EASY-RES

Summer School
"Enabling DRES to offer ancillary services"
20th – 24th September 2021

The protection challenges in distribution grids under high DRES penetration

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Contents

- Motivation
- Protection of conventional distribution networks
- Missoperation of the protection system due to RES
- DRES hosting capacity to avoid missoperation of the protection system
- Short-circuit current provision as an ancillary service
- Conclusions and future research

Motivation

- Conventional power system:
    - Large power plants connected to transmission systems
    - Generation based on synchronous machines
    - Short-circuit faults may happen:
        - High short-circuit currents:
            - Provided by rotating electrical machines
            - Thermal and mechanical effects on the power system
    - A protection system is required:
        - Trip the short-circuit fault: breaking capacity of the protection devices
        - Isolate the faulted part of the system as fast as possible: coordination

Motivation

- Future power system:
  - Decarbonization of the generation
  - Replacement of synchronous generation by RES
  - RES are mostly based on power electronic converters
- Power electronic converters:
  - Expensive component
  - Use to work with controlled currents below 1 p.u.
  - Performance with short-circuit faults depending on the grid code:
    - RES early days: disconnection to prevent malfunctions
    - Nowadays: Fault Ride Through (FRT) capability
    - They cannot provide short-circuit currents

Motivation

- Should be possible a fully decarbonized power system based on converter-interfaced DRES without affecting the protection system?
- Is it expected any problem of the protection system due to the DRES?
- May the protection system represent a technical barrier reducing the DRES hosting capability?
- Should be possible to overload the DRES to provide short-circuit fault currents?
- Should be possible to consider this as an ancillary service?

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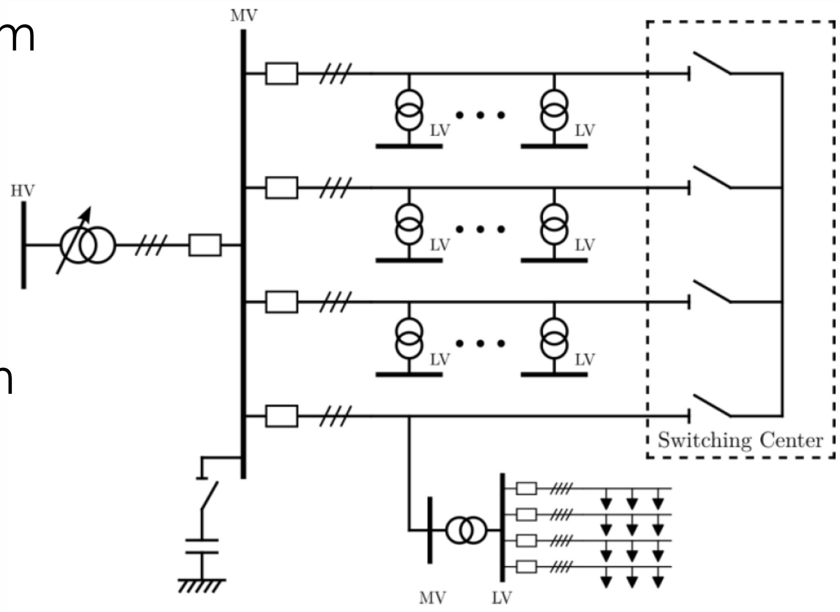
- **Protection of conventional distribution networks**
- Missoperation of the protection system due to RES
- DRES hosting capacity to avoid missoperation of the protection system
- Short-circuit current provision as an ancillary service
- Conclusions and future research

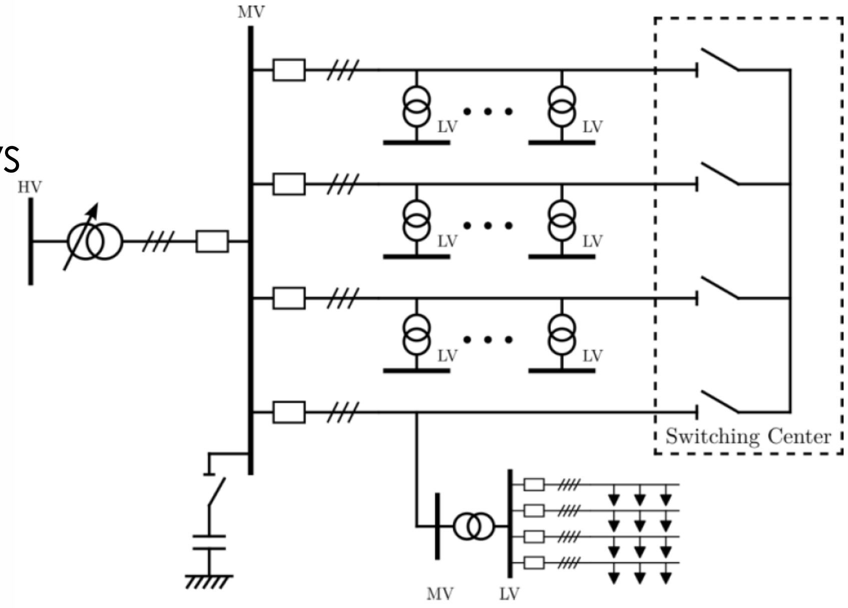
Protection of conventional distribution networks

- Conventional distribution networks:
  - MV radial feeders departing from a primary HV/MV substation
  - Switching centers in urban networks
  - Secondary MV/LV substations along the feeder
  - LV radial feeders departing from secondary MV/LV substations



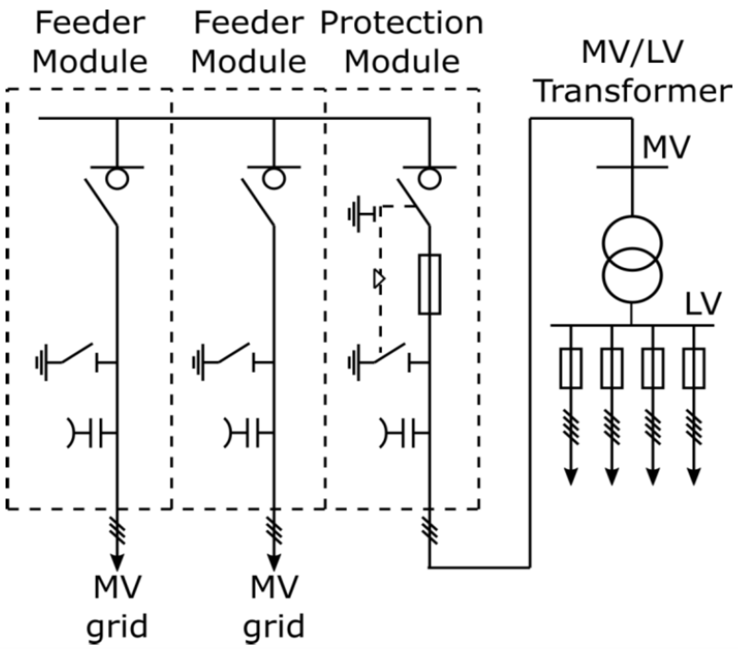
Protection of conventional distribution networks

- Conventional distribution networks:
  - Passive network:
    - Normal state:
      - Unidirectional power flows
      - Voltage drop along the feeders
    - Faulted state:
      - Short-circuit current from the HV upstream grid
      - Simple protection philosophy: overcurrent devices



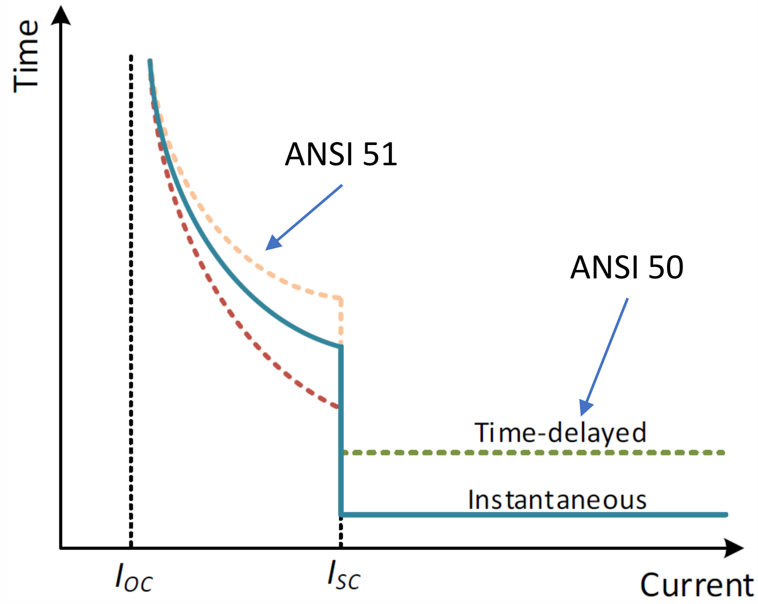
Protection of conventional distribution networks

- Overcurrent devices:
  - MV network:
    - Primary MV/LV substation:
      - Circuit breakers
      - Overcurrent relays
    - Secondary MV/LV substations
      - Utility: MV fuses
      - Private owners:
        - Circuit breakers
        - Overcurrent relays



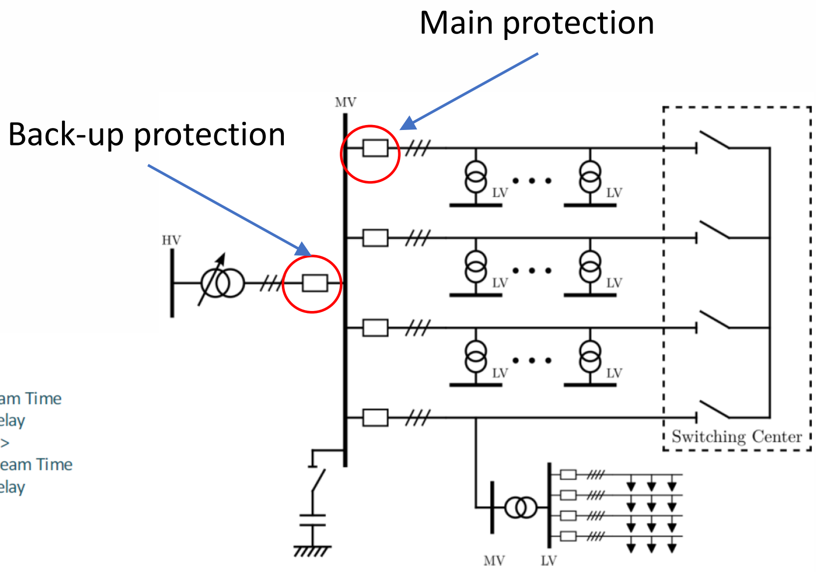
Protection of conventional distribution networks

- Overcurrent relays:
  - Overload (I>, ANSI 51):
    - Inverse time relay
  - 2- 3-phase faults (I>>, ANSI 50)
    - Instantaneous trip
    - Time-delayed trip (selectivity)
  - 1-phase faults (I_N>>, ANSI 50N)
    - Earthed neutral networks

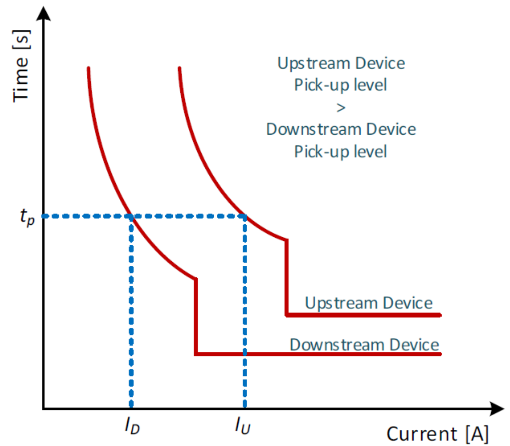


Protection of conventional distribution networks

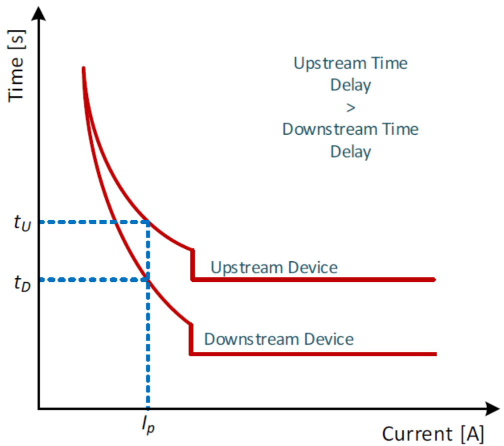
- Selectivity of protection devices:
  - Main protection feeder
  - Backup protection



Pickup current settings

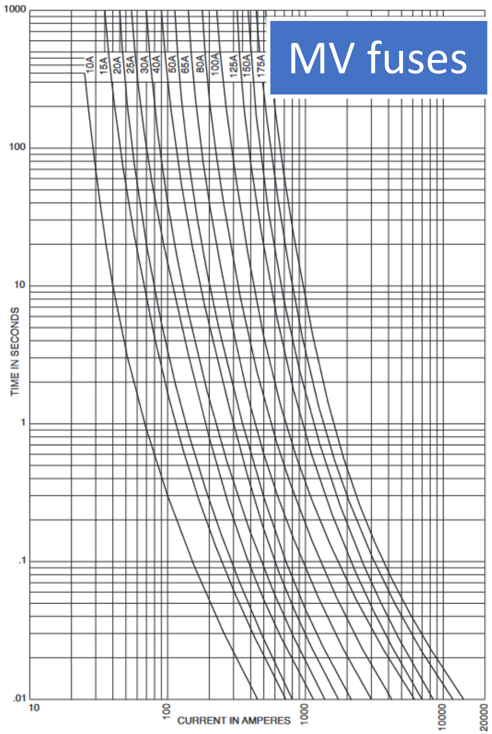


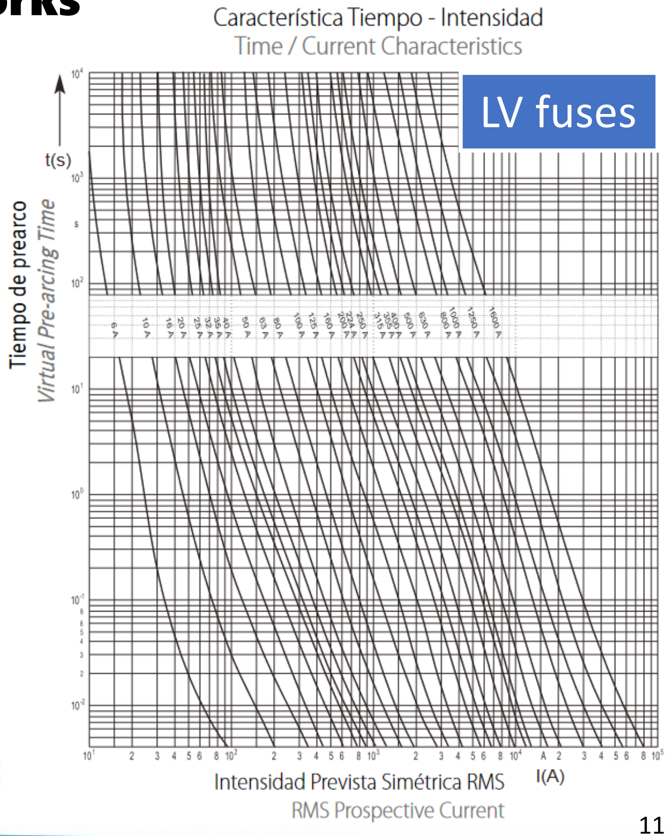
Delay settings



Protection of conventional distribution networks

- MV and LV fuses:
    - Inverse time delay





Protection of conventional distribution networks

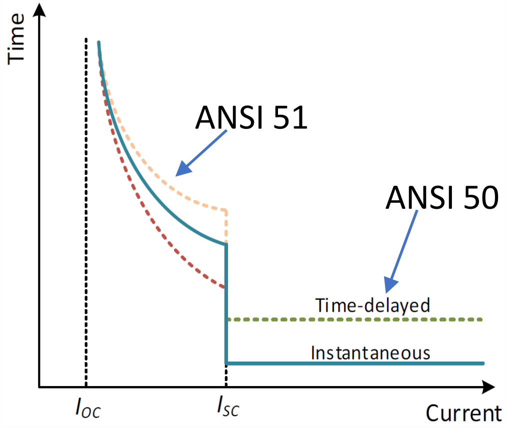
- Design criteria of overcurrent relays for MV networks:
  - Main protection feeder:
    - Overload protection (I> ANSI 5):
      - Pickup current:

$$I_{OC} = I_{th}$$

    - Short-circuit fault (I>>, ANSI 50):
      - Pickup current:

$$I_{SC} = \max[1.5I_{th}, \min(0.9I_{sc-min}, 3.0I_{th})]$$

      - Time setting: instantaneous trip



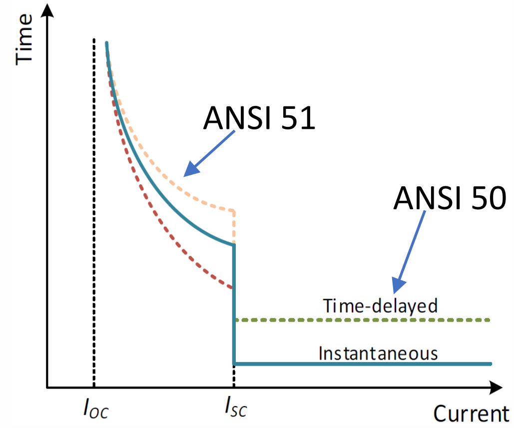
I_{th}: feeder ampacity limit

I_{sc-min}: minimum sc current

Protection of conventional distribution networks

- Design criteria of overcurrent relays for MV networks:
  - Backup protection:
    - Overload protection (I> ANSI 5):
      - Pickup current:

$$I_{OC} = I_{th-tr}$$



- Short-circuit fault (I>>, ANSI 50):
  - Pickup current:

$$I_{SC} = \max[1.5 I_{th-tr}, \min(0.9 I_{sc-min-all}, 3.0 I_{th-tr})]$$

  - Time setting: 300 ms delay

$I_{th-\mathrm{tr}}$: transf. rated current

$I_{\mathrm{sc-min-all}}$: minimum sc current

Protection of conventional distribution networks

- Design criteria for LV networks:
  - Overload criterion:

$$I_b \leq I_n \leq I_z$$

$$I_f \leq 1.45 I_z$$

$$I_f \leq 1.6 I_n \text{ (gG fuses)}$$

$$\Rightarrow I_n \leq 0.9062 I_z$$

I_b: feeder desing current
I_n: fuse nominal current
I_z: feeder ampacity limit
I_f: conventional fusing current

  - Maximum short-circuit current criterion: always verified

Protection of conventional distribution networks

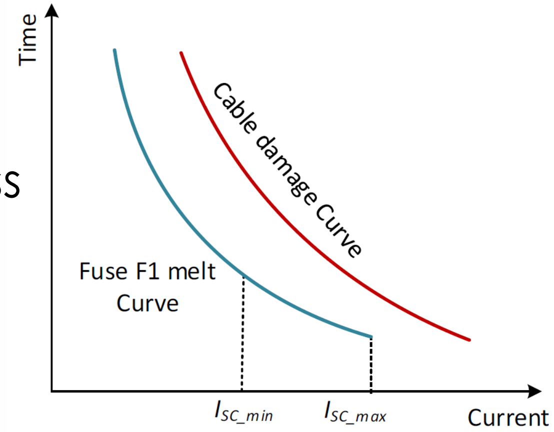
- Design criteria for LV networks:
    - Energy flowing through the fuse:

$$I_{cc}^2 t)_f \leq I_{cc}^2 t)_c$$

- Cable dame curve:
    - Short-circuit fault: adiabatic process

$$I_{cc}^2 t)_c = (KS)^2$$

$$t_c = \frac{(KS)^2}{I_{cc}^2}$$

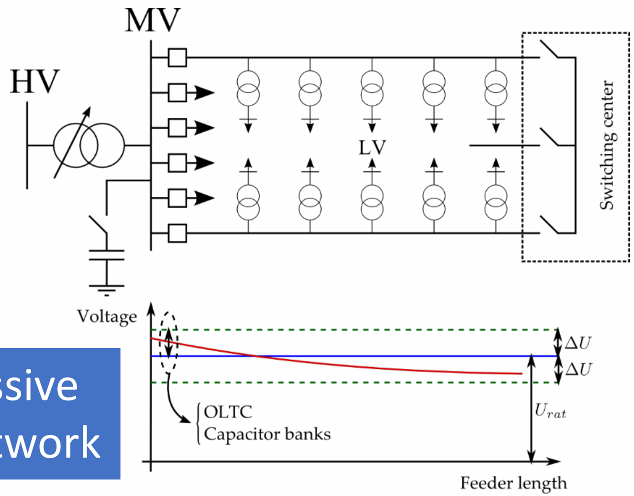


K: constant (conductor & insulation)
S: cross section of the feeder

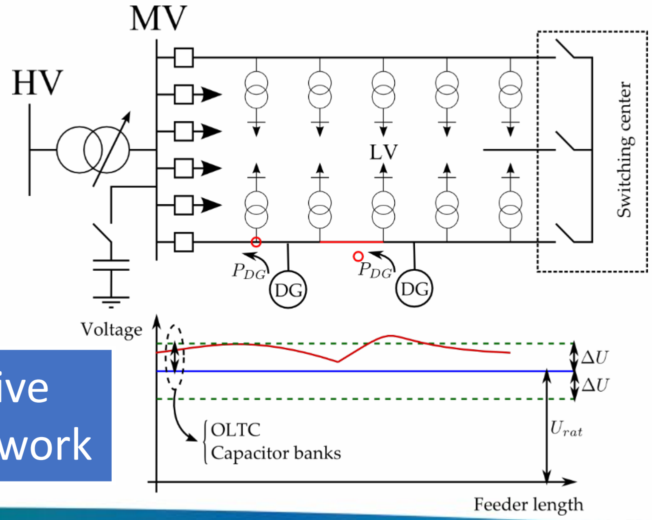
Contents

Missoperation of the protection system due to RES

- Active distribution networks:
  - Normal operation:
    - Bidirectional power flows (two-way feeders)
    - Voltage profiles cannot be controlled easily



Passive network



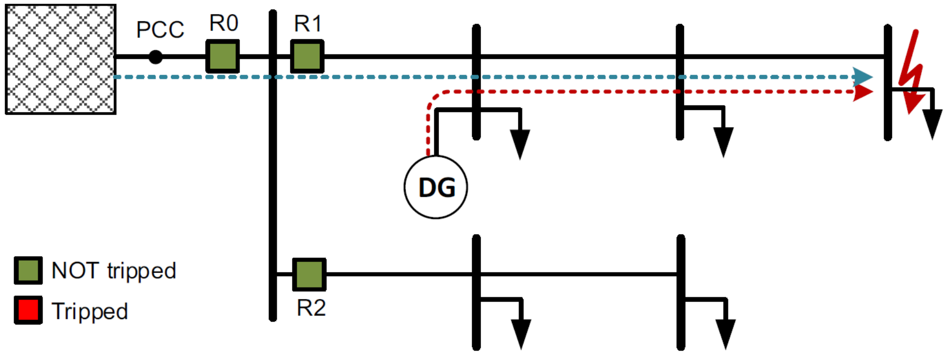
Active network

Missoperation of the protection system due to RES

- Active distribution networks:
  - Faulted operation:
    - FRT capability:
      - DRES remain connected
      - DRES inject a controlled current according to grid codes
    - Short-circuit currents modified with respect to the passive case
    - Possible failures of the protection system:
      - Protection blinding
      - Sympathetic tripping
      - Increase of short-circuit currents

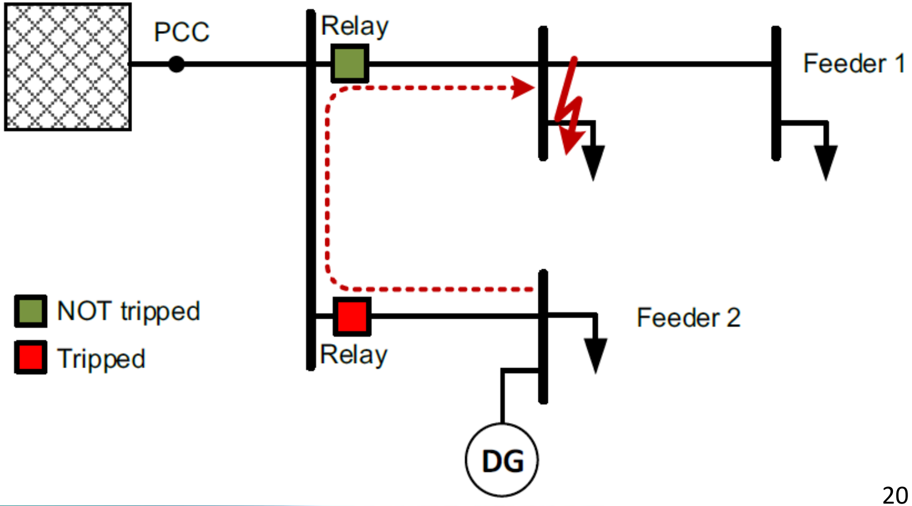
Missoperation of the protection system due to RES

- Protection blinding:
  - DRES inject additional short-circuit currents
  - Reduced short-circuit current contribution of the upstream grid
  - May occur in the faulty feeders
  - Two degrees of blinding:
    - Partial blinding:
      - ANSI 50 does not trip
      - ANSI 51 trips
    - Total blinding:
      - ANSI 50 does not trip
      - ANSI 51 does not trip



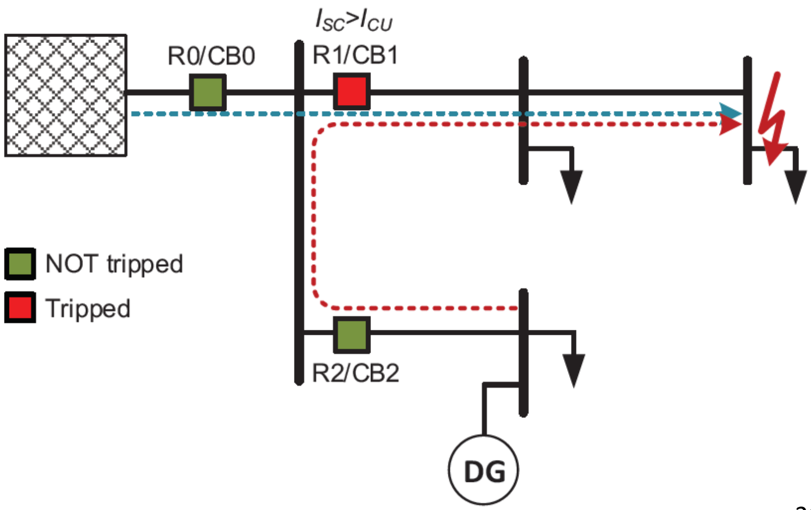
Missoperation of the protection system due to RES

- Sympathetic tripping:
  - DRES inject additional short-circuit currents
  - Overcurrent protections in distribution systems
  - May occur in the healthy feeders



Missoperation of the protection system due to RES

- Short-circuit current increase:
  - DRES inject additional short-circuit current
  - Short-circuit current above the breaking capacity
  - May occur in the faulty feeders

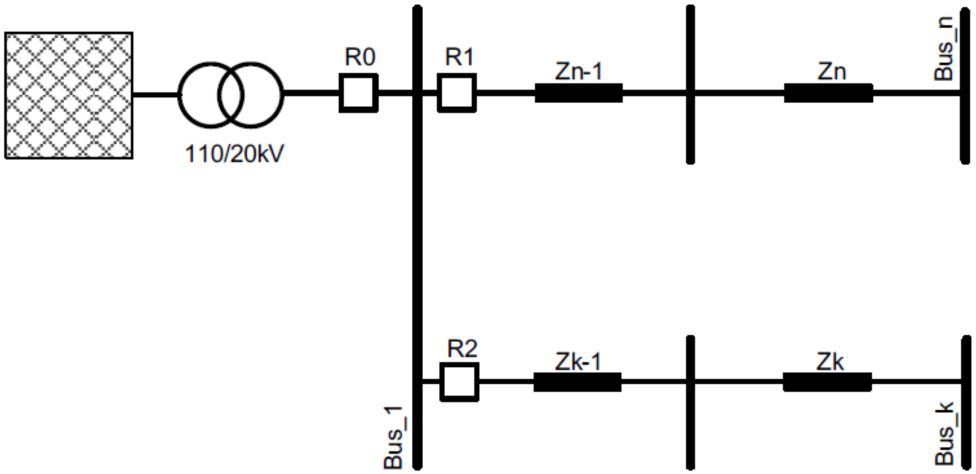


Missoperation of the protection system due to RES

- Many parameters may affect the protection system missoperation:
  - Short-circuit power of the upstream grid
  - DRES type:
    - Synchronous generation
    - Converter interfaced
  - Fault location
  - DRES location
  - Concentrated versus distributed DRES

Missoperation of the protection system due to RES

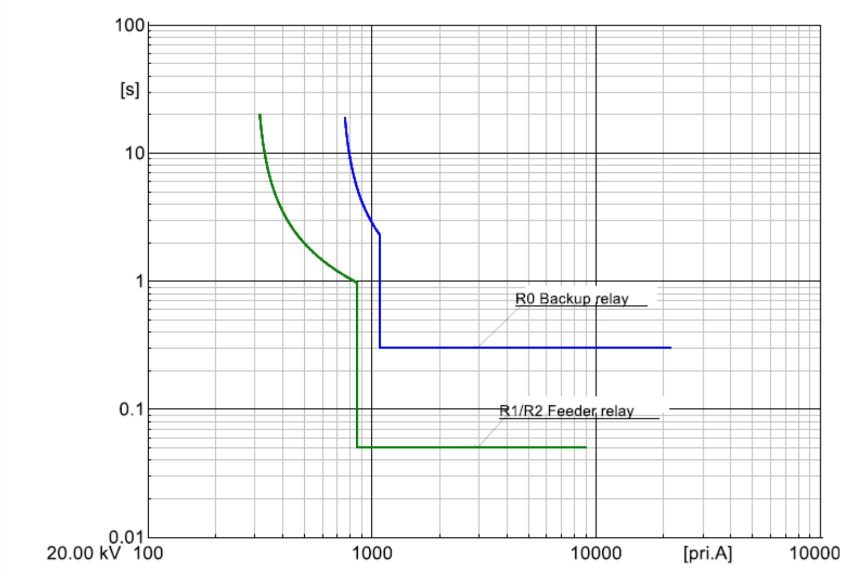
- Example:
  - Short-circuit analysis: IEC 60909

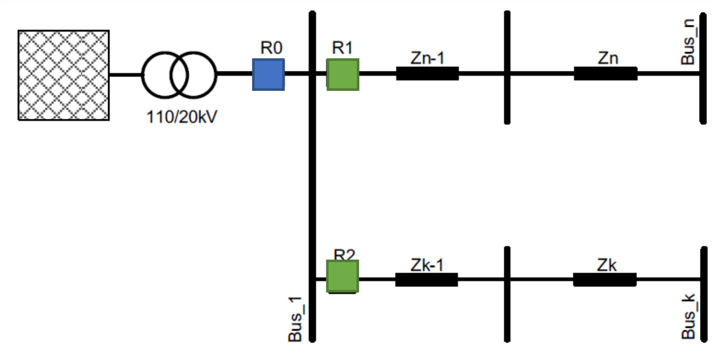


PARAMETER	VALUE
Upstream grid short circuit capacity (MVA)	100 … 500
Upstream grid R/X ratio	0.1
Transformer ratio (kV)	110/20
Transformer power (MVA)	25
Transformer short-circuit voltage u_k	12%
Transformer cooper losses (kW)	25
DRES rated power (MVA)	1 … 10
Synch. Gen sub-transient reactance (pu)	0.2
Converter short-circuit contribution (pu)	1.2
Cable type	NA2XS2Y
Cable cross-section (mm^2)	120
Cable positive seq. resistance (Ω/km)	0.501
Cable positive seq. reactance (Ω/km)	0.716
Cable Length d1 (km)	1… 10
Cable Length d2 (km)	1… 10

Missoperation of the protection system due to RES

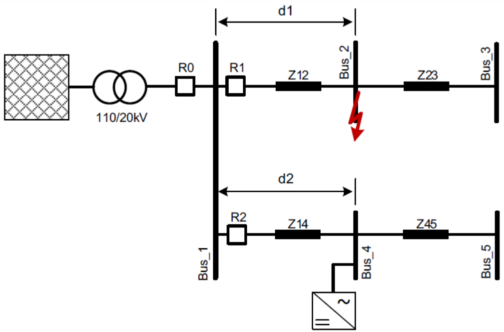
- Example:
  - Definition of protections (passive case)

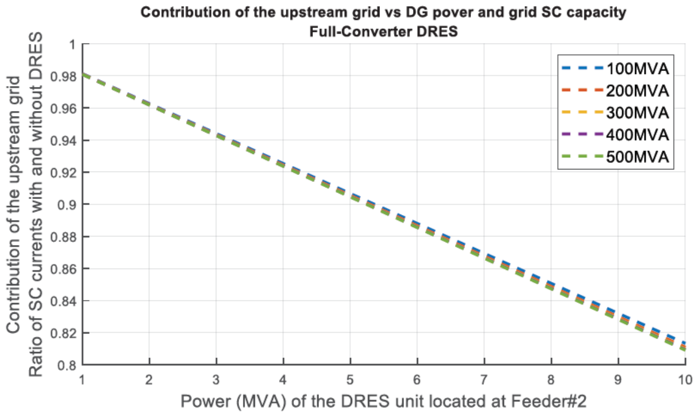


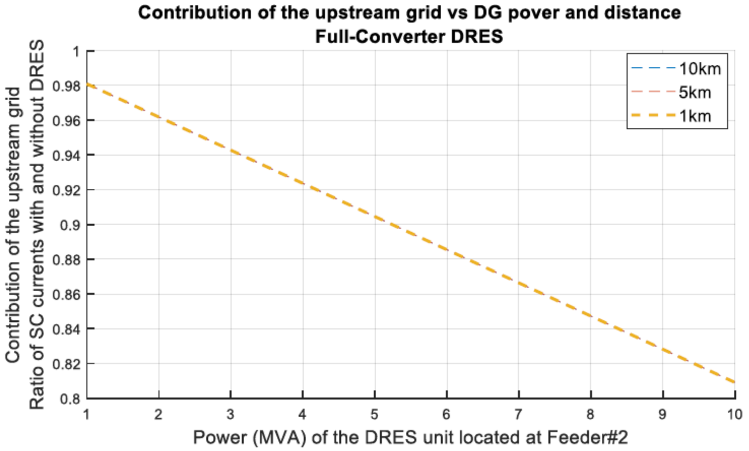


Missoperation of the protection system due to RES

- Example:
  - Protection blinding:
    - DRES rated power
    - DRES location

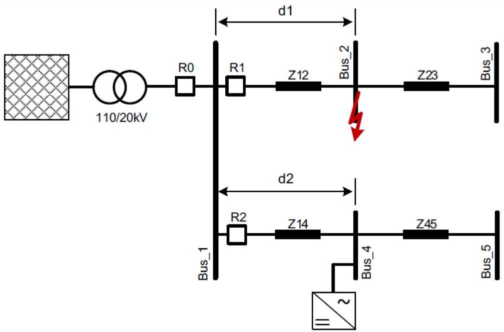


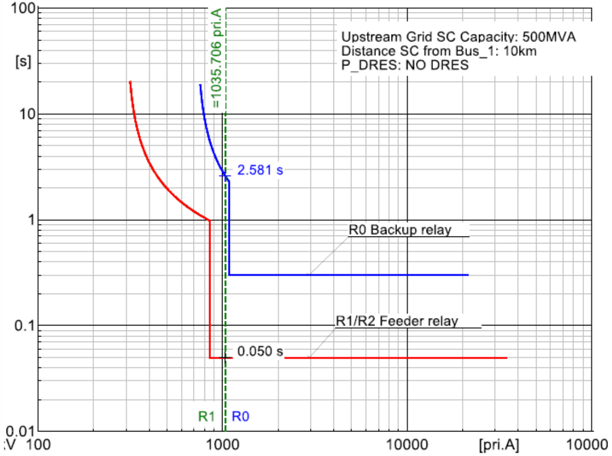


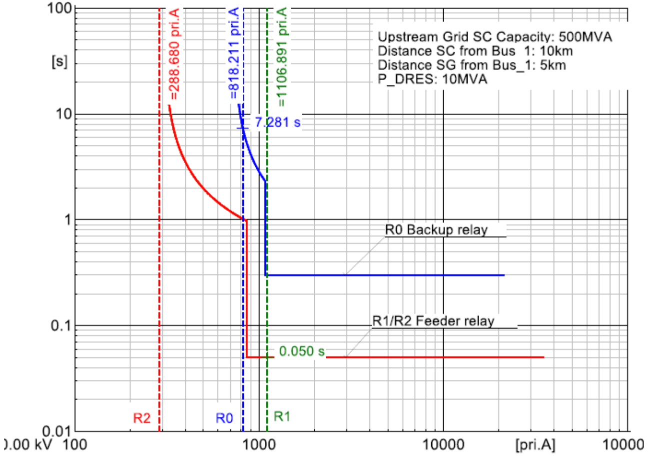


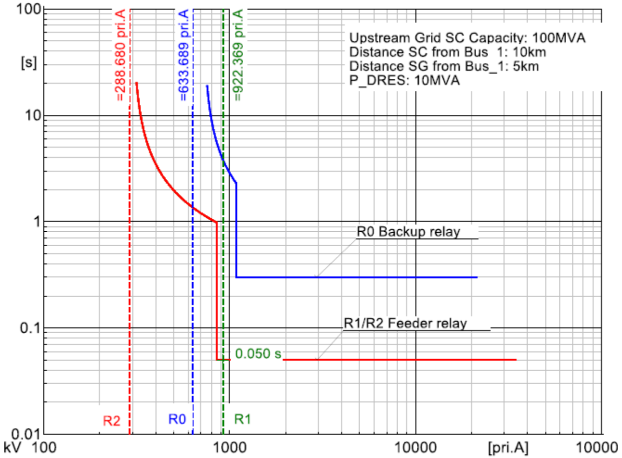
Missoperation of the protection system due to RES

- Example:
  - Protection blinding:
    - Partial protection blinding

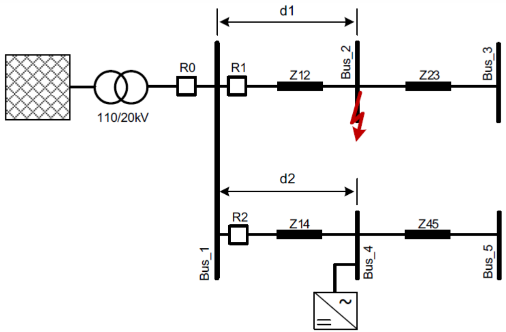




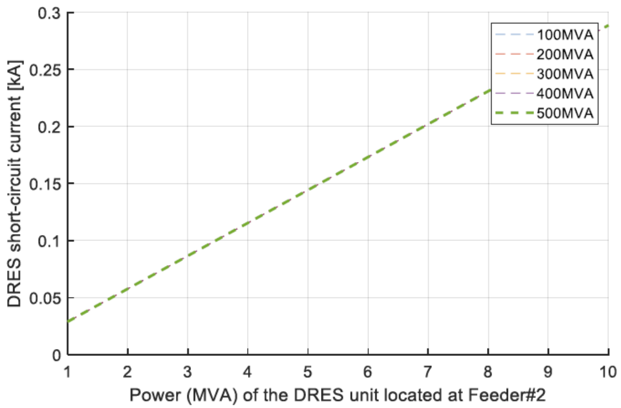


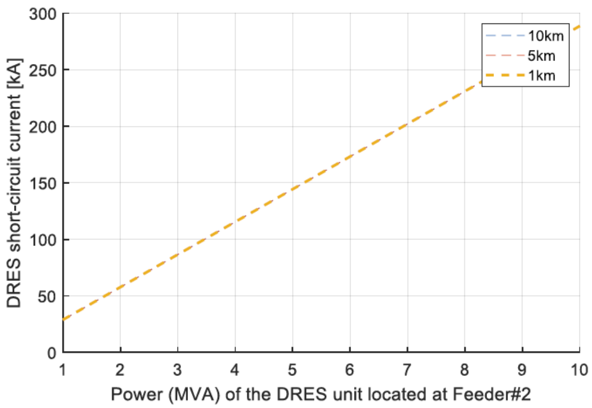


Missoperation of the protection system due to RES

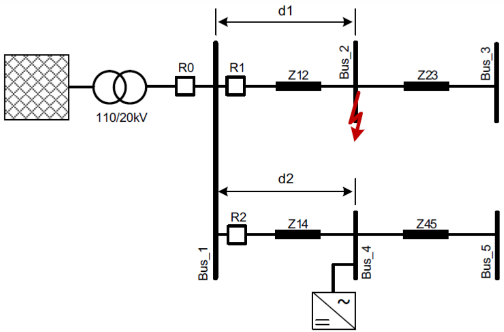


- Example:
  - Sympathetic tripping:
    - DRES rated power
    - DRES location

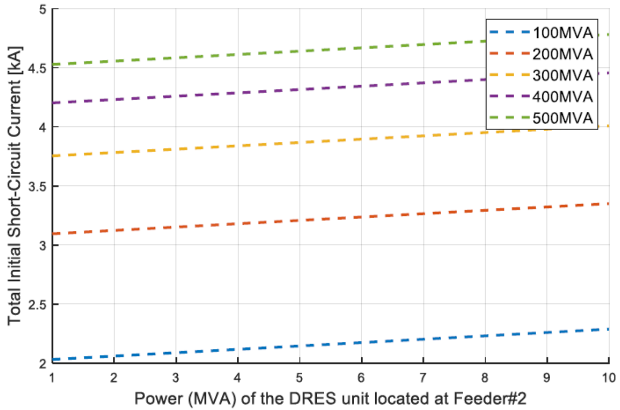


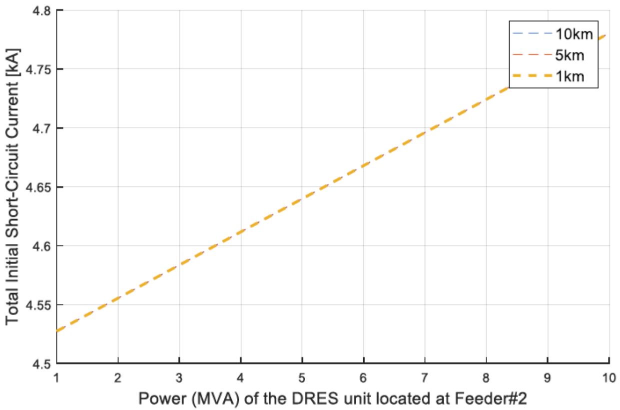


Missoperation of the protection system due to RES



- Example:
  - Short-circuit current increase:
    - DRES rated power
    - DRES location

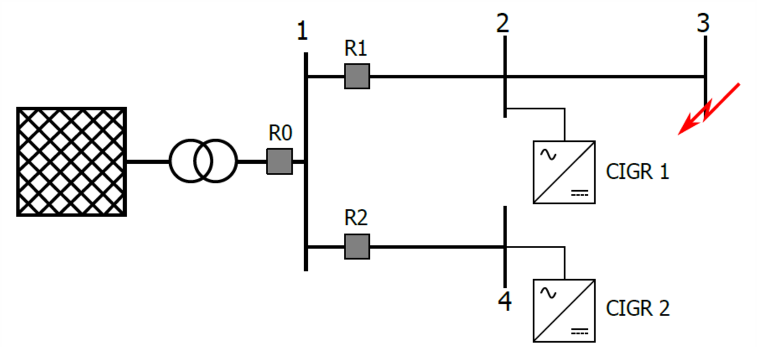


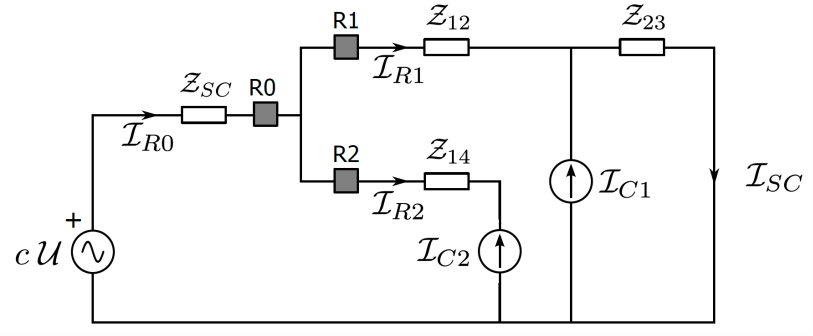


Contents

DRES hosting capacity to avoid missoperation of the protection system

- Simple yet representative one-line diagram:





- DRES represented as current source (IEC 60909):

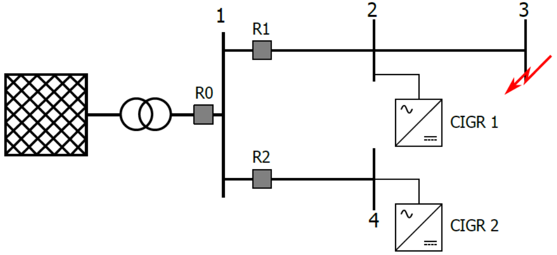
$$I_c = k_{sc} I_{rat}$$

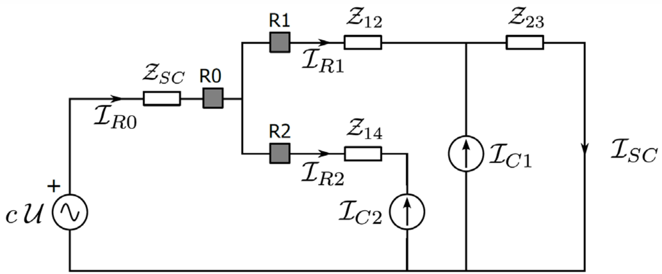
DRES hosting capacity to avoid missoperation of the protection system

- Protection blinding:
  - Main protection:

$$I_{R1}^{pb} = \left| \frac{c\,\mathcal{U}}{\mathcal{Z}_{sc} + \mathcal{Z}_f} \right| - \left| \frac{\mathcal{Z}_{23}}{\mathcal{Z}_{sc} + \mathcal{Z}_f} \mathcal{I}_{c1} \right| + \left| \frac{\mathcal{Z}_{sc}}{\mathcal{Z}_{sc} + \mathcal{Z}_f} \mathcal{I}_{c2} \right|$$

$$\frac{I_{R1}^{pb}}{I_{R1}^{0}} = 1 - \left| \frac{\mathcal{Z}_{23}}{c\,\mathcal{U}} \mathcal{I}_{c1} \right| + \left| \frac{\mathcal{Z}_{sc}}{c\,\mathcal{U}} \mathcal{I}_{c2} \right|$$

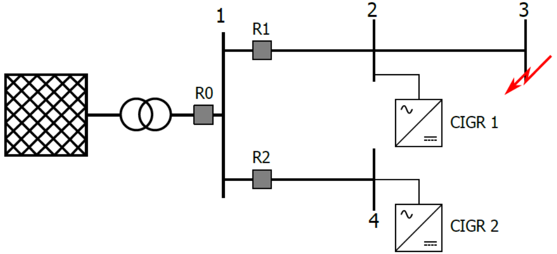




  - DRES located in:
    - Faulty feeder: Blind the protection
    - Healthy feeder: Do not blind the protection

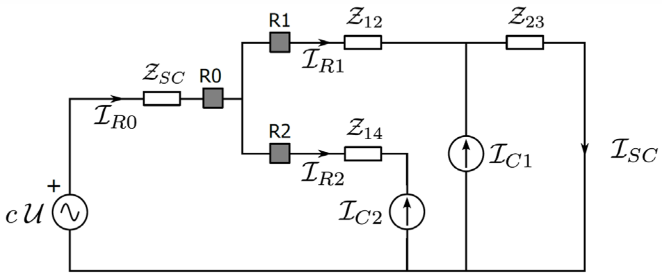
DRES hosting capacity to avoid missoperation of the protection system

- Protection blinding:
    - Back-up protection:



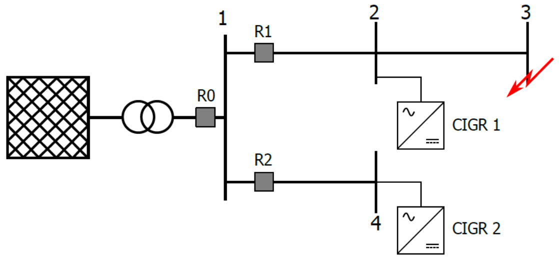
$$I_{R0}^{pb} = \left|\frac{c\,\mathcal{U}}{\mathcal{Z}_{sc}+\mathcal{Z}_f}\right| - \left|\frac{\mathcal{Z}_{23}}{\mathcal{Z}_{sc}+\mathcal{Z}_f}\mathcal{I}_{c1}\right| - \left|\frac{\mathcal{Z}_f}{\mathcal{Z}_{sc}+\mathcal{Z}_f}\mathcal{I}_{c2}\right|$$

$$\frac{I_{R0}^{pb}}{I_{R0}^{0}} = 1 - \left|\frac{\mathcal{Z}_{23}}{c\,\mathcal{U}}\mathcal{I}_{c1}\right| - \left|\frac{\mathcal{Z}_f}{c\,\mathcal{U}}\mathcal{I}_{c2}\right|$$



- DRES blind the protection irrespective of their location

DRES hosting capacity to avoid missoperation of the protection system



- Short-circuit current increase:

$$\frac{I_{R1}^{pb}}{I_{R1}^{0}} = 1 - \left|\frac{\mathcal{Z}_{23}}{c\,\mathcal{U}}\mathcal{I}_{c1}\right| + \left|\frac{\mathcal{Z}_{sc}}{c\,\mathcal{U}}\mathcal{I}_{c2}\right|$$

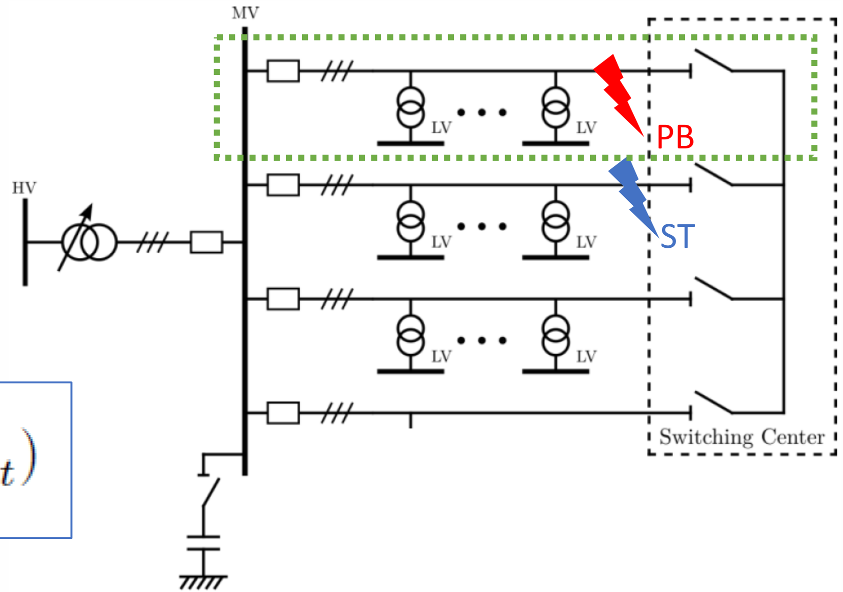
  - DRES located in:
    - Faulty feeder: decrease the short-circuit current
    - Healthy feeder: increase the short-circuit current
- Sympathetic tripping:

$$I_{R2}^{st} = I_{c2}$$

DRES hosting capacity to avoid missoperation of the protection system

- Maximum DRES hosting capacity of an individual feeder:
  - Limited by main protection feeder:
    - Protection blinding (PB)
    - Sympathetic tripping (ST)
  - Worst-case scenario:
    - Protection blinding: I_{rat}^{pb}
    - Sympathetic tripping: I_{rat}^{st}

$$I_{rat} \leq min(I_{rat}^{pb}, I_{rat}^{st})$$

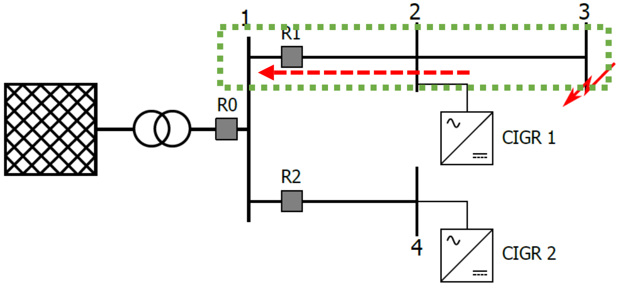


DRES hosting capacity to avoid missoperation of the protection system

- Maximum DRES hosting capacity of an individual feeder:
  - Main protection blinding:
    - Worst-case scenario conditions:
      - No generation in healthy feeders ($I_{c2}=0$)
      - DRES at bus 1 ($Z_{12}=0$, $Z_{23}= Z_f$)
    - Blinding is not produced if:

$$I_{R1}^{pb} \geq I_{R1}^{min}$$

$$I_{rat}^{pb} \leq \frac{c\,\mathcal{U} - I_{R1}^{min}|\mathcal{Z}_{sc} + \mathcal{Z}_f|}{k_{sc}|\mathcal{Z}_f|}$$

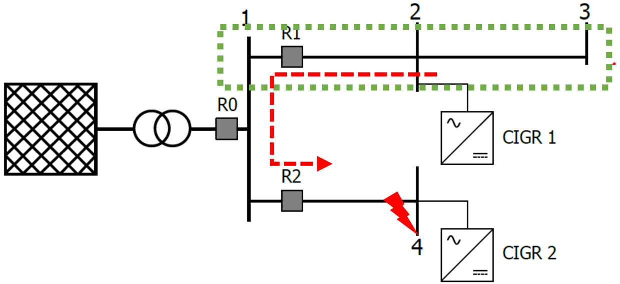


$$\frac{I_{R1}^{pb}}{I_{R1}^{0}} = 1 - \left|\frac{\mathcal{Z}_{23}}{c\,\mathcal{U}}\mathcal{I}_{c1}\right| + \left|\frac{\mathcal{Z}_{sc}}{c\,\mathcal{U}}\mathcal{I}_{c2}\right|$$

DRES hosting capacity to avoid missoperation of the protection system

- Maximum hosting capacity of an individual feeder:
    - Sympathetic tripping is not produced if:

$$I_{rat}^{st} \leq \frac{I_{min}}{k_{sc}}$$

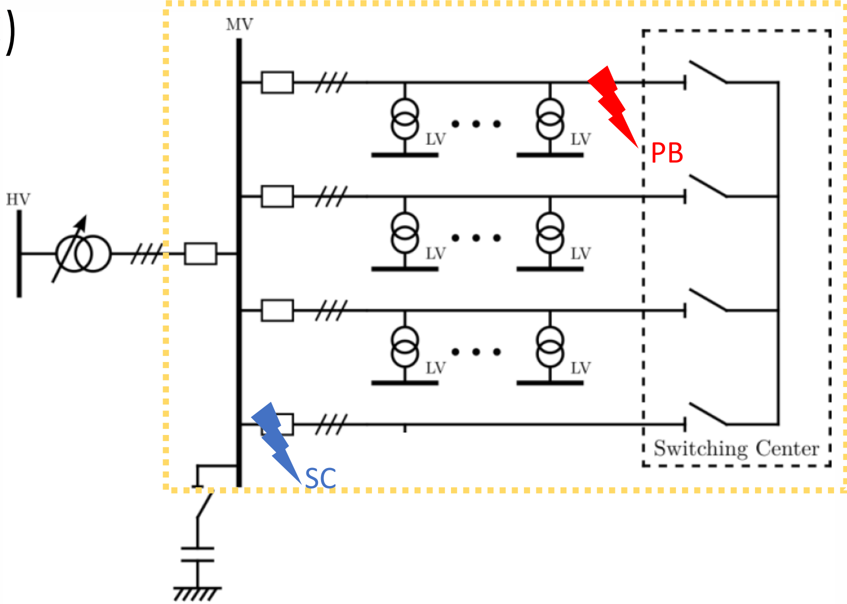


$$I_{R2}^{st} = I_{c2}$$

DRES hosting capacity to avoid missoperation of the protection system

- Maximum DRES hosting capacity of a distribution network:
  - Back-up protection blinding(PB)
  - Short-circuit current increase (SC)
  - Worst-case scenario:
    - Protection blinding: $\sum_i I_{ci-pb}$
    - Fault current increase: $\sum_i I_{ci-sc}$

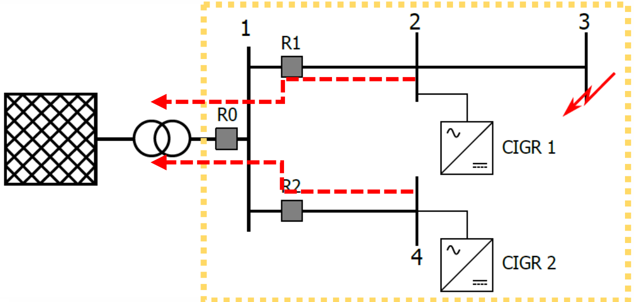
$$\sum_i I_{ci} < min(\sum_i I_{ci-pb}, \sum_i I_{ci-sc})$$



DRES hosting capacity to avoid missoperation of the protection system

- Maximum hosting capacity of a set of feeders:
  - Back-up protection blinding:
    - Worst-case scenario conditions:
      - Fault in the longest feeder
      - DRES at bus 1 (Z_{12}=0, Z_{23}= Z_f)

$$I_{R0}^{pb} = \left|\frac{c\,\mathcal{U}}{\mathcal{Z}_{sc}+\mathcal{Z}_f}\right| - \left|\frac{\mathcal{Z}_f}{\mathcal{Z}_{sc}+\mathcal{Z}_f}\right| \sum_i I_{ci}$$



    - Blinding is not produced if:

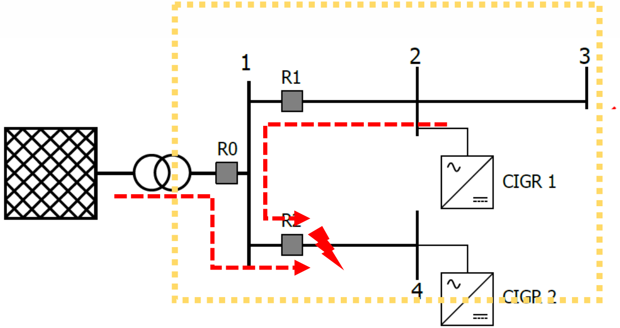
$$\sum_i I_{ci-pb} < \frac{|c\,\mathcal{U}| - I_{R0}^{min}\,|Z_{sc}+Z_f|}{k_{sc}\,|Z_f|}$$

$$\frac{I_{R0}^{pb}}{I_{R0}^{0}} = 1 - \left|\frac{\mathcal{Z}_{23}}{c\,\mathcal{U}}\mathcal{I}_{c1}\right| - \left|\frac{\mathcal{Z}_f}{c\,\mathcal{U}}\mathcal{I}_{c2}\right|$$

DRES hosting capacity to avoid missoperation of the protection system

- Maximum hosting capacity of a set of feeders:
  - Short-circuit current increase:
    - Worst-case scenario conditions:
      - Fault in bus 1 (Z_f=0)
      - DRES located in the healthy feeder
  - No problem if:

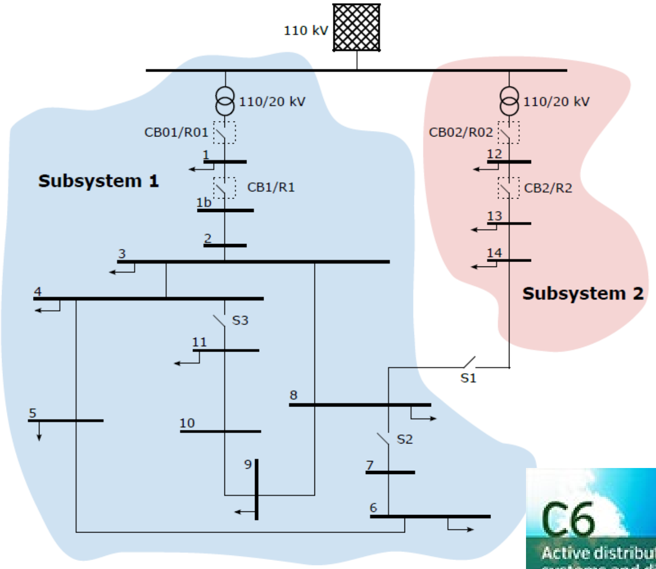
$$I_{R1}^{sc} \leq I_{max} \Rightarrow \sum_i I_{ci-sc} \leq \frac{I_{max} - |c\,\mathcal{U}\,\mathcal{Y}_{sc}|}{k_{sc}}$$

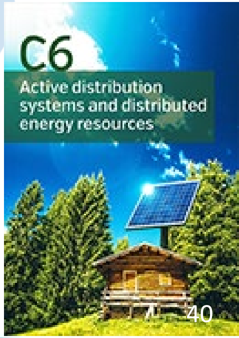


$$I_{R1}^{pb} = \left|\frac{c\,\mathcal{U}}{\mathcal{Z}_{sc}+\mathcal{Z}_f}\right| - \left|\frac{\mathcal{Z}_{23}}{\mathcal{Z}_{sc}+\mathcal{Z}_f}\mathcal{I}_{c1}\right| + \left|\frac{\mathcal{Z}_{sc}}{\mathcal{Z}_{sc}+\mathcal{Z}_f}\mathcal{I}_{c2}\right|$$

DRES hosting capacity to avoid missoperation of the protection system

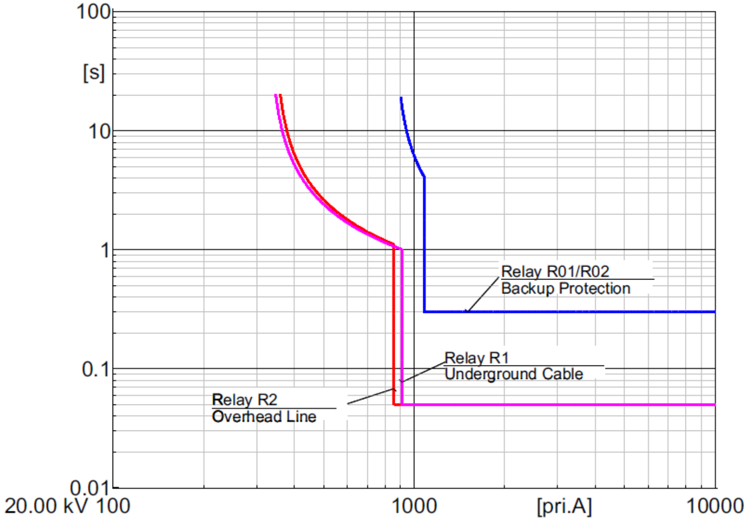
- Case study:
    - CIGRE Task Force C06.04.02:
        - MV Benchmark network:
            - Simplified German network
            - Primary substations: 110/20 kV
            - Two radial feeders: 20 kV
                - Subsystem 1: underground
                - Subsystem 2: overhead
            - 14 nodes, 15 branches
            - Without information of the protection system

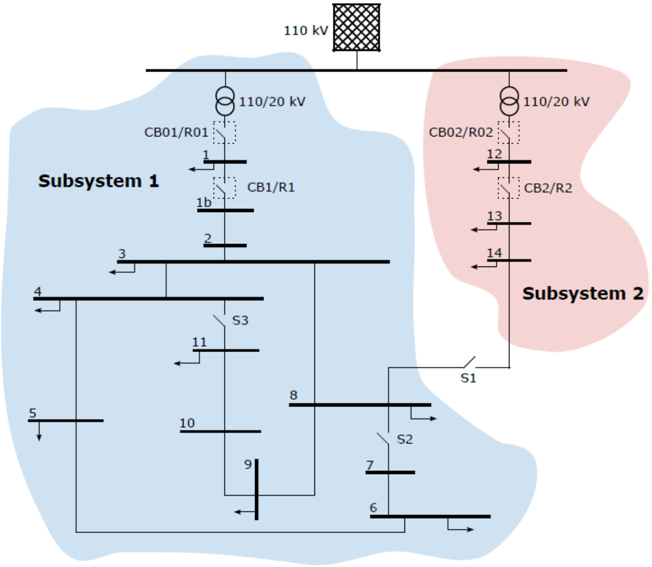




DRES hosting capacity to avoid missoperation of the protection system

- Case study:
  - CIGRE TF C06.04.02 MV network:
    - Definition of a protection system

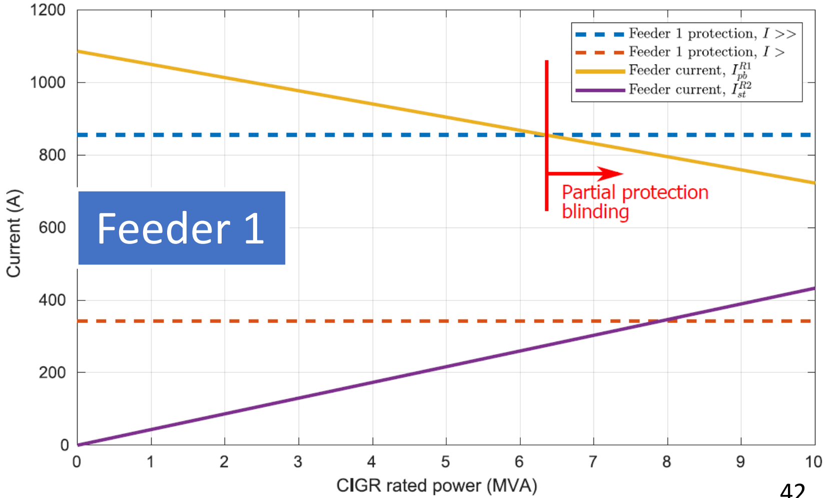




Circuit breaker	I_{max} (kA)	ANSI 51 (A)	ANSI 50 I_{SC} (A)	ANSI 50 Delay (ms)
R1	12.5	342	855	50
R2	12.5	331	828	50
R01, R02	12.5	866	1083	300

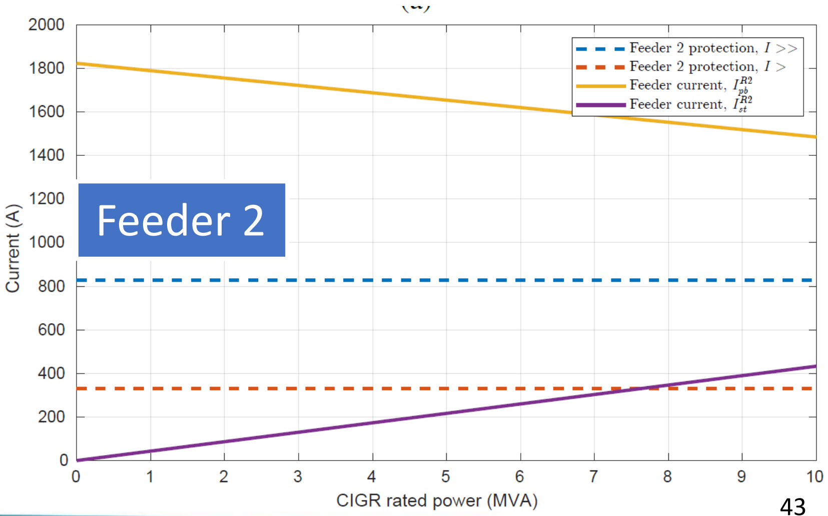
DRES hosting capacity to avoid missoperation of the protection system

- Case study:
  - CIGRE TF C06.04.02 MV network:
    - DRES hosting capacity of feeder 1:
      - Main protection blinding:
        - Partial blinding
        - DRES<6.36 MVA
      - Sympathetic tripping:
        - DRES<7.9 MVA
        - Unlikely to occur (FRT)
      - Conclusion:
        - DRES<6.36 MVA



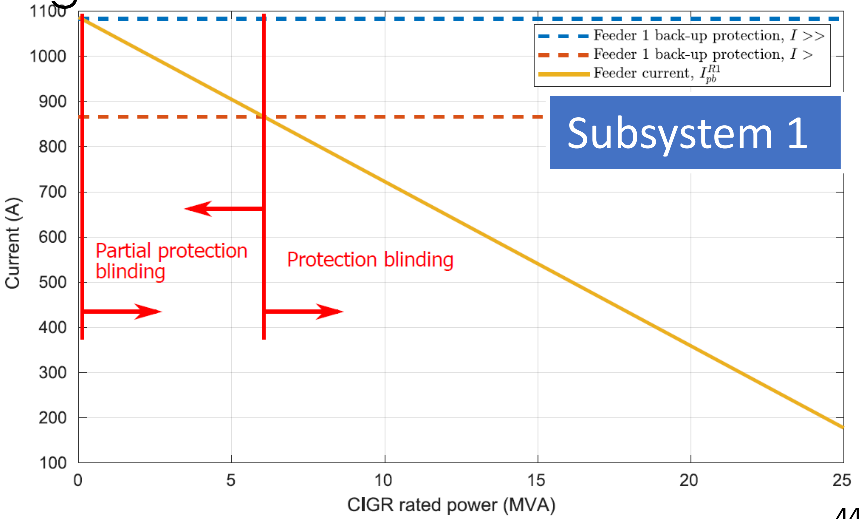
DRES hosting capacity to avoid missoperation of the protection system

- Case study:
  - CIGRE TF C06.04.02 MV network:
    - DRES hosting capacity of feeder 2:
      - Main protection blinding:
        - No blinding
      - Sympathetic tripping:
        - DRES<7.9 MVA
        - Unlikely to occur
      - Conclusion:
        - No problems



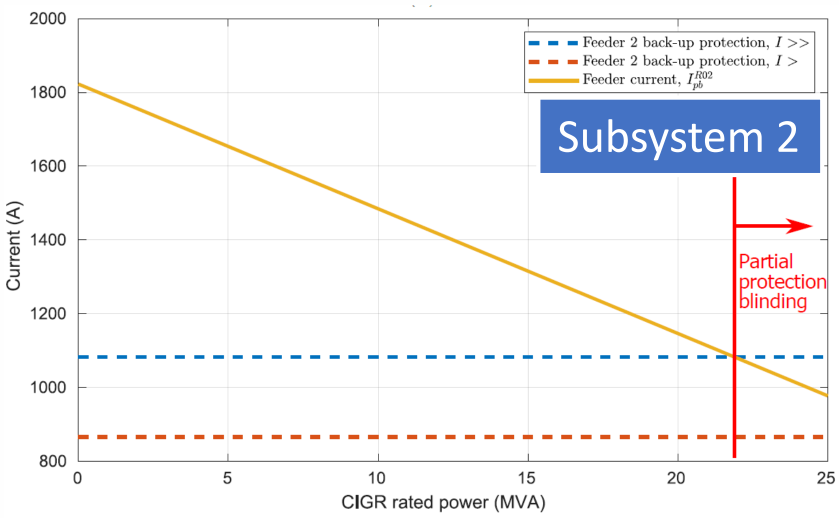
DRES hosting capacity to avoid missoperation of the protection system

- Case study:
  - CIGRE TF C06.04.02 MV network:
    - DRES hosting capacity of subsystem 1:
      - Back-up protection blinding:
        - Total: DRES>6 MVA
      - Short-circuit current:
        - No problem



DRES hosting capacity to avoid missoperation of the protection system

- Case study:
  - CIGRE TF C06.04.02 MV network:
    - DRES hosting capacity of subsystem 2:
      - Protection blinding:
        - Partial: DRES>22 MVA
      - Short-circuit current:
        - No problem

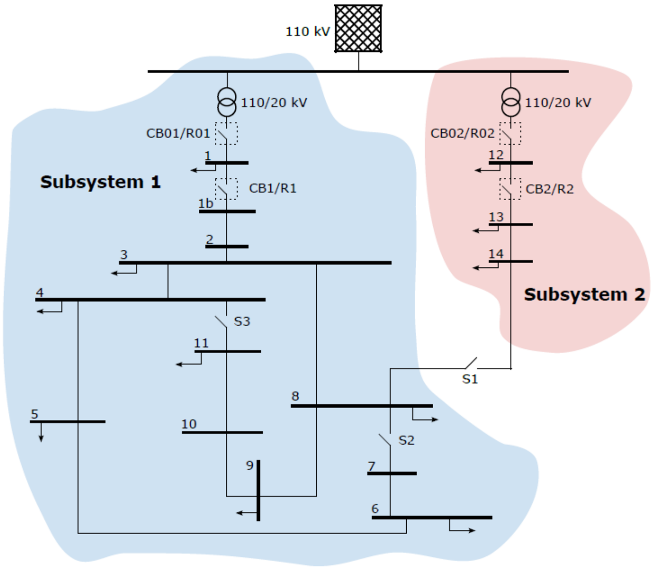


DRES hosting capacity to avoid missoperation of the protection system

- Case study:
  - CIGRE TF C06.04.02 MV network:
    - Validation by short-circuit analysis
      - DIgSILENT PowerFactory 2020

Feeder 1: DRES<6.36 MVA
Subsystem 1: DRES<6MVA

Scenario	$CIGR_1$ (MVA)	$CIGR_2$ (MVA)	I^{pb}_{CB1} (A)	I^{pb}_{CB01} (A)	I^{st}_{CB1} (A)
1	6.0 (N1b)	-	878	878	260
1	6.5 (N1b)	-	860	**860**	281
1	7.0 (N1b)	-	**842**	**842**	303
1	7.5 (N1b)	-	**825**	**825**	325
2	3.0 (N1b)	3.0 (N2)	905	905	260
2	3.5 (N1b)	3.5 (N2)	875	875	303
2	4.0 (N1b)	4 (N2)	**844**	**844**	**346**
2	4.25 (N1b)	4.25 (N2)	**829**	**829**	**368**
3	3.0 (N1b)	3.0 (N1)	1008	878	260
3	3.5 (N1b)	3.5 (N1)	994	**842**	303
3	4.0 (N1b)	4.0 (N1)	980	**807**	**346**
3	4.5 (N1b)	4.5 (N1)	967	**772**	**390**

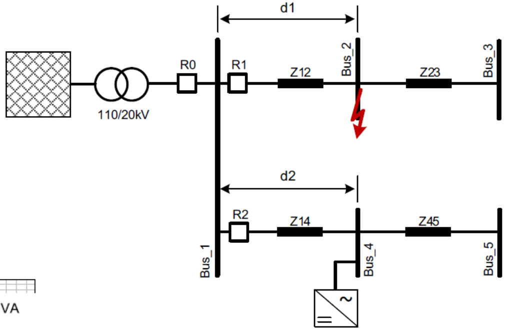


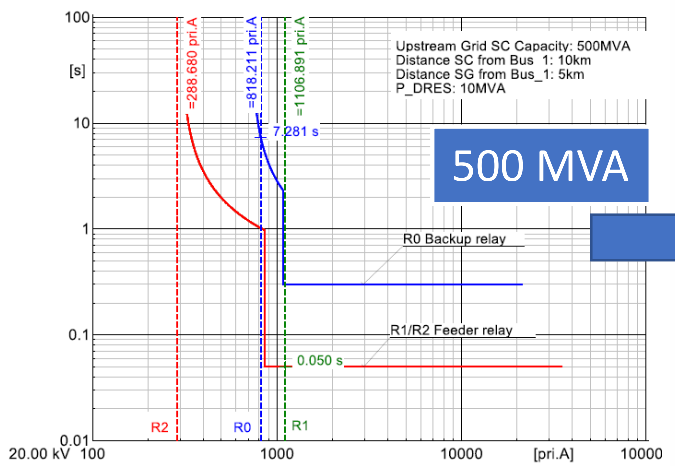
Contents

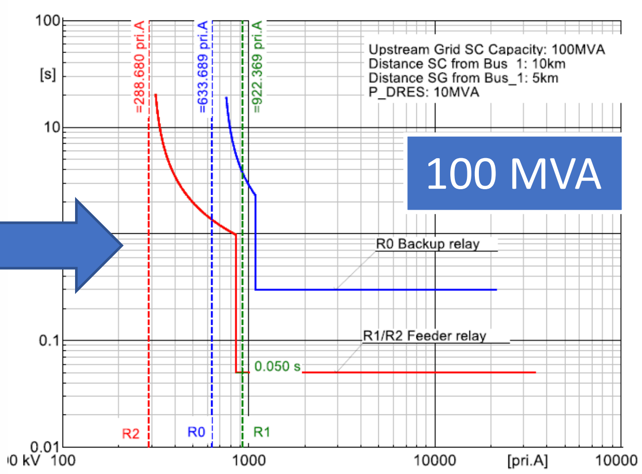
- Motivation
- Protection of conventional distribution networks
- Missoperation of the protection system due to RES
- DRES hosting capacity to avoid missoperation of the protection system
- **Short-circuit current provision as an ancillary service**
- Conclusions and future research

Short-circuit current provision as an ancillary service

- Future power systems:
  - Reduced short-circuit power:
    - Protection blinding is likely to occur

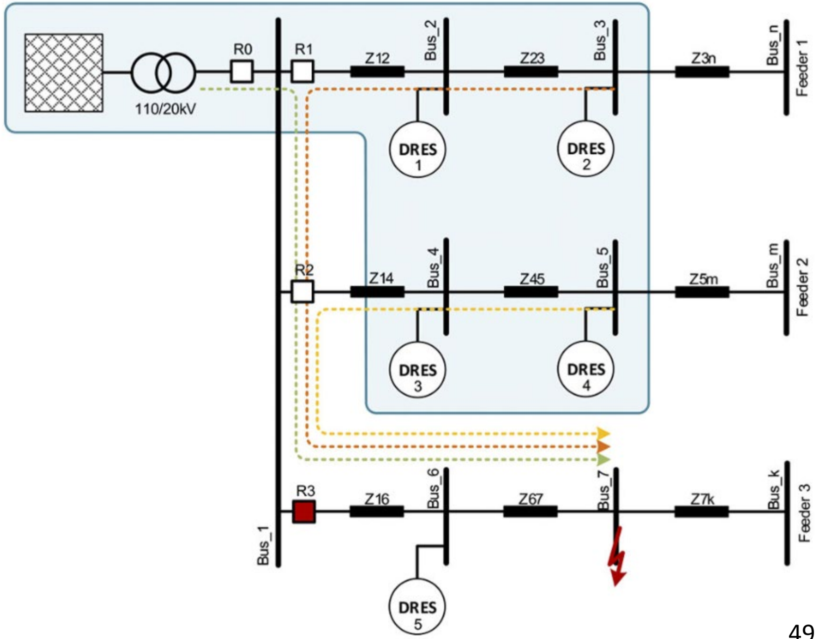






Short-circuit current provision as an ancillary service

- Future power systems:
  - Proposed protection philosophy:
    - DRES may help in the fault clearing of protection devices
    - Protection system remains unchanged
  - Fault clearing can be considered as an ancillary service

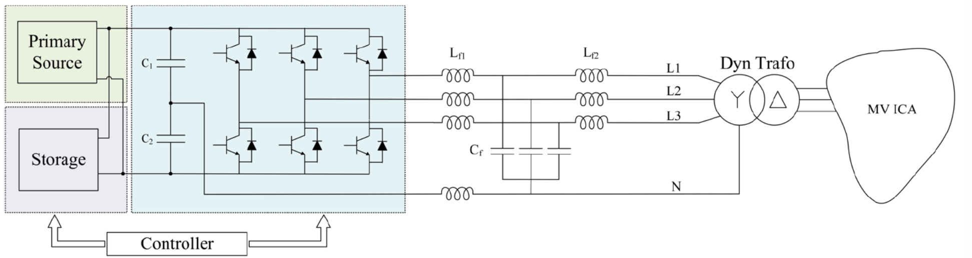


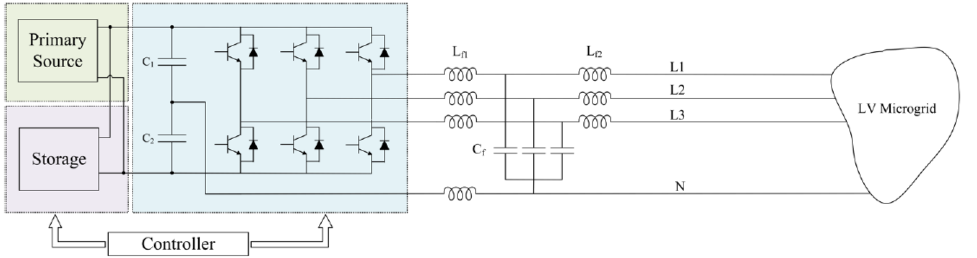
Short-circuit current provision as an ancillary service

- DRES have to actively contribute during short-circuit faults:
    - Fast and accurate fault detection and location
    - Inject fault currents in a controllable way to support fault clearing
    - It is required to define a metric for remuneration purposes

Short-circuit current provision as an ancillary service

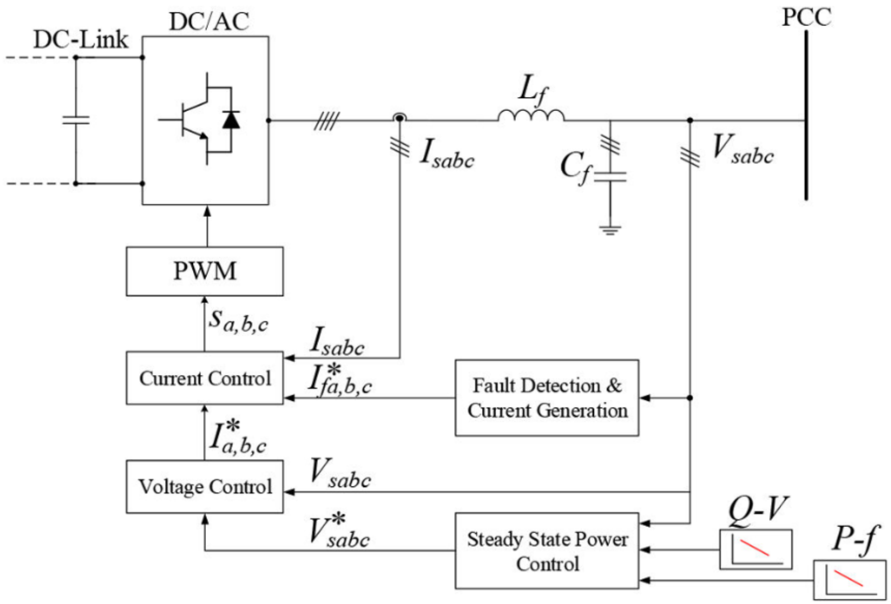
- DRES hardware components:
  - Primary energy source
  - Energy storage
  - 3P 4W VSC
  - LCL coupling filter
  - Coupling transformer





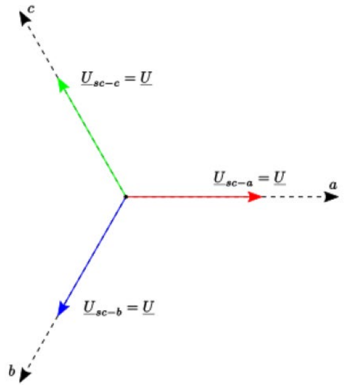
Short-circuit current provision as an ancillary service

- DRES control:
  - Normal operation:
    - Current source
    - Voltage source
  - Short-circuit fault:
    - Current source

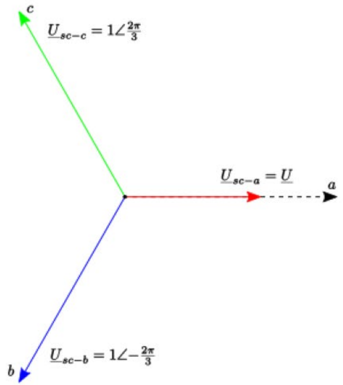


Short-circuit current provision as an ancillary service

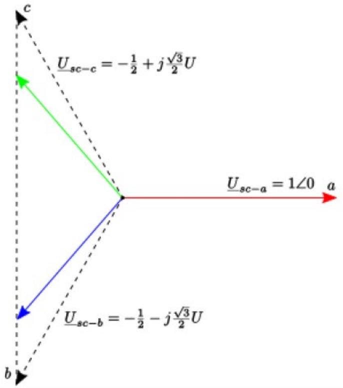
- Fast and accurate fault detection and location:
  - Fault detection based on voltage measurement:
    - Unbalanced faults
    - Importance of the coupling transformers



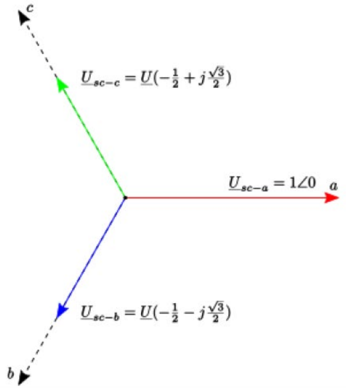
Three-phase



Single-phase



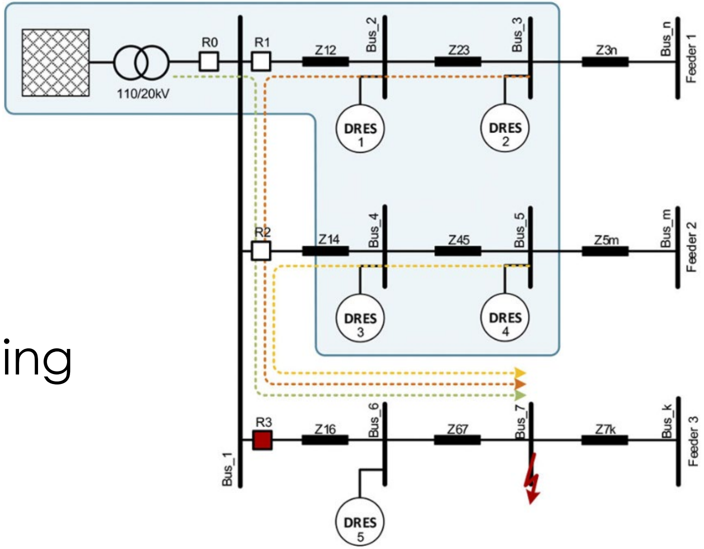
Two-phase



Two-phase to ground

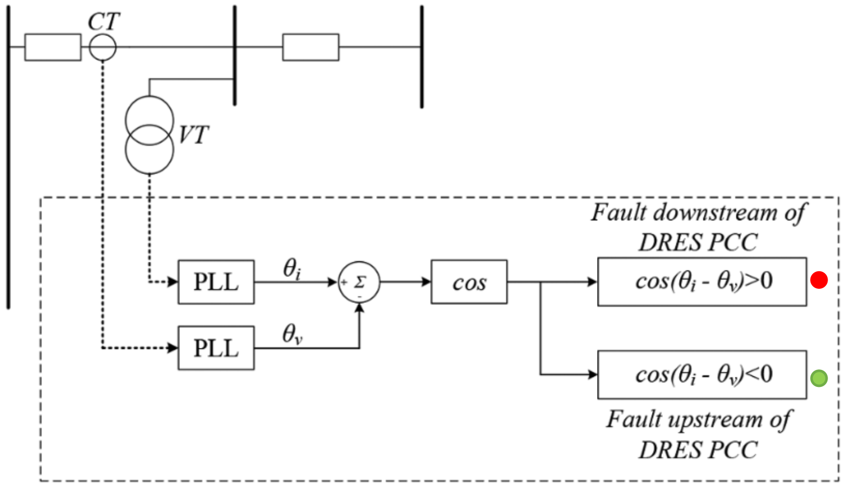
Short-circuit current provision as an ancillary service

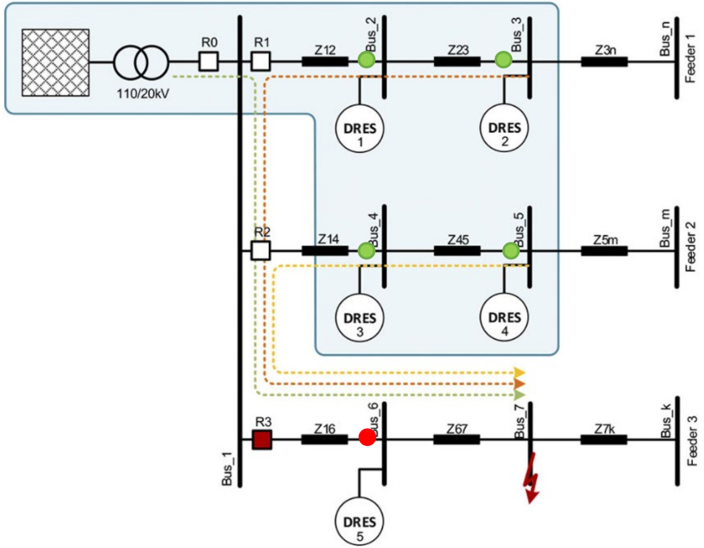
- Fast and accurate fault detection and location:
  - DRES location with respect the fault:
    - Determine the DRES reaction:
      - Faulty feeder:
        - No current injection
      - Healthy feeder:
        - Inject a controlled current
        - Limited by sympathetic tripping



Short-circuit current provision as an ancillary service

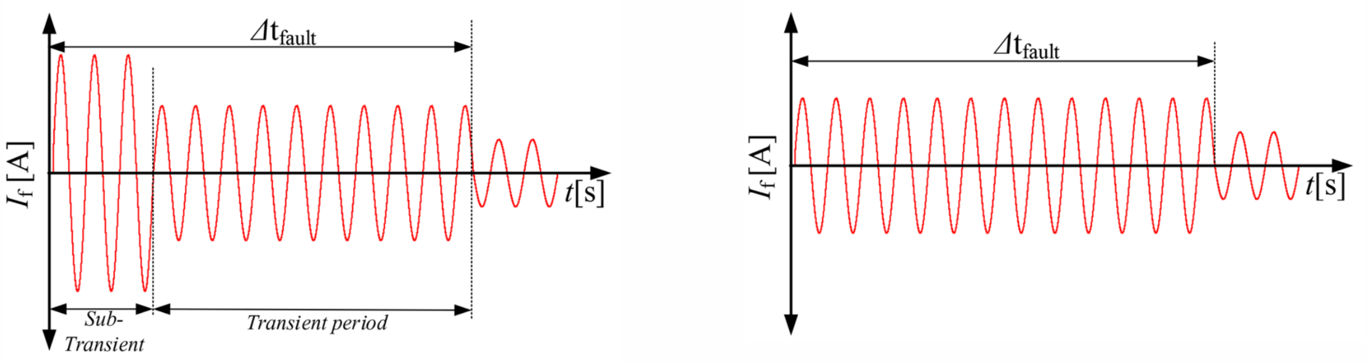
- Fast and accurate fault detection and location:
  - DRES location with respect the fault:
    - Simple methodology based on line measurements





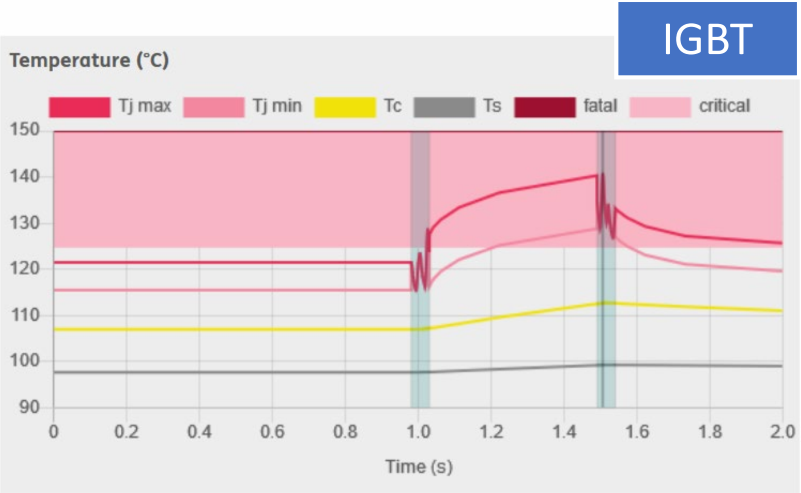
Short-circuit current provision as an ancillary service

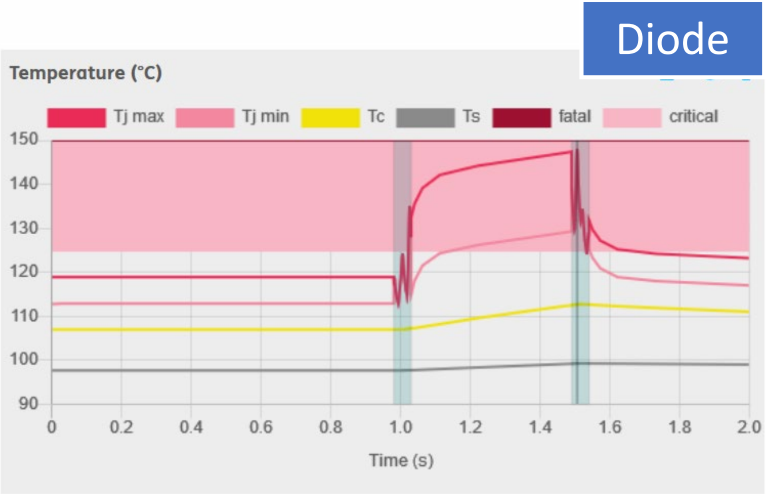
- Inject fault currents in a controllable way to support fault clearing:
  - Two possibilities:
    - Subtransient and transient periods
    - Transient periods
  - Unbalanced faults require an unbalanced current injection



Short-circuit current provision as an ancillary service

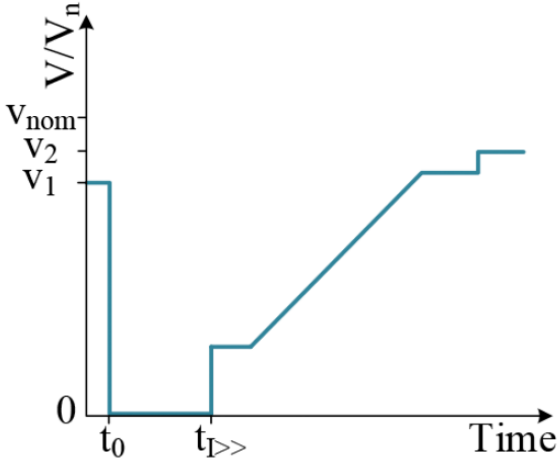
- Inject fault currents in a controllable way to support fault clearing:
    - Overload is possible
    - Example: 100 kVA VSC, overload 2 p.u.

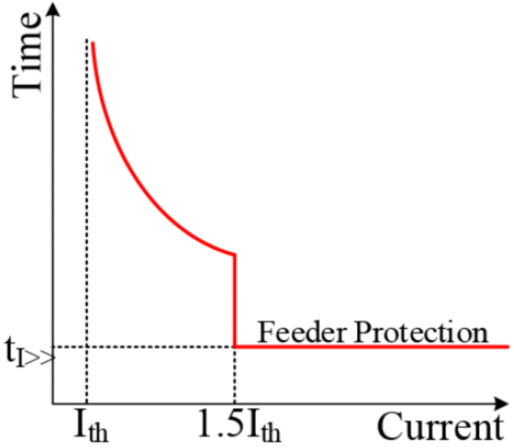




Short-circuit current provision as an ancillary service

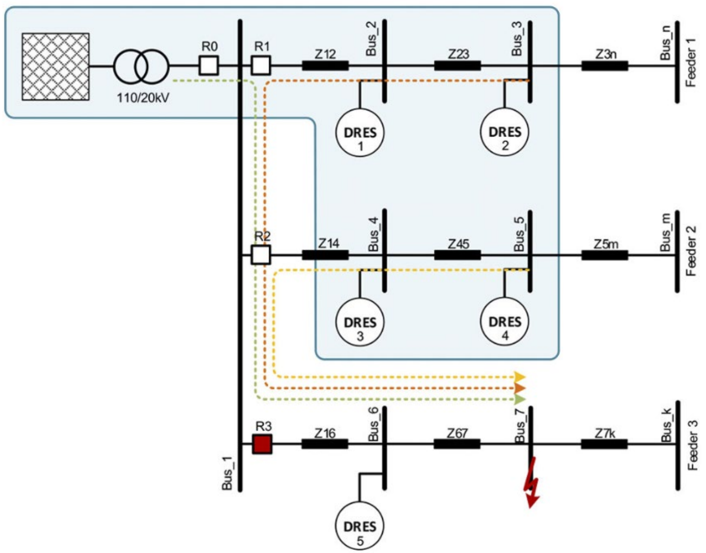
- Inject fault currents in a controllable way to support fault clearing:
  - The injected current must be maintained up to the protection tripping
  - Coordination with protections: FRT capability





Short-circuit current provision as an ancillary service

- Case study:
    - Network data:

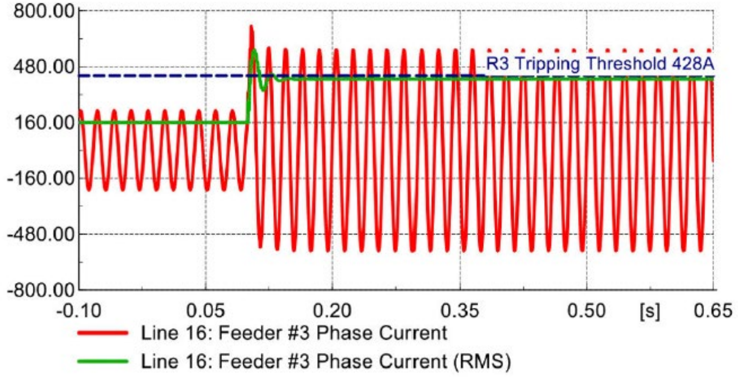


Parameter	Value
upstream grid short-circuit level, MVA	25
upstream grid *R/X* ratio	0.1
transformer ratio, kV	110/20
transformer power, MVA	25
transformer short-circuit voltage u_k	12%
transformer cooper losses, kW	25
cable type	NA2XS2Y
cable cross-section, mm^2	120
cable positive seq. resistance, Ω/km	0.501
cable positive seq. reactance, Ω/km	0.716
cable rated current, kA	0.285
bus_7 distance from Bus_1	10 km
CI-DRES No 1 and 3 distance from Bus_1	5 km
CI-DRES No 2 and 4 distance from Bus_1	10 km
CI-DRES No 5 distance from Bus_1	5 km

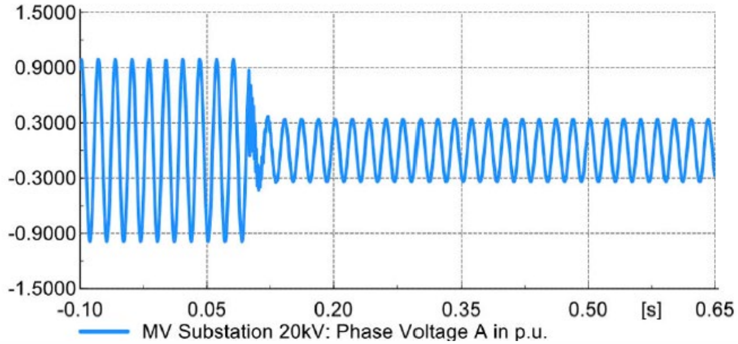
Short-circuit current provision as an ancillary service

- Case study:
  - Scenario 1:
    - DRES injects 1 p.u. during the short-circuit fault
    - Instantaneous protection does not trip the fault

Current

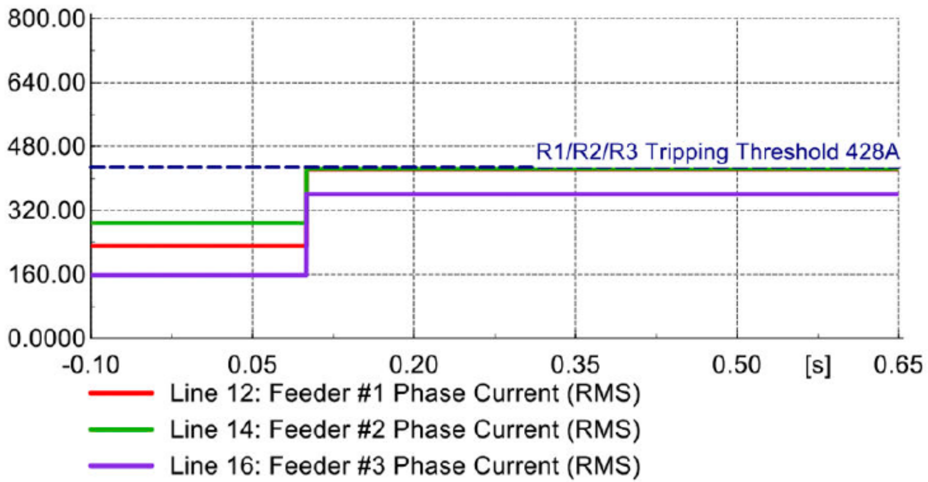


Voltage



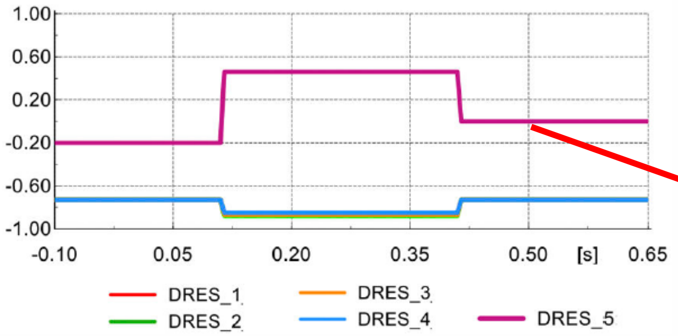
Short-circuit current provision as an ancillary service

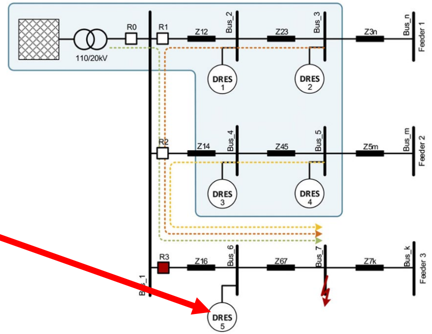
- Case study:
  - Scenario 2:
    - DRES injects the maximum current (overloading, symp. tripping)
    - Instantaneous protection does not trip the fault



Short-circuit current provision as an ancillary service

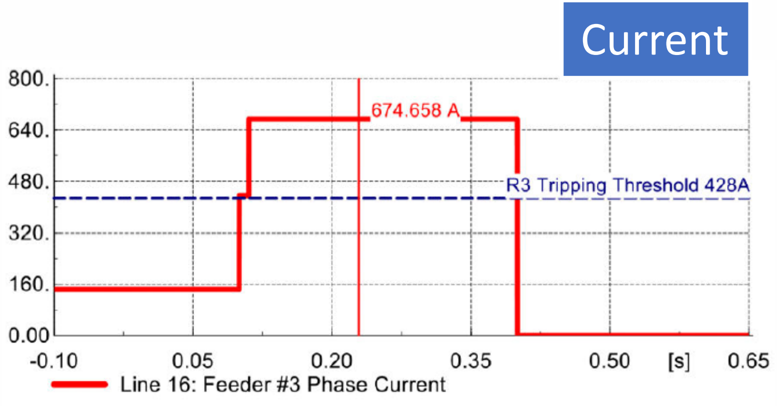
- Case study:
  - Scenario 3:
    - DRES reacts in a smarter manner:
      - Depending on their location
      - Overcurrent but without producing sympathetic tripping
    - Location detection

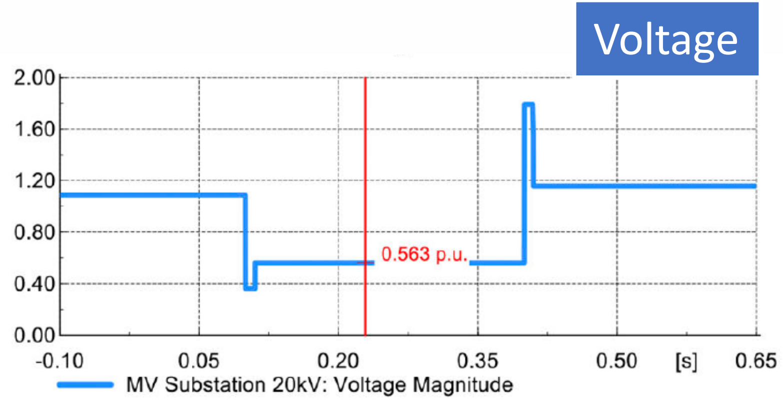




Short-circuit current provision as an ancillary service

- Case study:
  - Scenario 3:
    - Instantaneous protection trips the fault



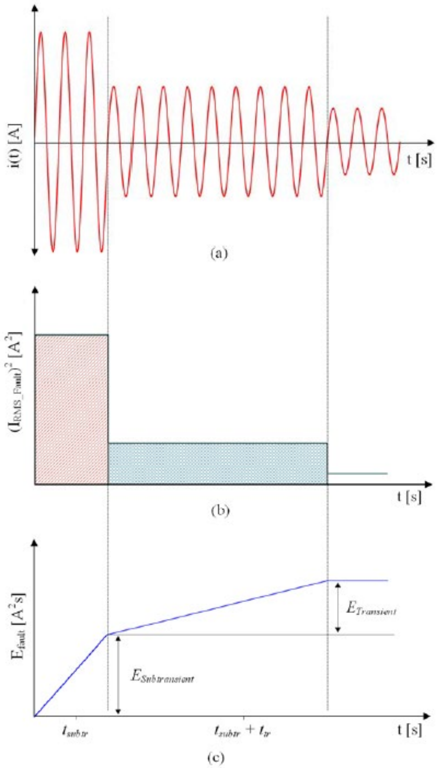


Short-circuit current provision as an ancillary service

- Metric for remuneration purposes:

$$E_{fault\_clearing} = E_{Subtransient} + E_{Transient}$$
$$E_{Subtransient} = \int (I'')^2 dt = (I'')^2 \cdot t_{subtr}$$
$$E_{Transient} = \int (I)^2 dt = (I')^2 \cdot t_{tr}$$

- Business model is still an open question:
  - Cost of providing the service:
    - Investment cost (oversizing)
    - Operational cost
  - Benefit: investment deferral



Contents

Conclusions and future research

- DRES turn the distribution system from passive to active
- DRES affect the performance of conventional protection systems
- Usual missoperation of the protection systems:
  - Protection blinding
  - Sympathetic tripping
  - Short-circuit current increase
- It is possible to compute the DRES hosting capacity without affecting the protection system
- Problems may happen in case of upstream grids with low short-circuit power

Conclusions and future research

- Fault clearing can be envisioned as an ancillary service:
  - Smart performance based on the DRES network position with respect to the fault
  - The required overload is technically feasible
  - Metric for accounting purposes is clear
- Future research:
  - Unbalance faults
  - Experimental testing
  - Business model

Further reading

- J.M. Maza-Ortega, F.J. Zarco-Soto, S. Gkavanoudis, D. Tampakis, C. Demoulias,"A short communication to define the overcurrent protection system of the CIGRE European benchmark distribution networks for RES penetration studies", *Electrical Engineering* (2021). https://doi.org/10.1007/s00202-021-01386-3
- K. Oureilidis, K. Malamaki, K. Gallos, A. Tsitsimelis, C. Dikaiakos, S. Gkavanoudis, M. Cvetkovic, J.M. Mauricio, J.M. Maza-Ortega, J.L. Martínez-Ramos, G. Papaioannou, C. Demoulias, "Ancillary Services Market Design in Distribution Networks: Review and Identification of Barriers" *Energies* 13, no. 4, 917, 2020. https://doi.org/10.3390/en13040917
- S. Gkavanoudis, D. Tampakis, K. Malamaki, G. Kryonidis, E. Kontis, K. Oureilidis, J.M. Maza-Ortega, C. Demoulias, "Protection philosophy in low short-circuit capacity distribution grids with high penetration of converter-interfaced distributed renewable energy sources', IET Gen.,Trans. & Dist. Vol. 14, no. 22, p. 4978-4988, 2020. DOI: 10.1049/iet-gtd.2020.0714

Further reading

- C. Demoulias, K. Malamaki, S. Gkavanoudis, J.M. Mauricio, G. Kryonidis, K. Oureilidis, E. Kontis, J.L. Martinez-Ramos, “Ancillary Services Offered by Distributed Renewable Energy Sources at the Distribution Grid Level: An Attempt at Proper Definition and Quantification”, *Applied Sciences* 10, no. 20: 7106. 2020, https://doi.org/10.3390/app10207106
- J.M. Maza-Ortega, F.J. Zarco-Soto, S. Gkavanoudis, C. Demoulias, “Assessing the converter interfaced generation hosting capacity to prevent the protection system misoperation of distribution networks”, Journal of Modern Power Systems and Clean Energy, 2021 *(in review)*.

Item 4: The EASY-RES Consortium

The Consortium

ARISTOTLE UNIVERSITY OF THESSALONIKI

UNIVERSIDAD DE SEVILLA

UNIVERSITÄT PASSAU

Lancaster University

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