Study Committee B5

Protection and Automation

Paper ID_872 2022

Hybrid neutral treatment solutions to support post-pandemic changes in work practices, economic recovery and de-carbonisation efforts

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Motivation

- SARS-CoV-2 (COVID-19) has radically changed working practices around the world.
- Many electricity users in rural areas are more reliant upon the continuity of their electricity service.
- Increasing penetration of electric vehicles and heating impact power system planning, design, operation, and protection.
- This paper focuses on hybrid neutral treatment solutions to safely and efficiently maximise continuity of electricity supply.

Object of investigation

- Rural MV overhead networks
- EN 50522 outlines a range of neutral treatment options, including common techniques:
  1. Solid (low impedance) earthed neutral (EN)
  2. High resistance earthed neutral (REN)
  3. Isolated neutral (IN)
  4. Compensated neutral (CN), also called arc suppressed

Method and approach

- The choice of type of neutral treatment is normally based on the following criteria (amongst others):
  1. Safety and damage due to earth faults
  2. Continuity of supply required for the network
  3. Selectivity and identification of fault location

CN systems exhibit

- Very low earth fault current
- Transient earth faults self-extinguish
- Customer interruptions are minimised, eliminated for transient earth faults.
- Controls touch and step voltages
- Needs phase insulation to line voltage
- A few amps of current remain at the fault site

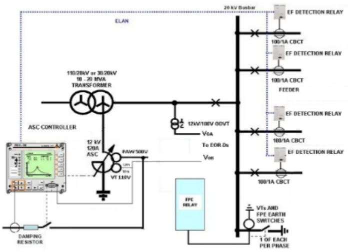
Augmentation of CN systems

- Deliver exceptionally low earth fault current
- Less than 1 A typically remains at the fault site

Experimental setup

- Five trial substations and their MV networks were fitted with automatically controlled arc suppression coils, one augmented with Faulted Phase Earthing (FPE) and one augmented with active injection (AI)
- Three different earth fault protection functions were employed
- Synchronised line monitoring (SLM) was used to efficiently localise earth faults

Photos of CN and FPE installations

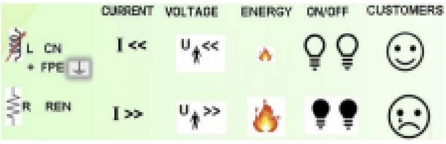


Schematic diagram of modern CN with FPE installation

Conclusions

Hybrid neutral treatment solutions provide:

- Optimised fault site safety
  - FPE and AI augmentation as necessary
- Maximised continuity of supply
  - Selective tripping only for higher risk feeders
- Fast and efficient fault localisation
  - Synchronised line monitoring
  - Mobile hand-held fault location devices.



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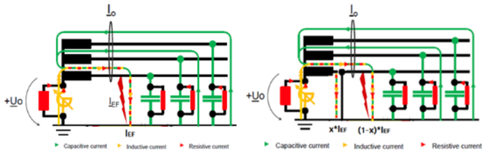
Safety - Earth fault current with CN

- Total current remaining on an 80 A system
  - Mismatch of 2.5% = j2 A;
  - Damping of 8% = 6.4 A;
  - Total $I_{EF} = I_L - I_C + I_R + I_{50}n > 6.7$ A

Reasons for adding FPE

- Reduce remaining earth fault current at the fault site
- Further improve fault site safety without tripping
- Further reduce touch and step voltages
- Minimise outages due to permanent earth faults
- Implemented using simple, reliable technology

See also References [3, 4, 5].



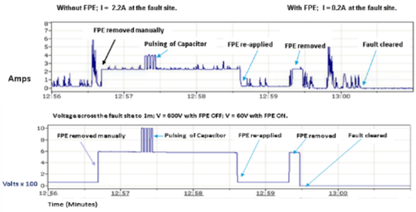
Diagramatic representation of FPE

Earth fault current with CN + FPE

- I_{EF} = ~ 0.1* $[(I_L - I_C) + I_R + I_{50}n < 0.7$ A and typically << 1 A

Impact of FPE on fault site conditions

Fault site performance	FPE OFF	FPE ON
Current at fault site	2.2A	0.2A
Voltage at the fault site to 1m	600V	60V



Recorded impact of FPE on fault site current and voltage

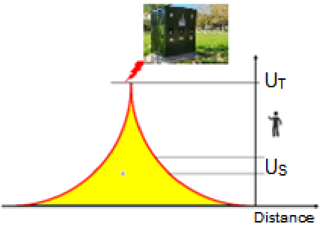
Earth fault current with CN + AI

- $I_{EF} \sim [(I_L - I_C) + (I_R - I^*_R) + (I_{50}n - I^*_{50}n)]$ and typically << 0.5 A

Where I^*_R and $I^*_{50}n$ are the injected components

Earth Potential Rise (EPR)

- EPR for an earth fault at an electrical installation EN 50522 [2a]



Diagrammatic representation of EPR from EN50522

Quantitative Safety Risk Assessment

- References are BS EN 50522 2b, Annex NB, 6, 7.

$$p_{fatality} = p_{coincidence} \cdot p_{fibrillation}$$

$$p_{fatality} = \frac{f_{earth\ fault} \cdot f_{presence} \cdot (T_{earth\ fault} + T_{presence})}{T_{observation}} \cdot p_{fibrillation}$$

- Example with trip time of 4 seconds

$$p_{coincidence} = \frac{0.0002 \cdot 730 \cdot (4 + 5)}{31536000} = 0.000000042 = 0.042 \cdot 10^{-6}$$

$$p_{fatality\ max} = 0.042 \cdot 10^{-6} \cdot (\approx)0.05 = 0.0000000002083 \approx 0.0021 \cdot 10^{-6} \ll 10^{-6}$$

- Example with trip time of 1,800 s (30 minutes)

$$p_{coincidence} = \frac{0.0002 \cdot 730 \cdot (1800 + 5)}{31536000} = 0.0000084 = 8.4 \cdot 10^{-6}$$

$$p_{fatality\ max} = 8.4 \cdot 10^{-6} \cdot (\approx)0.05 = 0.00000042 \approx 0.42 \cdot 10^{-6} < 10^{-6}$$

Reliability

The relative outage performance of CN networks compared to neighbouring REN networks per km and per customer were established to be:

- 75% reduction in Customer Interruptions (SAIFI)
- 66% reduction in Interruption Duration (SAIDI)
- 70% reduction in total outage costs
- 49% reduction in outage frequency
- 50% reduction in customers impacted

E. Diskin, A. Keane 'Parameterised risk sharing in smart distribution system investments'; Proceedings of the 23rd International Conference on Electricity Distribution, CIRED 2015.

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EF Protection

Legacy solutions for common feeder selective earth-fault detection include:

- I_O*CosΦ/ Wattmetric
- Fault inception transient (FIT)
- Admittance at fundamental frequency (Y_O)
- Harmonics
- Neutral voltage displacement (U_O)

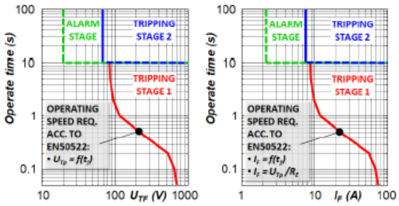
More recent developments

- Enhanced FIT
  - Charge voltage (qu) – integral of residual current
  - Transient Reactive Power (TRP) – differential of U_O
- Multi-frequency admittance (Yn_O)
- Delta mode (ΔY_O)
- Change in negative sequence current (Δ 3* I_2)

These provide greater sensitivity and stability of performance.

Sensitivity comparisons

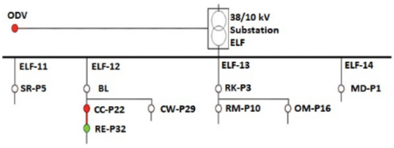
- Earthed neutral systems typically 200 – 2,000 Ω
- CN systems typically 5,000 – 20, 000 Ω



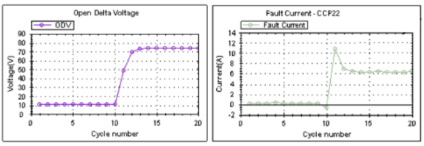
Characteristics of (Δ 3* I_2) functionality versus EN50522

Efficiency

- Even with optimised neutral treatment some outages are inevitable
- Efficient resupply of customers is important
- Synchronised line monitoring (SLM)
- Mobile fault indicators



Fault location diagram from SLM (at control centre and on smartphone or tablet)



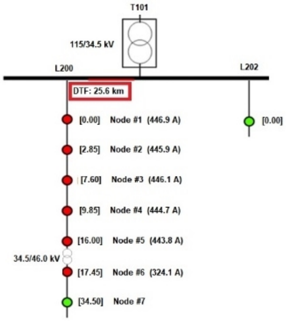
Fault voltage and current traces from SLM

In service performance of fault location

- Consistent location over 100 kms total network in < 1 hour

On the way

- SLM embedded in ADMS and FLISR
- Distance to fault on CN systems
  - Earth fault protection relays
  - SLM type fault location systems



Distance to fault diagram from SLM (earthed neutral system)

Conclusion

Hybrid neutral treatment solutions provide:

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