

Research Article

Study of Short-circuit Faults Affecting Electrical Networks

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Abstract

Most faults in power lines are caused by short circuits resulting from phenomena such as lightning, severe weather, or power surges linked to circuit breaker operations. These short circuits, whether temporary or permanent, require accurate detection and location to enable rapid repair and restoration of power supply. To protect the system against short-circuit currents, which can cause irreversible damage to key equipment, it is essential to quickly disconnect the faulty part of the network. In order to correctly size this equipment, it is essential to estimate the magnitude of the currents likely to flow during a short circuit. This study involved calculating single-phase short-circuit currents in the event of a fault on the Cable, Soluxe, Aéroport, Talladje, and Gawaye feeders at the Niamey3 electrical substation. The method used to calculate short-circuit currents in HTB and HTA networks is based on the principle of symmetrical components. This method was chosen for its accuracy and analytical nature. The results obtained show that the Soluxe feeder has the highest short-circuit current, with a value of 1.95 kA, compared to those of the Cable, Aéroport, Talladje, and Gawaye feeders, which are 1.86 kA, 0.67 kA, 0.64 kA, and 0.56 kA, respectively. This is explained by the fact that the calculated impedances (direct, inverse, and zero-sequence) of this feeder are lower than those of the other four feeders.

Keywords

Short-circuit, Electrical Networks, Power Lines, Faults, Current, Impedances

1. Introduction

It is well known that an electrical network can be considered as a huge electricity transmission network connecting part of a country or the entire country [1, 2]. In addition, such a network can also connect several countries. The electrical network is composed of numerous electrical devices such as generators, transformers, transmission lines, relays, and circuit breakers [1, 2, 5].

Electrical installations almost always require protection against short circuits wherever there is an electrical discontinuity. This most often corresponds to points where there is a change in conductor cross-section. The short-circuit current

must be calculated at each level of the installation in order to determine the characteristics of the equipment required to withstand or interrupt the fault current [3].

A short circuit is a transient electromagnetic condition during which the impedance of the system decreases, causing a considerable increase in currents in the branches and a decrease in voltages in the various parts of the network, especially at the point where the short circuit occurred [4-6].

The objective of this work is to determine the single-phase short-circuit currents in the event of a fault on the Cable, Soluxe, Aéroport, Talladje, and Gawaye feeders.

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2. Study Methodology

2.1. Parameters that Influence the Short-circuit Current Value

The intensity of the short-circuit current is an important characteristic, as it determines the severity of the stress applied to the network and the faulty equipment. The value of the short-circuit current intensity at a point in a network depends on:

- 1) the nature of the elements that make up the network: alternator, transformer, lines, cables;
- 2) the topological structure of the network (radial, looped, meshed);
- 3) the operating mode of the network: isolated neutral or grounded neutral;
- 4) the resistance of the fault;
- 5) the type of fault: three-phase, two-phase, or single-phase [4].

2.2. Determination of Various Short-circuit Impedances

Determining the impedances of the network allows the short-circuit currents affecting it to be calculated. To do this, all the characteristics of the network must be known. The principle of this method consists of determining the short-circuit currents based on the impedance represented by the "circuit" through which the short-circuit current flows. This impedance is calculated after separately totaling the various resistances and reactances of the fault loop, from and including the circuit's power source to the point in question.

2.2.1. Upstream Network Impedance

In most calculations, the impedance of the upstream network does not extend beyond the energy delivery point. Knowledge of the upstream network is therefore generally limited to the information provided by the distributor, namely only the short-circuit power SCC (in MVA). It is calculated using formula (1).

$$Z_a = \frac{U_n^2}{S_{cc}} \quad (1)$$

The zero impedance is given by formula (2).

$$\underline{Z}_0 = 3\underline{Z}_a \quad (2)$$

2.2.2. Internal Impedance of the Transformer

It is determined based on the short-circuit voltage in % (U_{cc} %), the no-load voltage of the transformer (U_n), and the apparent power of the latter (S_n). It is given by equation (3).

$$Z_T = \frac{U_{cc}}{100} \times \frac{(U_n)^2}{S_n} \quad (3)$$

The internal impedance Z_T of transformers can be equated to the reactance X_T (4)

$$Z_T = X_T \quad (4)$$

For a transformer:

$$Z_d = Z_i = X_d = X_i \quad (5)$$

The zero-sequence reactance X_0 of the transformer generally depends on the possibilities for looping back earth fault currents.

2.2.3. Line Impedance

The impedance of a line depends on its resistance and reactance and is given by expression (6):

$$\underline{Z} = R_l + jX_l \quad (6)$$

With

R_l is the total resistance of the line, calculated using formula (7)

$$R_l = \rho \times \frac{l}{S} \quad (7)$$

S = Conductor cross-sectional area (mm²)

ρ = Conductor resistivity ($\Omega\text{mm}^2/\text{m}$)

l : Line length (km)

Table 1 shows some resistivity values for materials used in the electrical network.

Table 1. Some resistivity values for materials.

Nature	Almelec	Copper	Aluminum
$\rho(\Omega\text{mm}^2/\text{m})$	0,033	0,018	0,030

X_l Total line reactance, given by the formula The total reactance of a line of length l is given by equation (8):

$$X_l = x \times l \quad (8)$$

x : linear reactance

$$x = L \times w = 0,144 \log \left(\frac{D_{moy}}{R} \right) + 0,016\mu \quad (9)$$

Where:

x : the line reactance, expressed in Ω/km ;

R : radius of a phase conductor;

D_{avg} : average geometric distance between the three

phases of the line;

μ : relative permeability of the conductive material: $\mu=1$ for aluminum, copper, and Almelec, and $\mu \gg 1$ for steel.

For the line, there is equality between the forward and reverse impedance, and the zero-sequence impedance is given by equation (10).

$$\underline{Z}_d = \underline{Z}_i = \underline{Z}_l \quad (10)$$

$$\underline{Z}_0 = (R_l + 0,15) + j3X_l \quad (11)$$

2.2.4. Generator Impedance

For rotating machines, impedance orders of magnitude are indicated as percentages. Generator impedance (Z_G) is calculated using formula (12).

$$Z_G = \frac{z_a}{100} \times \frac{(U_n)^2}{S_n} \quad (12)$$

The zero impedance of a generator is given by formula (13):

$$\underline{Z}_0 = 0,5\underline{Z}_G \quad (13)$$

2.3. Relationship Between Impedances and Voltages

All impedances must be calculated by relating them to the voltage at the fault point. Thus, the impedance of an EHV line must be multiplied by the square of the inverse of the transformation ratio (14) to calculate a fault on the HV side of the transformer.

$$Z_{HTA} = Z_{HTB} \times \left(\frac{U_{HTA}}{U_{HTB}} \right)^2 \quad (14)$$

2.4. Case Study

Consider the electrical circuit shown in Figure 1, which consists of the Birnin Kebbi line, the Gorou Banda power plant, the Gorou Banda substation, the solar power plant lines, the Niamey 2 and Niamey 3 substations, and five feeders from the Niamey 3 substation.

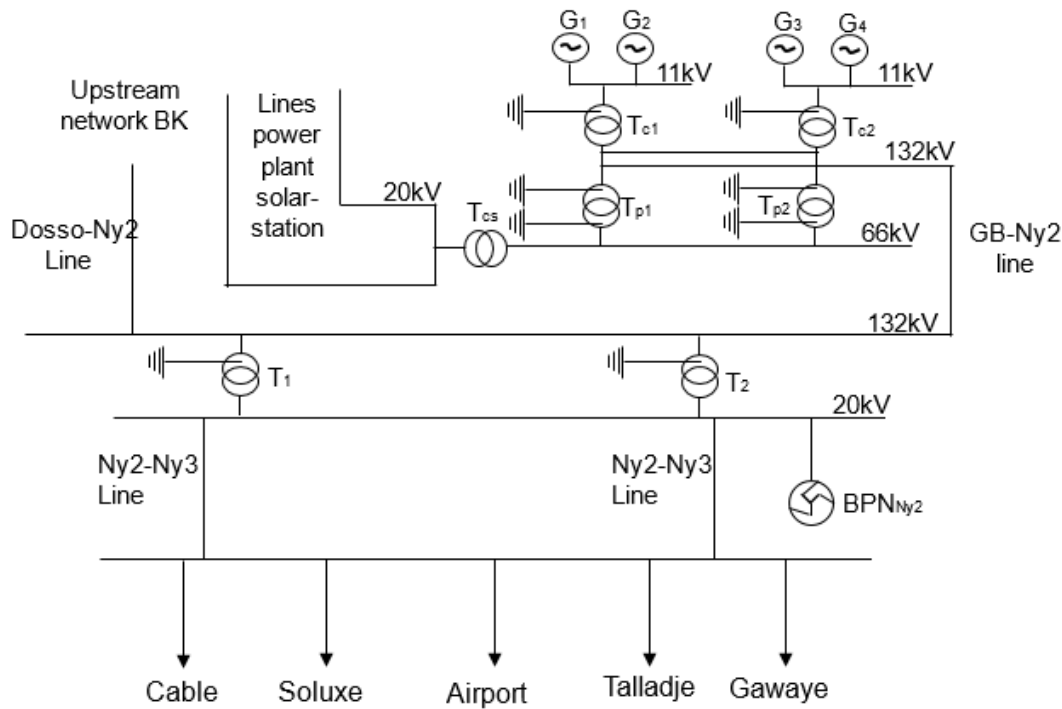


Figure 1. Electrical diagram to be studied.

The values of linear reactance for overhead and underground lines are considered to be $0.4 \Omega/\text{km}$ and $0.1 \Omega/\text{km}$, respectively.

The task is to calculate the single-phase short-circuit currents in the event of a fault on the Cable, Soluxe, Airoport, Talladje, and Gawaye feeders.

2.4.1. Assumptions

The assumptions made to simplify the calculation of short-circuit currents are:

- 1) The electrical networks are symmetrical.
- 2) The line capacities are negligible.
- 3) Only the established sinusoidal regime is considered.
- 4) it is assumed that there is no power transfer before the fault (no-load network)
- 5) the impedances of protective devices and busbars are

neglected.

- 6) the impedances of neutral point coils (BPN) are neglected except for that of the Niamey 2 substation.

These data include certain characteristics of the elements of the network under consideration that are essential to our study. Tables 2 and 3 present the main characteristics of the elements of the upstream network of the Niamey 3 substation.

2.4.2. Data Used

Table 2. Some characteristics of transformers and SCC short-circuit power.

	Power (MVA)	Voltage (kV)	Voltage Ucc (%)	Coupling
Upstream network seen from Dosso (BK)	400	132		
Niamey 2 transformer (T1 and T2)	40	132/20	9,02	YNd11
Gorou Banda group (GB)	26,45	11		
GB central transformer (Tc)	53	11/132	13	YNd11
GB substation transformer (Tp)	63	132/66	11,2	YNyn0
GB20 substation transformer (Ts)	30	66/20	6	YNd11

- 1) The upstream network power seen from Dosso is the short-circuit power S_{cc} .
- 2) The Gorou Banda power plant units are synchronous machines with salient poles.

Table 3. Some characteristics of the network lines.

	Voltage (kV)	Length (km)	Section/phase (mm ²)	Network Type	Nature of the conductor
Dosso-Niamey2 line (L _{dn})	132	132	242	Aerial	Almelec
Niamey 2- Niamey 3 line (L ₂₃)	20	0,32	2×630	Underground	Aluminum
Centrale - Gorou Banda station line (L _{cp})	132	1	2×291	Aerial	Almelec
Gorou Banda station -Niamey 2 line (L _{pn})	132	10	2×291	Aerial	Almelec
Solar power line - station (L _{cs})	20	1	2×630	Underground	Aluminum

Table 4 shows the characteristics of the neutral point coil at the Niamey 2 substation.

Table 4. Characteristics of the neutral point coil at the Niamey 2 substation.

	Z_0	U_n (kV)
BPN _{Ny2}	26,5	20

Table 5. Data on different departures from Niamey 3.

HTA departures	SECTION (mm ²)	Length (km)	Type of conductor
Câble	Underground	240	7,287
			Aluminum

HTA departures	SECTION (mm ²)		Length (km)	Type of conductor
Soluxe	Underground	240	6,502	Aluminum
		75,5	7,730	Almelec
	Overhead	54,6	4,059	Almelec
Aéroport	Underground	240	0,296	Copper
		150	3,552	Aluminum
	Overhead	75,5	11,616	Almelec
Talladje	Overhead	54,6	8,292	Almelec
		240	4,544	Aluminum
	Underground	75,5	4,273	Almelec
Gawaye	Overhead	54,6	2,623	Almelec
		240	7,804	Aluminum
	Underground	150	0,067	Aluminum

2.5. Determination of the Equivalent Impedances of the Various Branches

Determining equivalent impedances involves adding up all the impedances in the electrical network under consideration.

The equivalent of two impedances in parallel is given by the ratio of their product to their sum. The equivalent of two impedances in series corresponds to their direct sum. Figure 3 shows the diagram of the network under study, where each element is represented by its impedance.

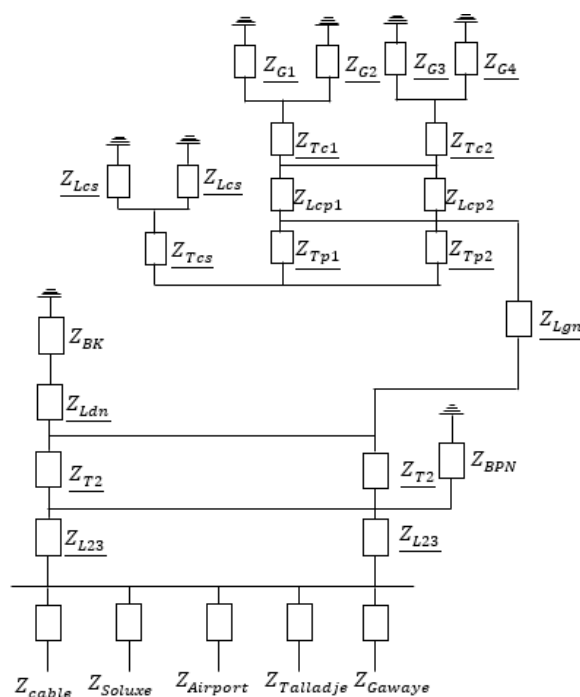


Figure 2. Diagram of the electrical network.

The equivalent impedance diagram of the upstream network of the outlets is shown in Figure 3.

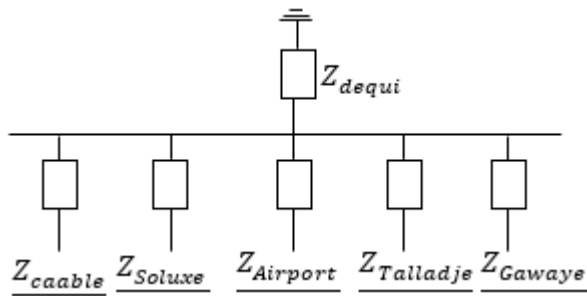


Figure 3. Diagram of equivalent impedance.

2.5.1. Determination of Equivalent Forward and Reverse Impedances of Feeders in the Event of a Fault

The equivalent impedance of a feeder in the event of a short circuit is obtained by adding the equivalent impedance of the network and the impedance specific to the feeder concerned.

$$\underline{Z_d} = \underline{Z_i} = \underline{Z_{dequi}} + \underline{Z_x} \quad (15)$$

Who: Z_d is equivalent forward impedance, Z_i is reverse impedance, Z_{dequi} is equivalent impedance of the network Z_x is impedance specific to the feeder concerned,

Fault on the Cable feeder

Figure 4 illustrates the fault on the Cable feeder.

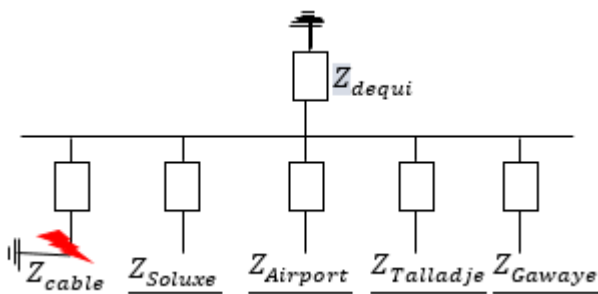


Figure 4. Fault on departure from Cable.

The direct and inverse equivalent impedance in the event of a short circuit on the cable outlet are given by formula (16):

$$\underline{Z_d} = \underline{Z_i} = \underline{Z_{dequi}} + \underline{Z_{cable}} \quad (16)$$

2.5.2. Determination of Equivalent Zero-sequence Impedances of Power Lines in the Event of a Fault

Since the secondary windings of the transformers at the Niamey 2 substation are connected in a delta configuration, the homopolar currents are blocked at their level. As a result, the upstream network does not detect these currents. Figure 5 shows the diagram of the network's homopolar circuit.

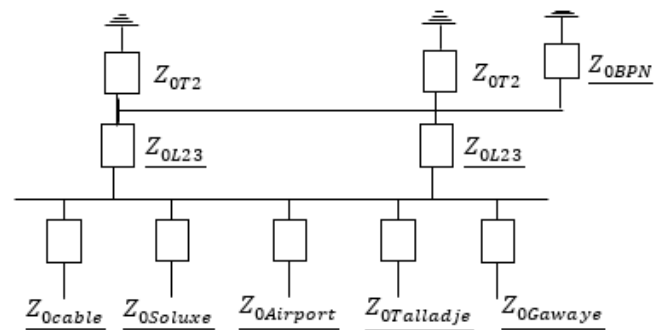


Figure 5. Diagram of the homopolar circuit of the network.

The equivalent zero-voltage impedance in the event of a short circuit on the feeder is shown in formula (17):

$$\underline{Z_0} = \underline{Z_{0equi}} + \underline{Z_{0x}} \quad (17)$$

Who Z_{0x} is equivalent zero-voltage impedance in the event of a short circuit on the feeder concerned.

3. Results and Analysis

3.1. Calculation of Network Element Impedances

Formulas (8), (10), (13), and (19) are used to calculate the impedances of the upstream network, transformers, lines, and groups, respectively. The results of these calculations are presented in Tables 6 and 7 for the different feeders.

Table 6. Impedances of network components.

Network components	R(Ω)	X(Ω)	Z(Ω)
Upstream network (BK)	0	9,59	j9,59
Dosso-Ny2 line (Ldn)	18	52,8	18+j52,8

Network components	$R(\Omega)$	$X(\Omega)$	$Z(\Omega)$
Niamey2 transformer (T2)	0	39,29	j39,29
Niamey2-Niamey3 line (L23)	0,0075	0,016	0,0075+j0,016
Gorou Banda group (G)	0	5,49	j5,49
Gorou Banda central transformer (Tc)	0	0,296	j0,296
Central- Gorou Banda substation line (Lcp)	0,11	0,4	0,11+j0,4
Gorou Banda substation transformer (Tp)	0	31	j31
Gorou Banda -Niamey2 line (Lgn)	0,57	4	0,57+j4
Solar central line – Gorou Banda substation (Lcs)	0,05	0,1	0,05+j0,1
Gorou Banda 20 transformer (Tcs)	0	8,71	j8,71

Table 7. Impedances of the branches.

Departures	$R(\Omega)$	$X(\Omega)$	$Z(\Omega)$
Cable	0,98	0,78	0,98+j0,78
Soluxe	0,81	0,65	0,81+j0,65
Airport	6,38	5,2	6,38+j5,2
Gawaye	4,47	3,55	4,47+j3,55
Talladje	10,65	8,42	10,65+j8,42

3.2. Impedances Reduced to the Fault Point

The fault point is located at a voltage of 20 kV. All impedances expressed at a different voltage will be converted to this value using formula (21). The results of the calculations are presented in Table 8.

Table 8. Impedances converted to the fault point.

Network components	$R(\Omega)$	$X(\Omega)$	$Z(\Omega)$
Upstream network (BK)	0	0,22	j0,22
Dosso-Niamey2 line (Ldn)	0,41	1,21	0,41+j1,21
Niamey2 transformer (T2)	0	0,9	j0,9
Niamey2-Niamey3 line (L23)	0,0075	0,016	0,0075+j0,016
Gorou Banda group (G)	0	18,15	j18,15
Gorou Banda central transformer (Tc)	0	0,98	j0,98
Central-Gorou Banda substation line (Lcp)	0,0026	0,0092	0,0026+j0,0092
Gorou Banda substation transformer (Tp)	0	0,71	j0,71
Gorou Banda-Ny2 line (Lgn)	0,13	0,92	0,13+j0,92
Solar central line – GD substation (Lcs)	0,05	0,1	0,05+j0,1
Gorou Banda 20 transformer (Tcs)	0	j0,8	j0,8

3.3. Calculation of Direct and Inverse Impedances

Since the faults are far from the generators, the forward and reverse impedances are identical. The corresponding results are shown in [Tables 7 and 8](#).

3.4. Calculation of Homopolar Impedances

The homopolar impedances are given in [Tables 9 and 10](#) for the feeders. The impedances are derived using equations (2), (4), (11) and [Table 1](#).

Table 9. Homopolar impedances of the upstream fault network.

Network components	$R(\Omega)$	$X(\Omega)$	$Z(\Omega)$
Upstream network (BK)	0	2,4	j2,4
Dosso-Ny2 line (Ldn)	1,23	3,63	1,23+j3,63
Ny2 transformer (T2)	0	0,9	j0,9
Ny2-Ny3 line (L23)	0,16	0,05	0,16+j0,05
Gorou Banda group (G)	0	1,125	j1,125
Gorou Banda central transformer (Tc)	0	0,98	j0,98
Central- Gorou Banda substation line (Lcp)	0,15	0,003	0,15+j0,003
Gorou Banda substation transformer (Tp)	0	0,71	j0,71
Gorou Banda -Ny2 line (Lgn)	0,075	0,276	0,075+j0,276
Solar central line – Gorou Banda substation (Lcs)	0,2	0,3	0,2+j0,3
Gorou Banda 20 transformer (Tcs)	0	j0,8	j0,8

Table 10. Homopolar impedances of the branches.

Departures	$R(\Omega)$	$X(\Omega)$	$Z(\Omega)$
Cable	2,94	2,34	2,94+j2,34
Soluxe	2,43	1,95	2,43+j1,95
Airport	19,14	15,6	19,14+j15,6
Gaweye	13,41	10,65	13,41+j10,65
Talladje	31,95	25,26	31,95+j25,26

The results of the direct and inverse equivalent impedance calculations are shown in [Table 11](#).

Table 11. Results of direct and inverse equivalent impedance calculations.

Equivalent impedances	Cable	Soluxe	Airport	Talladje	Gaweye
$Z_d = Z_i (\Omega)$	1,24 + j1,98	1,07+j1,85	6,64+j6,4	10,91+j9,62	4,73+j4,75

The results of the calculation of the equivalent zero-voltage impedances are presented in [Table 12](#).

Table 12. Results of the calculation of the equivalent zero-voltage impedances.

Equivalent impedances	Cable	Soluxe	Airport	Talladje	Gawaye
Z_0 (Ω)	3,32+j13,76	2,81+j13,32	19,52+j27,02	13,79+j22,07	32,33+j36,68

3.5. Calculation of Single-phase Short-circuit Current

The results of the calculations for single-phase short-circuit currents in the event of a fault on the various feeders are presented in Table 13.

Table 13. Calculation results for single-phase short-circuit currents in the event of a fault.

Short-circuit currents	Cable	Soluxe	Airport	Talladje	Gawaye
I_{cc1} (kA)	1,86	1,95	0,67	0,64	0,56

This table shows that the Soluxe feeder has the highest short-circuit current among the five feeders. This is because the impedances (direct, inverse, and zero-sequence) of this feeder are lower than those of the other four feeders. We can therefore conclude that impedances have a significant influence on short-circuit current: the lower the impedances, the higher the short-circuit current.

4. Conclusion

This work made it possible to calculate the single-phase short-circuit currents on the five feeders of Niamey 3. To do this, the impedances of all the components of the network were first determined. The results obtained made it possible to observe the influence of impedances on these currents.

Abbreviations

Ω	Ohm
A	Ampere
B K	Birnin Kebbi
GB	Gorou Banda
Ny2	Niamey 2
Ny3	Niamey 3
R	Resistor
X	Reactance
Z	Impedance
Z_{equi}	Equivalent Impedance

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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