WHITE PAPER

MDGF, Modified Differential Ground Fault

Index

Introduction

The need for more reliable electric power in commercial and industrial applications has caused the design of low-voltage distribution systems to migrate from simple, single-ended loadcenter unit substations to power systems with multiple utility sources, emergency and back-up generators and uninterruptible power sources.

In most of these double-ended substations, the use of the single-point ground method is unfeasible (for example when sources are located remotely from the switchgear and grounded at their location) therefore each source is grounded at a separate location and connected via the neutral bus in the low-voltage switchgear or switchboard. When there is a ground fault, this common neutral connection between sources provides an alternate path, in addition to the normal ground path, for ground fault current to flow. As result, standard ground fault protections (e.g. G or Gext) may not accurately detect the level of ground fault current and the overall ground protection system may not detect the source of the fault to prevent or reduce the severity of events.

The most efficient method of sensing ground fault current in multiple-source, 4-wire systems is a “modified differential ground fault” MDGF scheme. It provides accurate detection of the ground fault current, determining which portion of the circuit has the fault and selectively isolate the smallest portion of the power system to clear the ground fault. It also distinguishes between the operating neutral current and the ground fault current.

Where

Multi-sourced electrical system with a solidly grounded common neutral conductor (system often found in double-ended substation and generation paralleling gear applications)

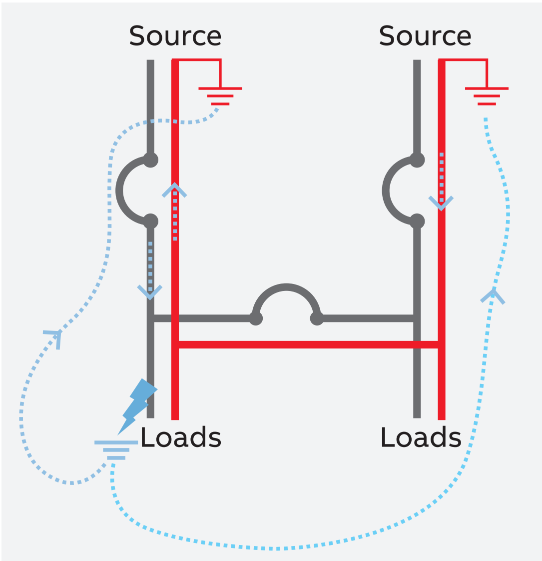
Why

Traditional ground fault protections do not work

How

Using an advance ground protection called MDGF

Figure 1: ground fault current distribution in a double-sourced electrical system with a solidly grounded common neutral conductor



This document aims to provide essential guidance for MDGF ABB solution, ensuring that all the components are used correctly and are seamlessly integrated to achieve optimal performance from the electrical system.

ABB solution

ABB provides a solution for different multi-sourced systems (MTM, MGTM, MGTMG, MG).

For example, the MTM system consists of 2 power sources main A and main B (e.g. transformers) with neutral solidly grounded at transformers' location and/or at service entrance equipment, shared between sources and loads.

The MDGF ABB solution for MTM configuration includes an algorithm inside circuit breakers, as well as some external hardware devices to detect the ground current correctly:

- 3 circuit breakers 3p (CB-A, CB-B and CB-C);
- 4 external phase current sensors (phase CTs) for each circuit breaker (12 in total);
- 3 external summing current sensors (summing CTs).

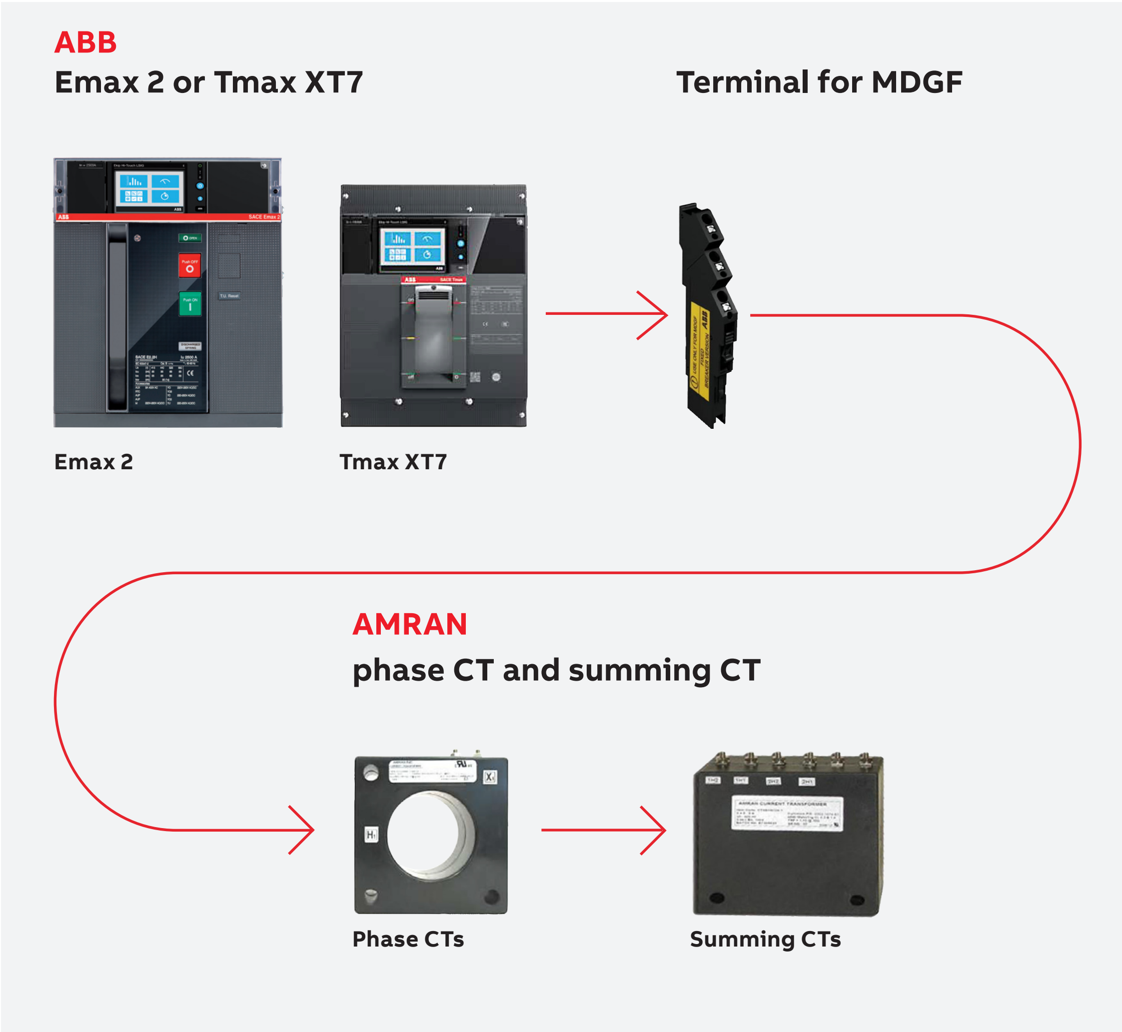
The following table shows solutions for all systems:

	N° circuit breakers	**N° phase CTs**	**N° summing CTs**
MTM	3	12	3
MGTM	4	16	4
MGTMG	5	20	5
MG	2	8	2

All the devices must be connected it as shown in the electrical wiring diagram 1SDM000019A1001

ABB solution

To use the MDGF protection with Emax 2 or Tmax XT7 circuit breakers, the following requirements are needed:
- touch trip unit with G protection;
- Mainboard firmware ≥3.23 and trip unit firmware ≥4.04;
- MDGF dedicated terminal for fixed or withdrawable version;
- Amran summing CTs and phase CTs to be purchased separately (http://www.amranit.com/)



Ordering examples

For ordering code, please refers so the catalog and remember that for MDGF solution:

- Circuit breakers must have 3 poles;
- G protection must be present;
- MDGF terminal must be chosen based on fixed or withdrawable CB version

It is important that all phase CTs related to the same summing CT and so to the same breaker, have the same size. But the groups of 4 CTs can have different sizes and summing CTs needs to be coherent with each group.

MTM

Description	Code	Quantity
E2.2B-A 1600 Ekip Touch LSIG 3p F HR	1SDA077233R1	3
Ekip Supply 110-240VAC/DC E1.2..E6.2-XT (1)	1SDA074172R1	3
MDGF Terminal for fixed circuit breaker	1SDA114800R1	3
Phase current sensor (2)	See the table below	12
Summing current sensor (2)	See the table below	3

(1) not mandatory for protection but suggested
(2) External phase CTs and summing CTs must be purchased separately

MGTM

Description	Code	Quantity
E1.2S-A 800 Ekip Touch LSIG 3p F F	1SDA076973R1	4
Ekip Supply 24-48VDC (1)	1SDA074173R1	4
MDGF Terminal for fixed circuit breaker	1SDA114800R1	4
Phase current sensor (2)	See the table below	16
Summing current sensor (2)	See the table below	4

(1) not mandatory for protection
(2) External phase CTs and summing CTs must be purchased separately

MGTMG

Description	Code	Quantity
E6.2H-A 5000 Ekip Touch LSIG 3p WMP	1SDA079083R1	5
E6.2-A W FP 5000 3p HR HR	1SDA079706R1	5
Ekip Supply 110-240VAC/DC E1.2..E6.2-XT (1)	1SDA074172R1	5
MDGF Terminal for withdrawable circuit breaker	1SDA114798R1	5
Phase current sensor (2)	See the table below	20
Summing current sensor (2)	See the table below	5

(1) not mandatory for protection
(2) External phase CTs and summing CTs must be purchased separately

MG

Description	Code	Quantity
E4.2V-A 800 Ekip Touch LSIG 3p WMP	1SDA078493R1	2
E4.2-A W FP 2500 3p HR HR	1SDA079700R1	2
Ekip Supply 110-240VAC/DC E1.2..E6.2-XT (1)	1SDA074172R1	2
MDGF Terminal for withdrawable circuit breaker	1SDA114798R1	2
Phase current sensor (2)	See the table below	8
Summing current sensor (2)	See the table below	2

(2) not mandatory for protection
(3) External phase CTs and summing CTs must be purchased separately

Amran Phase CTs and Summing CTs compatible with SACE Emax 2 MDGF scheme must be purchased separately with following codes:

Current rating (A)	Phase current transformer	Summing current transformer
800	CT409-801-01 or CT420-801-01 or CT430-801-01	CT550-5X4-01000
1200	CT409-122-01 or CT420-122-01 or CT430-122-01	CT550-5X4-01515
1600	CT409-162-01 or CT430-162-01	CT550-5X4-02000
2000	CT409-202-01 or CT421-202-01 or CT430-202-01	CT550-5X4-02500
2500	CT409-252-01 or CT421-252-01 or CT430-252-01	CT550-5X4-03125
3200	CT409-322-01 or CT421-322-01 or CT430-322-01	CT550-5X4-04167
4000	CT421-402-01 or CT430-402-01	CT550-5X4-05000
5000	CT421-502-01 or CT430-502-01	CT550-5X4-06250
6000	CT422-602-01 or CT430-602-01	CT550-5C4-07692

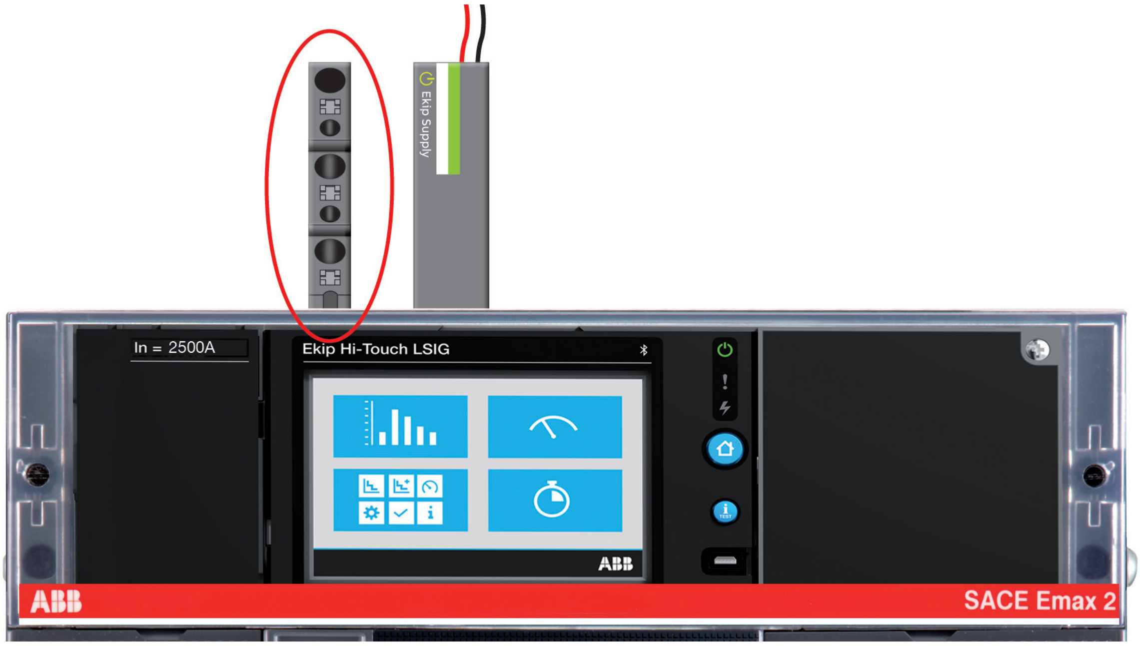
User guide

Step-by-step settings with Emax 2 and XT7 HMI are shown in this part. Please have a look at *1SDH001330R1002* and *1SDH001316R1002* to ensure the trip unit’s firmware and HMI's firmware are sufficient to manage MDGF.

Consider the following definition:

- "In" refers to the rating plug size which is supplied with the trip unit and established the rated current. It is visible on the HMI left side;
- "Iu" is the Rated uninterrupted current at 40°C. It is specified in the CB plate;
- "MDGF In Size" refers to the size of the phase CTs and summing CTs related to that breaker. It has to match exactly with the phase CT primary current to work correctly. The value can be set within the 100 A to Iu value range, given in 1 A steps.
  For example for CT421-402-01 (Amran), "MDGF In Size" needs to be set to 4000A;
- "I41" is the MDGF protection threshold which establishes the value that activates the protection and contributes towards calculating the trip time.
  Value is given as both absolute value (Amperes) and relative value (In which in this case refers to "MDGF In Size") and can be set within a range: 0.1 In to 1 In, in 0.001 In steps. For UL, the I41 can reach maximum 1200 A.

1. Provide power to the Ekip Supply module (using 110-240 Vac/dc or 24-48 Vdc) or directly with 24 Vdc. Install the MDGF terminal in order to be able to connect the pins Ge+ and Ge-;



2. Click on the “settings” menu;

3. Click “Circuit Breaker” setting and click on “Ground Protection”;

4. Click “External Toroid” and select “MDGF”;

5. Define the size of the phase CTs related to the CB pressing "MDGF In Size". "MDGF In Size" can be set up to the Iu;

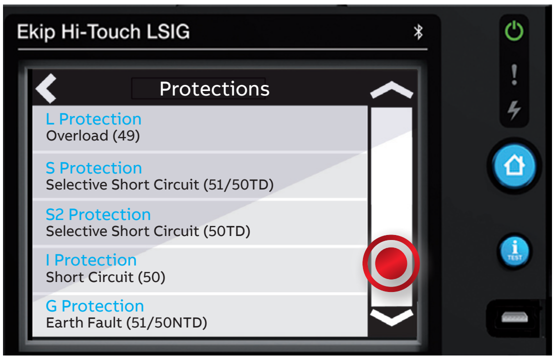
User guide

6. Press home button to return to the default screen and click “confirm” to finalize the configuration;

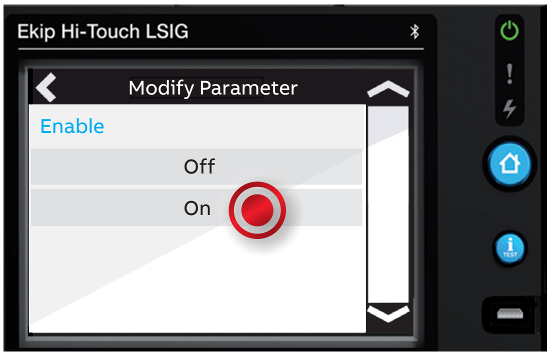
7. Navigate to the protection settings menu;

8. Click “protection” settings;

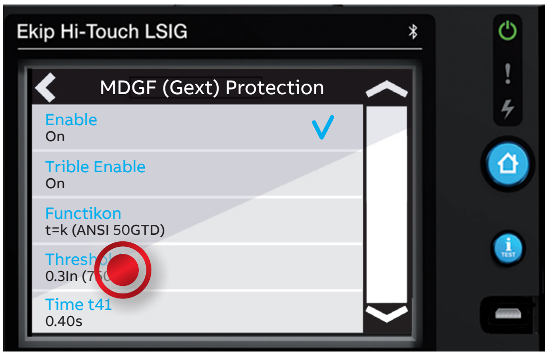
9. Scroll down and click on “MDGF (Gext) Protection”;



10. Select “Enable” and then select “on”;

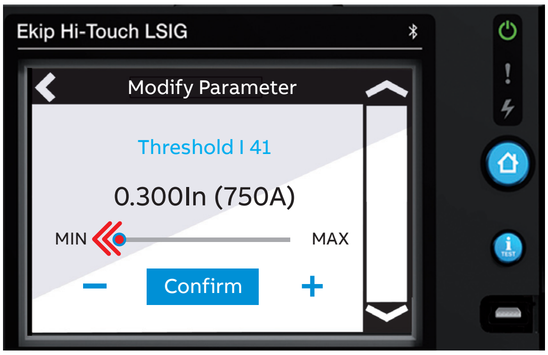


11. Click on “Threshold”;

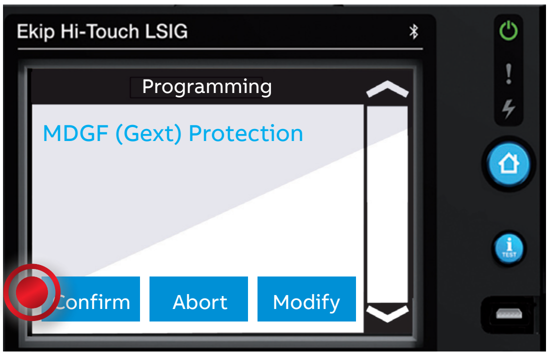


User guide

12. Set the MDGF threshold (I41). The value is given as both absolute value (A) and relative value of In (where In is the "MDGF In Size" set before). For UL breakers, I41 can be set up to 1200 A.



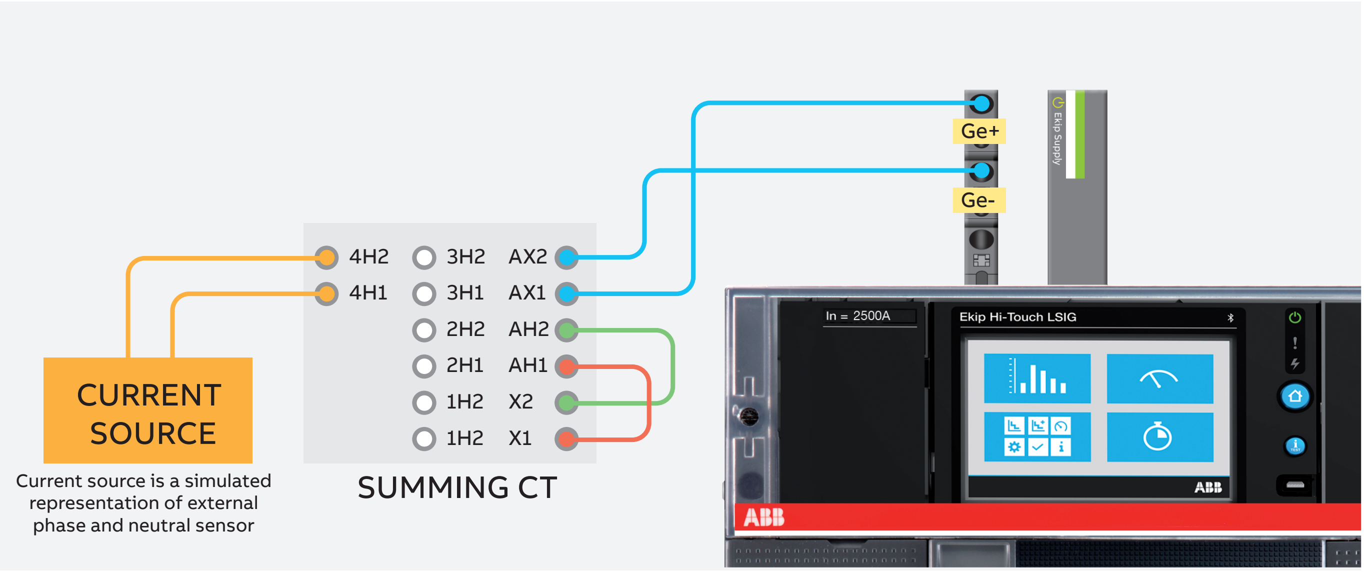
13. Press home button and click “confirm” to finalize the configuration.



Similar procedure can be done through Ekip Connect 3

Test

Follow the procedure below to test the summing CTs, check the wiring to the CB terminal and ensure that MDGF is turned on and configured properly. Please note that this procedure does not test any phase CTs, phase CT wiring or polarity. It can be done via the touch HMI or using Ekip Connect.



At first follow the previous "User Guide" chapter and set I41 at 0.2In. Then:

- Provide power to the Ekip Supply module (using 110-240V AC/DC or 24 48Vdc) or directly with 24Vdc
- Connect X1 to AH1, connect X2 to AH2
- Connect AX1 to Ge+, connect AX2 to Ge-
- Inject 0.85A AC on input 4H1 & 4H2, check to make sure the circuit breaker DOES NOT TRIP
- Inject 1.15A AC on input 4H1 & 4H2, check to make sure the circuit breaker DOES TRIP
- Repeat the same test for all other summing CT inputs

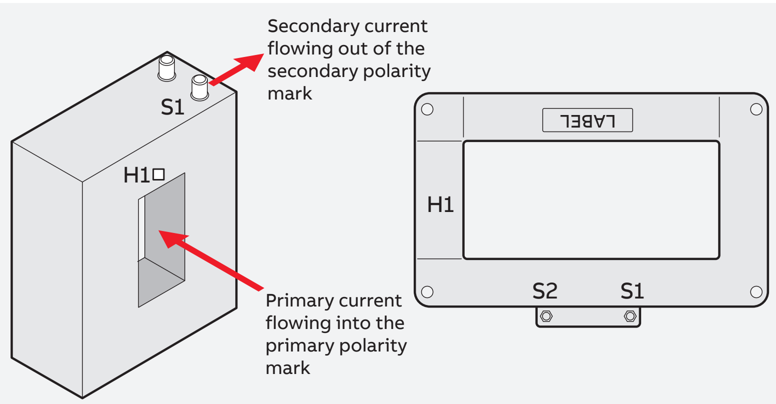
Circuit analysis

Fundamental principles

To analyze circuits like those shown in figure 4, 11, 13 and 15, some fundamental principles are described:

1- phase CTs are polarity marked and they are of the window type. The primary polarity mark (e.g. H1) is placed on the surface of the primary window and the secondary polarity mark (e.g. S1) is next to one of the two secondary terminals (Figure 2).
These symbols mean that at any point of time, if a current is flowing into a primary polarity mark, a corresponding secondary current will flow out of the secondary polarity marked terminal;

Figure 2



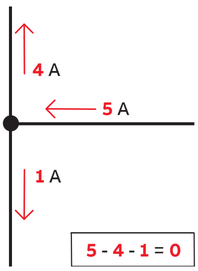


Figure 3: the algebric sum of the currents toward any point in a network is zero

2- the secondary current of phase CT or summing CT is proportional to the primary current. If the primary current is zero, the secondary current is zero. It is important that all CTs related to the same summing CT and so to the same breaker have the same ratio; in general, the groups of 4 CTs can have different ratios and summing CTs needs to be coherent with each group.

3- Kirchhoff's current law states that the sum of the currents flowing toward a junction point in a network is equal to the sum of the currents flowing away from that point (Figure 3).

Procedure

For main-tie-main (MTM) configuration, three different scenarios have been analyzed and tested:

Scenario	Main A CB-A	Tie CB-C	Main B CB-B
1	closed	open	closed
2	open	closed	closed
3	closed	closed	closed

For each of the three scenarios, the analysis considers the system response due to:

- a single-phase current (unbalanced system, no ground fault);
- a single-phase ground fault.

While for MGTM, MGTMG and MG all possible scenarios have been tested but for simplicity of representation only 1 scenario for each is analyzed in the document.

1- Each scenario assumes a specific value of the ground fault current and a particular ground return path. Even if some seem illogical, as long as Kirchhoff's rules are followed correctly, the circuit works correctly, isolating only the affected portion of the electrical circuit.

2- Depending on the current flow, each phase CT measures a certain value of current. To simplify the theoretical analysis, the ratio of the phase CTs is ignored, and primary and secondary currents are considered on a per-unit basis. If a one-per-unit current flows into a polarity marked primary winding (e.g. H1), then a one-per-unit current flow must out of the polarity mark on the secondary side (e.g. S1). If the primary current is zero, any current flows in the secondary winding.

3- Using Kirchhoff's law, the secondary currents are resolved at every node. Sometimes a node may have one known and two unknown values, which initially makes it impossible to resolve the analysis. The analysis at this node is temporarily abandoned and another node is analyzed. Node by node, satisfying all the principles of circuit analysis, the right balance of currents will be achieved.
It is important to ensure that each current associated with a secondary phase CT connection (e.g. S1) is properly divided, recombined, and returned to the other secondary connection of that CT (e.g. S2).

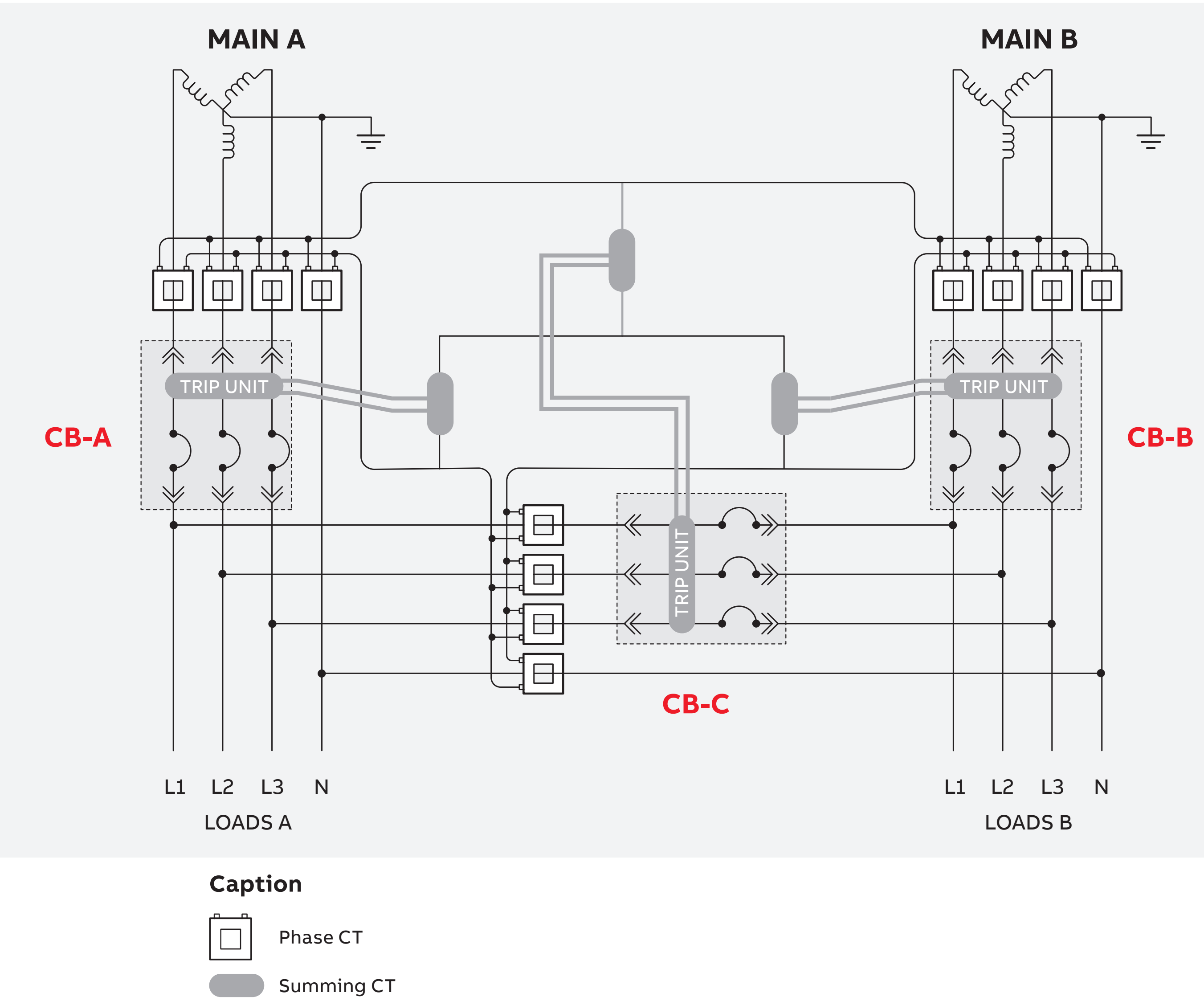
4- Finally, once the secondary circuit current flow is established, each summing CT measures a current and it sends that current to the corresponding CB relay opening it if this value is different from 0.

Application examples

To better understand the MTM working principle, the equivalent circuit is considered in Figure 4. MTM consists of two sources as well as a Tie.

This configuration involves the use of 3 circuit-breakers, 12 phase CTs and 3 summing CTs.

Figure 4: Equivalent MDGF scheme for MTM configuration



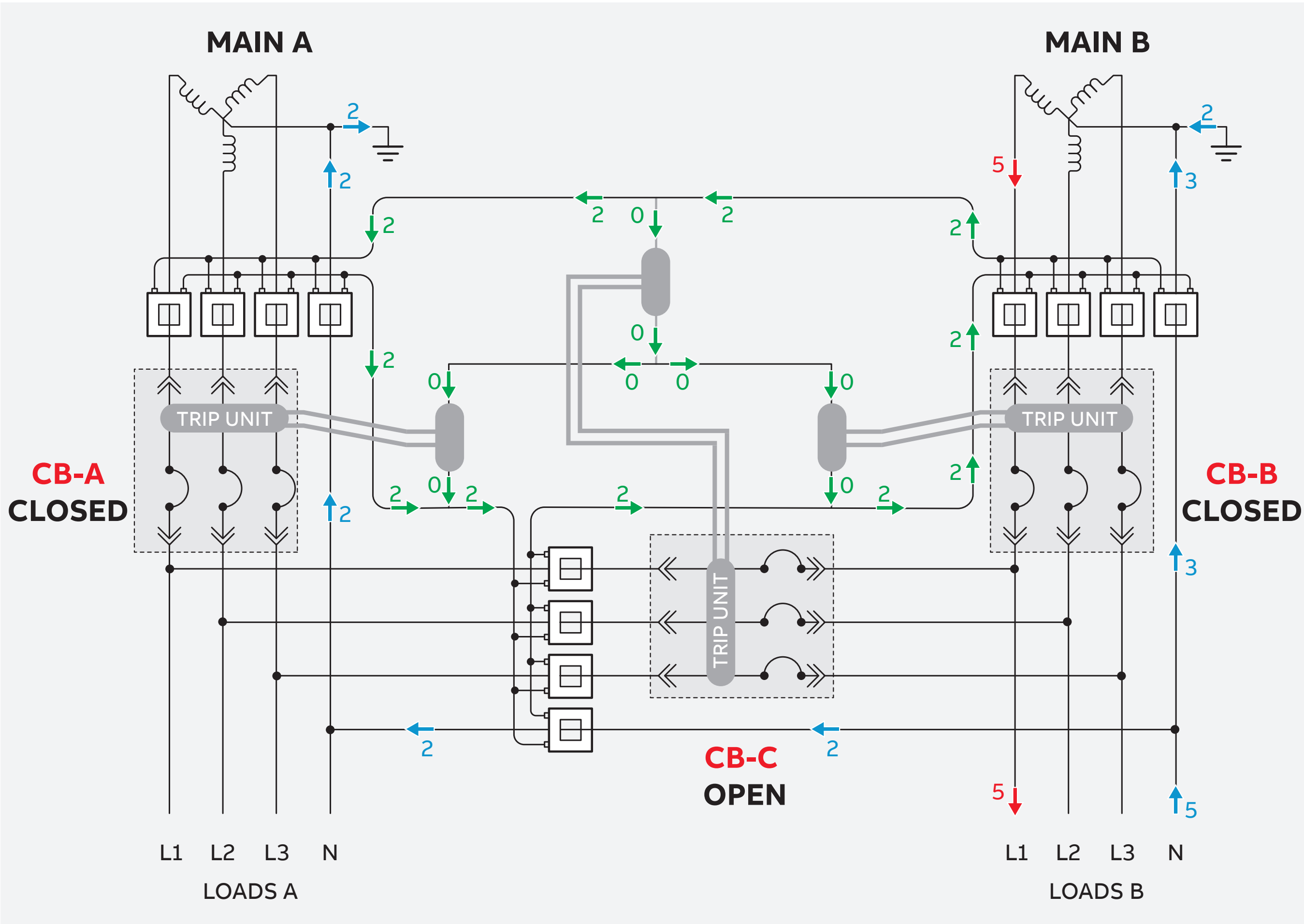
Application examples

1st scenario: CB-A and CB-B closed, CB-C open

1- Single phase current (unbalanced system, no ground fault): it is assumed that 5 p.u. single load flows on L1 phase (loads B side), and that 3 p.u. returns through the neutral conductor to the main B transformer.

The remaining 2 p.u. returns to main B through the neutral tie, main A ground, earth, main B ground. Resolving the circuit, each summing CT measures 0 p.u. and the system continues to operate correctly without false tripping for each CB.

Figure 5 - MTM configuration, 1st scenario , no ground fault



Caption

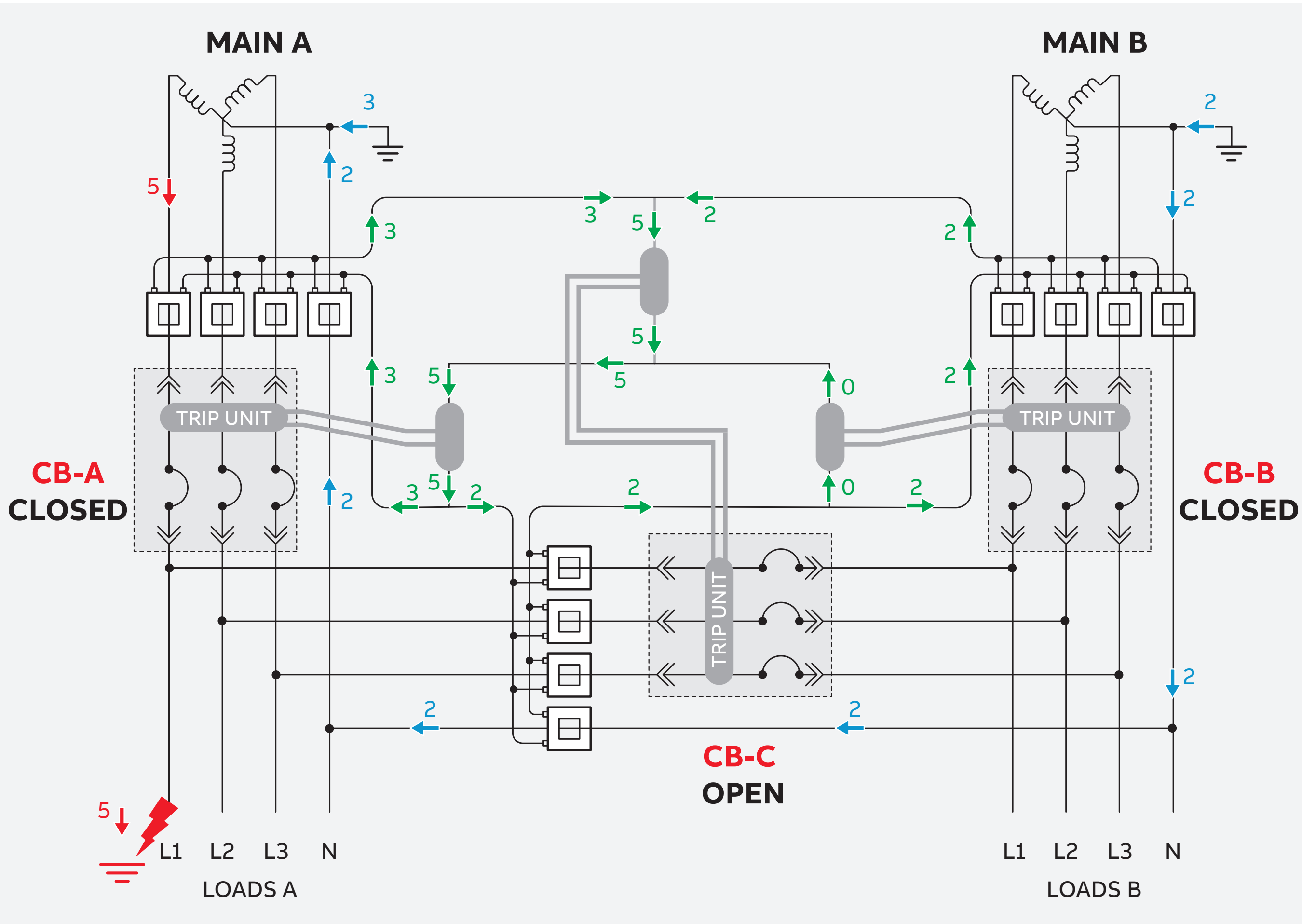
Phase CT

Summing CT

2- Ground fault: if there is a single-phase ground fault on bus L1 (loads A side), the current should divide as a function of the relative ground impedance parameters, which are extremely difficult to assess since it has two paths through which can return to transformer A.
Any magnitude may be chosen to enter the two grounded point, but the circuit analysis would achieve identical results upon summing CT.
Let us suppose that 3 p.u. enters the source A ground and the remaining 2 p.u. enters source B ground. It will go through neutral to source A.

Resolving the circuit, the result is that summing CT connected to CB-C and CB-A receives a signal current equal in p.u. value to the current provided from the supply source into the ground fault (5 p.u.). How the current returns to source A does not affect the current summation in the summing CT. A trip signal is sent to both CB-A (as expected) and to the already open CB-C (this is not an issue).

Figure 6 - MTM configuration, 1st scenario, ground fault



Caption

Phase CT

Summing CT

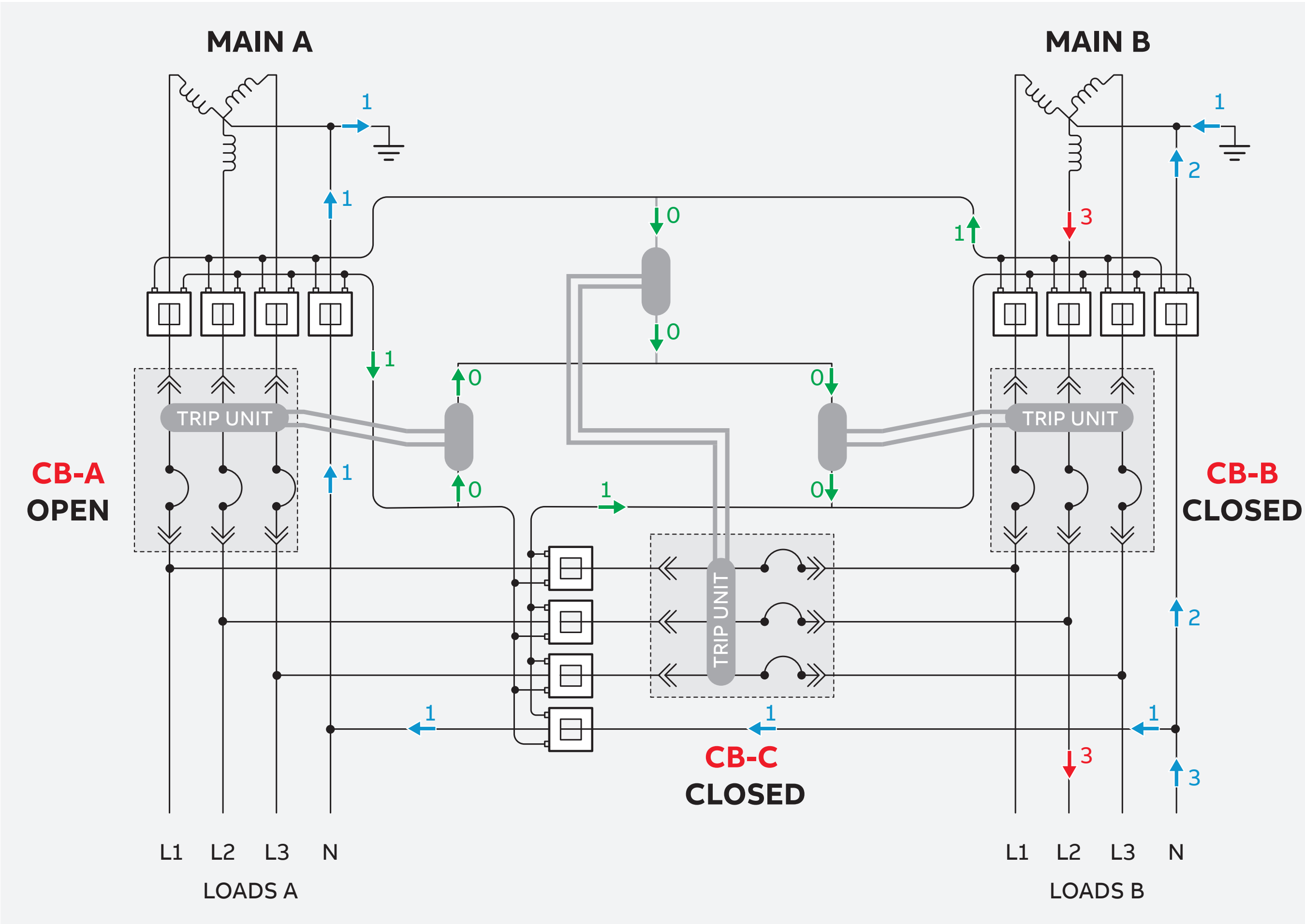
Application examples

2nd scenario CB-A open, CB-B closed, CB-C closed

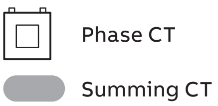
1- Single phase current (unbalanced system, no ground fault): it is assumed that 3 p.u. single load flows on L2 phase (loads B side) and that 2 p.u. returns through the neutral conductor to the main B transformer.

The remaining 1 p.u. returns to main B through the neutral tie, main A ground, earth, main B ground.
Resolving the circuit, each summing CT measures 0 p.u., and the system continues to operate correctly without false tripping for each CB.

Figure 7 - MTM configuration, 2nd scenario, no ground fault



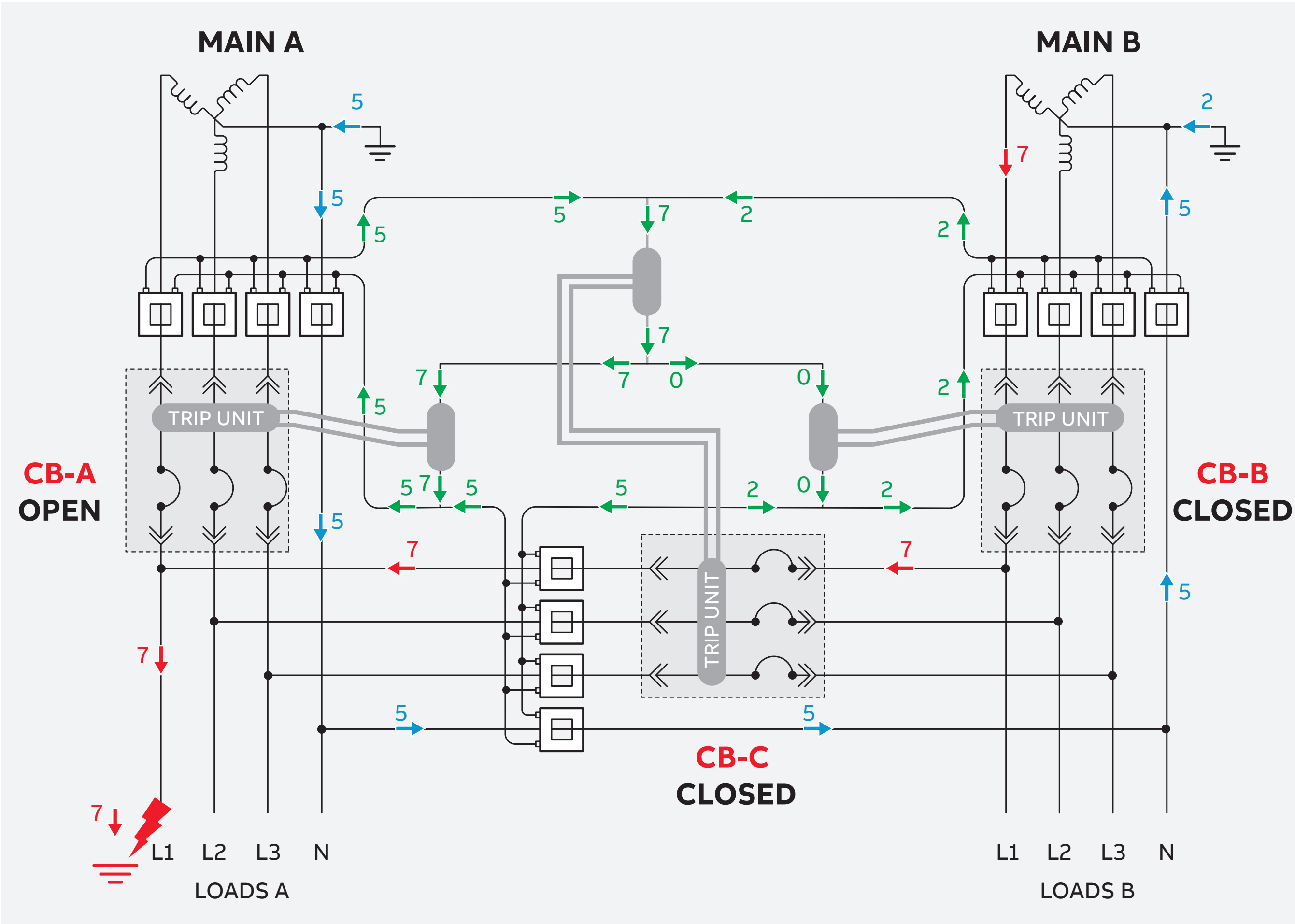
Caption



2- Ground fault: if there is a single-phase ground fault on bus 1 (Loads A side), resolving the circuit with similar previous assumptions, the system works properly (only CB-C opens and CB-A remains open).

In general, in the case of a double-ended substation with one of the two main circuit breakers closed and the tie circuit breaker closed, the system will trip the tie circuit breaker only if the ground fault is located on the side with the open main.

Figure 8 - MTM configuration, 2nd scenario, ground fault



Caption

Phase CT

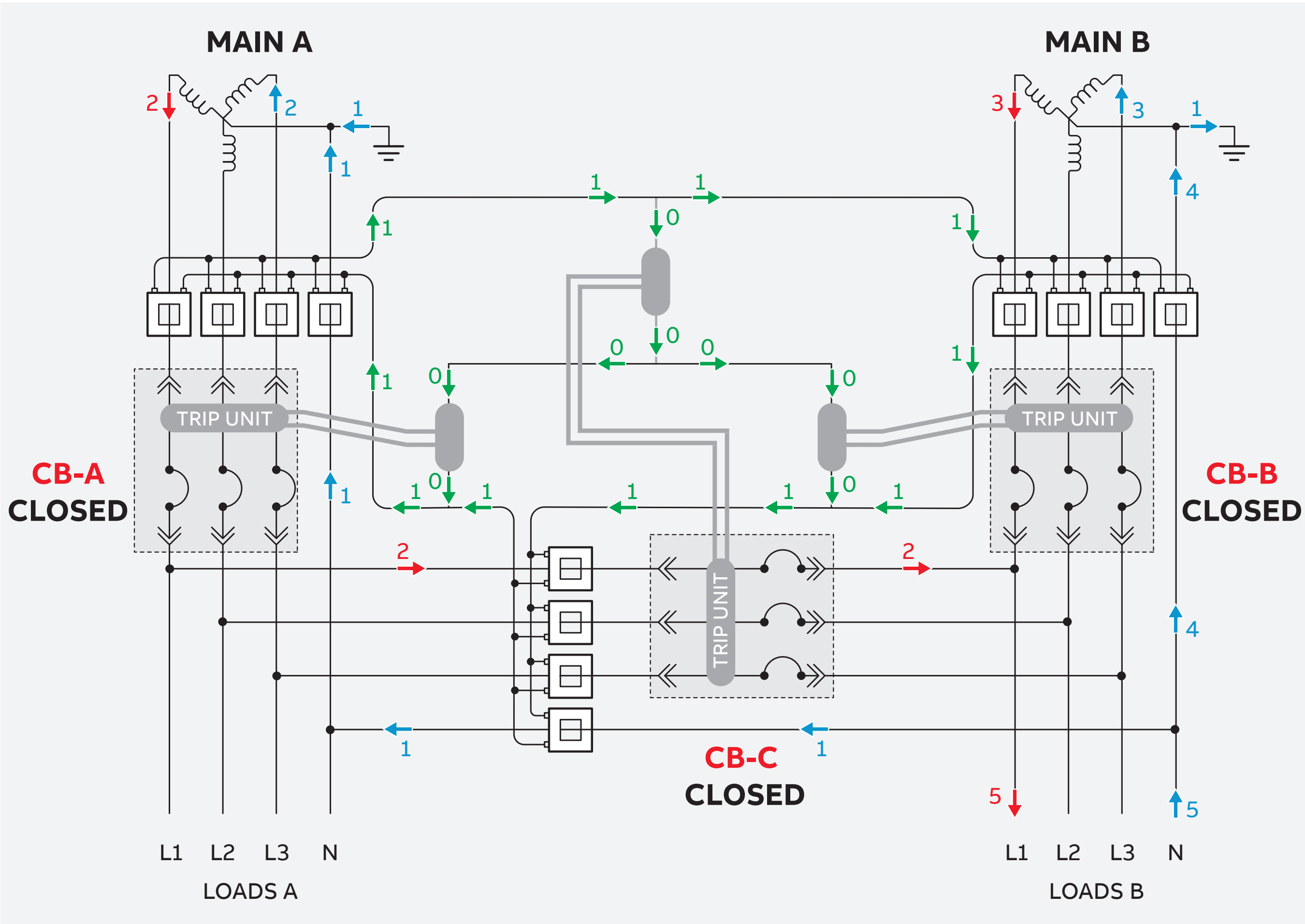
Summing CT

Application examples

3rd scenario: CB-A, CB-B and CB-C closed

1- Single phase current (unbalanced system, no ground fault): it is assumed that a 5 p.u. single load flows in the L1 phase (loads B side). Since all CBs are closed, the single-phase load is supplied by both sources. It is assumed that 2 p.u. is supplied by source A, and the remaining 3 p.u. from source B. It is assumed that 4 p.u. returns through the neutral conductor to the source B transformer. For Kirchhoff's law, 1 p.u. will flow to source A neutral.
Resolving all the circuit, the summing CT measures 0 p.u., and the system continues to operate correctly without false tripping for each CB.

Figure 9 - MTM configuration, 3rd scenario, no ground fault



Caption

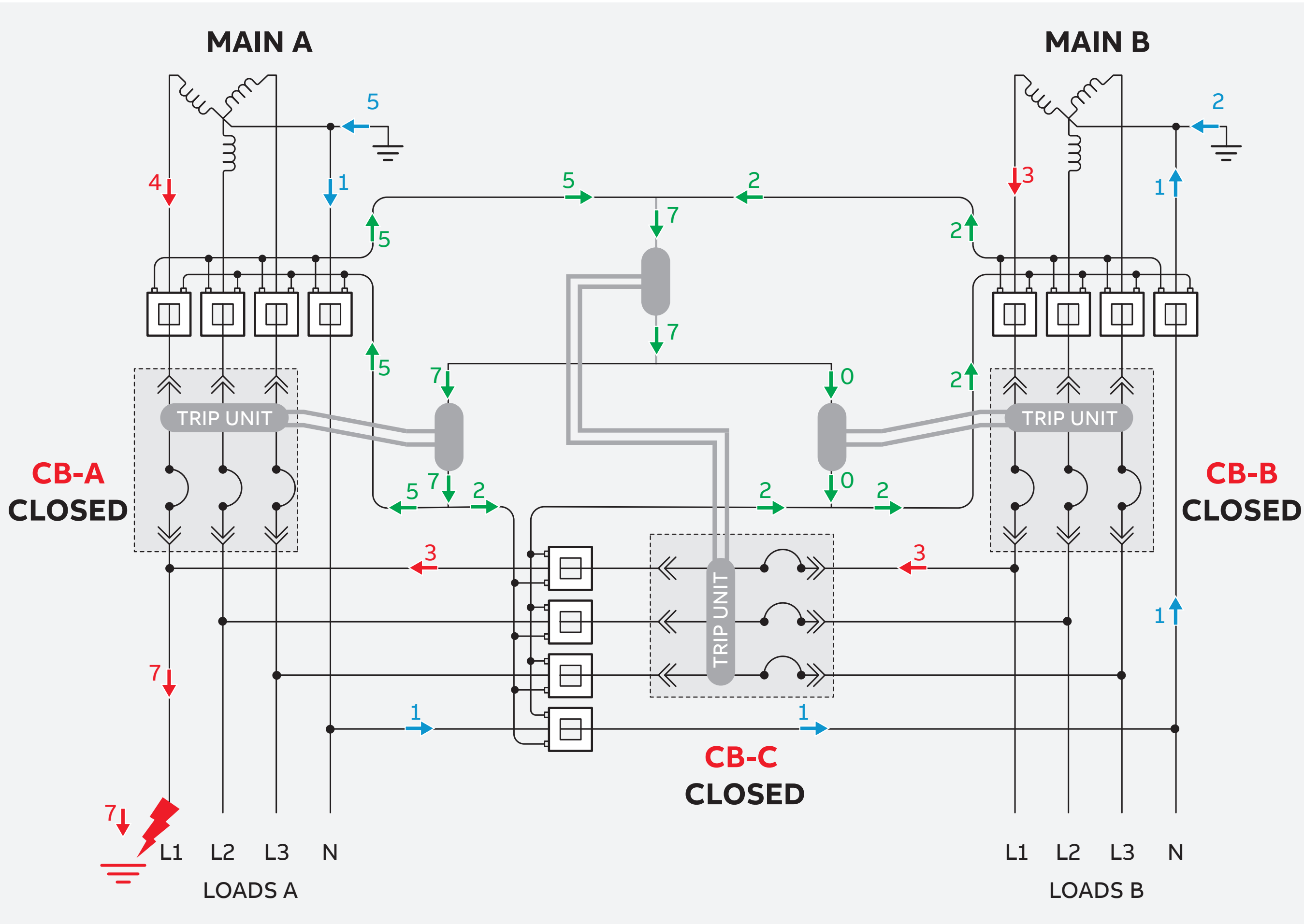
Phase CT

Summing CT

2- Ground fault: if there is a single-phase ground fault on bus 1, resolving the circuit with similar previous assumptions, the system works properly (both CB-A and CB-C open)

In general, in the case of a double-ended substation with all three circuit breakers closed, the system will trip the two circuit breakers capable of supplying power to the faulted bus.

Figure 10 - MTM configuration, 2nd scenario, ground fault



Caption

Phase CT

Summing CT

Tabel summary of the analyzed scenarios

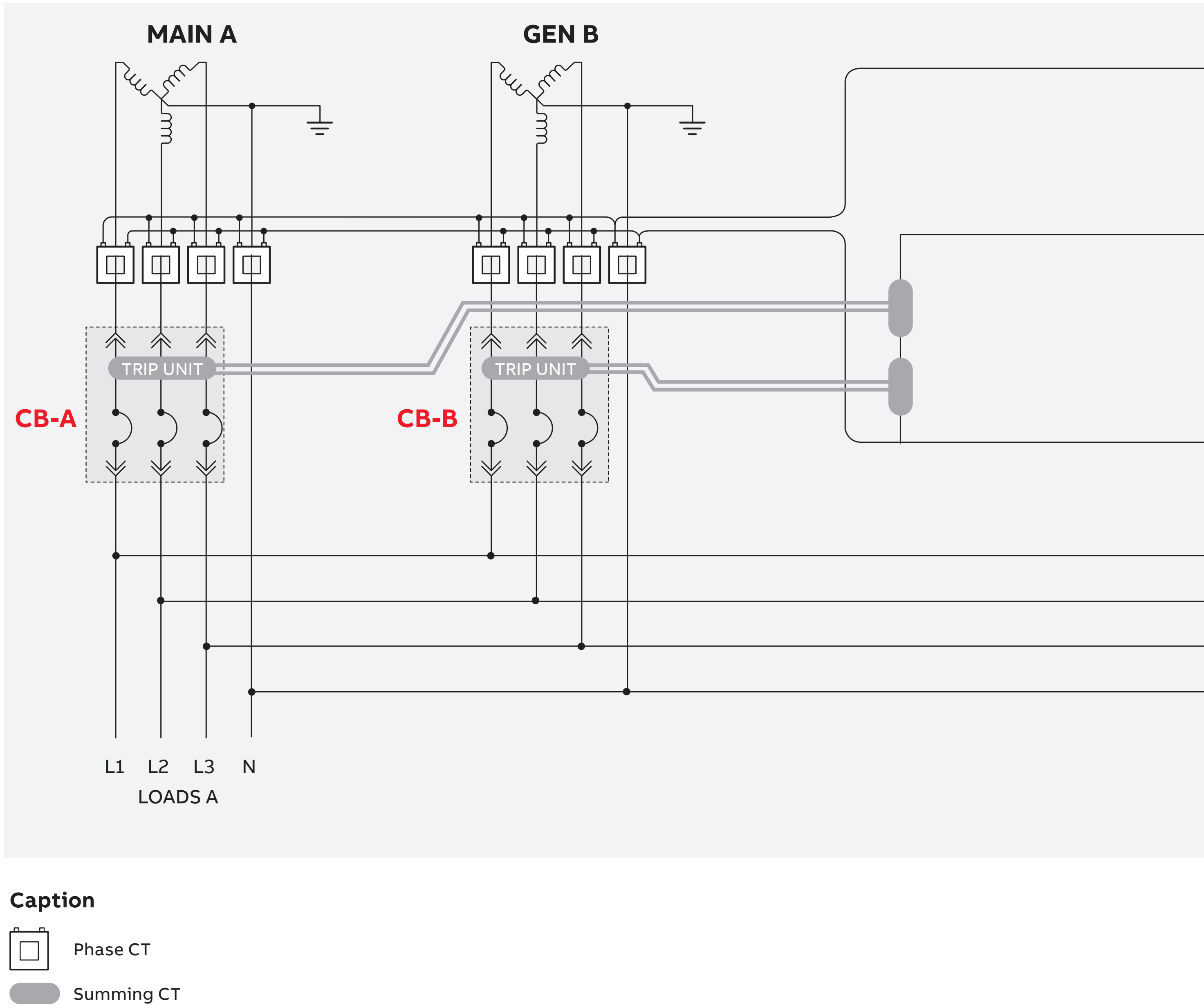
Scenario	CB-A	CB-C	CB-B	Fault	Expected results after fault
1	CLOSED	OPEN	CLOSED		Trip CB-A No trip CB-B
2	CLOSED	CLOSED	CLOSED	Side A	Trip CB-A Trip CB-C No trip CB-B
3	OPEN	CLOSED	CLOSED		Trip CB-C No trip CB-B

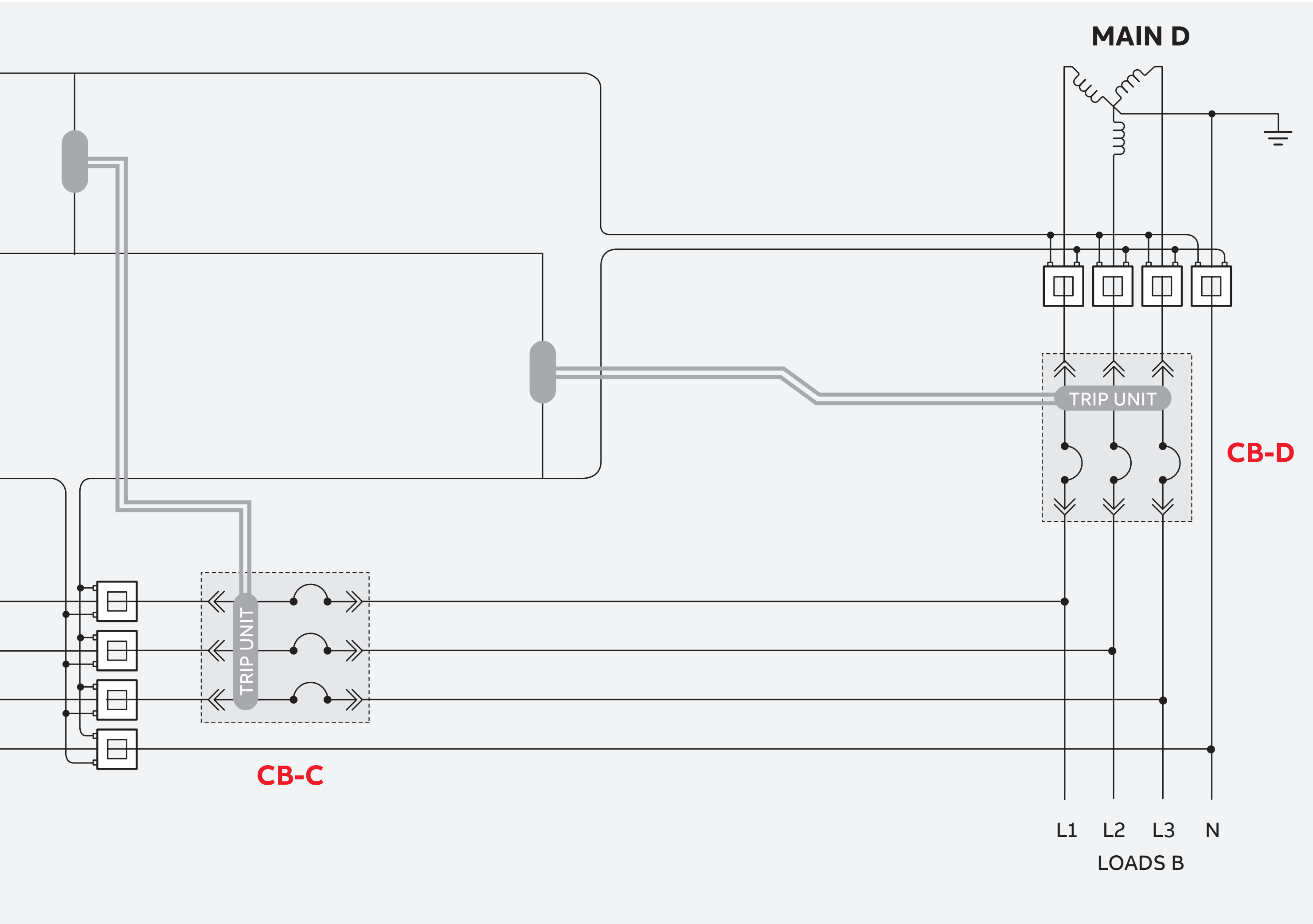
Since all the scenarios can also be considered symmetrical, the same principles and considerations apply to a fault on the B side.

Application examples

To better understand the MGTM working principle, the equivalent circuit is considered in Figure 11. MGTM consists of two sources and a generator (in case it is necessary to use it as an alternative or to support source A) as well as a Tie. This configuration involves the use of 4 circuit-breakers, 16 phase CTs and 4 summing CTs.

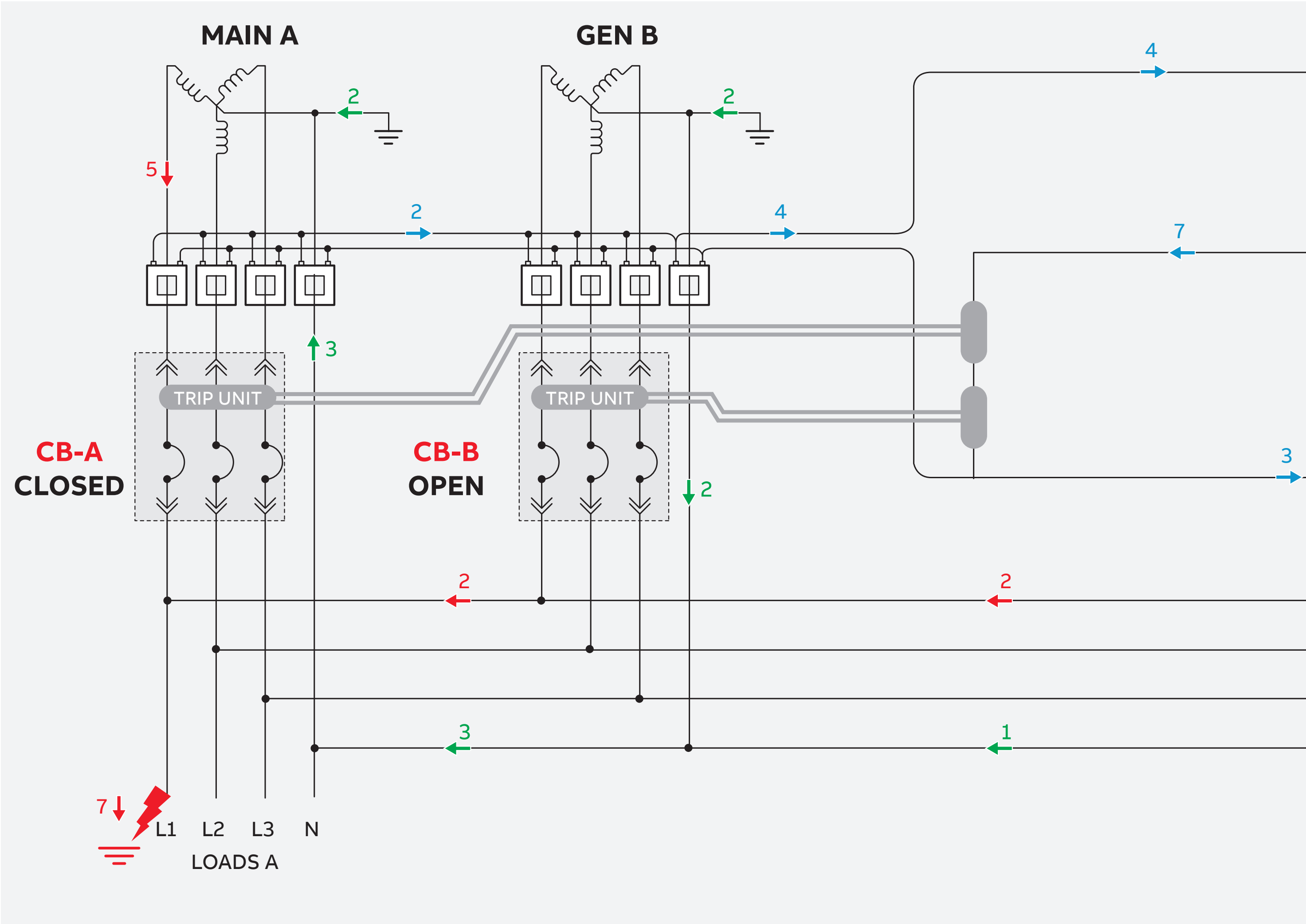
Figure 11 - Equivalent MDGF scheme for MGTM configuration



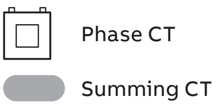

MAIN D
TRIP UNIT
CB-D
TRIP UNIT
CB-C
L1
L2
L3
N
LOADS B

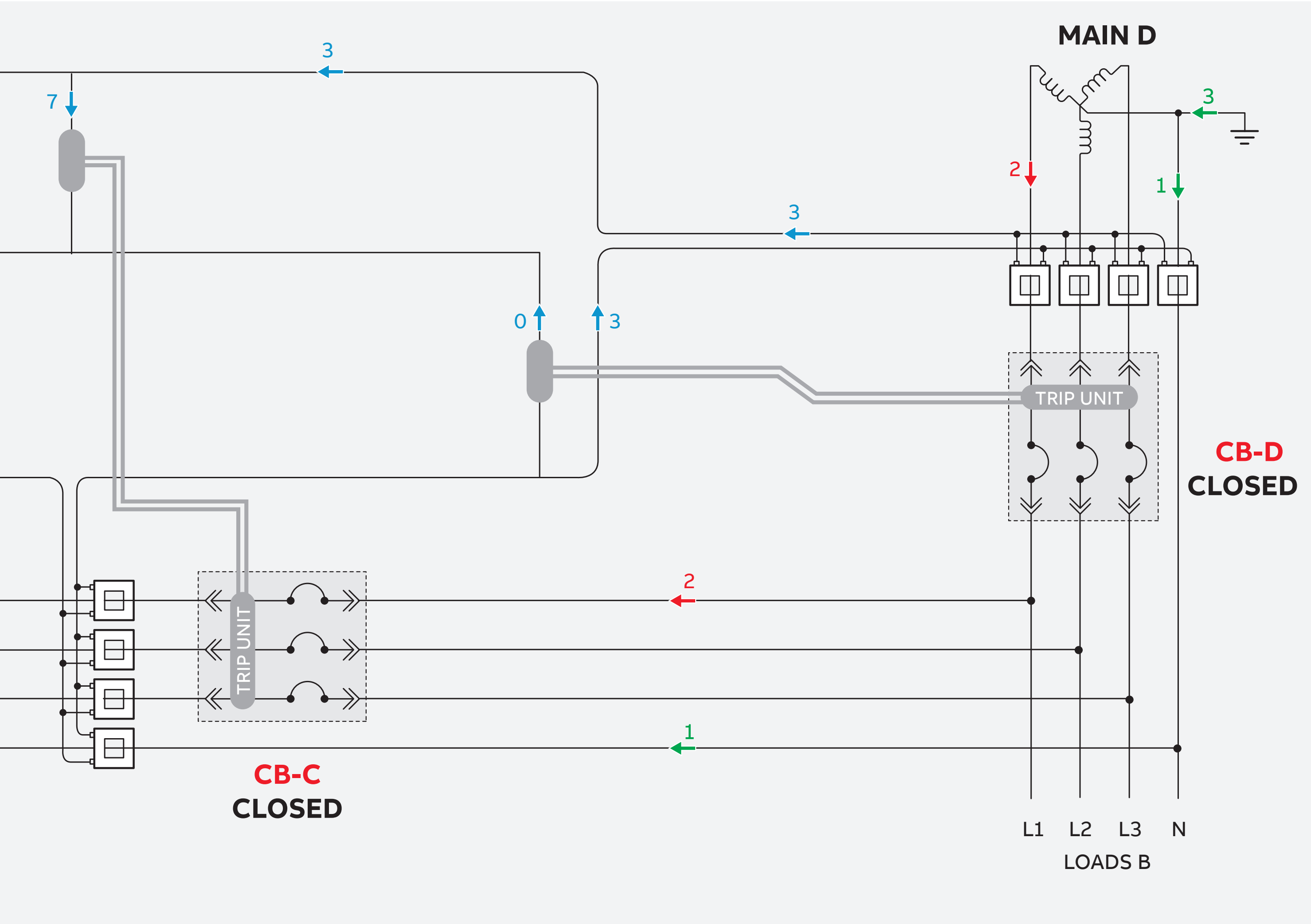
Application examples

Figure 12 - MGTM configuration, ground fault



Caption





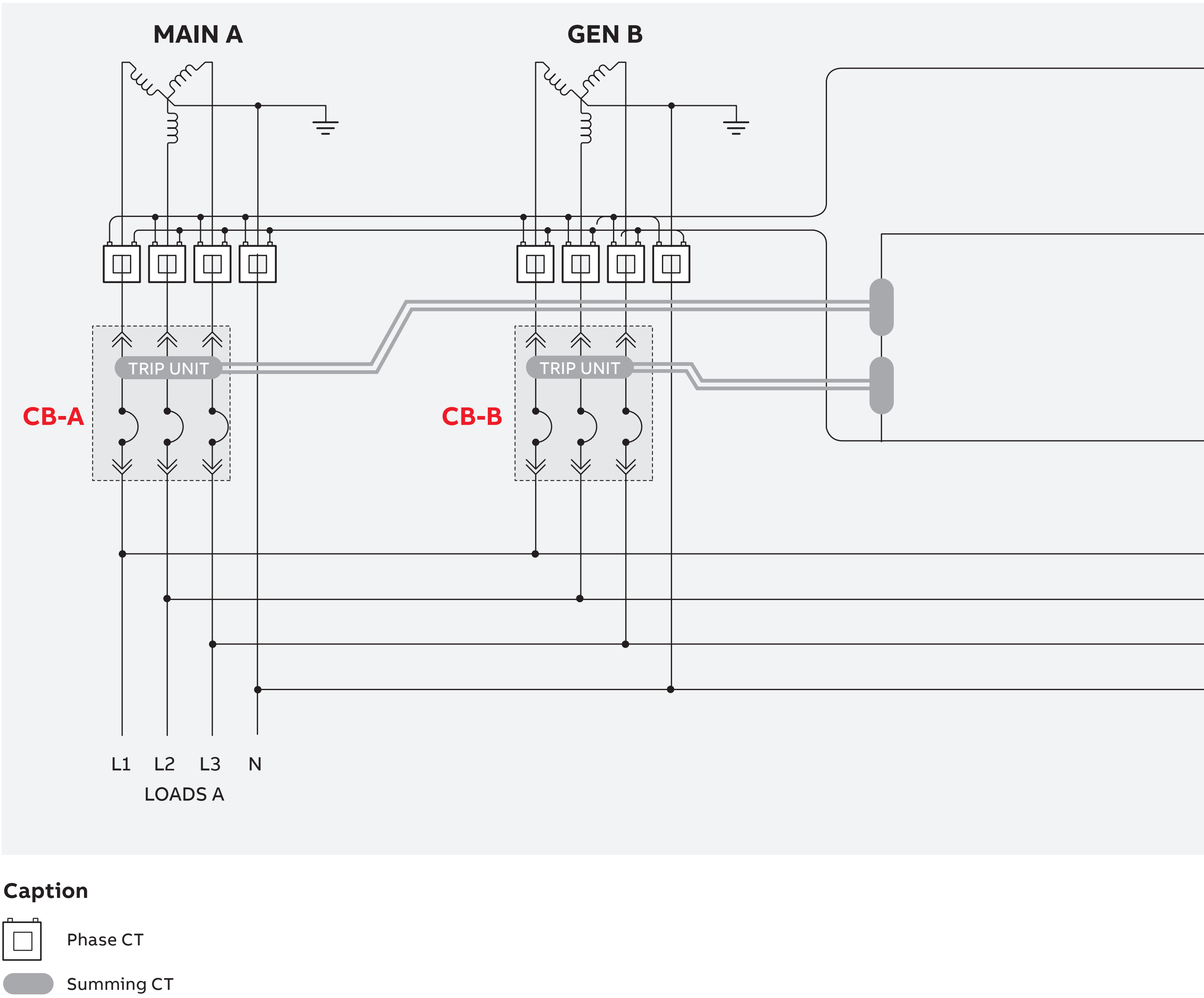
MAIN D
3
7
3
2
1
3
0
3
TRIP UNIT
CB-D
CLOSED
2
TRIP UNIT
1
CB-C
CLOSED
L1
L2
L3
N
LOADS B

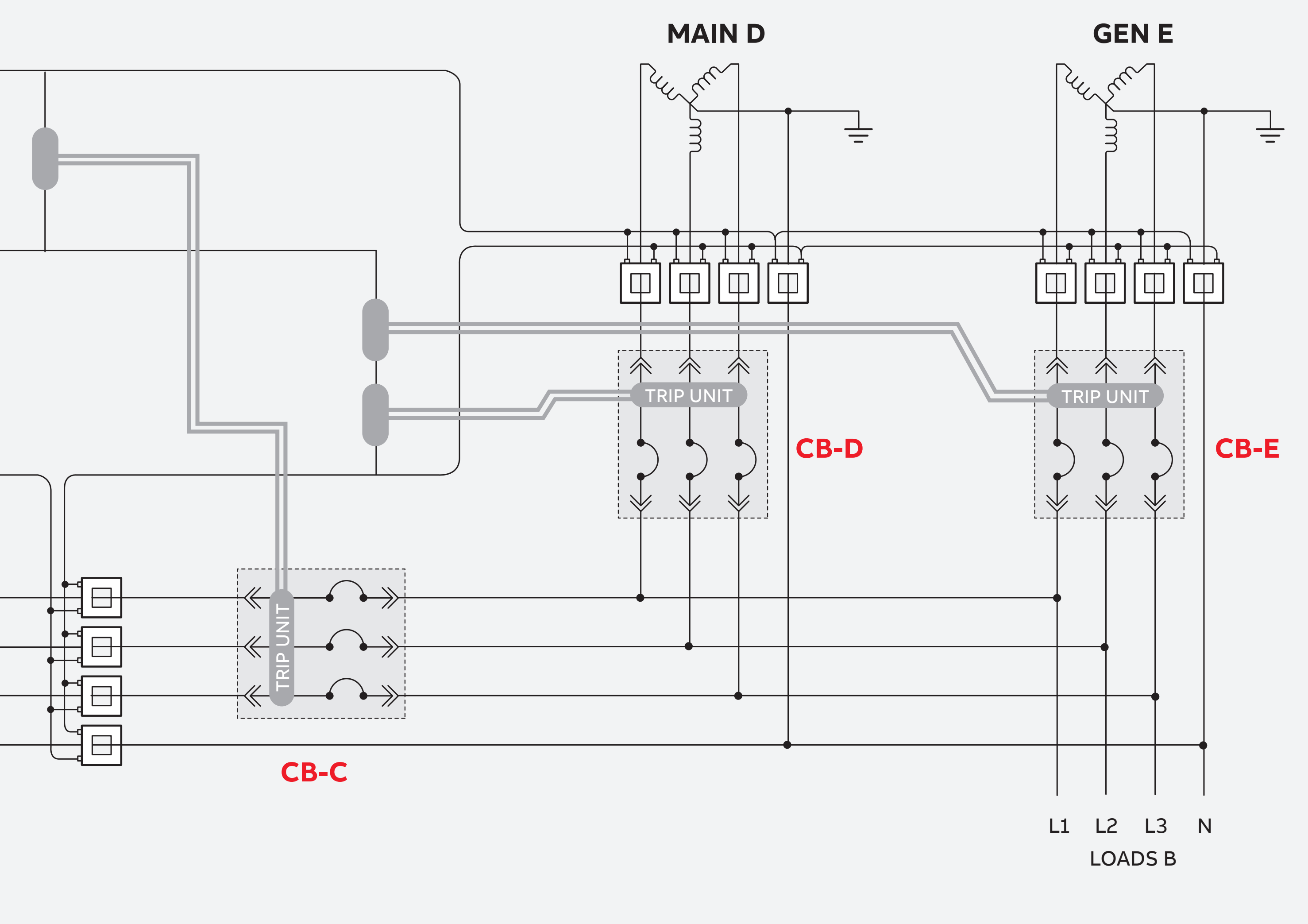
Application examples

To better understand the MGTMG working principle, the equivalent circuit is considered in Figure 13. MGTMG consists of two sources and two generators, as well as a Tie.

This configuration involves the use of 5 circuit-breakers, 20 phase CTs and 5 summing CTs.

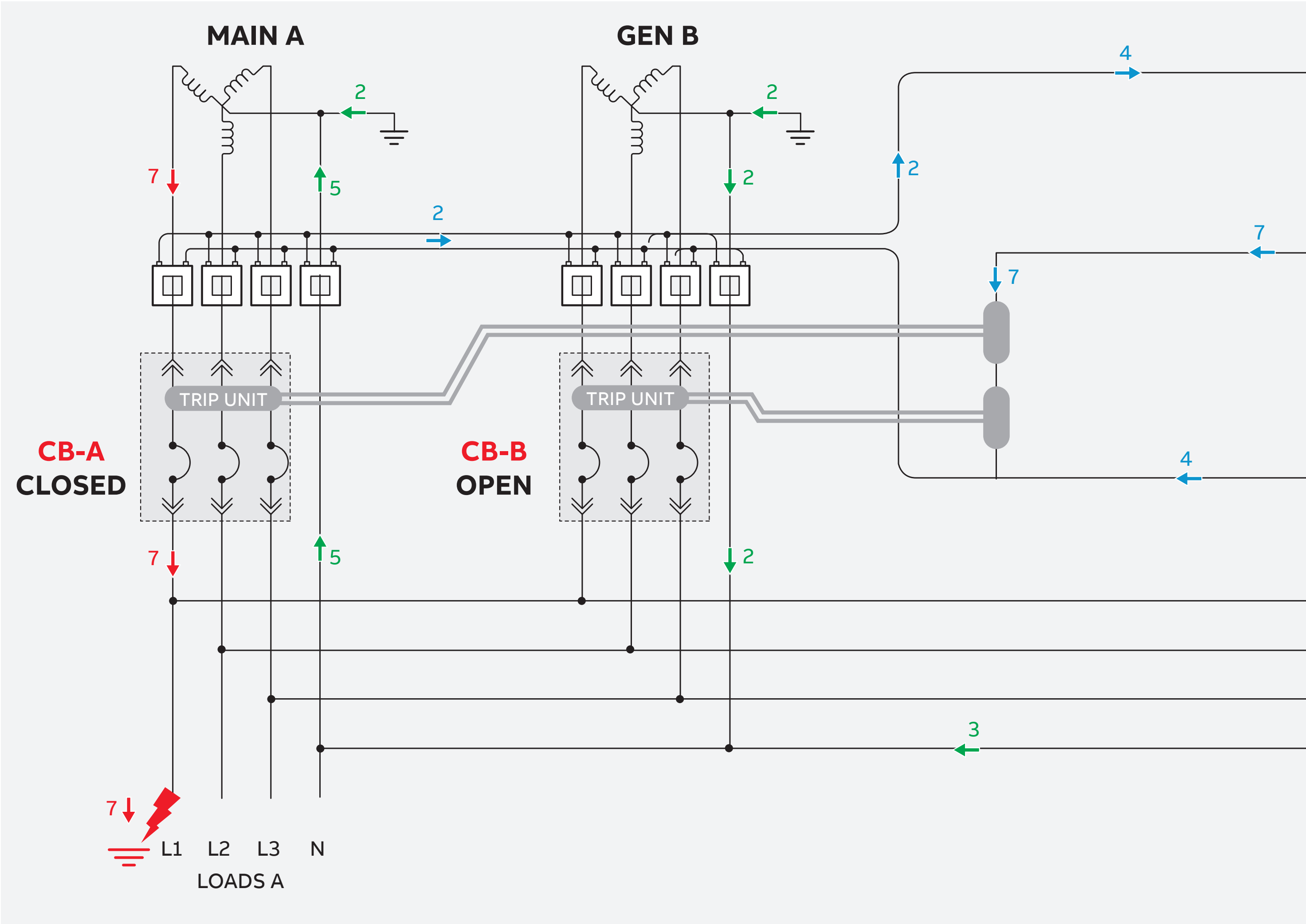
Figure 13 - Equivalent MDGF scheme for MGTMG configuration



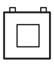

MAIN D
GEN E
TRIP UNIT
TRIP UNIT
TRIP UNIT
CB-D
CB-E
CB-C
L1
L2
L3
N
LOADS B

Application examples

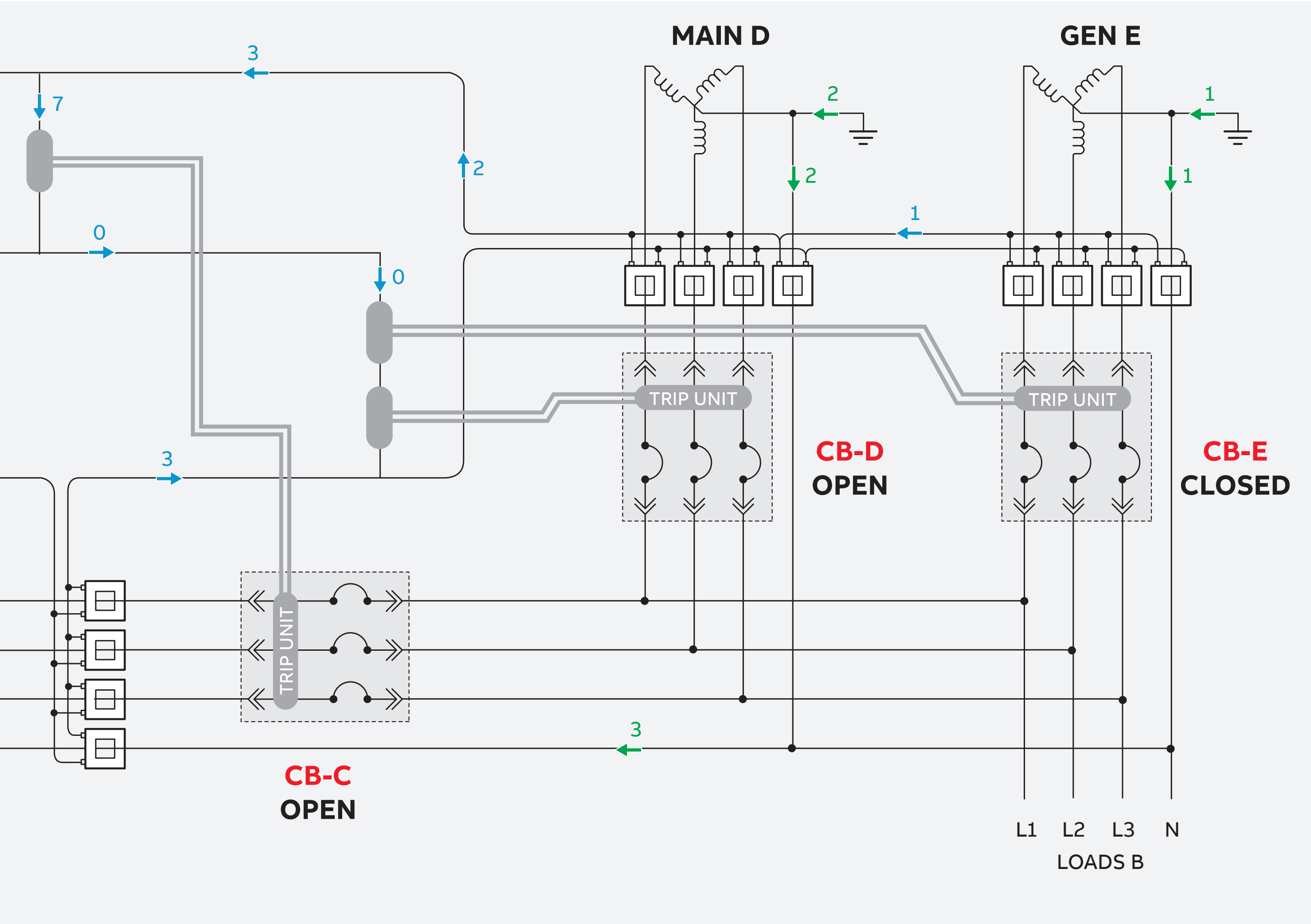
Figure 14 - MGTGM configuration, ground fault



Caption


Phase CT


Summing CT

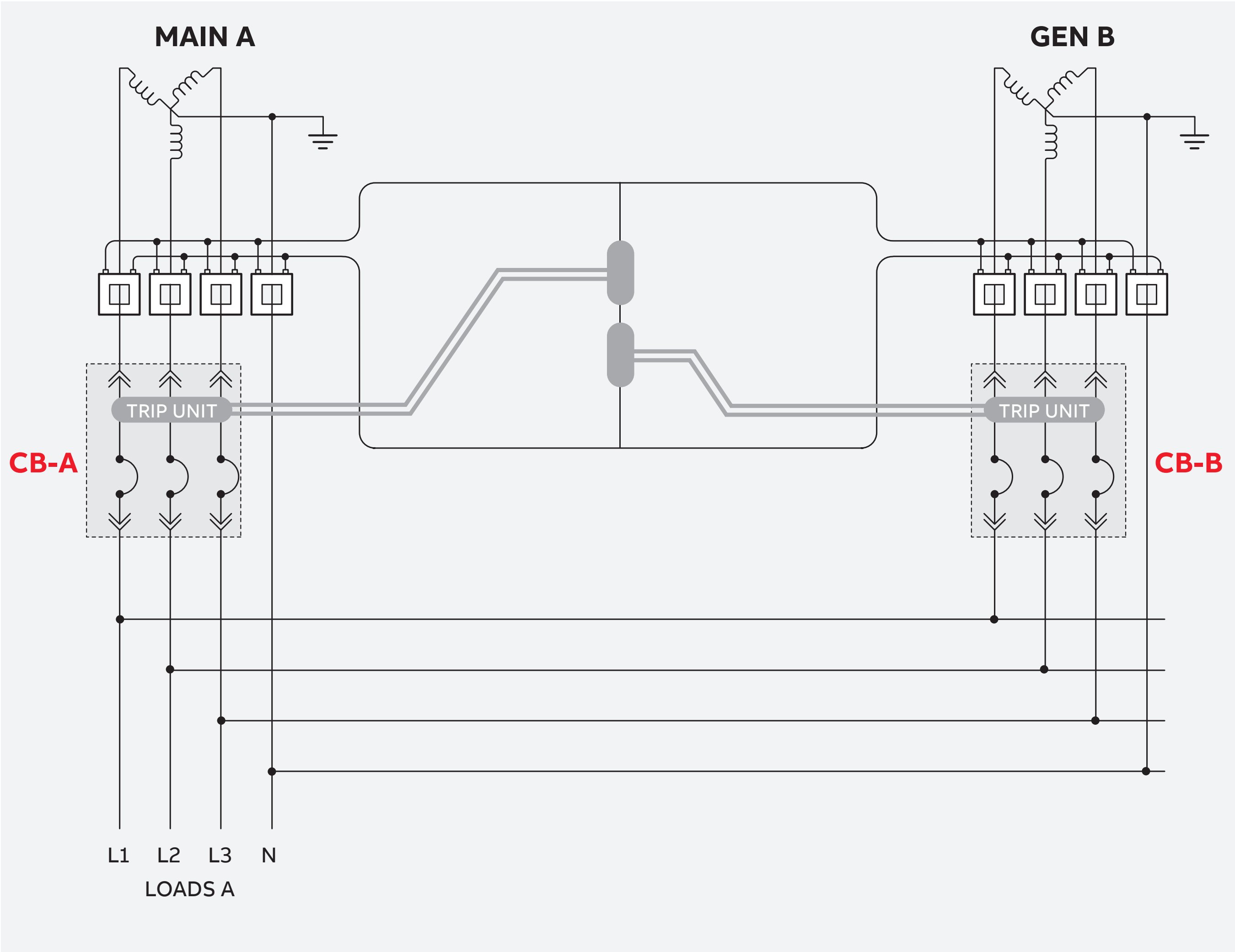

MAIN D
GEN E
3
7
2
0
0
2
2
1
1
1
TRIP UNIT
TRIP UNIT
TRIP UNIT
3
3
CB-D
OPEN
CB-E
CLOSED
CB-C
OPEN
L1
L2
L3
N
LOADS B

Application examples

To better understand the MG working principle, the equivalent circuit is considered in Figure 15.

MG consists of two sources and requires 2 circuit-breakers, 8 phase CTs and 2 summing CTs.

Figure 15 - Equivalent MDGF scheme for MG configuration



Caption

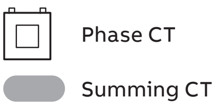
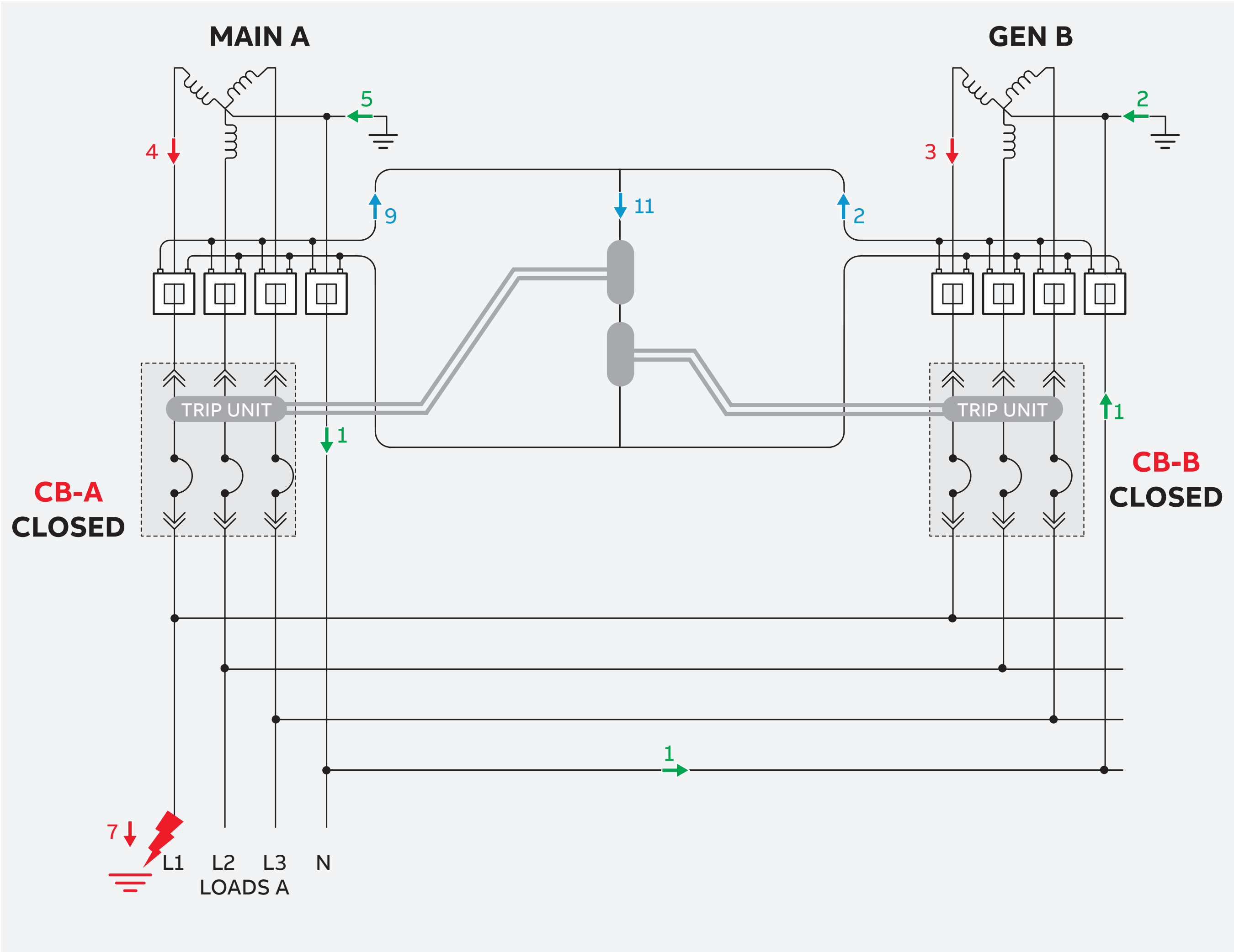


Figure 16 - MG configuration, ground fault



Caption

Phase CT

Summing CT

Conclusion

In conclusion, MDGF is an important concept in the field of electrical engineering and it has many practical applications in industrial and commercial settings.

By implementing proper grounding and fault protection mechanisms, we can help prevent and mitigate the effects of multiple source ground faults which can have serious implications for safety and equipment damage.

This white paper has provided a comprehensive understanding of MDGF and its implementation with Emax2 or XT7 circuit breakers.

At ABB, we remain committed to contributing to the development of safe, reliable, and efficient electrical systems.

If you have any questions or require further information about MDGF and how we can assist you in leveraging this solution, please do not hesitate to contact us.

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