Can compensated networks be an alternate solution to reduce the risk of ground faults causing forest fires?

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Content

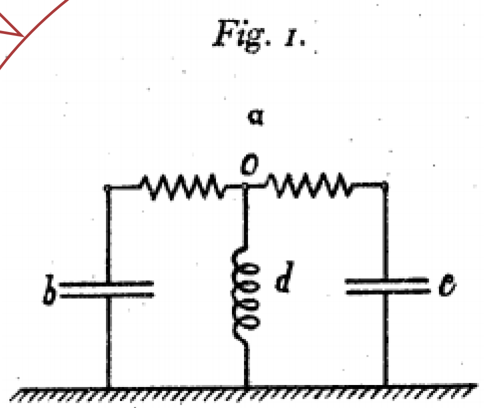
- Fundamentals of compensated networks
- Calculation of fault quantities for basic ground fault protection analysis purposes
- Considerations to convert from a solidly/low resistance grounded system to a compensated network
- Reduction of fire risk during a 'wire down' fault
- Special protection challenges in compensated networks
- Multi-frequency admittance based ground-fault protection

Fundamentals of compensated networks

- Compensated network

- Resonant(ly) grounded network

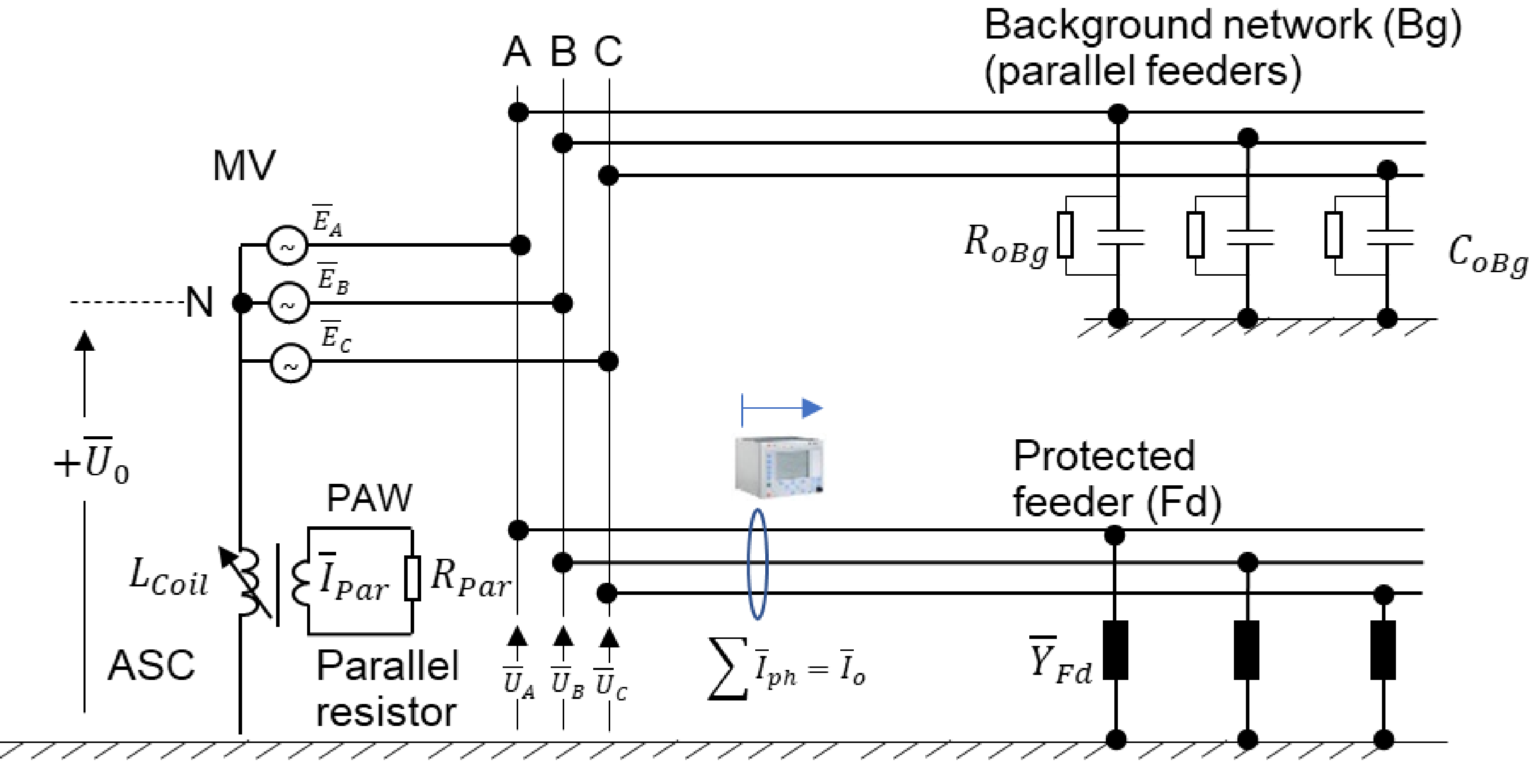
- High impedance grounded network



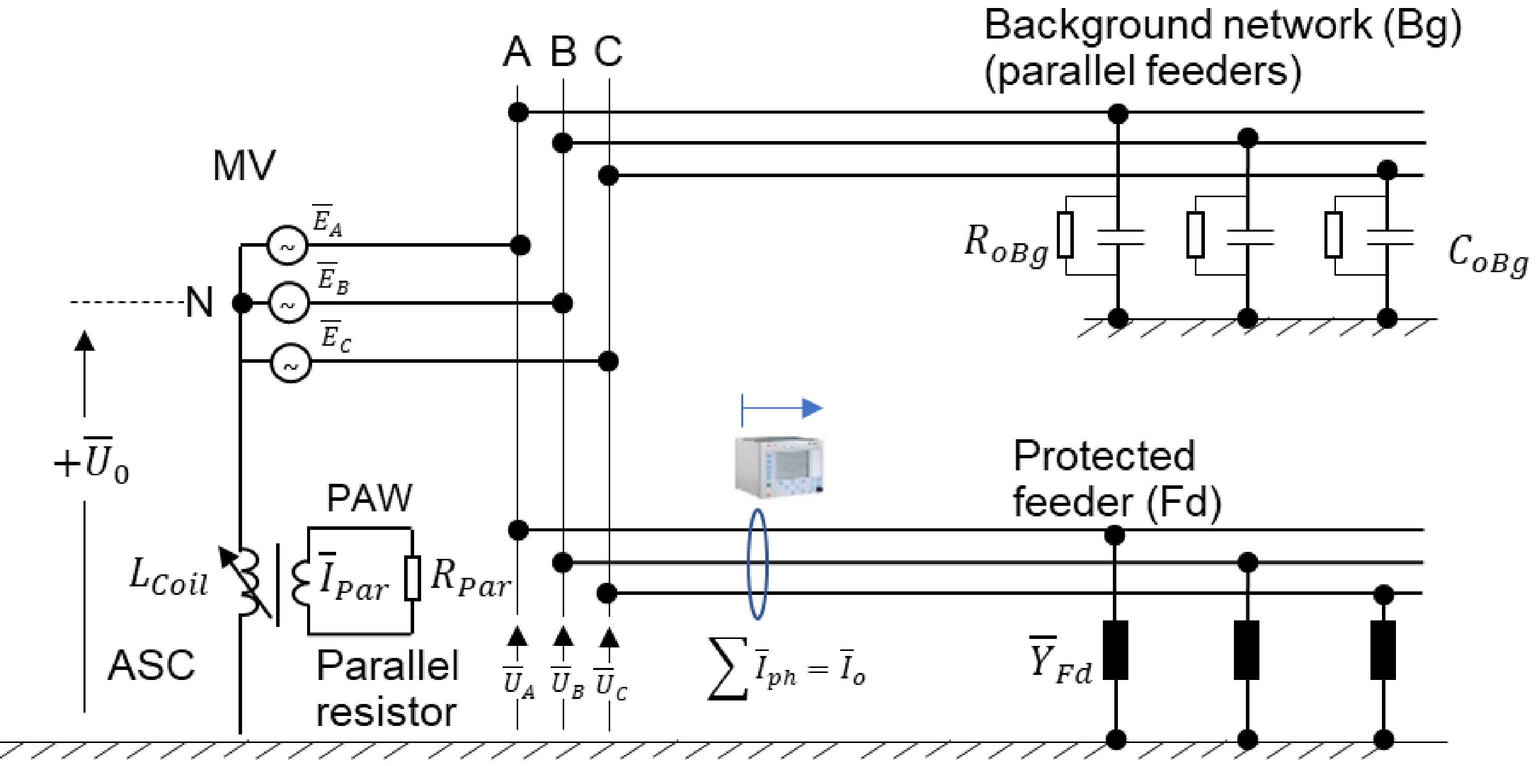
- Arc Suppression Coil (ASC) or Petersen coil

- Parallel RLC-resonance circuit

Fundamentals of compensated networks



Fundamentals of compensated networks



Network damping (I_d)

The total shunt losses are known as the network damping (I_d), which is due to shunt losses of conductors, losses of the ASC and losses introduced by parallel resistor (if applied).

Network detuning (I_v)

Detuning is the relative value of the inductive current of the coil or coils compared to the capacitive current of network phase-to-ground capacitances

Typically both quantities are expressed in primary amperes!

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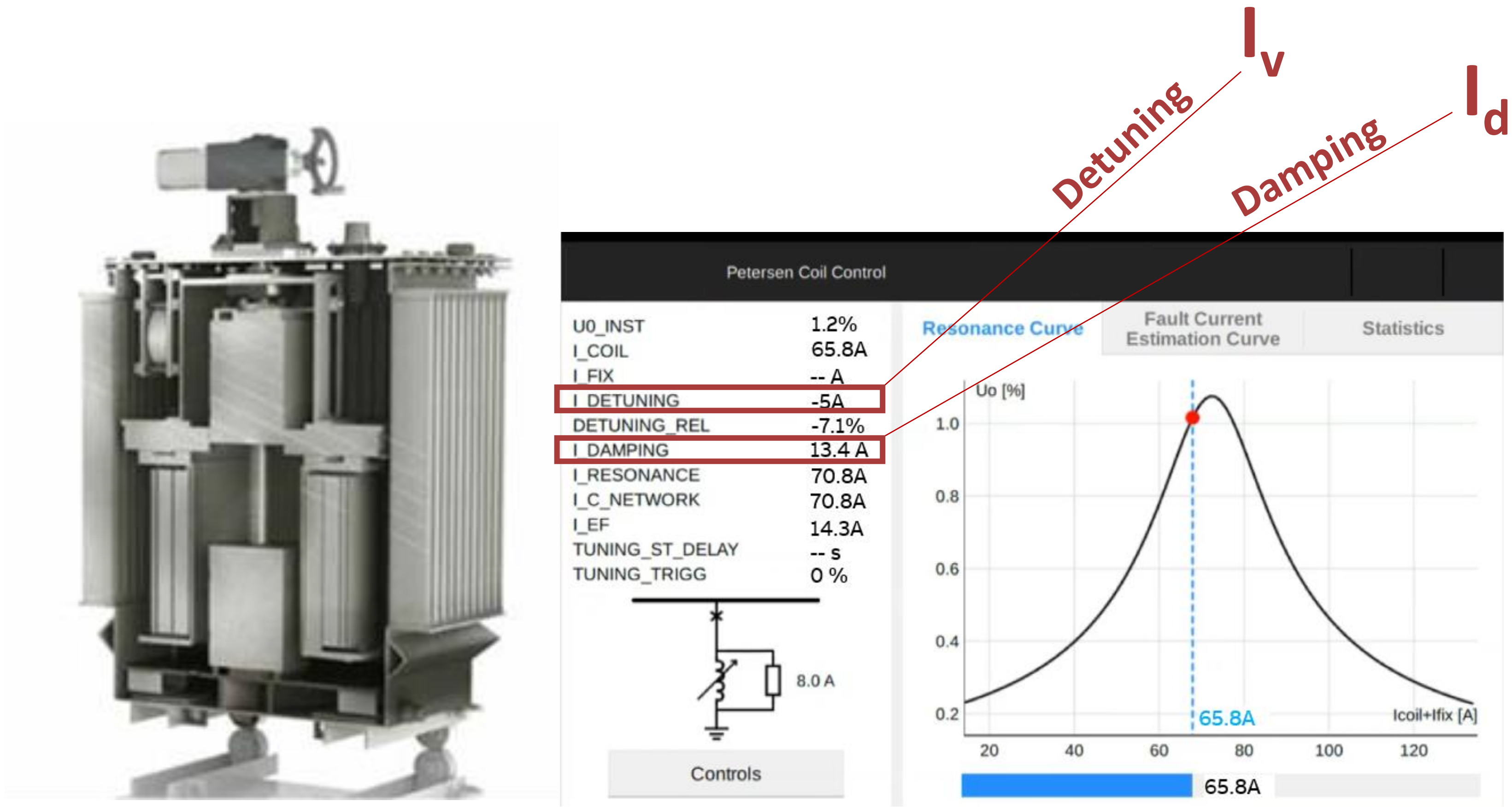
Fundamentals of compensated networks



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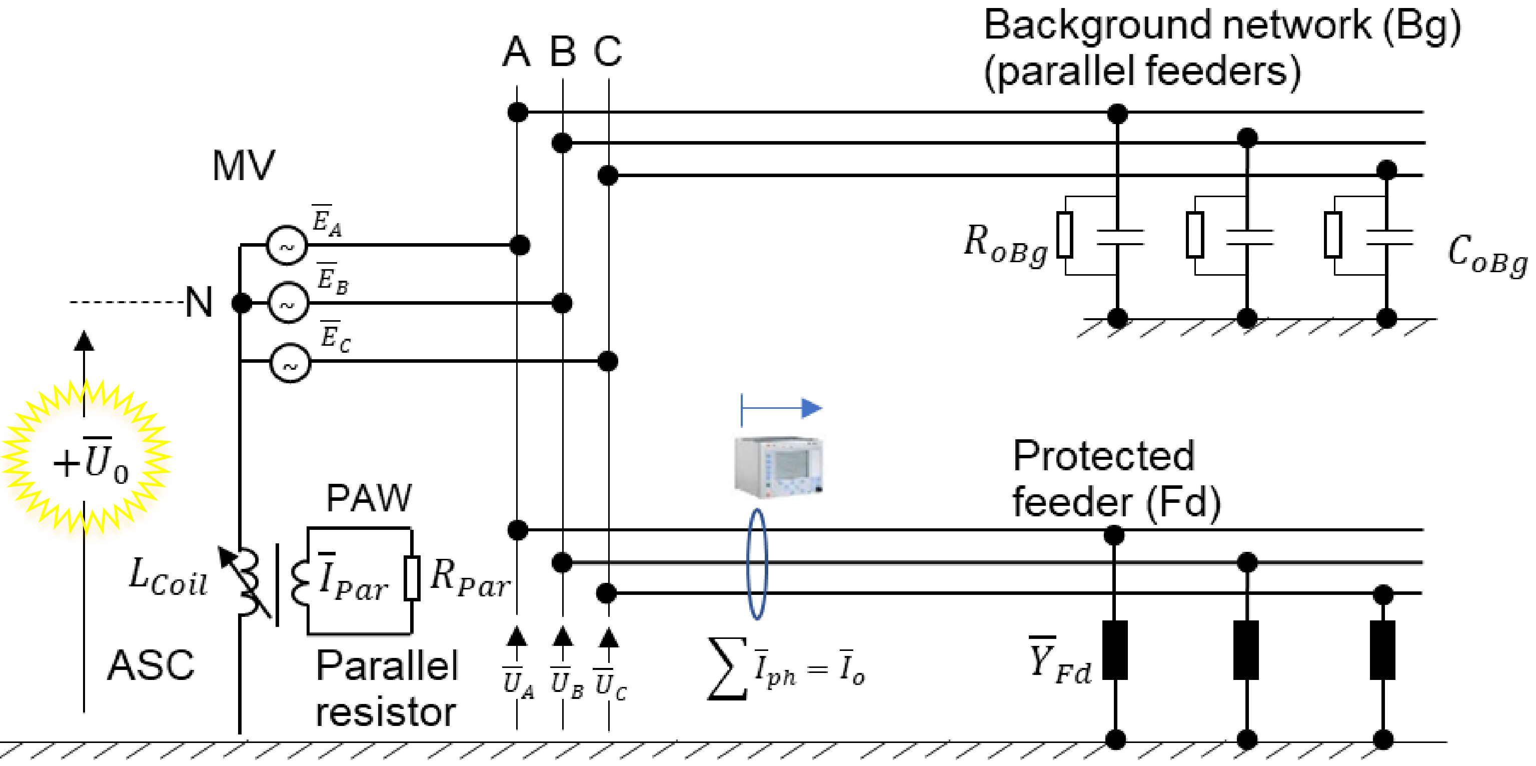
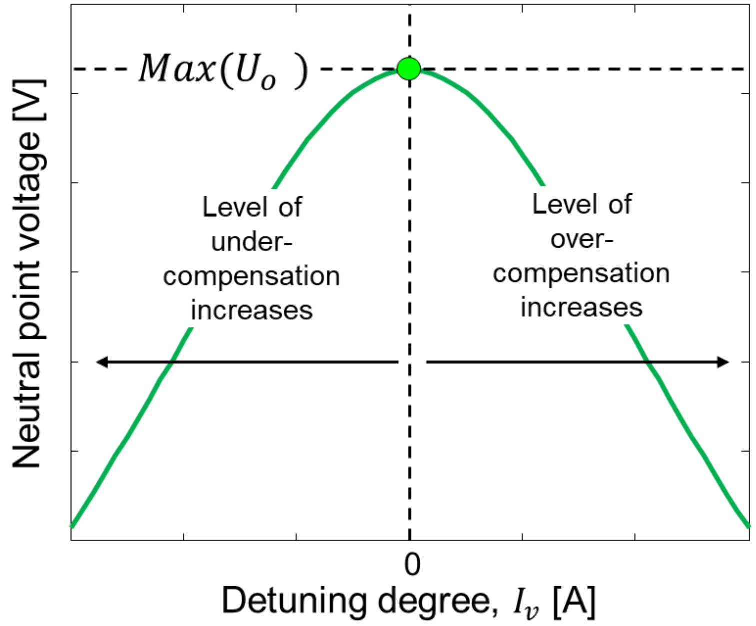
Fundamentals of compensated networks:

Neutral point voltage during healthy state



Healthy state "Resonance curve"



$$\overline{U}_o^{healthy} = -U_{PE} \cdot \frac{\overline{I}_{uNettot}}{I_d - j \cdot I_v}$$

- $\overline{I}_{uNettot}$ = asymmetrical part of the total network admittance [A]
- U_{PE} = the operating phase-to-ground voltage [V]
- I_d = Network damping [A]
- I_v = Network detuning [A]

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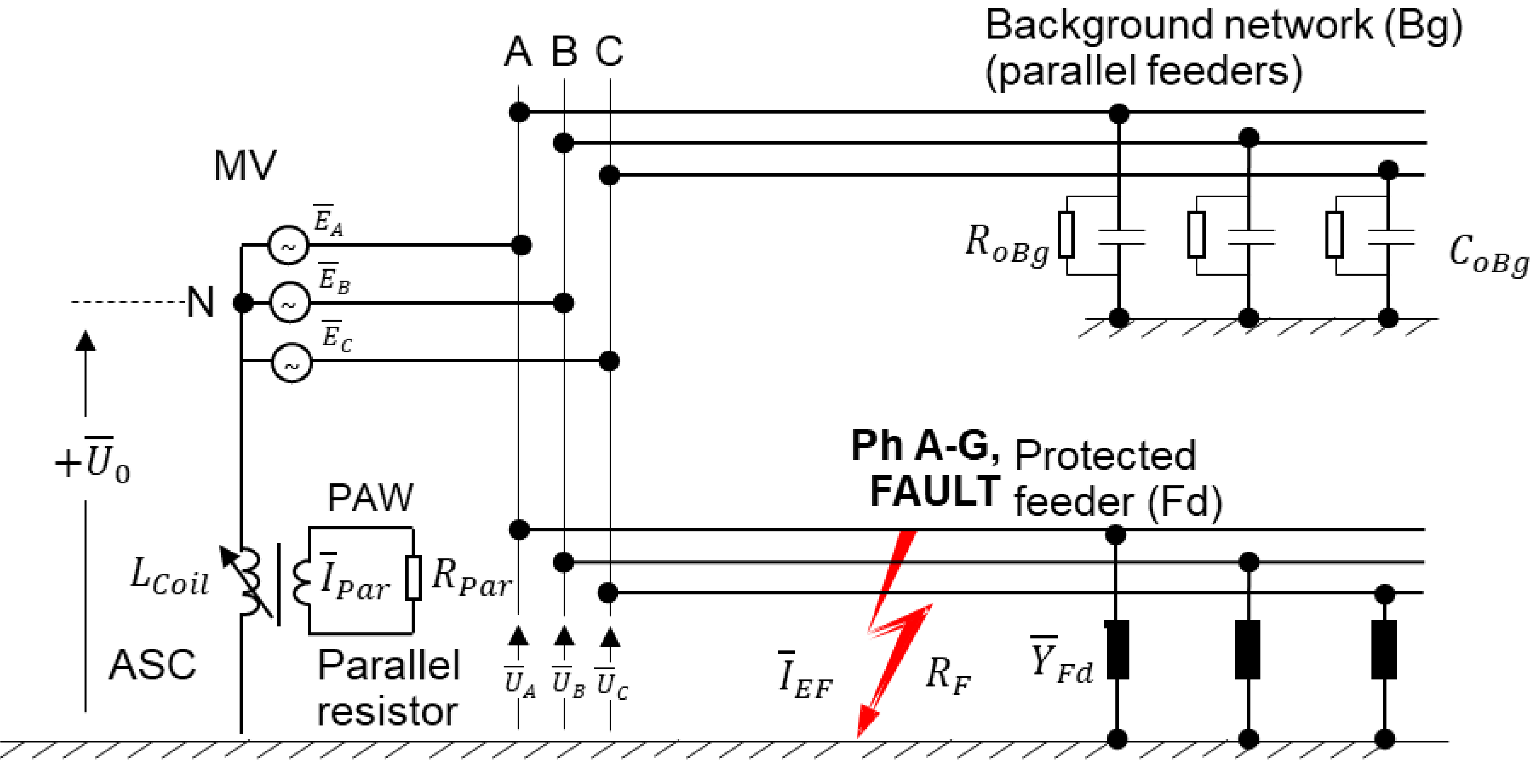
Fundamentals of compensated networks:

Neutral point voltage during ground fault



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Fundamentals of compensated networks:

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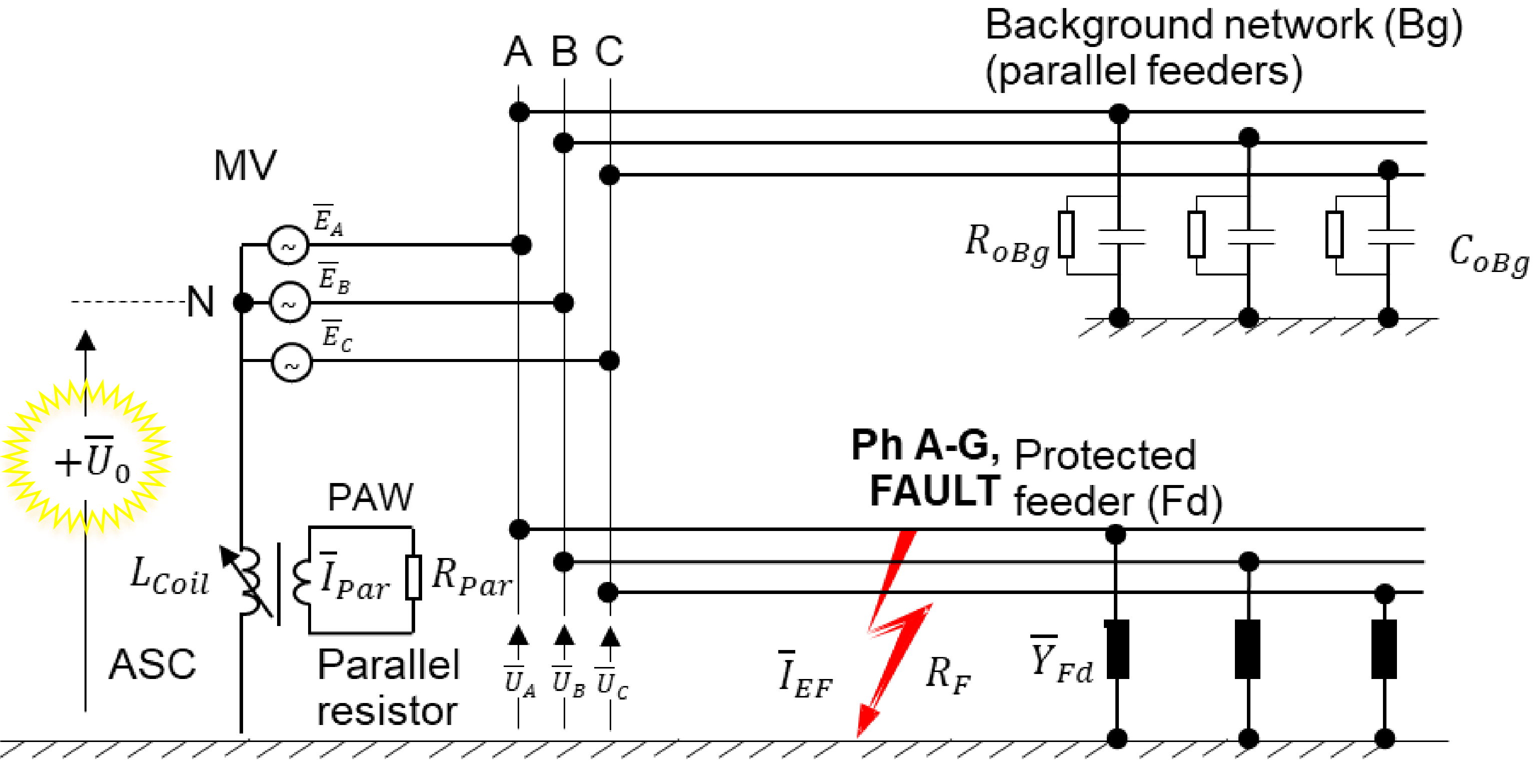
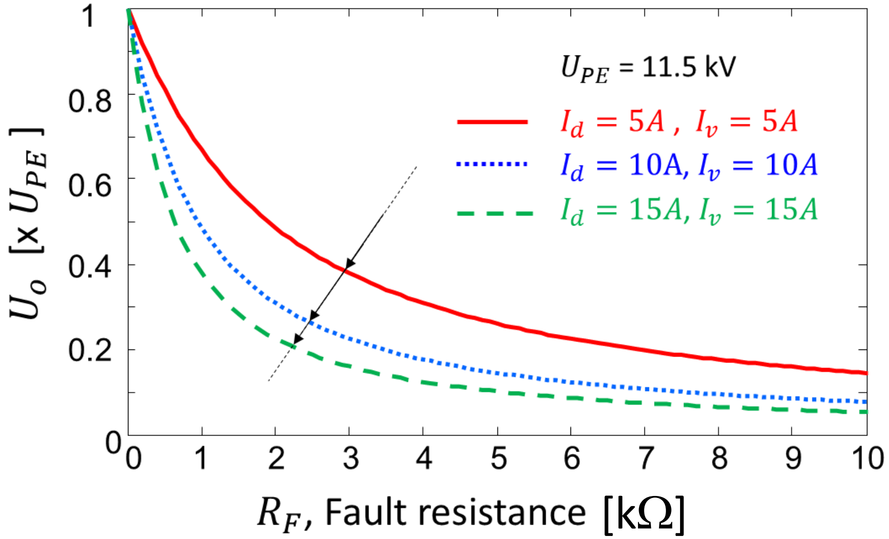


Neutral point voltage magnitude U_o [pu] as a function of fault resistance R_F [kΩ]



$$\overline{U}_o^{faulty} = -\frac{U_{PE}^2}{R_F \cdot (I_d - j \cdot I_v) + U_{PE}}$$

- U_{PE} = operating phase-to-ground voltage [V]
- R_F = fault resistance [Ω]
- I_d = network damping [A]
- I_v =network detuning value [A]

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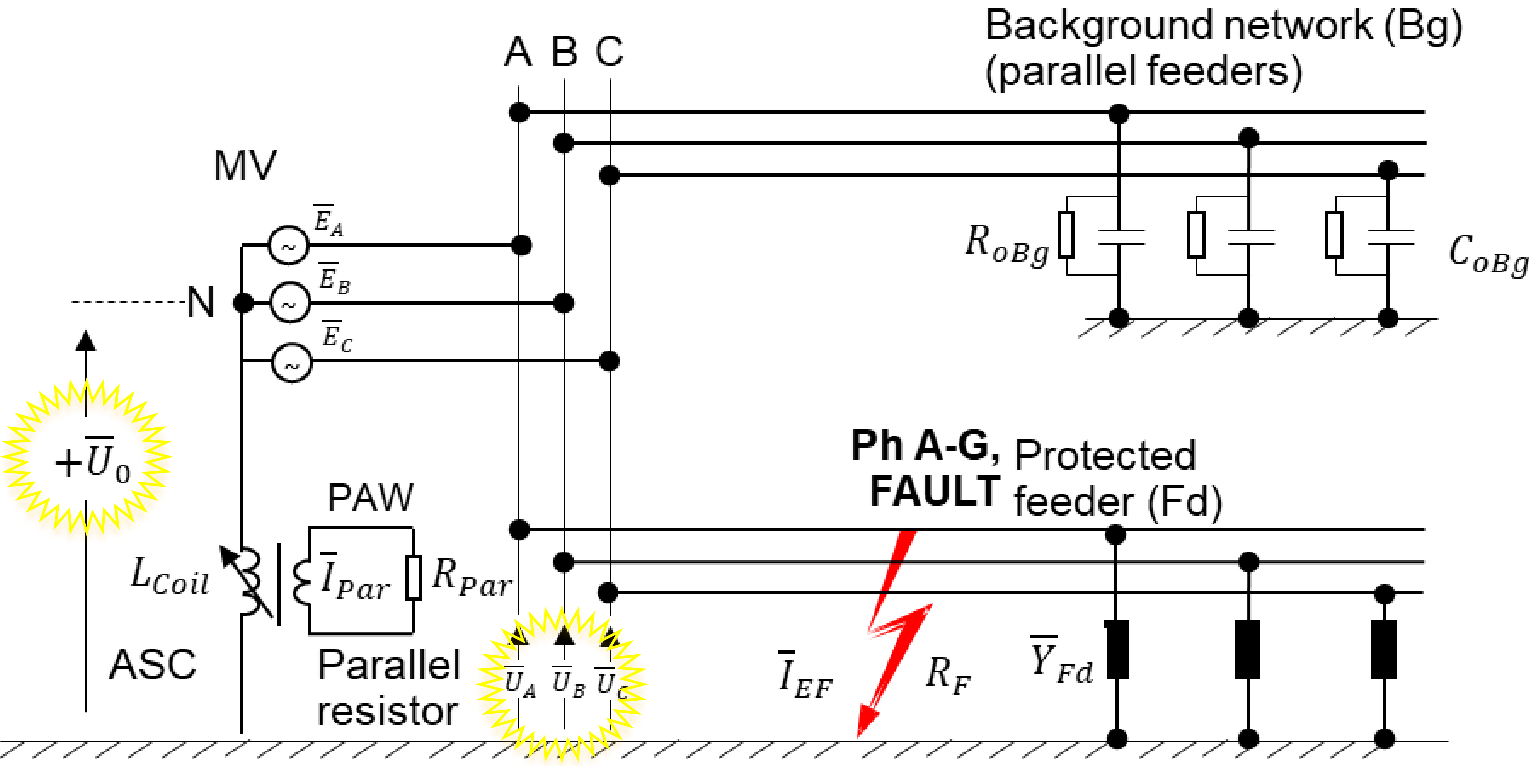
Fundamentals of compensated networks:

Phase voltages during ground fault



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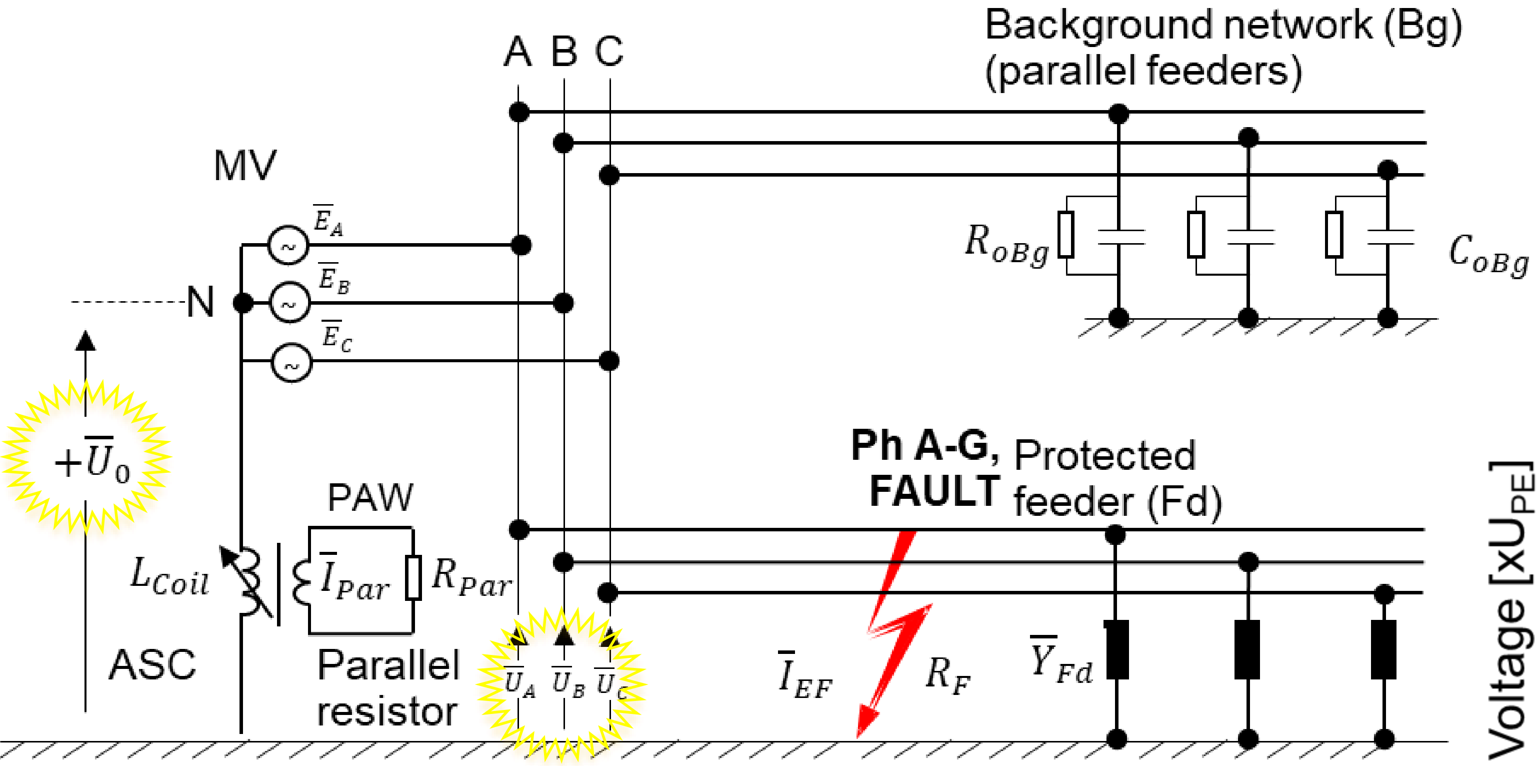
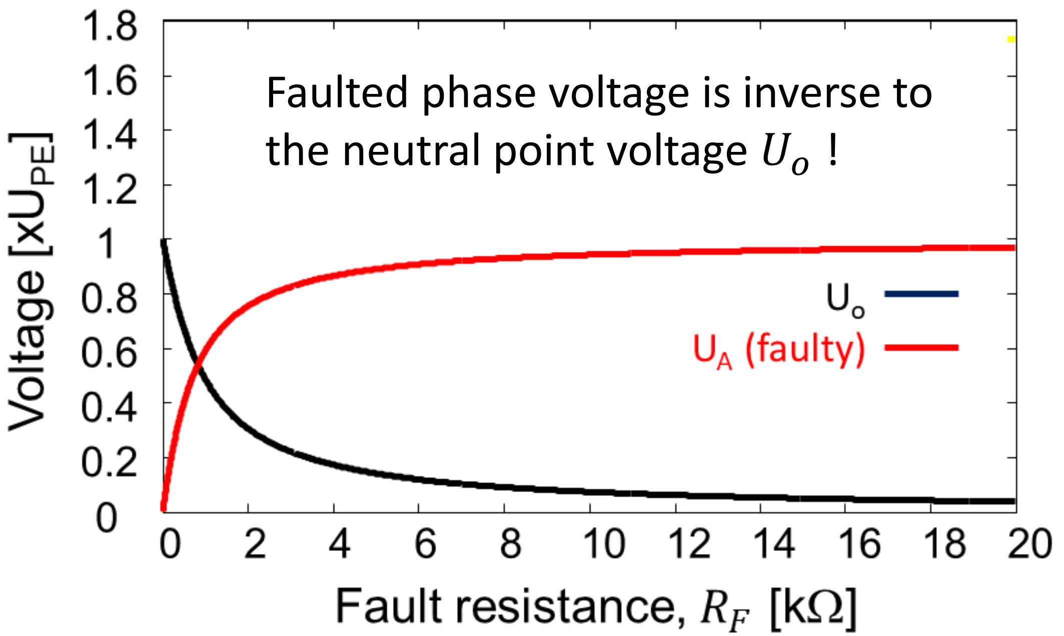
Fundamentals of compensated networks:

Phase voltages during ground fault



The phase voltages are affected by the neutral point voltage:

$$\overline{U}_A = \overline{E}_A + \overline{U}_o$$
$$\overline{U}_B = \overline{E}_B + \overline{U}_o$$
$$\overline{U}_C = \overline{E}_C + \overline{U}_o$$
$$\overline{E}_A = U_{PE},\ \overline{E}_B = \overline{a} \cdot U_{PE},\ E_C = \overline{a}^2 \cdot U_{PE}$$



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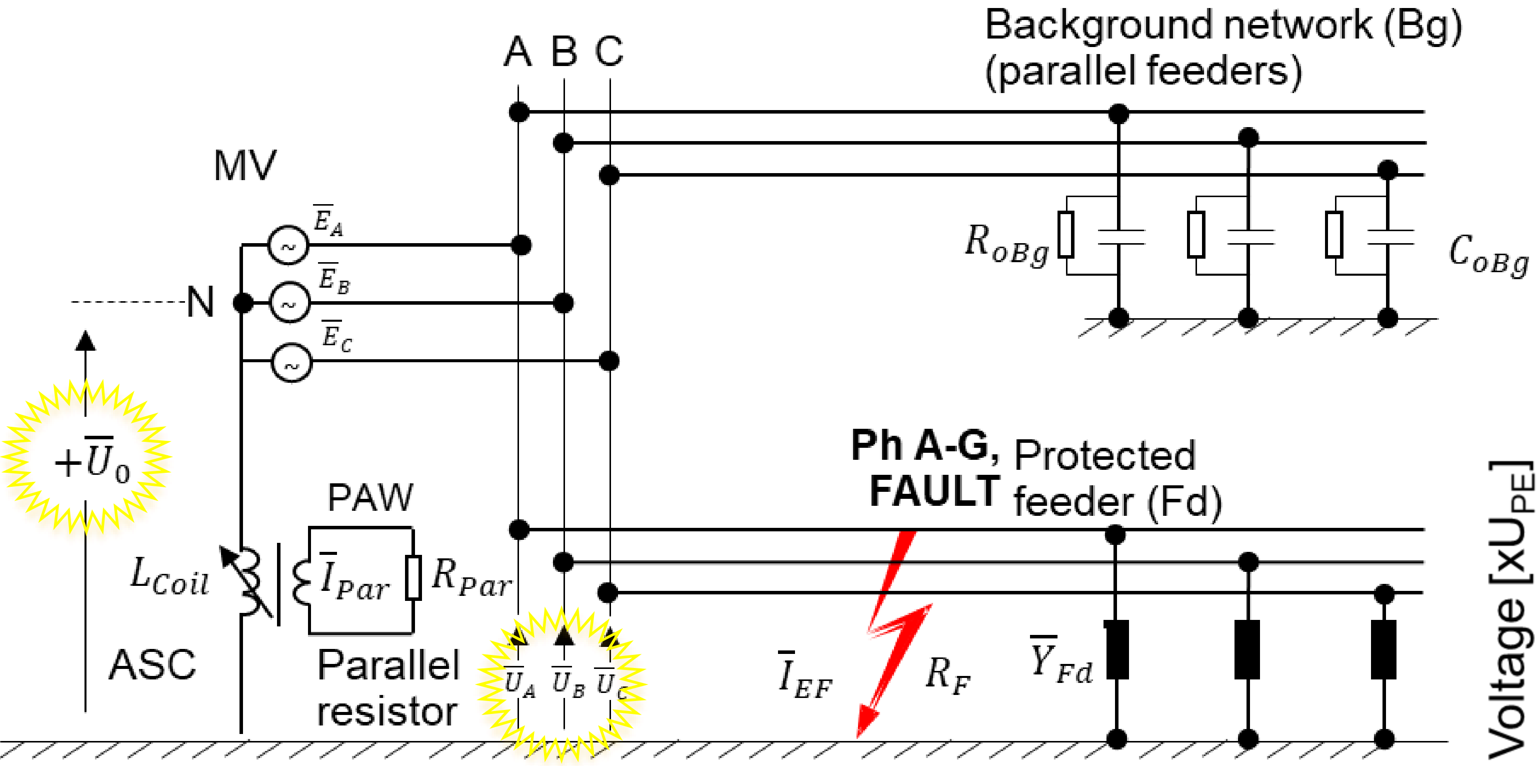
Fundamentals of compensated networks:

Phase voltages during ground fault



The phase voltages are affected by the neutral point voltage:

$$\bar{U}_A = \bar{E}_A + \bar{U}_o$$

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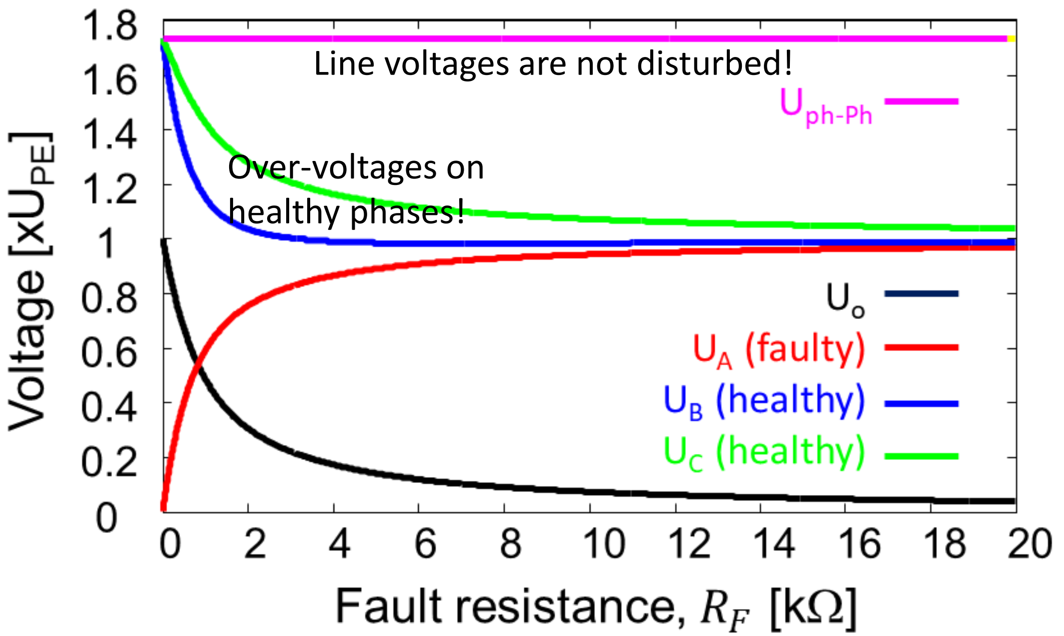
$$\bar{U}_C = \bar{E}_C + \bar{U}_o$$

$$\bar{E}_A = U_{PE},\ \bar{E}_B = \bar{a} \cdot U_{PE},\ E_C = \bar{a}^2 \cdot U_{PE}$$



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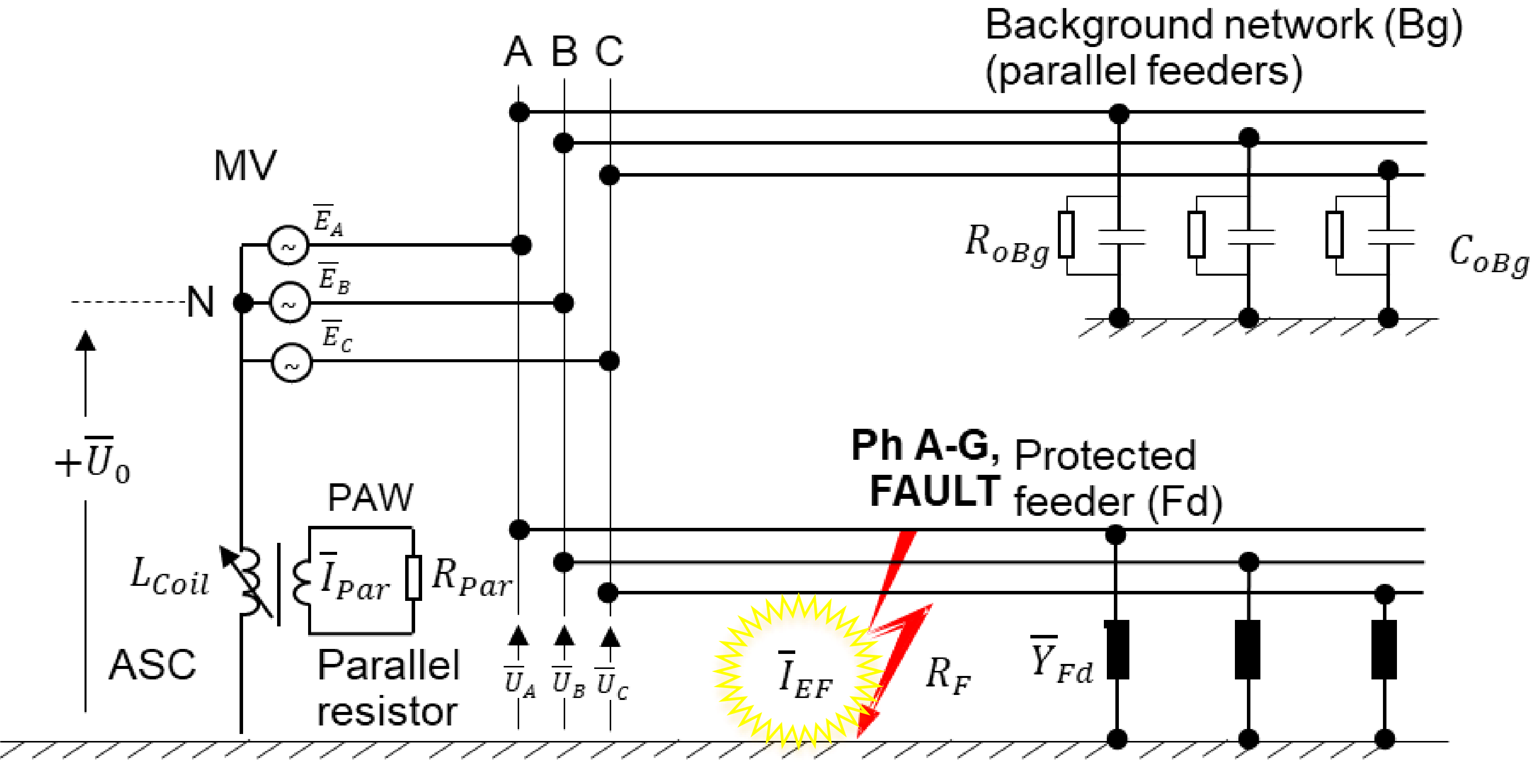
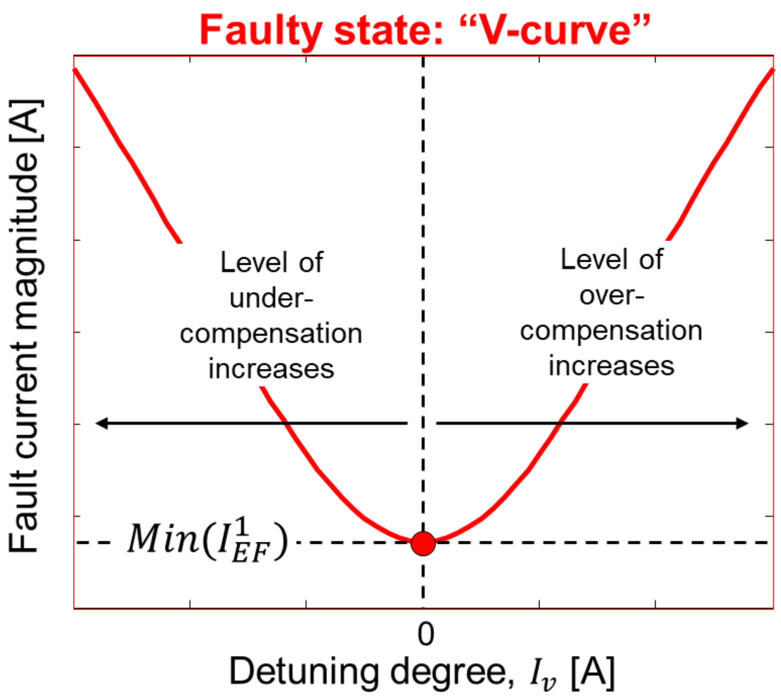
Fundamentals of compensated networks:

Ground fault current





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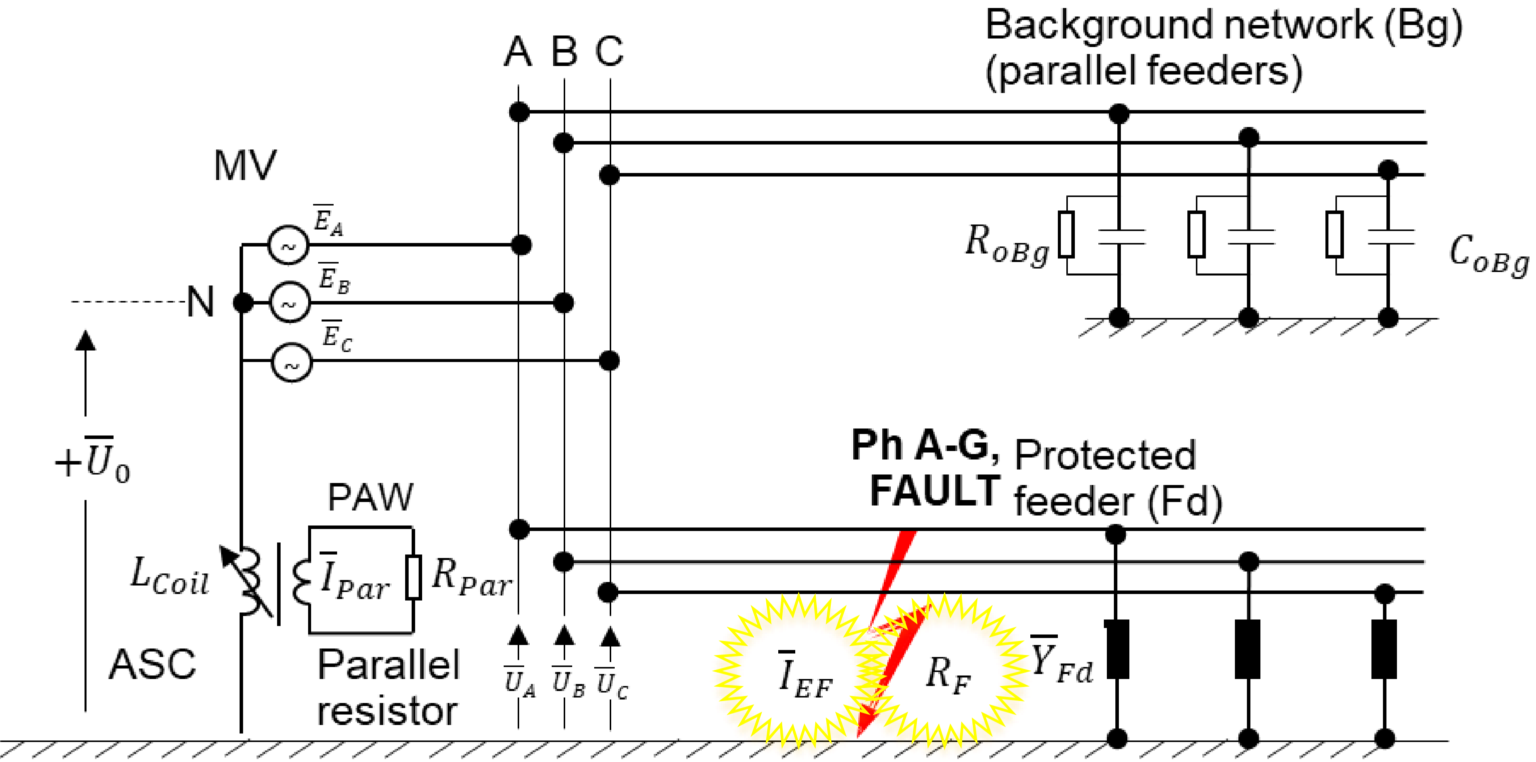
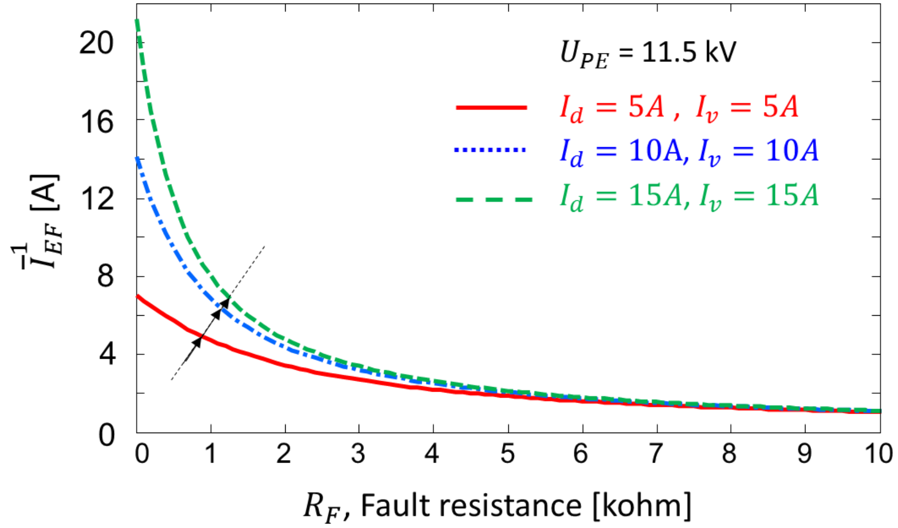
Fundamentals of compensated networks:

Ground fault current



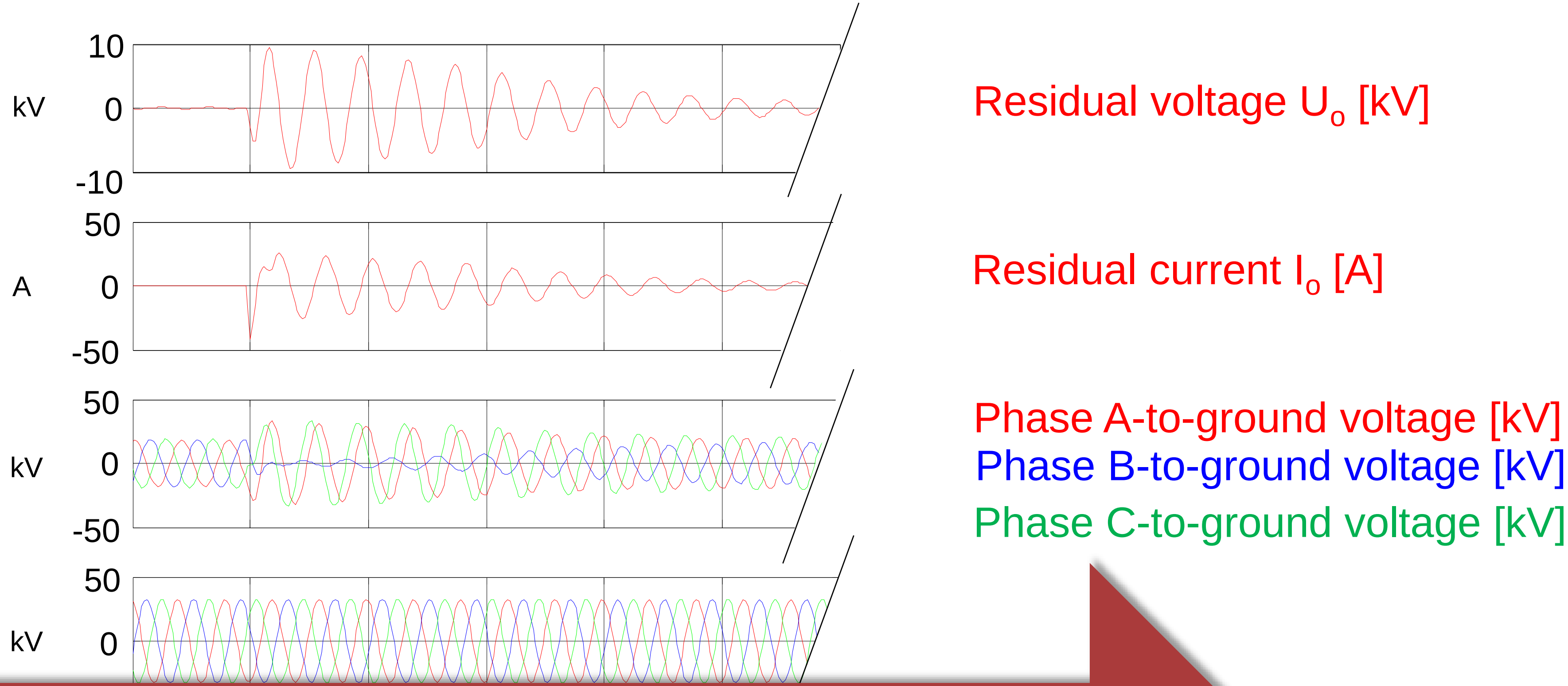
Ground fault current magnitude as a function of fault resistance R_F [kΩ].



$$\overline{I}_{EF}^{1} = \frac{(I_d - j \cdot I_v) \cdot U_{PE}}{R_F \cdot (I_d - j \cdot I_v) + U_{PE}}$$

- U_{PE} = operating phase-to-ground voltage [V]
- R_F = fault resistance [Ω]
- I_d = network damping [A]
- I_v =network detuning [A]

Considerations to convert from a solidly/low resistance grounded system to a compensated network



- Network hardening, voltage ratings, compatible equipment
- Network balancing
- Set-up of ASC, coil controller and ground-fault detection functions

Can compensated networks be an alternate solution to reduce the risk of ground faults causing forest fires?

Reduction of fire risk during a ‘wire down’ fault

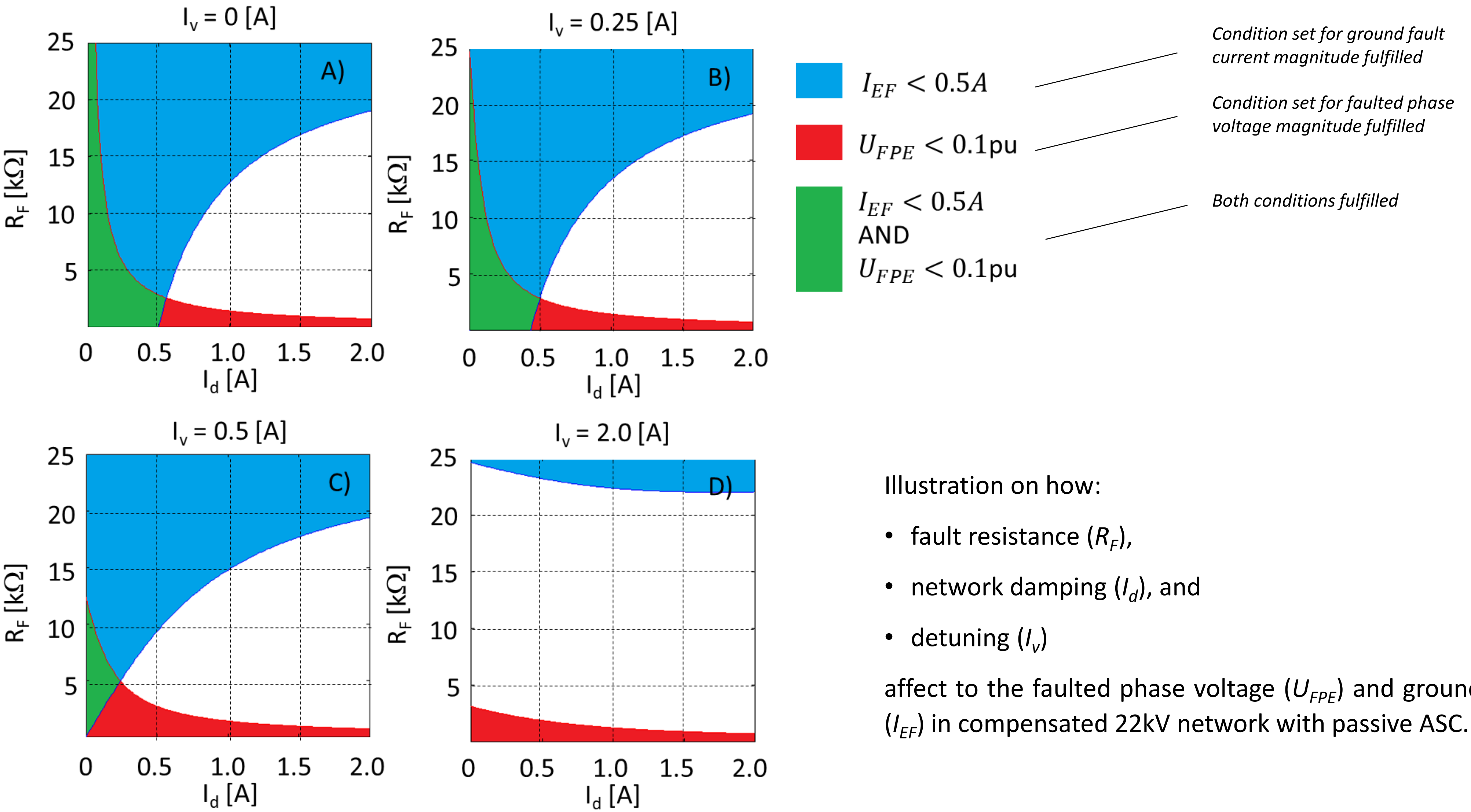


Illustration on how:

- fault resistance (R_F),
- network damping (I_d), and
- detuning (I_v)

affect to the faulted phase voltage (U_{FPE}) and ground fault current magnitude (I_{EF}) in compensated 22kV network with passive ASC.

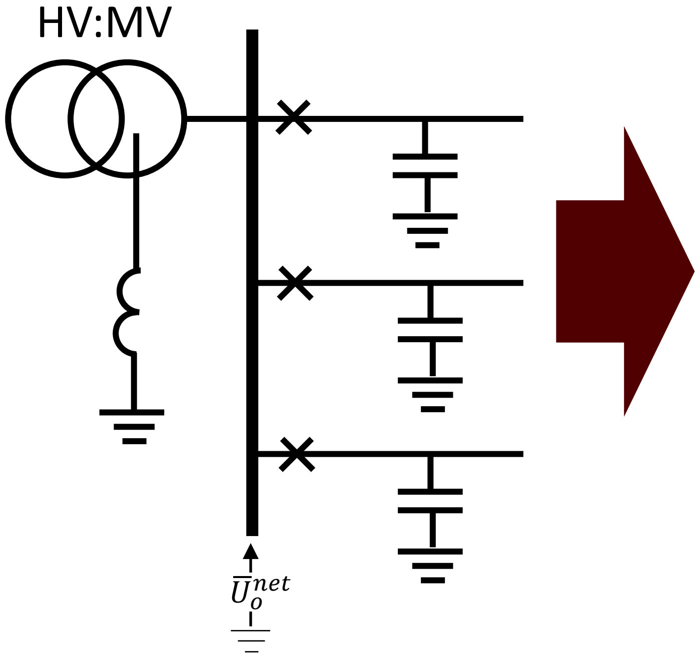
Can compensated networks be an alternate solution to reduce the risk of ground faults causing forest fires?

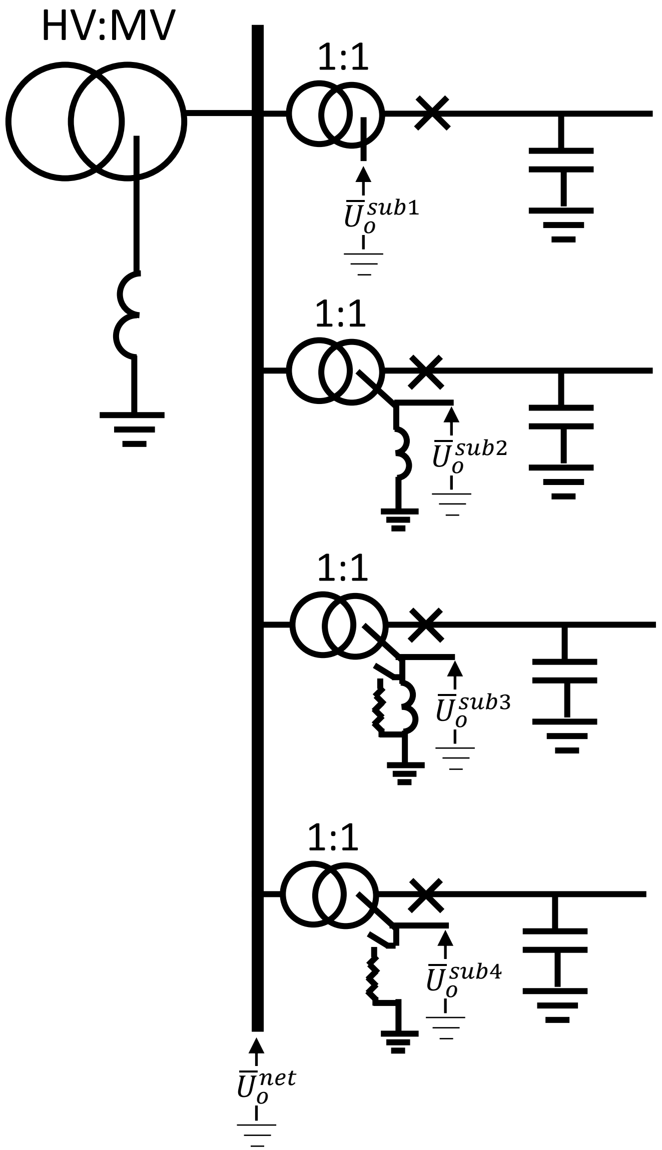
Reduction of fire risk during a ‘wire down’ fault

- In order to construct a compensated network with passive ASC with extremely low damping and detuning value, large network can be splitted into smaller networks

- Challenges of such small compensated network with very small value of damping and detuning include:

  - Inherent sensitivity to admittance unbalance
  - Risk of over-voltages during open-phase conditions
  - Long time constant of DC-component of fault current, oscillations, and transients during faults and after their disconnection
  - Ferroresonance





“Large network can be splitted into smaller networks” by applying isolation transformers

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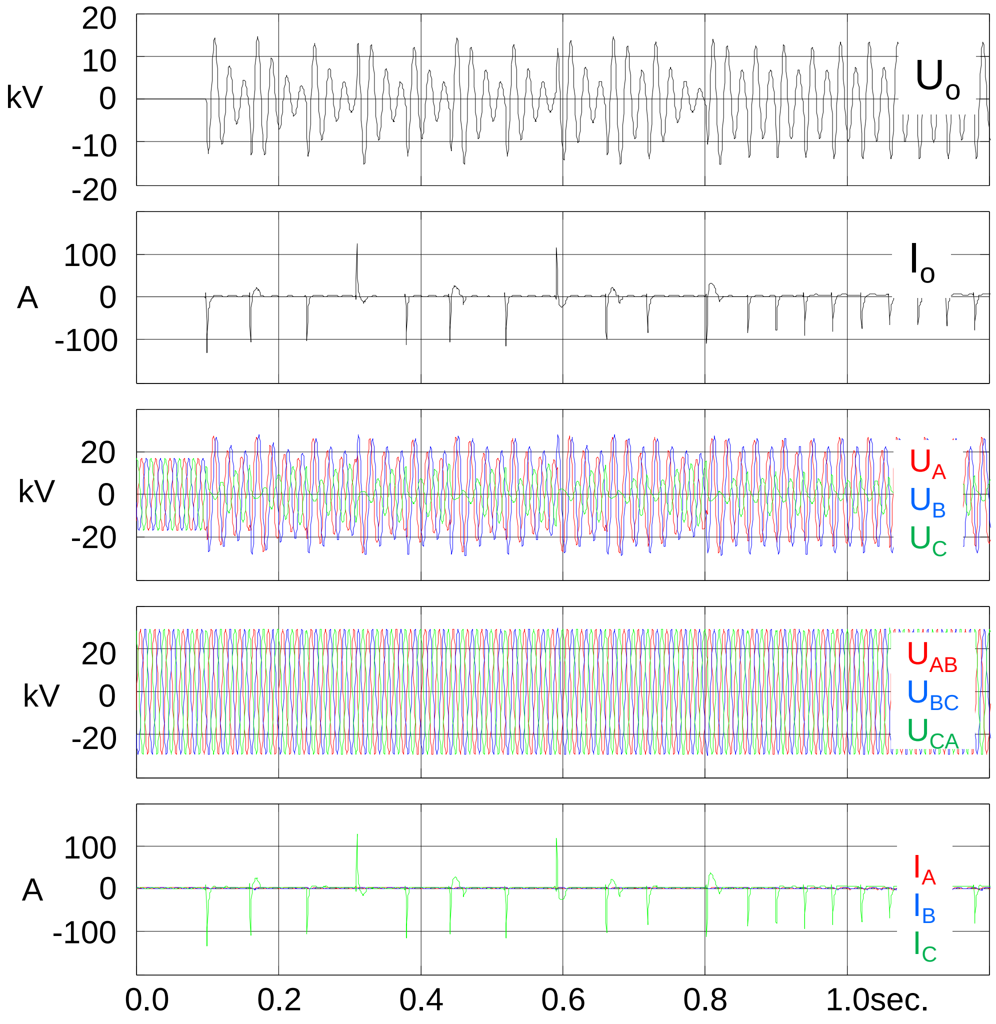
Special protection challenges: re-striking or intermittent ground fault



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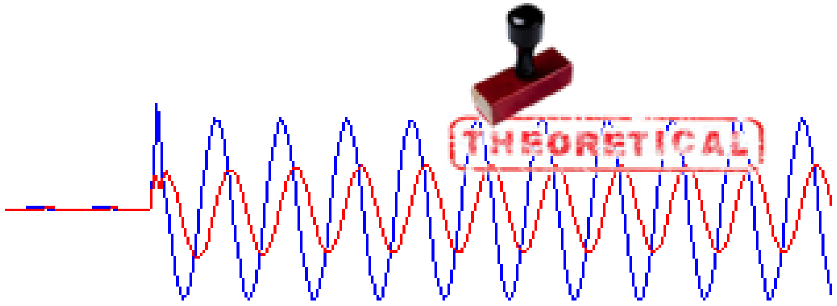
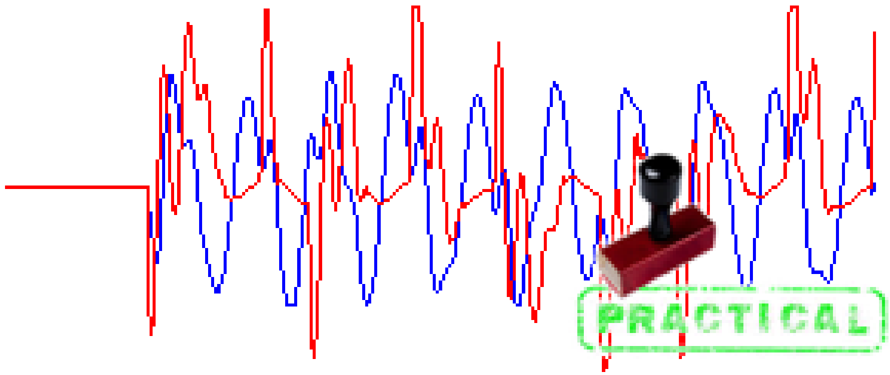
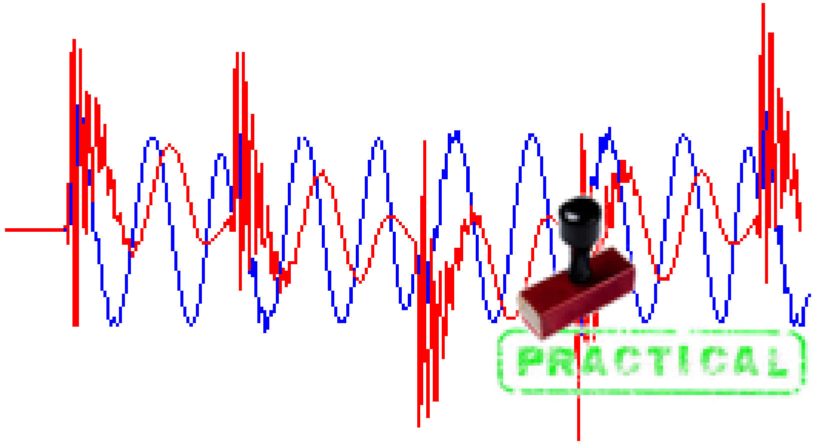
Novel Multi-Frequency Admittance based ground fault protection, MFA







Facts

- Single function valid for all ground fault types
- Several novel features:
  - Multi-frequency admittance (MFA) measurement, Cumulative Phasor Summing (CPS) calculation, etc.
- Thoroughly tested in practical live networks!

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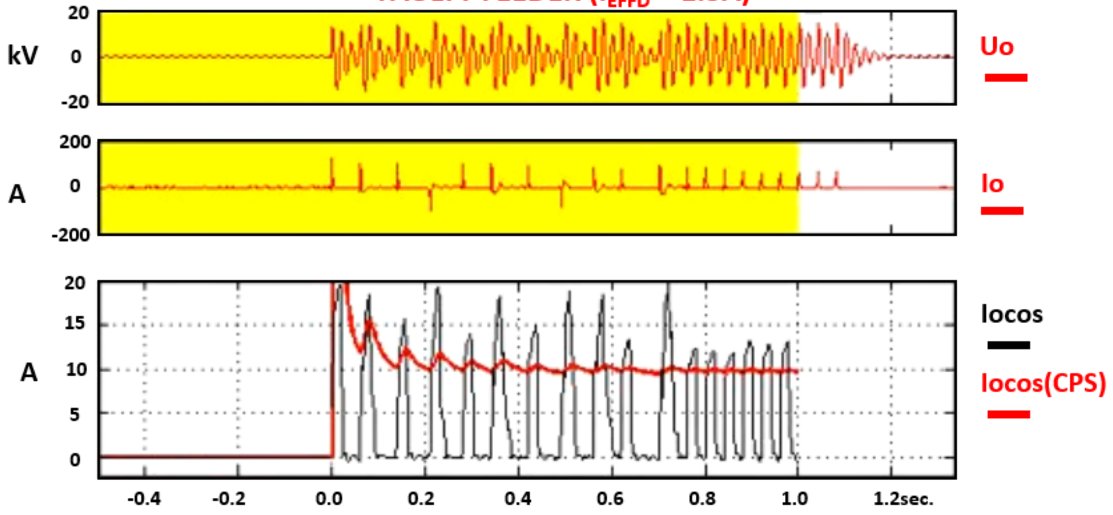
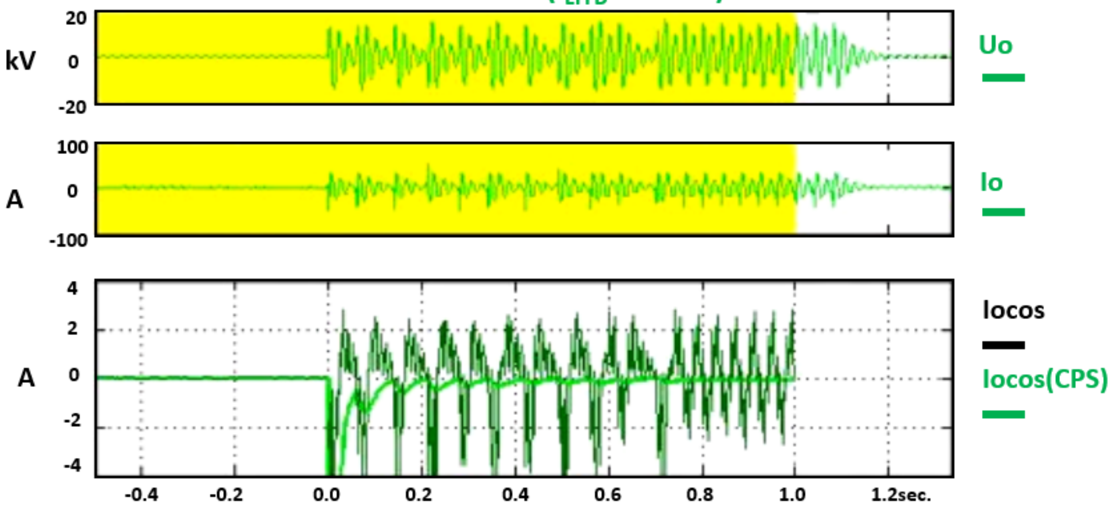
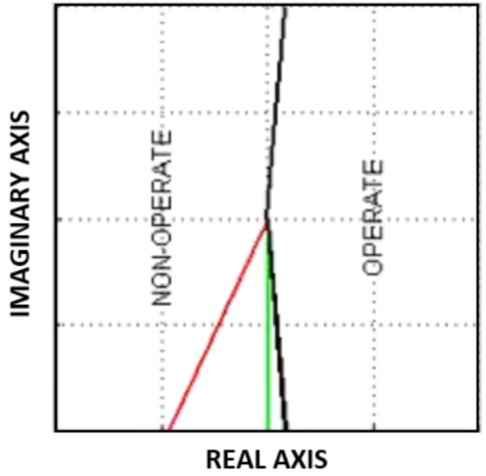
TEST: R_F=0 OHM, RE-STRIKING FAULT, COIL DETUNING: -2A, DAMPING: 11A, FAULT DUR.: 1.5 SEC., PROTECTION OPERATE TIME: 1.0 SEC.

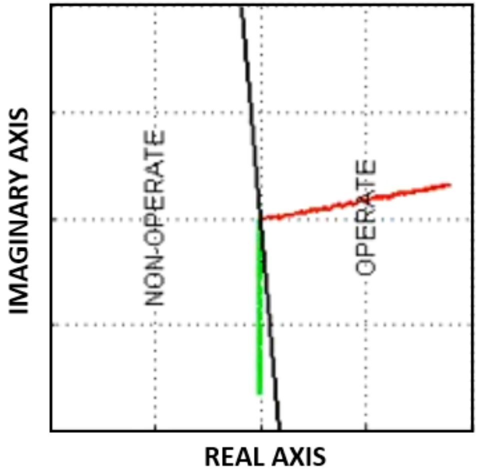




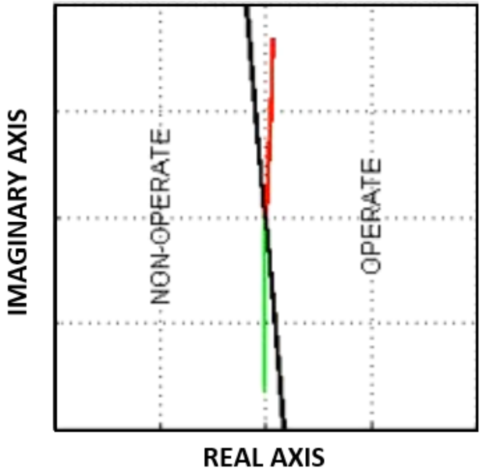
TRADITIONAL METHOD
DISCRETE DFT (50Hz)



NOVEL METHOD
CUMULATIVE CPS (50Hz)



NOVEL METHOD
CUMULATIVE CPS (MULTIFREQ.)



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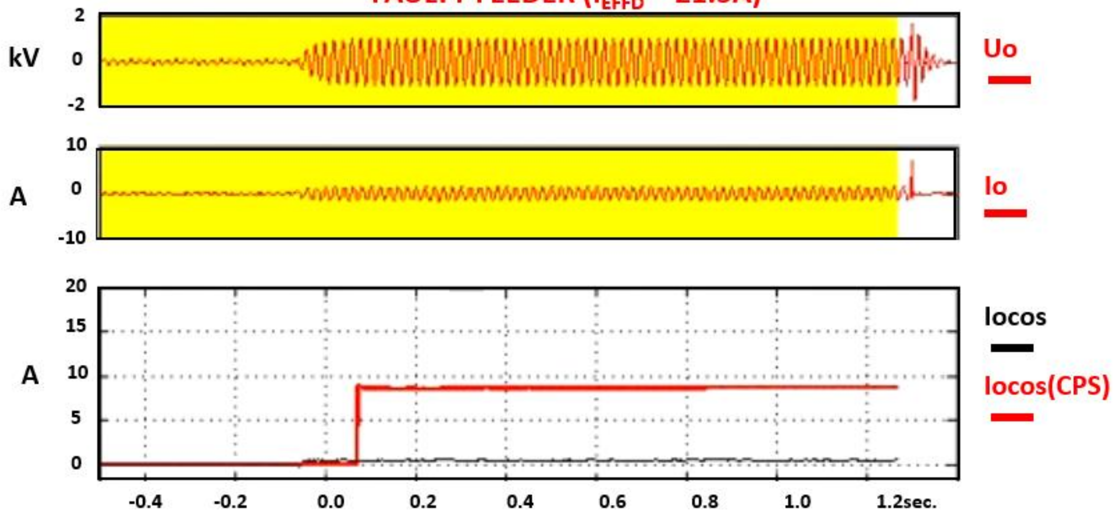
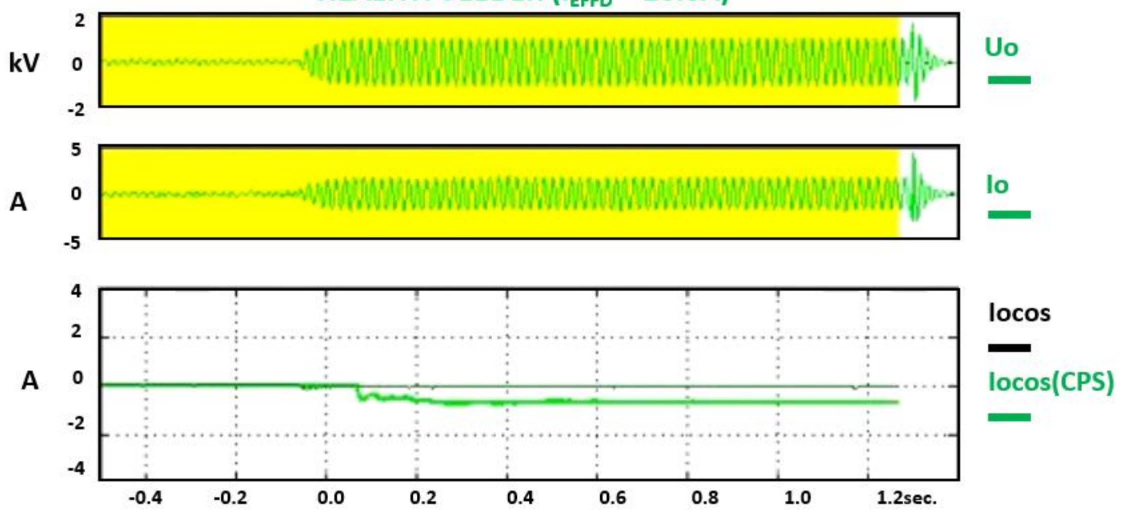
TEST: R_F=20000 OHM, CONTINUOUS FAULT, COIL DETUNING: -2A, DAMPING: 11A, FAULT DUR.: 1.5 SEC., PROTECTION OPERATE TIME: 1.0 SEC.

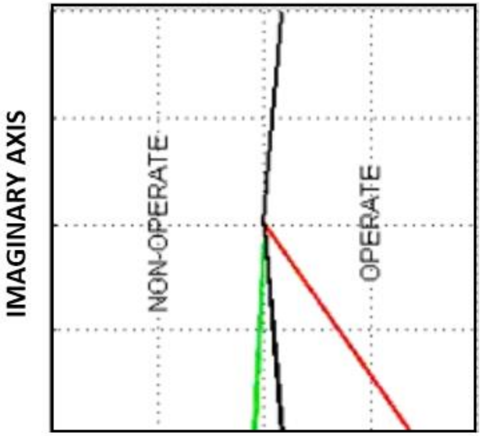
FAULTY FEEDER (I_{EFFD} = 21.5A)



HEALTHY FEEDER (I_{EFFD} = 20.0A)

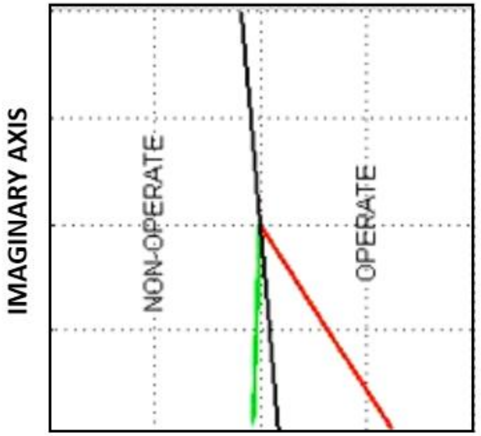


TRADITIONAL METHOD
DISCRETE DFT (50Hz)



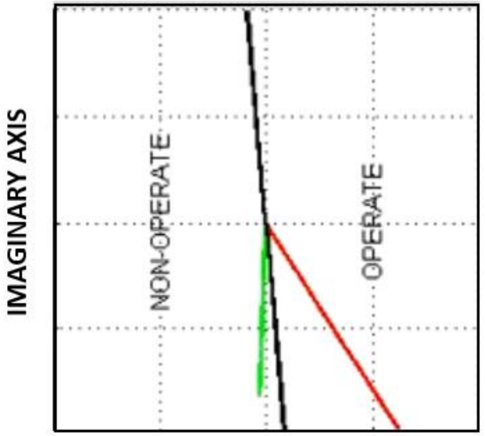
REAL AXIS

NOVEL METHOD
CUMULATIVE CPS (50Hz)



REAL AXIS

NOVEL METHOD
CUMULATIVE CPS (MULTIFREQ.)



REAL AXIS

Conclusion

- Compensated networks could be a solution to the challenges faced today by North American utilities to detect high impedance faults in electrical grids.
- Compensated networks offer the greatly lower energy levels in case of a ground fault compared with solidly grounded networks, and therefore the likelihood of initiating a fire is reduced dramatically.
- The network design of solidly grounded network may not be applicable or need modifications to comply with resonant earthing - change from high fault currents to high over-voltages
- Ground fault in compensated networks is very different fault type than short-circuit - dedicated protection functionality is needed for example against restriking ground faults
- With modern protection algorithms such as the **multi-frequency admittance based protection** provide a reliable and selective protection scheme!

Thank You!

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