LIÈGE université
Sciences Appliquées

ELEC0029 - Electric power systems analysis

Case study: analysis of unbalanced faults in a small distribution network

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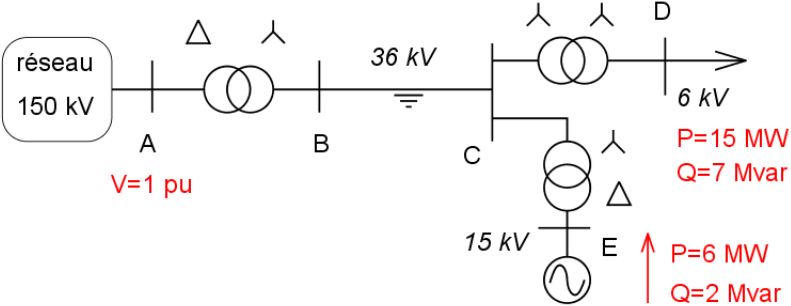
Objective

Perform a three-phase analysis of the small system shown below subjected to various faults

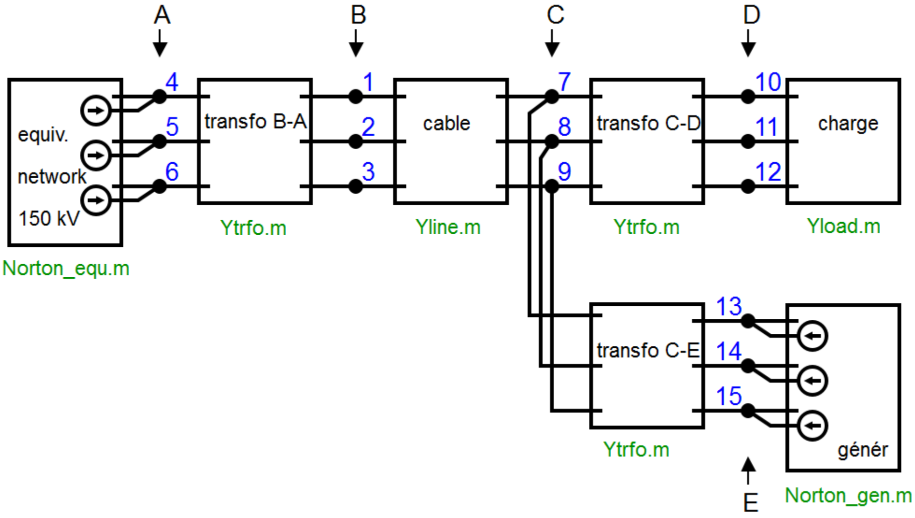


Procedure

1. Assuming that the system operates initially in balanced steady state, a power flow computation is performed to obtain the pre-fault voltages
2. the models and Matlab scripts detailed in the slides "Three-phase analysis of unbalanced systems" are used to assemble the nodal admittance matrix $\boldsymbol{Y}$ and the vector $\boldsymbol{I}$ of injected currents.
   This is performed in the Matlab script named `case_study_3ph.m`
3. (it is checked that the solution $\boldsymbol{V}$ of $\boldsymbol{Y}\boldsymbol{V} = \boldsymbol{I}$ matches the voltages given by the power flow computation)
4. the $\boldsymbol{Y}$ matrix is modified to account for the fault
5. the resulting linear system $\boldsymbol{Y}\boldsymbol{V} = \boldsymbol{I}$ is solved with respect to $\boldsymbol{V}$, from which all branch currents are computed.

Note. Zero-impedance short-circuits are simulated by adding a very large admittance in the three-phase circuit and adjusting accordingly the term(s) of $\boldsymbol{Y}$

Three-phase model: bus numbering



System parameters

- Cable B-C
  - thermal limit: 24 MVA
  - positive-sequence parameters: $R_+ = 0.909\Omega$, $X_+ = 1.659\Omega$, $B_+ = 645.1\mu S$
  - zero-sequence parameters: $R_o = 7.87\Omega$, $X_o = 3.470\Omega$, $B_o = 645.1\mu S$
- Transformer B-A
  - nominal apparent (three-phase) power: 27 MVA
  - ratio 150-kV voltage / 36-kV voltage $= 0.95 \angle 30^o$
  - positive-sequence parameters: $R = 0.005$, $X = 0.11$, $B = 0$ pu
  - zero-sequence parameters: $R_o = 0.005$, $X_o = 0.175$, $B_o = 0$ pu
- Transformer C-D
  - nominal apparent (three-phase) power: 20 MVA
  - ratio 6-kV voltage / 36-kV voltage $= 1.03 \angle 0$
  - positive-sequence parameters: $R = 0.006$, $X = 0.10$, $B = 0$ pu
  - zero-sequence parameters: $R_o = 0.006$, $X_o = 0.15$, $B_o = 0$ pu
- Transformer C-E
  - nominal apparent (three-phase) power: 10 MVA
  - ratio 15-kV voltage / 36-kV voltage $= 0.97 \angle 30^o$
  - positive-sequence parameters: $R = 0.006$, $X = 0.126$, $B = 0$ pu
  - zero-sequence parameters: $R_o = 0.006$, $X_o = 0.136$, $B_o = 0$ pu

- Generator at bus E
  - nominal apparent (three-phase) power: 10 MVA, connected in star
  - positive-sequence parameters: $R_+ = 0.005$, $X_+ = X'' = 0.13$ pu
  - negative-sequence parameters: $R_- = 0.01$, $X_- = 0.13$ pu
  - zero-sequence parameters: $R_o = 0.005$, $X_o = 0.07$ pu
- Load at bus D
  - connected in star
- 150-kV network equivalent
  - short-circuit capacity: 3 GVA

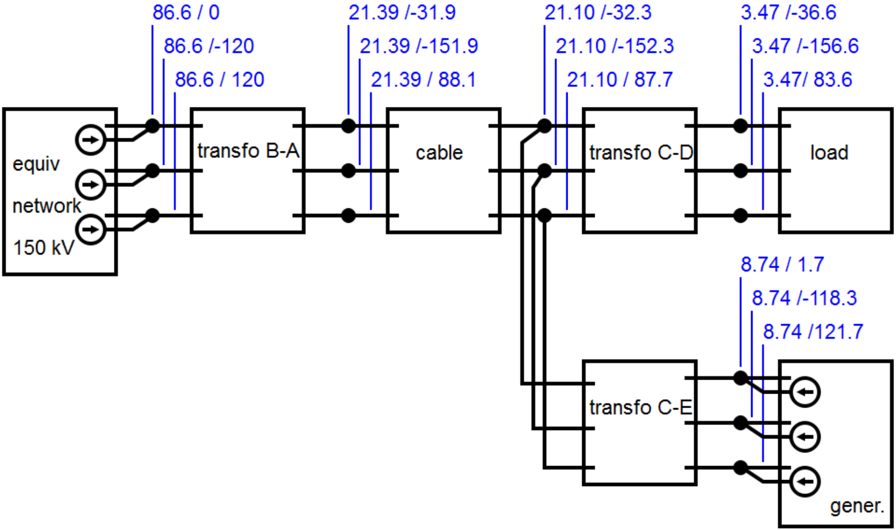
Results of initial power flow computation

```
bus  A          :         V= 1.0000 pu    0.00 deg        150.00 kV
        > B-A                        P=     9.2     Q=     5.7        > B
    gener  A                         P=     9.2     Q=     5.7      Vimp= 1.0000

bus  B          :         V= 1.0293 pu   -1.93 deg         37.06 kV
        > B-A                        P=    -9.2     Q=    -5.3        > A
        > B-C                        P=     9.2     Q=     5.3        > C

bus  C          :         V= 1.0154 pu   -2.33 deg         36.55 kV
        > C-D                        P=    15.1     Q=     8.5        > D
        > C-E                        P=    -6.0     Q=    -1.5        > E
        > B-C                        P=    -9.1     Q=    -6.9        > B

bus  D          :         V= 1.0011 pu   -6.57 deg          6.01 kV
        > C-D                        P=   -15.0     Q=    -7.0        > C
     load                            P=    15.0     Q=     7.0

bus  E          :         V= 1.0093 pu    1.70 deg         15.14 kV
        > C-E                        P=     6.0     Q=     2.0        > C
    gener  E                         P=     6.0     Q=     2.0      Vimp= 0.0000
```

- As explained in course ELEC0014, the phase shifts introduced by transformers are ignored in power flow computations
- hence the real voltage phase angles are obtained by subtracting 30^o from the above phase angles at buses B, C and D.

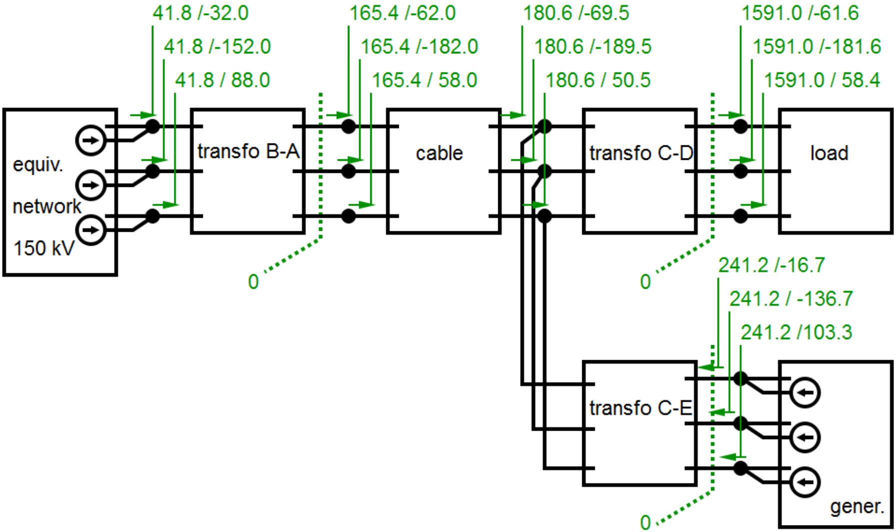
Initial operating point (before any fault)

Line to neutral (or line to ground) voltages (kV and deg)



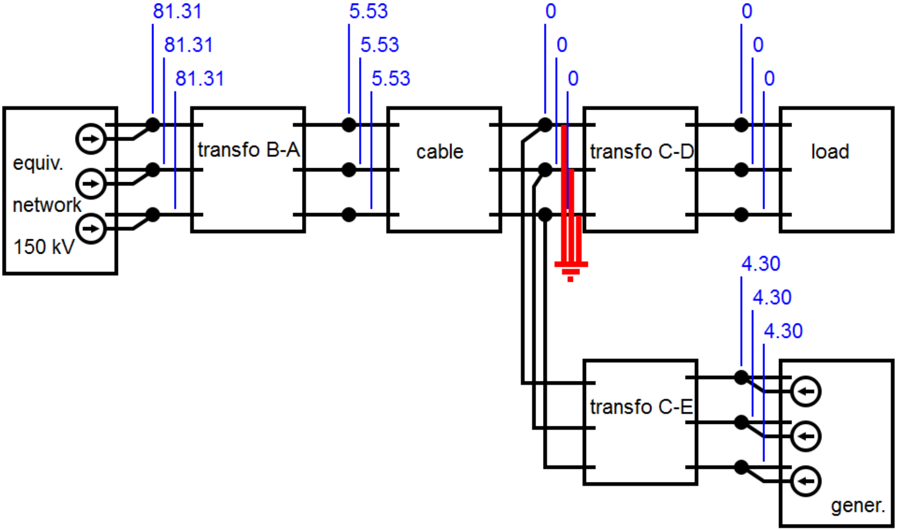
Initial operating point (before any fault)

Line currents and their algebraic sums (in A and deg)



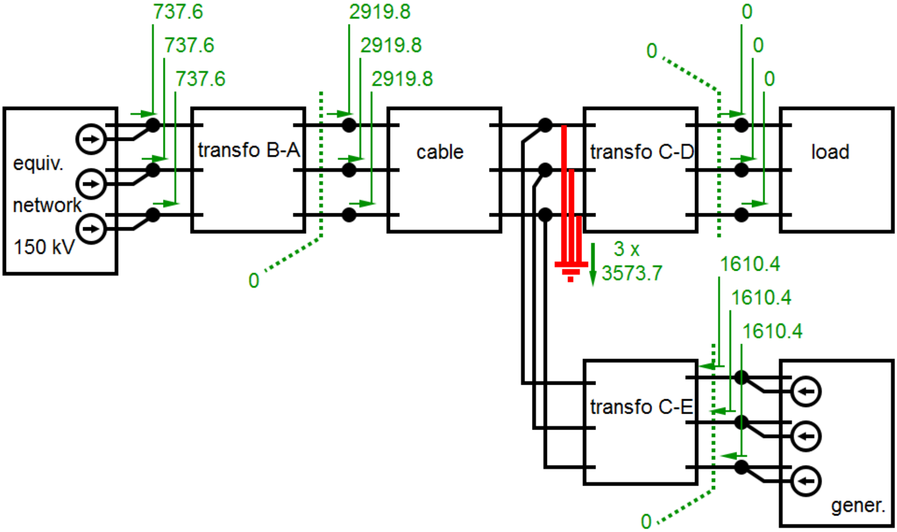
Three-phase short-circuit without impedance at bus C

Magnitudes of line to neutral (or line to ground) voltages (kV)



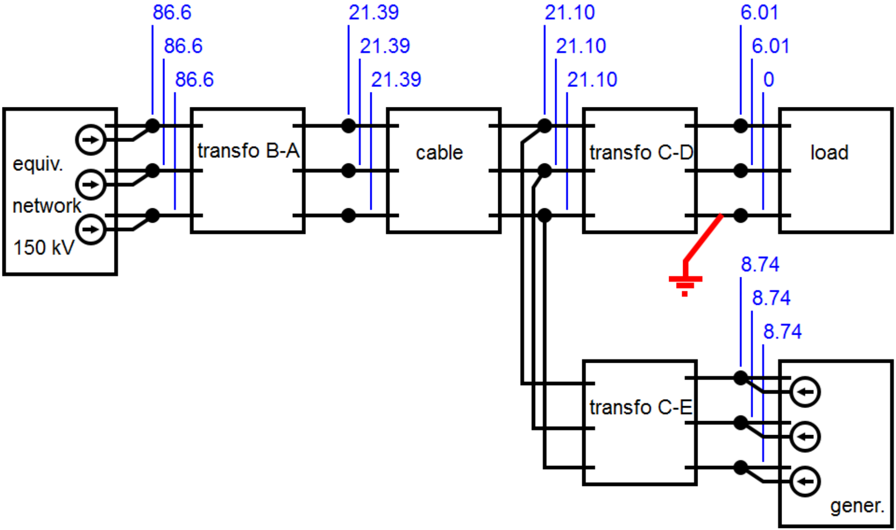
Three-phase short-circuit without impedance at bus C

Magnitudes of line currents and of their algebraic sums (A)



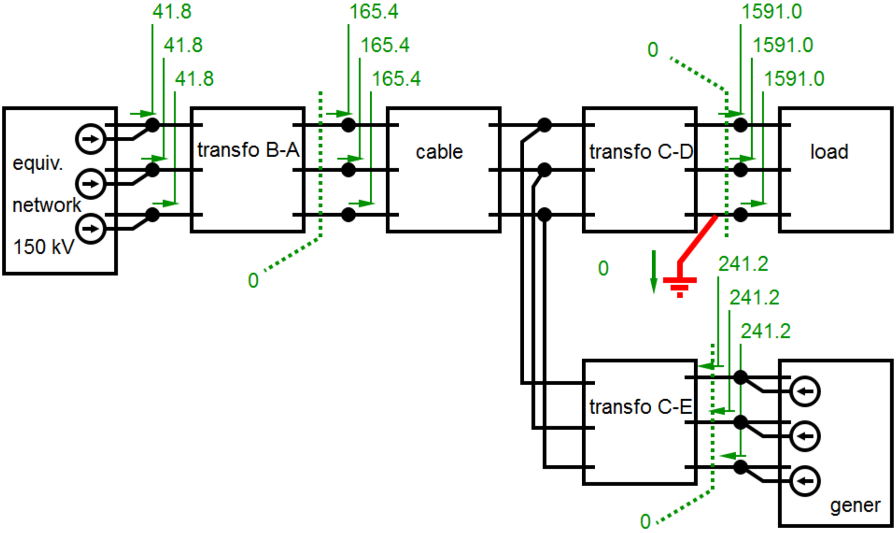
Single phase to ground at bus D - neutrals NOT grounded

Magnitudes of line to ground voltages (kV)



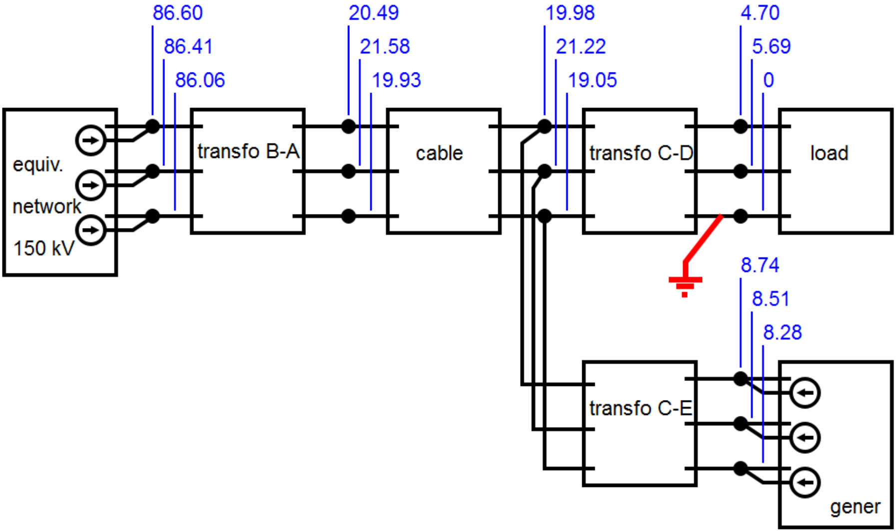
Single phase to ground at bus D - neutrals NOT grounded

Magnitudes of line currents and of their algebraic sums (A)



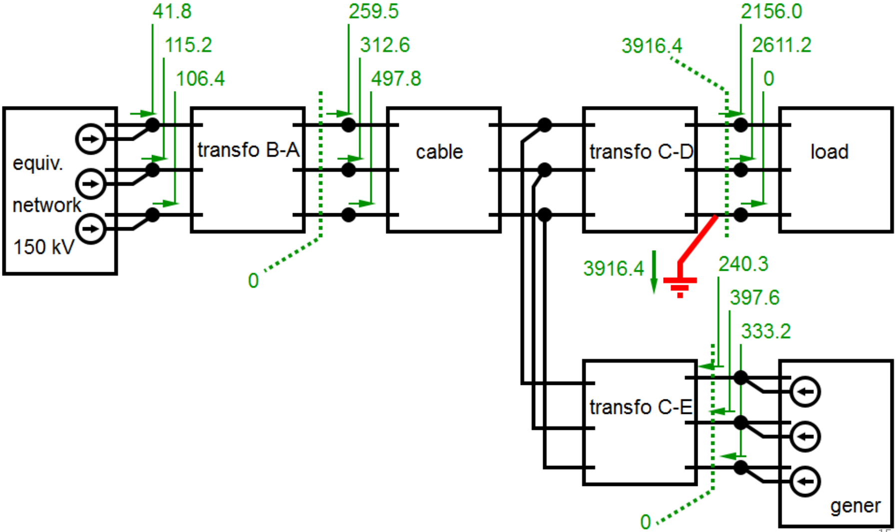
Single phase to ground at bus D - neutral of load grounded with zero impedance

Magnitudes of line to ground voltages (kV)



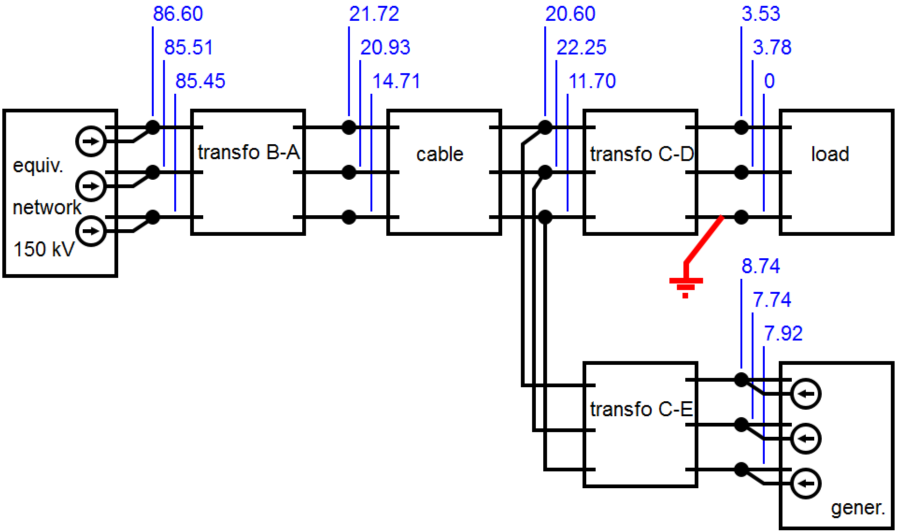
Single phase to ground at bus D - neutral of load grounded with zero impedance

Magnitudes of line currents and of their algebraic sums (A)



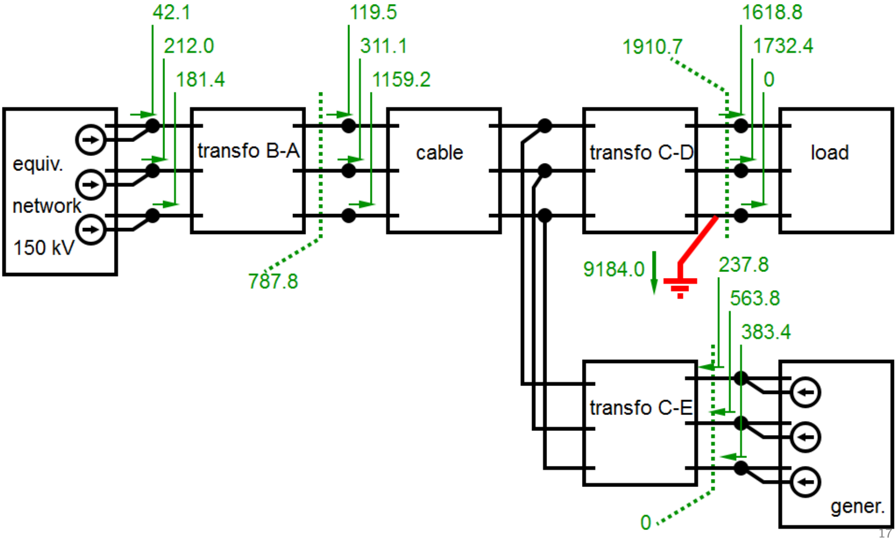
Single phase to ground at bus D - neutrals of load and transformers grounded with zero impedance

Magnitudes of line to ground voltages (kV)



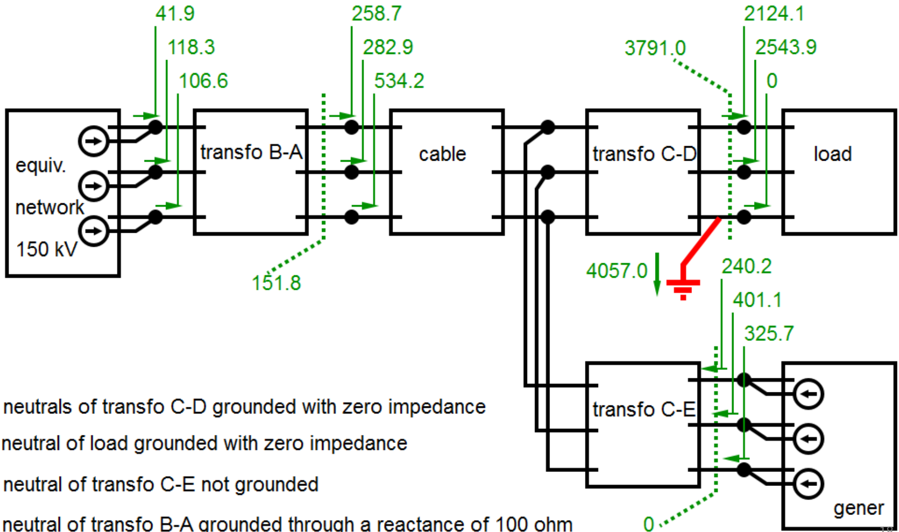
Single phase to ground at bus D - neutrals of load and transformers grounded with zero impedance

Magnitudes of line currents and of their algebraic sums (A)



Single phase to ground at bus D - one neutral grounded through a “Petersen” coil

Magnitudes of line currents and of their algebraic sums (A)



neutrals of transfo C-D grounded with zero impedance

neutral of load grounded with zero impedance

neutral of transfo C-E not grounded

neutral of transfo B-A grounded through a reactance of 100 ohm