Design of Zone-Based Hierarchical Protection System for 100% Renewable Microgrids

Soham Chakraborty and Jing Wang
Power Systems Engineering Center, National Renewable Energy Laboratory, Golden, Colorado 80401, USA.

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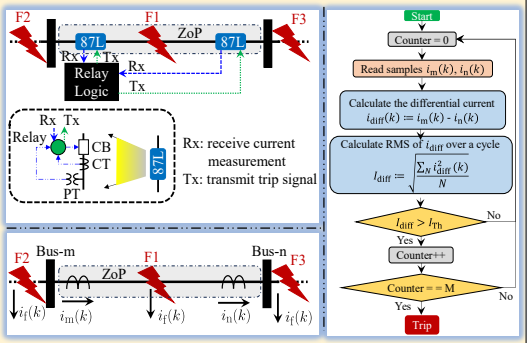
Challenges

- Efforts on microgrids with **mixed-type DERs** (rotating machine-based, IBR-based (GFL+GFM)
- In 100% renewable microgrids, challenges are:
  - **Low fault current contributions** by the IBRs, restricted by switch ratings and fault limiter
  - **Varying fault current levels of DERs** due to the variability of the renewable resources.
- Reduced fault current results in complete **failure/delayed tripping** by overcurrent relays.
- Varying levels of the low fault current impacts the **threshold-based** protection system and relay coordination.

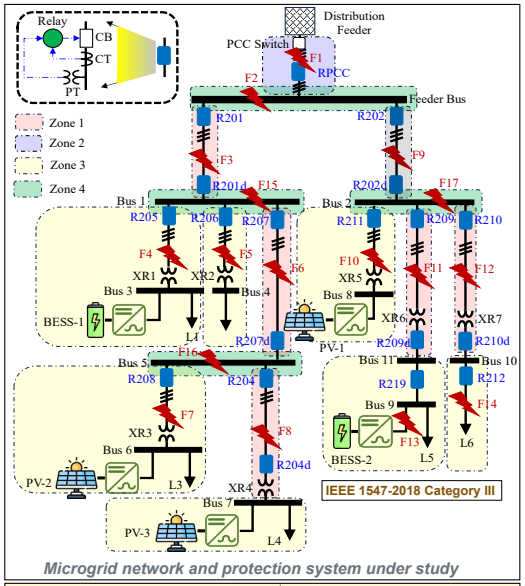
Contribution

- Methodology to **partition the microgrid into multiple zones based** on lines, buses, etc. (**regardless of the topology**)
- **Unique protection schemes for zone** with the best reliability
- **Hierarchical structure** enabling relay coordination by assigning **different speeds** for zones.

Zone 1 Protection

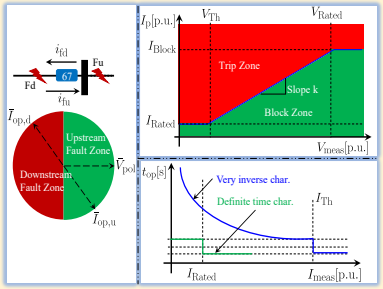


Line differential-based protection

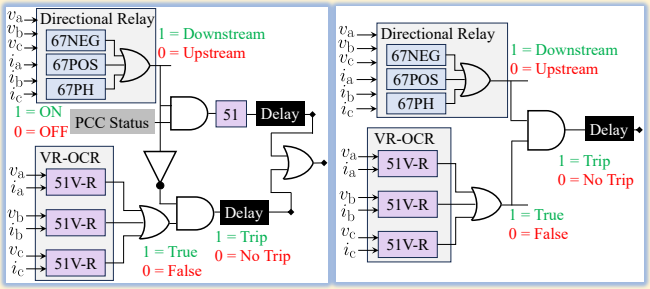


Microgrid network and protection system under study

Zone 2 and Zone 3 Protection

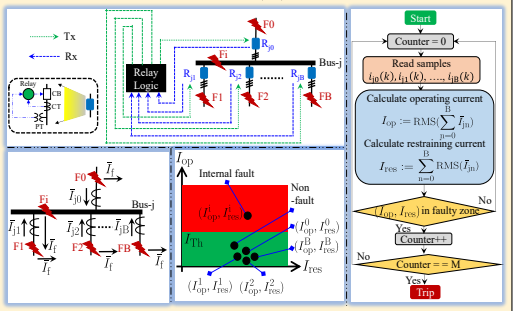


Adaptive directional voltage-restrained overcurrent relays



Logic diagram

Zone 4 Protection



Scheme based on operating-restraining phenomenon

$I_{Th} = \alpha \times \sqrt{2} \times I_{rated} \sin[2\pi(n+D)/N]$

- α: CT saturation factor (IEEE C37.110-2007)
- I_{rated}: Rated line current of ZoP
- N: Number of samples/cycle
- n: Index of sample
- D: Sample delay in communication

Avoid nuisance tripping:

- a condition hold (counter=M),
- α, N, D, M are 2, 100, 2, and 200, respectively.

$T_{dir} = |\hat{V}_{pol}||\hat{I}_{pol}|\cos(\angle\hat{V}_{pol} - \angle\hat{I}_{pol})$

- 67NEG, 67POS, 67PH

I_{Block} = 4 times rated current

V_{Th}= 25% of rated voltage

Definite-time overcurrent characteristic,

- t_{op} = 5 cycles

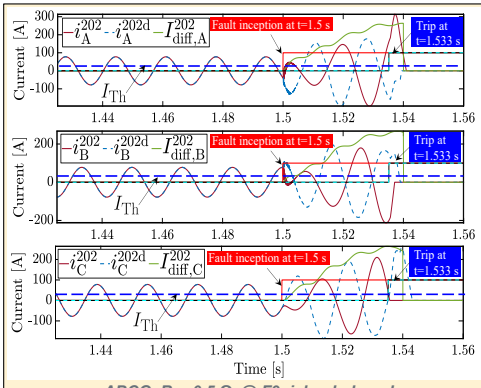
$I_{Th} = \alpha \times \max(I_{j0}^r, I_{j1}^r, \ldots, I_{jB}^r)$,

- α: CT saturation factor (IEEE C37.110-2007)
- I_{jn}^r: Rated nodal current measured by n^{th} relay

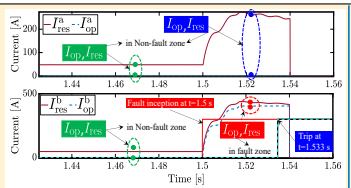
Avoid nuisance tripping:

- A condition hold (counter=M)
- α, M are 2 and 200, respectively.

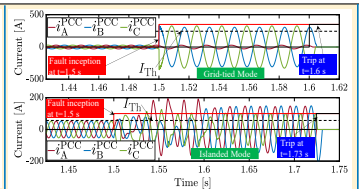
VR-overcurrent tripping characteristics are employed in the relays situated in Zone 1 and Zone 4 as a backup protection system with proper relay coordination.



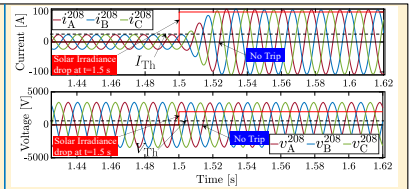
ABCG, R_f = 0.5 Ω, @ F9, islanded mode



BG, R_f = 10 Ω, @ F2, grid-tied mode



BC, R_f = 0.01 Ω, @ F1.



Solar drop (100% to 10%)

Mode	Rel.	Dep.	Sec.
Grid-tied	98.26	98.12	98.27
Islanded	97.77	97.63	97.78
Overall	98.00	97.89	98.02

Mode	Speed [s]	
	max.	min.
Grid-tied	0.033	0.27
Islanded	0.033	0.32

Rel. : Reliability[%], Dep. : Dependability[%], Sec. : Security[%]

Performance of proposed protection scheme

- **1,620** cases are simulated:
  - **1,150** cases of fault types, locations, and impedances
  - **470** fault-like cases (load/capacitor switching, solar irradiance drop/rise, etc.)

Type	F1(G) (ag) 0.01Ω	F2(I) (abcg) 25Ω	F3(G) (bg) 15Ω	F4(I) (cg) 1Ω	F5(G) (bg) 2Ω	F6(I) (abc) 20Ω	F7(G) (ag) 0.05Ω	F8(I) (bg) 10Ω
Relay	RPCC, PCC −switch	RPCC, R201, R202	R201, R201d	R205, BESS1 −switch	R206	R207, R207d	R208, PV2 −switch	R204, R204d
Time[s]	0.17	0.033	0.033	0.21	0.09	0.033	0.19	0.033
F9(G) (cg) 30Ω	F10(I) (acg) 0.01Ω	F11(G) (bc) 5Ω	F12(I) (ag) 8Ω	F13(G) (bg) 3Ω	F14(I) (bcg) 2.5Ω	F15(G) (ac) 10Ω	F16(I) (bg) 25Ω	F17(G) (ag) 5Ω
R202, R202d	R211, PV1 −switch	R209, R209d	R210, R210d	R219, BESS2 −switch	R212	R201d, R205, R206, R207	R207d, R208, R204	R202d, R209, R210, R211
0.033	0.18	0.033	0.033	0.17	0.11	0.033	0.033	0.033

Operating times for proposed protection scheme

Future Work

- Improving the operating time of the protection schemes—especially for Zone 3—is considered for future work to further enhance the proposed protection scheme.

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