Co located events

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Protective Relay Testing in Distribution Networks - Best Practices

Introduction - Distribution & Smart Grid

The Power Grid is divided in two main grids

TRANSMISSION

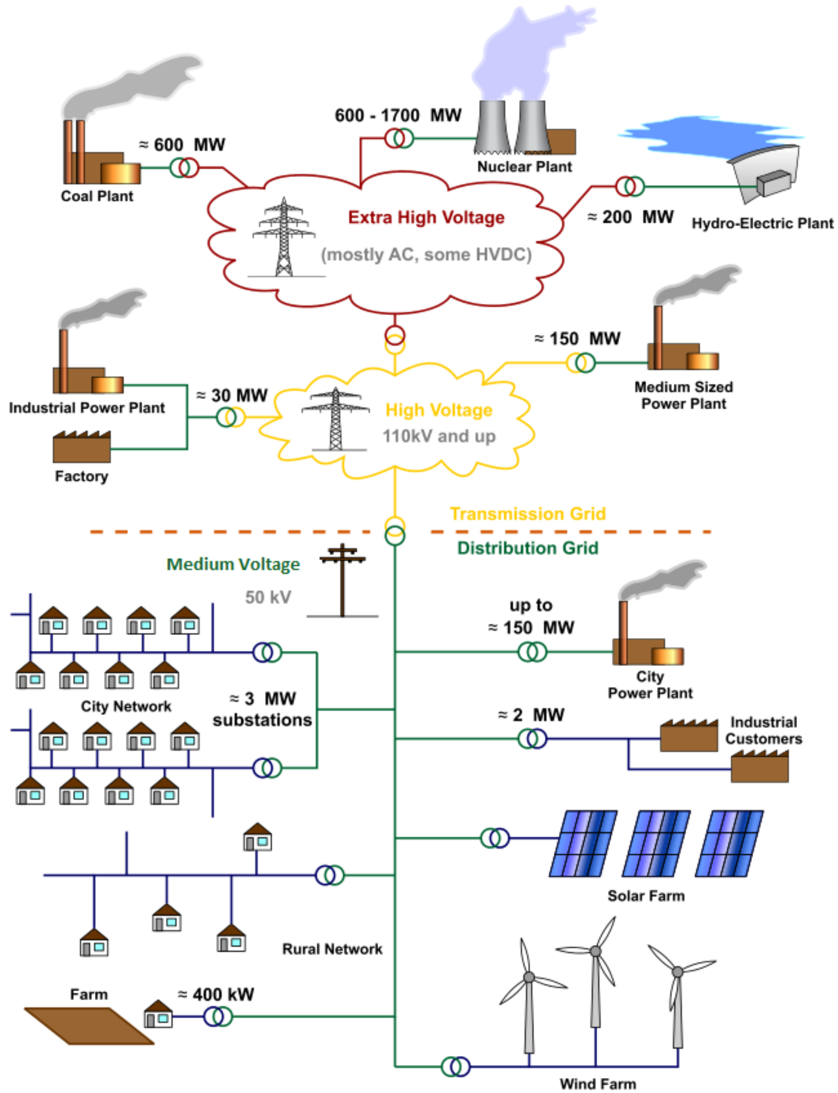
High Voltage grid (> 110 kV) composed by

- Large power plants, where the electrical energy is produced and fed into the network
- Substations, where the energy is routed according to the requirements

DISTRIBUTION

Medium and Low voltage grid composed by

- Medium size power plants
- Substations
- Consumers (Industries, cities, ecc…)



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The transmission grid is

- Meshed, all nodes of the grid are interconnected
- Fully automated
- Equipped with faults location devices

↓

In case of faults the probability of wide service outages is dramatically reduced

↓

- Fast service recovering
- Very good power quality
- Network stability and reliability

The distribution grid is

- Not meshed, due to the presence of many consumers
- Not fully automated, especially in the low voltage grid
- Not often equipped with faults location devices

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In case of faults there is the probability of disconnection of some grid areas, the fault location is often difficult and the intervention of an operator is often necessary to recover the service

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Can a solution be found?

Yes, the solution is the SMART GRID, but what is it? It is the evolution of the todays network!

The main benefits of a SMART GRID are

- Distributed generation: many small power plants instead of few and huge power plants
- Renewable energy: the energy from not programmable sources like sun and wind can be efficiently used
- Less pollution
- Good and flexible power management
- Energy storage

To build a SMART GRID are necessary

- High tecnology devices
- Broadband communication channels
- Smart metering

The grid is composed by many complex and very expensive equipments

In case of fault, the faulty area must be identified and disconnected as soon as possible from the rest of the grid to avoid

- serious damages due to strong electrical stress
- wide outages due to loss of stability
- danger for the people
- economic losses

A proper protective system must be implemented

The core of the protective system are the

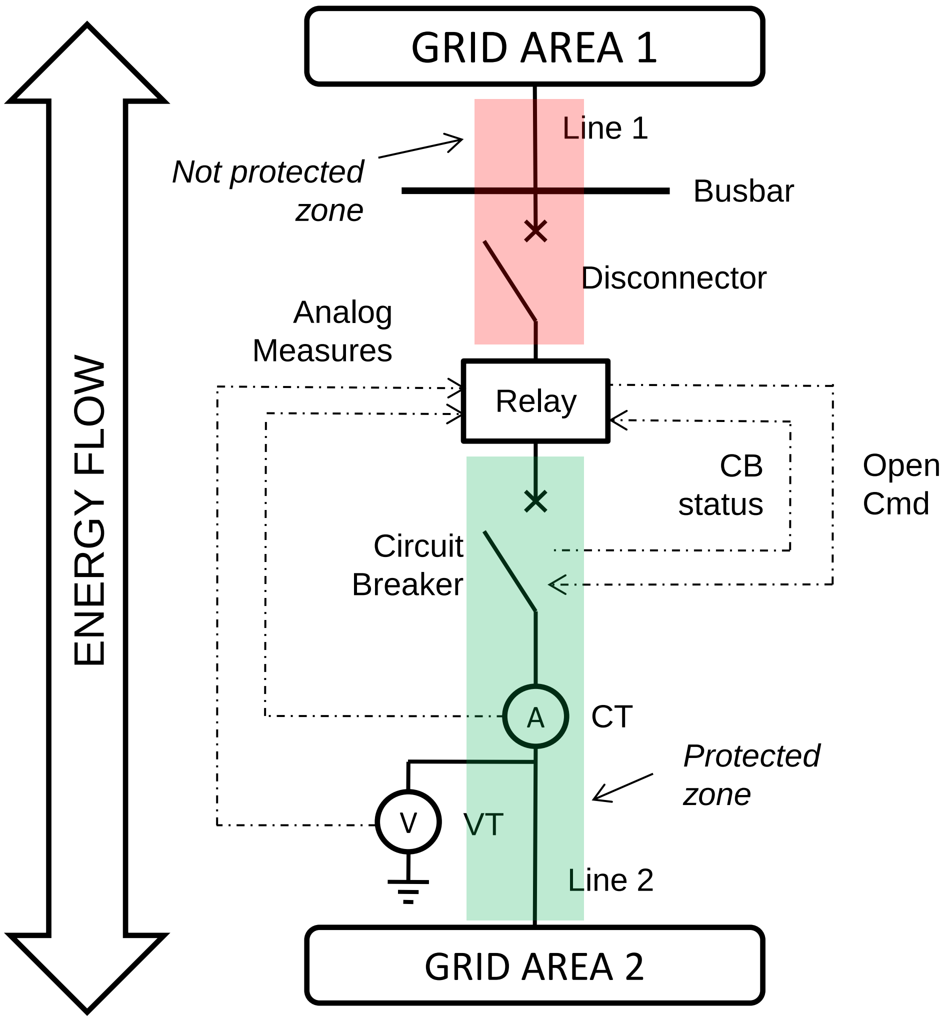
PROTECTION RELAYS

They continuosly monitor the status of the grid by measuring electrical quantities as

- Voltage
- Current
- Frequency
- Phase shift

According to the grid design, specific protection relays must be installed and properly setted

PRINCIPLE SCHEME



Relay tasks:

- discriminate a fault from a transient disturbance
- if the fault is located in the protected zone, an open command must be sent to CB
- if the fault is NOT located in the protected zone, ANY open command must be sent to CB

VOLTAGE PROTECTION

UNDERVOLTAGE (27)
OVERVOLTAGE (59)

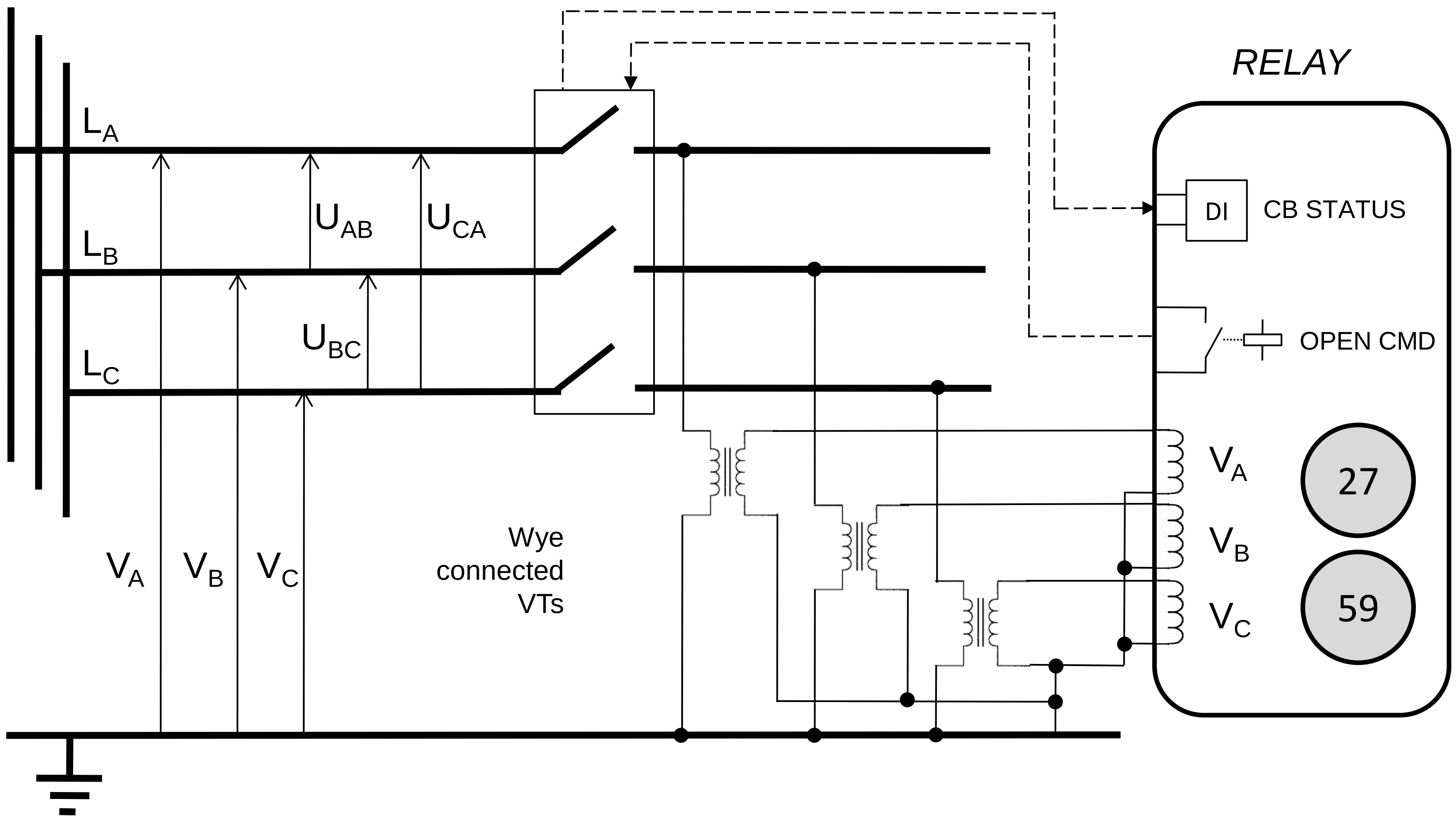
The voltage in a grid is quite constant everywhere and it's very close to the value for which it has been designed.
This voltage is called NOMINAL VOLTAGE

Voltage protections must open the circuit breaker when the measured voltage differs too much from the nominal voltage

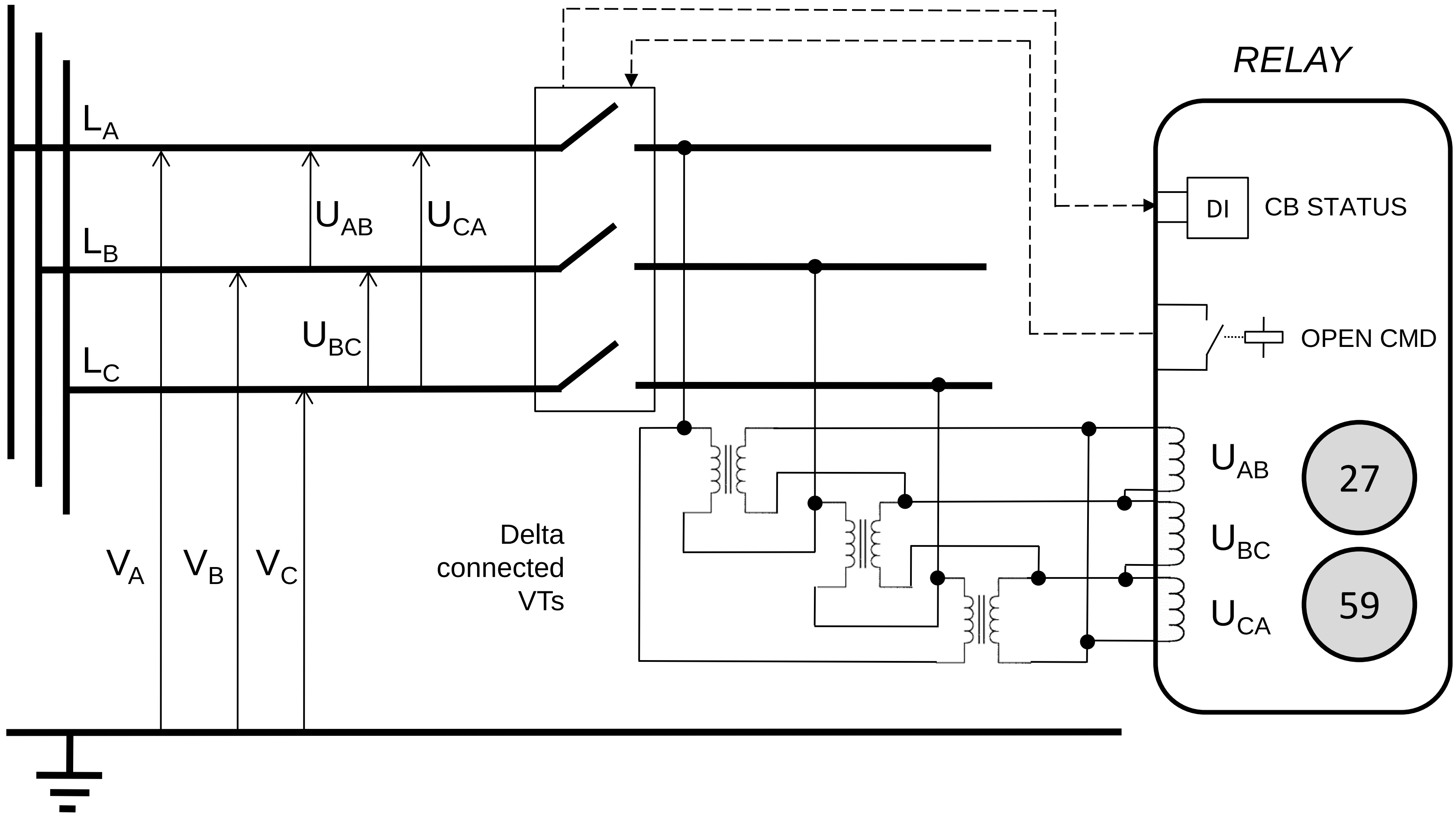
Undervoltage conditions → Loss of stability

Overvoltage conditions → Collapse of insulation equipments

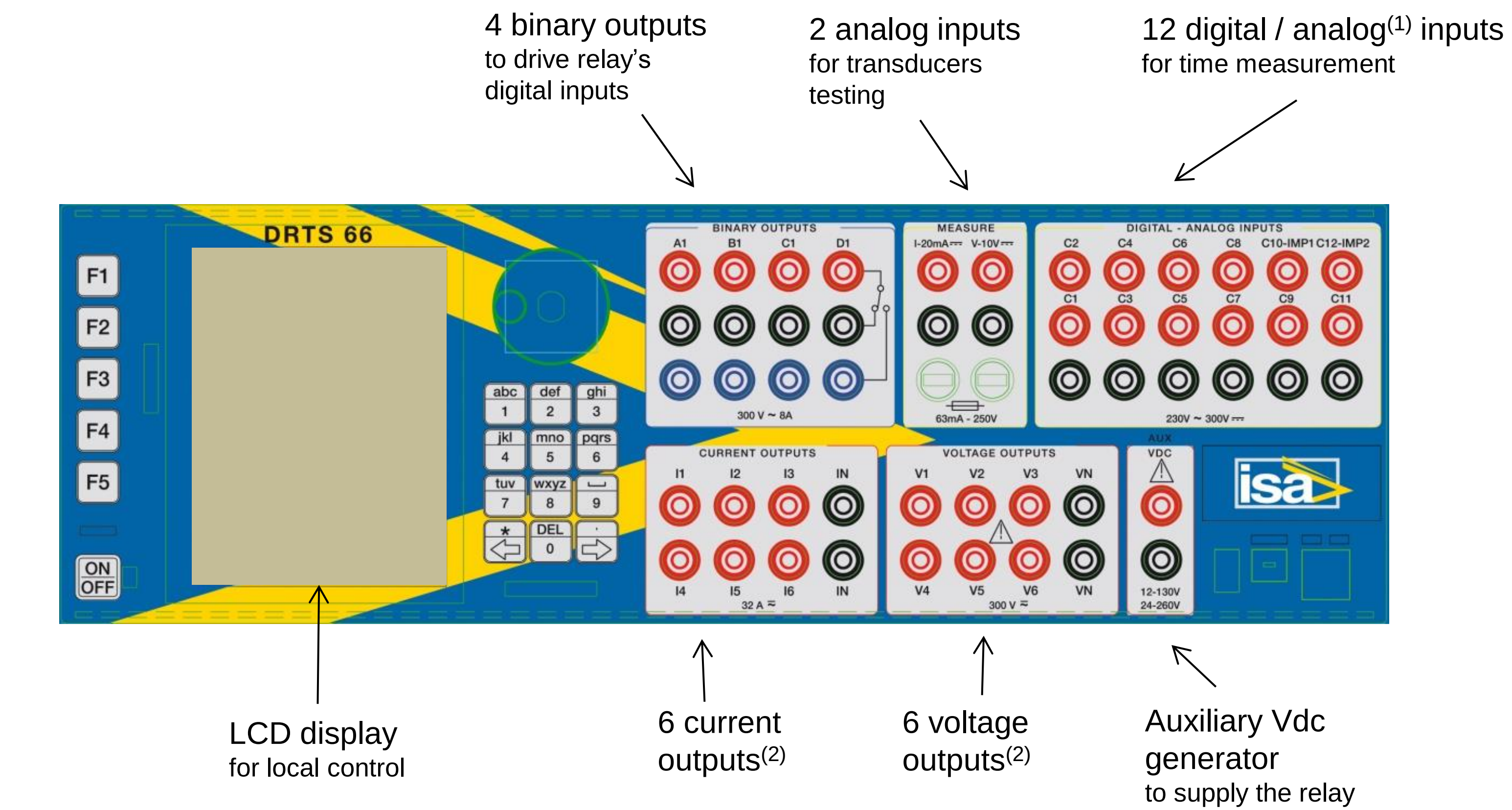
RELAY CONNECTIONS (phase to ground)



RELAY CONNECTIONS (phase to phase)



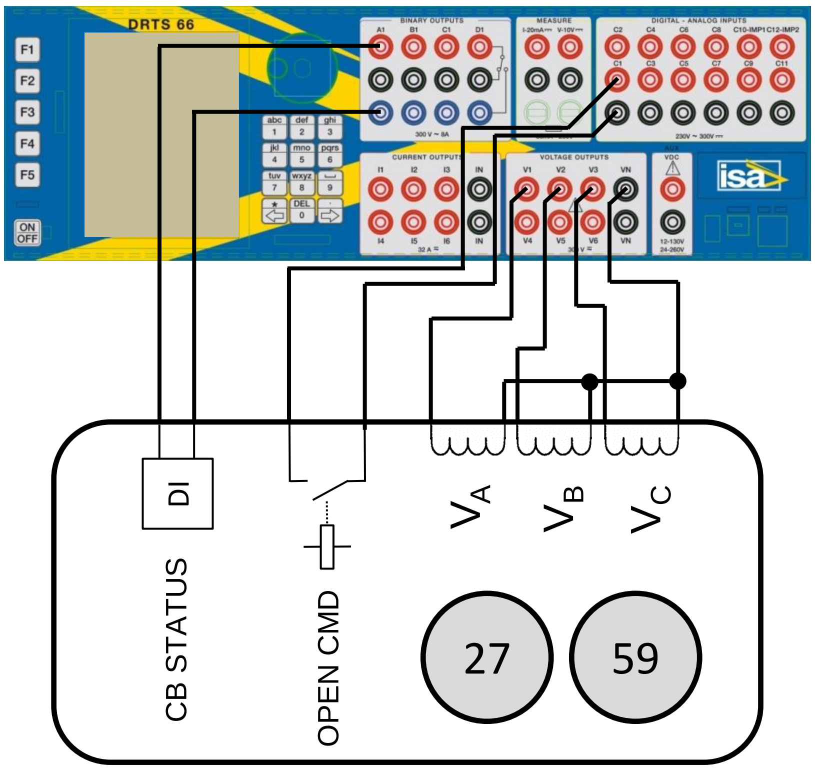
DRTS 66 description



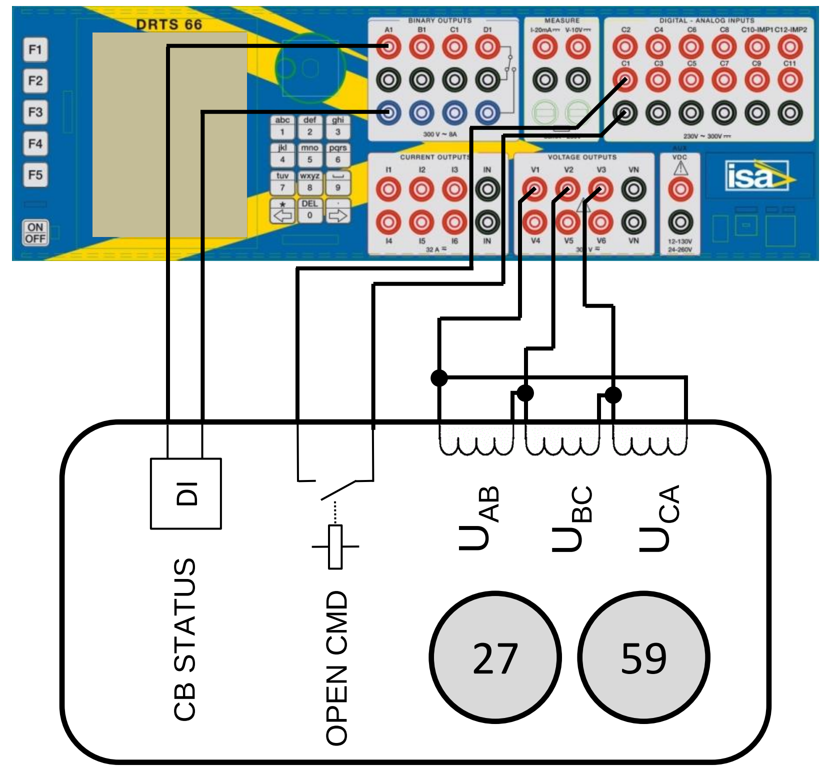
(1) *These inputs become analogic in case of Transcope option inside*

(2) *The number of current and voltage outputs changes with DRTS XX model*

RELAY CONNECTIONS TO DRTS (examples)



Phase to ground



Phase to phase

RELAY PARAMETERS

V (or U) pickup

Voltage threshold that defines when the relay must be ready to release the trip (open) command

Trip Time

Time delay for the releasing of the trip (open) command, starting from the instant in which the measured voltage reaches the pickup value

V (or U) reset

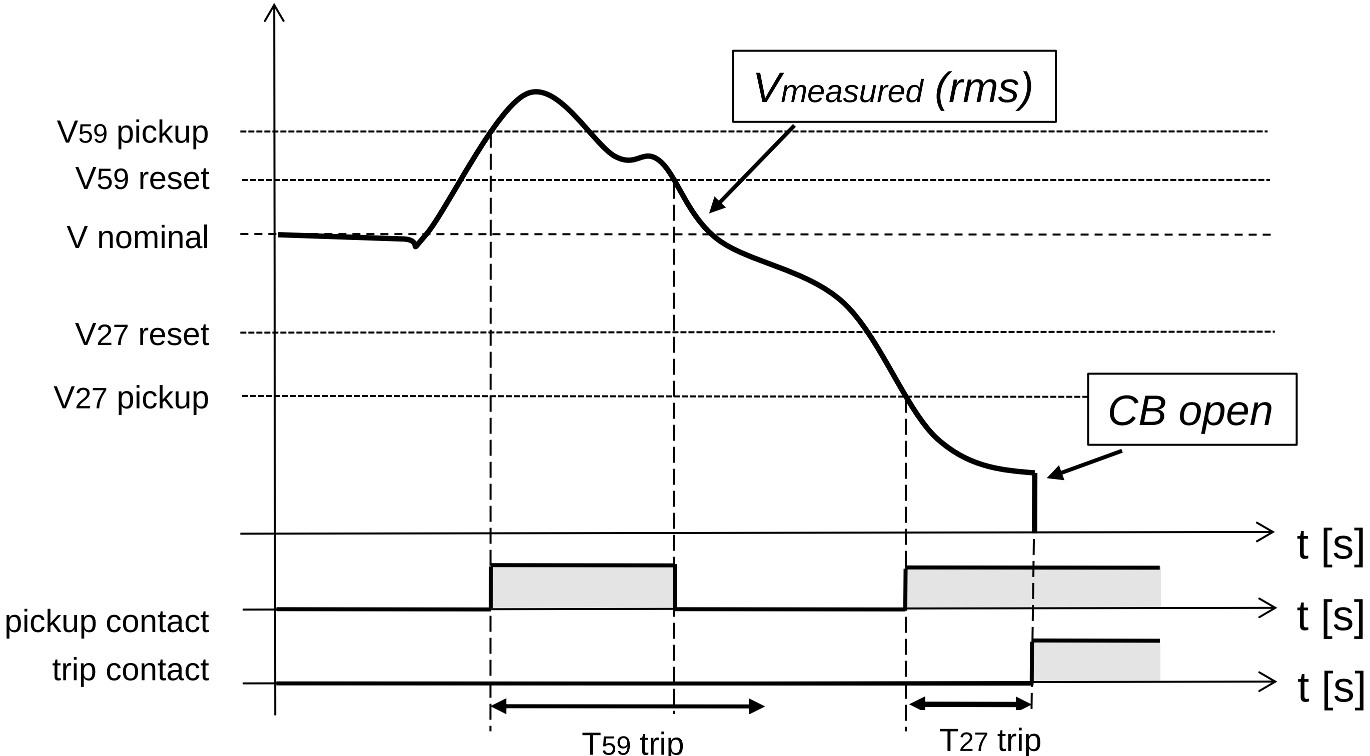
Voltage value that defines when the relay must reset the Trip Time counter

Drop-out ratio

It is the ratio *V (or U) reset / V (or U) pickup*

Each voltage threshold *V (or U) pickup* has an associated *Trip Time*

Voltage protection 27 / 59 - Distribution & Smart Grid



The measured voltage reaches *V_{59} pickup* but decreases below *V_{59} reset* before *T_{59} trip* expires

⇩

Trip command NOT released

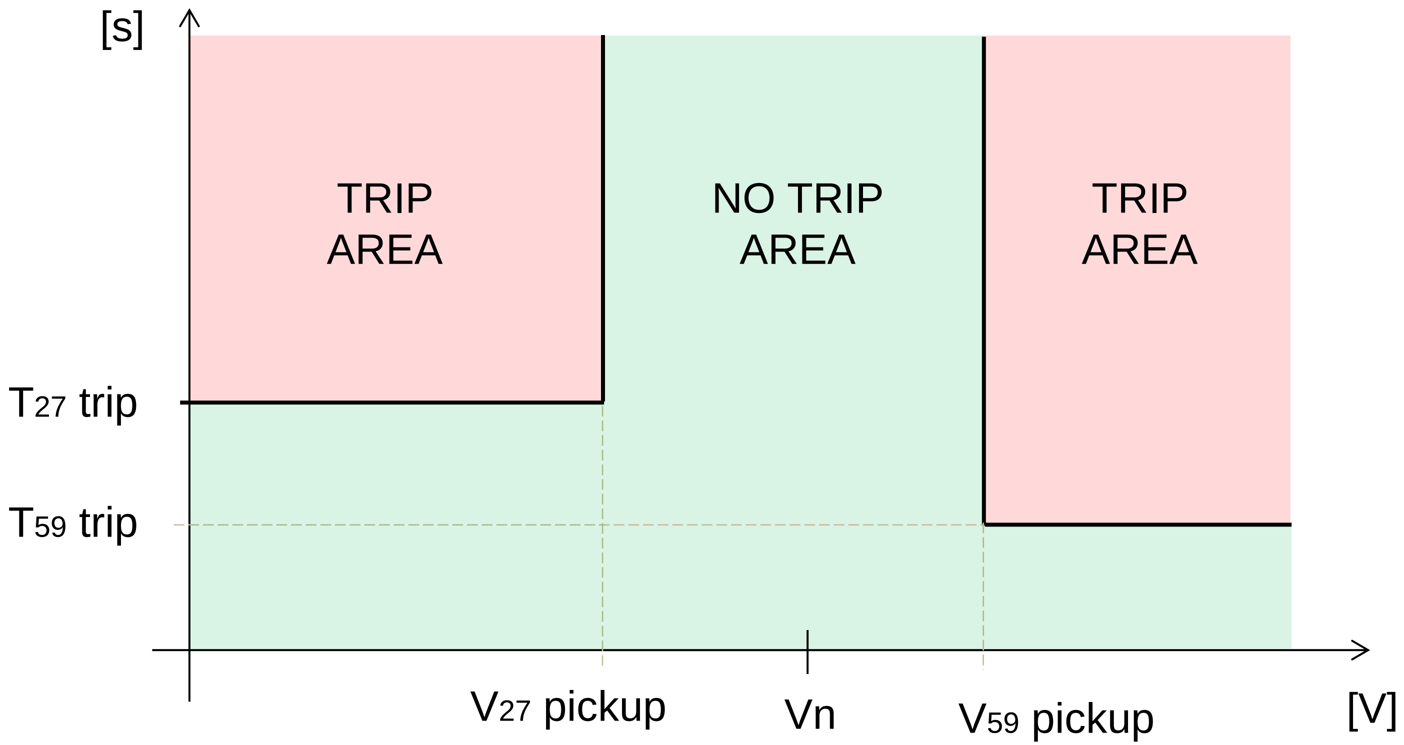
The measured voltage reaches *V_{27} pickup* and remains below *V_{27} reset* within *T_{59} trip*

⇩

Trip command released

RELAY TRIP CHARACTERISTIC

Time independent characteristic curves



How to test a Time Independent characteristic?

Generate the PREFAULT condition
In case of voltage protection, the prefault condition is represented by the nominal and symmetrical 3 phase voltage system

→ the voltages must be measured properly by the relay
→ this condition places the voltages inside the *no trip area*
→ the trip contact must be in the *no trip position (normally open or normally closed)*

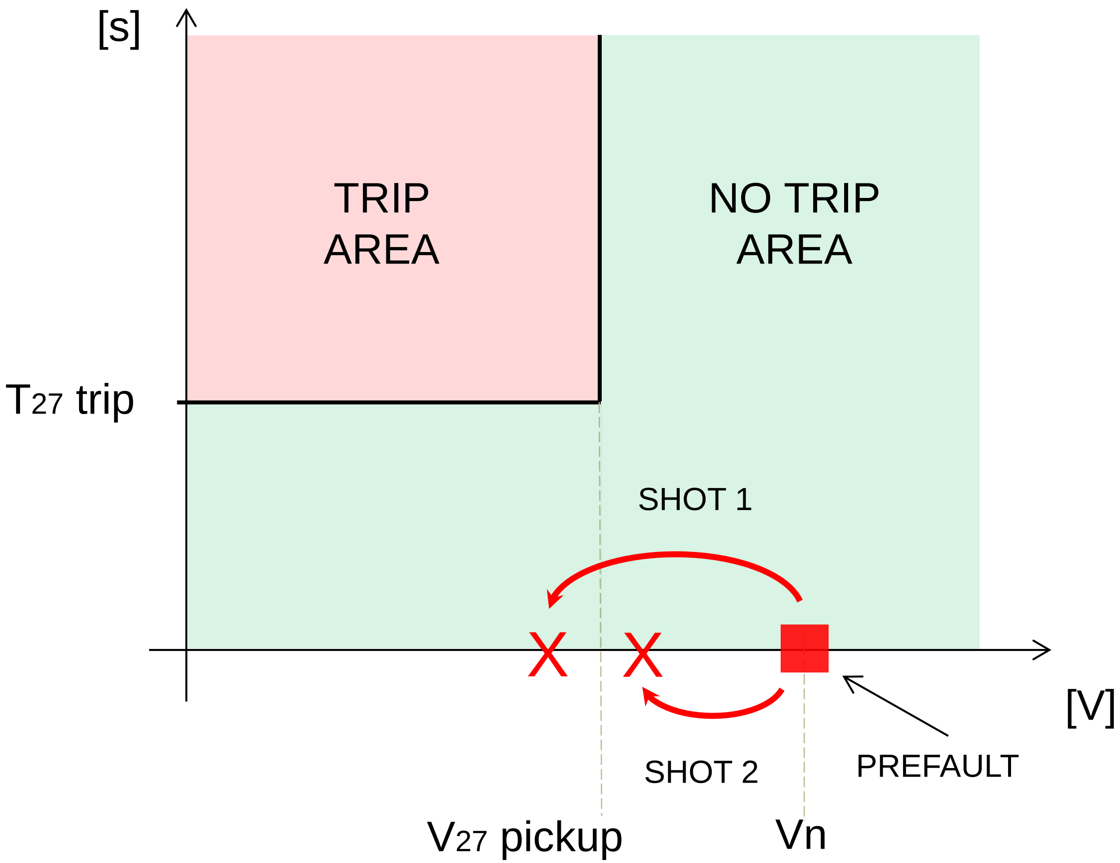
↓

Generate the FAULT condition
The voltage is reduced or increased in order to reach the *trip area*

→ The relay must release the trip command so the trip time can be measured

SHOT TEST *the easiest way to simulate a fault*

The voltage is reduced or increased with a voltage step



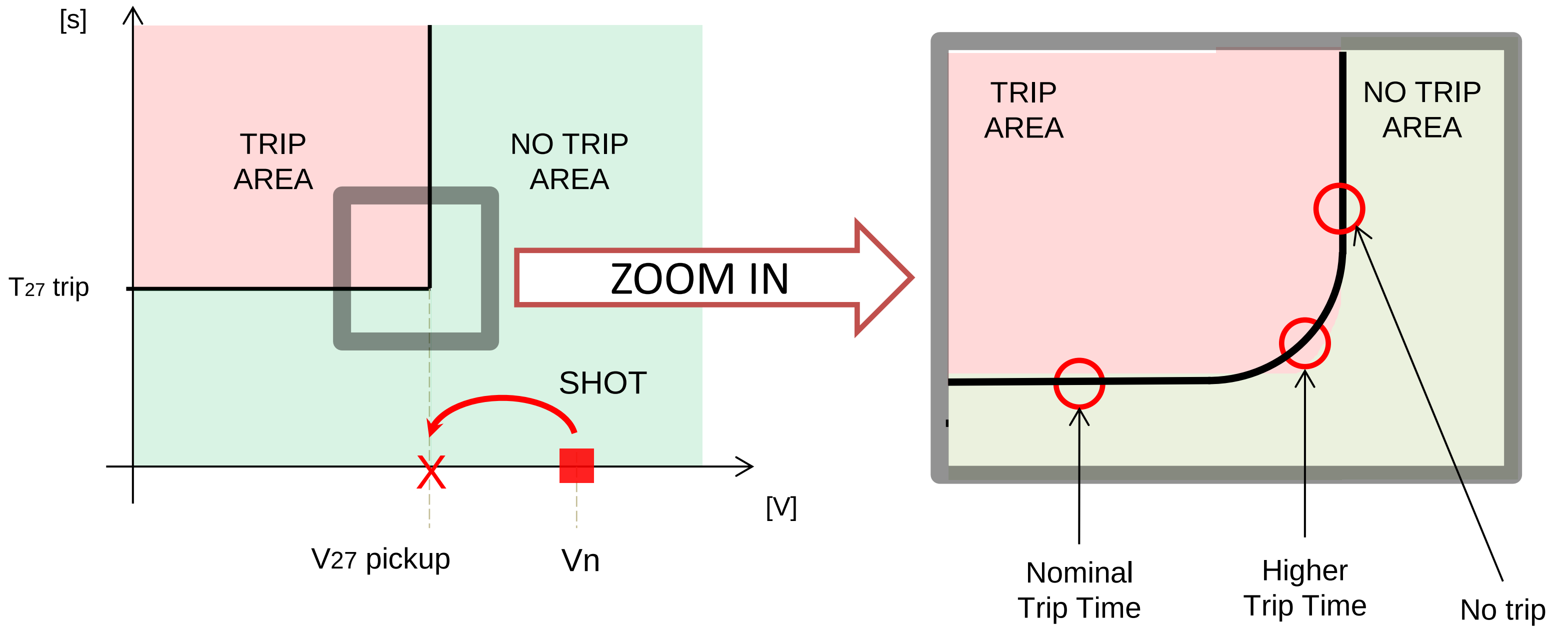
The trip time can be verified with only one test *(SHOT 1)*

The pickup voltage is verified with at least two tests *(SHOT 1 + SHOT 2)*

REMINDER: the fault condition must be applied for more than the trip time

REMARK 1

The fault voltage cannot be equal to the pickup voltage value !

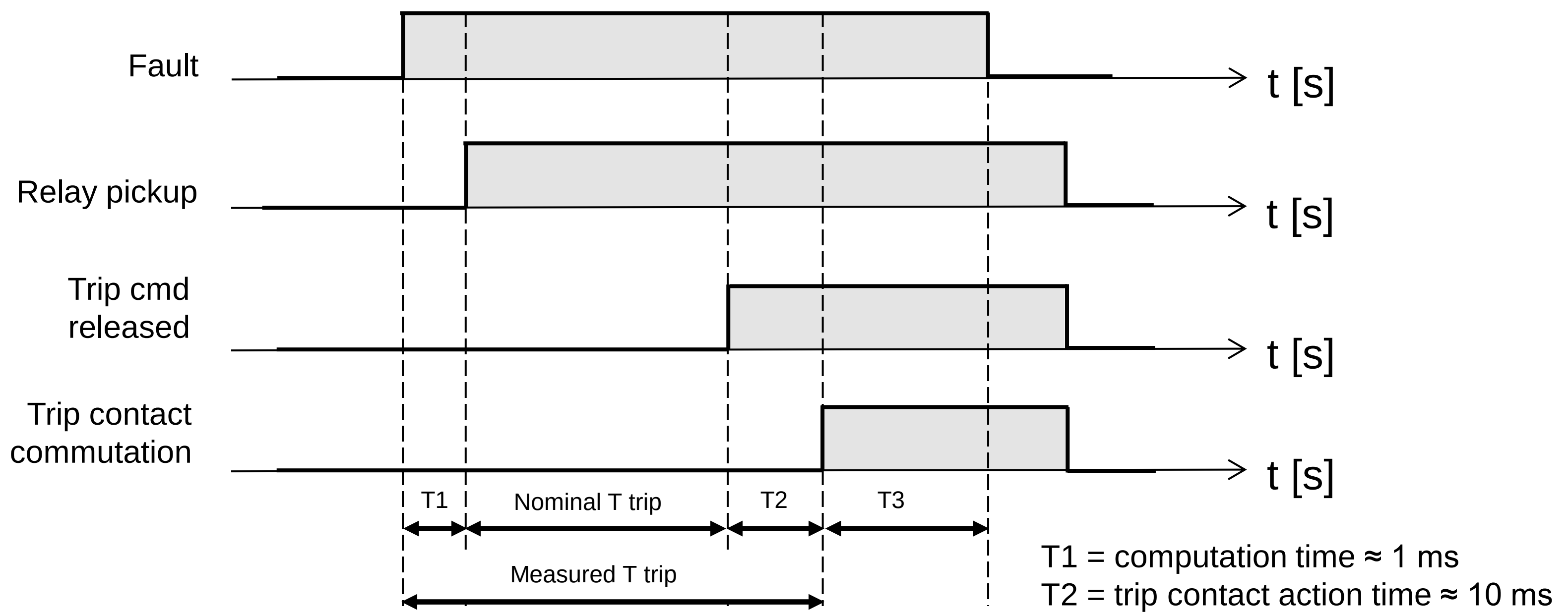


Very close around the threshold there is an uncertainty area

The fault voltage must be far enough from the border (little percentage of the pickup value)

REMARK 2

The measured trip time will be slightly longer than the relay setting



Measured T trip = T1 + Nominal T trip + T2

SHOT EXAMPLE

Relay settings:

U nominal = 100 [V] ; U pickup = 60 [V] ; T trip = 0.2 [s]

Voltage tolerance = ±5% ; Time tolerance = ± 3%+10 [ms]

Test settings:

PREFAULT	SHOT1
$V1 = 57.735\angle 0^\circ$ $V2 = 57.735\angle 240^\circ$ $V3 = 57.735\angle 120^\circ$	$V1 = 57.735*(60/100)*1.05\angle 0^\circ$ $V2 = 57.735*(60/100)*1.05\angle 240^\circ$ $V3 = 57.735*(60/100)*1.05\angle 120^\circ$ $T\max = 0.5[s]$
---	Measured T trip = timeout Voltage assessment : PASS Time assessment : PASS

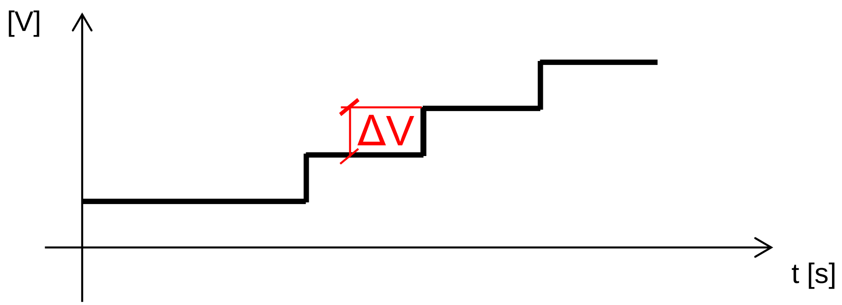
PREFAULT	SHOT 2
$V1 = 57.735\angle 0^\circ$ $V2 = 57.735\angle 240^\circ$ $V3 = 57.735\angle 120^\circ$	$V1 = 57.735*(60/100)*0.95\angle 0^\circ$ $V2 = 57.735*(60/100)*0.95\angle 240^\circ$ $V3 = 57.735*(60/100)*0.95\angle 120^\circ$ $T\max = 0.5[s]$
---	Measured T trip = 0.213 [s] Voltage assessment : PASS Time assessment : PASS

RAMP TEST *find the pickup voltage*

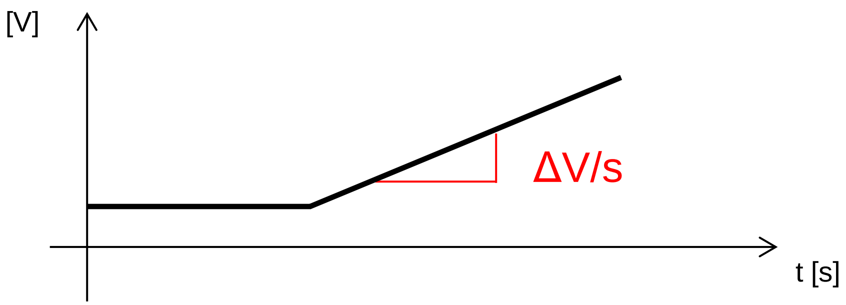
The voltage is continuosly reduced or increased

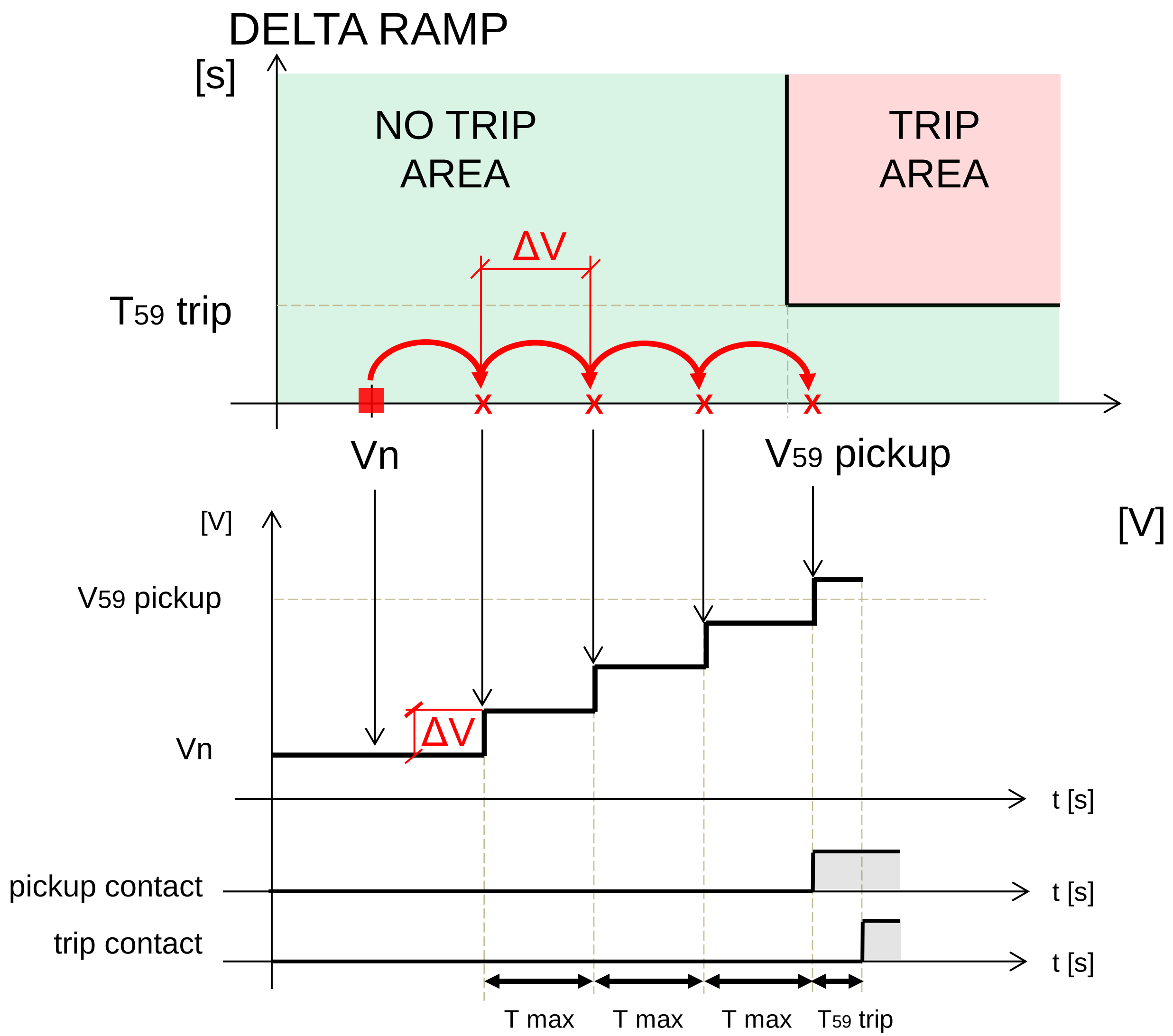
There are two different ramp type

DELTA RAMP : the voltage changes with a series of continuos steps



GRADIENT : the voltage changes with a defined slope ΔV/s



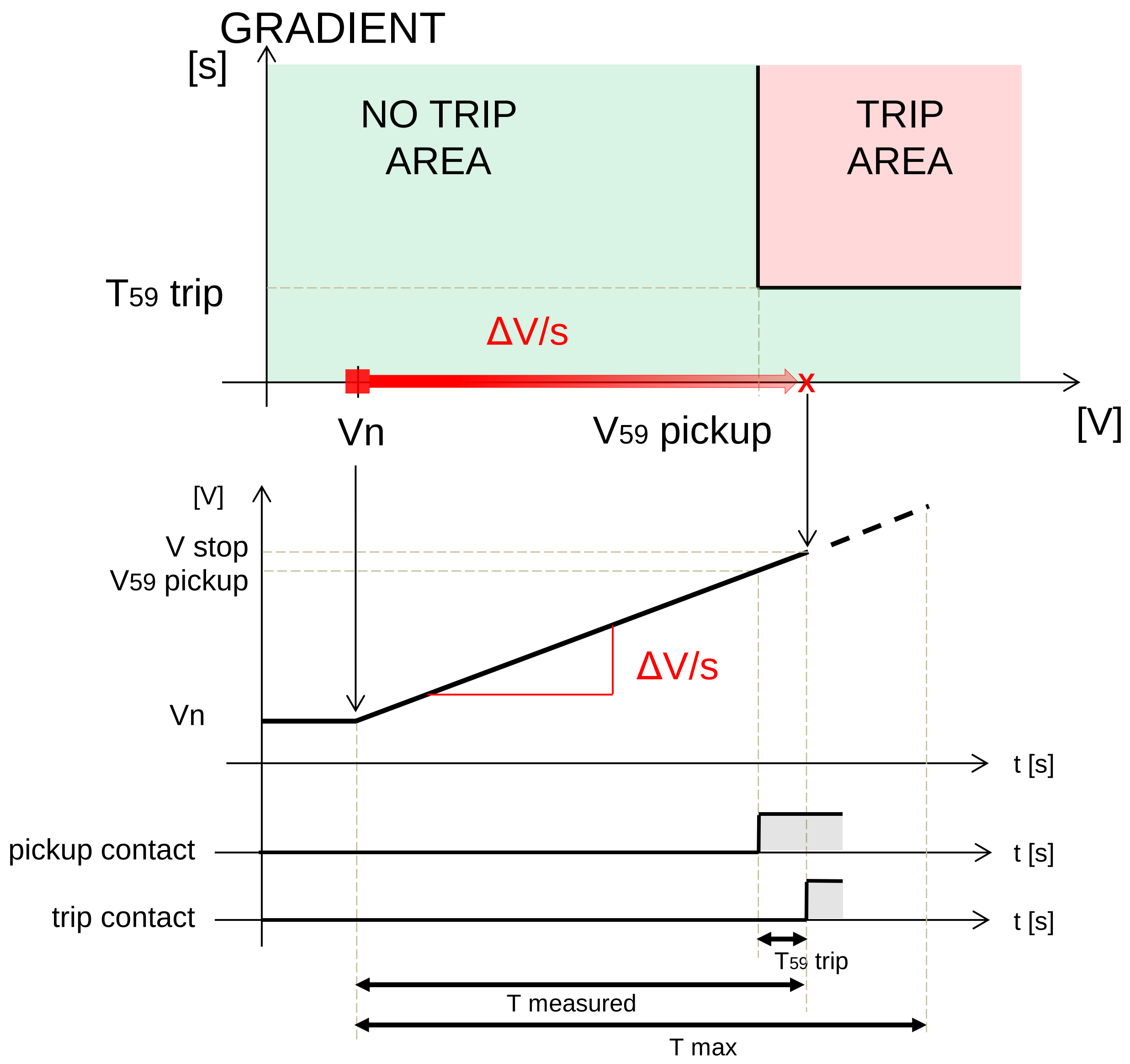


Delta ramp parameters

ΔV : voltage step amplitude

T max : maximum duration time of the applied voltage step (longer than T trip)

The time counter is reset at each step in order to measure T trip



Gradient parameters

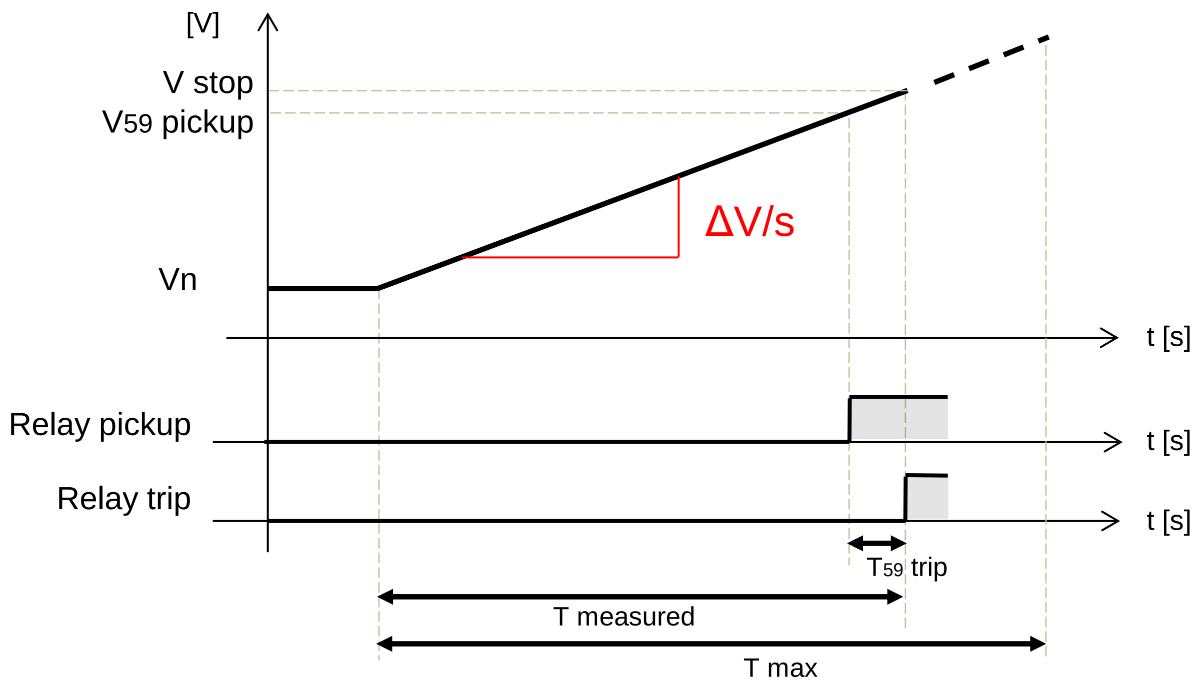
ΔV/s : voltage slope

T max : maximum duration time of the applied voltage gradient (enough to reach V pickup)

T measured ≠ T trip

V stop ≠ V pickup

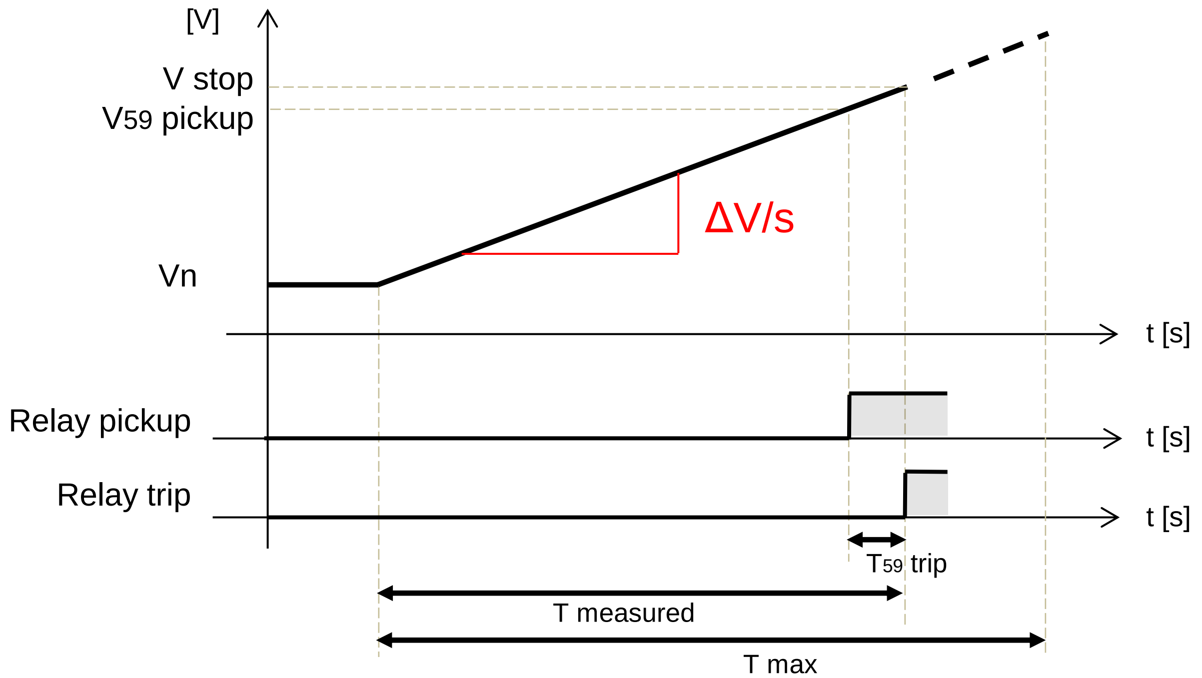
REMARK 1



The measured time is different than the trip time

The trip time must be measured with a shot test

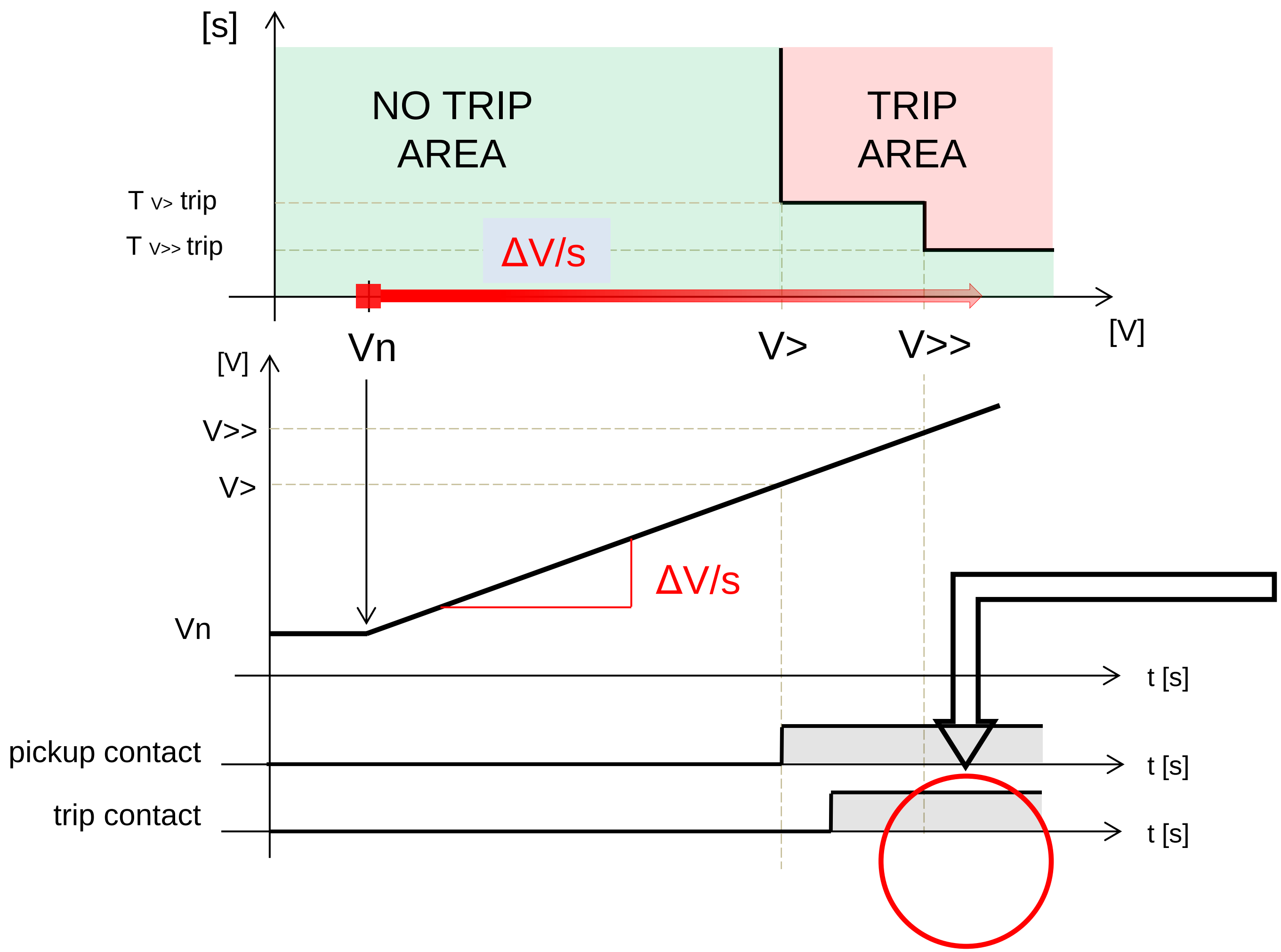
REMARK 2



$$V_{pickup} = V_{stop} - \Delta V/s \cdot T_{trip}$$ ⇨ T trip must be accurately measured !

$$V_{pickup} = V_{stop} - \Delta V/s \cdot T_{pickup}$$ ⇨ T pickup ≈ pickup contact action time → BEST CHOICE

REMARK 3



How to find multiple pickup values?

These contacts are already commutated

Different contacts must be programmed

GRADIENT EXAMPLE

Relay settings:

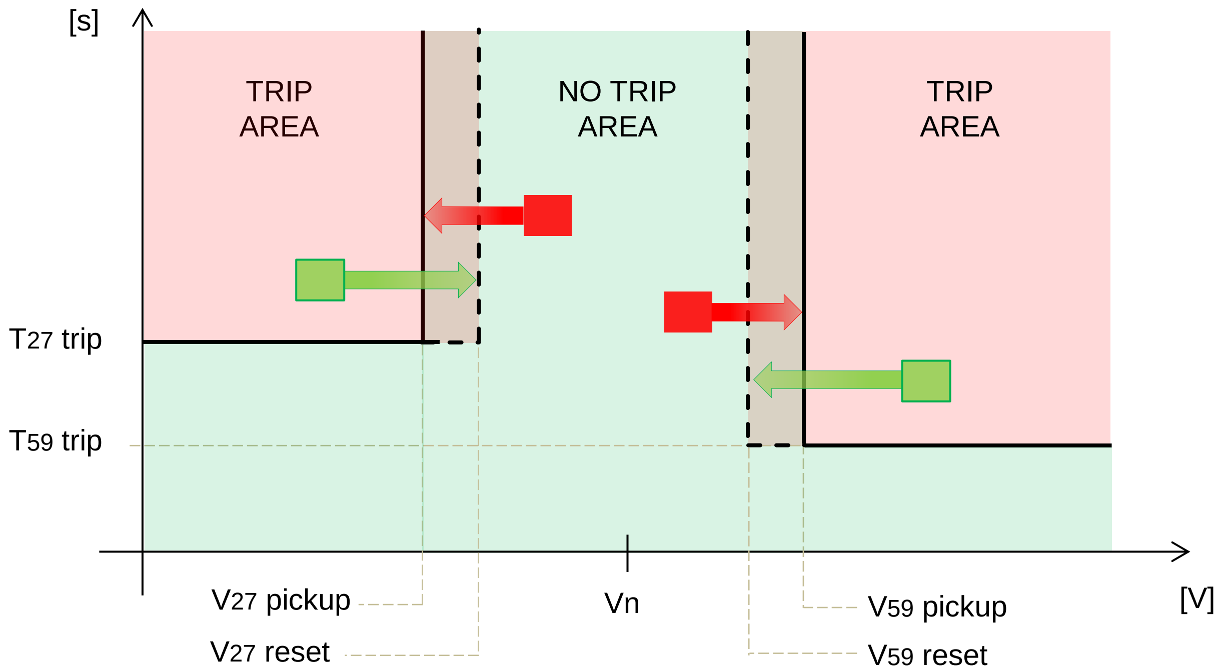
U nominal = 100 [V] ; U pickup = 140 [V] ; T trip = 0.4 [s]

Test settings:

PREFAULT	SHOT
$V1 = 57.735\angle 0°$ $V2 = 57.735\angle 240°$ $V3 = 57.735\angle 120°$	$V1 = 57.735*(140/100)*1.2\angle 0°$ $V2 = 57.735*(140/100)*1.2\angle 240°$ $V3 = 57.735*(140/100)*1.2\angle 120°$ $T\max = 0.8[s]$
---	Measured T trip = 0,416

PREFAULT	GRADIENT
$V1 = 57.735\angle 0°$ $V2 = 57.735\angle 240°$ $V3 = 57.735\angle 120°$	$V_{start} = V1 = V2 = V2 = 57.735[V]$ $slope = 5[V/s]$ $T\max = 10[s]$
---	$V_{stop} = V_{pickup}[V] + (5[V/s]*0.016[s]) =$ $= 80.91[V]$ $T_{measured} = 80.91[V]/(5[V/s]) = 4.618[s]$

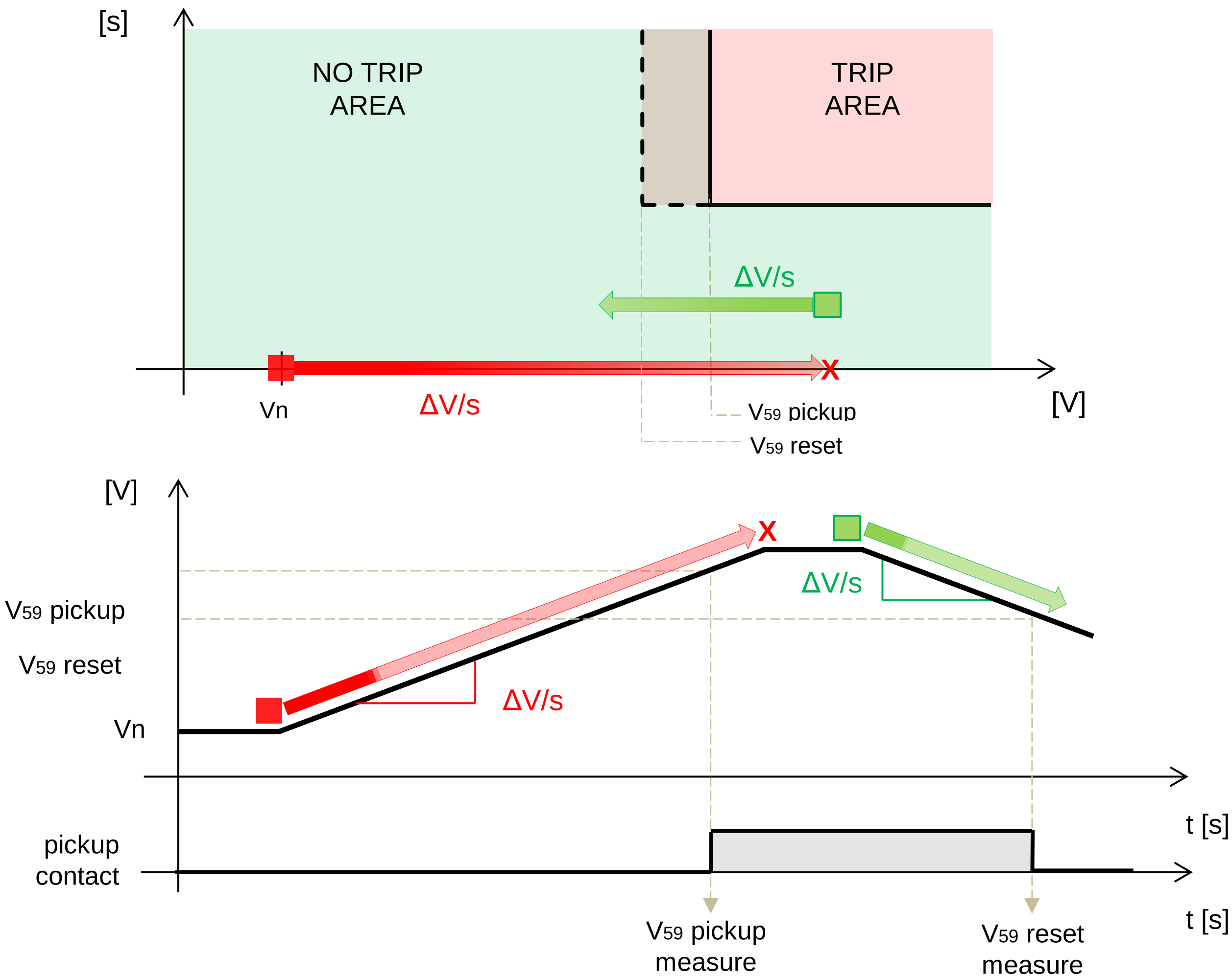
How to test the Drop-out ratio?



Moving toward the *no trip area*, the pickup and trip contacts are reset when the voltage reaches the reset values

Two ramps are necessary to find the pickup and reset voltages

The best choice is to use gradients and monitor the pickup contact to accurately measure the pickup and reset voltage values



$$\frac{V_{59}reset}{V_{59}pickup} < 1$$

$$\frac{V_{27}reset}{V_{27}pickup} > 1$$

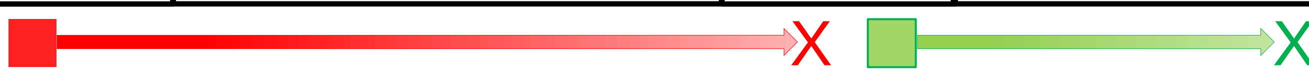
DROP-OUT RATIO EXAMPLE

Relay settings:

U nominal = 100 [V] ; U pickup = 140 [V] ; Drop-out ratio = 0.95

Test settings:

PREFAULT	GRADIENT 1	HOLD	GRADIENT 2
$V1 = 57.735\angle 0°$ $V2 = 57.735\angle 240°$ $V3 = 57.735\angle 120°$	$V_{start} = V1 = V2 = V2 = 57.735[V]$ $slope = 5[V/s]$ $T\max = 10[s]$	$V1 = 80.91[V]$ $V2 = 80.91[V]$ $V3 = 80.91[V]$ $T\max = 0.2[s]$	$V_{start} = V1 = V2 = V2 = 80.91[V]$ $slope = -2[V/s]$ $T\max = 10[s]$
---	$V_{stop} = V_{pickup}[V] + (5[V/s] * 0.016[s]) =$ $= 80.91[V]$ $T_{meas} = \frac{80.91[V]}{5[V/s]} = 4.618[s]$	---	$V_{stop} = V_{reset} + (-2[V/s] * 0.016[s]) = 76.74[V]$ $T_{meas} = \frac{80.91[V] - 76.74[V]}{2[V/s]} = 2.085[s]$



Drop-out ratio measured = 76.74 / 80.91 = 0.948