Elia Training Center

A short introduction to Protection and Automation Philosophy

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- Definitions and basic concepts
- Differential and distance protection functions – a short introduction
- Protection system of 150 / 220 / 380 kV interconnections
- Protection system of busbars
- Protection system of transformers between busbars
- Bay arrangements
- Transformer 150 / 70 teed on 150 kV interconnection line

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Definitions and basic concepts

What is a fault?

In the context of this lecture, a fault is:

"a low-resistance connection between two points in an electric circuit through which the current tends to flow rather than along the Intended path"

Faults are characterized by:

-Their **nature**

Typical examples: 1-phase / 2-phase / 3-phase, phase-to-phase / phase-to-ground, metallic / with arc resistance, transient / permanent

-Their **cause**

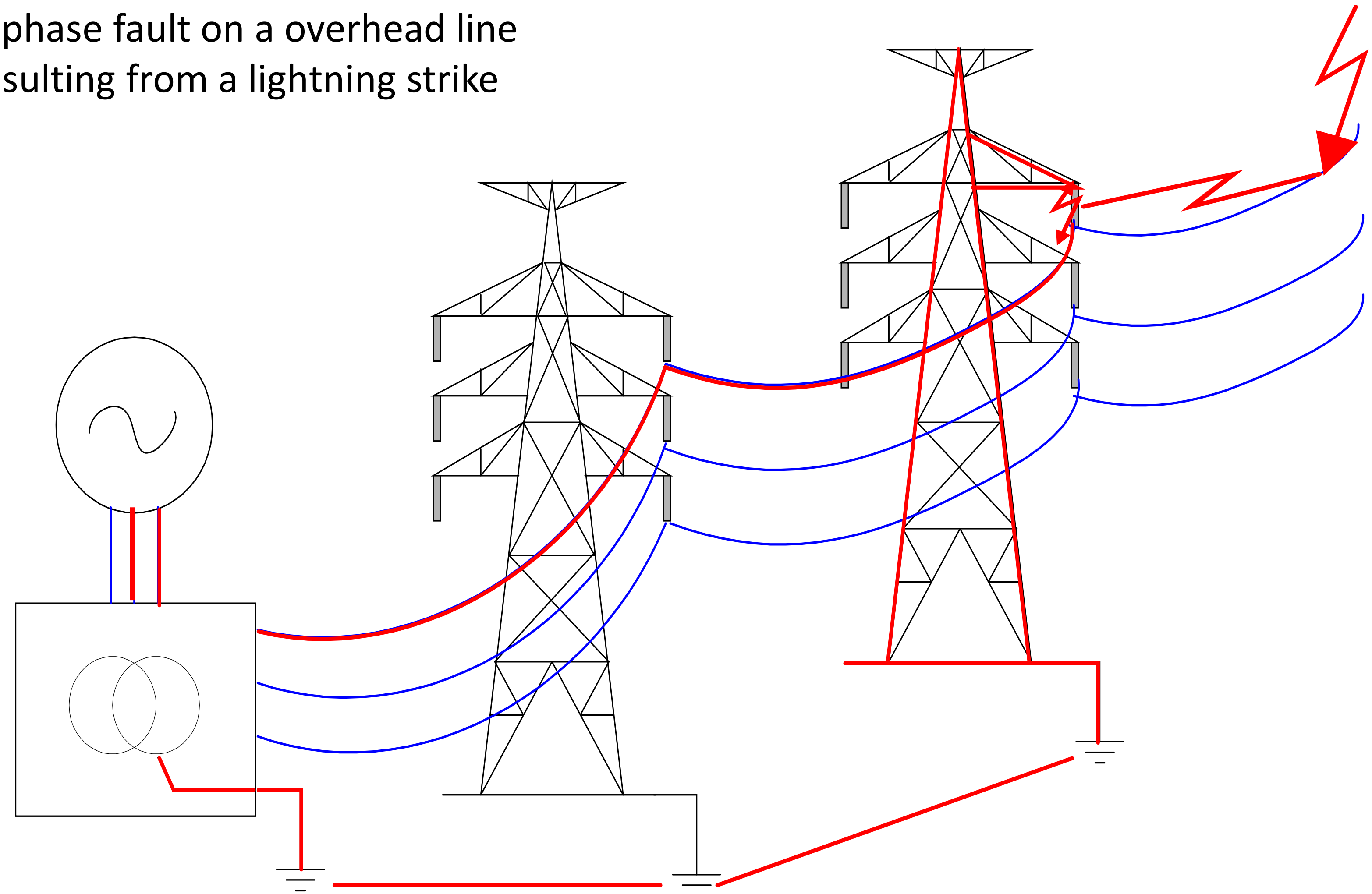
Typical examples: lightning strokes, equipment failure, human errors ...

-Their **consequences**

Direct consequences are low voltage(s) and / or high current(s)

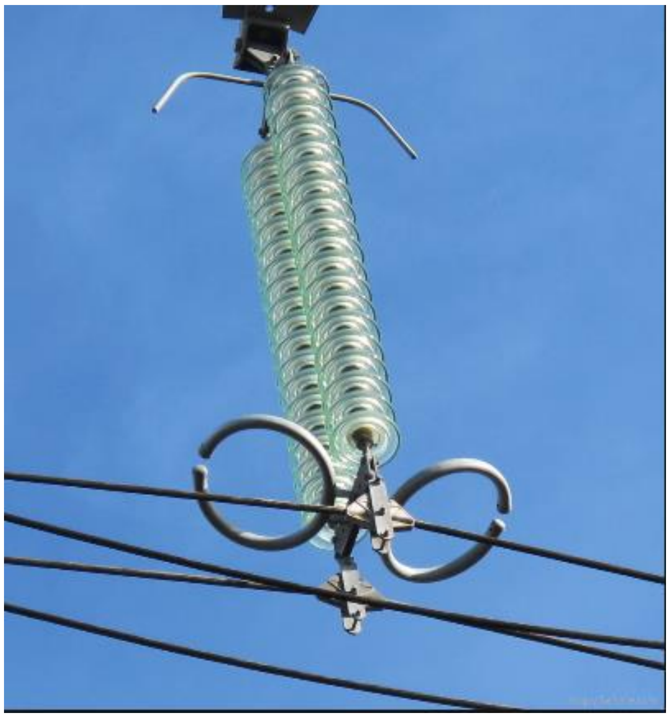
Typical example

1-phase fault on a overhead line
resulting from a lightning strike



Surge arrester

Goal: stop the propagation of the overvoltage wave travelling on the transmission line



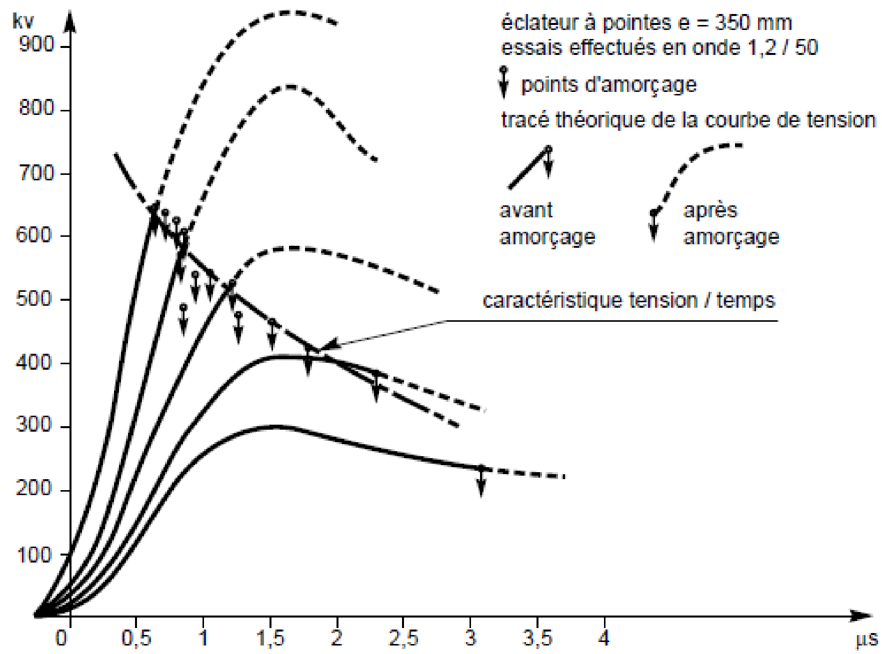
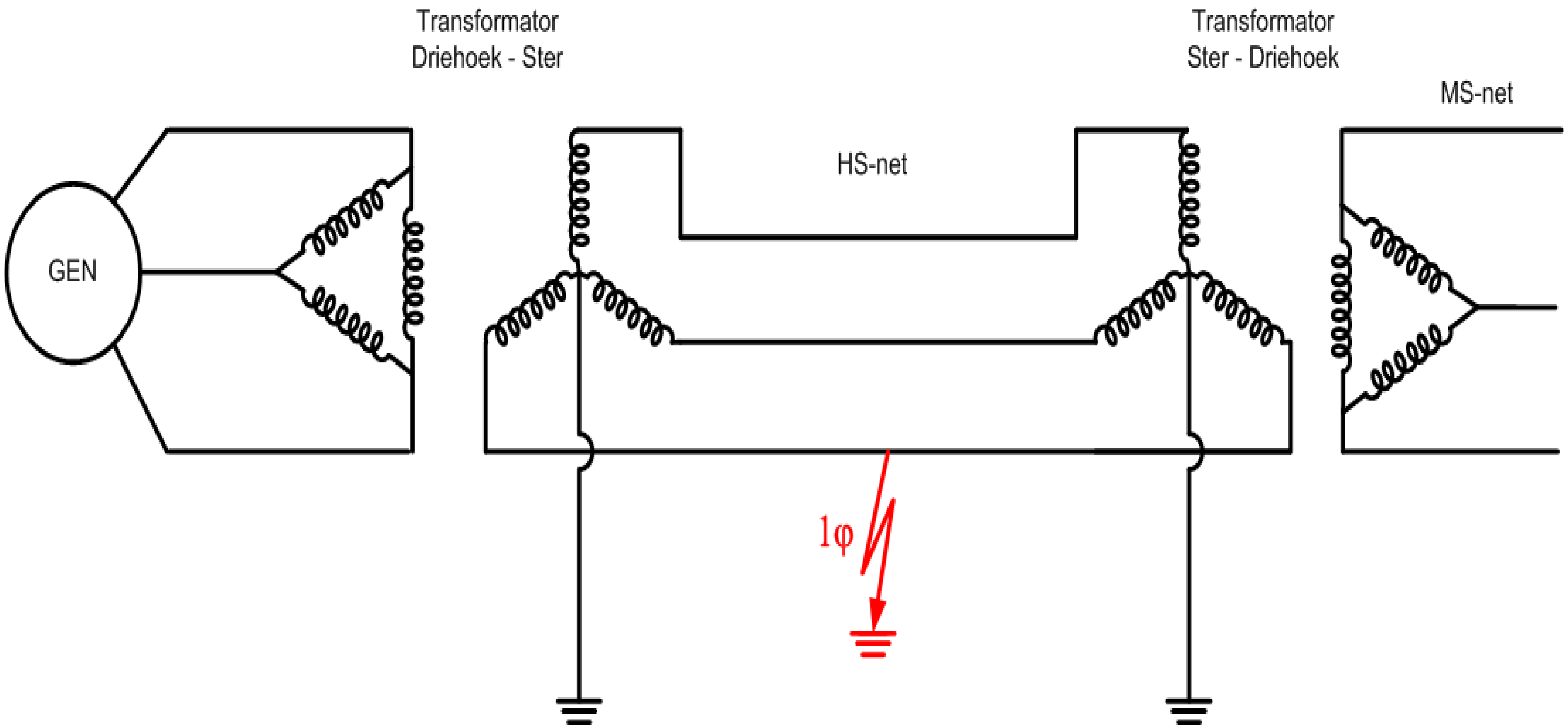


fig. 22 : comportement d'un éclateur à pointes, en choc de foudre normalisé, en fonction de la valeur de crête.

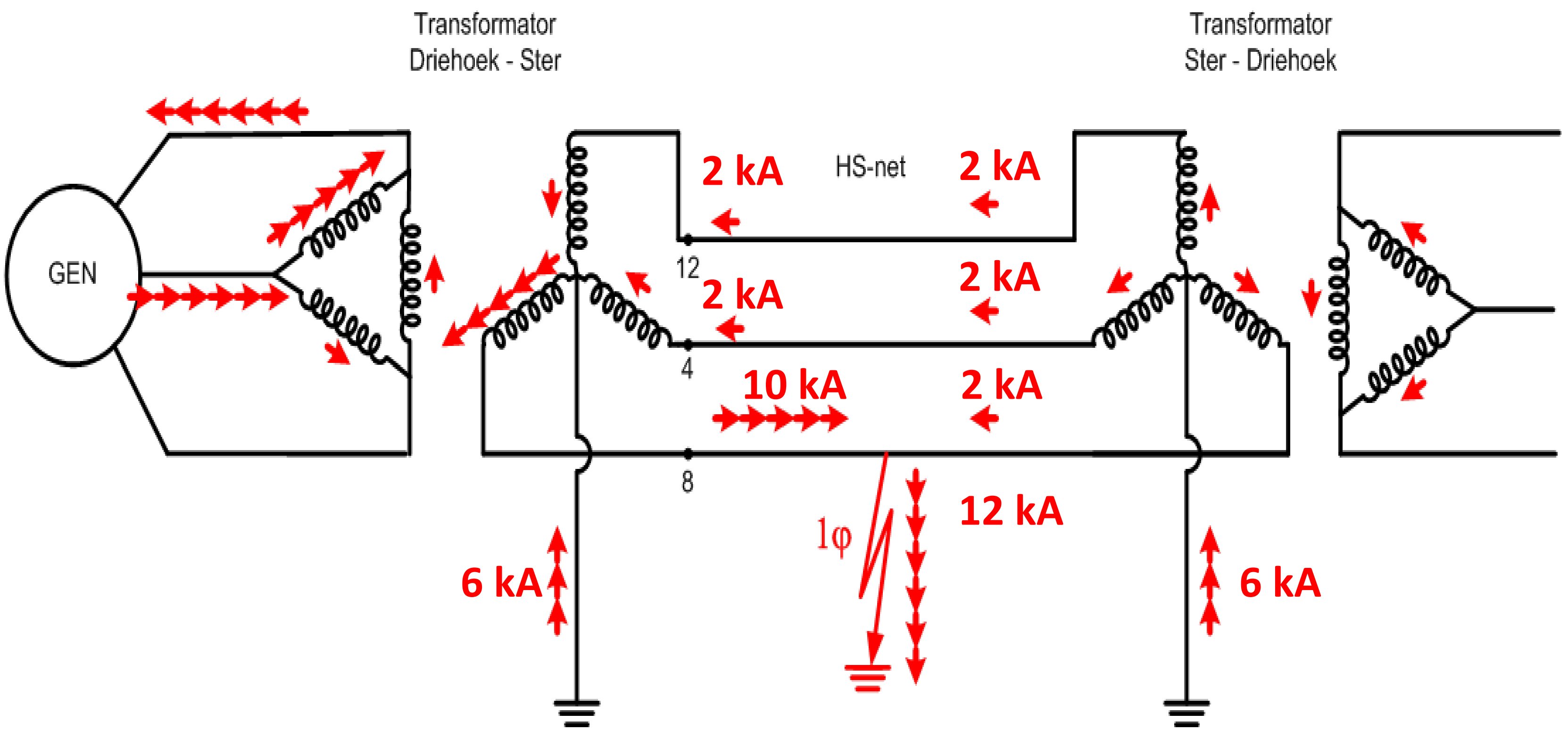
Typical example

1-phase fault on a overhead line
resulting from a lightning strike



Typical example

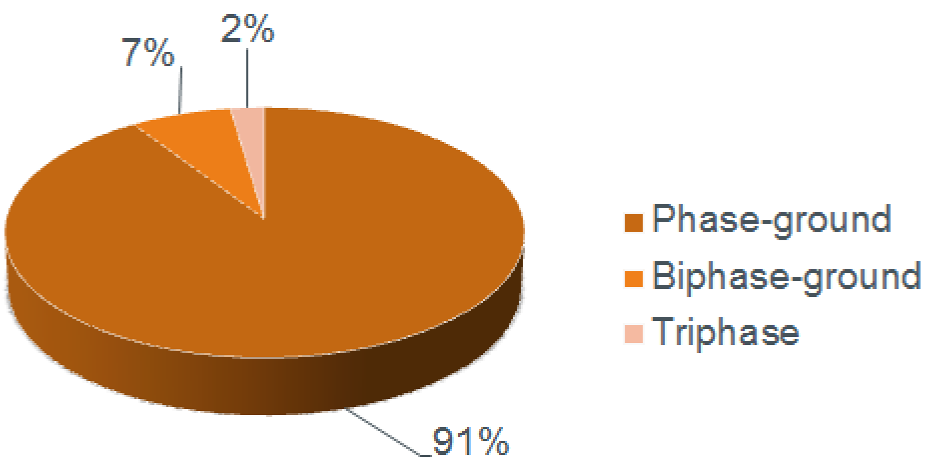
1-phase fault on a overhead line resulting from a lightning strike



$$Uo = \frac{U_4 + U_8 + U_{12}}{3} \qquad Io = \frac{I_4 + I_8 + I_{12}}{3}$$

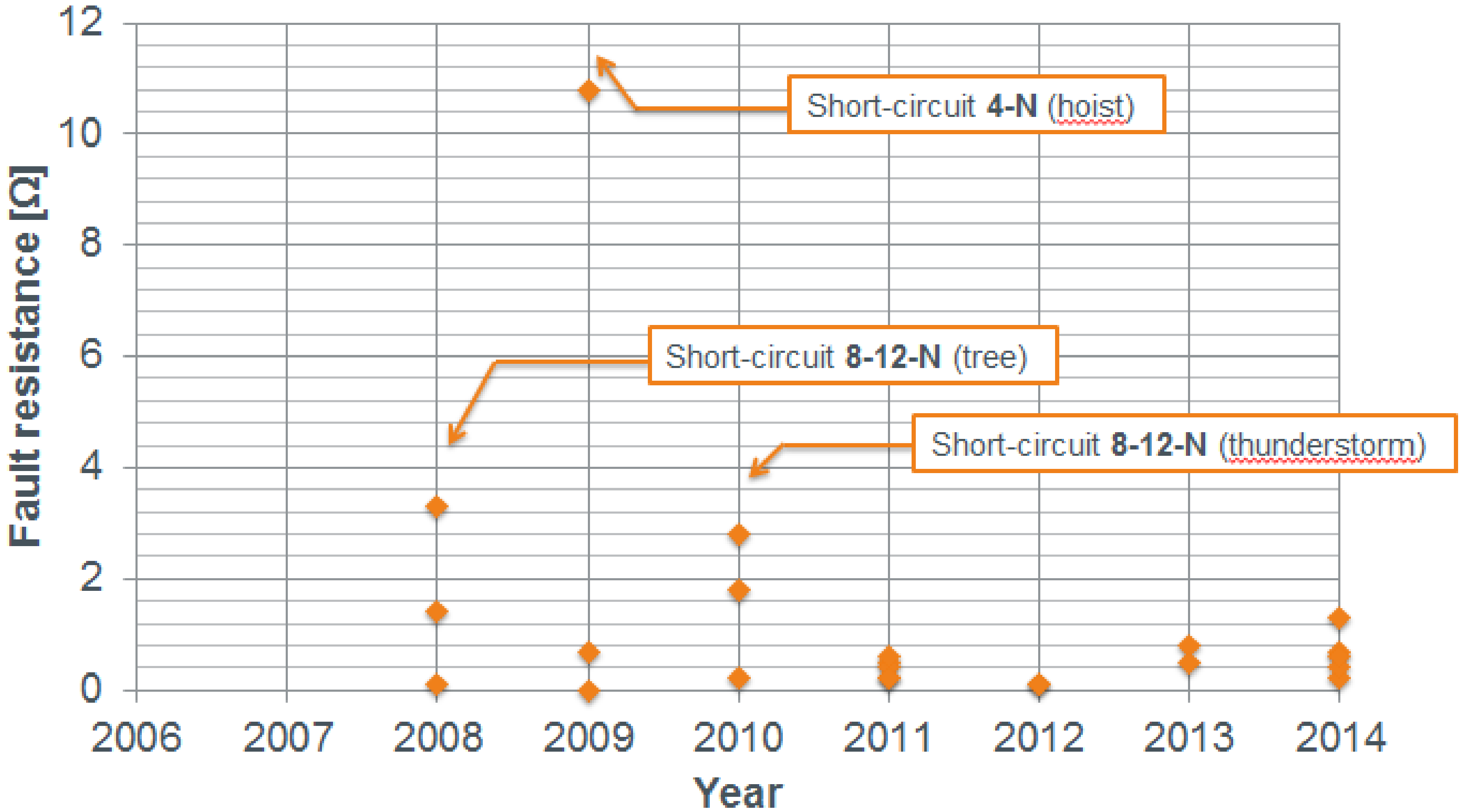
What is a fault?

Type of faults registered on the 380 kV between 2006 and 2014



What is a fault?

Faults restistance values registered on the 380 kV between 2008 and 2014



What is a fault?

Faults can also have important impacts:

- **Safety**

https://www.youtube.com/watch?v=YPsALFWtuqY

- **Thermal effects on equipment,** with risk of damage / destructions

https://www.youtube.com/watch?v=D8EQPx-ptKk

- **Mechanical efforts on equipment**, with risk of damage / destructions

https://www.youtube.com/watch?v=2j8D_N1v0tU

- **System instability**

- Customers installations / processes (**power quality / voltage dips**)

Once a fault happens, it must be eliminated as fast as possible

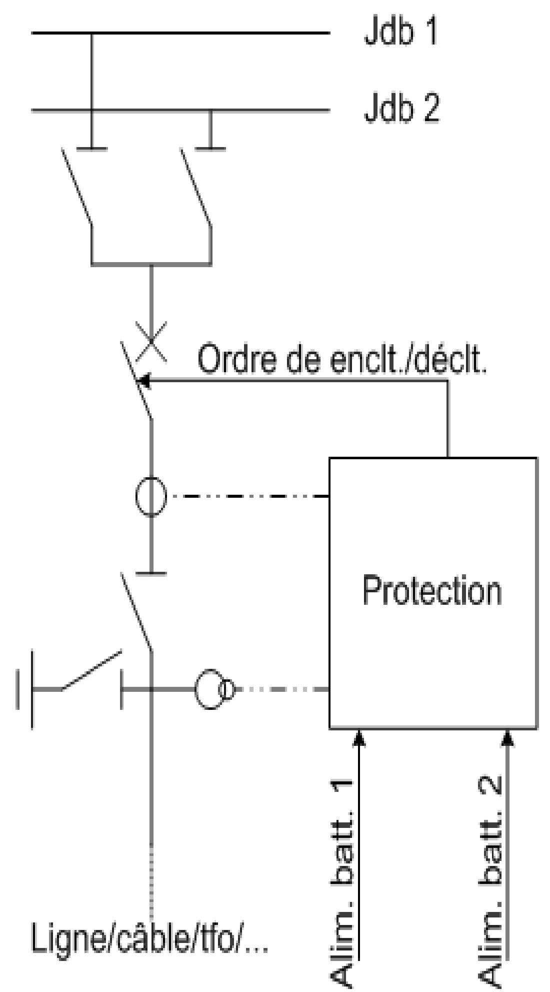
What is a protection system?

A protection system is the set of equipment and functions aimed at detecting a fault and tripping the network component where this fault is located.

Main components of a protection system:

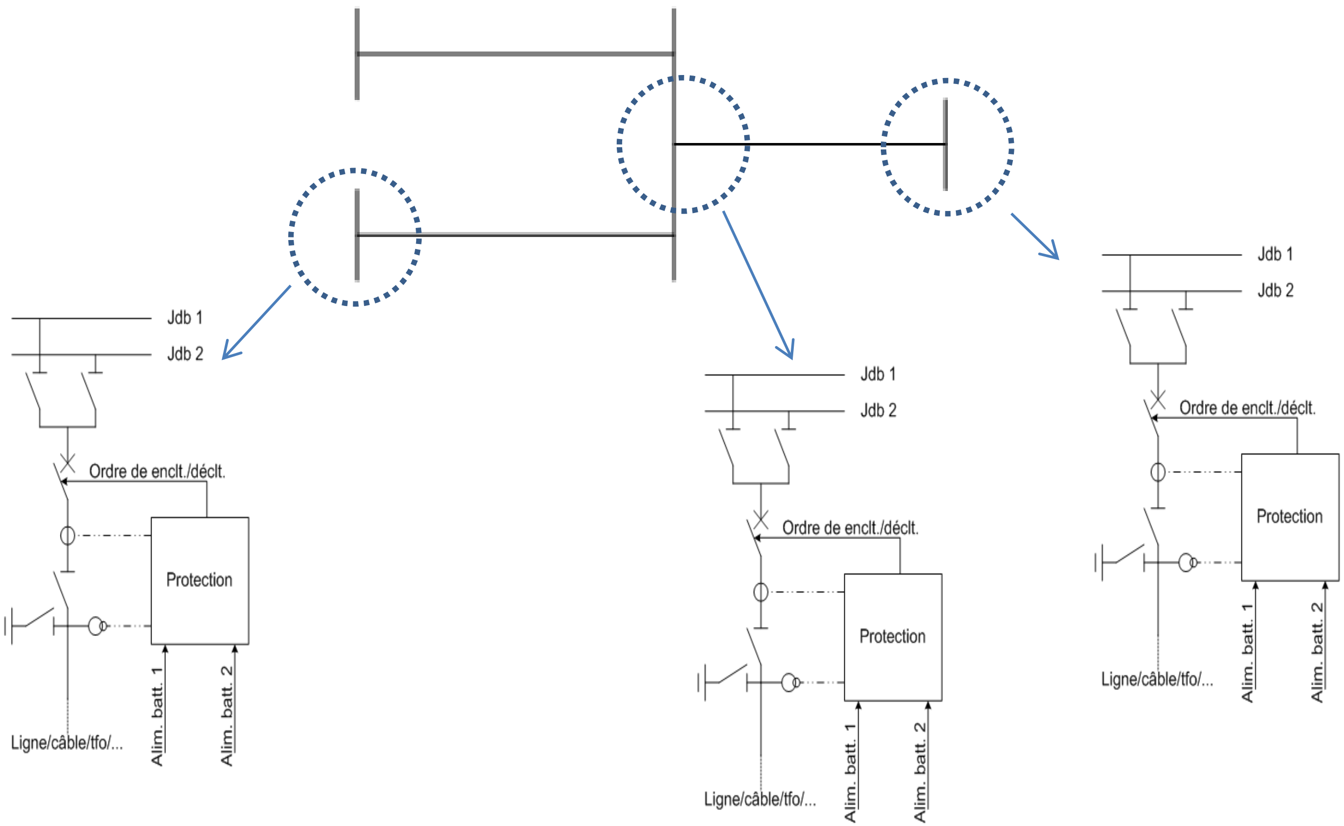
- **Measurement transformers:** Current Transformers (CTs) and Voltage Transformers (VTs)
- **Protection function(s):** makes the decision to trip the circuit breaker from CTs and VTs measurements
- **Circuit breaker:** trips the network component and interrupts the shortcircuit current

This lecture is limited to equipment protections (system protections are not considered)



What is a protection system?

A protection system does not only relate to one bay, but to a set of bays through appropriate coordination of the corresponding protection functions



Measurement transformers

Measurement transformers are devices designed to provide in their secondary coil a signal proportional to the voltage or current in its primary side

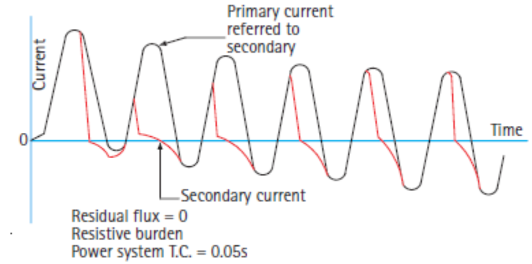
Voltage transformer

Can introduce measurement errors but cannot saturate (low voltage during faults)

Current transformer

Can introduce measurement errors and saturate (large current measured during fault)

Saturation must be avoided during the time required by the protection to make the decision to trip, through appropriate design of the CT (max Icc, burden on secondary side, precision class)



Circuit breakers

Circuit breakers are devices designed to energize / trip network components, with the possibility to interrupt shortcircuit currents.

Main characteristics of a circuit breaker:

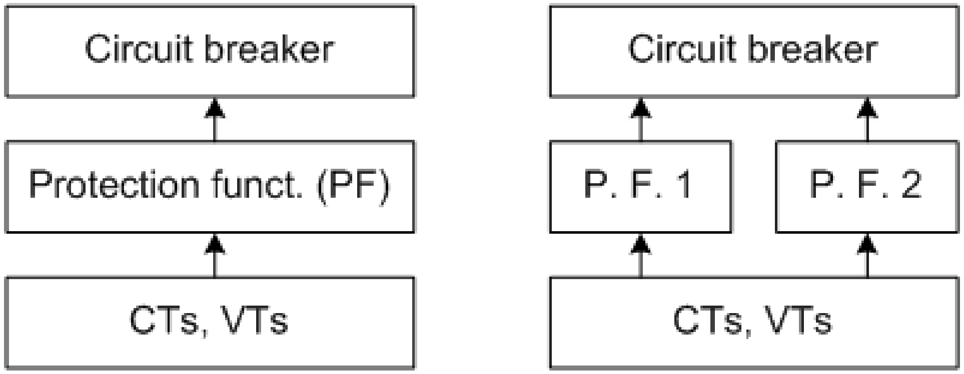
- Nominal voltage
- Shortcircuit current
- Medium used for arc extinction: SF6, vacuum, air blast, CO2 …
- Max I^2t allowed
- Speed of operation

Characteristics of protections

Protection systems can be characterized with the following attributes:

- **Dependability**: « A dependable protection is one that always operates for conditions for which it is designed to operate » [3]
- **Security**: « A secure protection is one that will not operate for conditions for which it is not intended to operate » [3]

Dependability enhancement leads to Security worsening, and Security enhancement leads to Dependability worsening



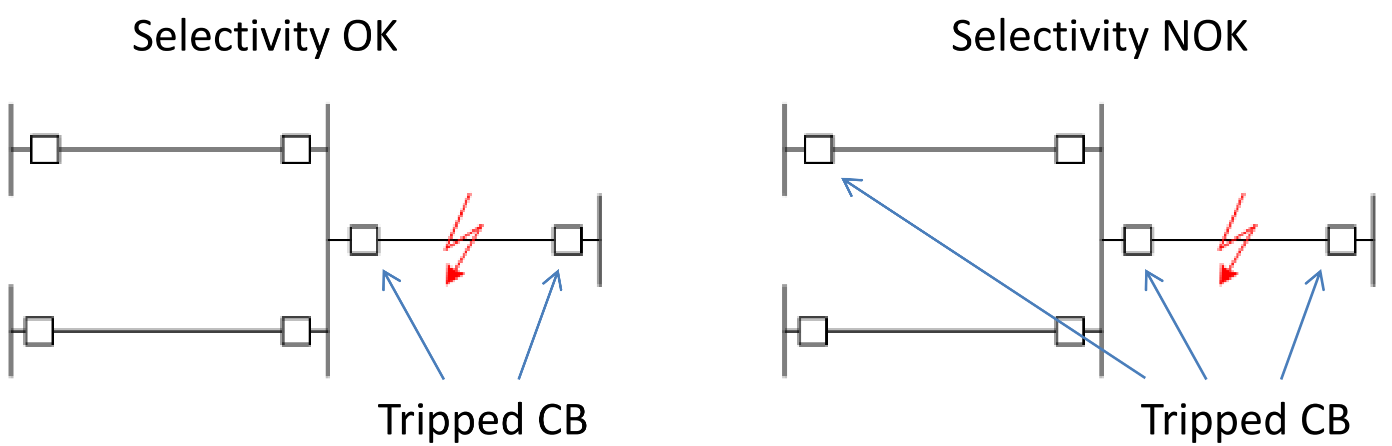
2 protection functions:

- more Dependable
- … but less Secure

[3] "The Electrical Engineering Handbook", IEEE press, pp 1270

Characteristics of protections

- **Reliability**: the protection system is both dependable and secure, according to the level of dependability and security for which it has been designed
- **Selectivity of a protection system**: the circuit breakers that must be tripped to eliminate the fault are the only ones to be tripped



- **Speed**: relates to the time needed by the protection system to eliminate the fault

Main type of protection functions

Most usual protection functions used in TSO application:

- Distance protection function (see next slides)
- Differential protection function (see next slides)
- Under/overcurrent protection function
- Under/overvoltage protection function

Nowadays, protection functions are implemented through numerical relays.
Several protection functions can be used in the same physical device.

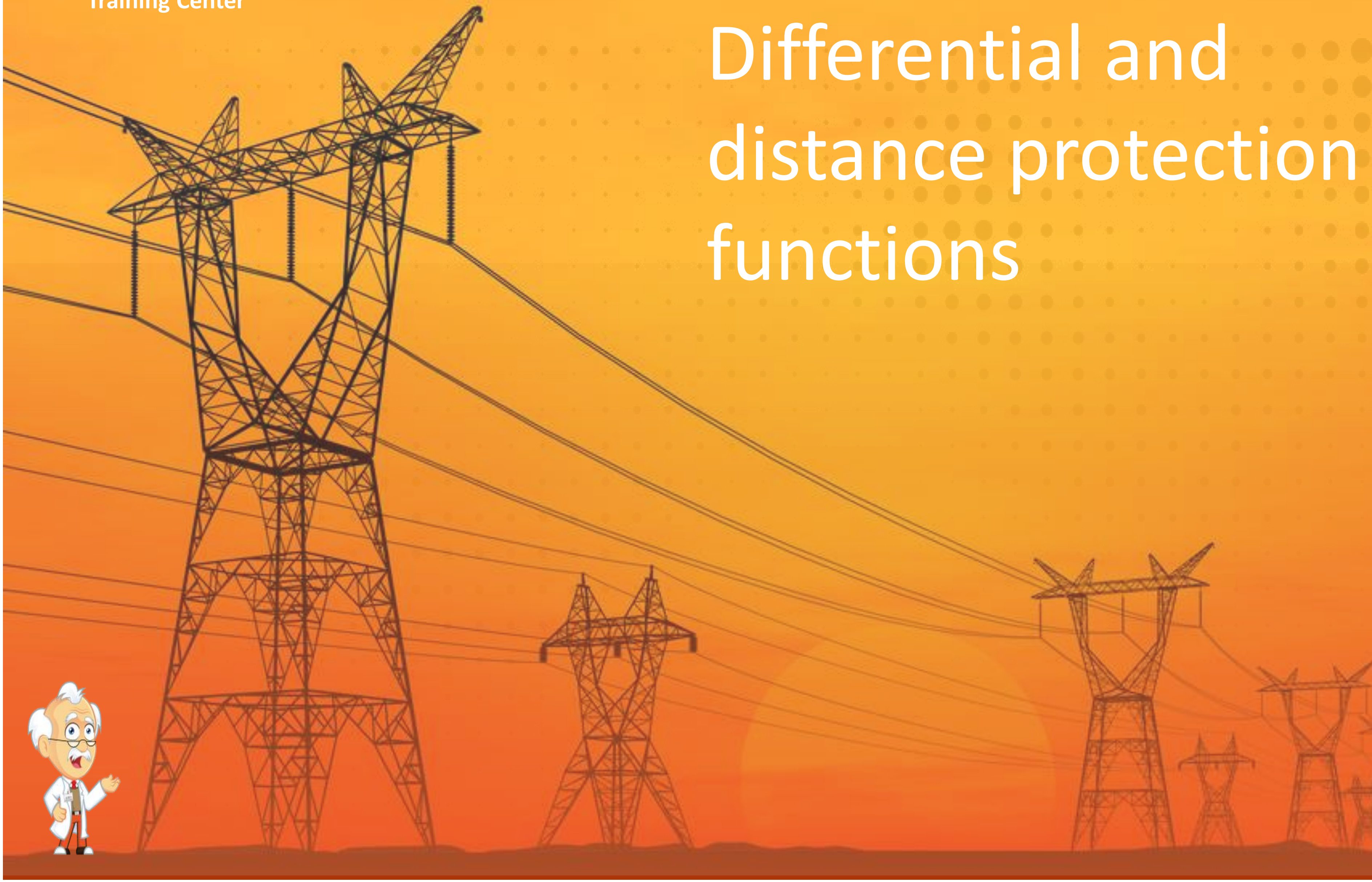
Fig. 7/41
SIPROTEC 4
7SD52/53 differential protection relay

Protection system design

Designing a protection system consists in deciding which protection functions and devices must be implemented at the various substations / bays in order to fulfill the requirements stated in the grid code (see below), while ensuring a good level of selectivity and reliablity.

Spannings-niveai (kV)	LIJNEN, KABELS, TRANSFORMATOREN *									RAILFOUT		
	Basis (ms)	Weigering Beveiliging (ms)	Weigering Verm. Schakel (ms)	Weigering Verm. Schakel (ms)	Reserve volgende lijgn/kabel (ms)	Réserve volgend railstel (ms) ****		Herinschakeling luchtlijn (ms)		Basis (ms)	Reserve van de koppeling (ms)	
			1 f. fout	meerf.		1 f. fout	meerf.	1 f. fout	meerf.		1 f. fout	meerf.
Niveau de tension (kV)	LIGNES, CABLES, TRANSFO *									DEFAUT JEUX DE BARRES		
	Base (ms)	Refus Protect (ms)	Refus Disj. (ms)	Refus Disj. (ms)	Réserve ligne/câble suivant (ms)	Réserve jeux de barres suivants (ms) ****		Réenclenchement ligne (ms)		Base (ms)	Réserve du couplage (ms)	
			déf. mono	déf. poly		déf. mono	déf. poly	mono.	Poly-phasé		déf. mono.	déf. poly
380	100	100	300	170	1000	500	250	1	10	100	250	170
220	120	120	-	-	1000	600	600	1	***	100	300	300
150	120	120	-	-	1000	600	600	1	***	100	300	300
70	120**	2250	-	-	1000	600	600	-	***	600	-	-
36	120	2250	-	-	1200	1200	1200	-	***	600	-	-
30	120	2250	-	-	1200	1200	1200	-	***	600	-	-
15	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
12	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
10	1100	3100	-	-	-	1800	1800	-	***	1800	-	-

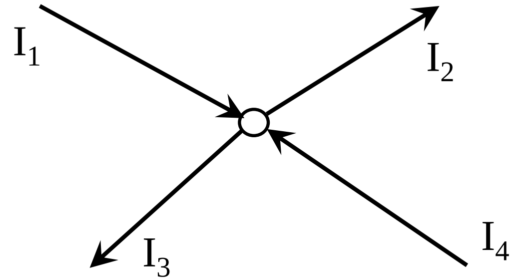
Differential and distance protection functions



Differential protection

First Kirchoff law: at any node in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node

.

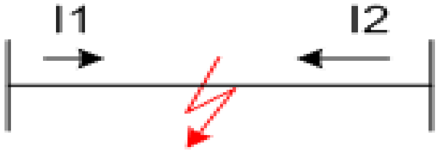


$$\Sigma I = 0$$

If the sum of all currents is not 0, there is a fault at the node

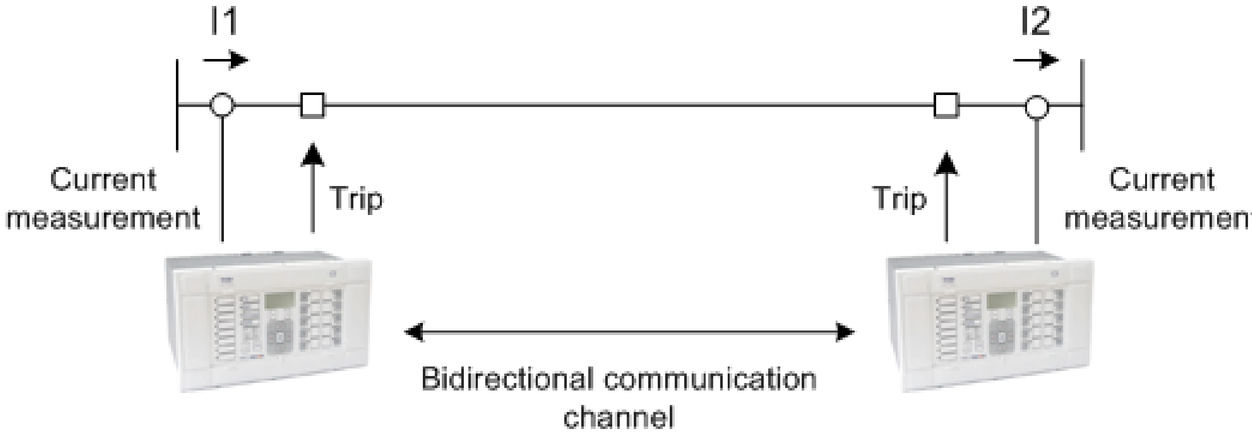
Application to overhead lines (shunt capacitors neglected):

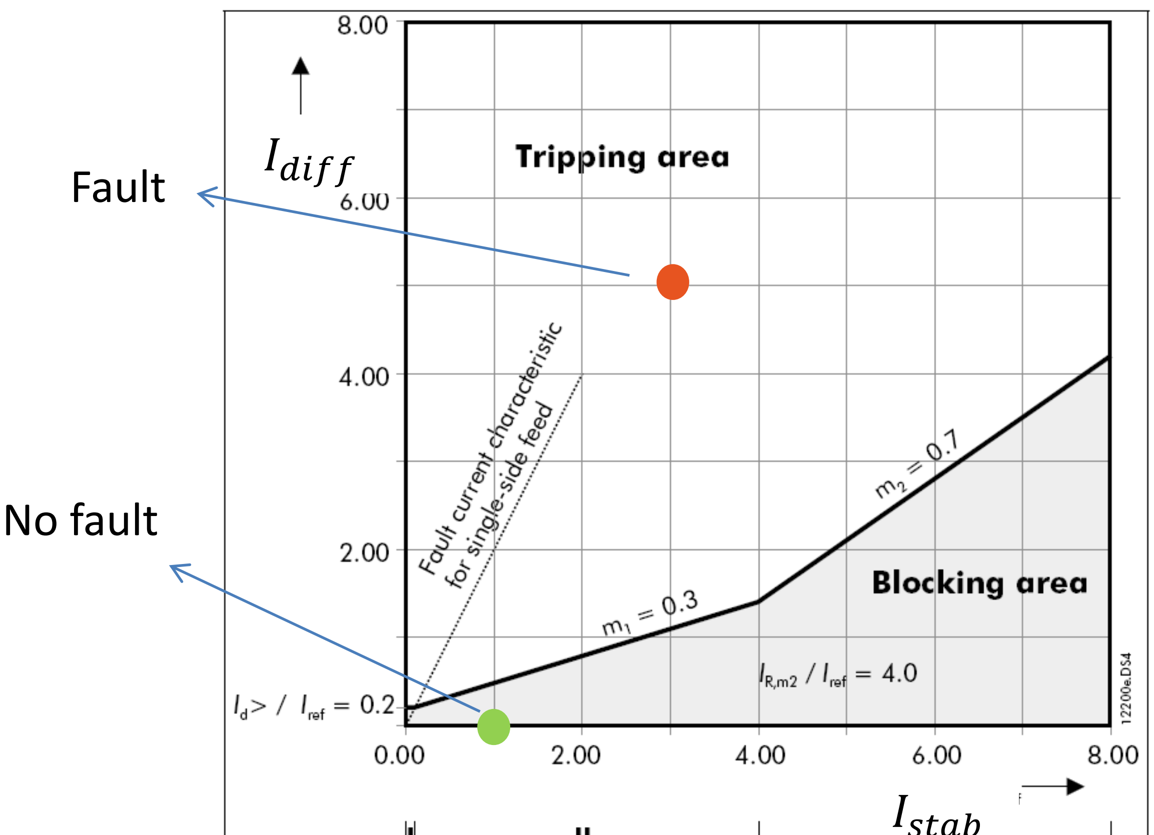
No fault: I1 + I2 = 0



Fault: I1 + I2 ≠ 0

Differential protection





$$I_{diff} = |\overline{I_1} + \overline{I_2}|$$

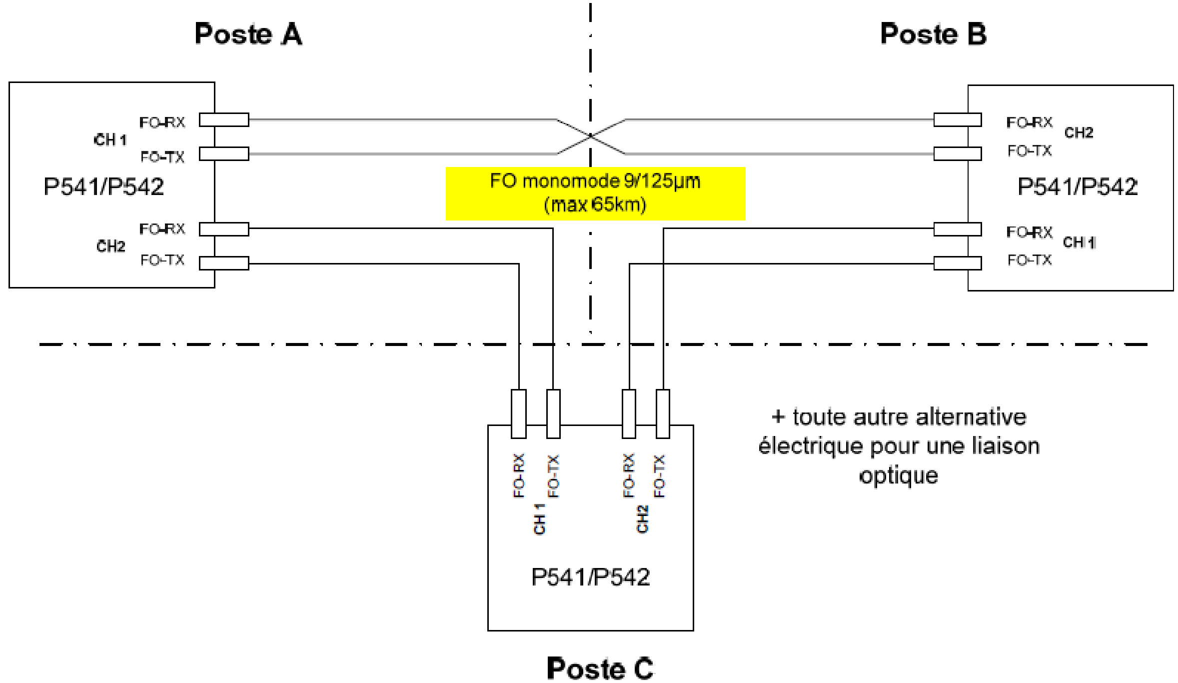
$$I_{stab} = 0,5|\overline{I_1} - \overline{I_2}|$$

Why stabilizing current and 2-slopes characteristic?

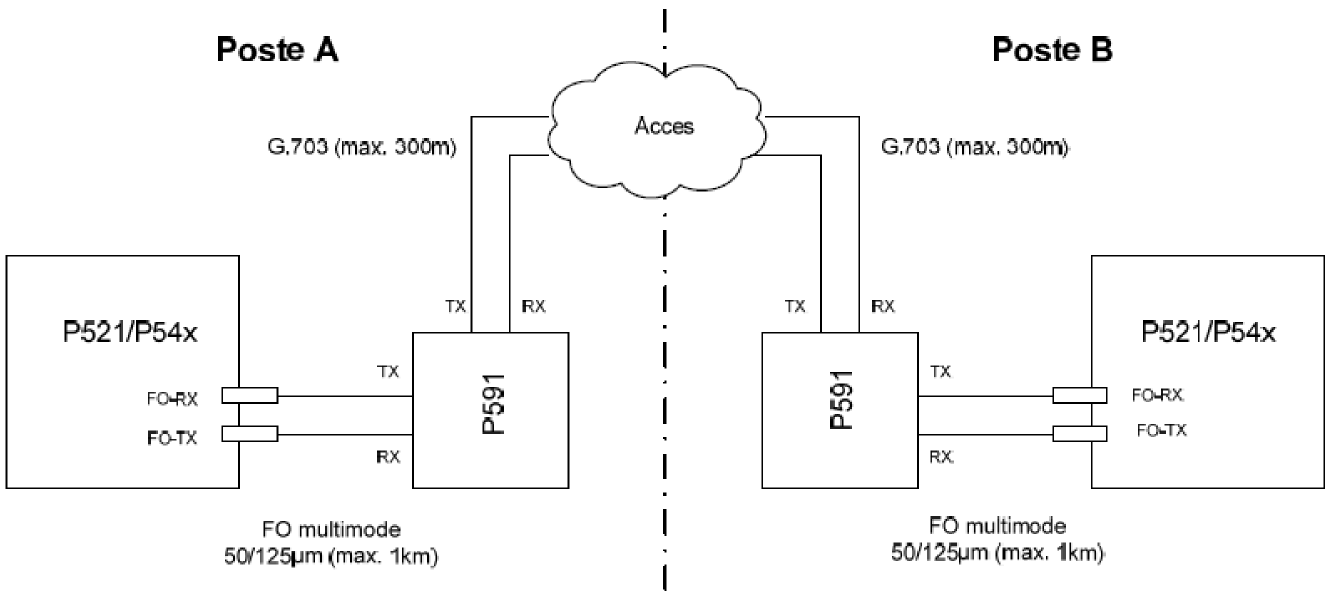
- Shunt capacitors
- On-load tap changers
- CTs errors
- CTs saturation

Telecommunication typical implementation

3-end line differential protection with direct communication through dedicated optical fiber



+ toute autre alternative électrique pour une liaison optique



2-end line differential protection with communication through TDM (« Access ») network

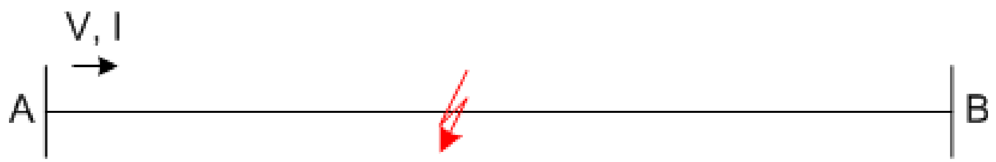
Differential protection

Differential principle applied to lines, cables, transfos and busbars

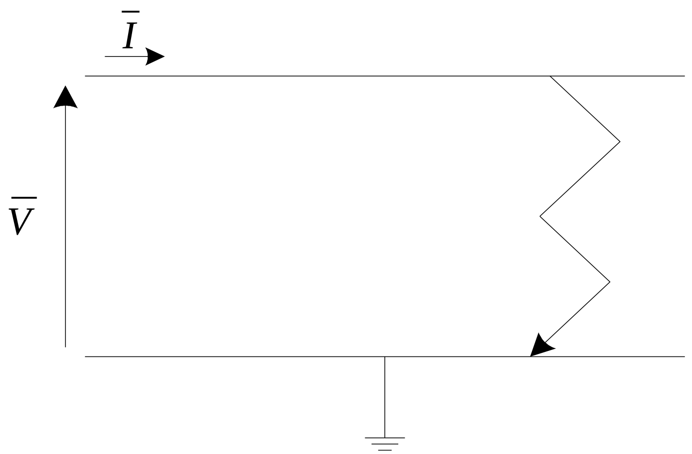
Main characteristics:

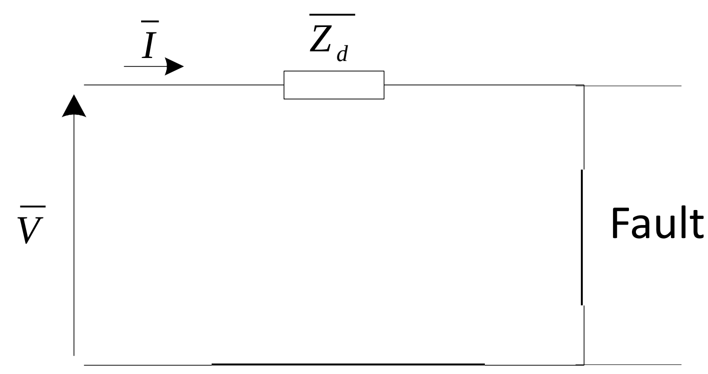
- Naturally selective
- Dependability and security barely dependant from network environment (short-circuits power at different ends, direct and zero-sequence impedances …)
- Requires CTs compatibility at all ends
- Requires permanent communication between the different ends (with symetrical paths)
- Differential protections must be replaced at all ends at the same time (no interoperability between different manufacturers / generations of devices)

Distance protection



3-ph fault without arc resistance



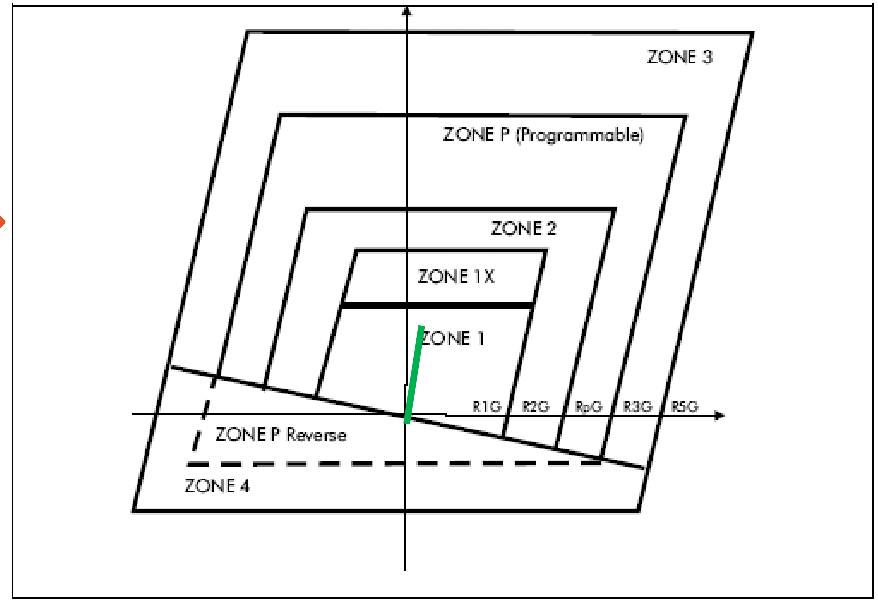


$$\frac{\overline{V}}{\overline{I}} = \overline{Z}_d$$

with Zd proportional to the distance between the busbar and the place of the fault

Conclusion: measurement of local voltages and currents allows to estimate the distance to the fault

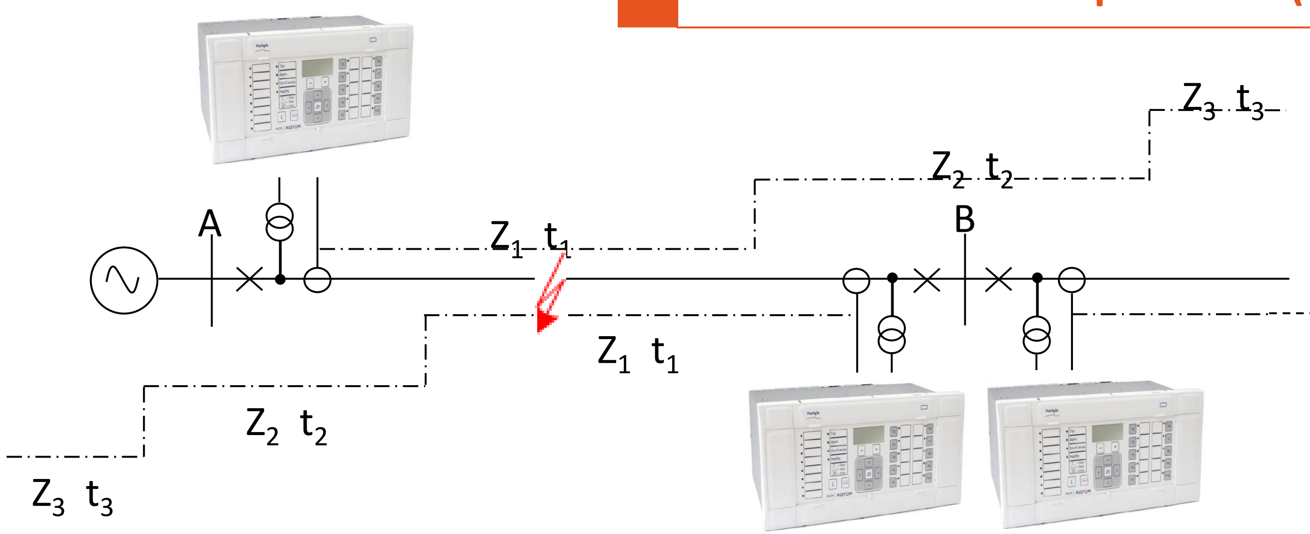
Distance protection



2 Locate Zd in the Z, R plane

1 From V and I, calculate Zd

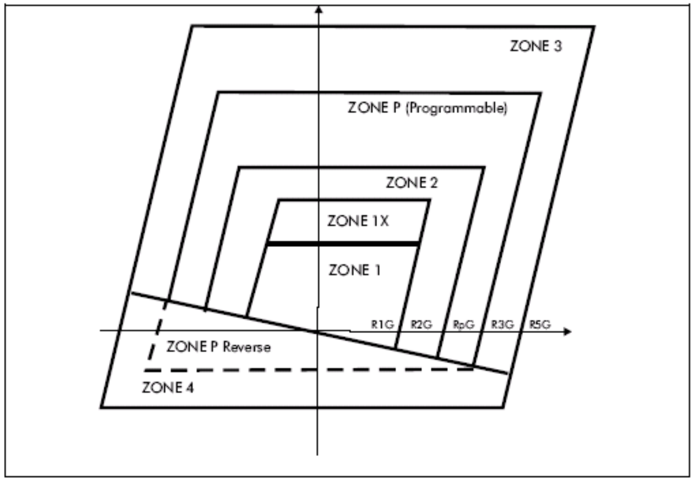
3 **Fault in zone 1 ⇨ trip after t1 (0 ms)**



Distance protection

Each zone is characterized by:

- Resistance and reactance limits
- Direction (forward / reverse)
- Time delay

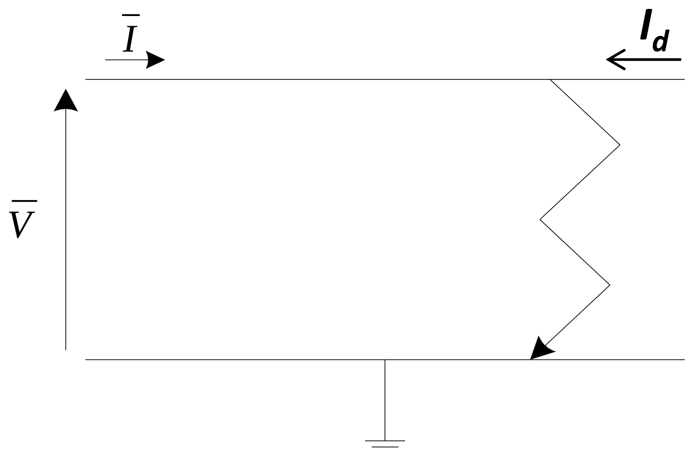


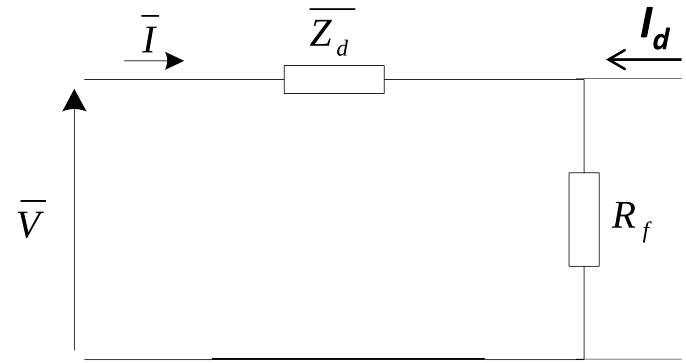
Zone 1: identification of a fault on the line, reactance limit usually set to 80% of the direct impedance of the line. Instantaneous tripping (decision after 30 ms)

Zone 2: backup for next forward busbar (busbar fault or circuit breaker failure in the corresponding bays). Reactance limit usually set to 120% of the direct impedance of the line. Typical Tripping time: 500 ms.

Zone 3: backup for next forward lines. Reactance limit usually set to cover the longest line. Typical tripping time: 900 ms.

Impact of fault resistance for 3-phase faults

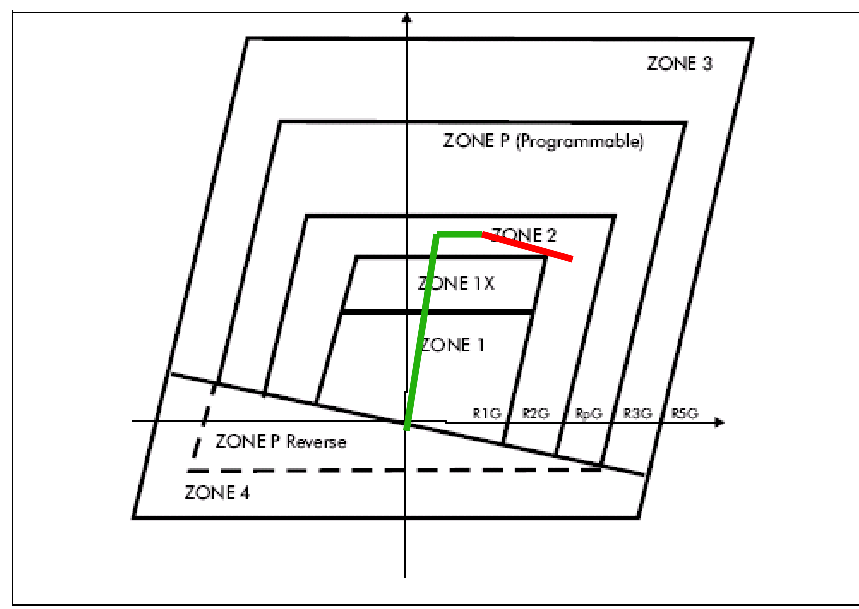




$$\frac{\overline{V}}{\overline{I}} = \underbrace{\overline{Z}_d + R_f}_{\text{Impedance to measure}} + \underbrace{R_f\left(\frac{\overline{I}_d}{\overline{I}}\right)}_{\text{Error}}$$

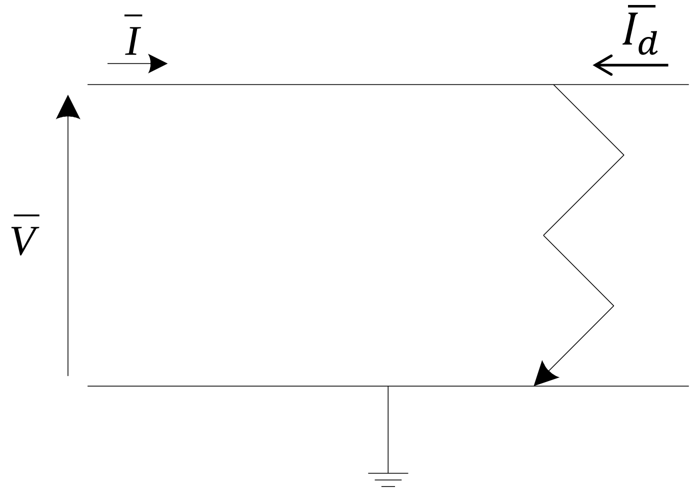
Impedance to measure

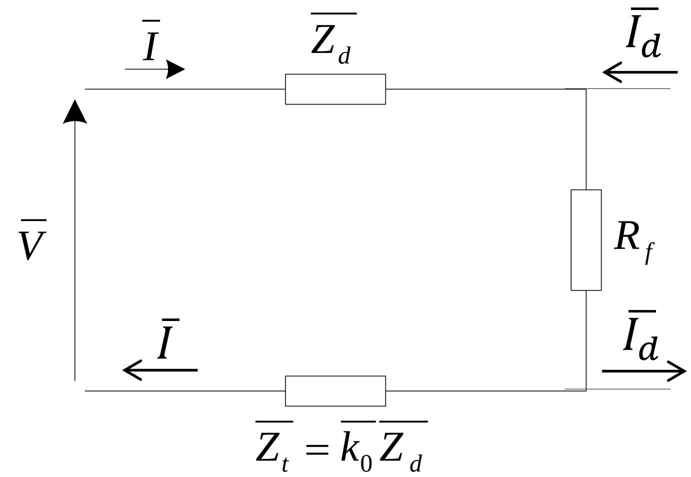
Error



Distance protection

Impact of fault resistance for 1-phase faults

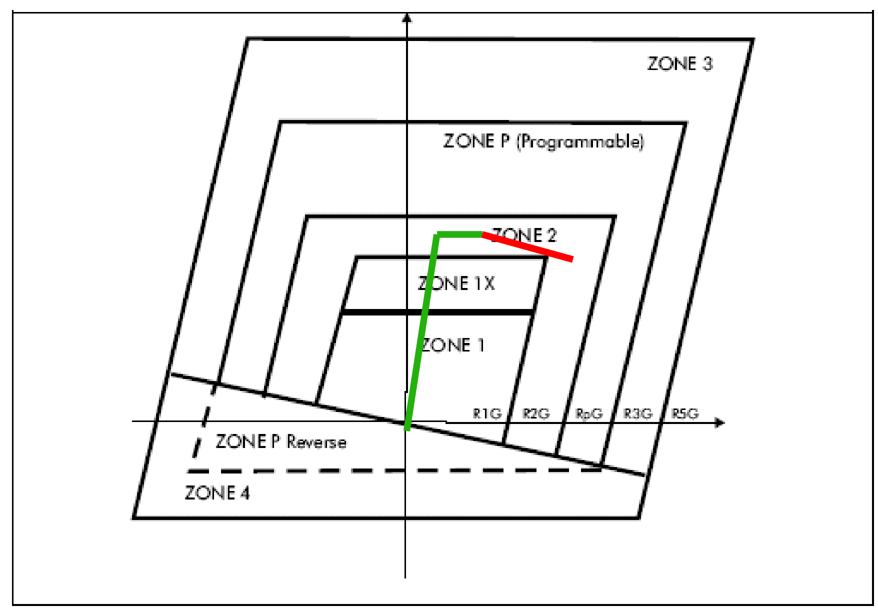




Impedance to measure

$$\frac{\overline{V}}{\overline{I}(1+\overline{k}_0)} = \overline{Z}_d + \frac{R_f}{1+\overline{k}_0} + \frac{R_f}{1+\overline{k}_0}\frac{\overline{I}_d}{\overline{I}}$$

Error



The value of K0 must be provided to the relay in order to compensate its effect

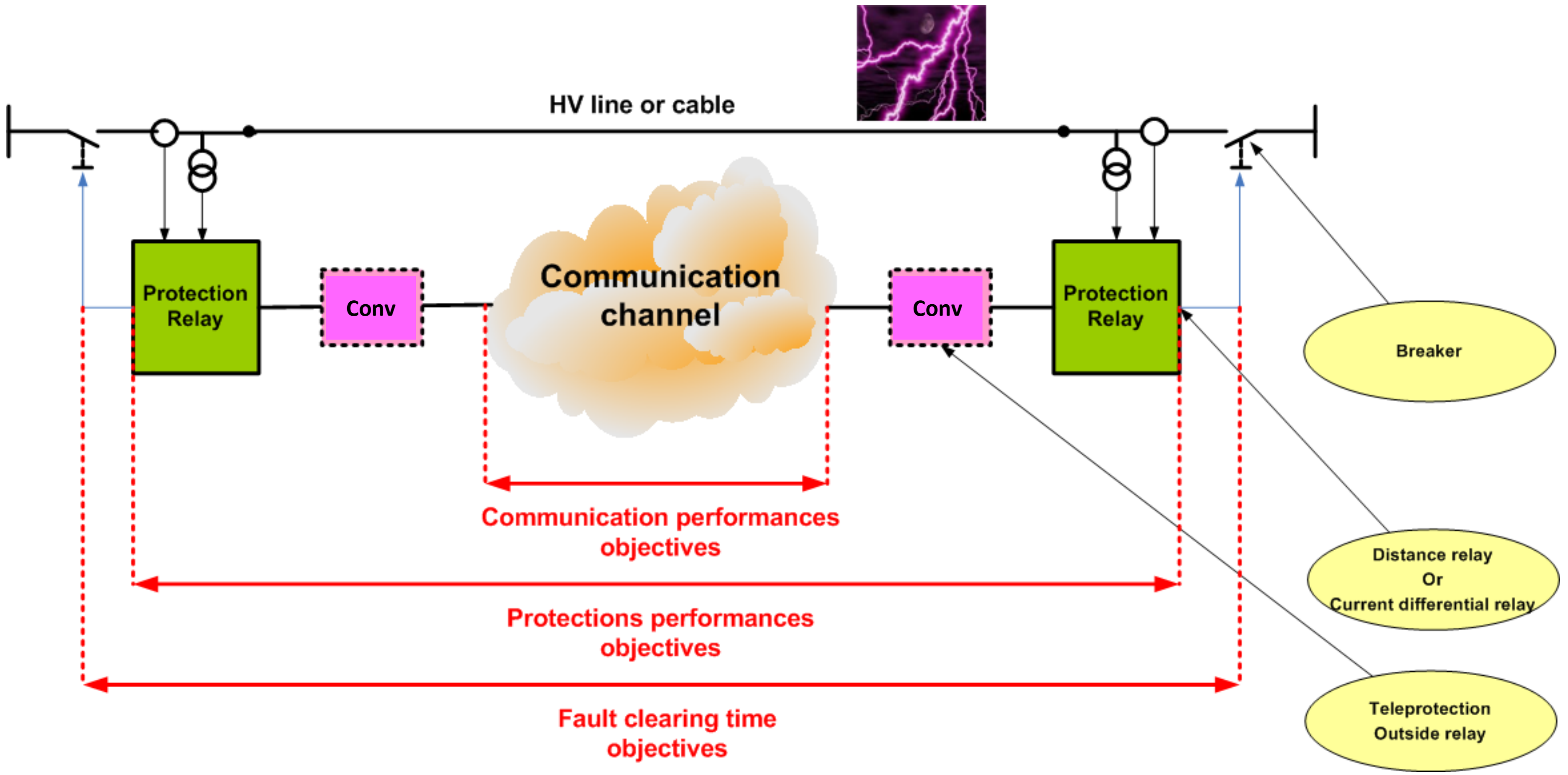
Distance protection

Distance principle applied to lines, cables, transformers

Main characteristics:

- Selectivity eached through distance protection settings coordination in various bays
- Dependability and security strongly dependent from network environment (short-circuits power at different ends, k0 factor, fault resistance …)
- Does not requires CTs compatibility at all ends
- Requires communication between different ends (only if POTT logic applied, see next slides)
- Distance protections must not be identical at all ends

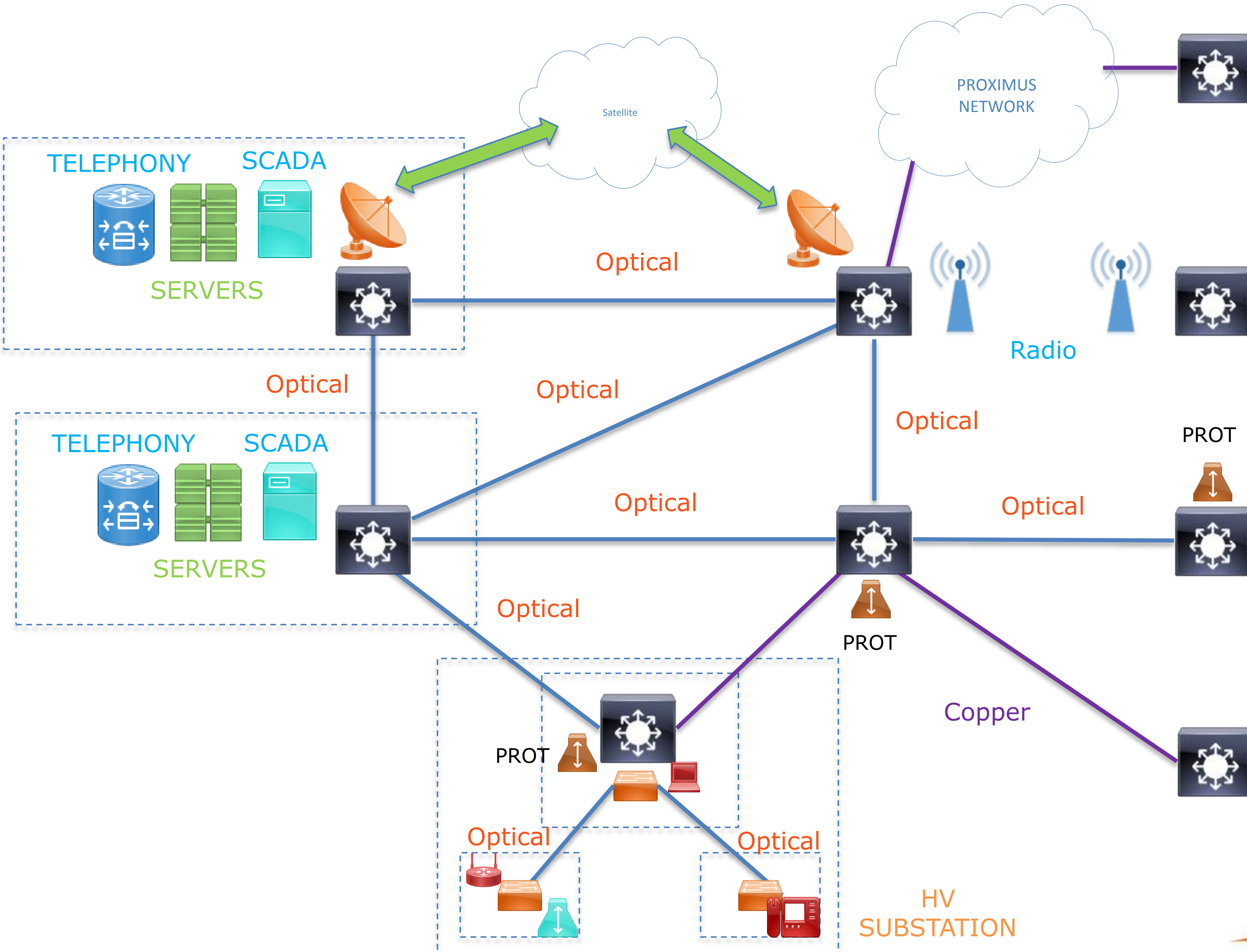
Telecommunication infrastructure requirements



- Fault clearing time objective at 380 kV: 100 ms (CB time included)
- Performance target for communication channel:

  100 – 40 (CB time) – 40 (prot. decision) – 15 (converter) = **5 ms**
- Other constraints: asymmetry on communication paths < 0,3 ms (current differential protection)

Telecommunication infrasructure overview



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Protection system of 150 / 220 / 380 kV interconnections

Protection system design

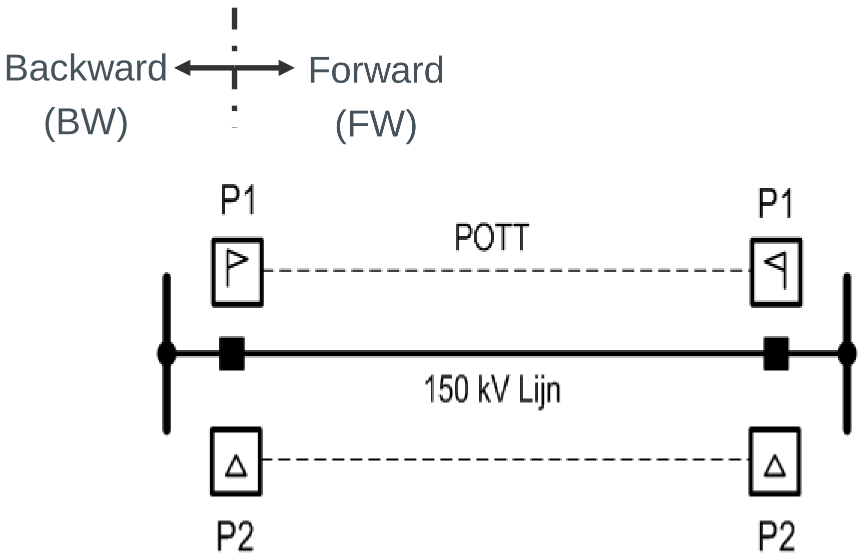
One of the protections must be a distance protection

Spannings-niveai (kV)	LIJNEN, KABELS, TRANSFORMATOREN *									RAILFOUT		
	Basis (ms)	Weigering Beveiliging (ms)	Weigering Verm. Schakel (ms)	Weigering Verm. Schakel (ms)	Reserve volgende lijn/kabel (ms)	Réserve volgend railstel (ms) ****		Herinschakeling luchtlijn (ms)		Basis (ms)	Reserve van de koppeling (ms)	
			1 f. fout	meerf.		1 f. fout	meerf.	1 f. fout	meerf.		1 f. fout	meerf.
Niveau de tension (kV)	**LIGNES, CABLES, TRANSFO ***									**DEFAUT JEUX DE BARRES**		
	Base (ms)	Refus Protect (ms)	Refus Disj. (ms)	Refus Disj. (ms)	Réserve ligne/câble suivant (ms)	Réserve jeux de barres suivants (ms) ****		Réenclenchement ligne (ms)		Base (ms)	Réserve du couplage (ms)	
			déf. mono	déf. poly		déf. mono	déf. poly	mono.	Poly-phasé		déf. mono.	déf. poly
380	100	100	300	170	1000	500	250	1	10	100	250	170
220	120	120	-	-	1000	600	600	1	***	100	300	300
150	120	120	-	-	1000	600	600	1	***	100	300	300
70	120**	2250	-	-	1000	600	600	-	***	600	-	-
36	120	2250	-	-	1200	1200	1200	-	***	600	-	-
30	120	2250	-	-	1200	1200	1200	-	***	600	-	-
15	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
12	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
10	1100	3100	-	-	-	1800	1800	-	***	1800	-	-

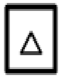
Two independant protections ⇨ priority to dependability

Consistent with N-1 criterium

Protection scheme150 / 220 / 380 interconnection link



P1 protection = distance protection with POTT teleprotection logic (see next slides)

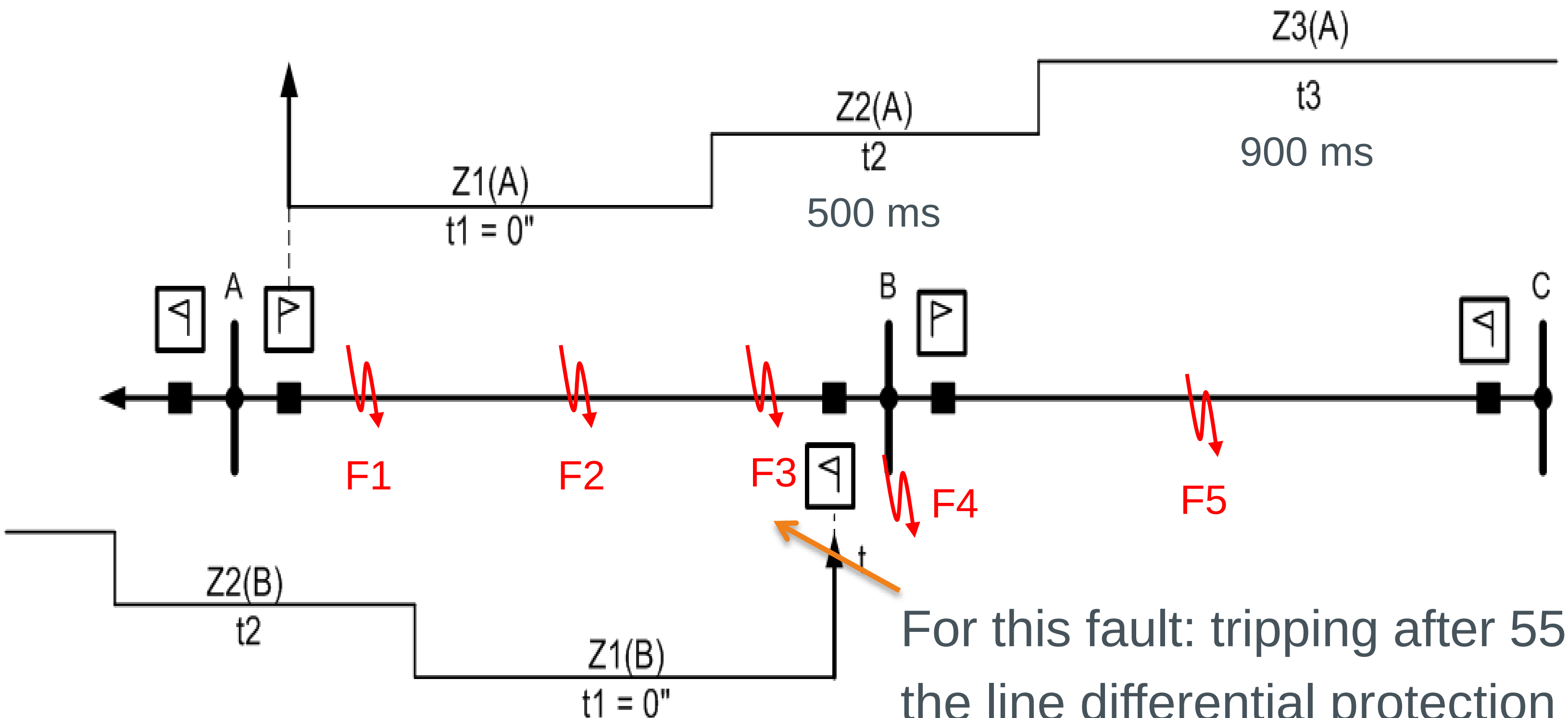


P2 protection = line differential protection

Communication channels:

- Distance protection: one for POTT logic
- Line differential protection: one for transmission of currents measurements

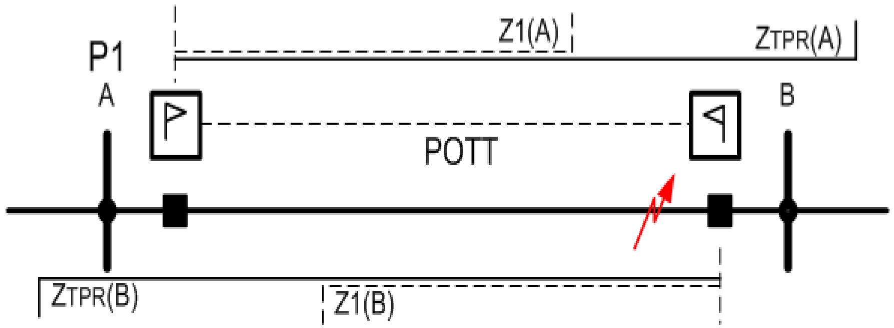
Distance protection ⇒ zones definition



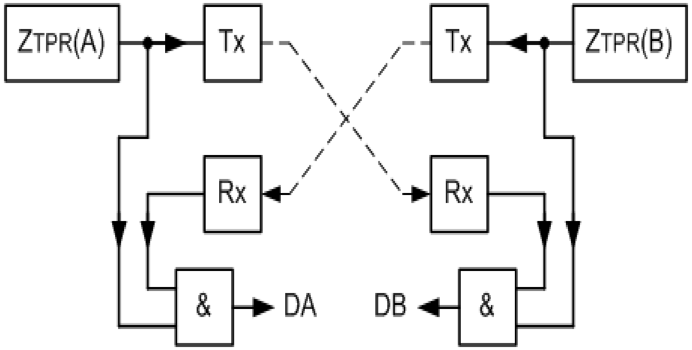
For this fault: tripping after 550 ms if the line differential protection is not in operation ⇨ not consistent with grid code requirement

POTT logic

POTT = Protective Overreach Transfer Trip



t = 0 ms

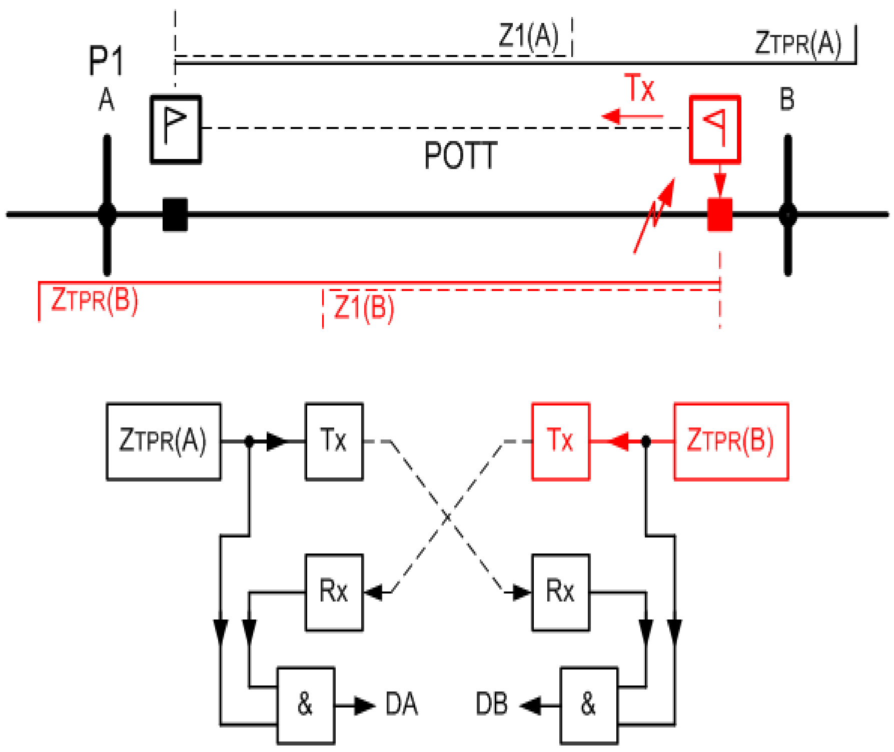


POTT logic

Distance protection on B side detects the fault in TPR zone

Sending of the corresponding TPR signal to A side

t = 30 ms

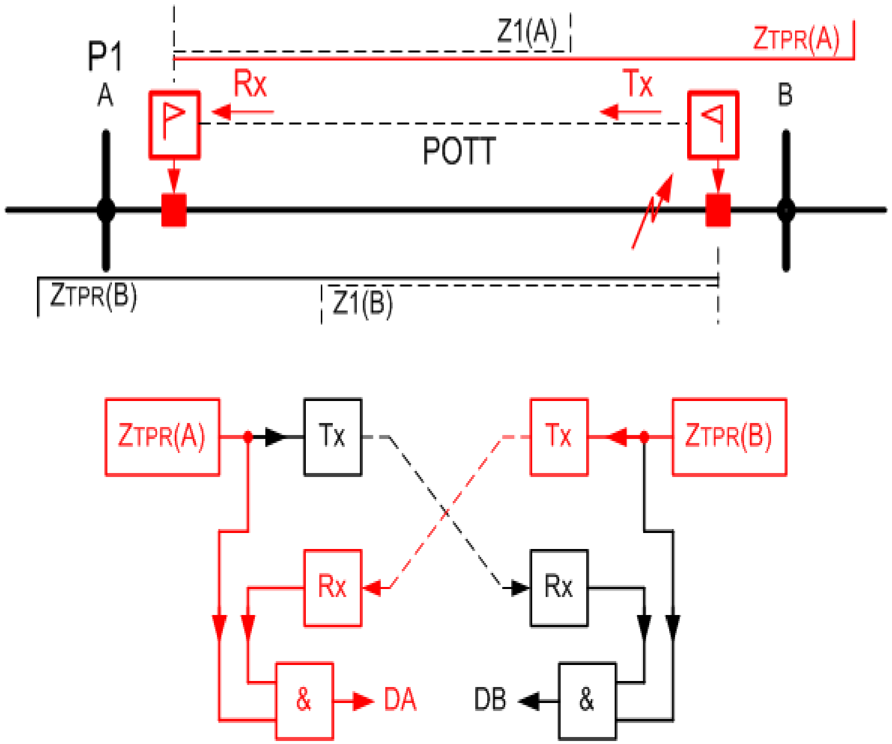


POTT logic

The TPR signal arrives to A side, where the distance protection has also detected the fault in TPR zone from t = 30 ms

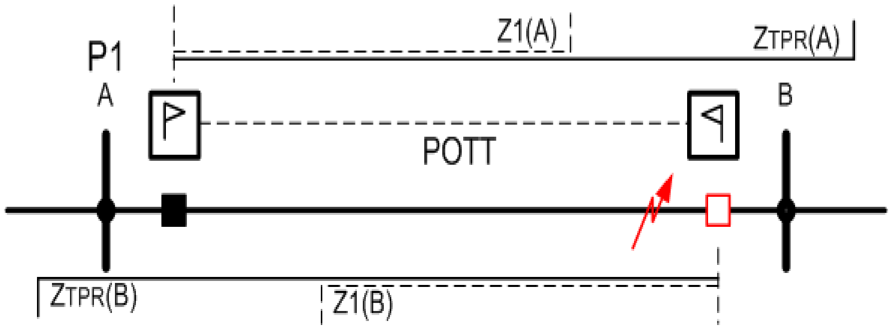
⇨ tripping decision without waiting unitl t2

t = 50 ms



POTT logic

Circuit breaker trips on B side

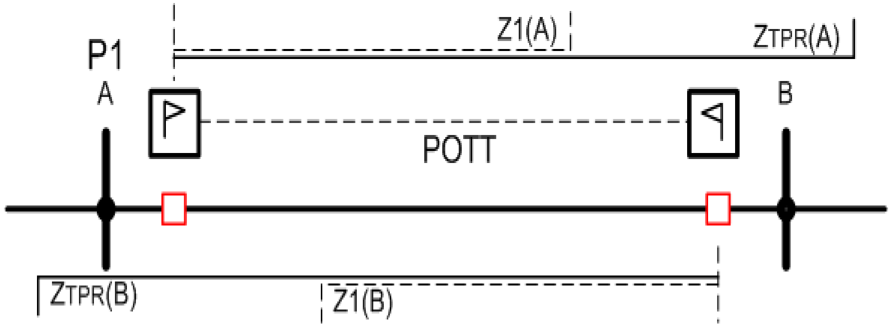


t = 80 ms

POTT logic

Circuit breaker trips on

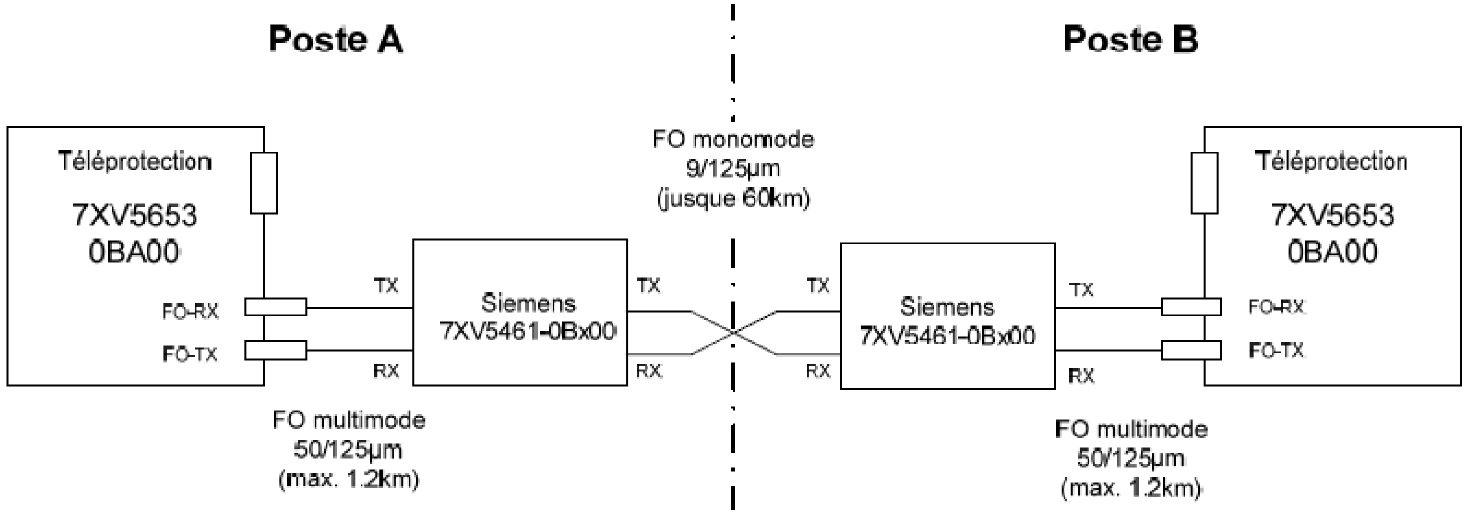
A side

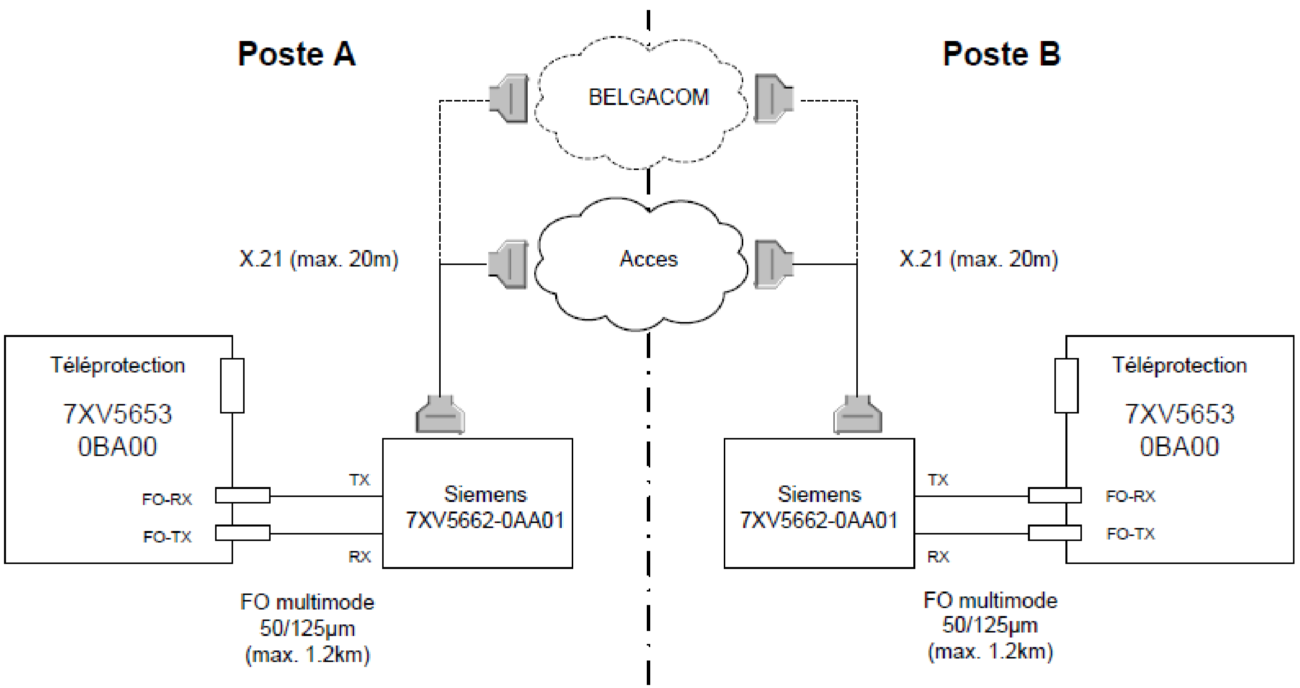


t = 100 ms

Telecommunication typical implementation

2-end line teleprotection with direct communication through dedicated optical fiber





2-end teleprotection with communication through TDM (« Access ») / Proximus network

Autoreclose function

The autoreclose function is an automatism aimed at reclosing the line as fast as possible (short delay) once the fault has been eliminated, in order to maximize its availability

Justification:

- Most of the faults on overhead lines are not permanent (typical example: lightning strikes), they disappear after arc extinction
- This function is particularly useful during thunderstorms (several trippings in short periods of time)

Principles:

- Only one tentative is allowed. If the fault is still present, definitive 3-ph tripping of the line.
- From 150 kV to 380 kV:
  - 1-phase fault: 1-phase tripping, followed by a 1-phase autoreclose attempt
  - 2- and 3-phase faults: 3-phase tripping followed by a 3-phase autoreclose attempt
- No autoreclose function on cables, transformers and busbars (most of the time: permanent fault)

Autoreclose function

	30 – 36 kV	70 – 110 kV	150 – 220 kV	380 kV
1-phase fault	None	None	1 s	1 s
3-phase fault	None	Half-fast (1 – 1,5s) of slow (10 s) Through “send – couple” logic	Half-fast (1 – 1,5s) of slow (10 s) Through “send – couple” logic	Half-fast (1 – 1,5s) of slow (10 s) Through “send – couple” logic.

Spannings-niveau (kV)	LIJNEN, KABELS, TRANSFORMATOREN *									RAILFOUT		
	Basis (ms)	Weigering Beveiliging (ms)	Weigering Verm. Schakel (ms) 1 f. fout	Weigering Verm. Schakel (ms) meerf.	Reserve volgende lijn/kabel (ms)	Réserve volgend railstel (ms) **** 1 f. fout	Réserve volgend railstel (ms) **** meerf.	Herinschakeling luchtlijn (ms) 1 f. fout	Herinschakeling luchtlijn (ms) meerf.	Basis (ms)	Reserve van de koppeling (ms) 1 f. fout	Reserve van de koppeling (ms) meerf.
Niveau de tension (kV)	LIGNES, CABLES, TRANSFO *									DEFAUT JEUX DE BARRES		
	Base (ms)	Refus Protect (ms)	Refus Disj. (ms) déf. mono	Refus Disj. (ms) déf. poly	Réserve ligne/câble suivant (ms)	Réserve jeux de barres suivants (ms) **** déf. mono	Réserve jeux de barres suivants (ms) **** déf. poly	Réenclenchement ligne (ms) mono.	Réenclenchement ligne (ms) Poly-phasé	Base (ms)	Réserve du couplage (ms) déf. mono.	Réserve du couplage (ms) déf. poly
380	100	100	300	170	1000	500	250	1	10	100	250	170
220	120	120	-	-	1000	600	600	1	***	100	300	300
150	120	120	-	-	1000	600	600	1	***	100	300	300
70	120**	2250	-	-	1000	600	600	-	***	600	-	-
36	120	2250	-	-	1200	1200	1200	-	***	600	-	-
30	120	2250	-	-	1200	1200	1200	-	***	600	-	-
15	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
12	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
10	1100	3100	-	-	-	1800	1800	-	***	1800	-	-

* Transformator : spanningsniveau = nominale maximumspanning van de transformator

** Voor de lijnen geldt deze waarde voor het uiteinde het dichtst bij de fout; voor het andere uiteinde wordt een afschakeltijd van 500 ms toegelaten

*** Te bepalen door de netbeheerder in functie van de regelingspa-rameters van de beveiligingen van nabije installaties

**** Ook toepasbaar voor fout tussen stroomtransformator en vermogenschakelaar

Opmerking : Alle opgegeven tijden zijn de maximaal toegelaten waarden.

Send – couple logic

- Only used with manual closing and 3–phase autoreclose function, in order to prevent false parallels
- Implemented through synchrocheck function
- Before transmitting the closing order to the circuit breaker, the synchrocheck checks that one of the following conditions is fulfilled:
  - Send condition: voltage on busbar side, no voltage on line side
  - Couple condition: voltage on both sides of the circuit breakers, with the following condition simultaneously met:
    - $\Delta U < 10\%$
    - $\Delta \varphi < 20°$
    - $\Delta f < 20mHz$

Illustration on 3φ autreclose

t = 0 ms

2φ of 3φ fault

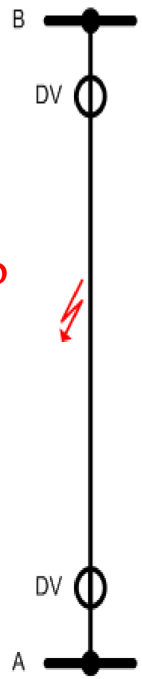


Illustration on 3φ autreclose

t ≈ 30 ms

Trip protection

2φ of 3φ fault

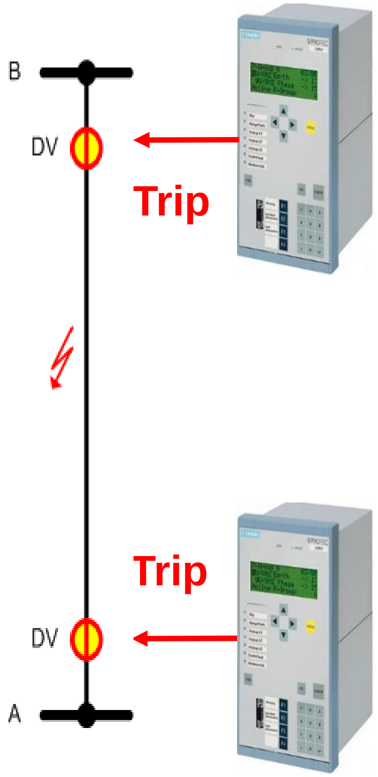


Illustration on 3φ autreclose

t = 80 ms

Fault eliminated

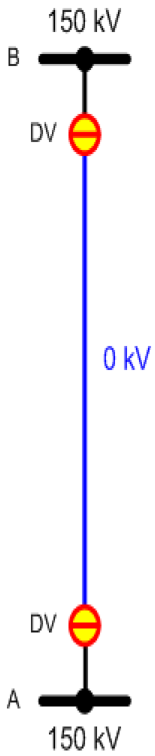
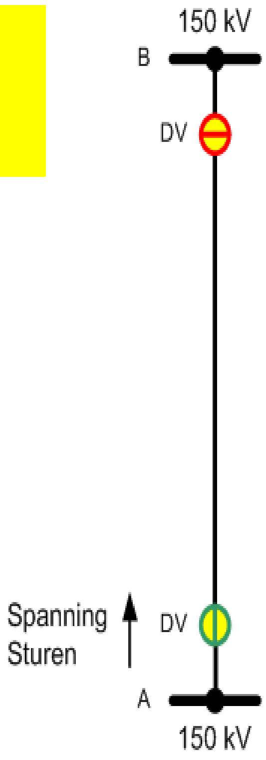


Illustration on 3φ autreclose

t = 1 s

Send



Each end of the line must be assigned to “send” or “couple”

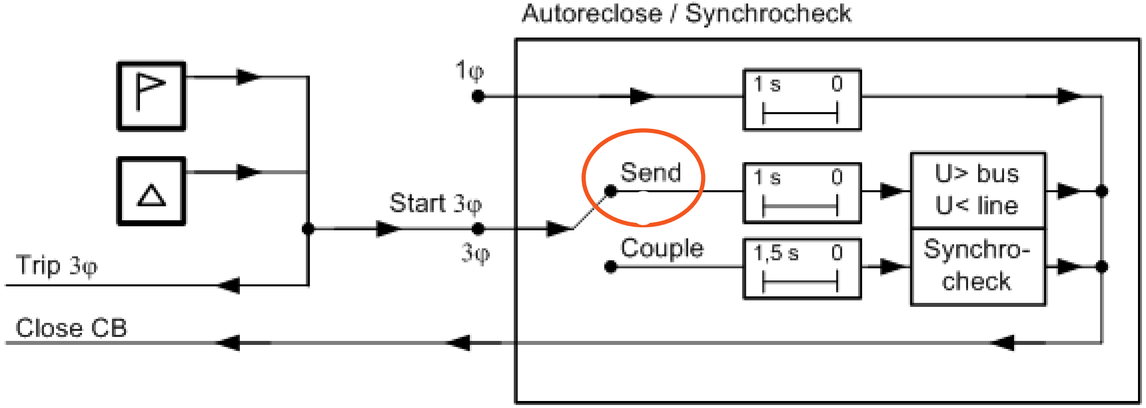


Illustration on 3φ autreclose

t = 1,5 s

Couple

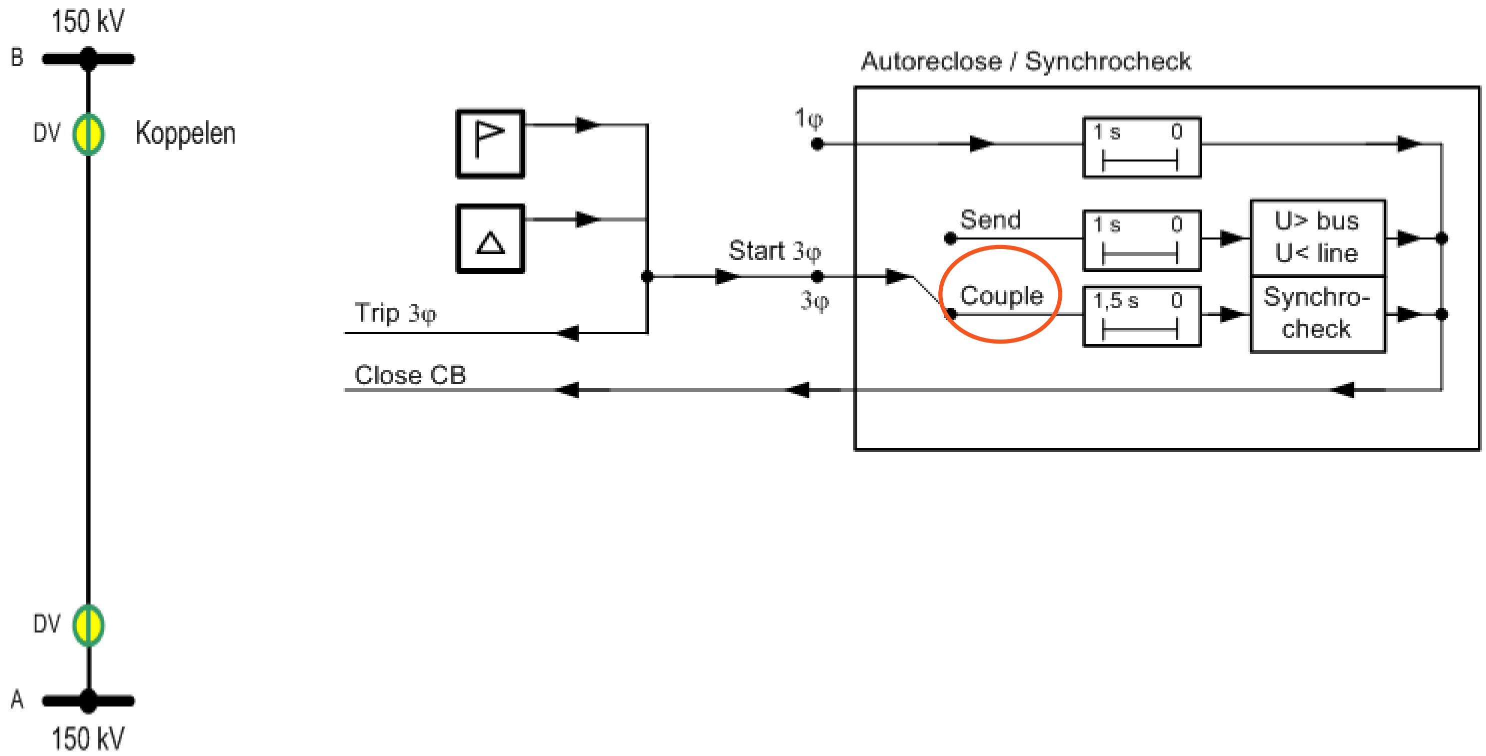


Illustration on 1φ autreclose

t = 0 ms

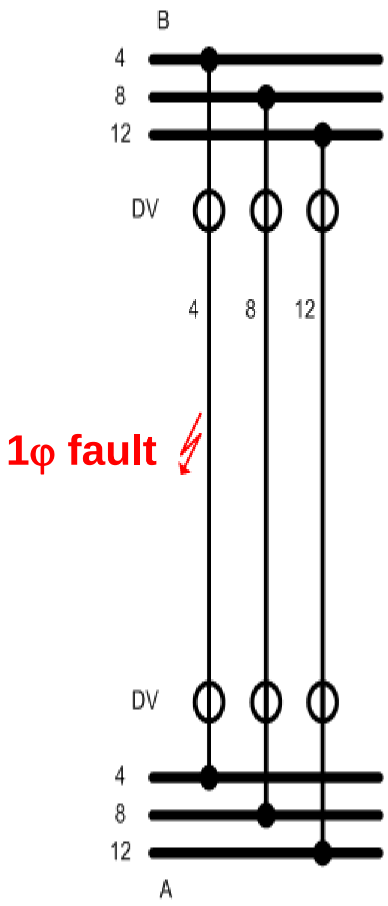


Illustration on 1φ autreclose

t ≈ 30 ms

Trip protections

Phase 4

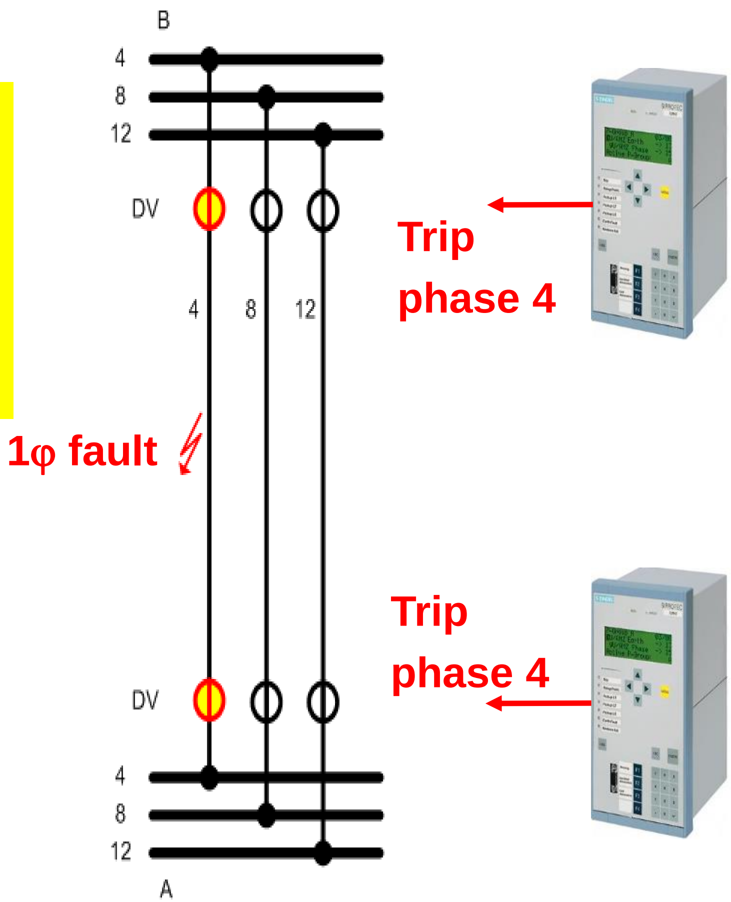


Illustration on 1φ autreclose

t = 80 ms

Fault eliminated

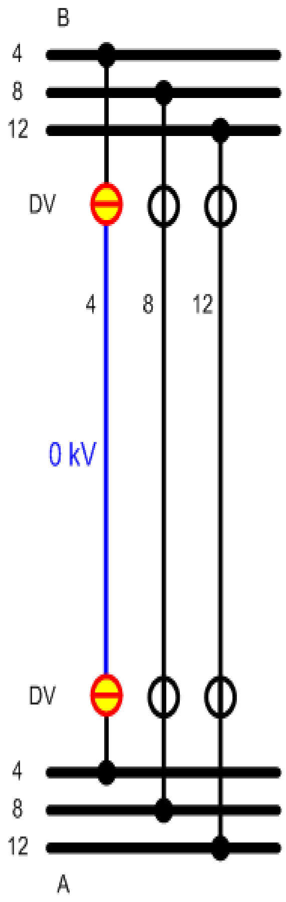
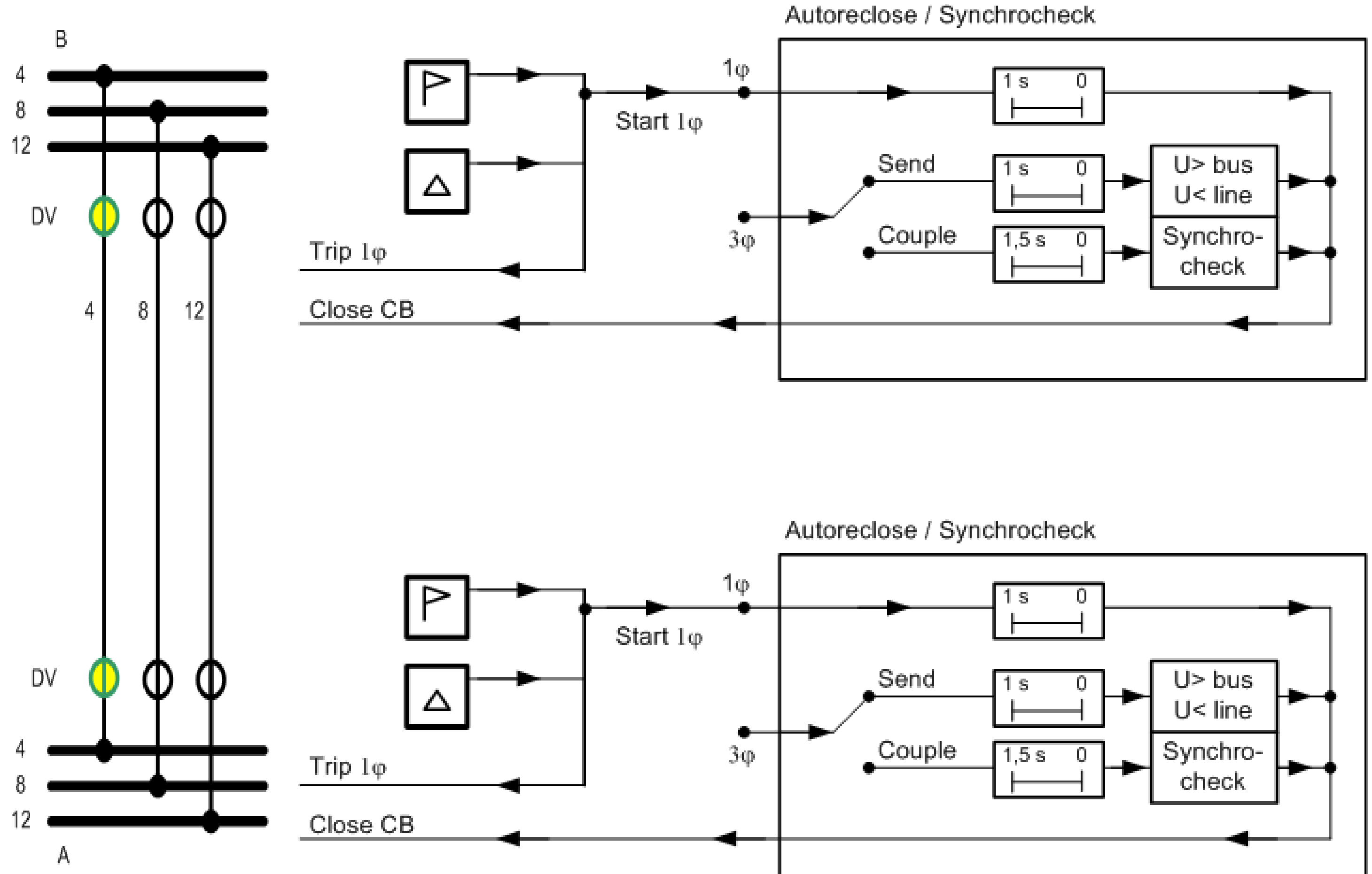


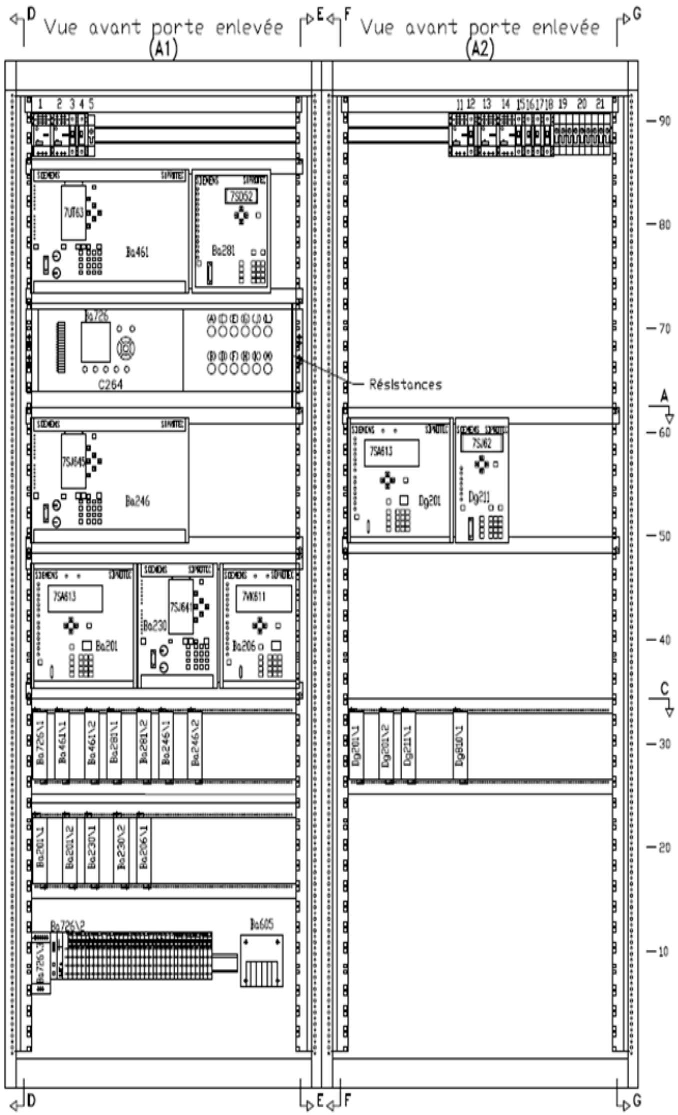
Illustration on 1φ autreclose

t = 1 s

Autoreclose at both sides



Implementation



Training Center

Protection system of busbars

Busbar and circuit breaker failure protection

One main protection is sufficient to cover busbar faults

Backup protections provided by distance protections

- 150 kV – 380 kV: all substations equippd with busbar and CB failure protections
- 30 kV – 110 kV: 2-busbar substations equipped with busbar and CB failure protections

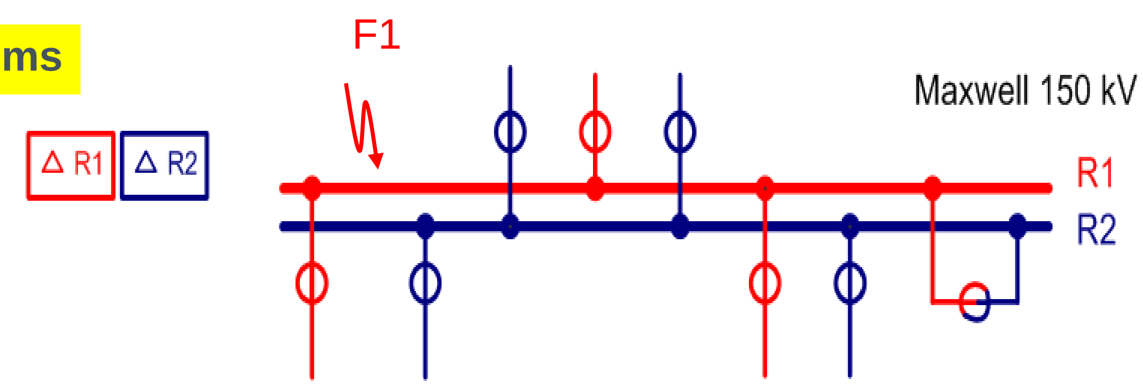
Spannings-niveai (kV)	LIJNEN, KABELS, TRANSFORMATOREN *									RAILFOUT		
	Basis (ms)	Weigering Beveiliging (ms)	Weigering Verm. Schakel (ms)	Weigering Verm. Schakel (ms)	Reserve volgende lijgn/kabel (ms)	Réserve volgend railstel (ms) ****		Herinschakeling luchtlijn (ms)		Basis (ms)	Reserve van de koppeling (ms)	
			1 f. fout	meerf.		1 f. fout	meerf.	1 f. fout	meerf.		1 f. fout	meerf.
Niveau de tension (kV)	LIGNES, CABLES, TRANSFO *									DEFAUT JEUX DE BARRES		
	Base (ms)	Refus Protect (ms)	Refus Disj. (ms)	Refus Disj. (ms)	Réserve ligne/câble suivant (ms)	Réserve jeux de barres suivants (ms) ****		Réenclenchement ligne (ms)		Base (ms)	Réserve du couplage (ms)	
			déf. mono	déf. poly		déf. mono	déf. poly	mono.	Poly-phasé		déf. mono.	déf. poly
380	100	100	300	170	1000	500	250	1	10	100	250	170
220	120	120	-	-	1000	600	600	1	***	100	300	300
150	120	120	-	-	1000	600	600	1	***	100	300	300
70	120**	2250	-	-	1000	600	600	-	***	600	-	-
36	120	2250	-	-	1200	1200	1200	-	***	600	-	-
30	120	2250	-	-	1200	1200	1200	-	***	600	-	-
15	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
12	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
10	1100	3100	-	-	-	1800	1800	-	***	1800	-	-

The CB failure protection is implemented in the busbar protection

Busbar protection principle

- Main protection = differential protection
- Each busbar is equipped with it own differential function, in order to trip only one busbar in case of fault
- Each differential function must know at each time which bay is connected to which busbar
- Example: fault F1 on R1

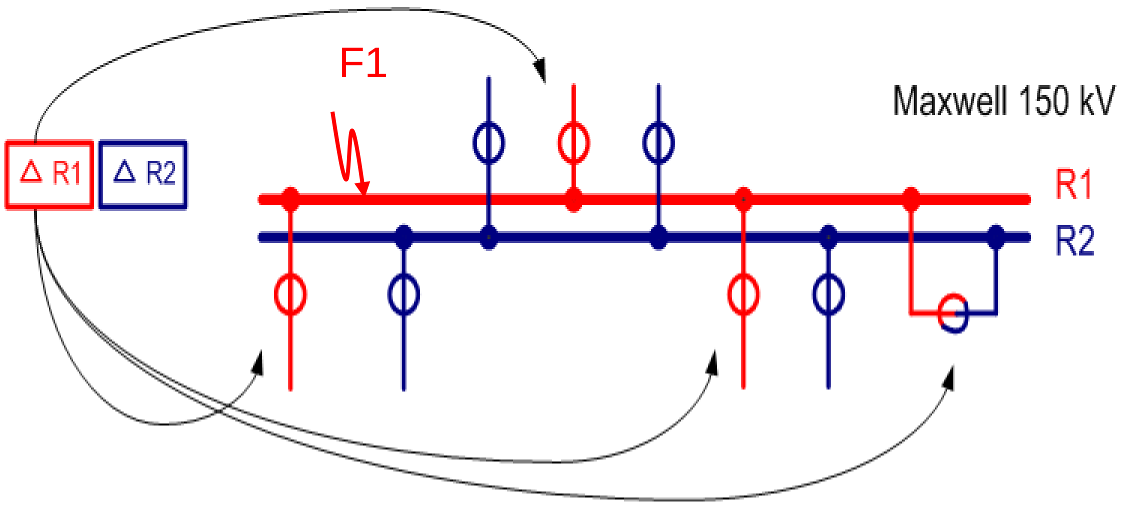
t = 0 ms



Busbar protection principle

t ≈ 10 to 20 ms

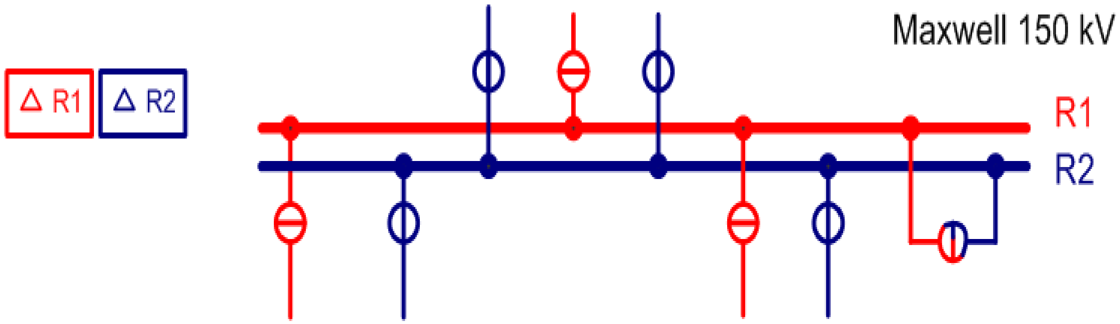
3-phase trip of R1 differential protection



Busbar protection principle

t ≈ 60 to 70ms

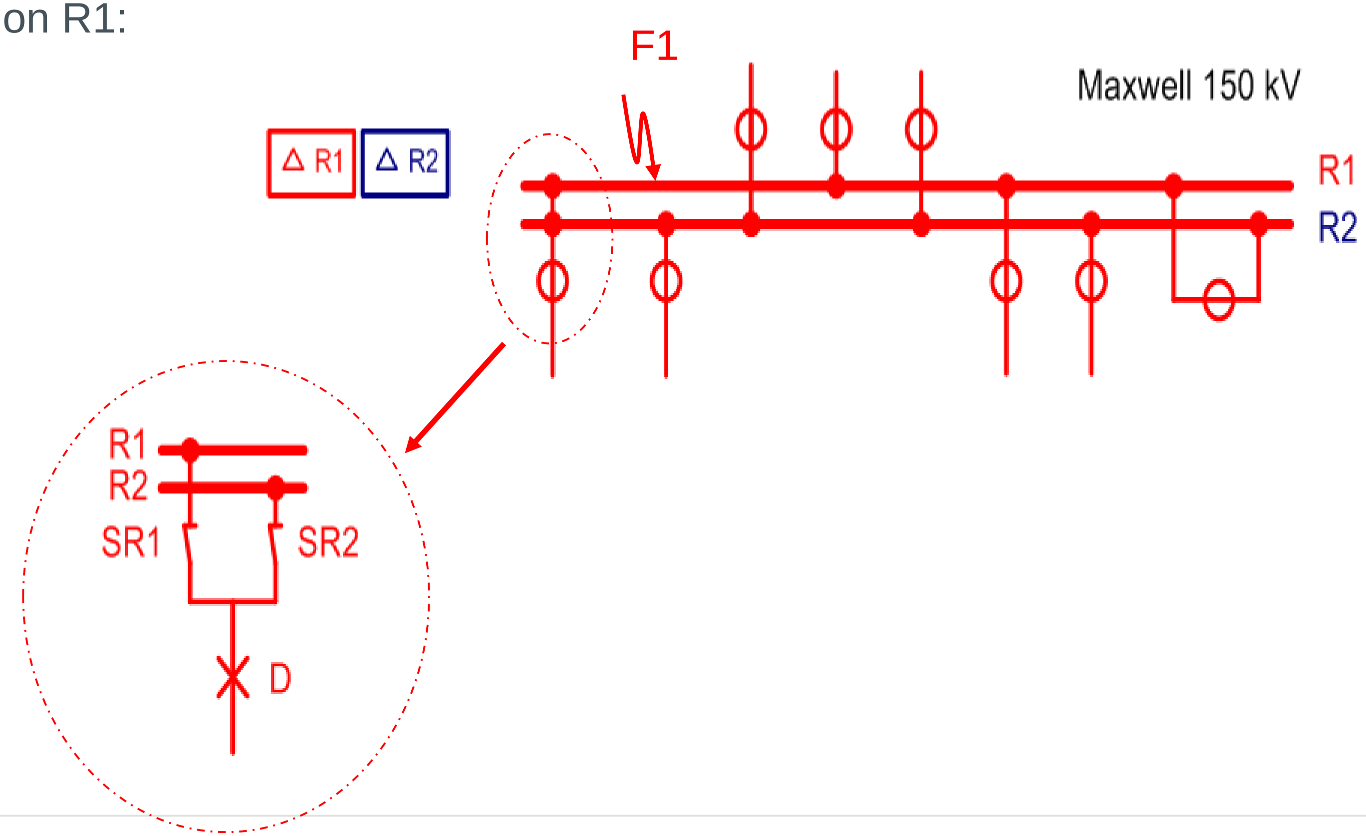
Fault eliminated



Busbar protection principle

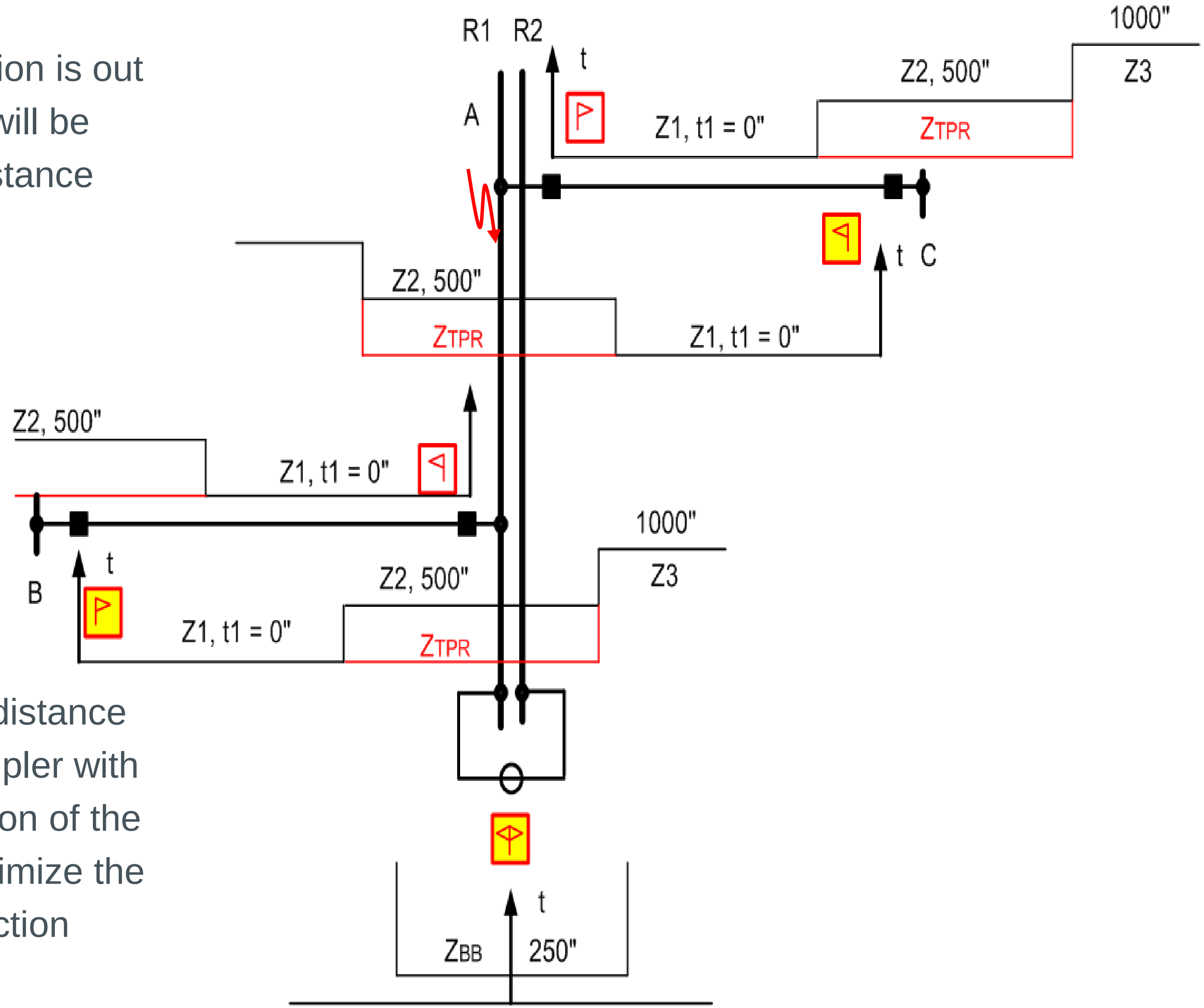
- During the transfer of one bay from one busbar to the other (both disconnectors closed), there is only one differential function that protects both busbars
- In case of a busbar fault at that moment: both busbars are tripped

Fault F1 on R1:



Busbar protection principle

If the busbar protection is out of service, the fault will be eliminated by the distance protections

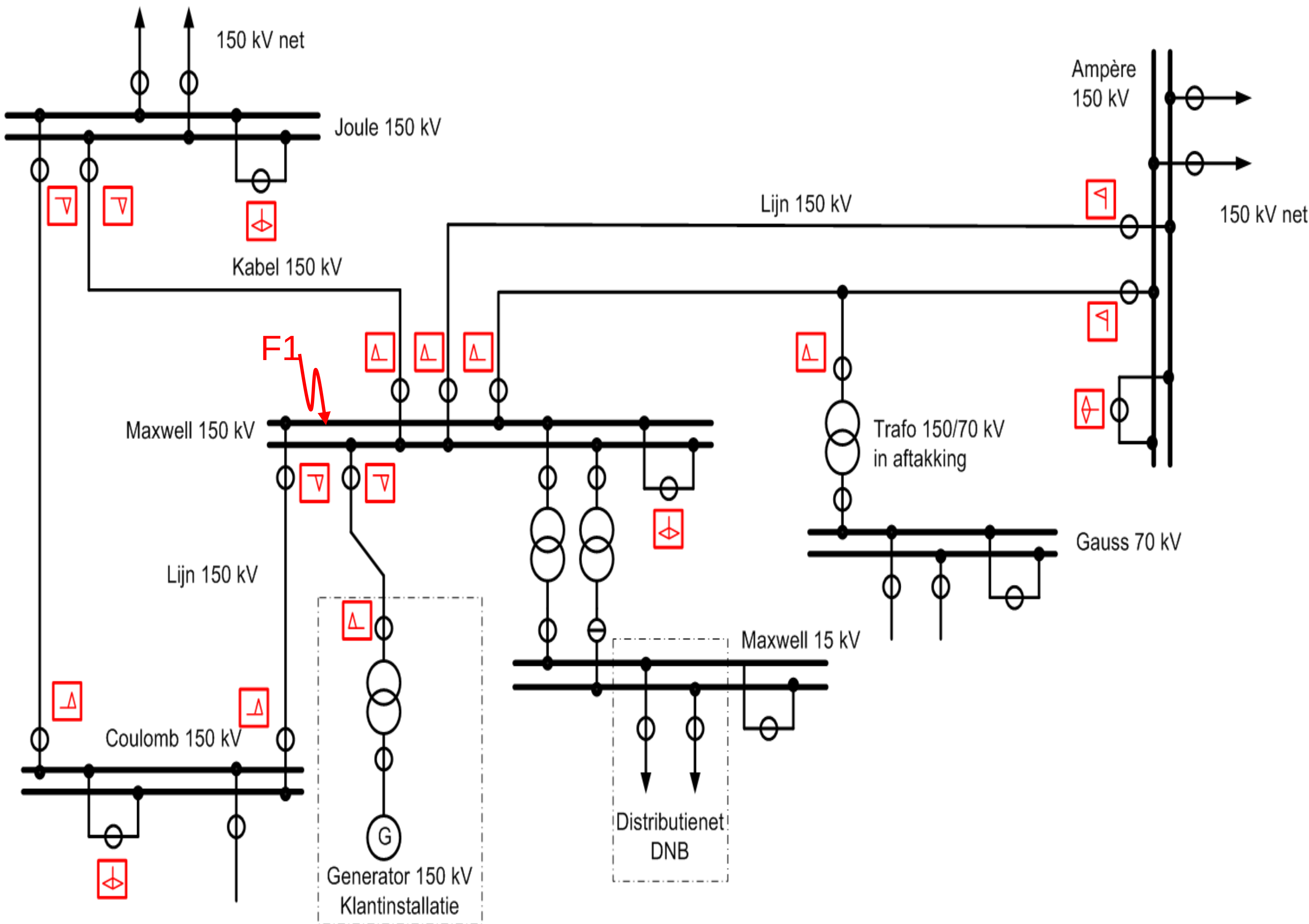


Coordination of the distance protection of the coupler with the distance protection of the lines is critical to optimize the security of the protection system

Busbar protection principle - illustration

t = 0 ms

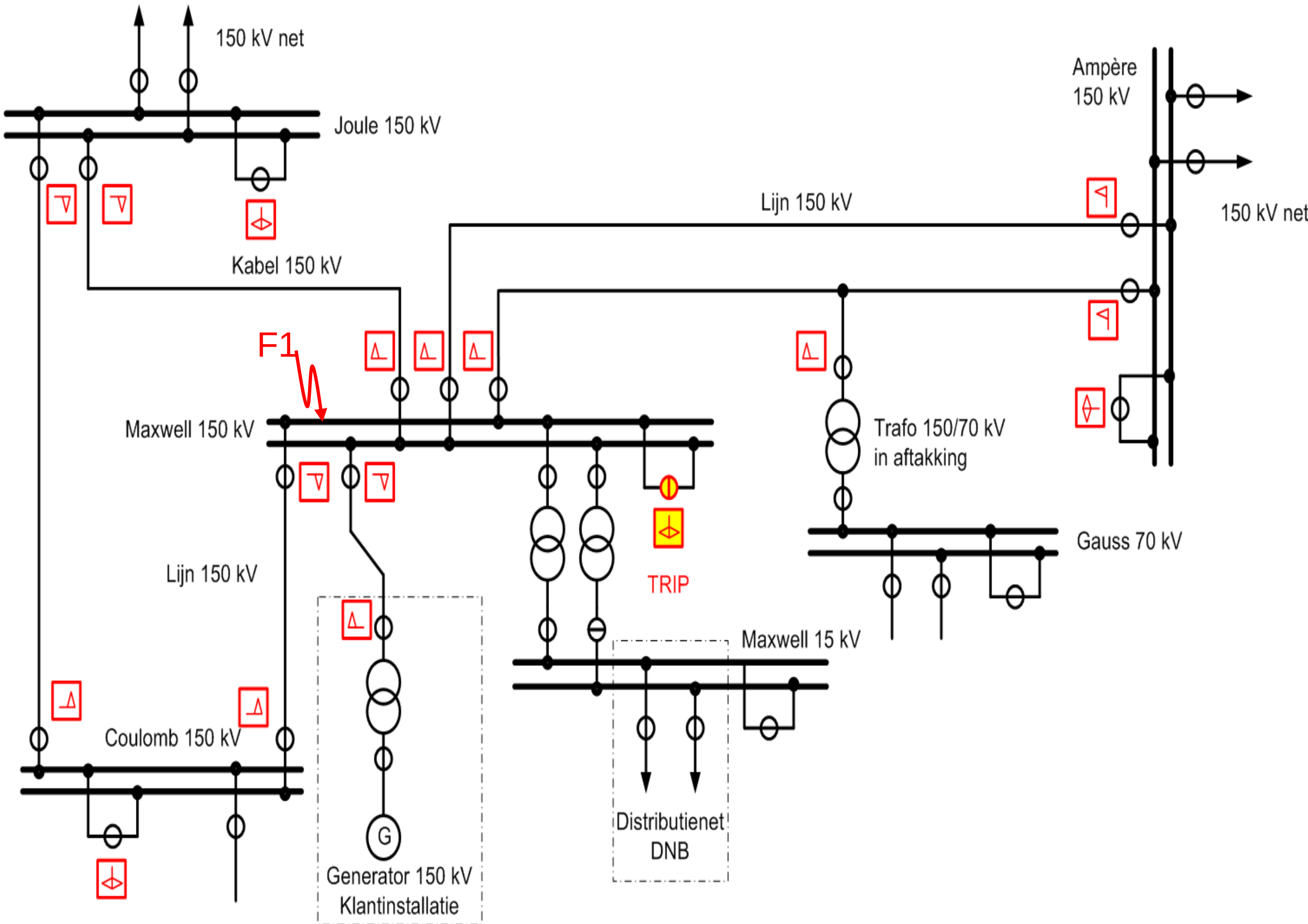
⇒ Fault F1



Busbar protection principle - illustration

t = 250 ms

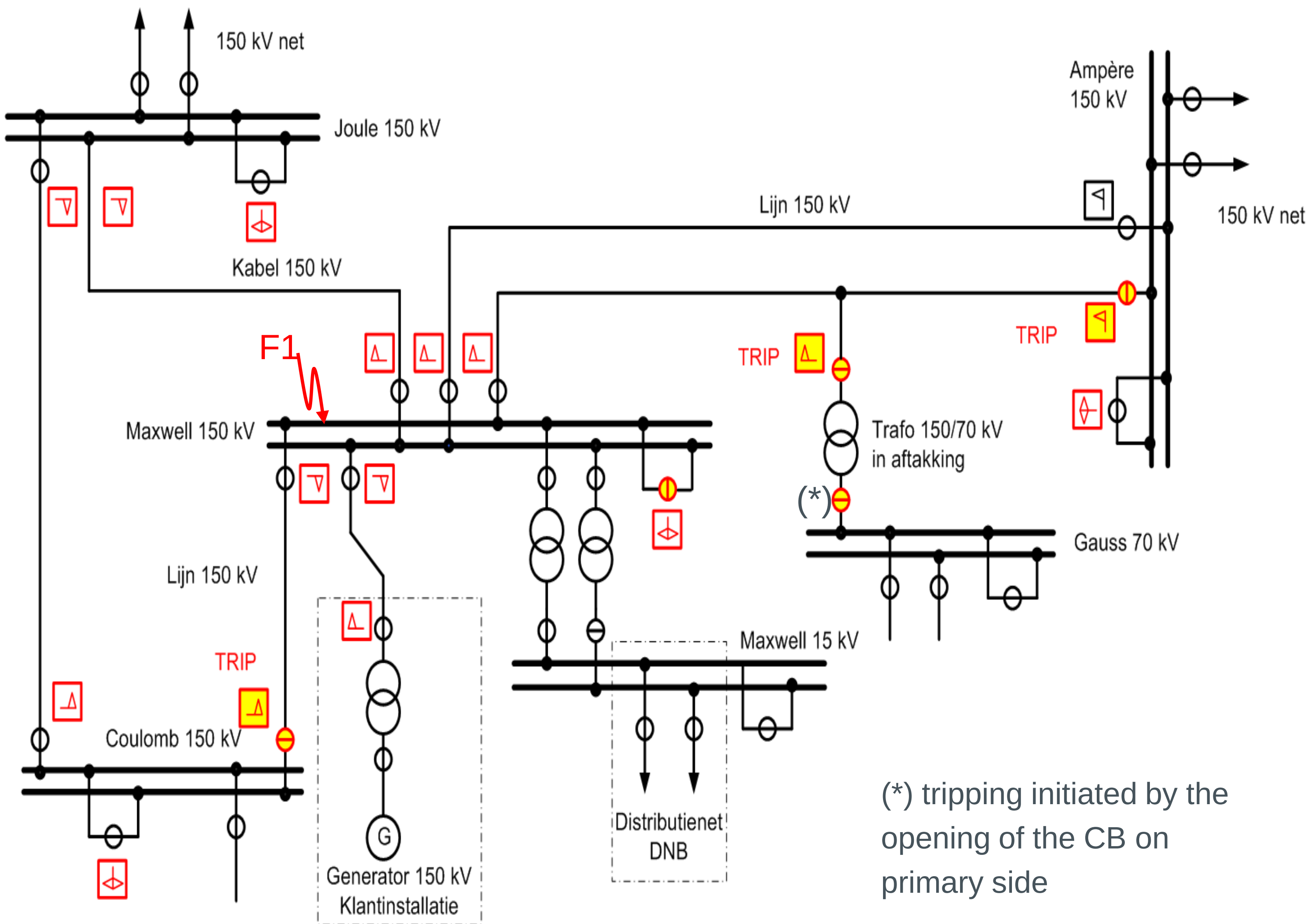
Tripping of the coupler



Busbar protection principle - illustration

t = 500 ms

Tripping through zone 2 of distance protections

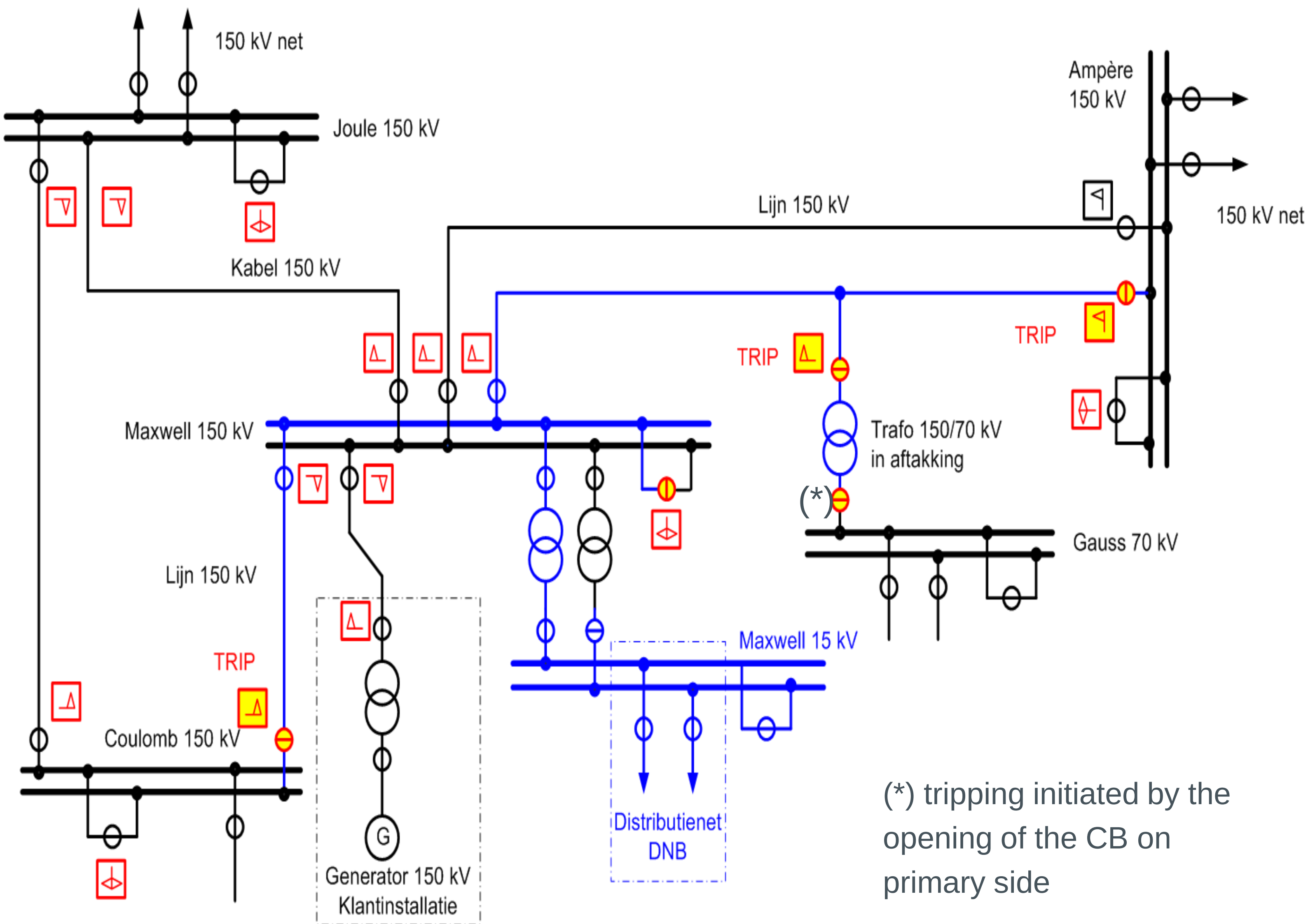


(*) tripping initiated by the opening of the CB on primary side

Busbar protection principle - illustration

t = 550 ms

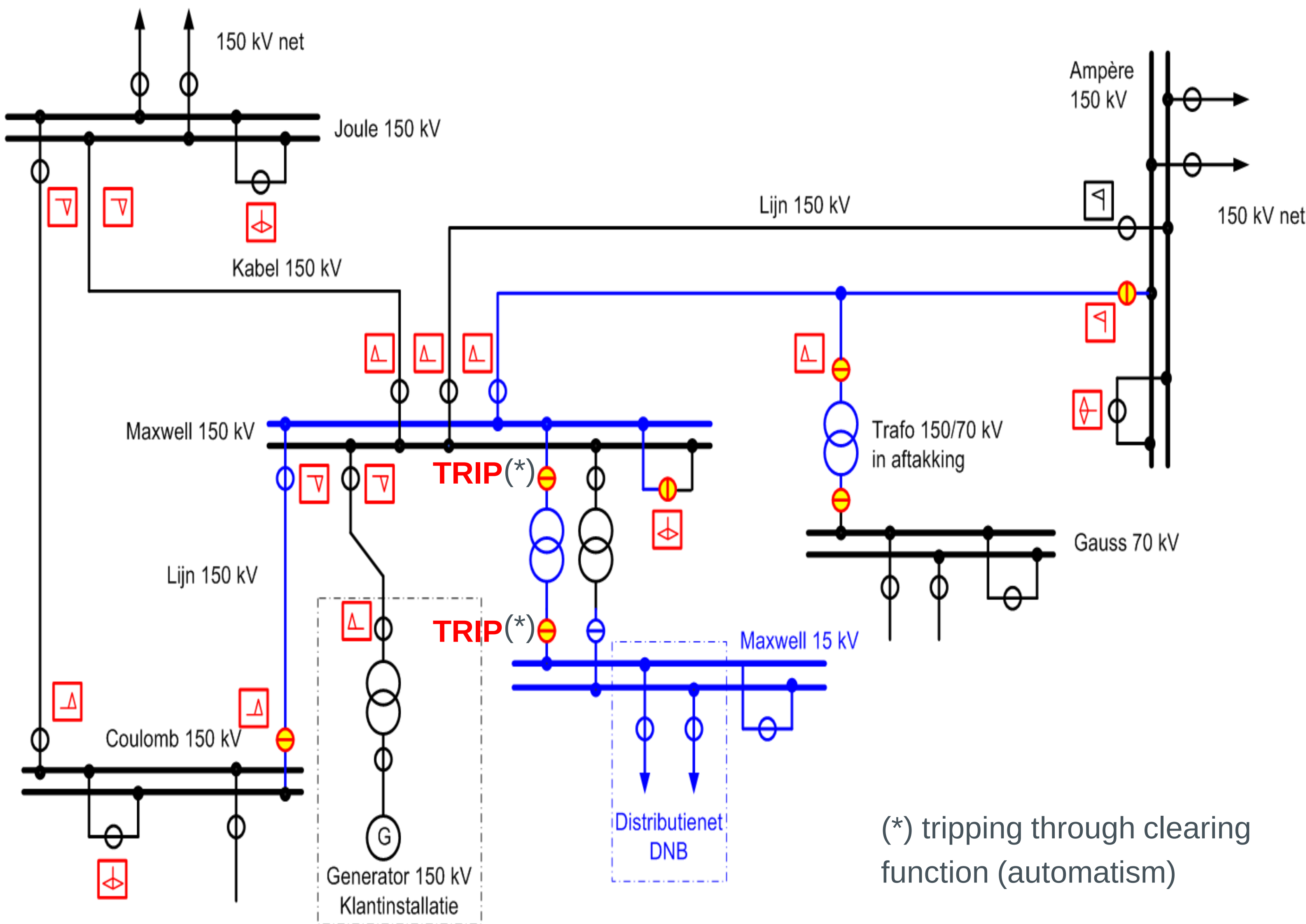
Fault elimination



(*) tripping initiated by the opening of the CB on primary side

Busbar protection principle - illustration

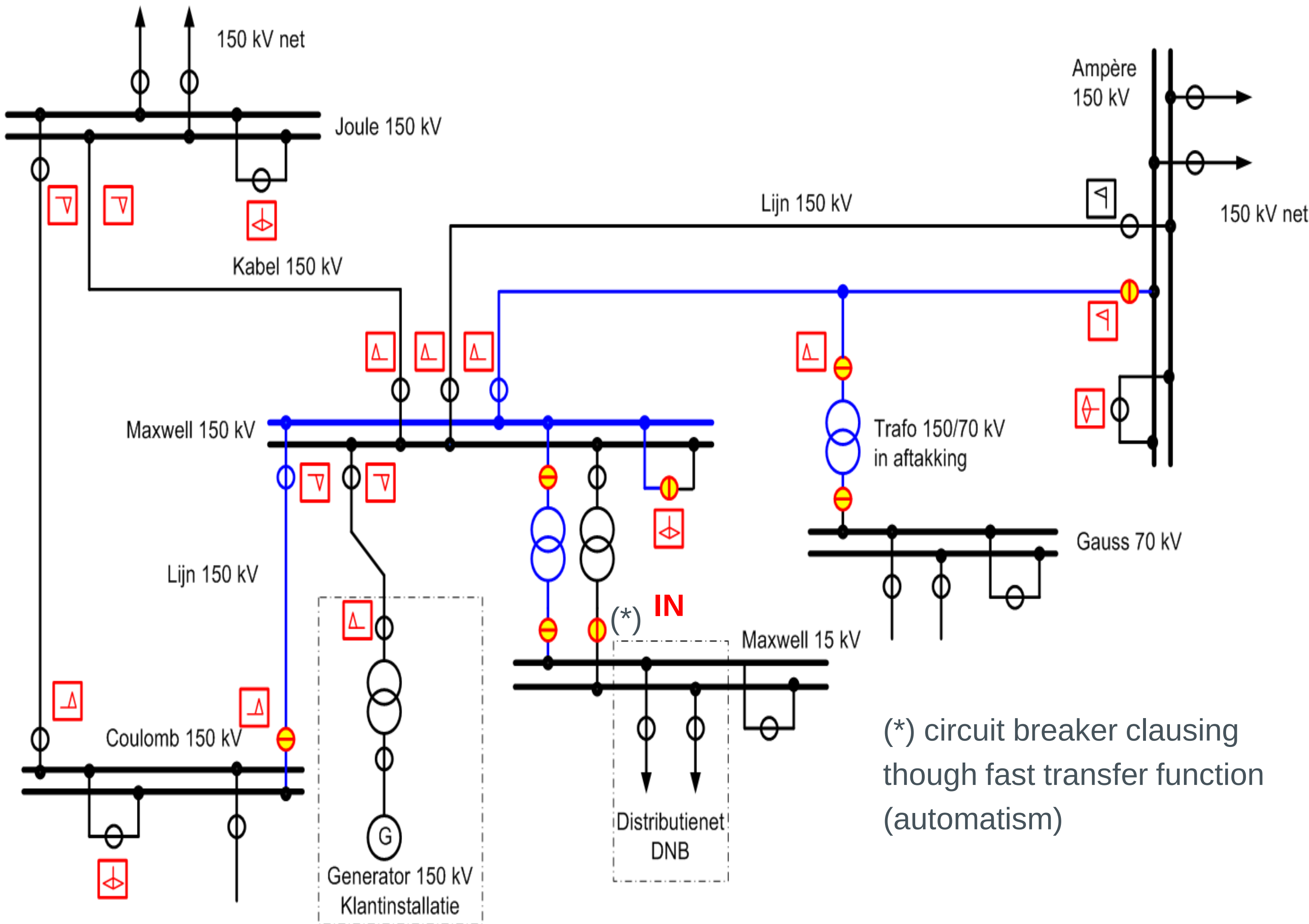
t = 5"



(*) tripping through clearing function (automatism)

Busbar protection principle - illustration

t = 5,7''

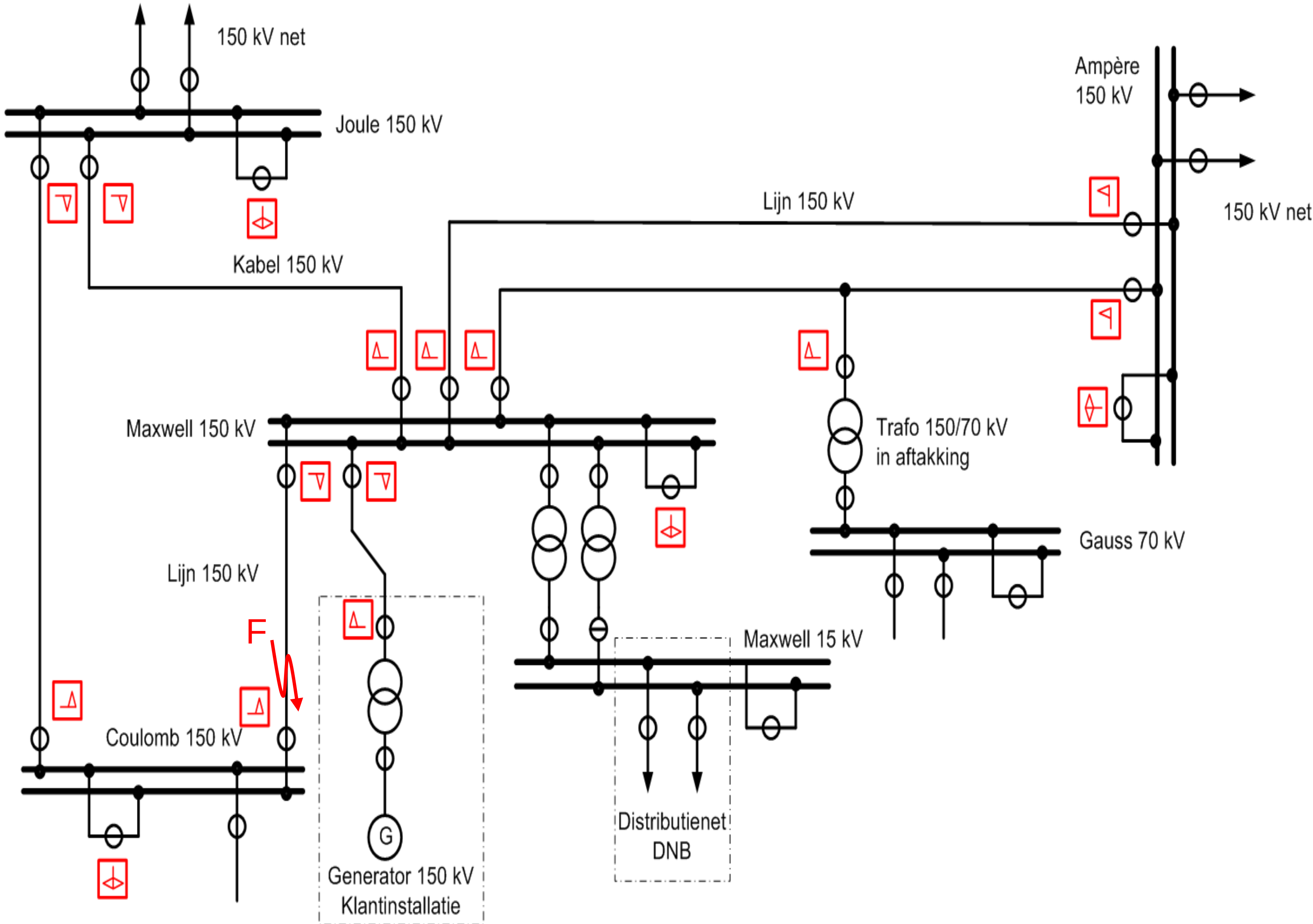


(*) circuit breaker clausing though fast transfer function (automatism)

Circuit breaker failure without CB failure protection

t = 0”

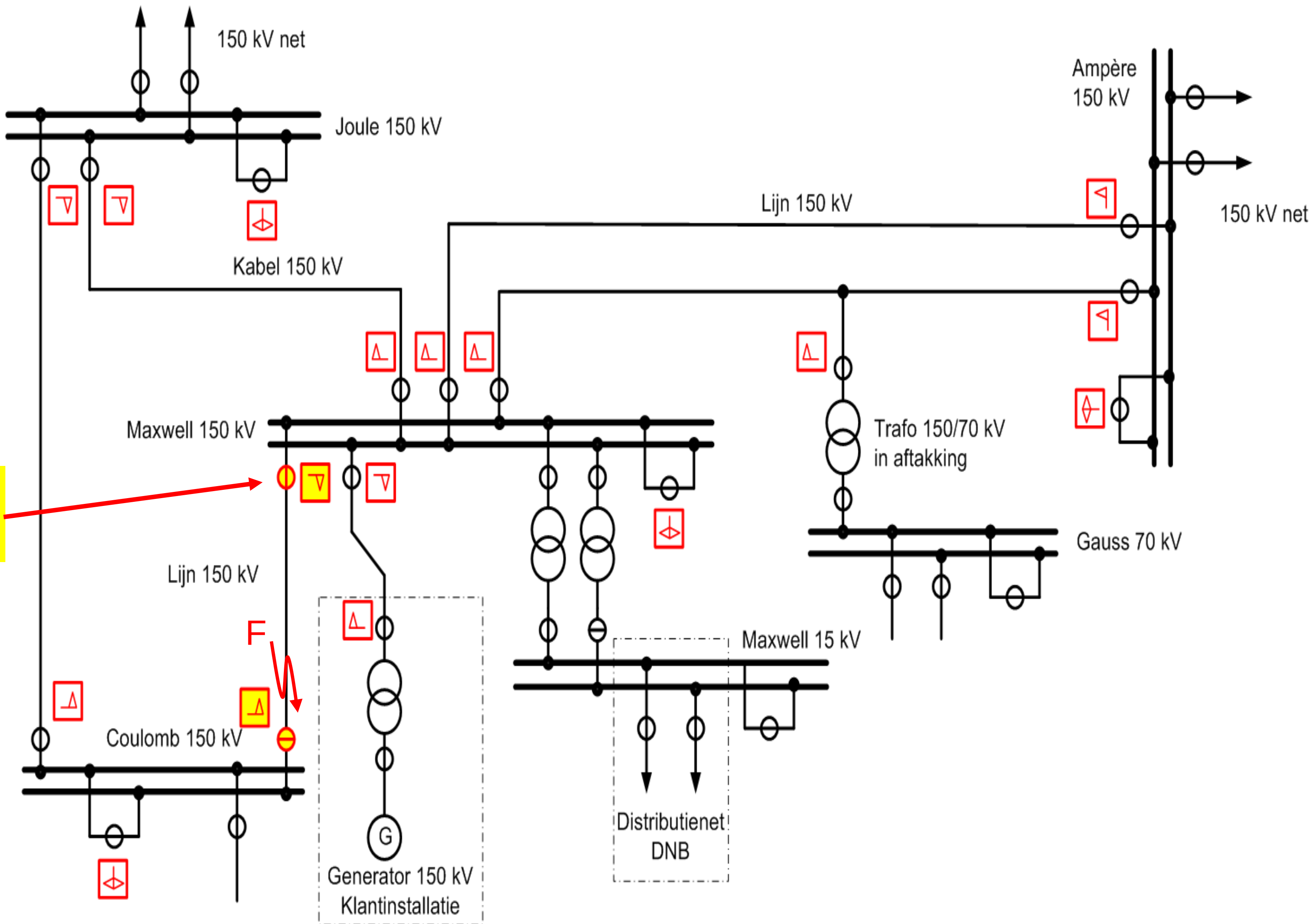
⇒ Fault F



Circuit breaker failure without CB failure protection

t = 120 ms

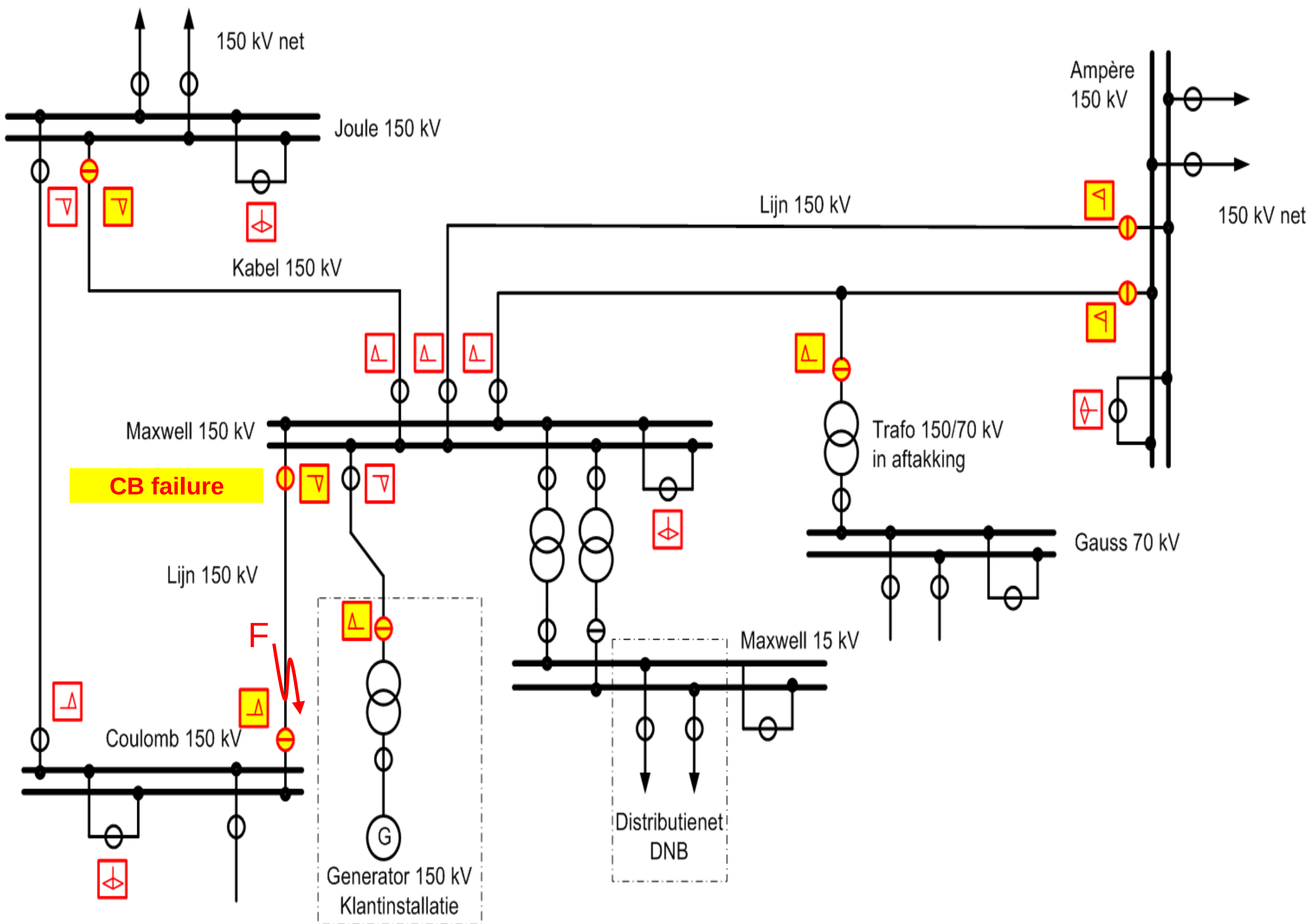
Circuit breaker failure (no tripping)



Circuit breaker failure without CB failure protection

t ≈ 1000 ms

Tripping through zone 2 or zone 3 of distance protections

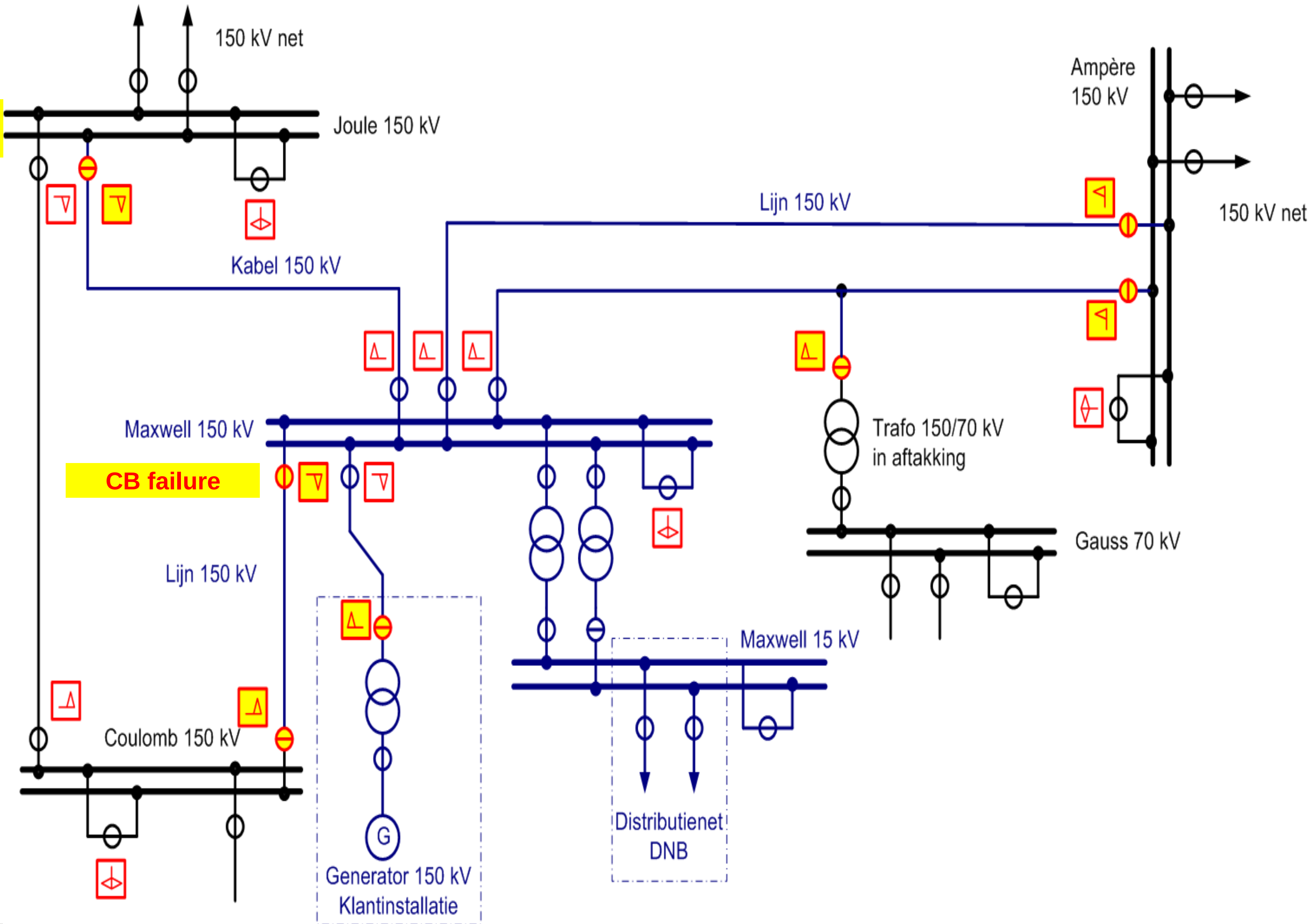


Circuit breaker failure without CB failure protection

t ≈ 1050 ms

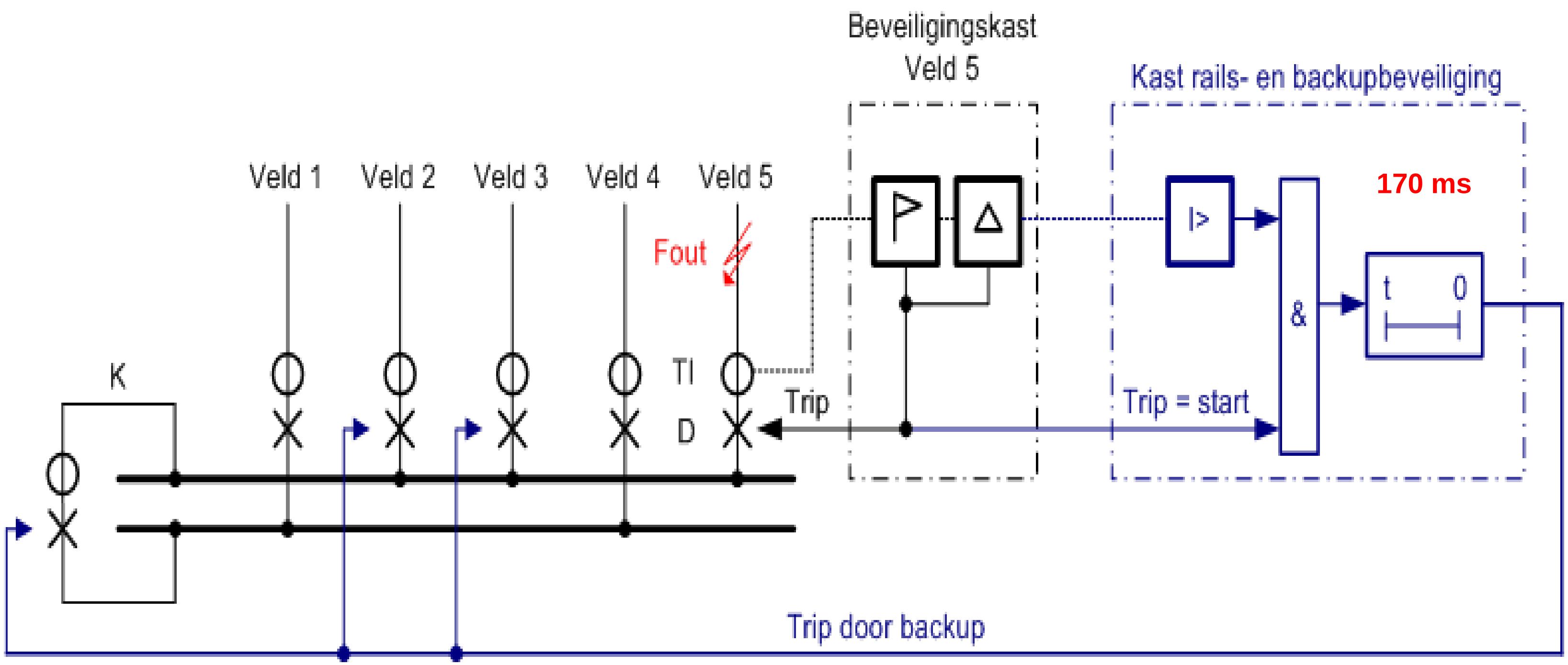
Fault eliminated

Both busbars lost due to the failure of a single equipment



CB failure protection principle

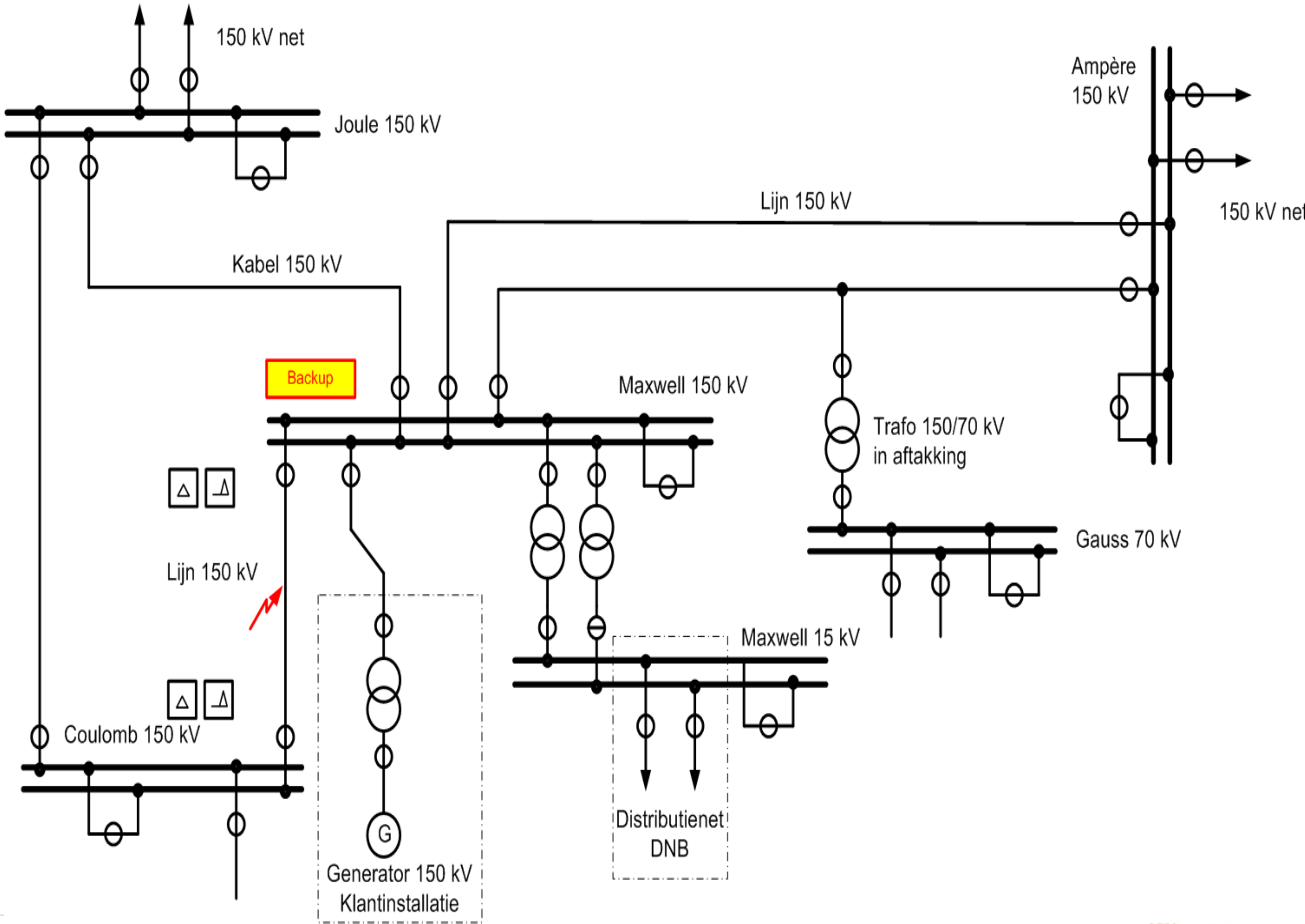
- The tripping signal issued by bay protections is sent to the circuit breaker and to the CB failure protection at the same time
- If current is still flowing through the CB 170 ms after the fault occurence, the other bays connected to the same busbar are tripped
- Consequence: the CB failure protection is implemented in the busbar protection



CB failure protection principle

t = 0 ms

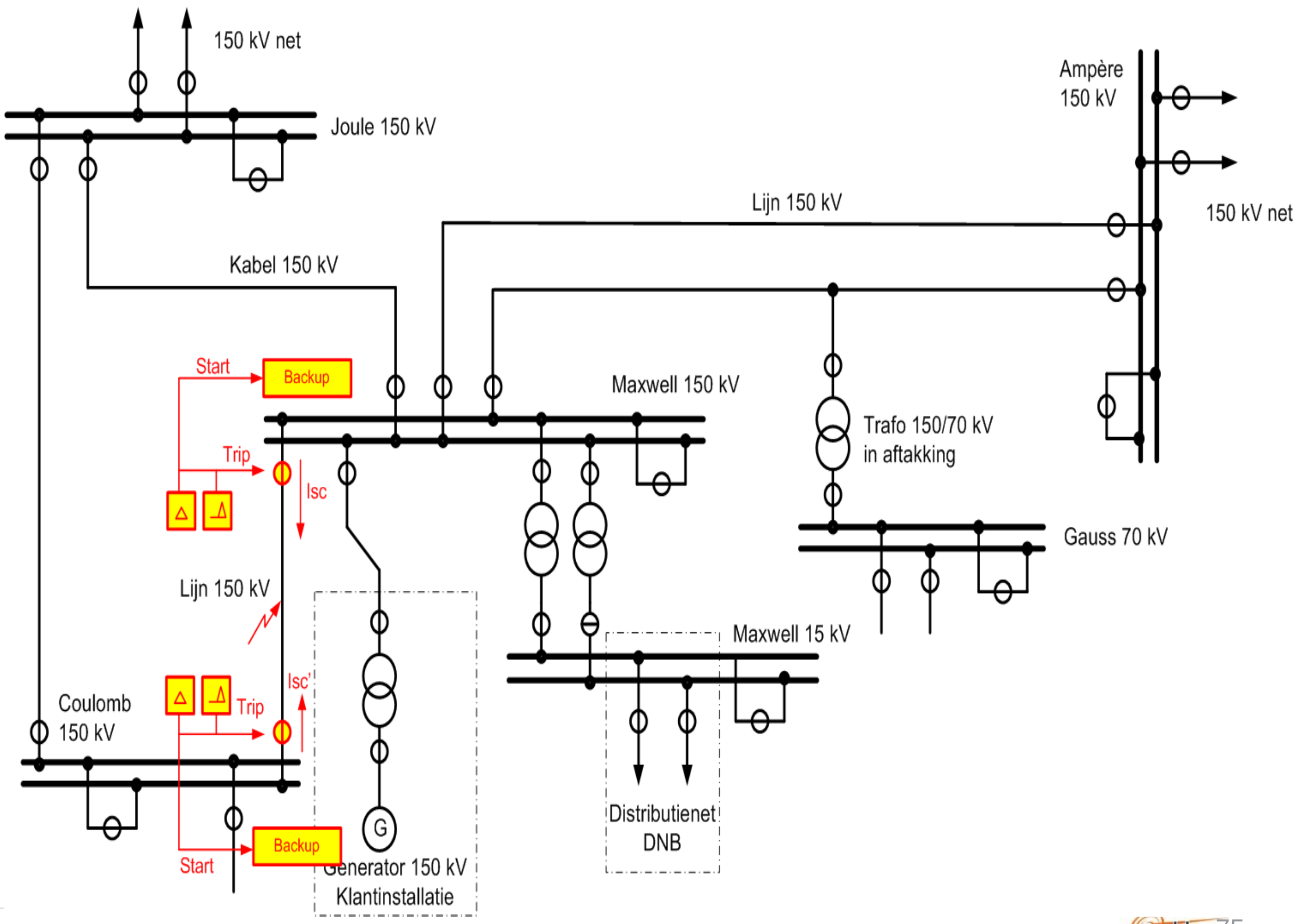
Fault



CB failure protection principle

t = 30 ms

Trip issued by bay protections

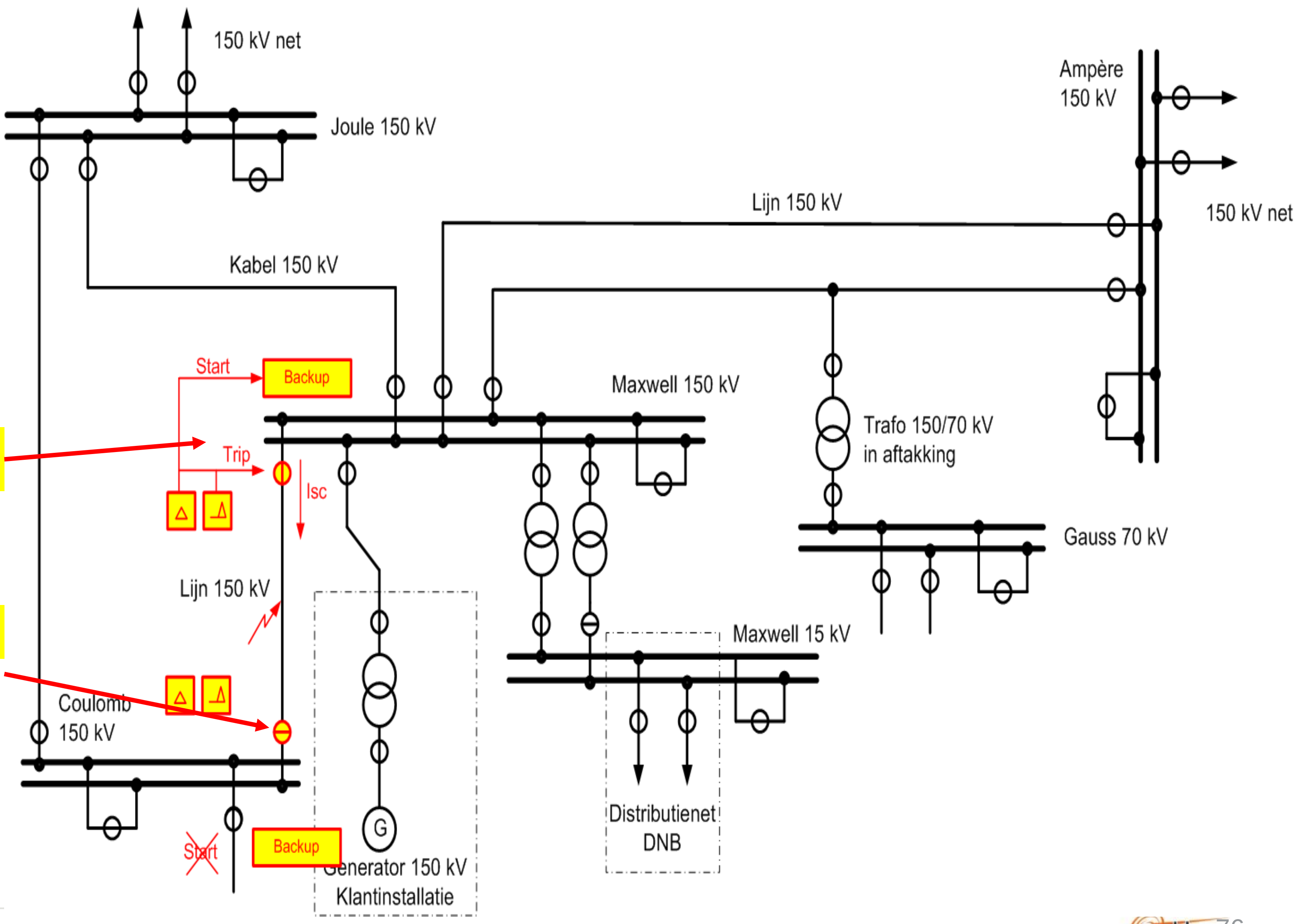


CB failure protection principle

t = 80 ms

CB failure

CB tripped

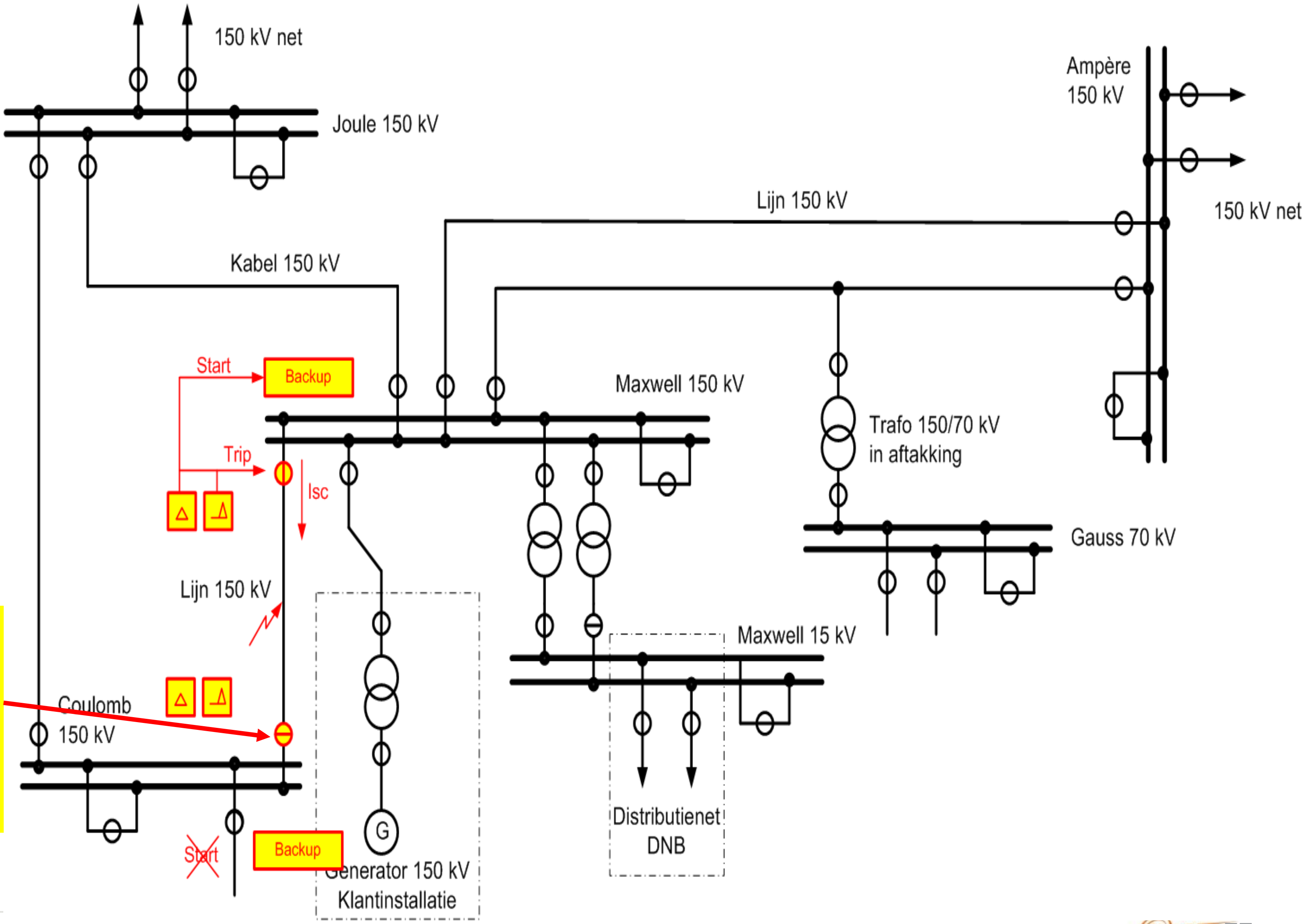


CB failure protection principle

t = 90 ms

No current

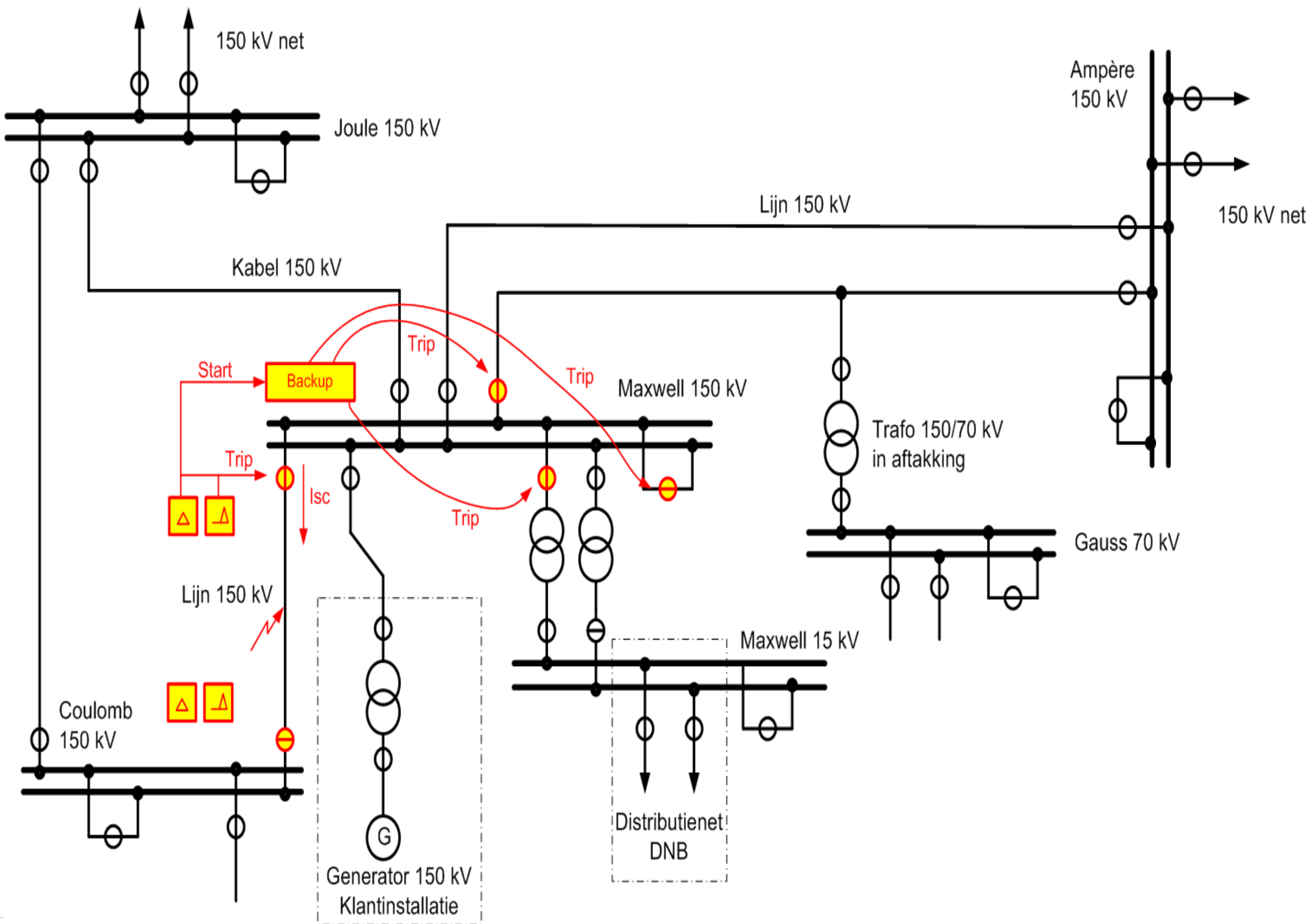
CB failure protection reset



CB failure protection principle

t = 200 ms

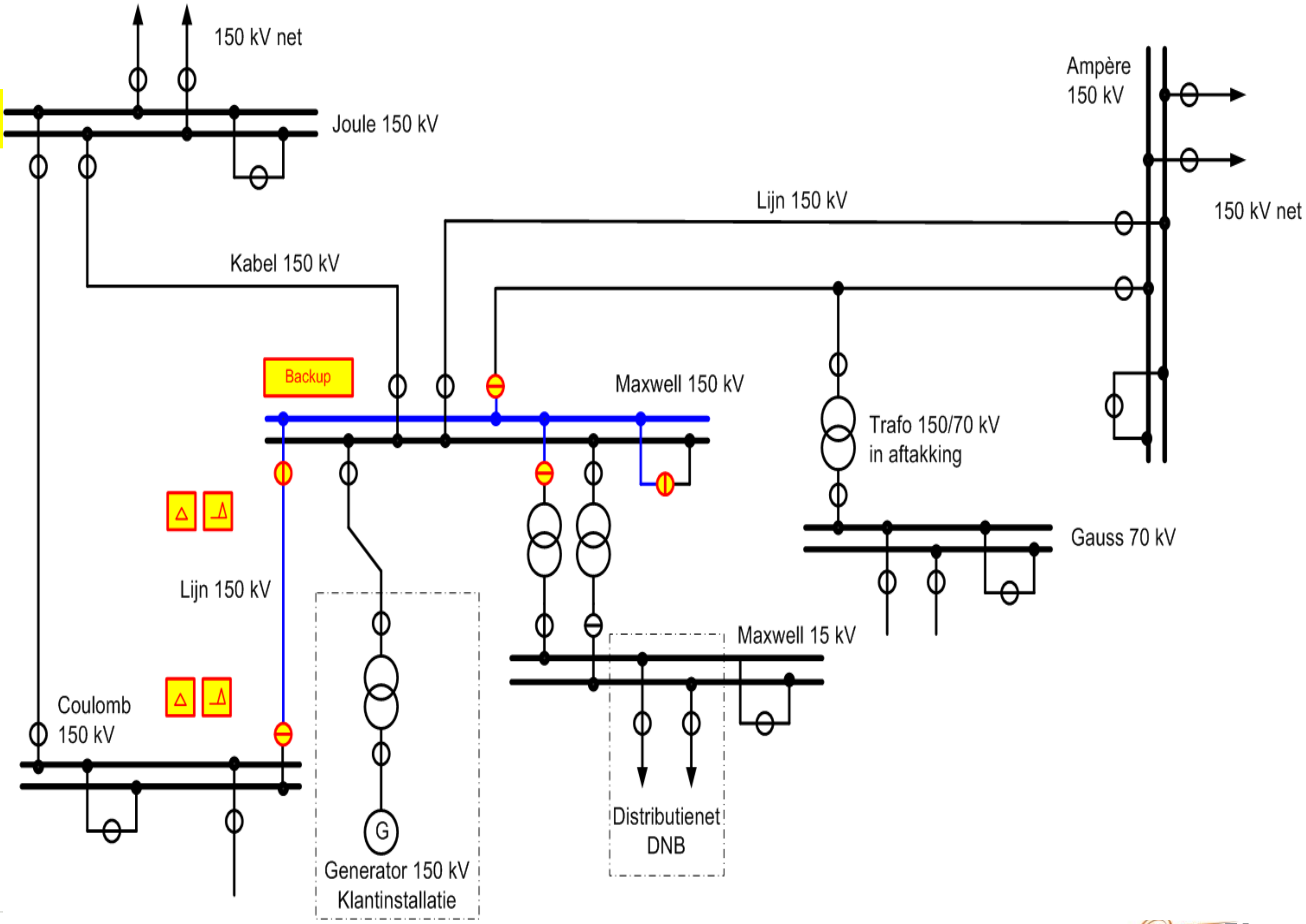
(170 ms after start back-up): trip to other bays



CB failure protection principle

t = 250 ms

Fault eliminated



Implementation

Training Center

Protection system of transformers between busbars

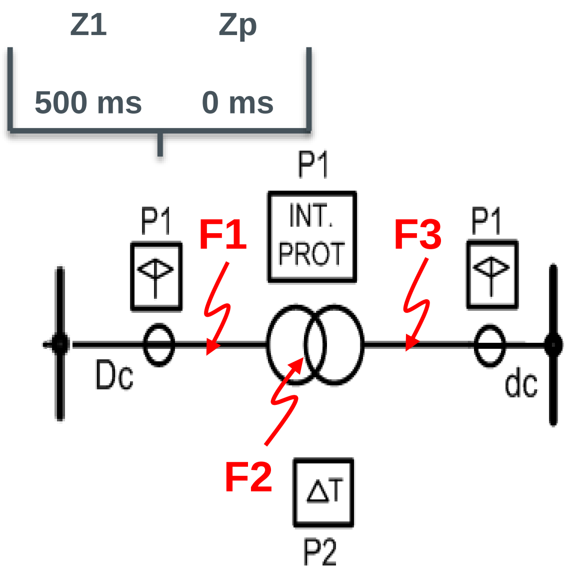
One of the protections must be a distance protection

Spannings-niveau (kV)	LIJNEN, KABELS, TRANSFORMATOREN *									RAILFOUT		
	Basis (ms)	Weigering Beveiliging (ms)	Weigering Verm. Schakel (ms) 1f. fout	Weigering Verm. Schakel (ms) meerf.	Reserve volgende lijn/kabel (ms)	Réserve volgend railstel (ms) **** 1f. fout	Réserve volgend railstel (ms) **** meerf.	Herinschakeling luchtlijn (ms) 1f. fout	Herinschakeling luchtlijn (ms) meerf.	Basis (ms)	Reserve van de koppeling (ms) 1f. fout	Reserve van de koppeling (ms) meerf.
Niveau de tension (kV)	LIGNES, CABLES, TRANSFO *									DEFAUT JEUX DE BARRES		
	Base (ms)	Refus Protect (ms)	Refus Disj. (ms) déf. mono	Refus Disj. (ms) déf. poly	Réserve ligne/câble suivant (ms)	Réserve jeux de barres suivants (ms) **** déf. mono	Réserve jeux de barres suivants (ms) **** déf. poly	Réenclenchement ligne (ms) mono.	Réenclenchement ligne (ms) Poly-phasé	Base (ms)	Réserve du couplage (ms) déf. mono.	Réserve du couplage (ms) déf. poly
380	100	100	300	170	1000	500	250	1	10	100	250	170
220	120	120	-	-	1000	600	600	1	***	100	300	300
150	120	120	-	-	1000	600	600	1	***	100	300	300
70	120**	2250	-	-	1000	600	600	-	***	600	-	-
36	120	2250	-	-	1200	1200	1200	-	***	600	-	-
30	120	2250	-	-	1200	1200	1200	-	***	600	-	-
15	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
12	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
10	1100	3100	-	-	-	1800	1800	-	***	1800	-	-

Two independant protections for each part of the protection zone ⇨ priority to dependability

Consistent with N-1 criterium

Transformer protection principle



P1

- **Distance protections on primary side of the transformer:** one zone to detect F1 fault, one zone to detect busbar fault on primary side
- **Internal protection of the transformer** (Buchholz): only able to detect internal faults through oil move detection (F2)
- **Distance protections on secondary side of the transformer:** one zone to detect F3 fault, one zone to detect busbar fault on secondary side

P2

Differentia protection (able to detect F1, F2 and F3 faults)

Bay arrangements

Double busbar one breaker substation arrangement

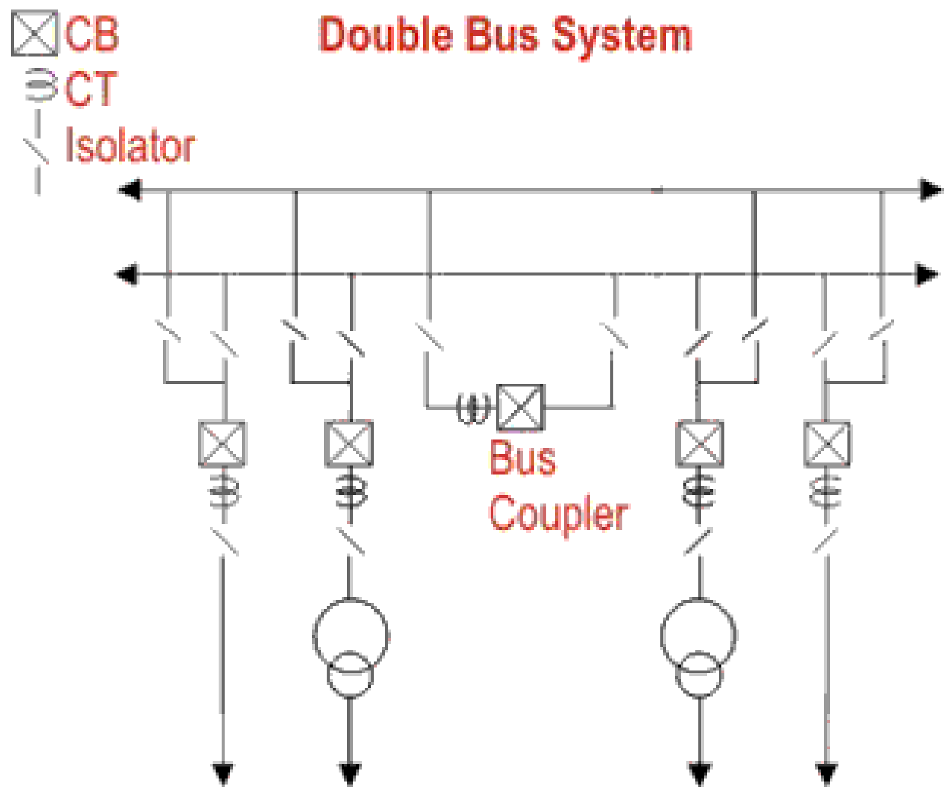
One circuit breaker for each bay

Main advantages:

- Any bay can be connected to any busbar without loss of supply
- Cost

Main drawbacks

- Loss of supply in case of busbar fault
- Loss of supply during circuit breaker maintenance
- Disconnector operation needed to supply any bay from the other busbar



One and Half substation arrangement

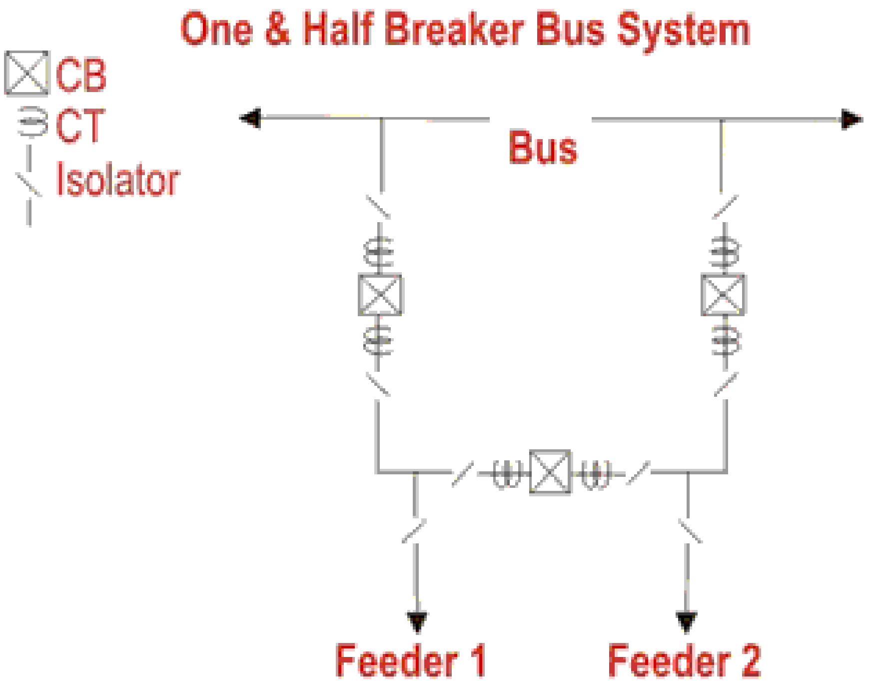
3 circuit breakers used to feed 2 bays ⇨ 1,5 circuit breaker for each bay

Main advantages:

- No loss of supply in case of busbar fault
- No loss of supply during circuit breaker maintenance
- No disconnector operation needed to supply any bay from the other busbar

Main drawbacks :

- Cost (more circuit breakers)
- Complexity of protections and relaying



Ring bus substation arrangement

No « classical » busbar, ring topology

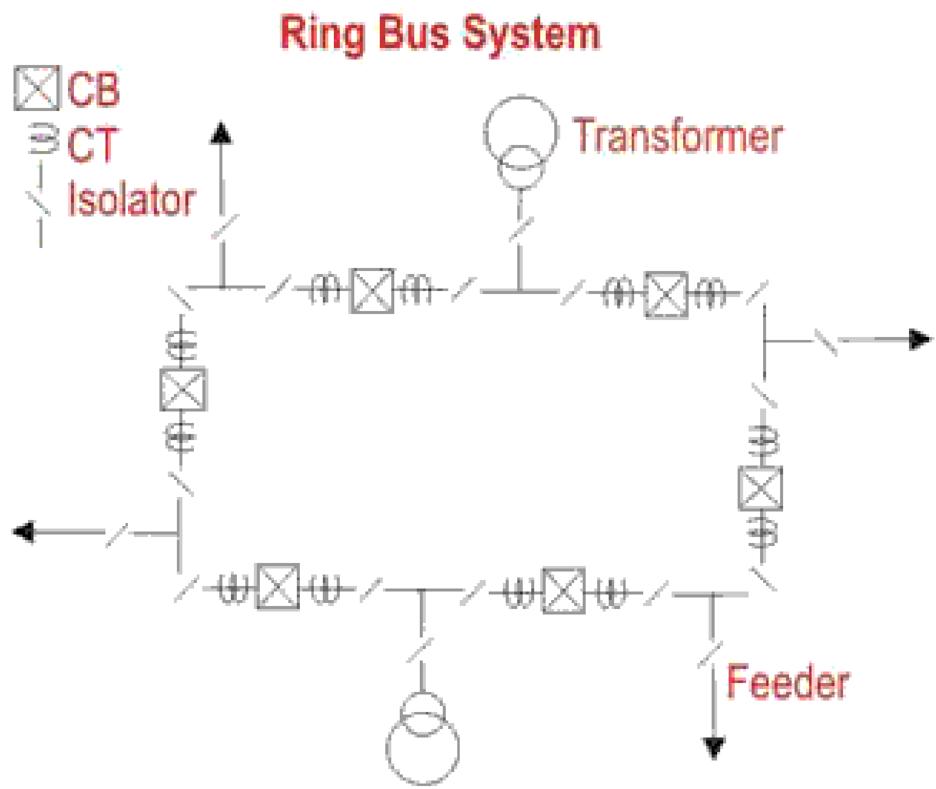
Main advantages:

- No loss of supply during circuit breaker maintenance

Main drawbacks :

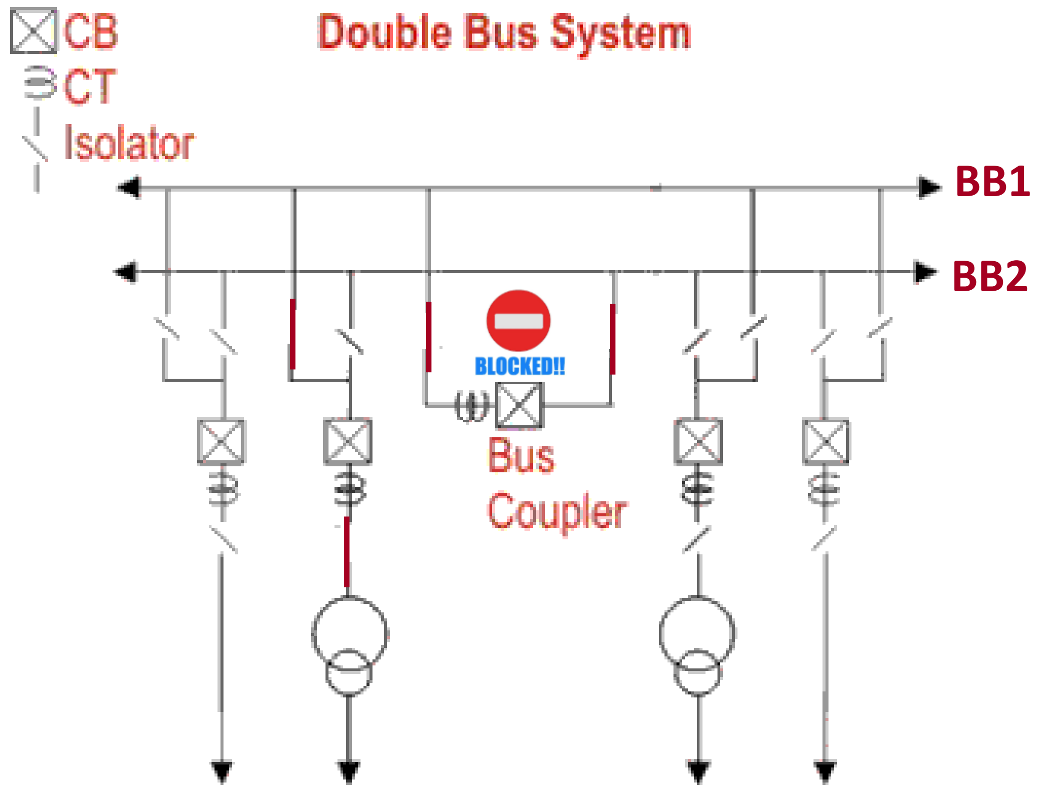
- Difficult to extend with a new bay

- Very bad reliability if one circuit breaker is out of operation



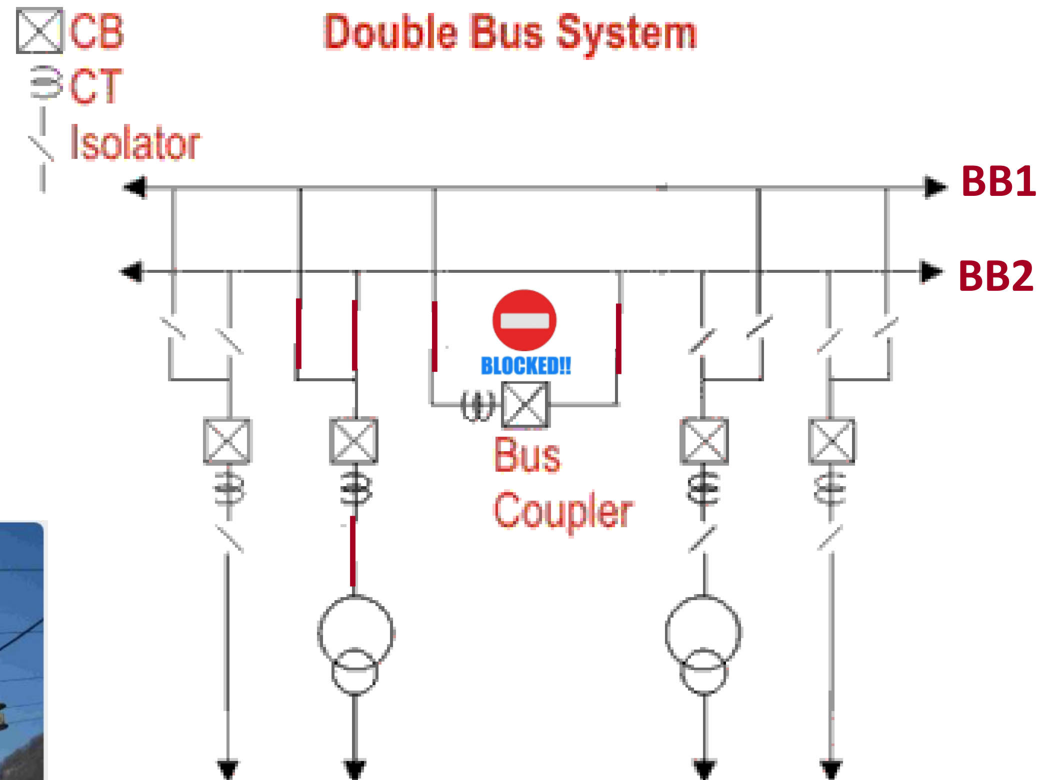
Sequence to switch one bay from busbar 1 to busbar 2

1. Close the CB of the bus coupler and block any tripping
2. Close disconnector to busbar 2
3. Open disconnector to busbar 1
4. Release CB of the bus coupler



Sequence to switch one bay from busbar 1 to busbar 2

1. Close the CB of the bus coupler and block any tripping
2. Close disconnector to busbar 2
3. Open disconnector to busbar 1
4. Release CB of the bus coupler



Sequence to switch one bay from busbar 1 to busbar 2

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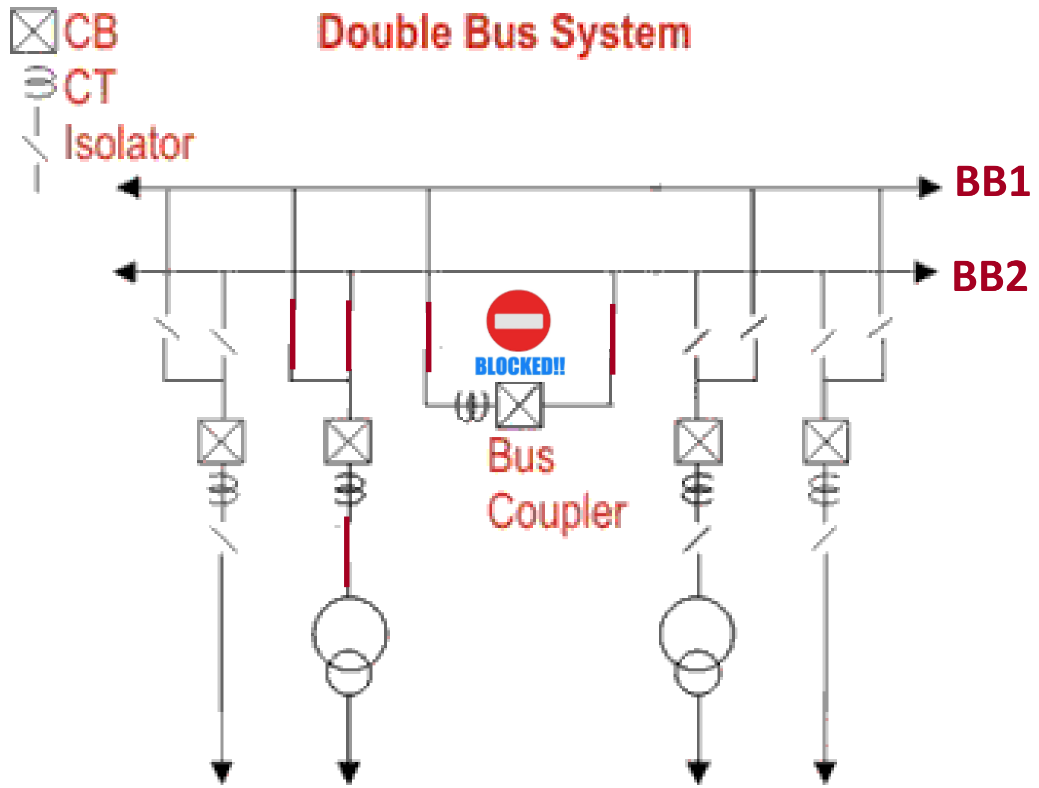
2. Close disconnector to busbar 2
3. Open disconnector to busbar 1
4. Release CB of the bus coupler



Sequence to switch one bay from busbar 1 to busbar 2

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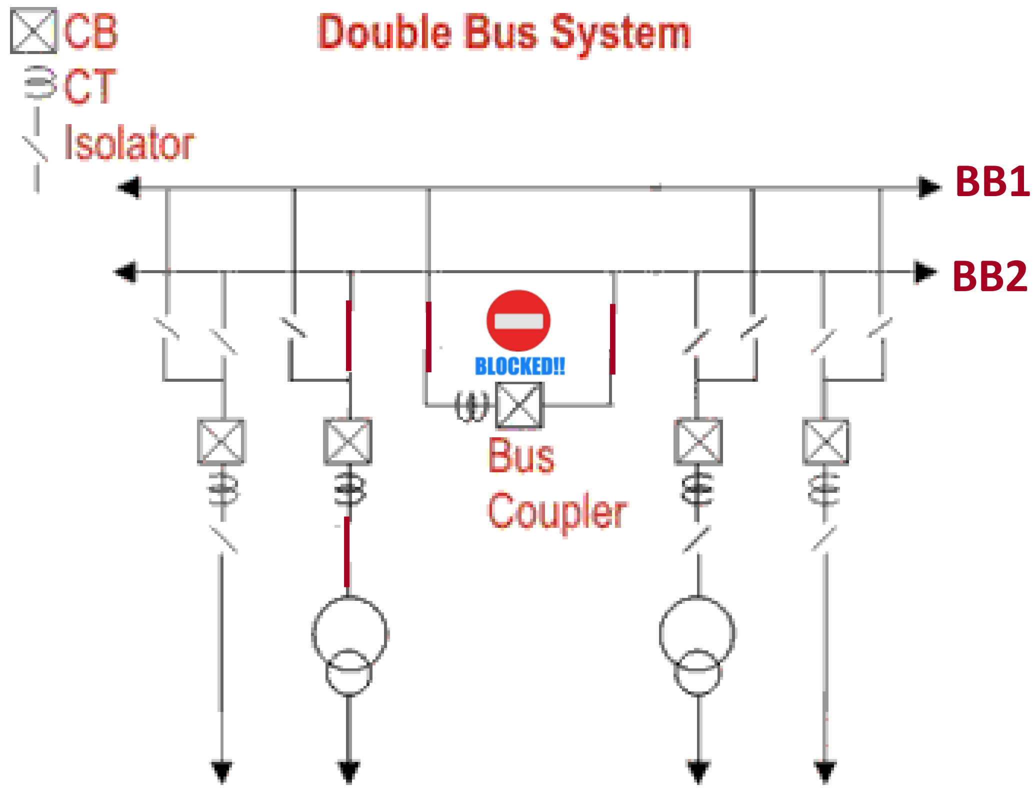
4. Release CB of the bus coupler



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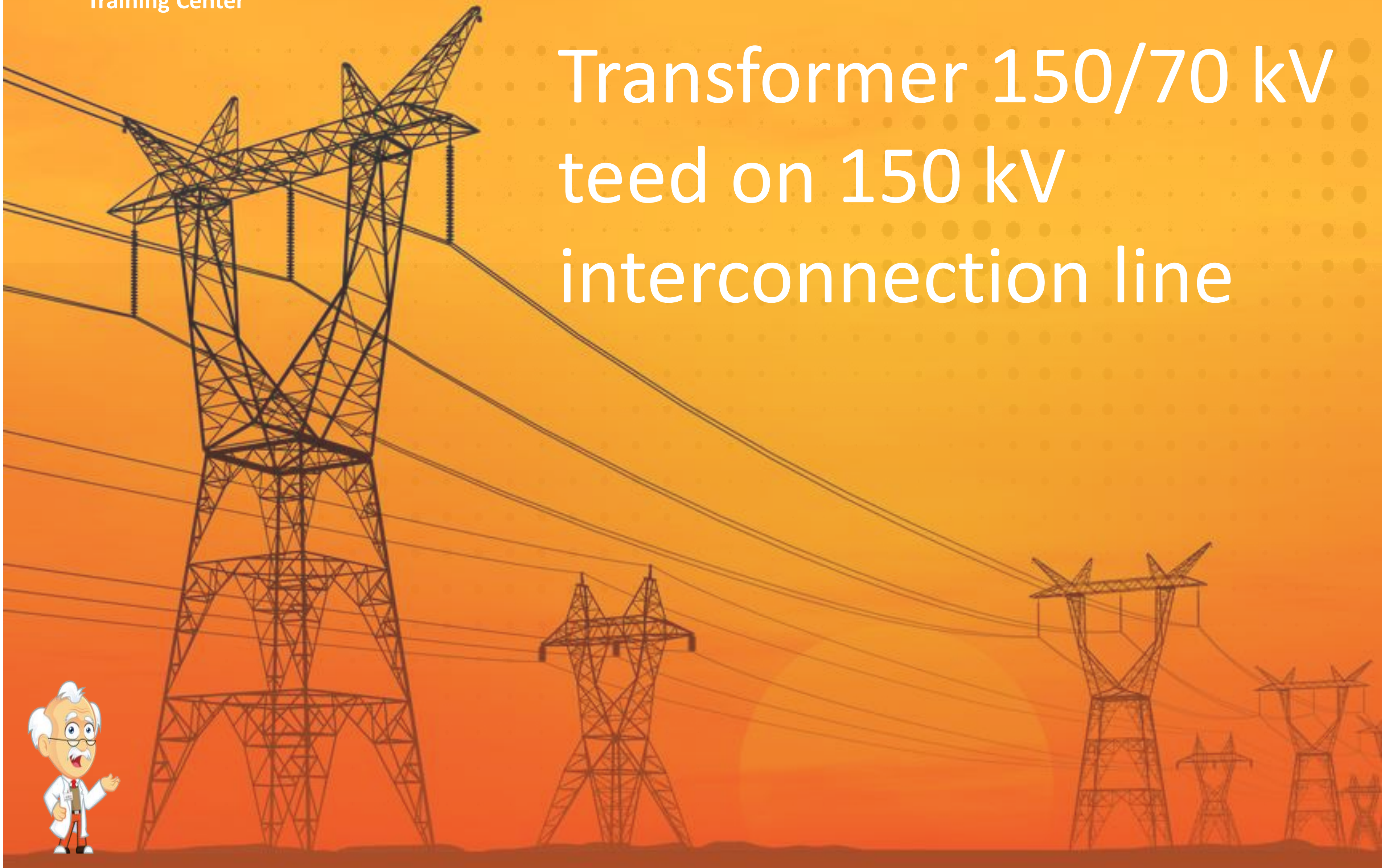
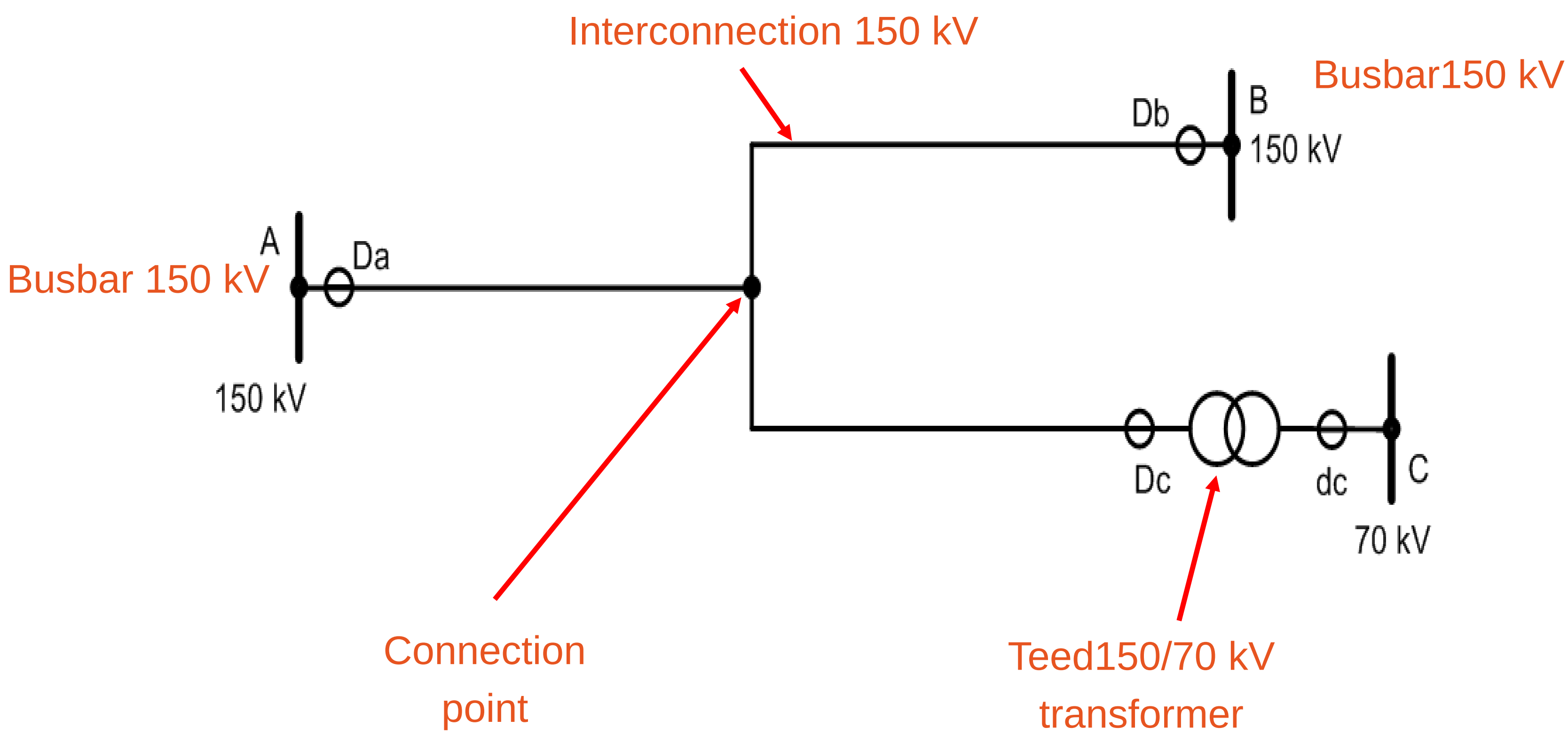
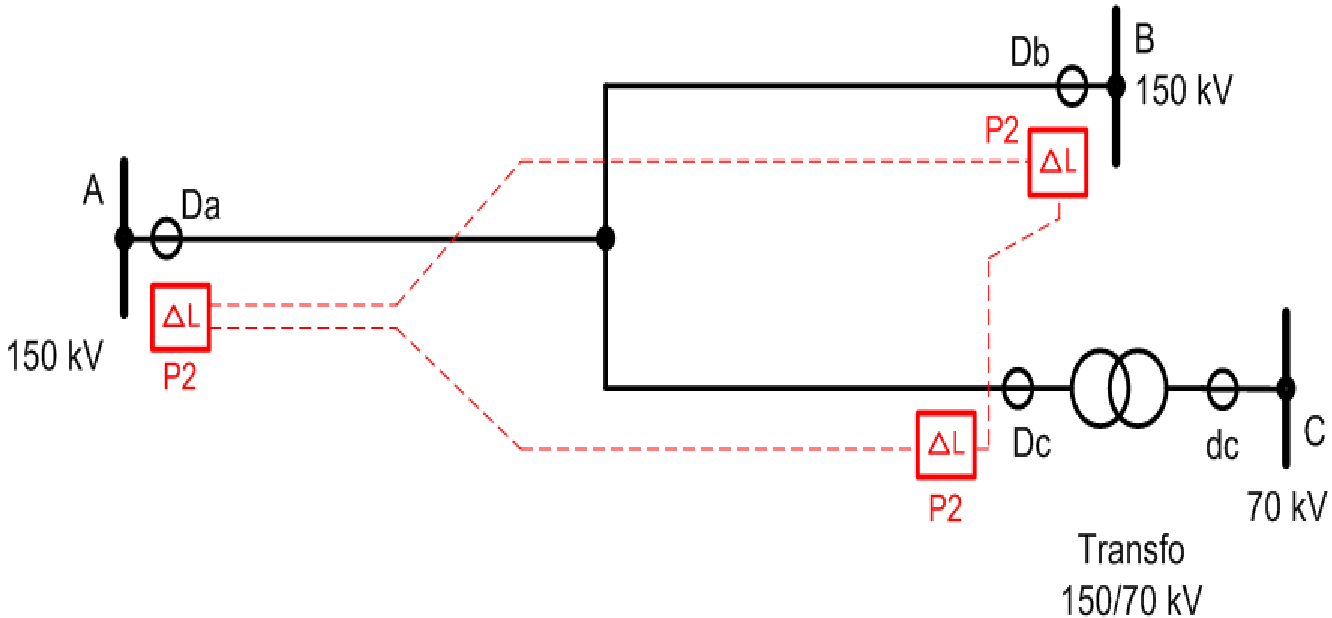
Transformer 150/70 kV teed on 150 kV interconnection line



Transformer 150/70 kV teed on 150 kV interconnection line



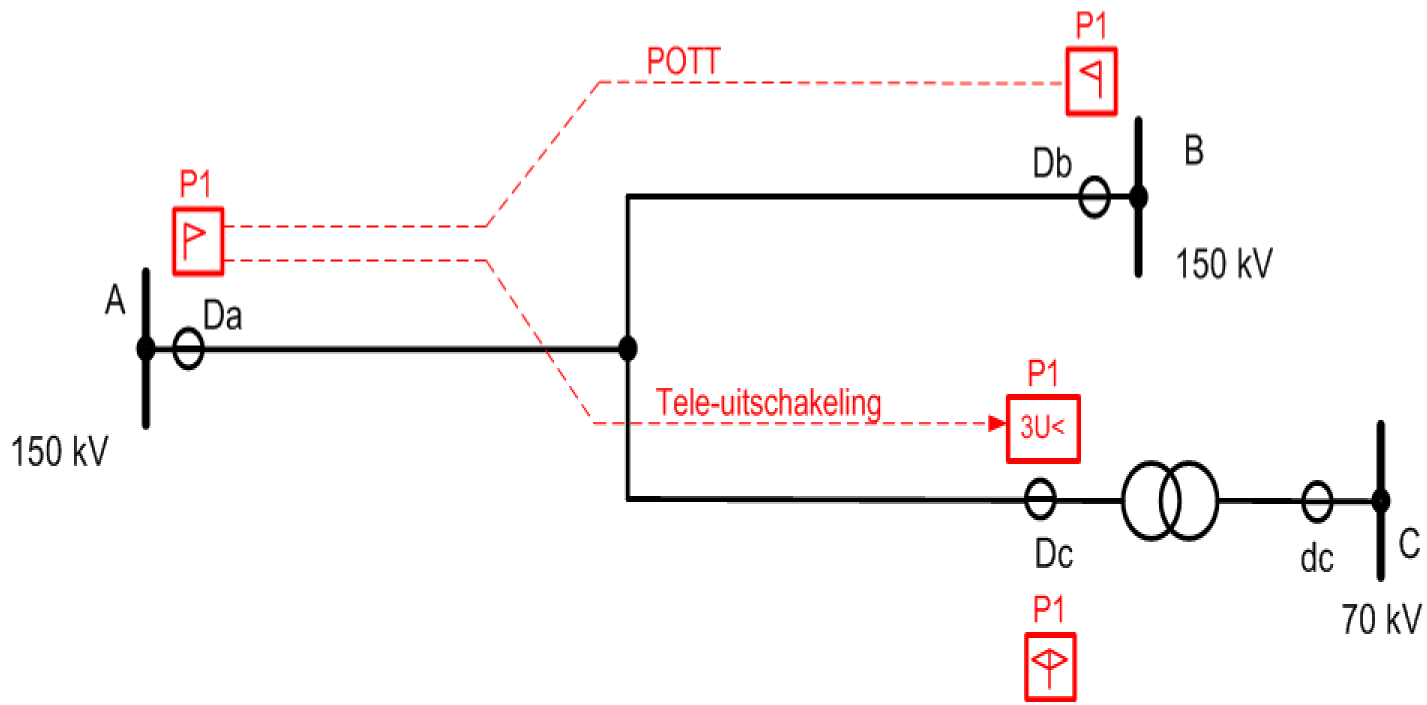
Transformer 150/70 kV teed on 150 kV interconnection line



P2 protection = ΔL

- 3-ends line differential protection
- Communication channel between each protection
- Instantaneous tripping of any fault on the interconnection line

Transformer 150/70 kV teed on 150 kV interconnection line



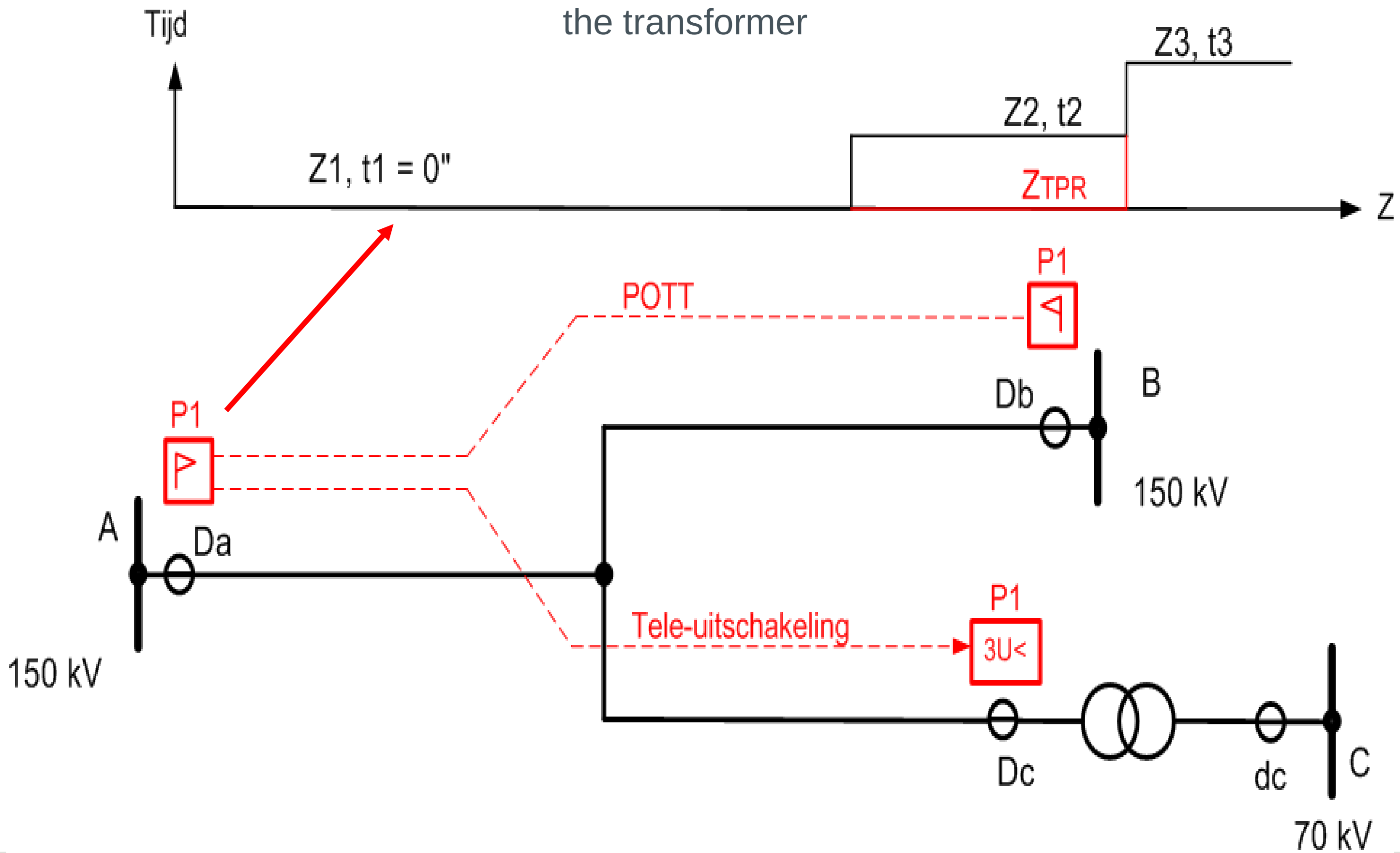
P1 = protection

- 2 distance protections with POTT logic between A and B ends, and remote tripping of the transformer (validation through local criterium)
- Communication channel between A and B ends (POTT), and between A and C ends

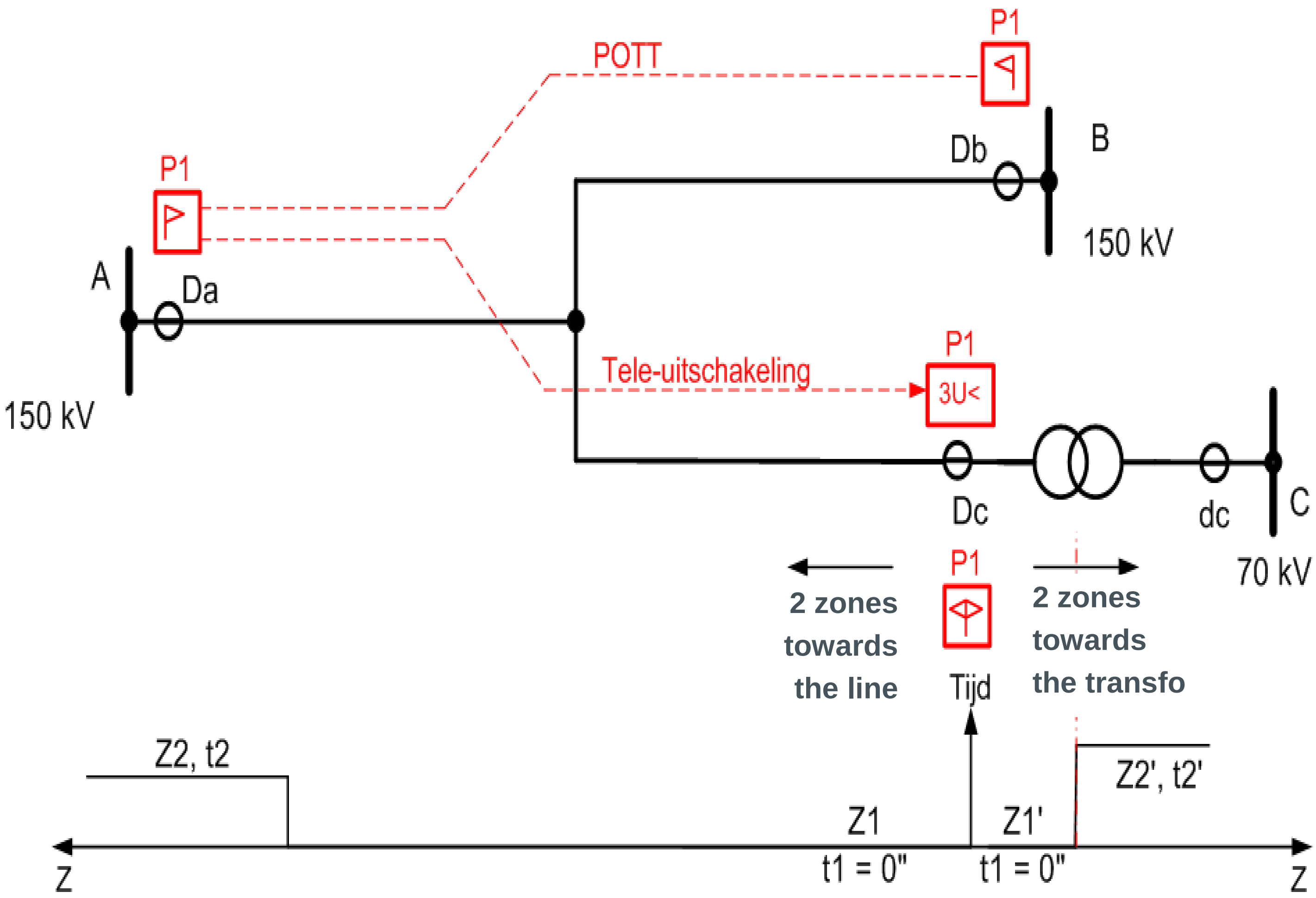
Transformer 150/70 kV teed on 150 kV interconnection line

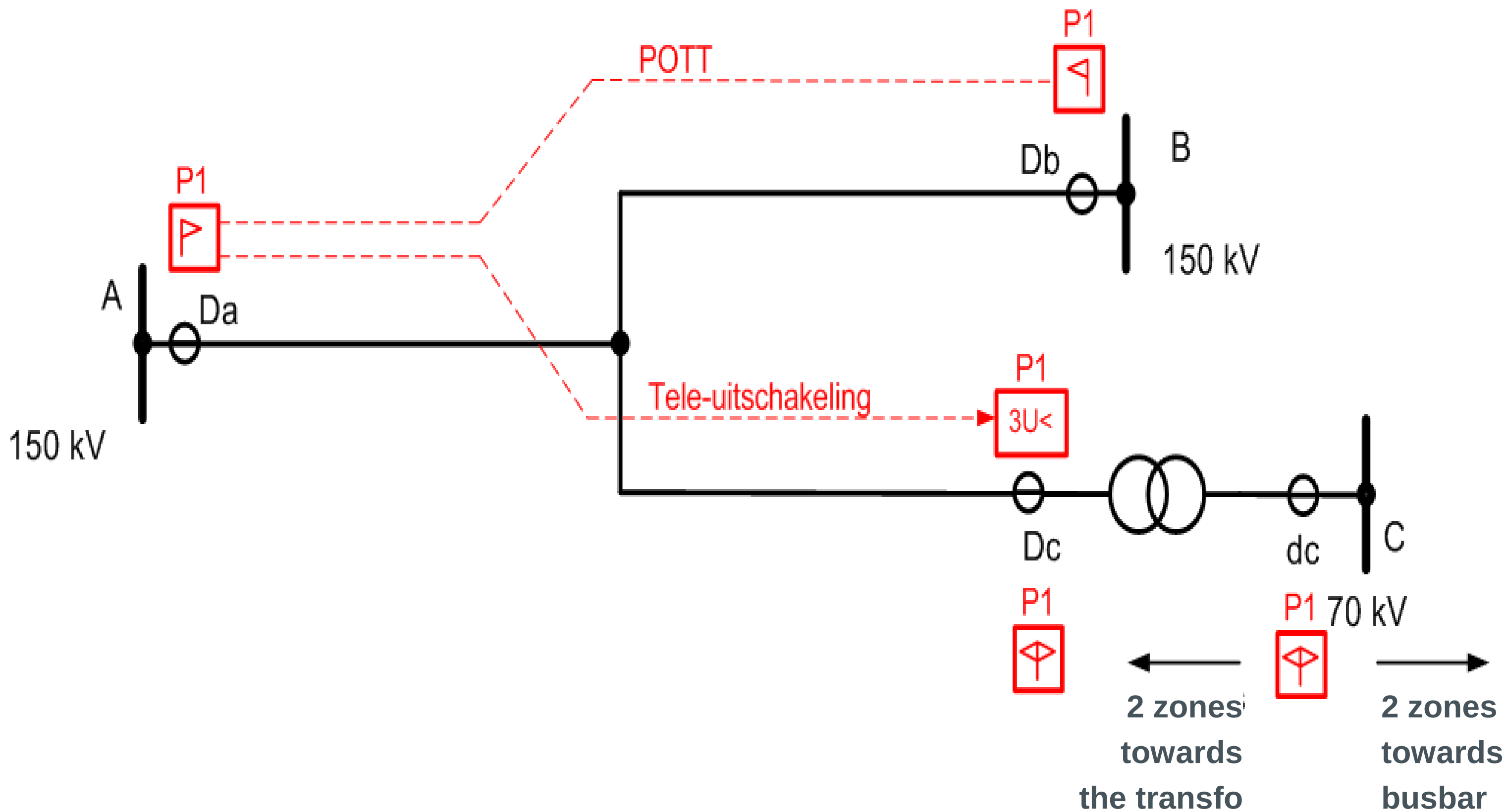
3 zones:

- Z1: covers. 80% of the line
- Z2: covers the next busbar (backup for busbar faults)
- Ztpr must cover the complete line, including a part of the transformer

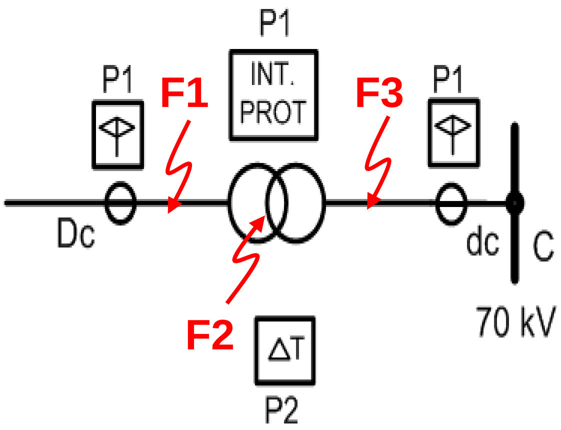


Transformer 150/70 kV teed on 150 kV interconnection line




POTT
P1
P1
B
Db
150 kV
A
Da
150 kV
P1
Tele-uitschakeling
3U<
Dc
dc
C
P1
P1
70 kV
2 zones towards the transfo
2 zones towards busbar

Transformer 150/70 kV teed on 150 kV interconnection line



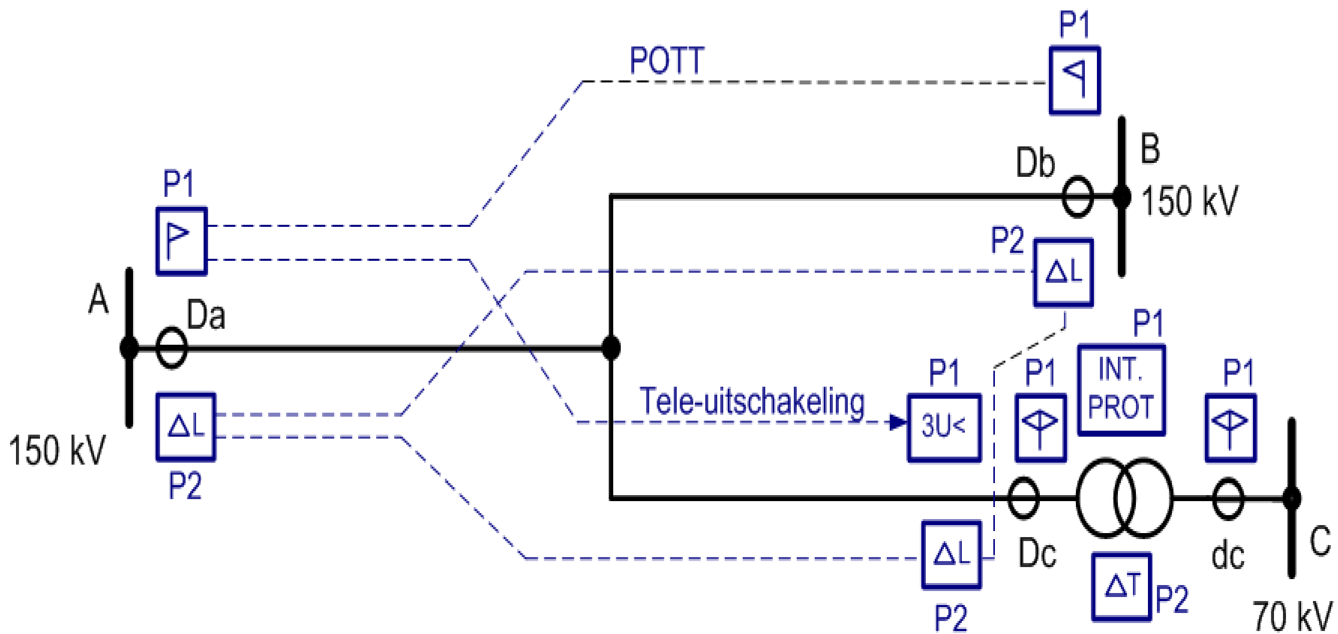
P1

- **Distance protections on primary side of the transformer:** one zone to detect F1 fault
- **Internal protection of the transformer** (Buchholz): only able to detect internal faults through oil move detection (F2)
- **Distance protections on secondary side of the transformer:** one zone to detect F3 fault

P2

Differentia protection (able to detect F1, F2 and F3 faults)

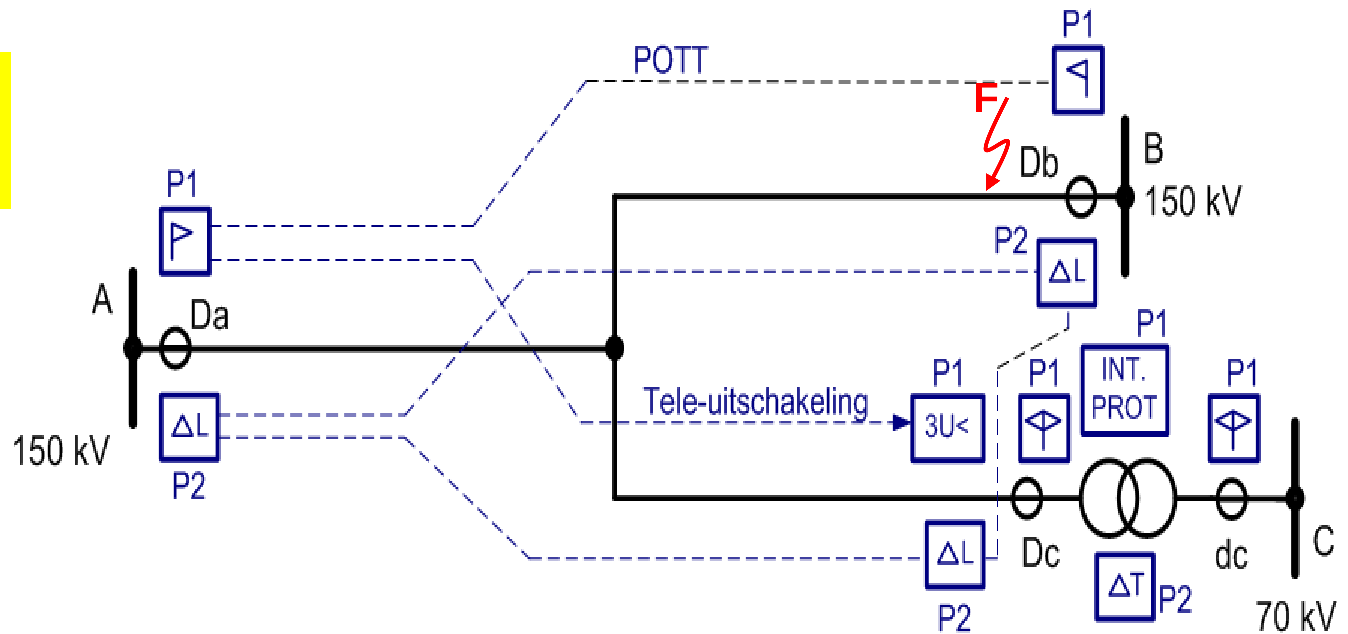
Transformer 150/70 kV teed on 150 kV interconnection line



Transformer 150/70 kV teed on 150 kV interconnection line

1) t = 0 ms

⇒ Fault F

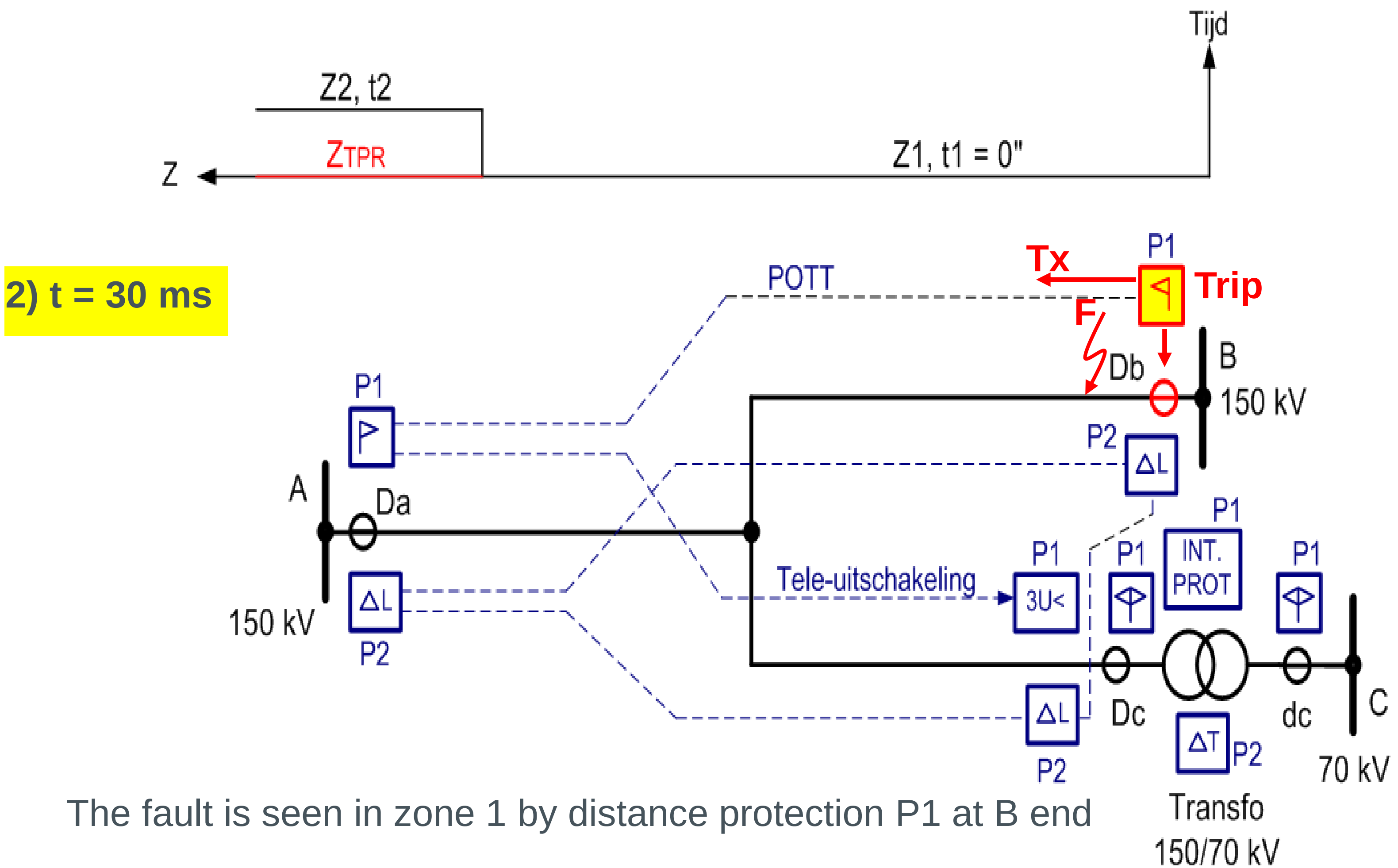


3-phase fault **F** beyond 85% of the line.

Line differential protection out of service

How will the fault be eliminated?

Transformer 150/70 kV teed on 150 kV interconnection line

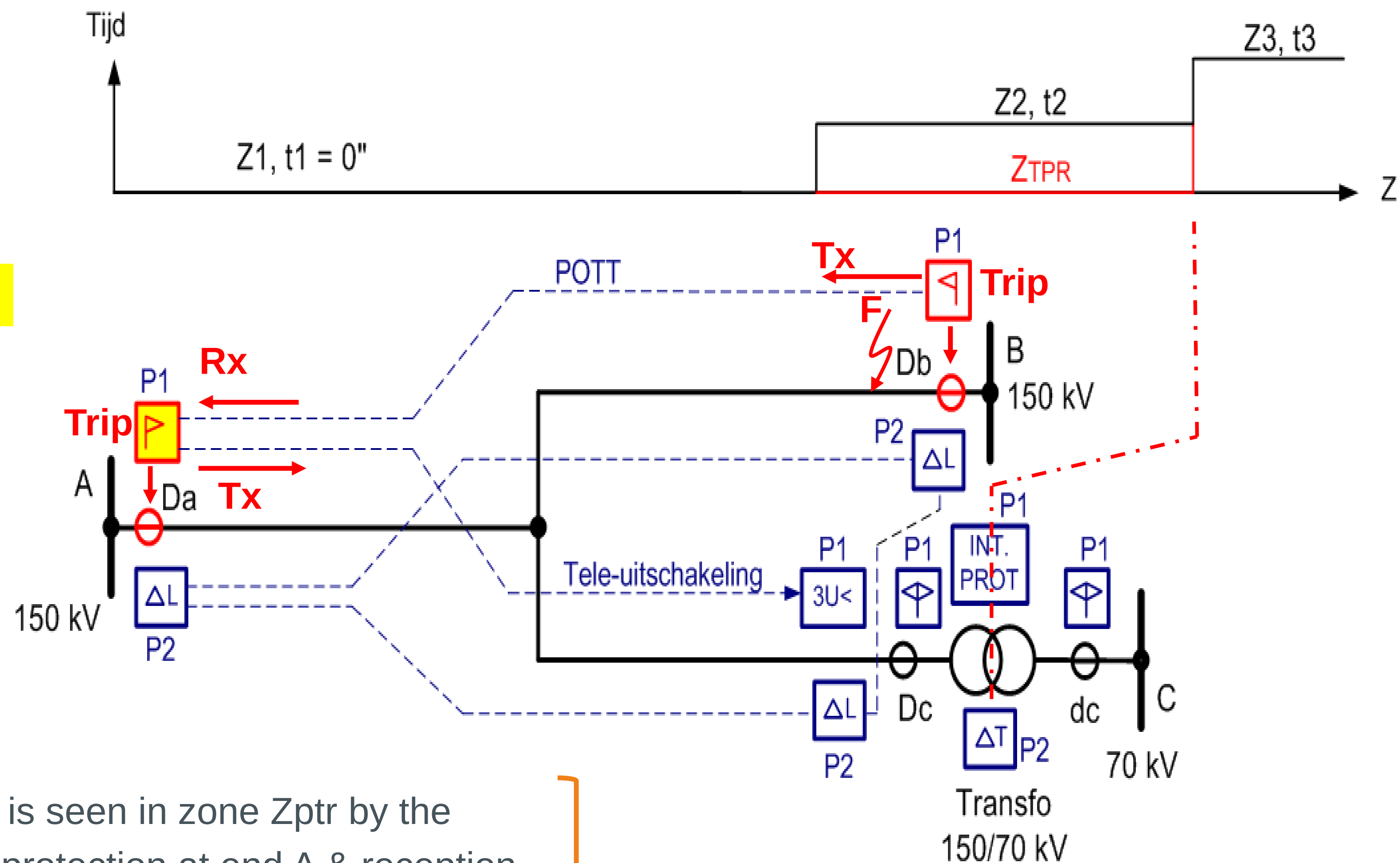


The fault is seen in zone 1 by distance protection P1 at B end

- Tripping order to Db circuit breaker
- “Tx” transmission to end A (POTT)

Transformer 150/70 kV teed on 150 kV interconnection line

3) t = 40 ms



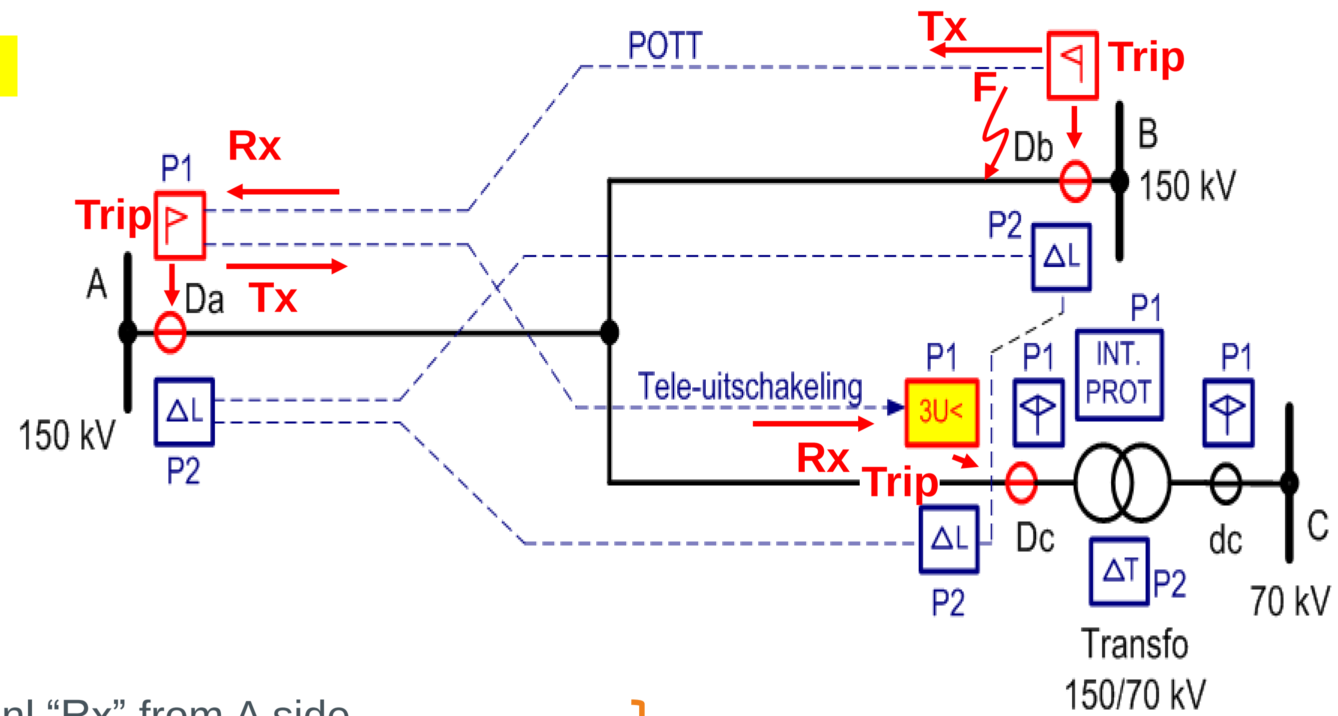
The fault is seen in zone Zptr by the distance protection at end A & reception "Rx" from end B (POTT)

⇒

- Tripping order to Da circuit breaker
- Transmission "Tx" to end C

Transformer 150/70 kV teed on 150 kV interconnection line

4) t = 50 ms

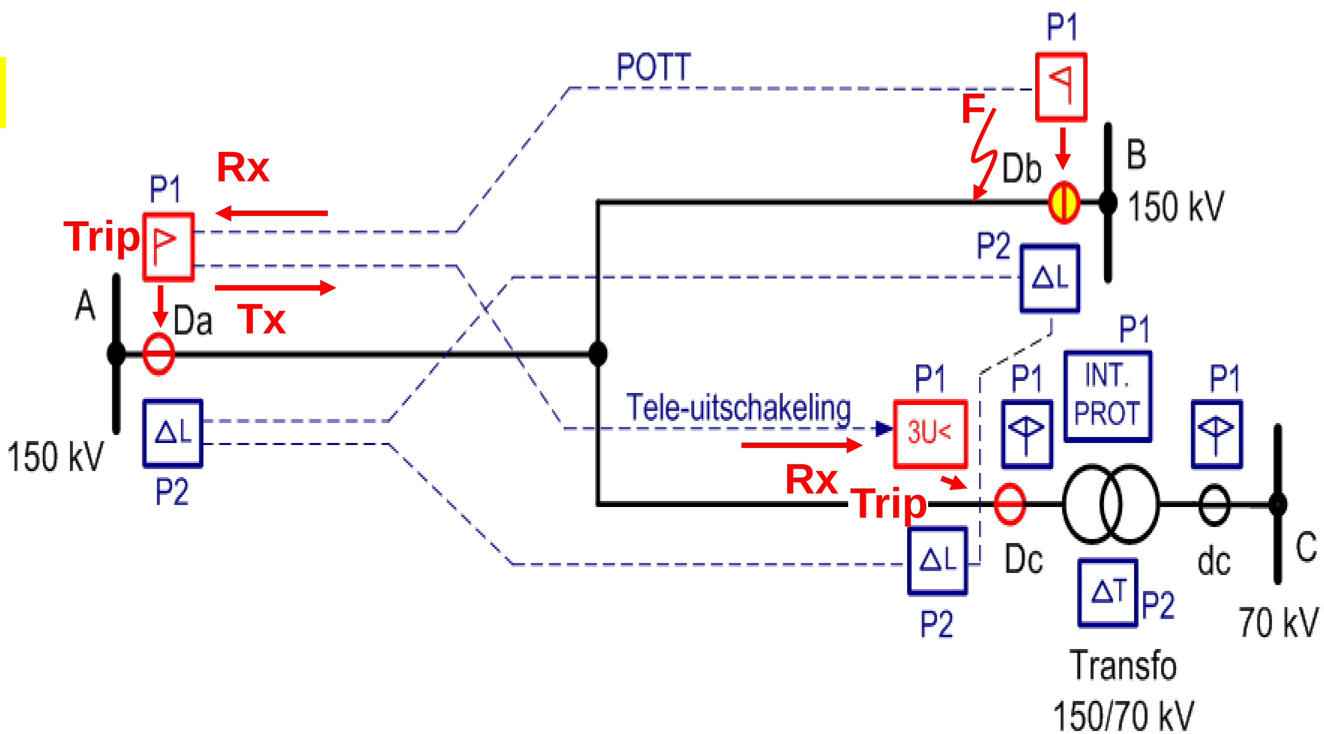


Receptionl “Rx” from A side

& validation through local criterium 3U<ph/n ⇒ Tripping order to Dc circuit breaker

Transformer 150/70 kV teed on 150 kV interconnection line

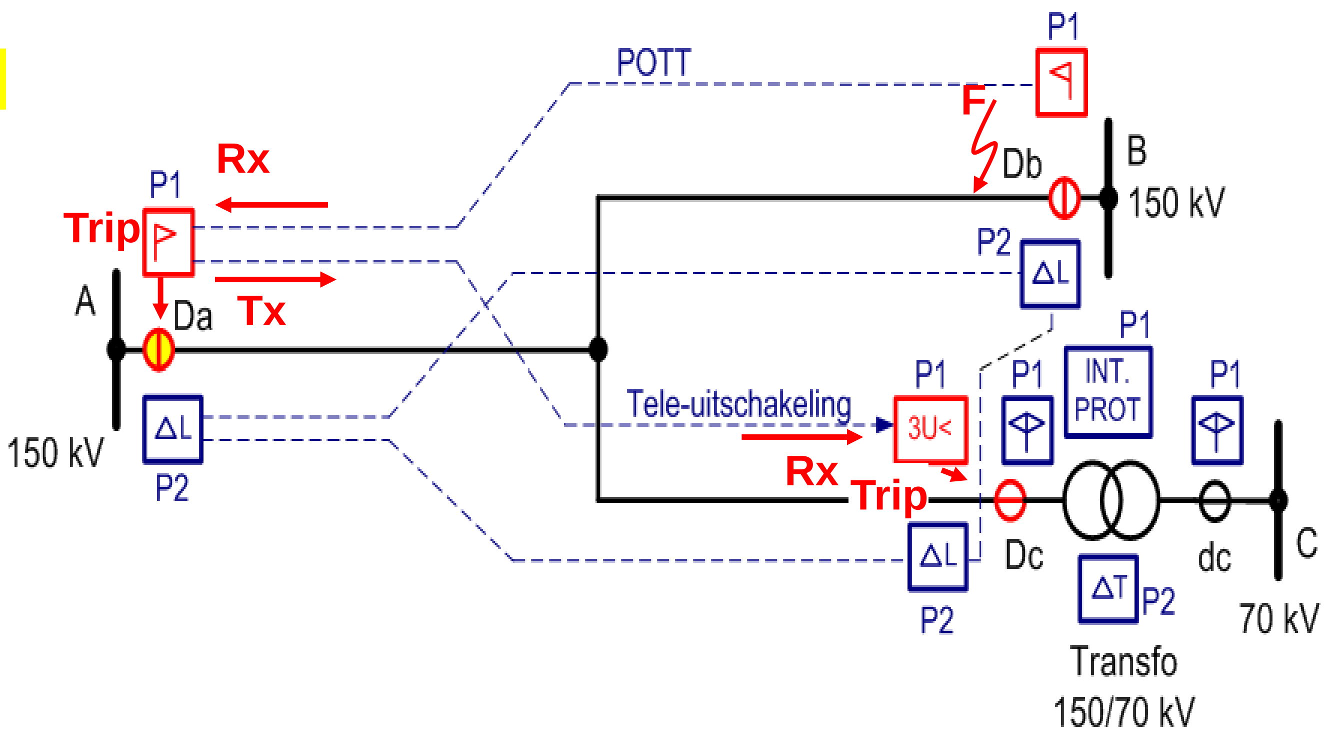
5) t = 80 ms



Db tripped

Transformer 150/70 kV teed on 150 kV interconnection line

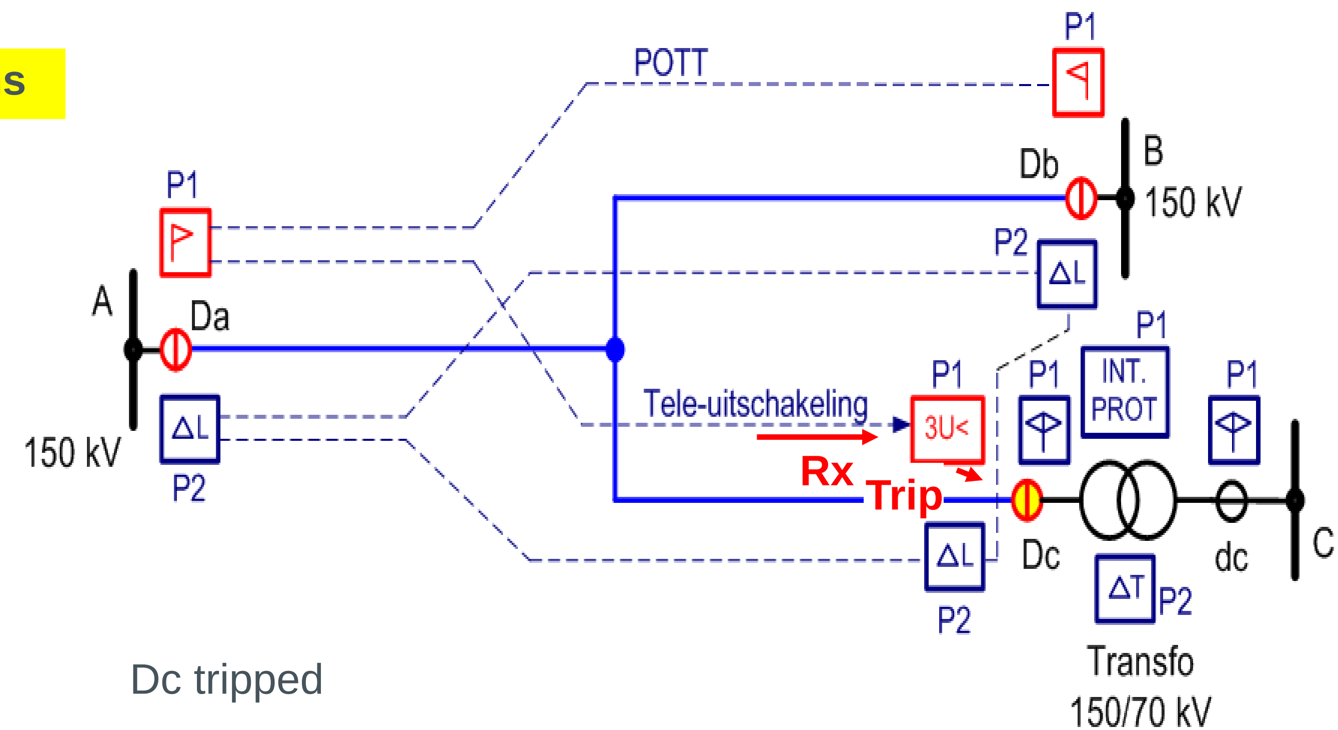
7) t = 90 ms



Da tripped

Transformer 150/70 kV teed on 150 kV interconnection line

8) t = 100 ms

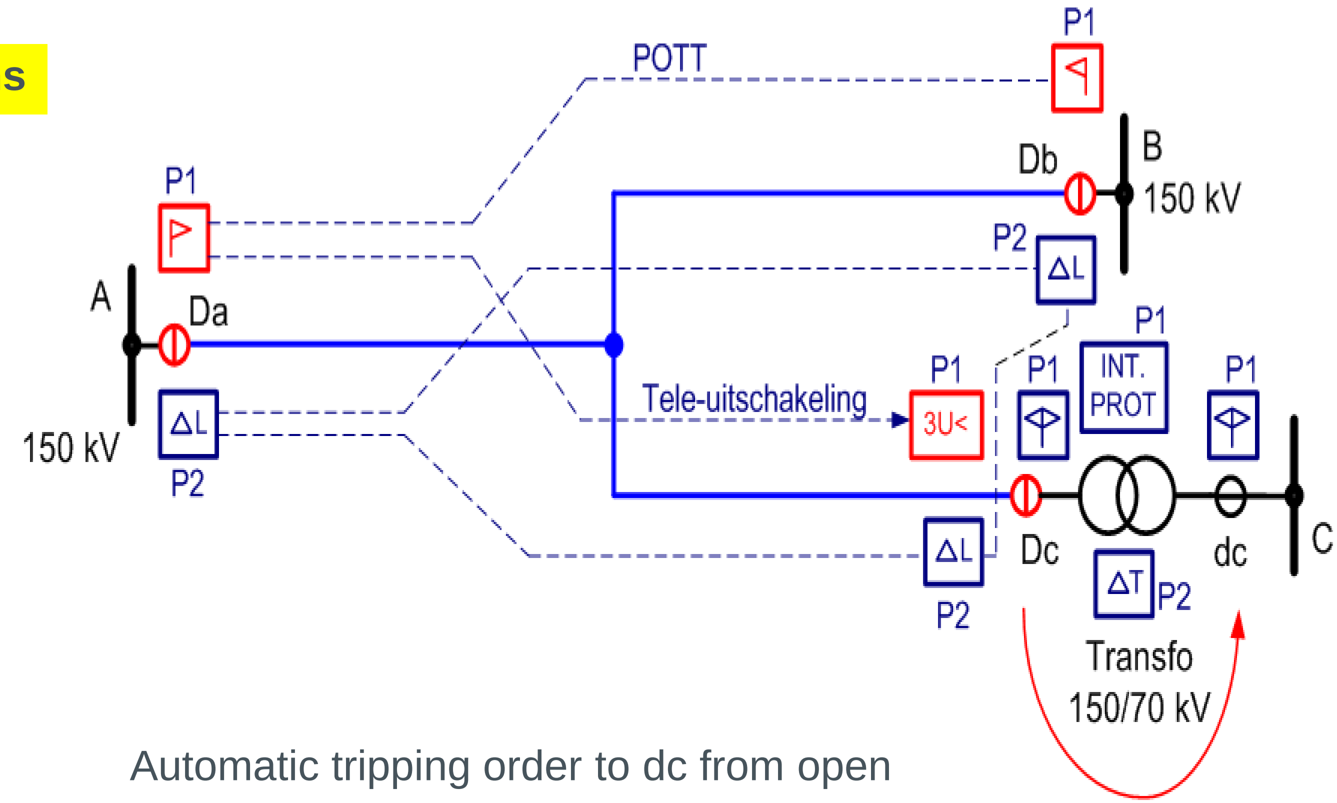


Dc tripped

⇒ Fault eliminated

Transformer 150/70 kV teed on 150 kV interconnection line

9) t = 100 ms

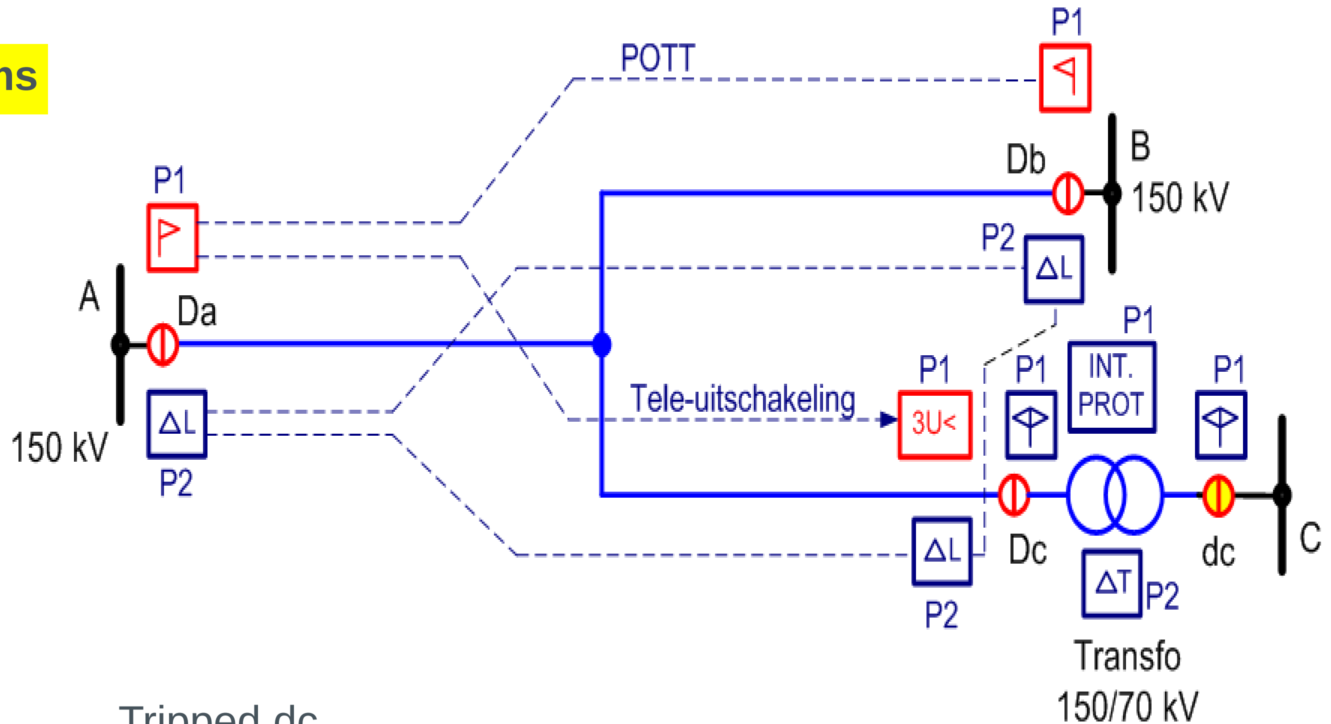


Automatic tripping order to dc from open position Dc

Meename

Transformer 150/70 kV teed on 150 kV interconnection line

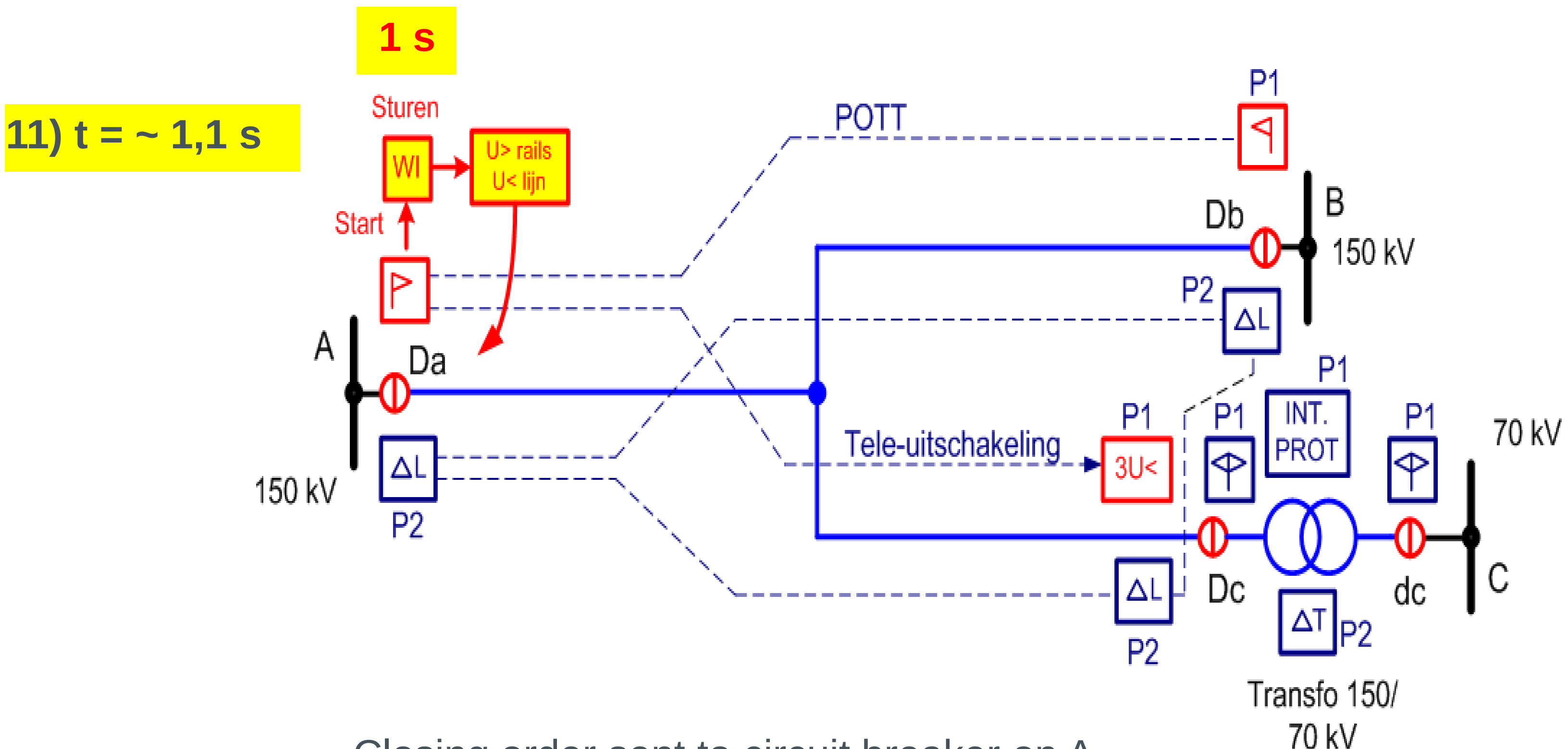
10) t = 150 ms



Tripped dc

Transfo 150/70 kV out of service

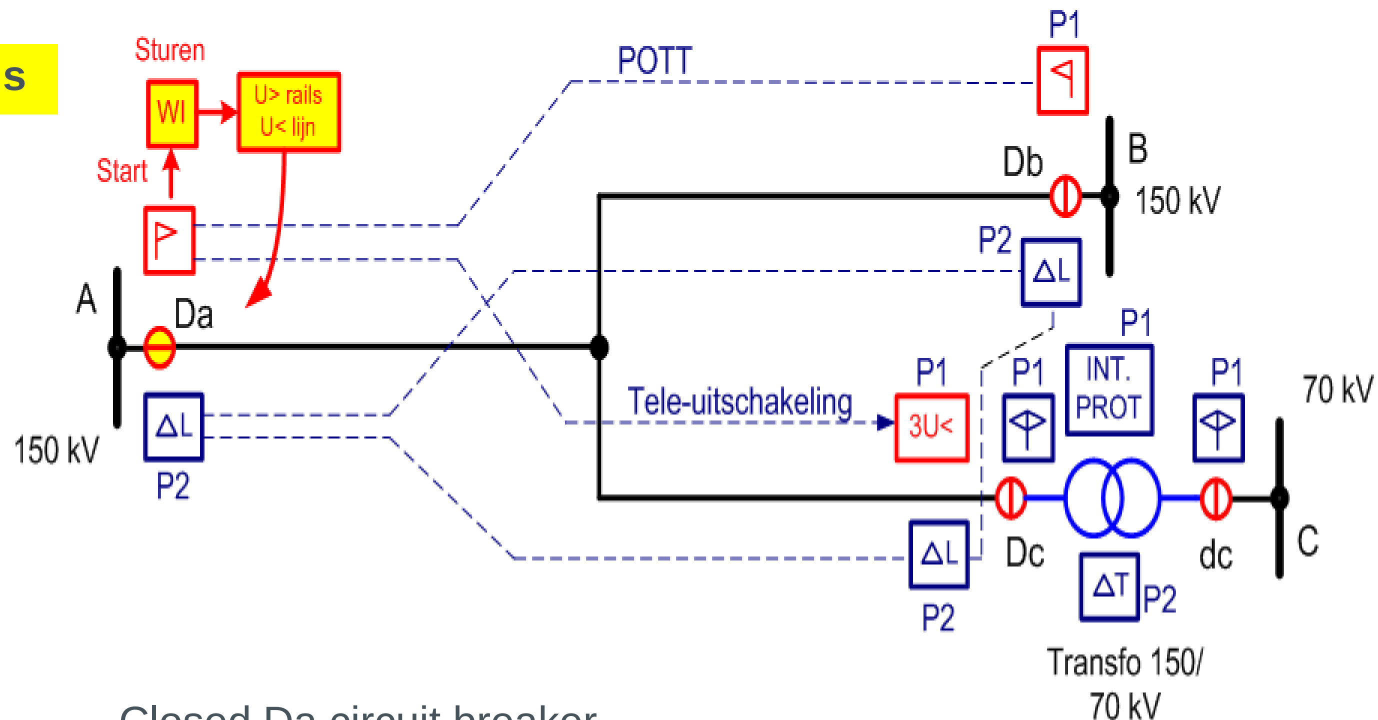
Autoreclose



Closing order sent to circuit breaker on A side thorgh “Send” function?

Autoreclose

12) t = ~ 1,2 s

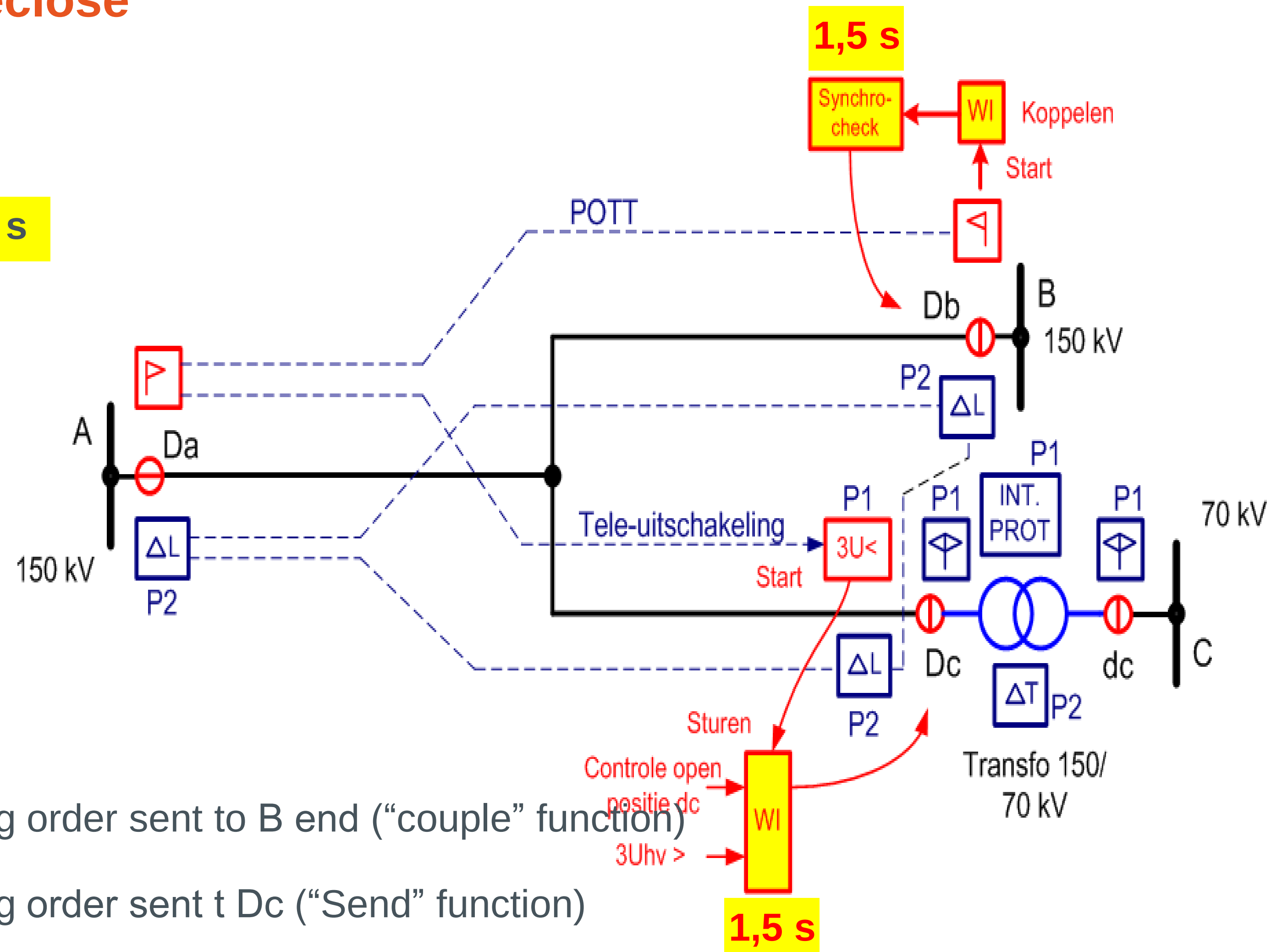


Closed Da circuit breaker

Line under voltage

Autoreclose

13) t = ~ 1,6 s



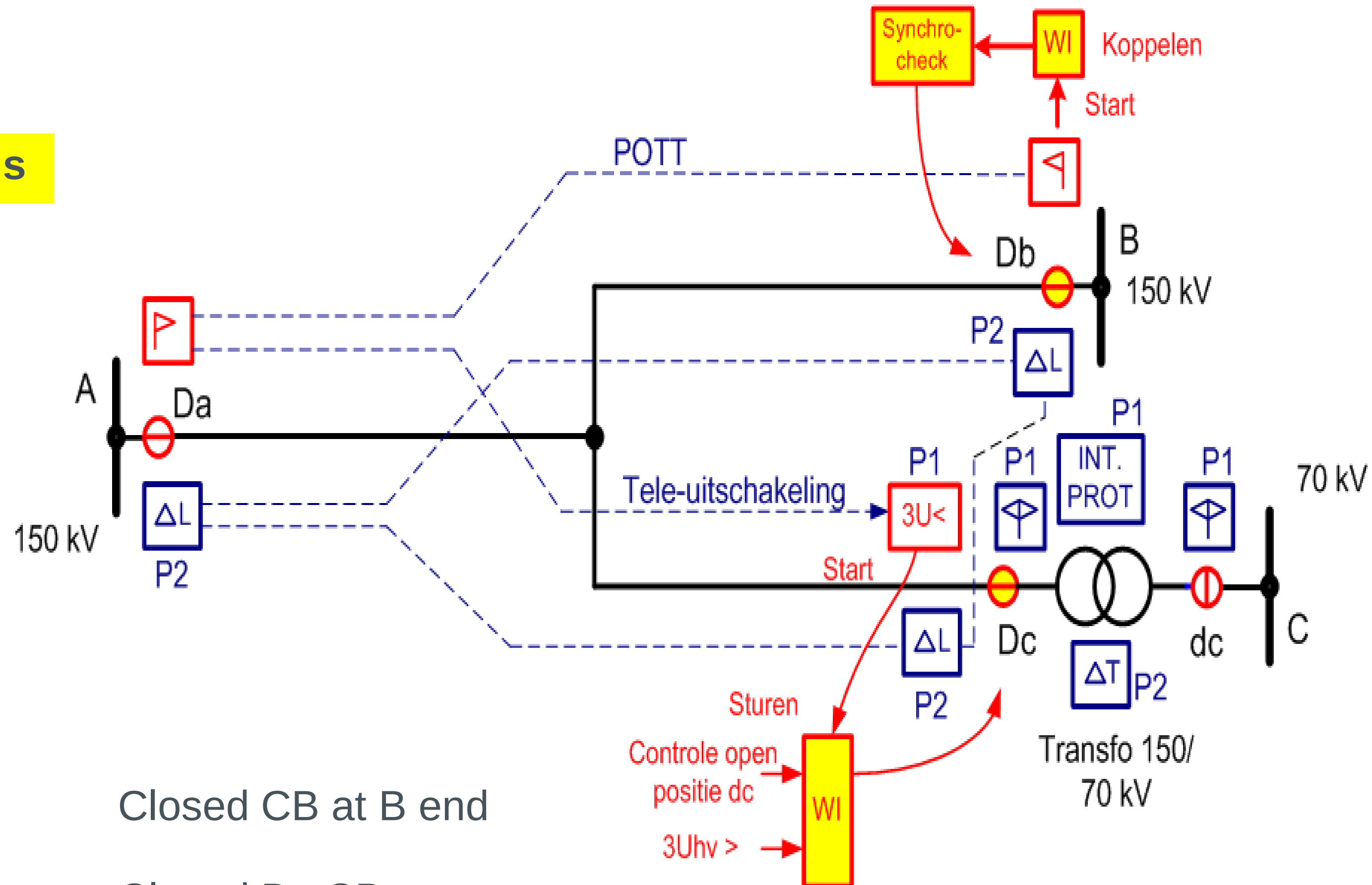
Closing order sent to B end ("couple" function)

Closing order sent t Dc ("Send" function)

Transformer 150/70 kV teed on 150 kV interconnection line

Autoreclose

14) t = ~ 1,7 s

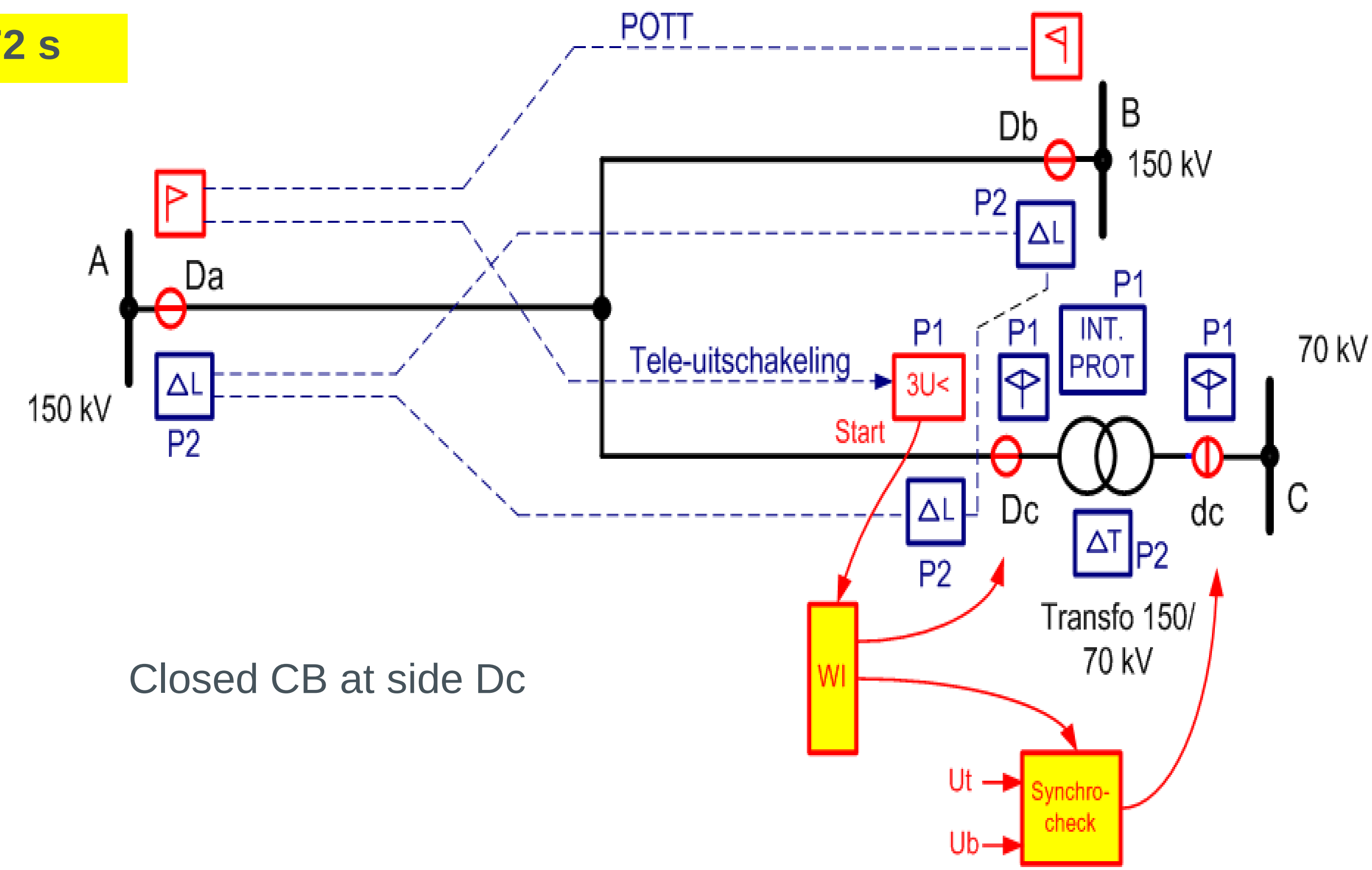


Closed CB at B end

Closed Dc CB

Autoreclose

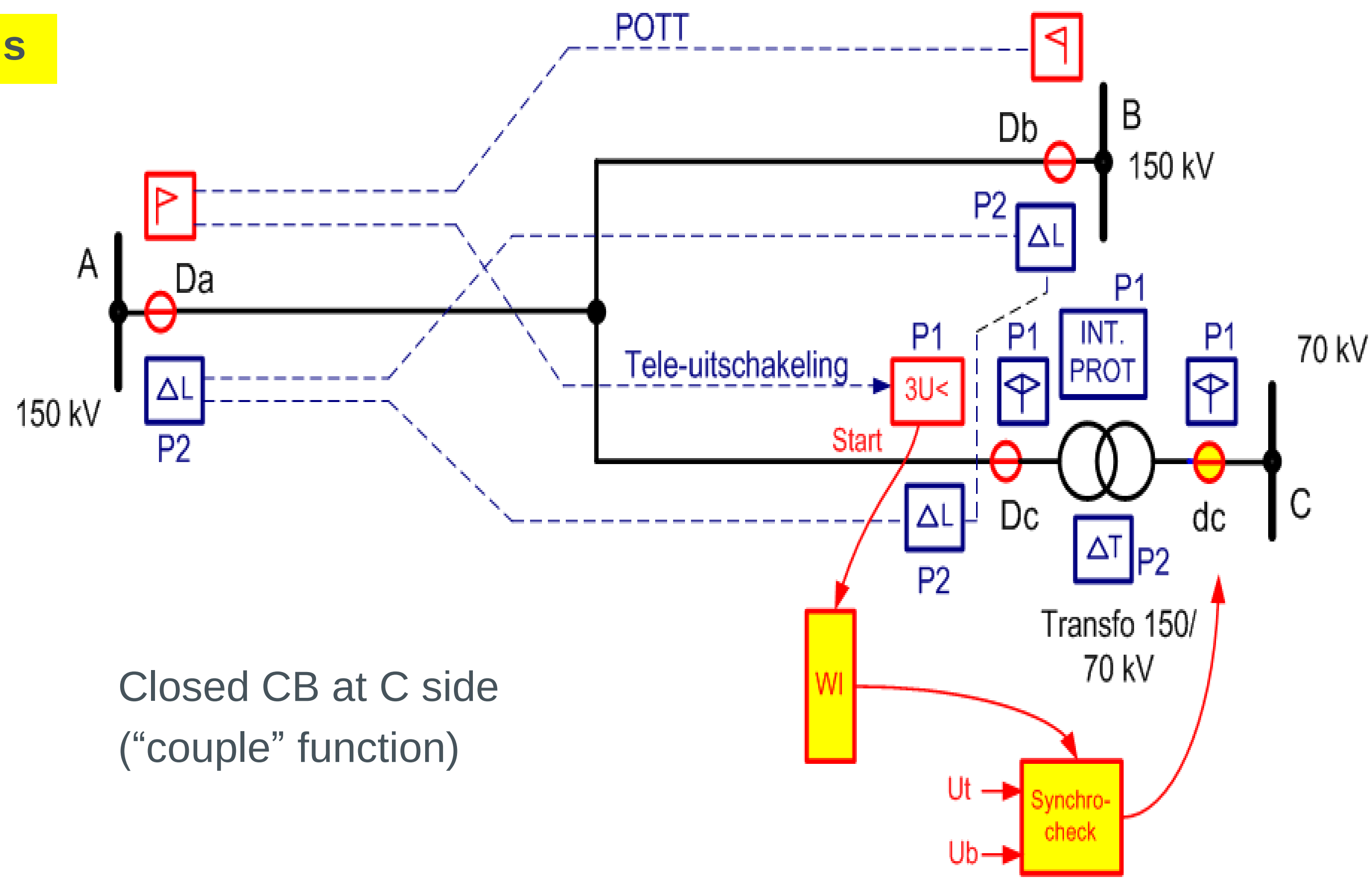
14) t = ~ 1,72 s



Closed CB at side Dc

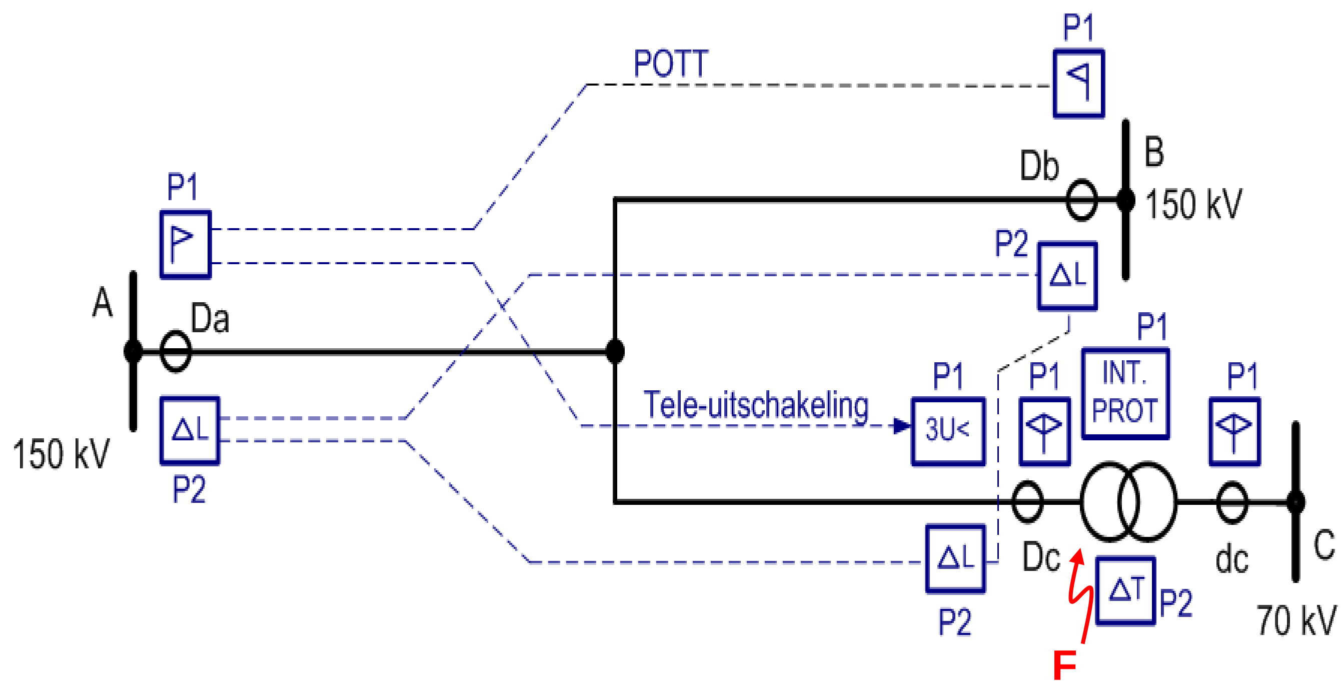
Autoreclose

15) t = ~ 1,8 s



Closed CB at C side
(“couple” function)

Transformer 150/70 kV teed on 150 kV interconnection line



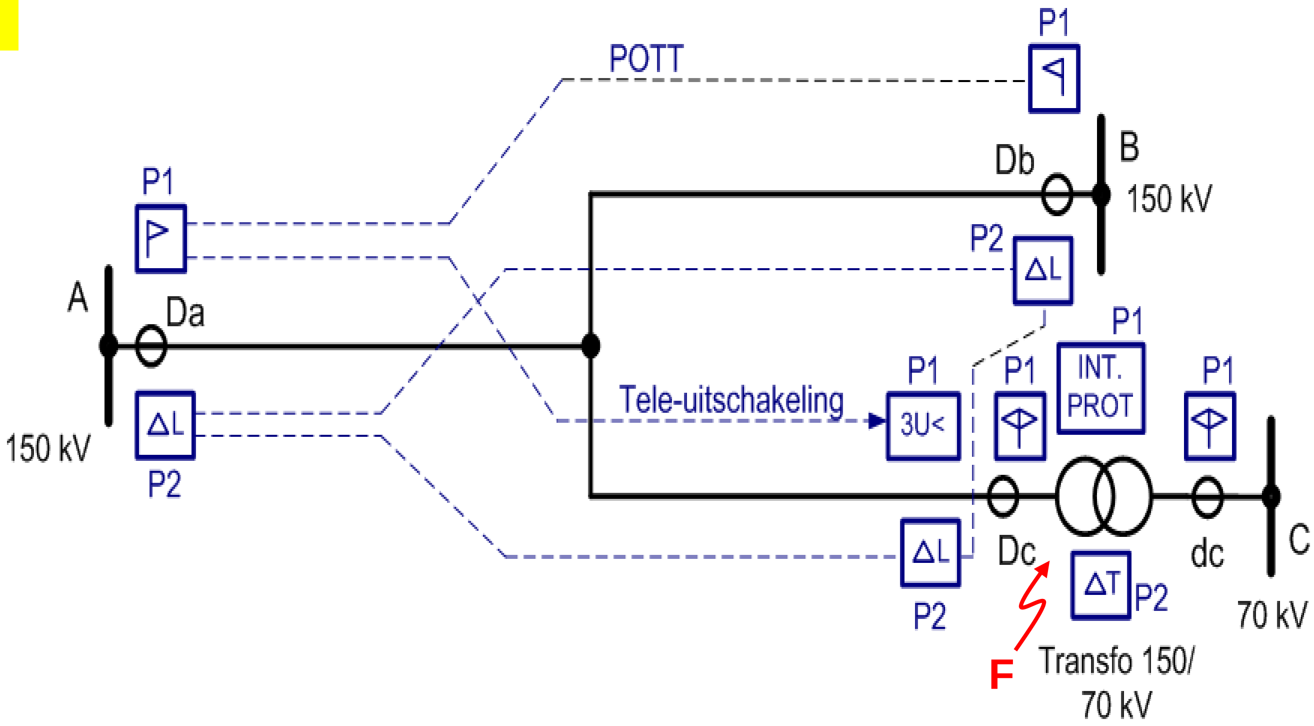
3-phase fault between the Dc CB and the transformer.

How will the fault be eliminated?

Transformer 150/70 kV teed on 150 kV interconnection line

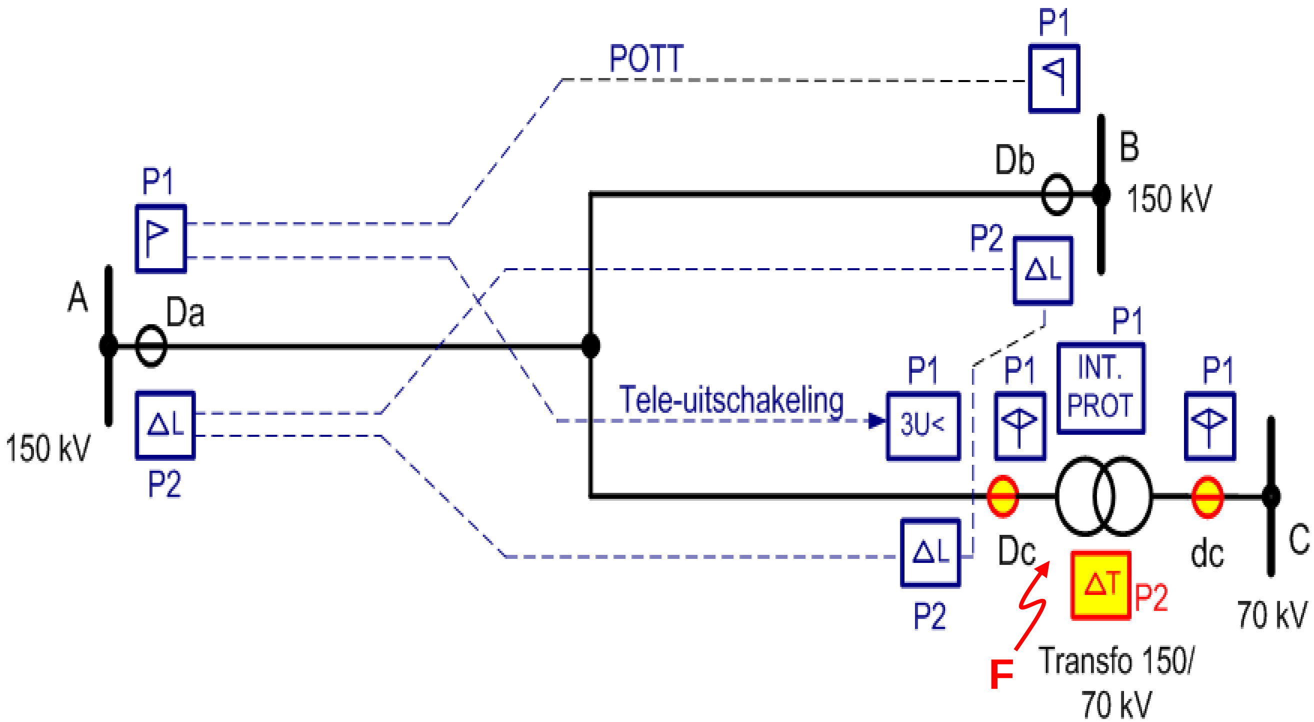
1) t = 0 ms

3-phase fault F



Transformer 150/70 kV teed on 150 kV interconnection line

2) t = 25 ms

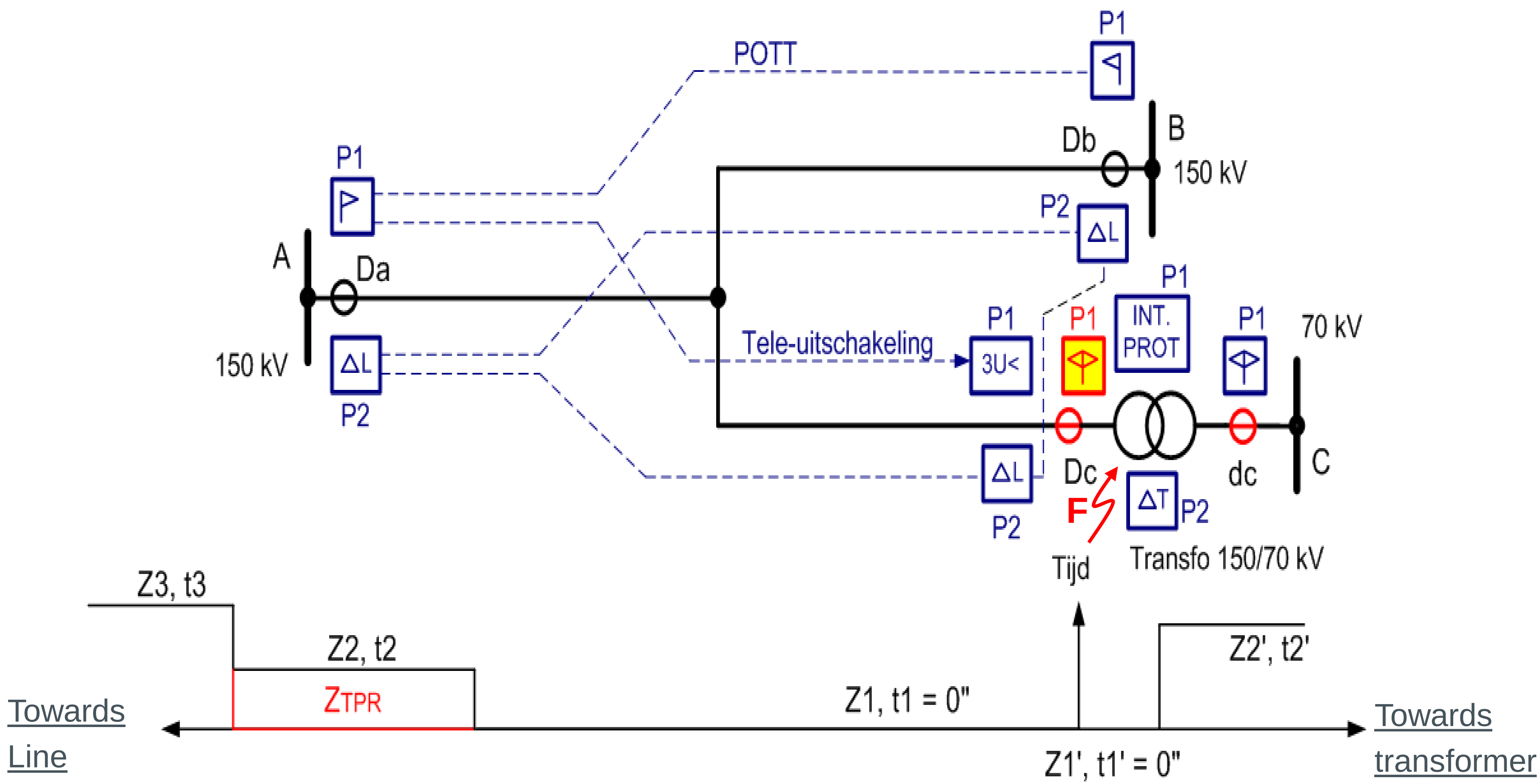


C end: tripping order sent to Dc and dc by transformer differential protection

Transformer 150/70 kV teed on 150 kV interconnection line

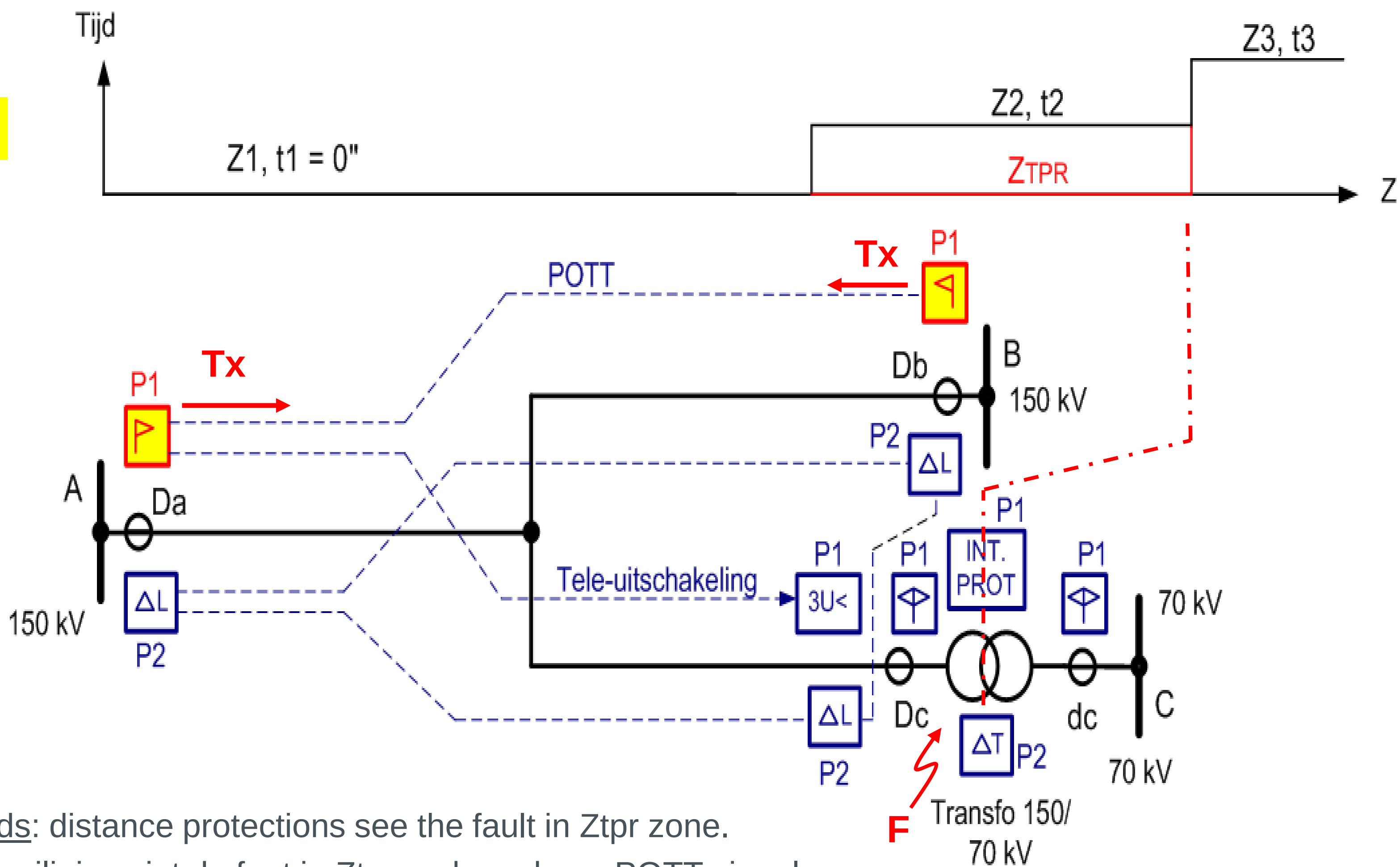
3) t = 30 ms

C end: distance protection at 150 kV side of the tranformer sees the faul in the first zone towards transformer and send tripping orders to DC



Transformer 150/70 kV teed on 150 kV interconnection line

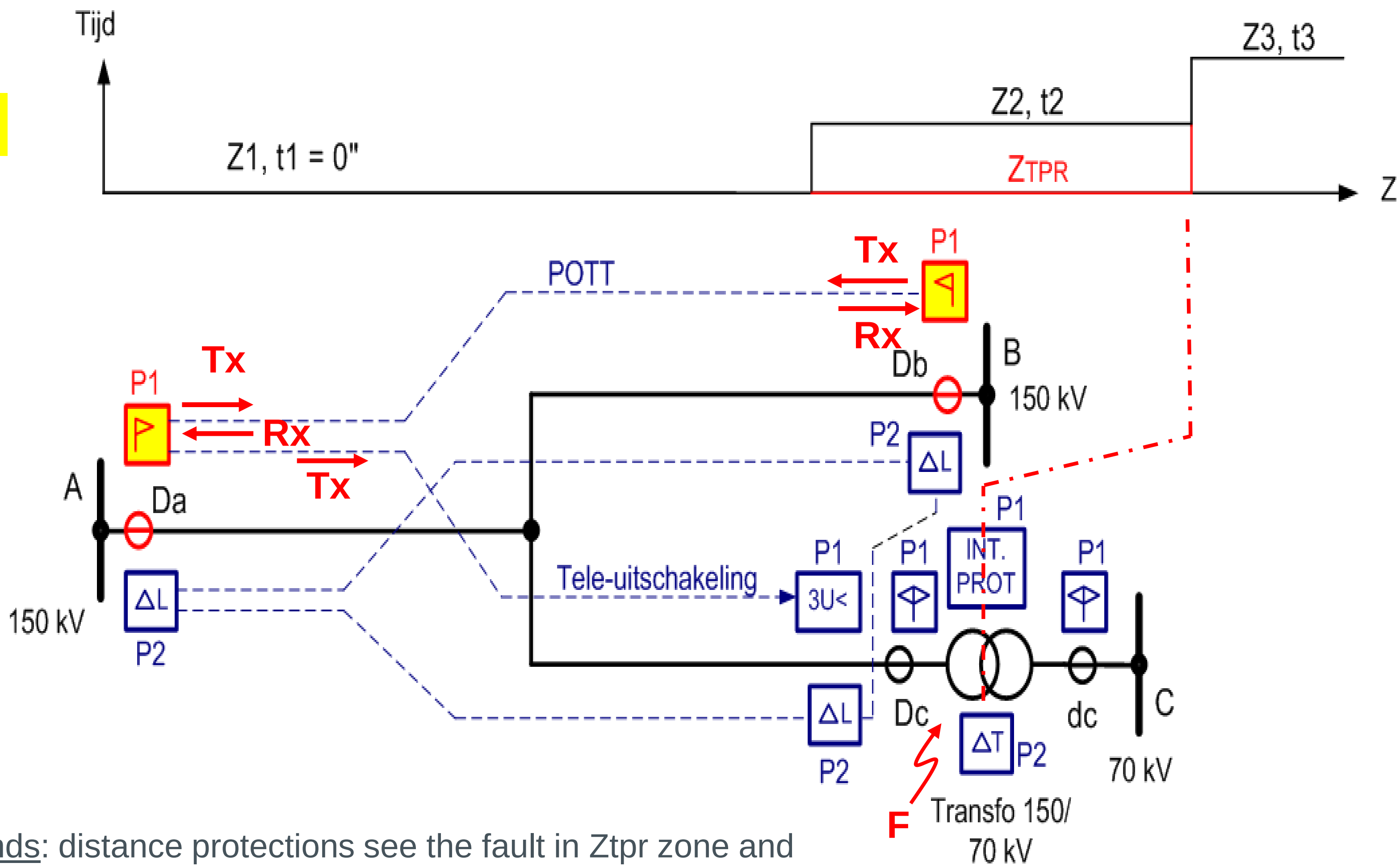
4) t = 30 ms



A and B ends: distance protections see the fault in Ztpr zone. Afstandsbeveiliging ziet de fout in Ztpr and send een POTT signal to the other end

Transformer 150/70 kV teed on 150 kV interconnection line

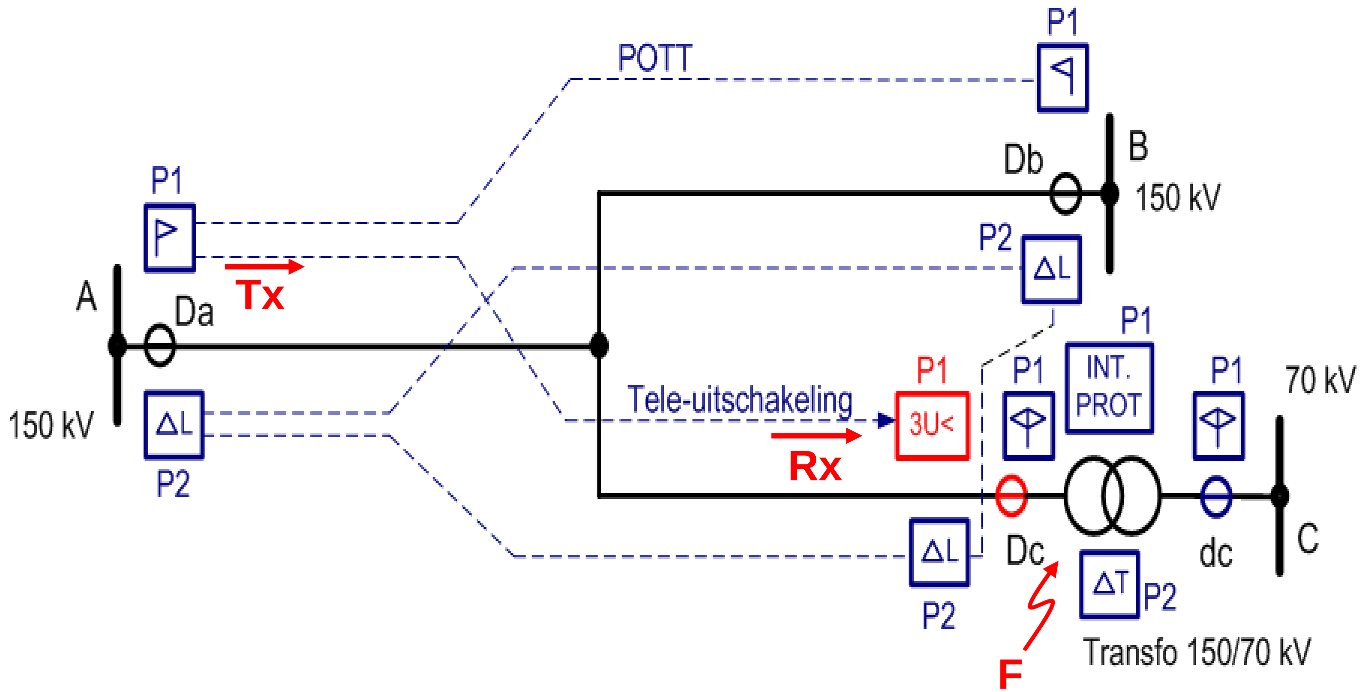
5) t = 40 ms



A and B ends: distance protections see the fault in Ztpr zone and receive POTT signals. ⇒ tripping order sent to Da and Db, translission of tripping signal towards C end

Transformer 150/70 kV teed on 150 kV interconnection line

6) t = 60 ms



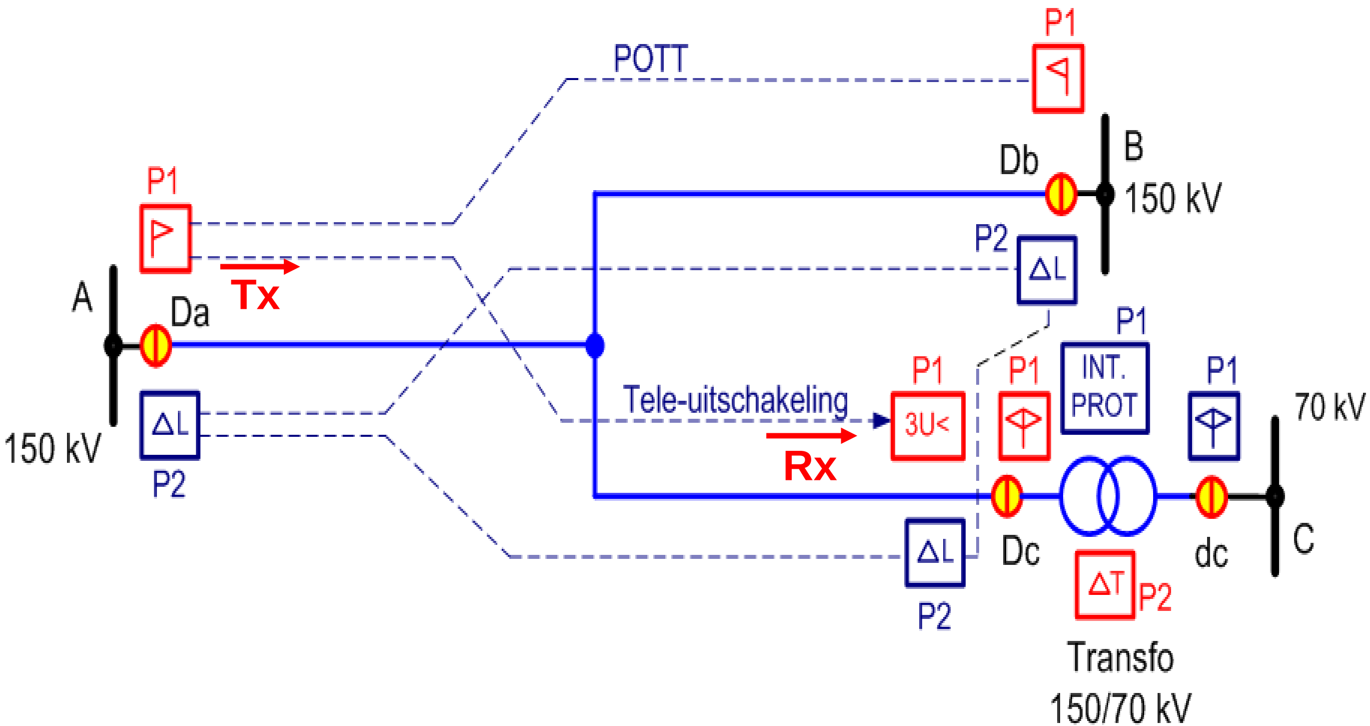
Receptionl “Rx” from A side

& validation through local criterium 3U<ph/n

⇒ Tripping order to Dc circuit breaker

Transformer 150/70 kV teed on 150 kV interconnection line

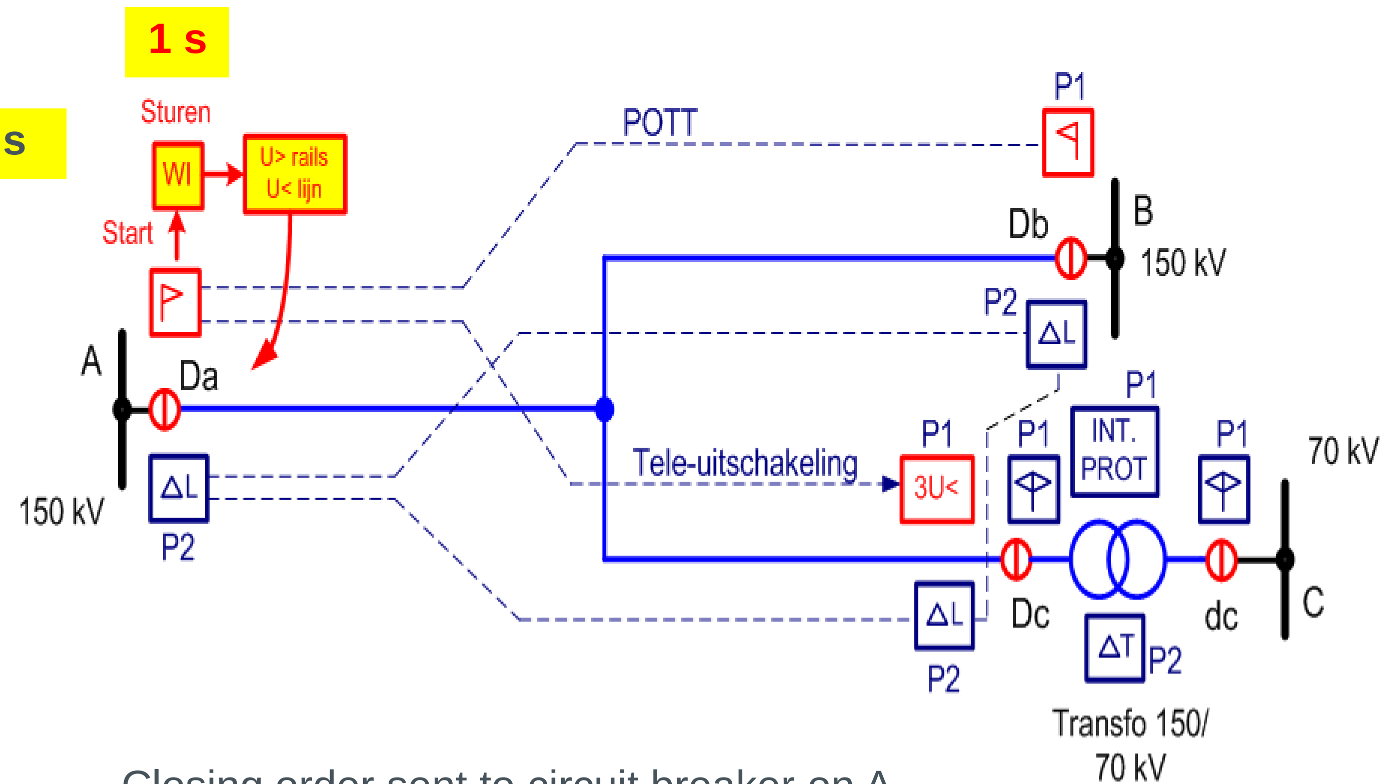
7) t = 80 ms … 90 ms



Tripping Da, Db, Dc and dc ⇒ Fault eliminated

Transformer 150/70 kV teed on 150 kV interconnection line

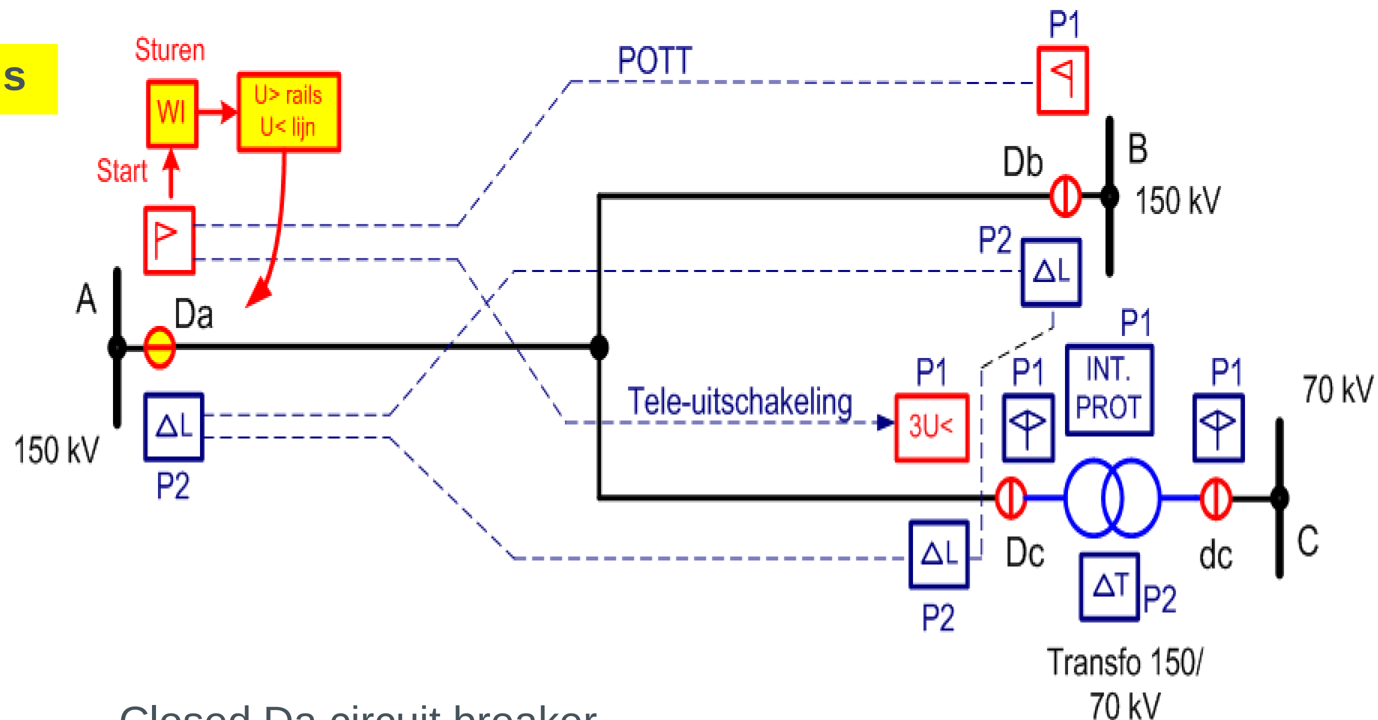
11) t = ~ 1,1 s



Closing order sent to circuit breaker on A side through "Send" function?

Transformer 150/70 kV teed on 150 kV interconnection line

12) t = ~ 1,2 s

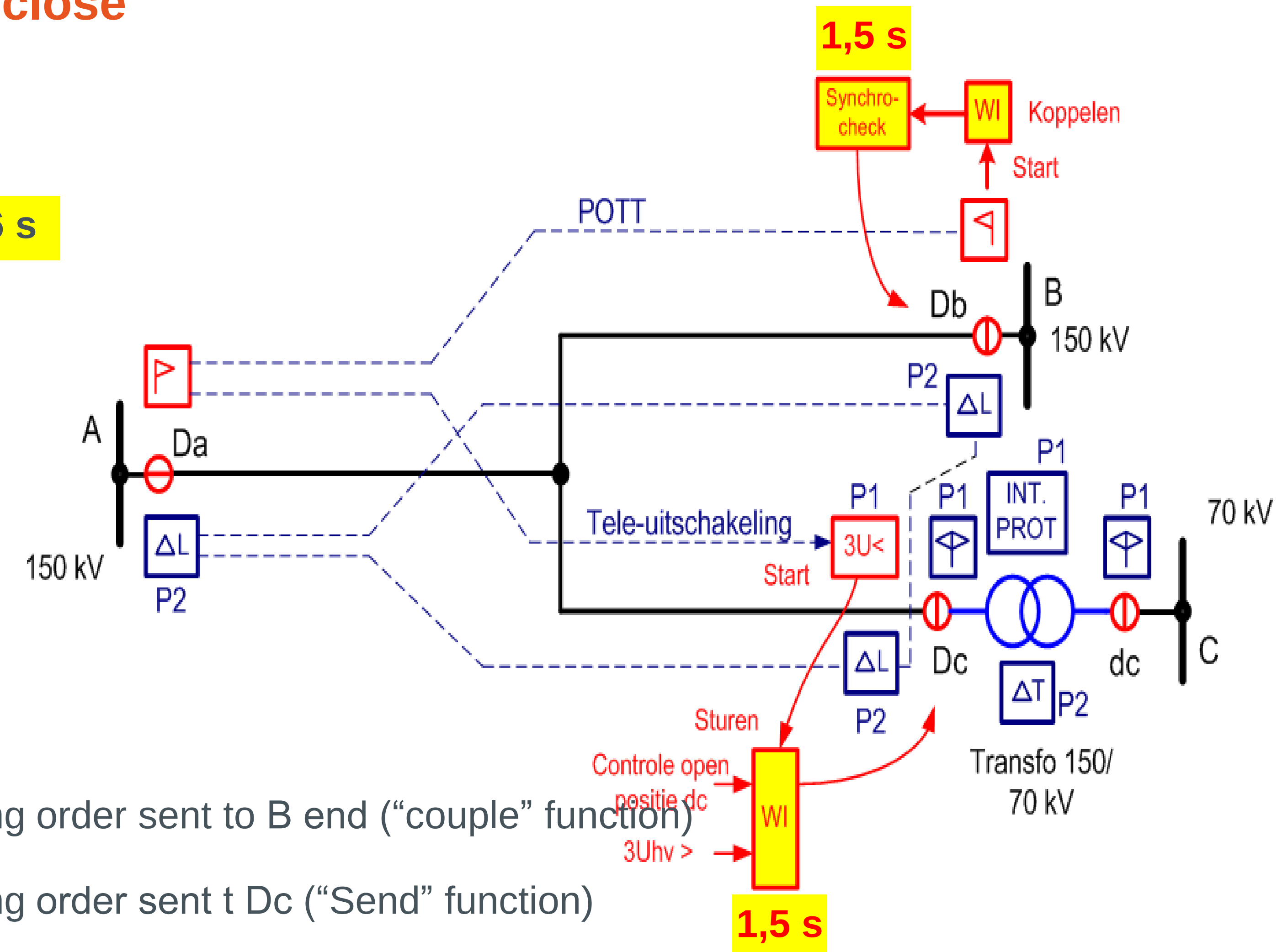


Closed Da circuit breaker

Line under voltage

Autoreclose

13) t = ~ 1,6 s

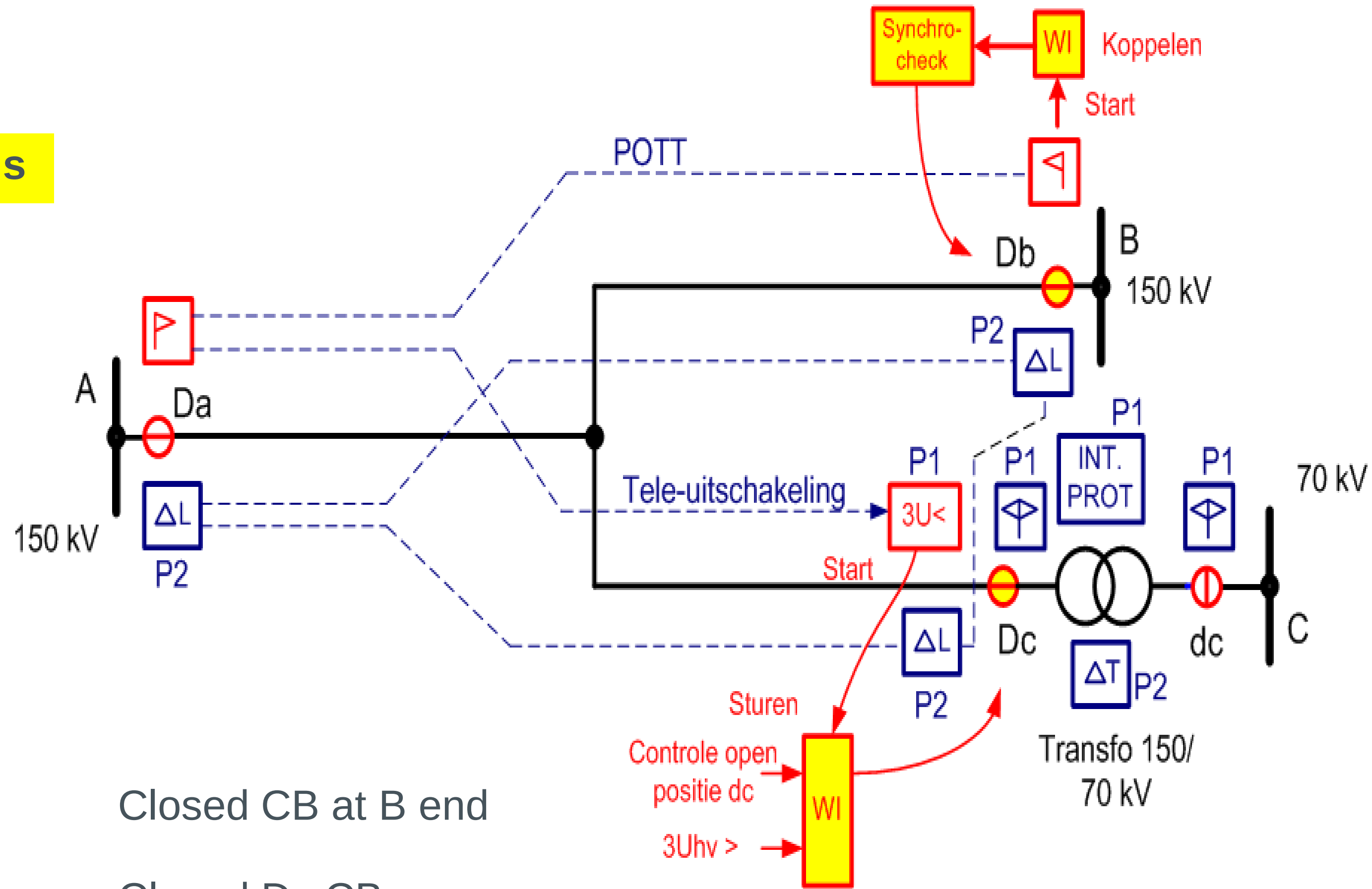


Closing order sent to B end ("couple" function)

Closing order sent t Dc ("Send" function)

Autoreclose

14) t = ~ 1,7 s

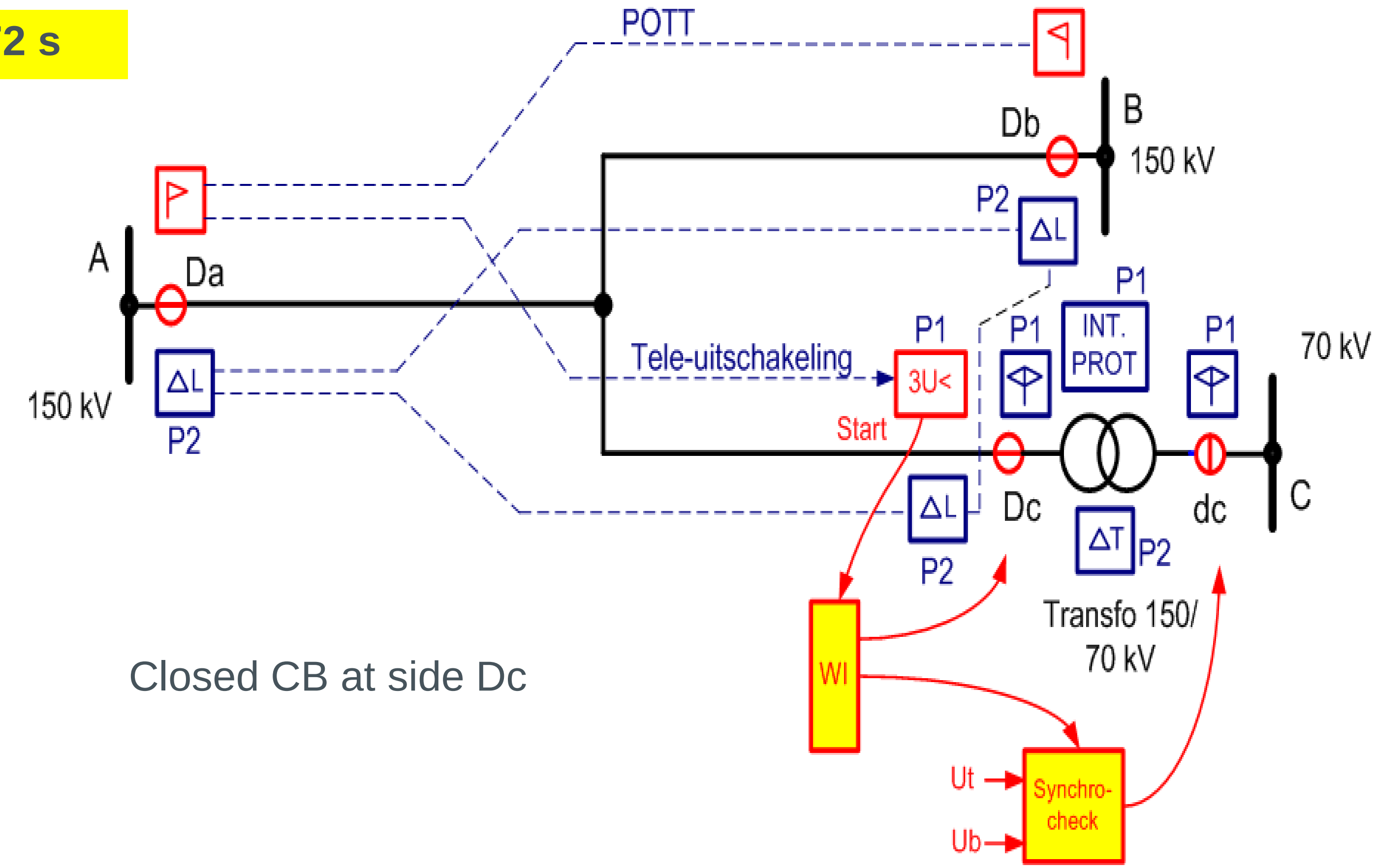


Closed CB at B end

Closed Dc CB

Autoreclose

14) t = ~ 1,72 s

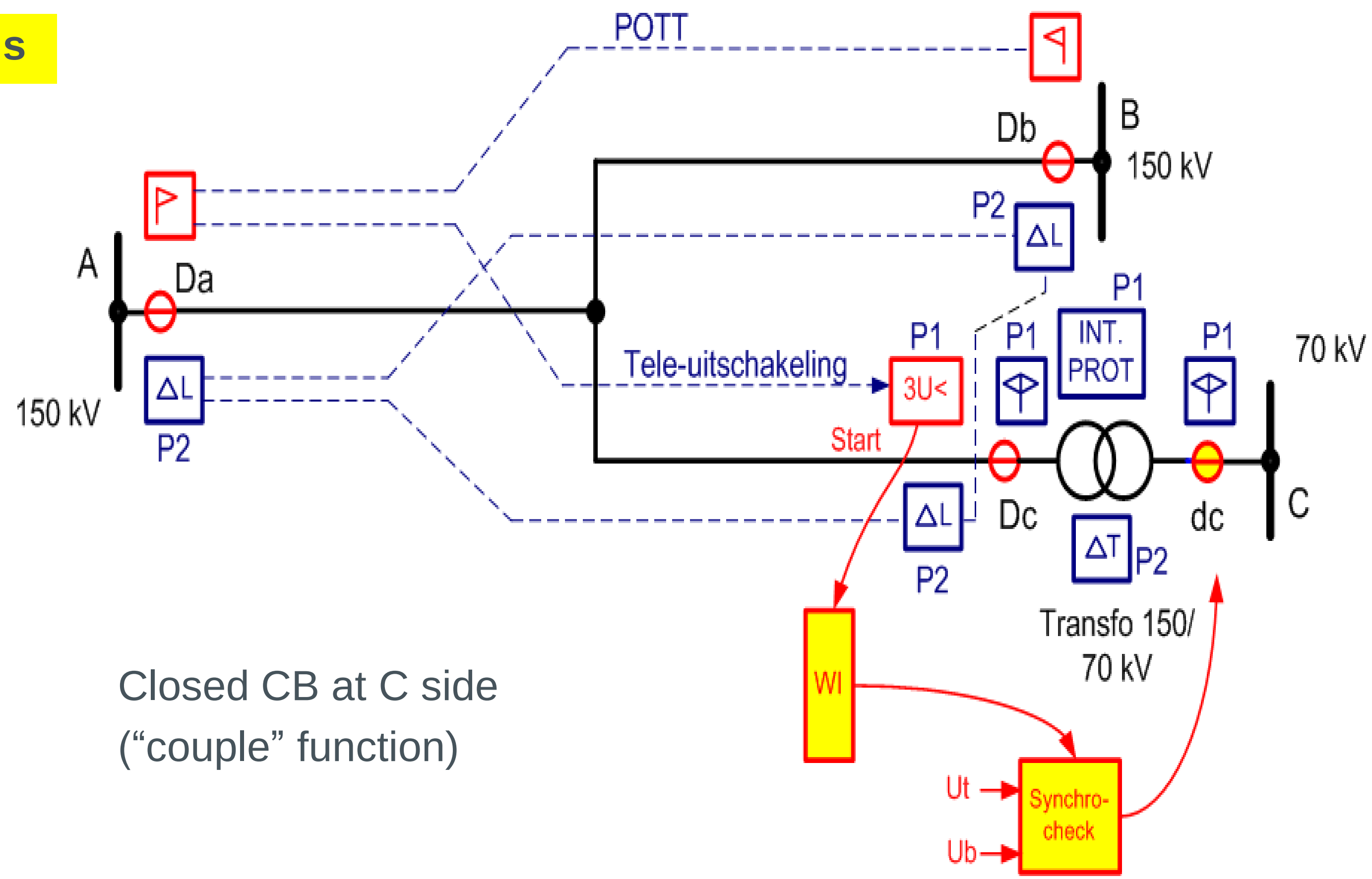


Closed CB at side Dc

Transformer 150/70 kV teed on 150 kV interconnection line

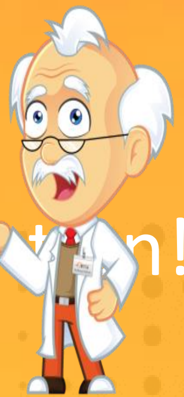
Autoreclose

15) t = ~ 1,8 s



Closed CB at C side
("couple" function)

Training Center



Many thanks for your attention!

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