SIEMENS

Adaptive Autoreclosure to Increase System Stability and Reduce Stress to Circuit Breakers

70th Annual Conference for Protective Relay Engineers

Why using autoreclosure

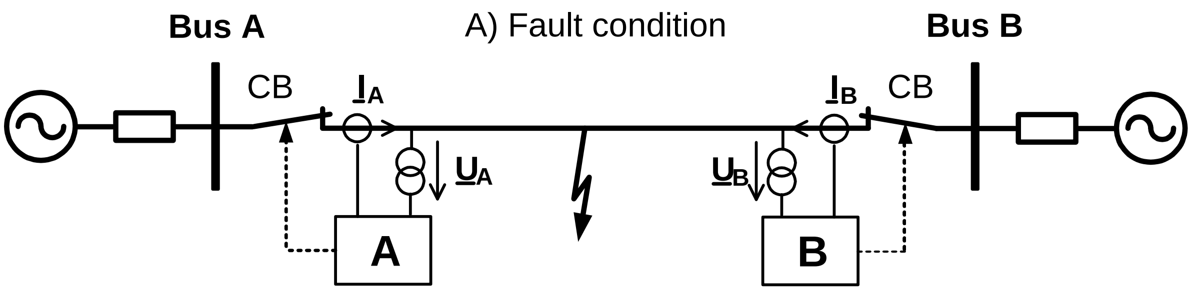
- **80 to 85 %** of faults at transmission and distribution lines are **temporary faults**
- Most important causes of temporary faults
  - Lightning is the most usual case for temporary faults
  - Bird streamers or vegetation reaching too close to the conductors
  - Swinging conductors contacting each other cause temporary phase to phase faults
- These faults disappear a certain time after de-energization of the faulted sections
- Automatic reclosure is used to **recover the original status of the network very fast** and **without any human interaction**

Black system event in south Australia on 28 September 2016

Table 3 Events resulting in Black System

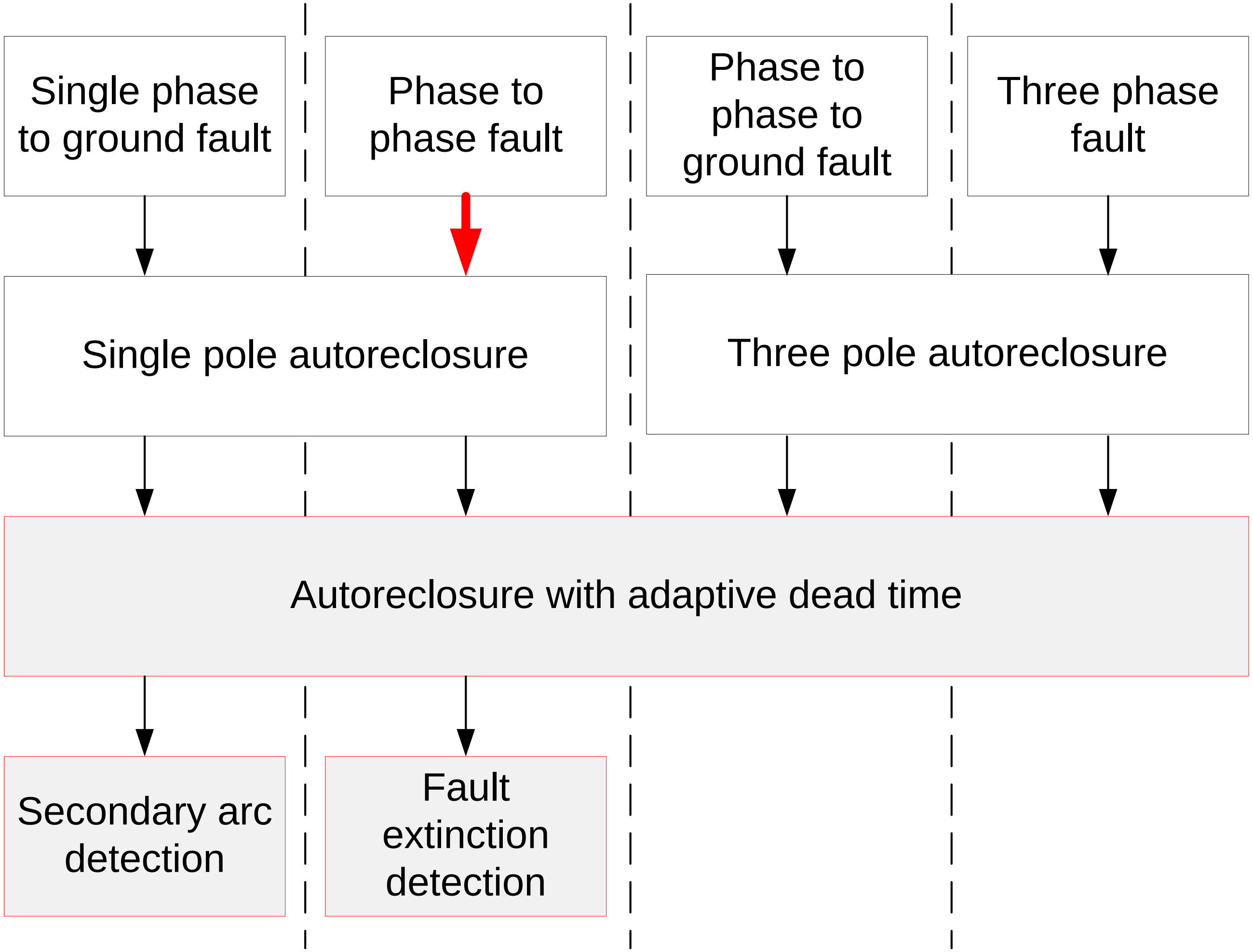
Time	Event
16:16:46 (T-90s)	Fault on Northfield–Harrow 66 kV feeder in Adelaide metropolitan area network. • Trip and successful reclose. No impact on main transmission system. • No significant change in generation or load observed.
16:17:33 (T-43s)	Two-phase-to-ground fault on Brinkworth – Templers West 275 kV line. • Line remains open, and requires physical patrol before re-energisation is attempted. • Line remains out of service as at 30/9/16 12:00. • No significant change in generation or load observed. Total – One 275 kV transmission line out of service.
16:17:59 (T-17s)	Single-phase-to-ground fault on Davenport – Belalie 275 kV line. • Fault location is estimated to have occurred on structure 93 (42 km from Davenport). • Line is successfully reclosed, after delay of 1 seconds. • No significant change in generation or load observed.
16:18:08 (T-8s)	Single-phase-to-ground fault on Davenport – Belalie 275 kV line. • As fault is within 30 seconds of previous fault (reclaim time window), no reclose attempted. • Line is opened on all 3 phases, and locked out. • Physical patrol of line required before re-energisation is attempted. Total – Two 275 kV transmission lines out of service.
16:18:09 (T-7s)	123 MW reduction in output from North Brown Hill Wind Farm, Bluff Wind Farm, Hallett Wind Farm, and Hallett Hill Wind Farm.
16:18:13 (T-3s)	Single-phase-to-ground fault on Davenport – Mt Lock 275 kV line. • Note: Davenport – Mt Lock 275 kV line is on other side of the same double circuit tower as the Davenport – Belalie 275 kV line. • Reclose attempted after approx. 1 second – 16:18:14 • Reclose unsuccessful, fault is still present, line opens on all 3 phases and is locked out. • Physical patrol of line required before re-energisation is attempted. • Fault location is recorded as structure 97 (43.5km from Davenport). Total – Three 275 kV transmission lines out of service.

Basic principle of autoreclosure



- a temporary fault appears on a line connecting Bus A and Bus B

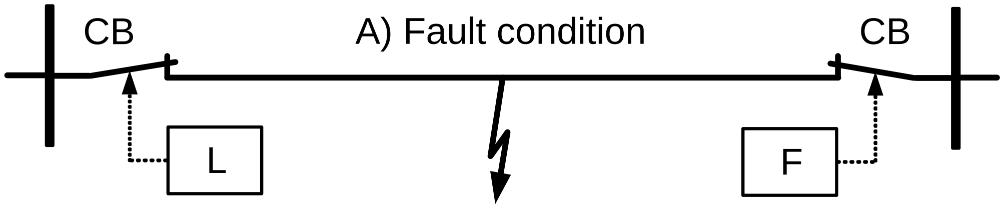
Autoreclosure schemes for different types of fault



Autoreclosure with an adaptive dead time

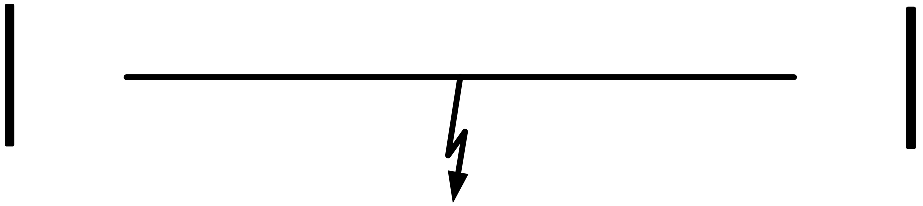
- typical autoreclosing scheme for transmission lines
- also known as “leader-follower autoreclosing scheme” [IEEE Std C37.104-2012]
- leader is defined as the line terminal that autorecloses first after a fixed dead time
- follower is the line terminal that recloses second
  and only if the reclosing of the leader was successful.
- leader is used to verify whether or not the fault is extinguished
  (during the dead time of the autoreclosure)
- if the fault still persists the leader will open the associated circuit breaker again
- if the fault still persists the follower does not attempt the autoreclosure
- great advantage of reducing unnecessary stress to the circuit breaker
  (at least at the follower end of the line)

Unsuccessful autoreclosure with adaptive dead time

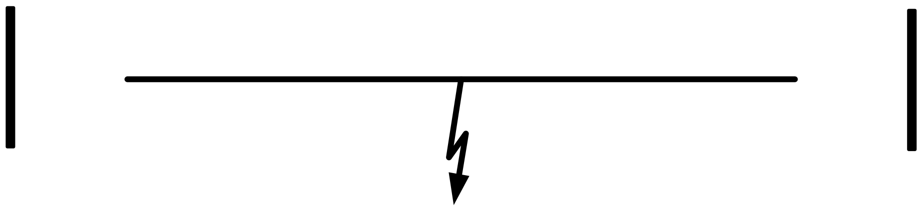


- a fault appears on a line protected by the relays called L (leader) and F (follower)

Successful autoreclosure using a remote close command



Successful autoreclosure using line side voltage measurement



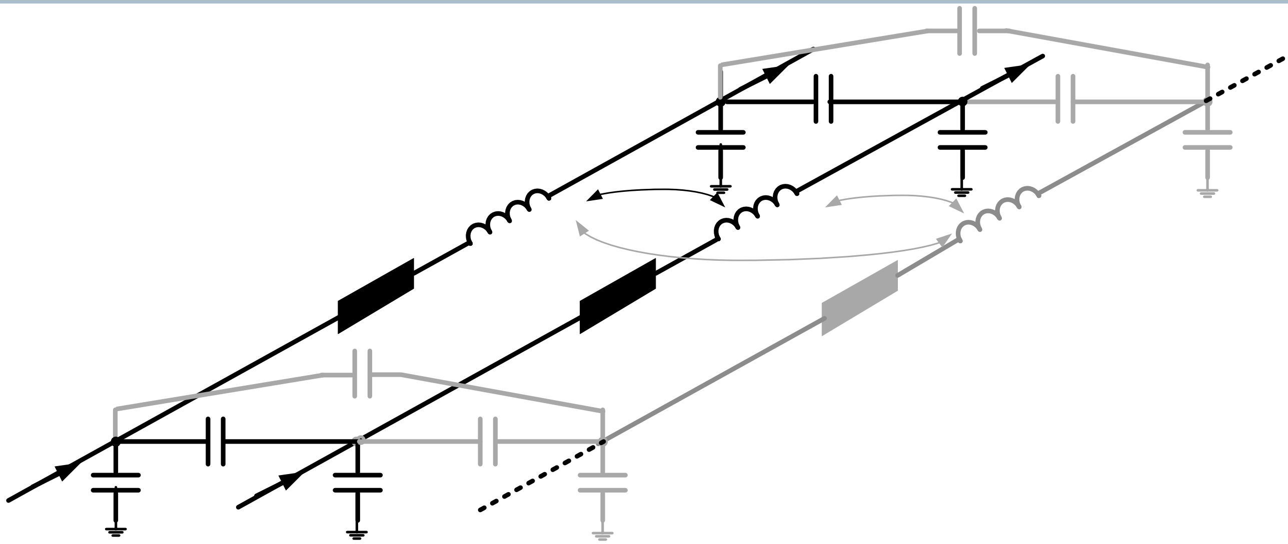
Secondary arc detection

A successful autoreclosure requires a dead time which exceeds the de-ionizing time, the time needed for the fault to extinguish.
The de-ionizing time depends on several factors including:

- arcing time (fault duration)
- fault current
- weather conditions like wind, air humidity and air pressure
- circuit voltage
- capacitive coupling to adjacent conductors

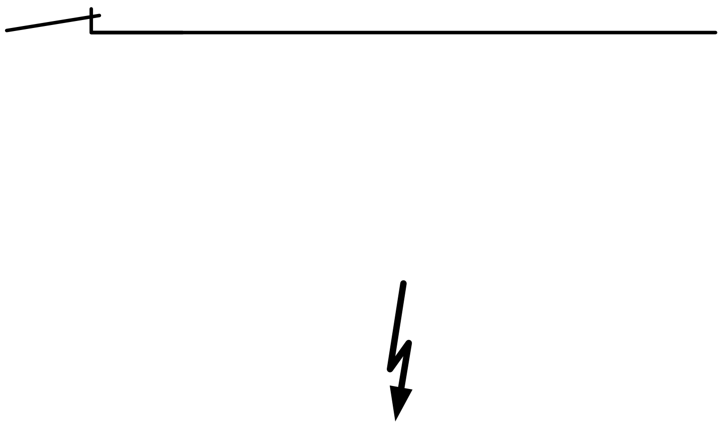
In general the circuit voltage is the predominating factor influencing the de-ionizing time. For single pole autoreclosure there is another effect which has a significant influence to the success of the autoreclosure. The primary arc current is interrupted by disconnecting the faulted phase from the sources by opening the circuit breakers at both ends of the line.
After this a secondary arc can prevent the fault clearance.

Secondary arc during single pole dead time



- capacitive and inductive coupling from the other two phases induces a voltage into the open phase conductor which feeds the secondary arc
- time to extinguish depends on the above mentioned influencing factors
- in worst case the secondary arc does not extinguish at all
  →reclosing in the presence of the secondary arc only re-energizes the fault

Simplified equivalent circuit of secondary arc, feeded by capacitive coupling from the two healthy phases



- the secondary arc is an arc between the open phase and ground
- the secondary arc is fed by the two healthy phases via capacitive coupling
- the voltage $\underline{U}_M$, measured at the disconnected phase is characterized by the ohmic nonlinear behavior of the secondary arc R_{ARC}

Simplified equivalent circuit after secondary arc is extinguished

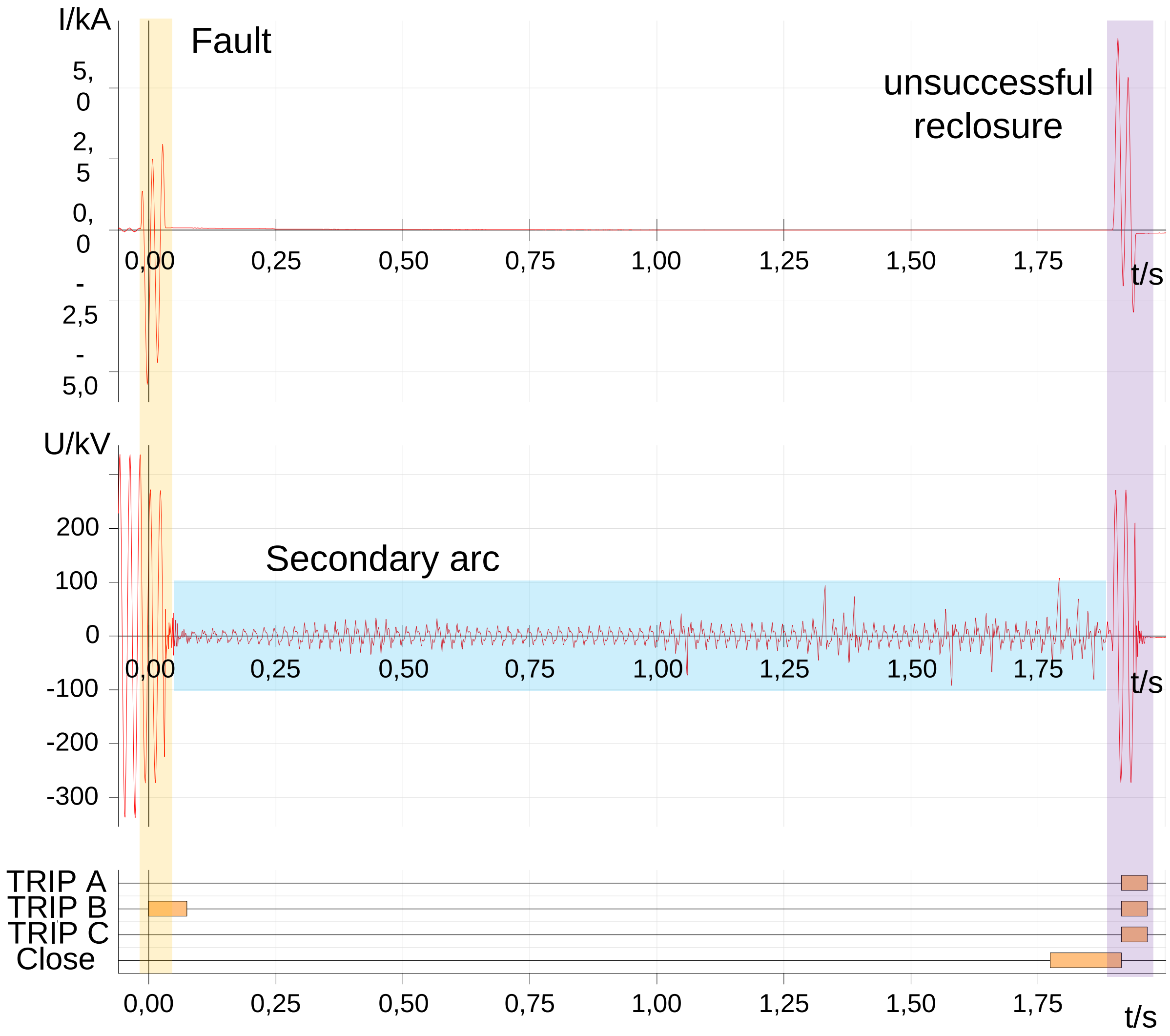
- equivalent circuit is changing to a different model
- the voltage $\underline{U}_M$, measured at the disconnected phase after extinguishing of the secondary arc is characterized by the linear capacitive behavior of the phase to ground capacitance C_{CG} of the open conductor

Secondary arc extinguishing during single pole dead time

- Ragow_400kV.cfg

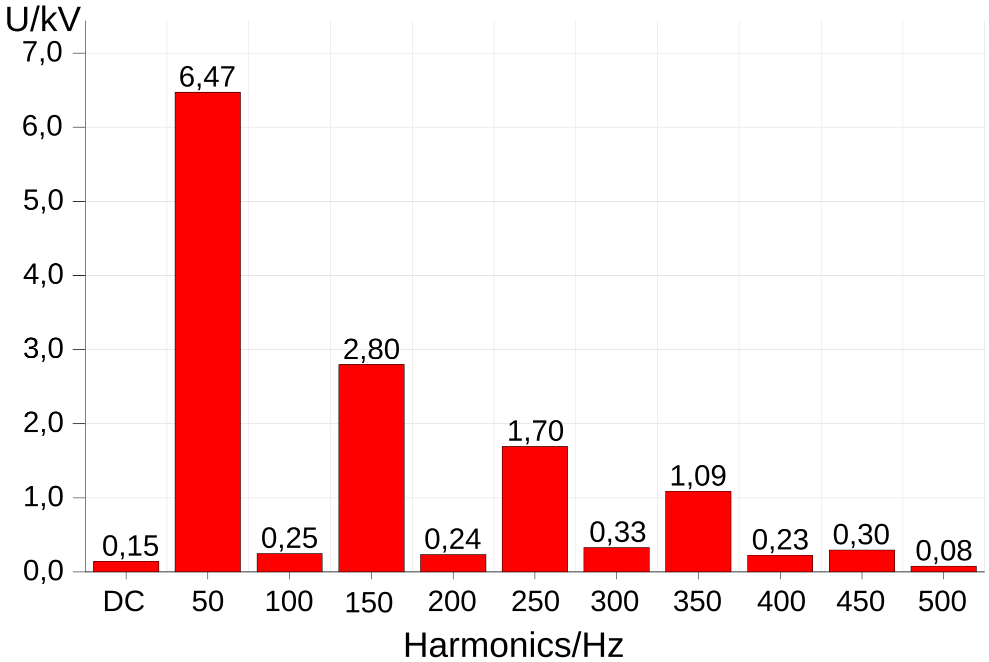
- after tripping the line we can see that the fault current disappears
- at the same time the voltage starts the typical nonlinear behavior of arcing
- secondary arc extinguishes and voltage is changing to a linear capacitive behavior
- finally voltage and current goes back to normal conditions after successful reclosing

Secondary arc not extinguishing during single pole dead time



- after reclosure the fault still persists which leads to a final trip of the protection

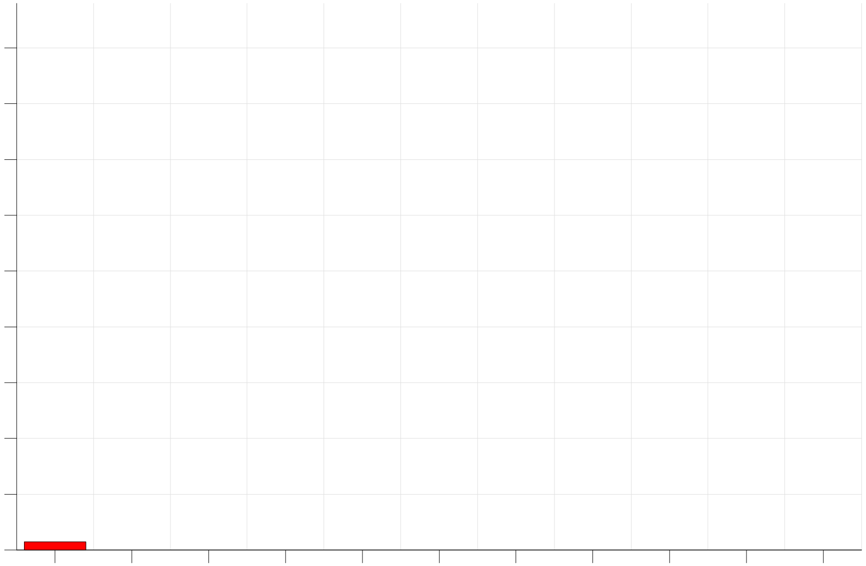
Harmonic content of voltage during the presence of the secondary arc



- there is a method to detect the presence of a secondary arc using the relation between the fundamental component and the harmonics of the phase to ground voltage of the open phase

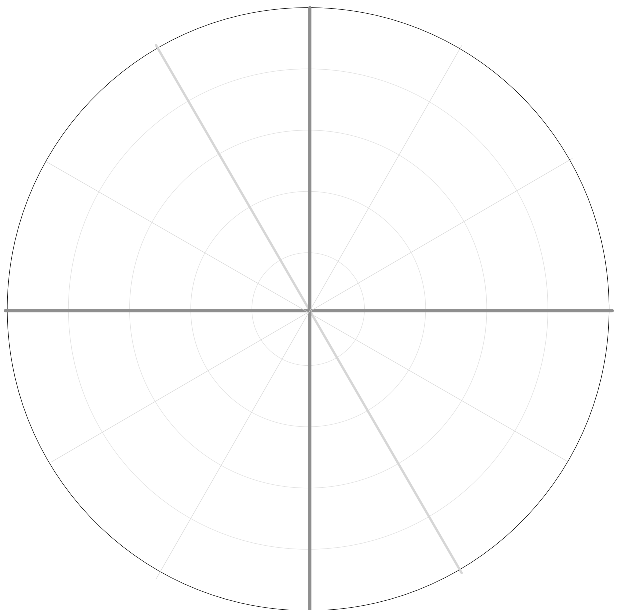
- the figure above shows the harmonic content of the open phase voltage during the presence of the secondary arc on a 400kV transmission line in Germany
- due to the nonlinear characteristic of the secondary arc there is a huge portion of 3^{rd}, 5^{th} and 7^{th} harmonic

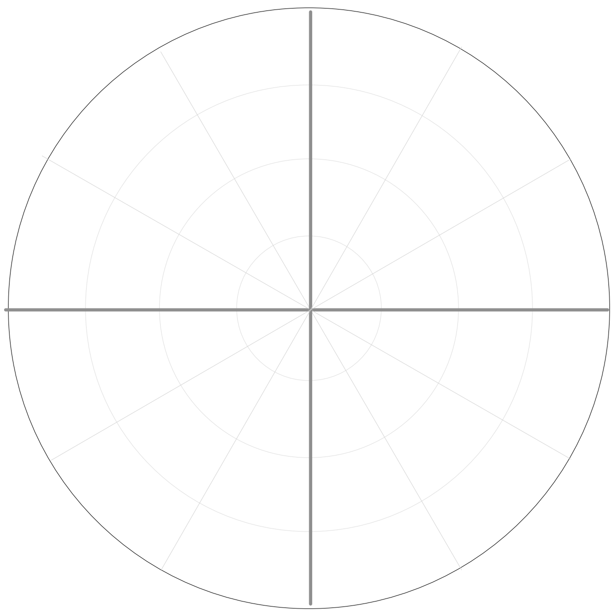
Harmonic content of voltage after secondary arc is extinguished



• after the secondary arc is extinguished the voltage is rising up to 42kV but without any harmonics like shown in the figure above

Phasor diagram of voltages during the presence of the secondary arc and after the secondary arc was extinguished

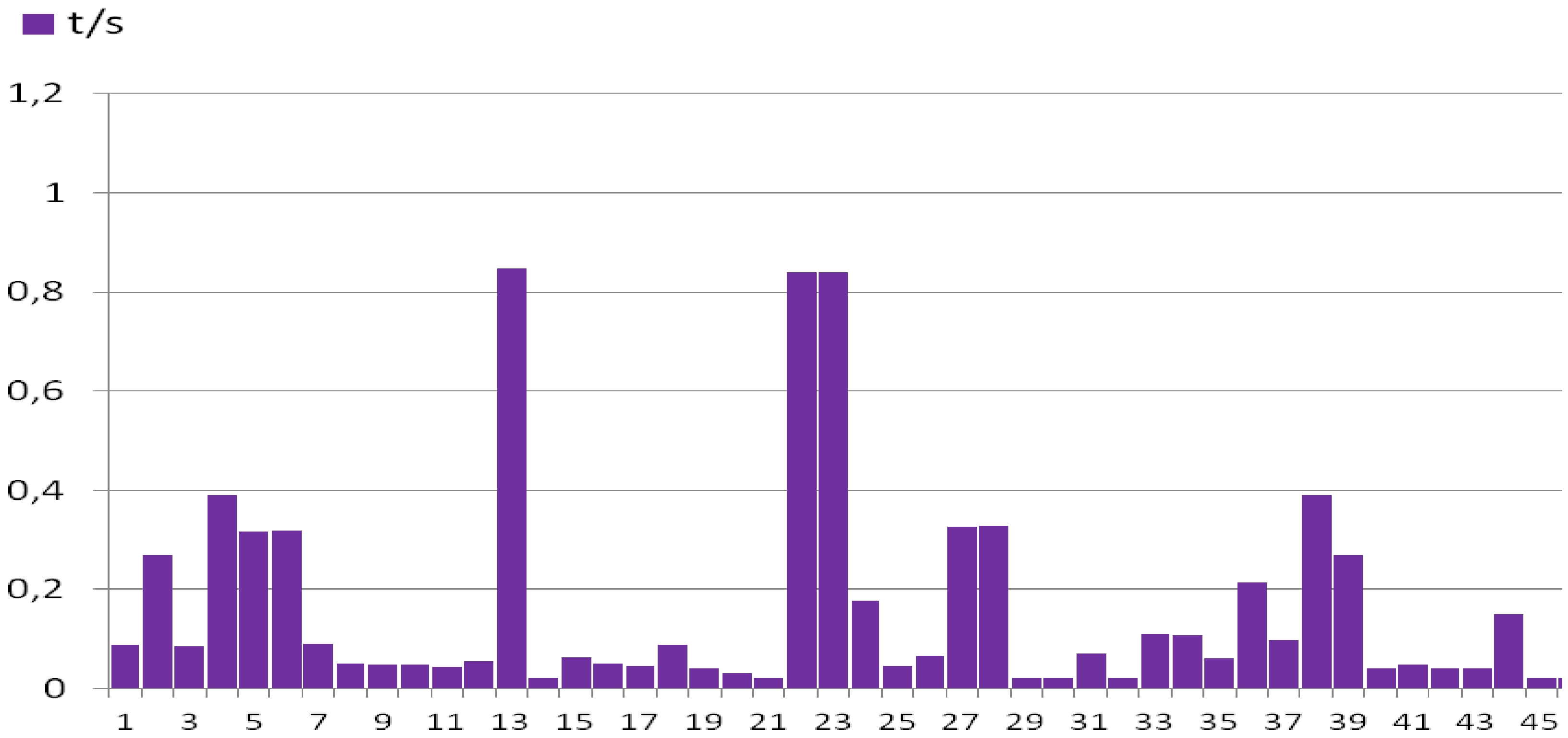




- Due to the ohmic characteristic of the secondary arc the voltage phasor of the open phase lags the voltage phasor of the pre-fault voltage by 90°

- After the secondary arc is extinguished the voltage phasor is rising in magnitude and is located between the two healthy voltage phasors like shown above

Time needed for the secondary arc to extinguish during the single pole dead time



- 50Hertz Transmission uses adaptive autoreclosure with a fixed dead time of 1.2s
- secondary arc was already extinguished after 0.2s in many cases

Advantages of secondary arc detection

Secondary arc detection as part of the autoreclosure function

- the fixed dead time for the leader could be reduced significantly in most cases
- reclosing onto permanent fault could be prevented for the leader

Secondary arc detection as part of post fault analysis

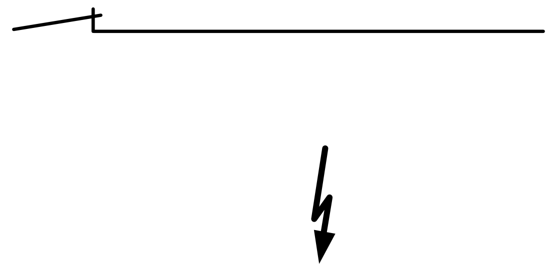
- if a secondary arc and not a permanent fault was the reason for the unsuccessful reclosure, a manual closing of the line is permitted without a time consuming line patrol in advance

Single pole tripping for phase to phase faults without ground

Under extreme weather conditions line swinging can cause an increasing number of phase to phase faults.

These faults are mostly flash-arcs between two wires of a transmission or distribution line.

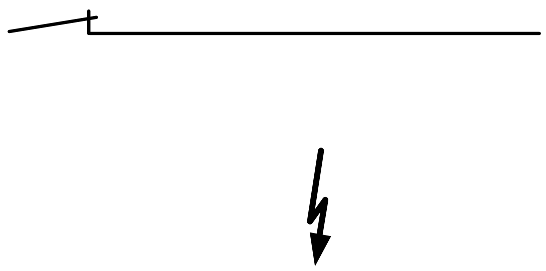
Single pole tripping for phase to phase faults without ground



It is obvious like shown in the figure that a single pole trip will clear a temporary phase to phase fault in most cases.

In 1972 a scheme was protected by patent to clear phase to phase faults without ground by means of a single pole autoreclosure.

Single pole tripping for phase to phase faults without ground

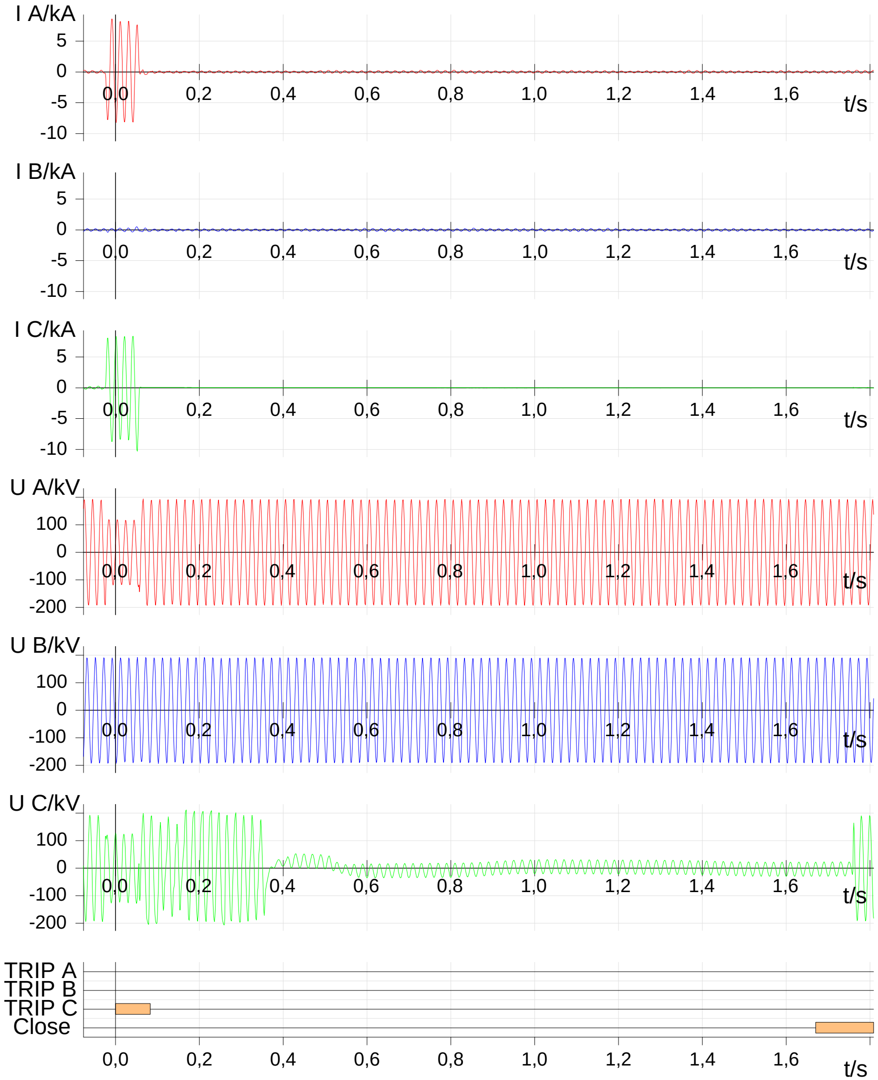


There are two options for single pole tripping in case of phase to phase faults without ground: trip leading phase or trip lagging phase.

It must be ensured that all protective relays in a given network use the same phase preference for single pole trip in case of phase to phase faults.

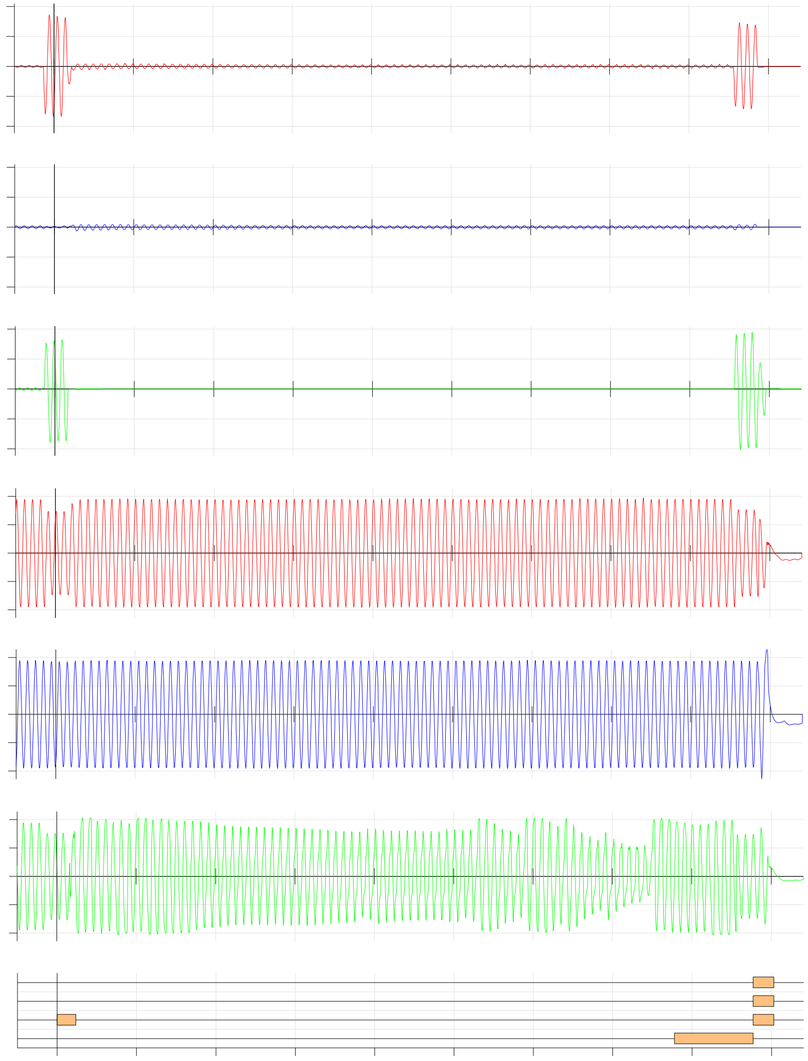
This scheme is successfully applied in Germany, Poland and Austria for many years to take the advantages of single pole autoreclosure also for phase to phase faults without ground.

Successful single pole autoreclosure of phase C for a fault between phase A and phase C



- After tripping of phase C the fault current in phase A and phase C disappears at the local end.
- Approximately 300ms later also the voltage $\underline{U}_C$ goes down indicating the isolation of the fault.
- Finally a successful reclosure brought the system back to normal conditions.
- A successful isolation of the arc between the two faulted phases is given if the phase to ground voltage of the tripped phase is measured to be below a certain value for a given time.

Unsuccessful single pole autoreclosure of phase C for a fault between phase A and phase C



- The phase to ground voltage of the tripped phase C does not fall below a certain value for a given time.
- Detecting this condition an unsuccessful autoreclosure could be prevented in the future.
- Voltage measurements during the single pole dead time can predict whether or not a reclosure will be successful.

Conclusion

- It was shown that using adaptive autoreclosure the system stability can be increased by **adaptively shorten the dead time** of the autoreclosure and **prevent unnecessary reclosing** onto faults.
- Several different methods were explained how to use voltage measurement during the single pole dead time to reduce unnecessary stress to the circuit breaker by reclosing onto faults.

Thank you for your attention!

Questions?