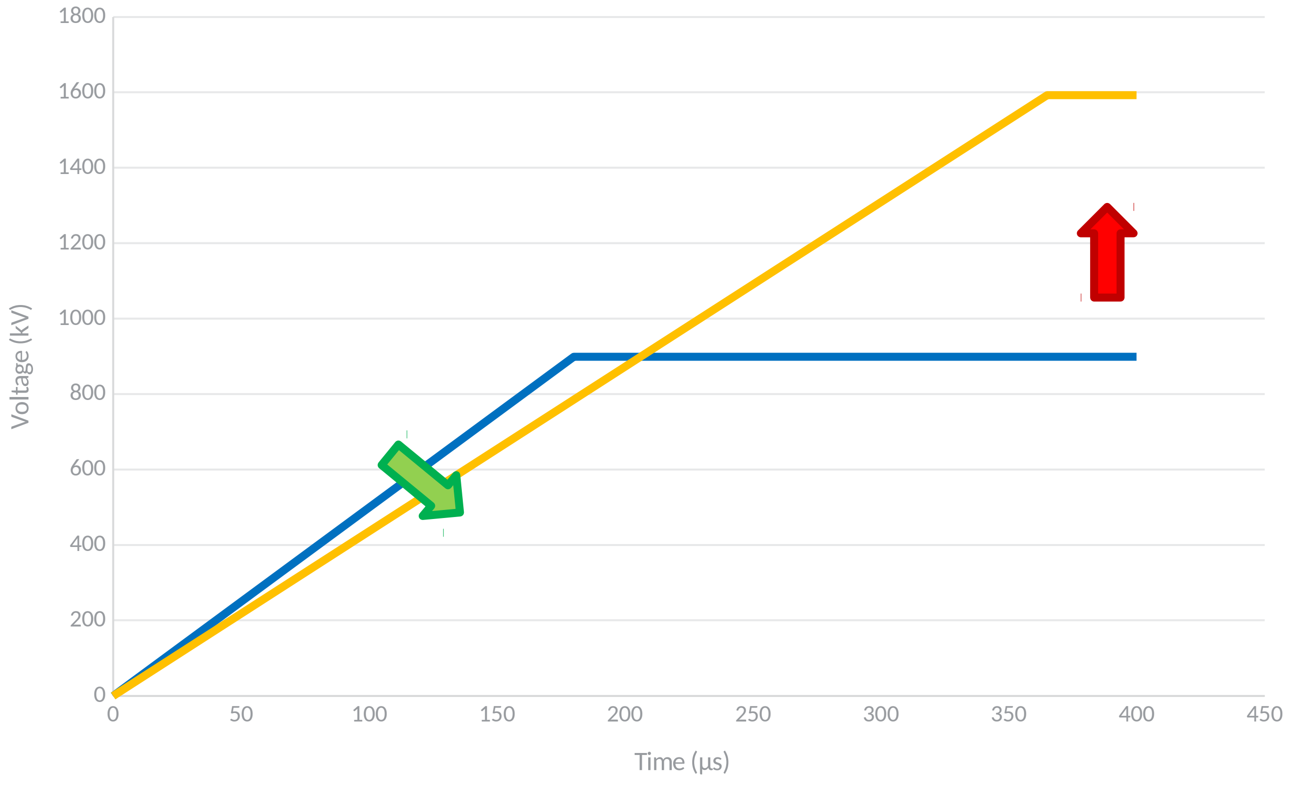
Performances already demonstrated

Other market (550kV chamber)

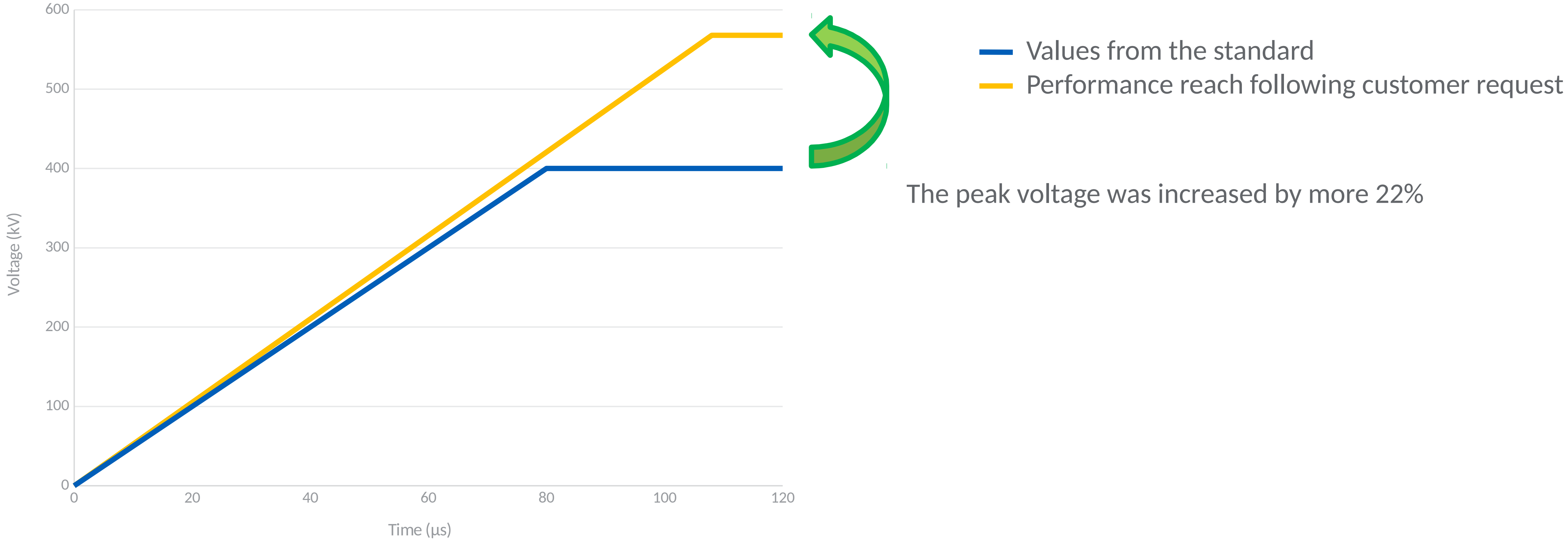


	RRRV (kV/µs)	Uc (kVp)
Standard (IEC)	5	899
Request	4.4	1592

CIGRE Chile: Transient Recovery Voltage (TRV)

Performances already demonstrated

Other market (245kV chamber)

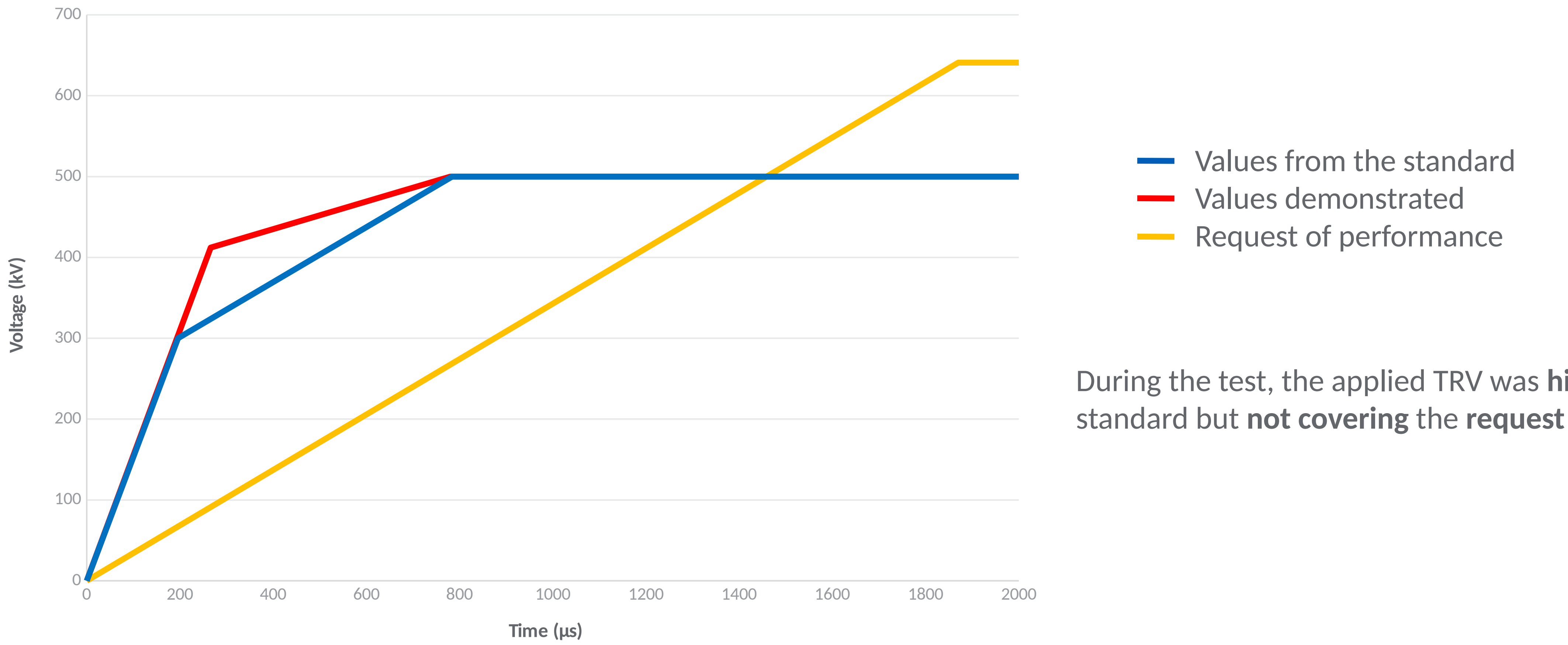


The peak voltage was increased by more 22%

All the **performances** were demonstrated at **300kV** with a **245kV chamber**

Performances already demonstrated

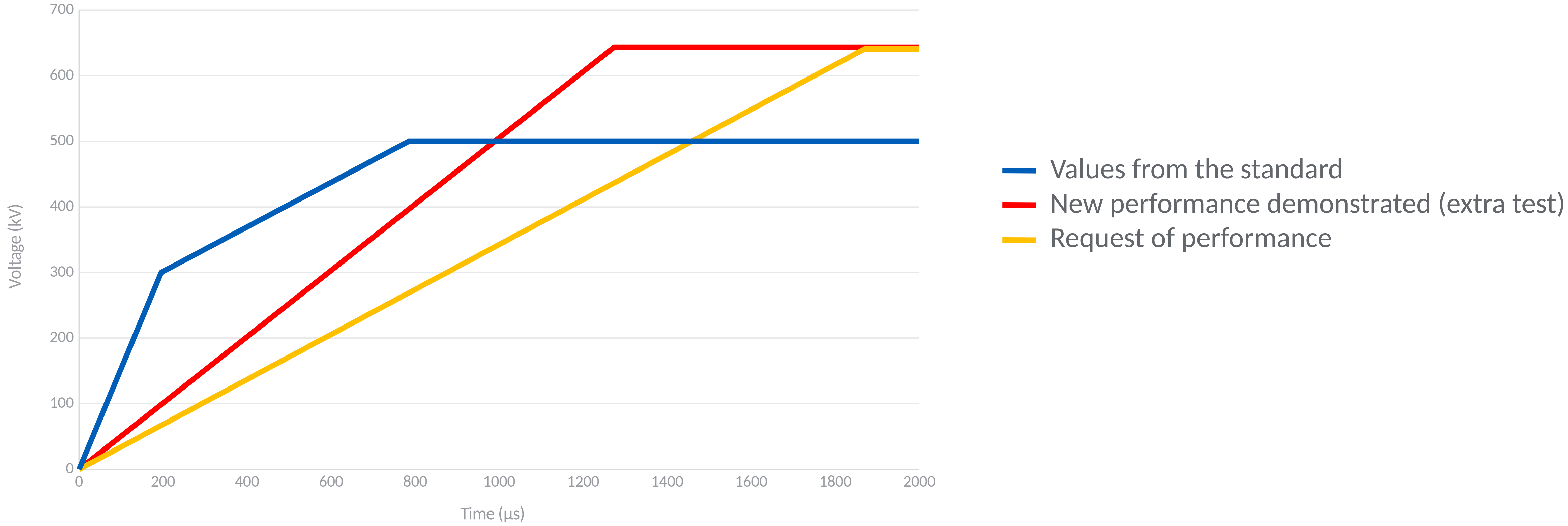
Chilean request (245kV chamber)



During the test, the applied TRV was **higher** than the standard but **not covering** the **request**

Performances already demonstrated

Chilean request



To cover the TRV, a **test** was done **according** the **request** and based on the IEC standard
Despite a higher peak of voltage, the **performance** was **demonstrated** with the **same chamber**

Agenda

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Increase the performances

How we proceed with a special request?

The performance is already demonstrated?

Yes

Quotation from tendering will be done

No

Analysis of the performance
Dielectric and breaking calculations to estimate the capability of an existing chamber
Risk analysis and selection of the chamber to perform a test and validate the performance

Increase the performances

- Dedicated chamber
- Perform extra tests on the today design
- Increase the pressure
- Add capacitor(s)
- Surge arrestors
- Add or increase the number of chamber(s) in series

Dedicated chamber

Really expensive solution (one chamber for one market) due to small volume

Not an efficient solution

Perform extra tests on the today design

No new development, only **tests** to be done

The today requests seems only higher peak of voltage (Uc) and smaller rise of voltage (RRRV) are requested

On these conditions, reach the requests seems possible (already done for Transelec and other markets)

Increase the performances

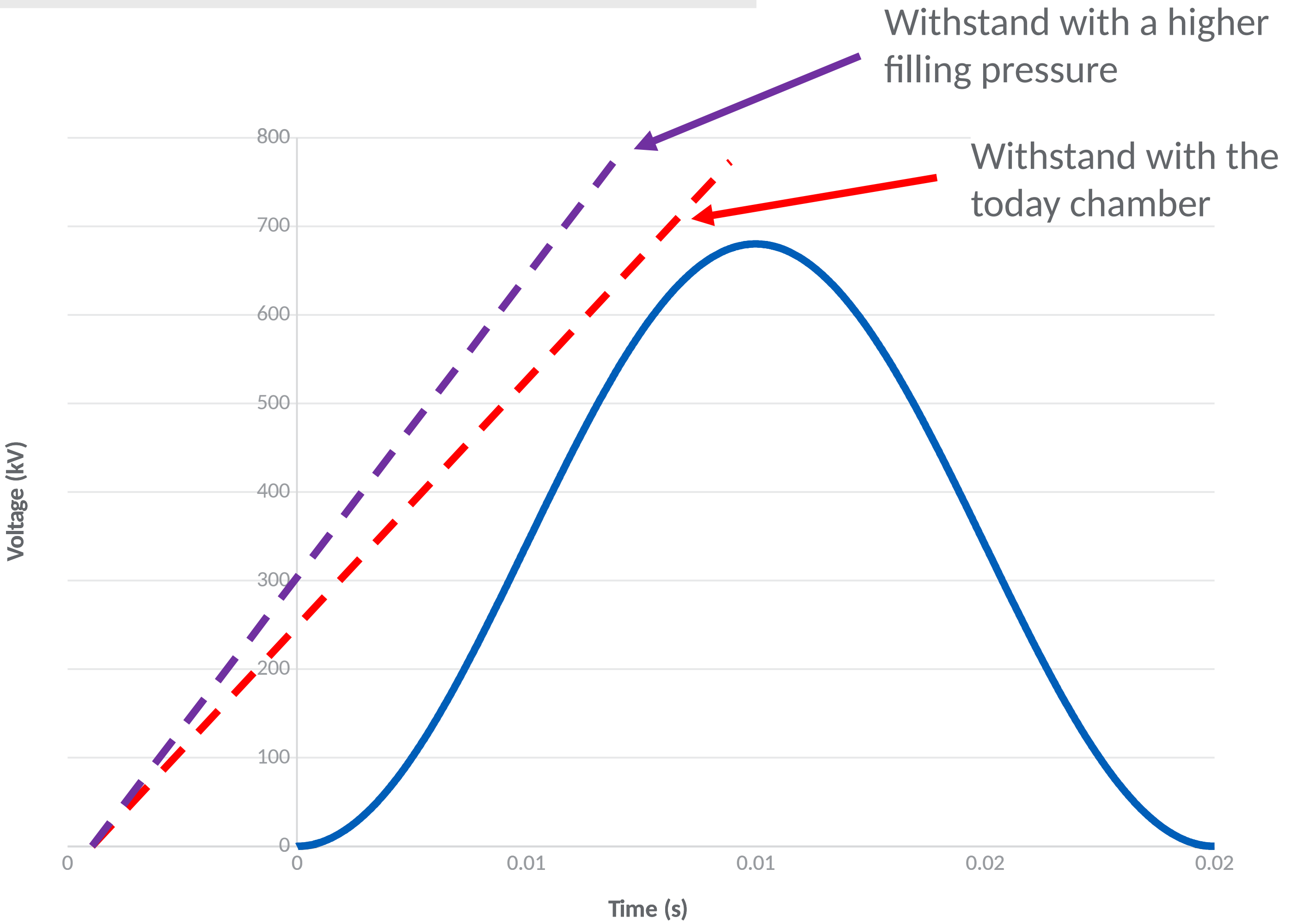
Possible adjustment: Increase the pressure

Another **solution**, is to do small **adjustments** on the **existing chambers** for the Chilean market

As example, the **dielectric withstand** is link to the **filling pressure** of the circuit-breaker

Increase the filling pressure will **increase** the **dielectric withstand**

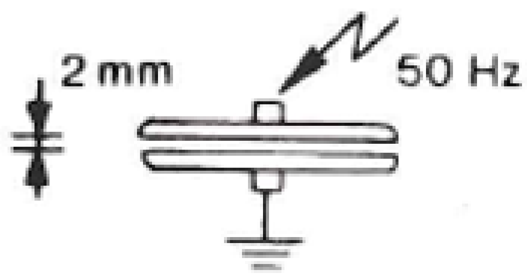
Increase the filling pressure will also **increase** the **thermal capability** of the chamber



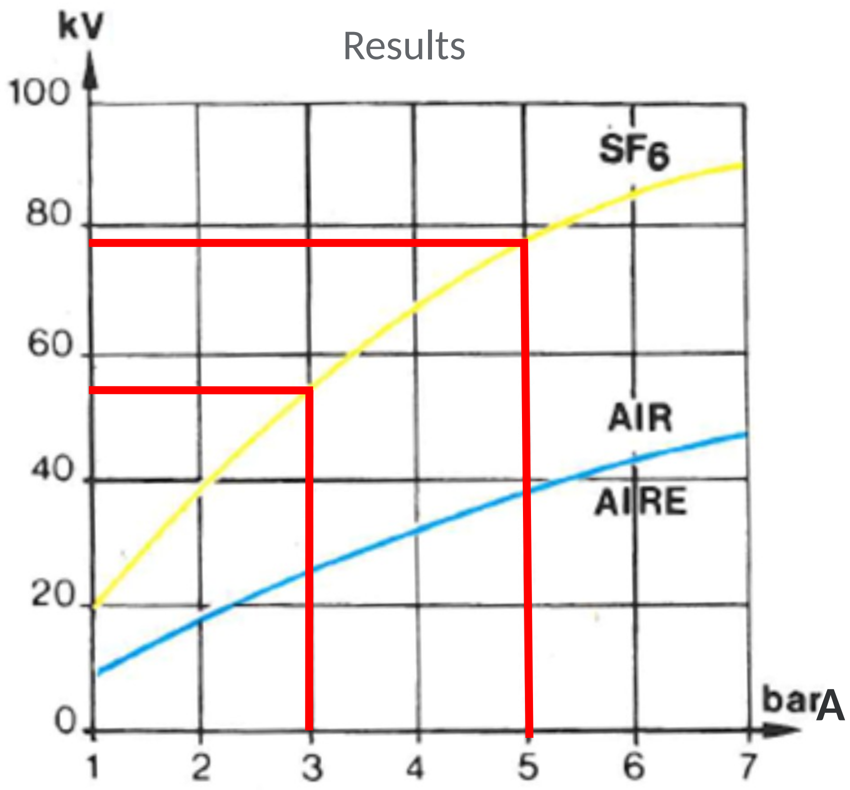
Increase the performances

Possible adjustment: Increase the pressure

Test



Results

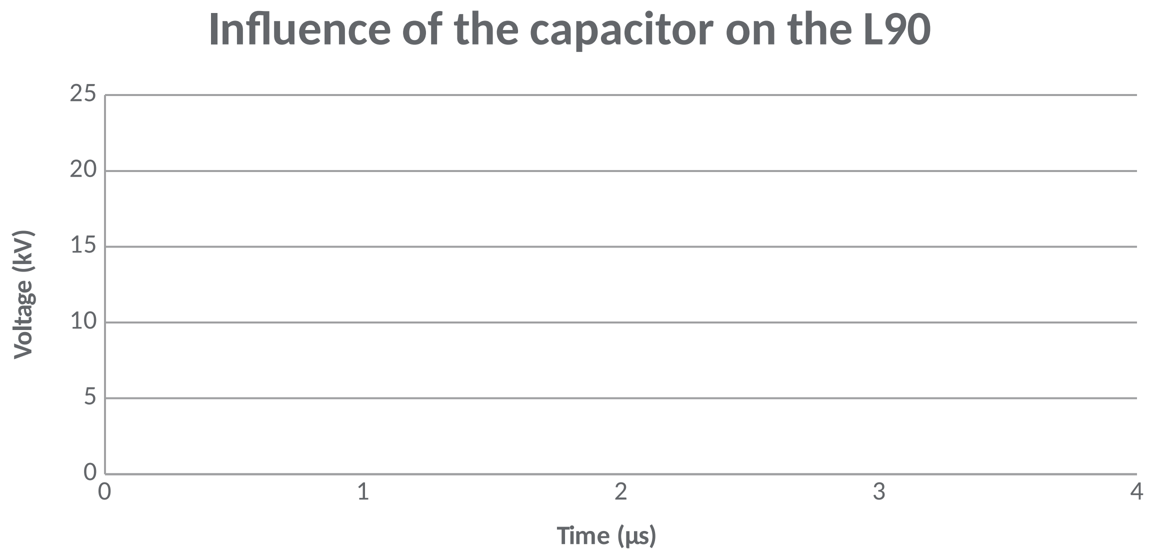


The **filling pressure** is linked to the **minimum temperature** to avoid liquefaction

As example, **increase** the filling **pressure** from 3barA to 5barA, the **voltage** can be **increase** from 50kV to 75kV (service pressure vessel are designed up to -15°C)

Increase the performances

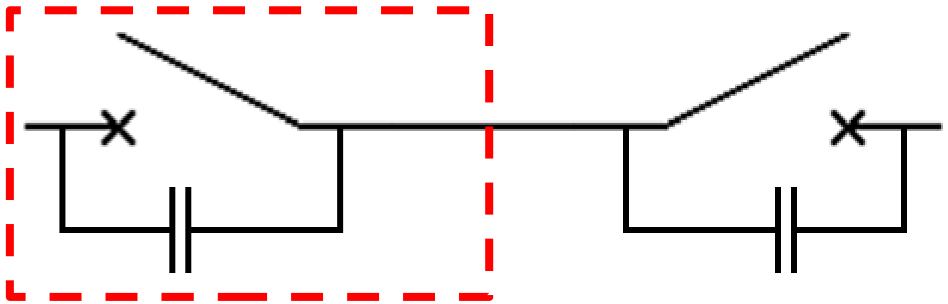
Possible adjustment: Add capacitors on the chambers



Rise of the voltage from the line without capacitor

Rise of the voltage from the line with the influence of a parallel capacitor (2nF)

Add capacitors will **delay** the rise of the line for short line fault



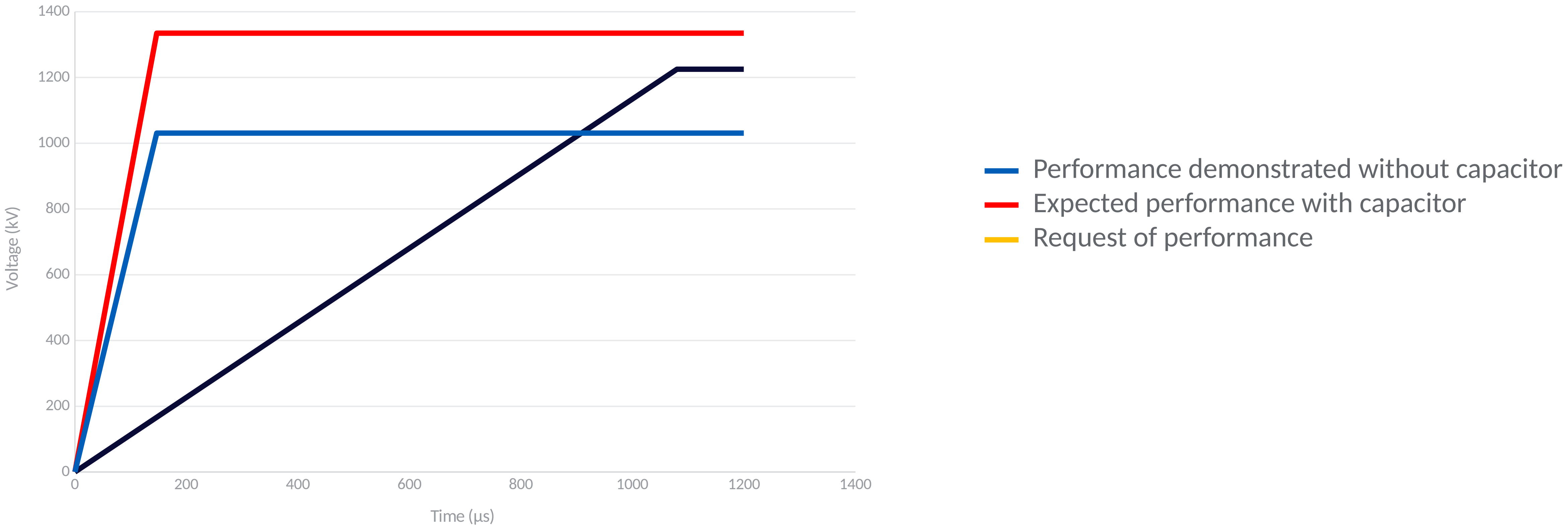
With capacitors, the **repartition** of the voltage on one chamber of a **two phases circuit-breaker** is closed to **70%** without grading capacitors and close to **50%** with grading capacitors

Once again, add **capacitors** on the chamber(s) will **increase** the **price** of the **circuit-breaker**

CIGRE Chile: Transient Recovery Voltage (TRV)

Increase the performances

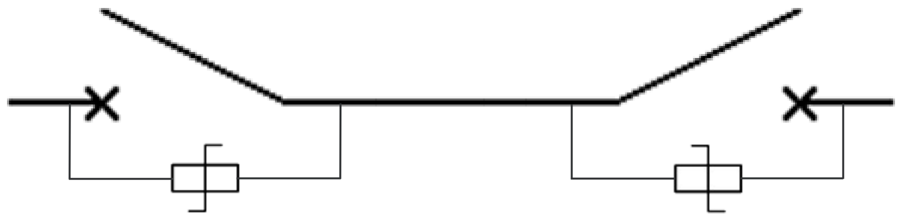
Possible adjustment: Add capacitors on the chambers

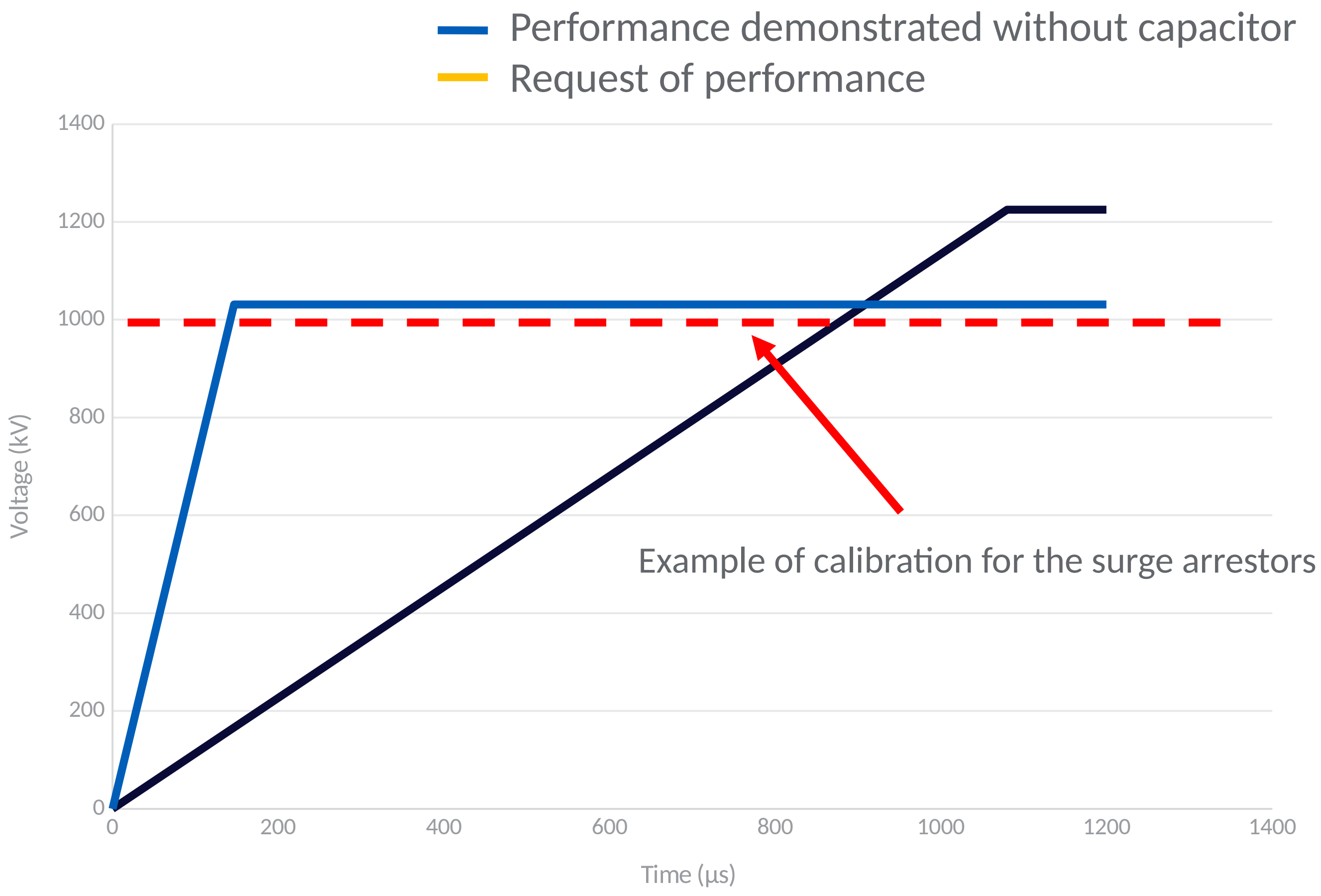


The **today chamber** with **capacitors** may be sufficient to **reach** the **peak** of the **voltage**

Increase the performances

Possible adjustment: Add surge arrestors





The surge arrestors will **limit** the **peak** of the **voltage**

Increase the performances

Possible adjustment: Add surge arrestors and/or capacitors

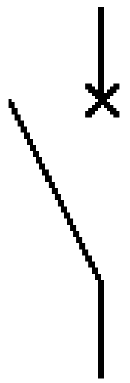
One **drawback** of these solutions is the **weight** of the total chamber(s) for the **seismic issue**

New developments are in progress to **solve this issue**

Increase the performances

Possible adjustment: Add chamber(s)

The 245kV is a one chamber circuit-breaker



Add a second chamber is series helps to increase the performance

The natural **repartition** of the **voltage** is **70-30%**

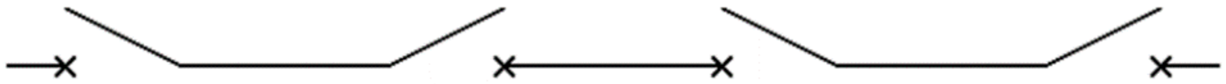
Add a **second chamber** will increase the **price** of the **global circuit breaker**

Increase the performances

Possible adjustment: Add chamber(s)

Add chambers can be also done for the 550kV

2 chambers (today design)



2 other chambers can be added in series

On this architecture, the **voltage** on **one chamber** is around **30%** of the full voltage (with capacitors)

Once again, this will **increase** the **price** of the **global circuit breaker**

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6) Experiences and other markets

Futures developments

The **today performances** are following the **market** and the **standard** to have volume
Keep the same **chamber** will also increase the **reliability** of the circuit-breaker

Voltage (Ur – kV)	Rated short circuit current (Icc – kA)	Frequency (Hz)	First pole to clear factor	Minimam temperature (°C)
245	40/50	50/60	1.3	-30/-25
550	40/50	50/60	1.3	-30/-25

The **demonstrations** of the TRVs were based on **these parameters**

Reach **higher performances** is **possible** with extra **tests** following the **requests** of costumers
Adjustments (minimum temperature for example) according **Chilean market** can be done to increase the performances

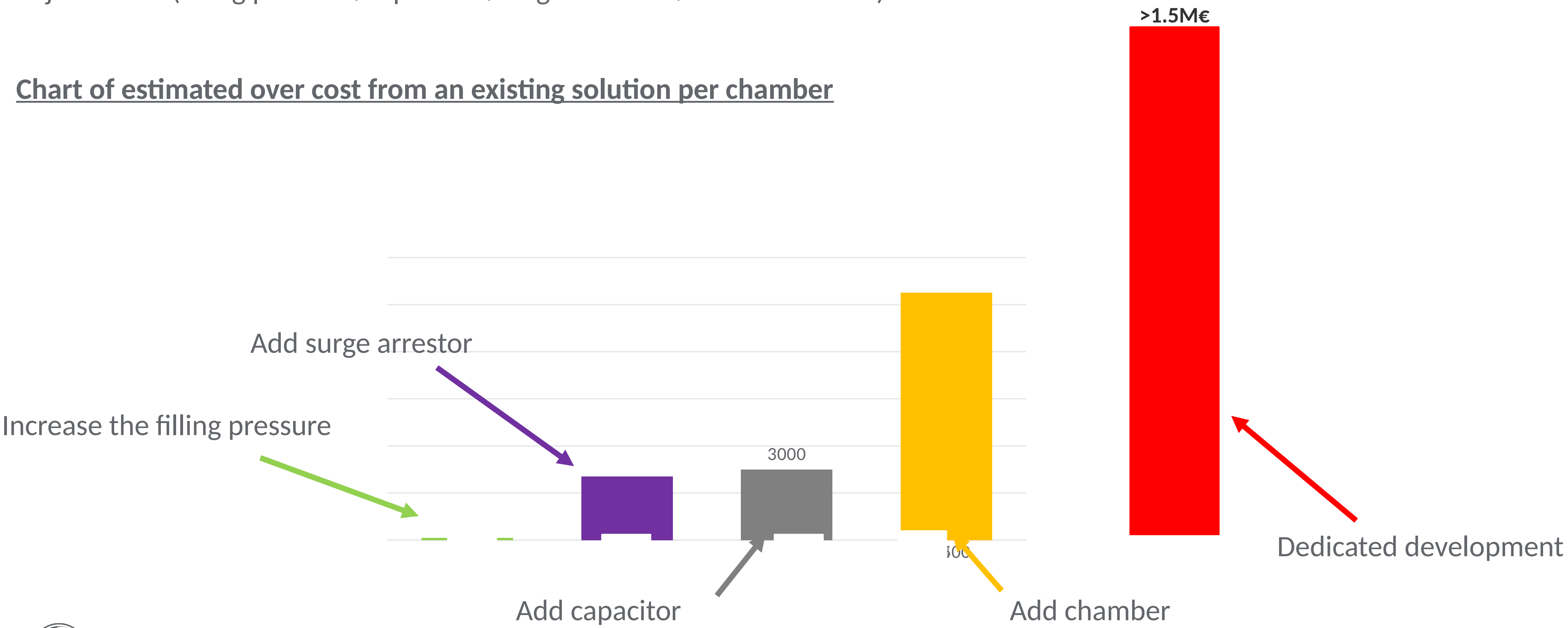
The **main requests** are with a reduction of the rise of the voltage and a higher peak
These conditions were **demonstrated** for the **Chilean market** and for other markets

Futures developments

New developments is possible (some are in progress), but **following** the values from the standard and **large markets**

For **special requests**, the best option is to do a **risks analyses** with an **existing design** and perform the **test** with the same design or with adjustments (filling pressure/capacitors/surge arrestors/more chambers)

<u>**Chart of estimated over cost from an existing solution per chamber**</u>



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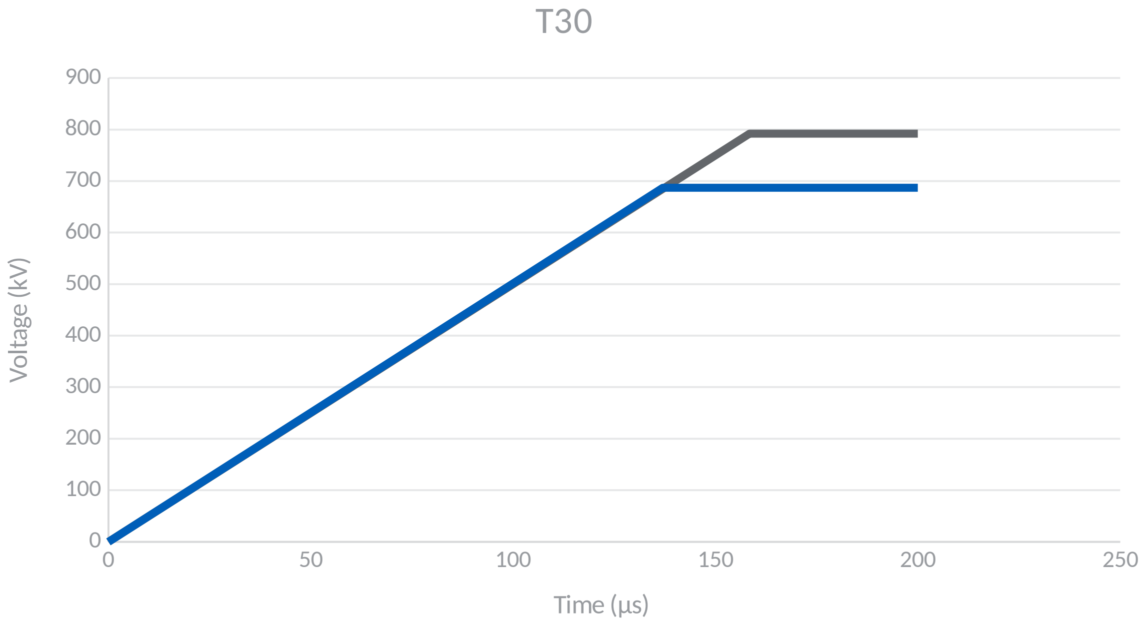
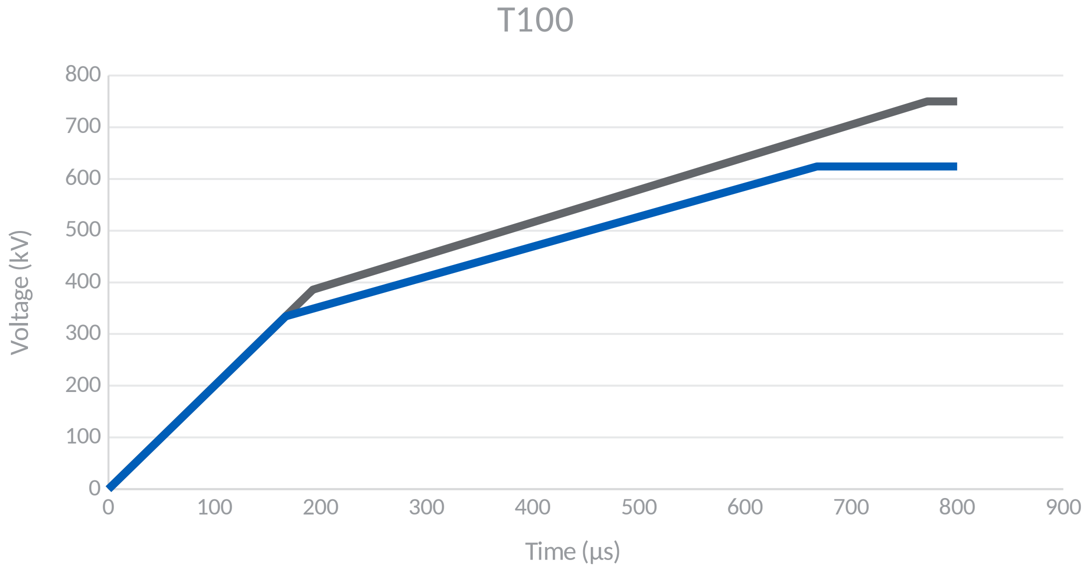
Experiences and other markets

On the other **markets**, the **requests** are following the **standard** (IEC & IEEE mainly)

The are **special requests** from the **customers**, but following the values from the **standard**





For example, the kpp was increased from **1.3** to **1.5** on a dedicated market with the **existing chamber**

Conclusion

The today **performances** demonstrated are **following** the **standards** (IEC and IEEE)

Reach **higher TRVs** is **possible** with the **today** circuit-breaker **range**
For that, **studies** can be done to select the **best design** and, if needed, adjust our **common chamber** (increase the minimum pressure for example)

In any case, we need to know your requests **as soon as possible** to analyze the request and **propose** the **best option**
An efficient **communication** should be set up to select the best design for **customer/application**

Conclusion

Thank you for your attention

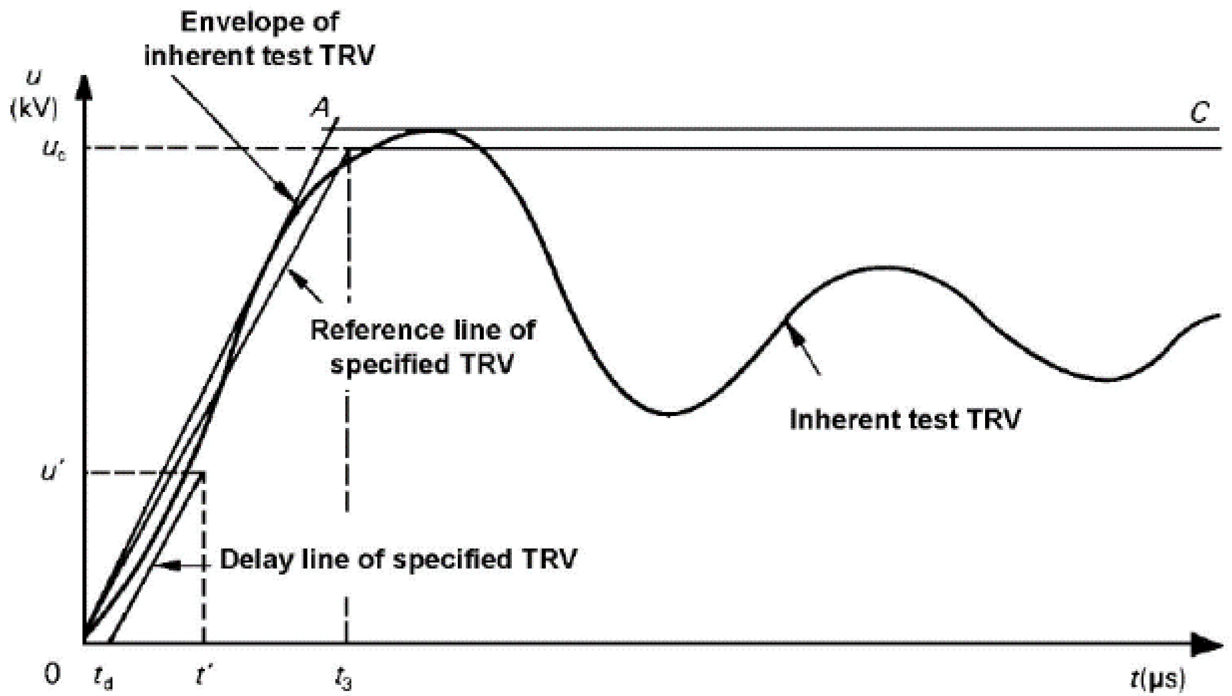
Do you have any question?

GE

General considerations

Terminal fault: Dielectric capability

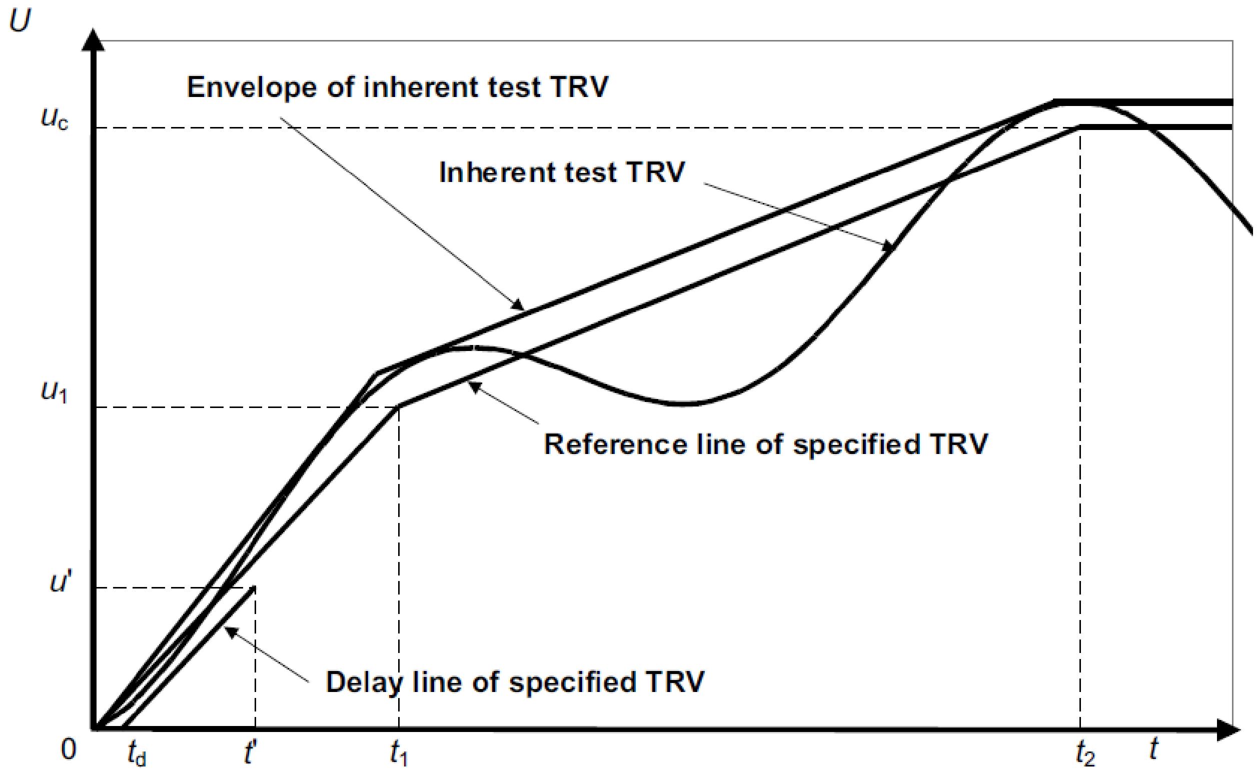
Example of TRV with two parameters



General considerations

Terminal fault: Dielectric capability

Example of TRV with four parameters



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