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Research Article

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Analysis Systems Imbalances Longitudinal Electric Systems: Case Line Double Terne Imboulou-Ngo in Congo

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Abstract This article focuses on the analysis of longitudinal unbalanced regimes applied electrical systems on line double dull Imboulou - Ngo of Congolese transport network.This analysis of longitudinal imbalances and complex fractures of the drivers identified the currents and voltages at different points of this line. In carrying out this analysis, it is considered that each phase of the line feeds a different impedance from that of other phases. To do so, we made a mathematical development for the establishment and solving the equations of the various zones using the method of symmetrical components. This study is supported by simulations carried out by the Matlab software, which show that during operation without phase cutting and whatever the value of the load the system remains stable. In the case of a phase failure the system returns to steady state after $\mathrm{t} = 8\mathrm{s}$a normal load$\mathrm{P_{ch}} = 40\mathrm{MW}$and when it is halved, the equilibrium condition is solved$\mathrm{t} = 5\mathrm{s}$. As against this, note that the system does not find the equilibrium state when the load is doubled in the case of a phase failure and in the case of breaking of two phases regardless of the value of the load.

Keywords Network, Transport, imbalance, longitudinal, Matlab

1. Introduction

In normal balanced symmetrical operation, the study of three-phase systems can be reduced to the study of a single-phase network equivalent of equal voltages to the voltages of the network, currents equal to those of the network and equal impedances to those of the network. That during asymmetric operation of a network may appear at a voltage imbalance or impedances of the electrical components (due to a fault) system. The short - circuit, phase loss are severe defects to validate models imbalance of power grid [1].

2. Setting a default

A fault is a disturbance that causes changes in electrical parameters of a structure, it is characterized by an illegal phenomenon to the normal operation of the network and can in some cases lead to an electrical breakdown of it and endangering its environment [2].

3. Origin defects

Defects in an electrical network may have different origins [2]:

- Mechanical: A break conductors or accidental electrical connection between the two capacitors by a foreign body;
- Power : A breakdown of insulation between phases or between one phase and ground or earth, or due to power surges due to operations or lightning strikes;

- human: for example, the grounding of one phase, a coupling between two different voltage sources or of different phases or the closure error of a switching device.

4. Different types of defects

Surges: called overvoltage any voltage between a phase conductor and earth or between two phase conductors, the maximum value exceeds the peak value corresponding to the highest voltage for the equipment. [2].

Overload: occur when the installed devices are too powerful for the supply lines [3].

Imbalances: called imbalance on a line or in a three-phase system the difference between the three phase currents. imbalance rate should not exceed 15%.

Short circuit: a short circuit is a defect which occurs when there is an accidental connection between conductors at zero impedance (dead short) or not (short-circuit impedance).

5. Method for calculation of unbalanced diets

- Method practical resolution

The network is divided into two areas :

- area D asymmetrical (unbalanced network);
- symmetric region S (balanced network).

We write the equations linking currents and voltages :

- In area D (real components) ;
- In the S region (symmetrical components) ;
- Continuity at the boundary DS : is obtained by combining together the equations of the real components in the area D and the equations of the symmetrical components in the S zone ;
- Operation in zone S.

The mathematical solution of the equations used to calculate the values of symmetrical components and actual components of currents and voltages D areas and S. It should be noted that the representative patterns symmetrical systems offer the possibility to calculate the values of symmetrical components [4].

Considering the current and voltage of phase 1 as fundamentals, we have :

Considering the current and voltage of phase 1 as fundamentals, we have :

$$\begin{cases} V_1 = V_d + V_i + V_0 \\ V_2 = a^2 V_d + aV_i + V_0 \\ V_3 = aV_d + a^2 V_i + V_0 \end{cases} \quad (1)$$

And

$$\begin{cases} I_1 = I_d + I_i + I_0 \\ I_2 = a^2 I_d + aI_i + I_0 \\ I_3 = aI_d + a^2 I_i + I_0 \end{cases} \quad (2)$$

with:

- V_1, V_2 et V_3: Phase unbalanced system voltages 1,2,3
- I_1, I_2 et I_3: Current per unit length of the unbalanced system
- V_d, V_i, V_0, I_d, I_i et I_0: Symmetrical components of current and direct voltage drops, negative and zero sequence

The currents in the phases of successions generate voltage drops of the respective successions of phases. Thus it can be written [5]:

$$\begin{cases} E = V_d + Z_d \times I_d \\ 0 = V_i + Z_i \times I_i \\ 0 = V_0 + Z_0 \times I_0 \end{cases} \quad (3)$$

With:

- E The sum of electromotive forces of energy sources;
- Z_d , Z_i et Z_0: The equivalent impedances of the various successions of phases relative to the point of appearance of the longitudinal imbalance.

5.1. Out of one phase in a three-phase circuit

Figure 1shows the breakage of a phase in a three phase power system [5].

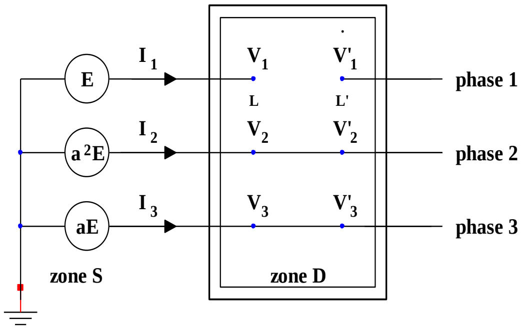


Figure 1: Diagram of a phase failure

5.1.1. Writing the equations

a. Equations of real components in zone D

Upon rupture of one phase in a three-phase circuit is characterized by the following requirements [5] :

$$\begin{cases} I_1 = 0 \\ V_2 = V_2' \\ V_3 = V_3' \end{cases} \rightarrow \begin{cases} I_1 = 0 \\ V_2 - V_2' = 0 \\ V_3 - V_3' = 0 \end{cases} \quad (4)$$

b. Equations of the symmetrical components in zone S

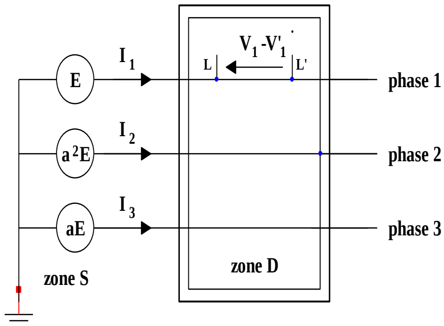
$$\begin{cases} I_1 = I_d + I_i + I_0 \\ I_2 = a^2 I_d + a I_i + I_0 \\ I_3 = a I_d + a^2 I_i + I_0 \\ V_1 = V_d + V_i + V_0 \\ V_2 = a^2 V_d + a V_i + V_0 \\ V_3 = a V_d + a^2 V_i + V_0 \\ V_1' = V_d' + V_i' + V_0' \\ V_2' = a^2 V_d' + a V_i' + V_0' \\ V_3' = a V_d' + a^2 V_i' + V_0' \end{cases}$$

c. operation equation of the zone S

$$\begin{cases} E = V_d + z_d \times I_d \\ 0 = V_i + z_i \times I_i \\ 0 = V_0 + z_0 \times I_0 \\ 0 = V_d' - z_d' \times I_d \\ 0 = V_i' - z_0' \times I_0 \\ 0 = V_0' - z_0' \times I_0 \end{cases}$$

$$\begin{cases} Z_d = z_d + z_d' \\ Z_i = z_i + z_i' \\ Z_0 = z_0 + z_0' \end{cases}$$

To analyze this damage regime, is inserted into the circuit a voltage generator $V_1 - V_1'$(Figure 2) [5].



Figures 2: Analytical diagram of a longitudinal imbalance following the breakage of a phase at the points L-L'

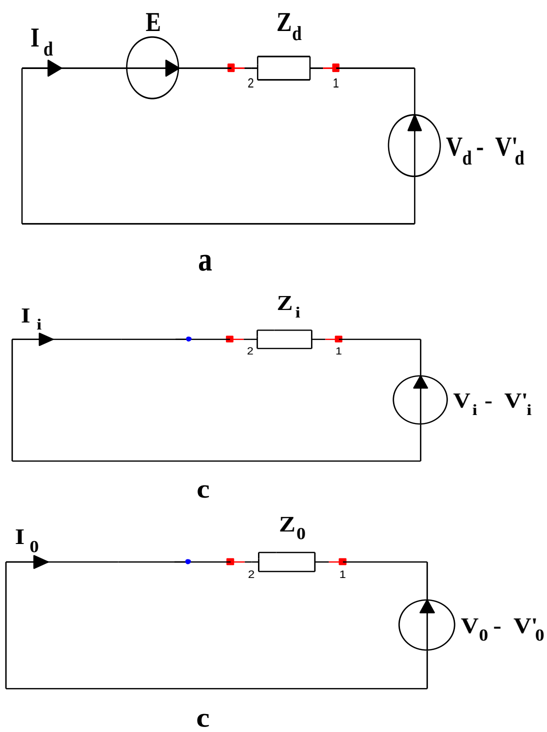


Figure 3: Schematic equivalent direct components (a), negative (b) and homopolar (c)

d. Continuity at the DS boundary

On the basis of symmetrical components, the boundary conditions (4) can be written as follows:

$$V_d - V_d' = V_i - V_i' = V_0 - V_0' = \frac{V_1 - V_1'}{3} \quad (5)$$

$$I_d = -(I_i + I_0) \quad (6)$$

5.1.2. Solving equations

The equivalent diagram of the longitudinal imbalance can be shown according to figure 4 [5]:

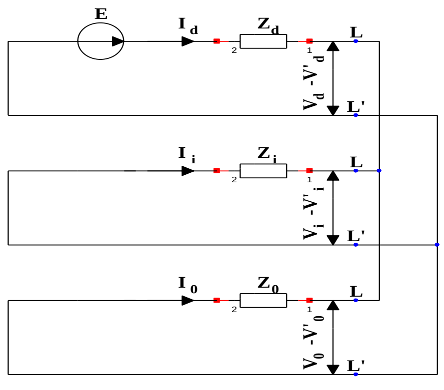


Figure 4: Schematic equivalent of a longitudinal imbalance in the event of a phase failure

5.1.2.1 Expressions of symmetrical components and actual currents and voltages

Figure 4 is used to write expressions of direct current:

$$I_d = \frac{E}{Z_d + Z_{LL1}} \quad (7)$$

The forward voltage drop at the breaking point of the phase:

$$V_d = I_d \times Z_{LL1} \quad (8)$$

- For symmetrical components of currents and voltages

$$\begin{cases} I_d = E\dfrac{Z_i+Z_0}{Z_d\times Z_i+Z_d\times Z_0+Z_i\times Z_0} \\ I_i = -E\dfrac{Z_0}{Z_d\times Z_i+Z_d\times Z_0+Z_i\times Z_0} \\ I_0 = -E\dfrac{Z_i}{Z_d\times Z_i+Z_d\times Z_0+Z_i\times Z_0} \\ V_d - V_d' = V_i - V_i' = V_0 - V_0' = E\dfrac{Z_i\times Z_0}{Z_d\times Z_i+Z_d\times Z_0+Z_i\times Z_0} \end{cases} \quad (9)$$

- For real components of currents and voltages

$$\begin{cases} I_1 = 0 \\ I_2 = E\dfrac{Z_i(a^2-1)-j\sqrt{3}Z_0}{Z_d\times Z_i+Z_d\times Z_0+Z_i\times Z_0} \\ I_3 = E\dfrac{Z_i(a^2-1)+j\sqrt{3}Z_0}{Z_d\times Z_i+Z_d\times Z_0+Z_i\times Z_0} \\ V_1 - V_1' = 3E\dfrac{Z_i\times Z_0}{Z_d\times Z_i+Z_d\times Z_0+Z_i\times Z_0} \\ V_2 - V_2' = 0 \\ V_3 - V_3' = 0 \end{cases} \quad (10)$$

5.2. Out of two phases of a three-phase circuit

Figure 5 illustrates the breakdown of two phases in a three phase power system.

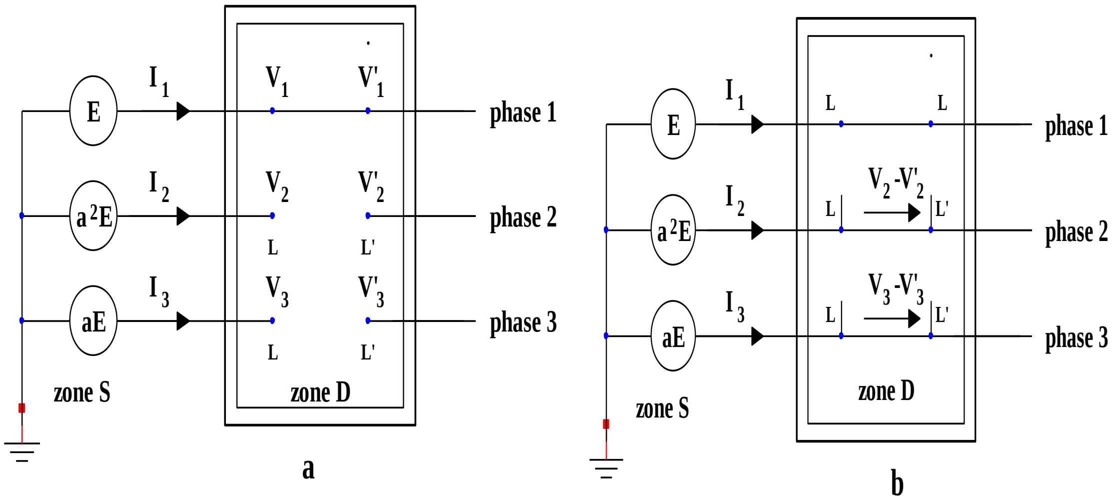


Figure 5: Out of two phases (a), analysis diagram (b)

5.2.1. Writing the equations

a. Equations of real components in zone D

$$\begin{cases} I_2 = 0 \\ I_3 = 0 \\ V_1 = V_1' \end{cases} \rightarrow \begin{cases} I_2 = 0 \\ I_3 = 0 \\ V_1 - V_1' = 0 \end{cases} \quad (11)$$

b. Equations of the symmetrical components in S

$$\begin{cases} I_1 = I_d + I_i + I_0 \\ I_2 = a^2I_d + aI_i + I_0 \\ I_3 = aI_d + a^2I_i + I_0 \\ V_1 = V_d + V_i + V_0 \\ V_2 = a^2V_d + aV_i + V_0 \\ V_3 = aV_d + a^2V_i + V_0 \\ V_1' = V_d' + V_i' + V_0' \\ V_2' = a^2V_d' + aV_i' + V_0' \\ V_3' = aV_d' + a^2V_i' + V_0' \end{cases}$$

c. operation equation of the zone S

$$\begin{cases} E = V_d + z_d \times I_d \\ 0 = V_i + z_i \times I_i \\ 0 = V_0 + z_0 \times I_0 \\ 0 = V_d' - z_d' \times I_d \\ 0 = V_i' - z_0' \times I_0 \\ 0 = V_0' - z_0' \times I_0 \end{cases}$$

$$\begin{cases} Z_d = z_d + z_d' \\ Z_i = z_i + z_i' \\ Z_0 = z_0 + z_0' \end{cases}$$

d. Continuity at the border

Considering the fundamental phase 1 (not broken), the boundary conditions (11) expressed through the symmetrical components can be written as follows [5]:

$$I_2 = a^2 I_d + aI_i + I_0 = 0 \quad (12)$$

$$I_3 = aI_d + a^2 I_i + I_0 = 0 \quad (13)$$

We have:

$$I_d = I_i \quad (14)$$

We deduce that:

$$I_d = I_i = I_0 = \frac{I_1}{3} \quad (15)$$

The development of the boundary condition through the symmetrical components gives: $V_1 - V_1' = 0$

$$V_d - V'_d = -[(V_i - V'_i) + (V_0 - V'_0)] \quad (16)$$

$$I_d = I_i = I_0 = \frac{E}{Z_d + Z_i + Z_0} \quad (17)$$

5.2.2. Solving equations

Figure (6) below shows the equivalent diagram of a longitudinal imbalance in the case of rupture of phases 2 and 3 [5]:

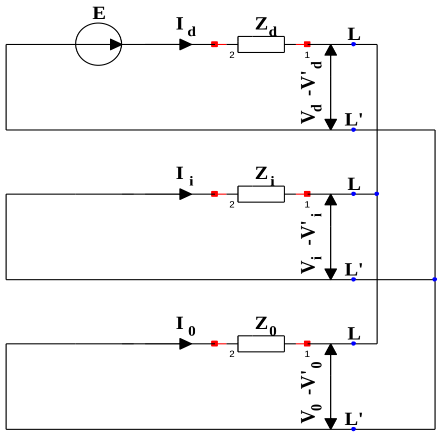


Figure 6: diagram equivalent to the rupture of phases 2 and 3

5.2.2.1. Expressions of symmetrical components and actual currents and voltages

- For symmetrical components of currents and voltages are such that:

$$\begin{cases} I_d = I_i = I_0 = \frac{E}{Z_d + Z_i + Z_0} \\ V_d - V_d' = E\frac{(Z_i + Z_0)}{Z_d + Z_i + Z_0} \\ V_i - V_i' = -E\frac{Z_i}{Z_d + Z_i + Z_0} \\ V_0 - V_0' = -E\frac{Z_0}{Z_d + Z_i + Z_0} \end{cases} \quad (18)$$

- For real components of currents and voltages

$$\begin{cases} I_1 = \frac{3E}{Z_d+Z_i+Z_0} \\ I_2 = 0 \\ I_3 = 0 \\ V_1 - V'_1 = 0 \\ V_2 - V'_2 = E\frac{a^2(Z_i+Z_0)-aZ_i-Z_0}{Z_d+Z_i+Z_0} \\ V_3 - V'_3 = \frac{-a^2Z_i+a(Z_i+Z_0)-Z_0}{Z_d+Z_i+Z_0} \end{cases} \qquad (19)$$

6. Simulations and Discussions

The line Imboulou - Ngo consists of:

- 2 alternators
- 2 processors
- 1 double circuit line
- 1 load at Ngo

6.1. Line Features Imboulou - Ngo

Figure 7 gives a representation of the electrical map of Congo transmission system, the line Imboulou - Ngo is framed in this figure [6].

Figure 7: Electrical map of Congo

The system characteristics are listed in Table 1 below:

Table 1: Feature of the system

For the central	For line	To load
$P_{cc} = 150$ MVA	L = 80km	$S_{ch} = 50$MVA
$x_d = x_i$	$x_d = 0.42\Omega/km$	$\cos\rho_{ch} = 0.8$
$x_0 = 2x_d$	$x_i = 0.21\Omega/km$	$Z_{dch} = Z_{ich}$
	$x_0 = 3.5x_d$	$Z_{0ch} = 0$
	$r_0 = 0.5\Omega/km$	

- **Normal operation (no fault)**

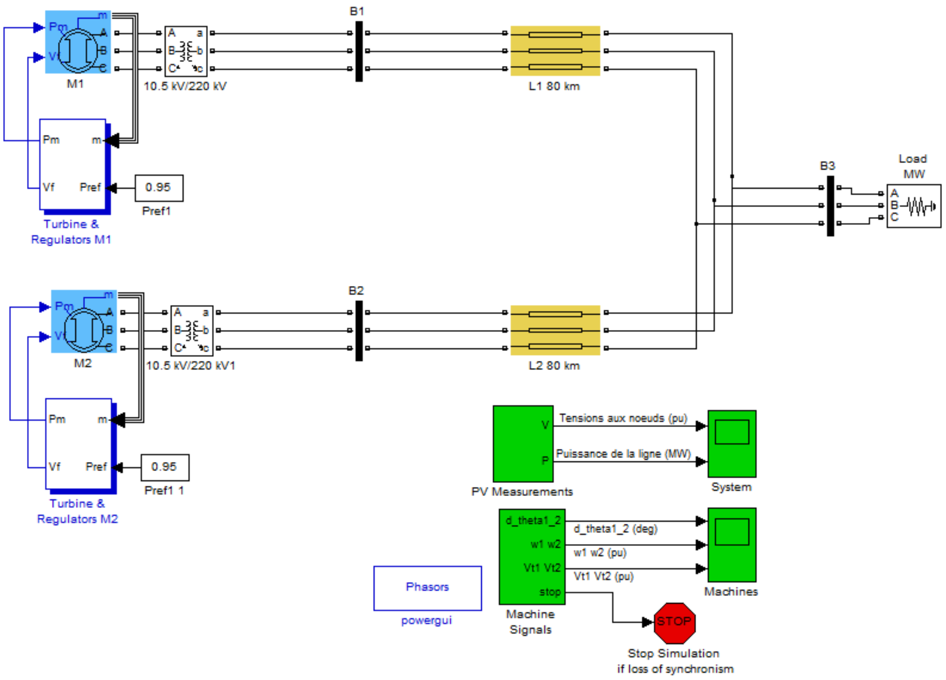


Figure 8: Normal operation

Case 1: normal load power

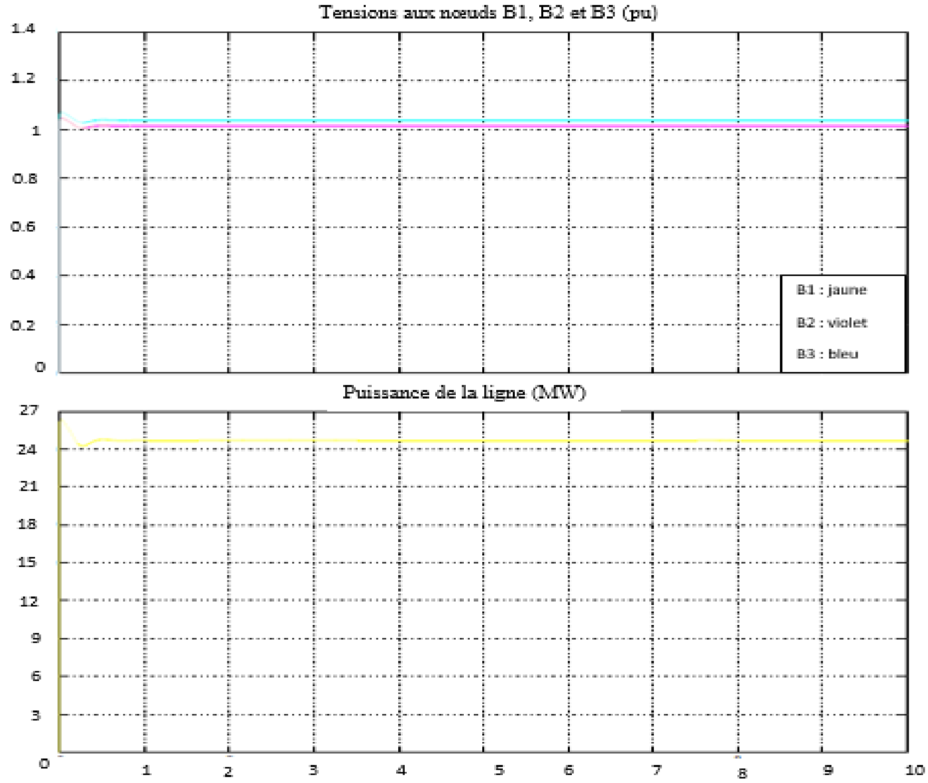


Figure 9: (V, P) normal load (1 test)

2nd case : reduced charge half

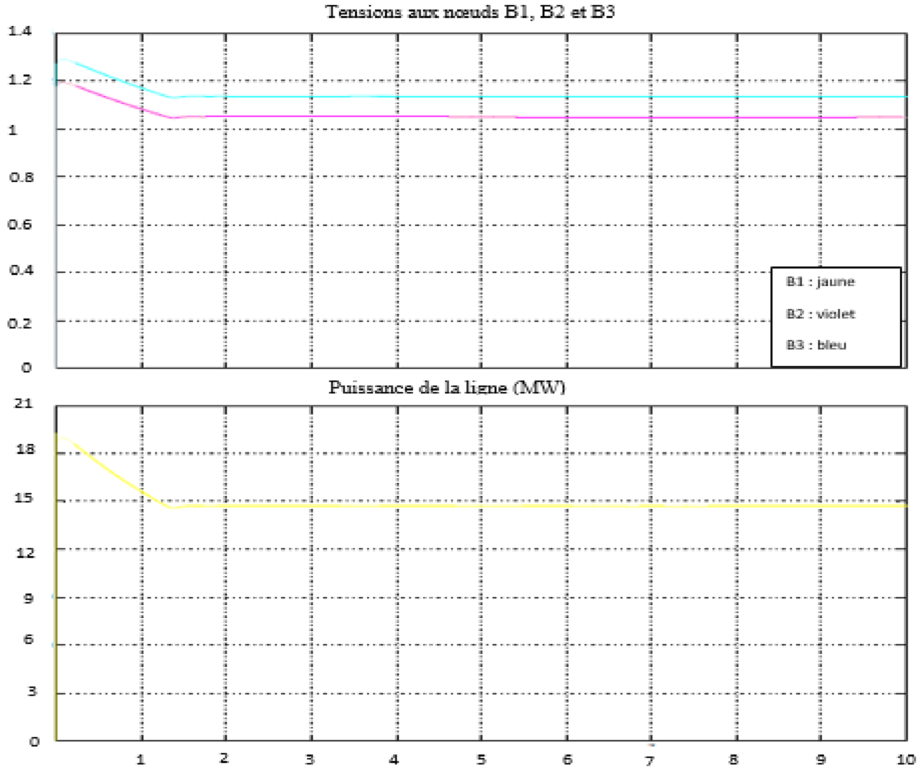


Figure 10: (V, P) reduced load half (second test)

Case 3: **Doubled load power**

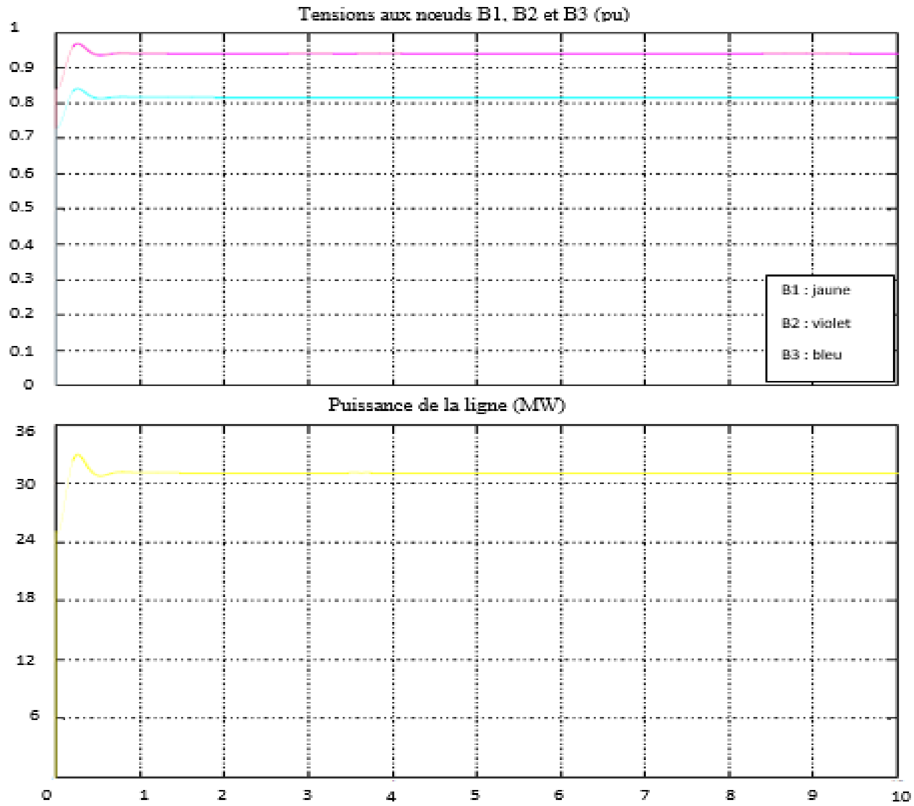


Figure 11: (V, P) coupled load (third test)

- **Phase interruption**

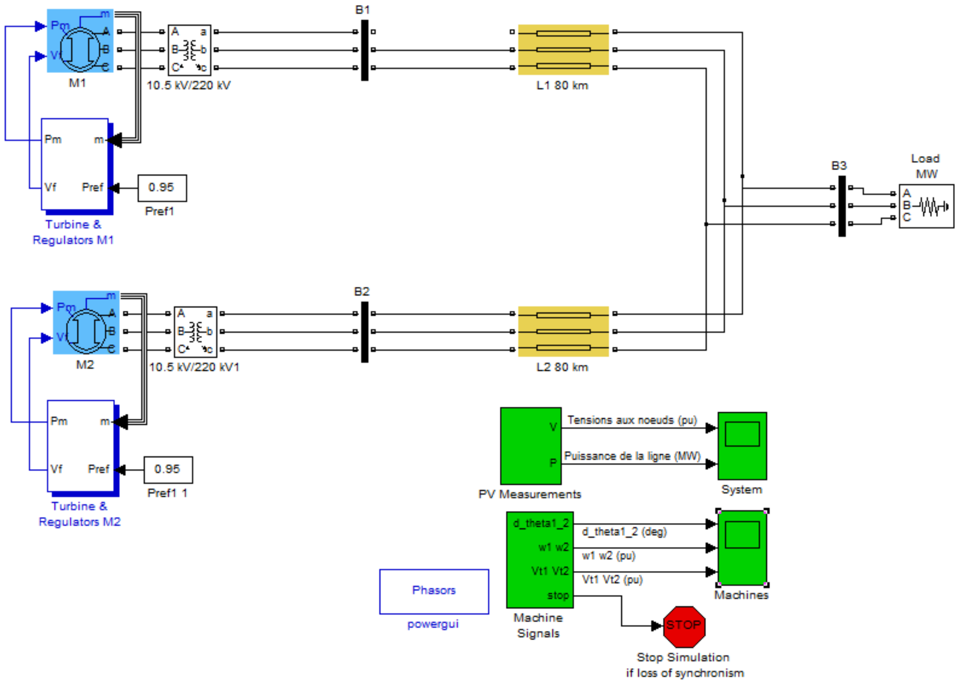


Figure 12: Operating with phase interruption

Case 1: the normal load

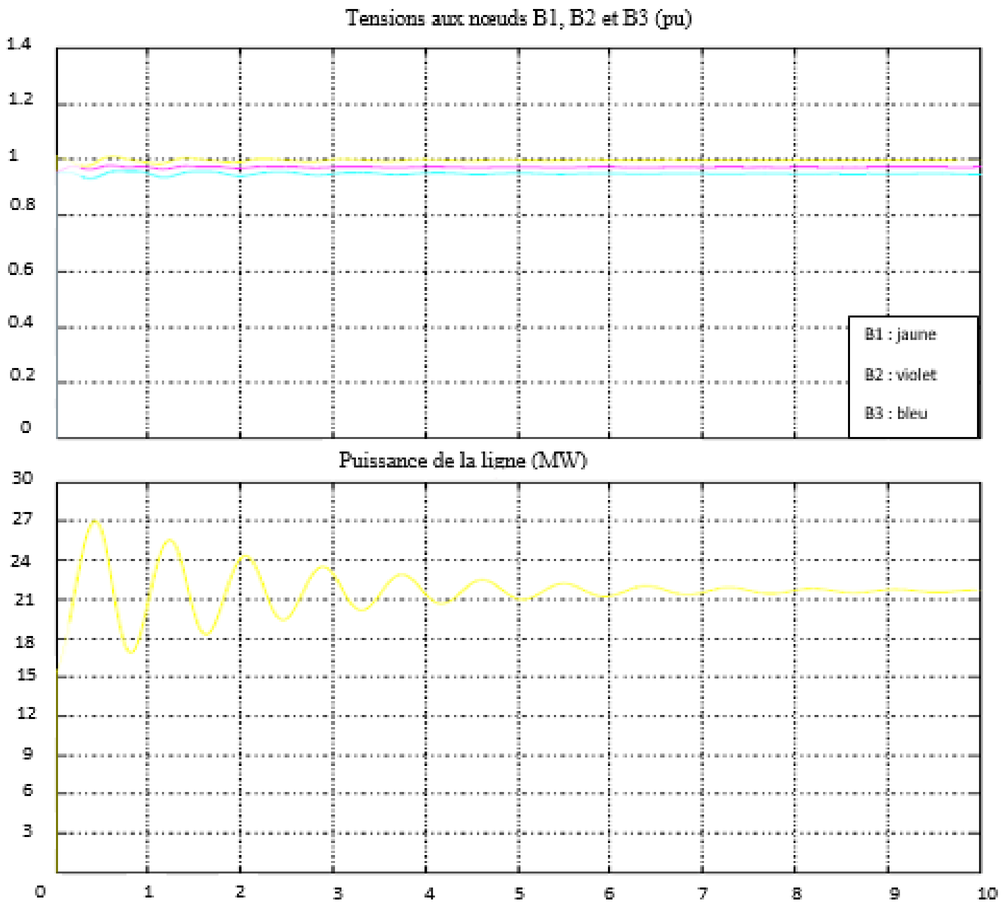


Figure 13: (V, P) normal load (1 test)

Case 2: reduced charge half

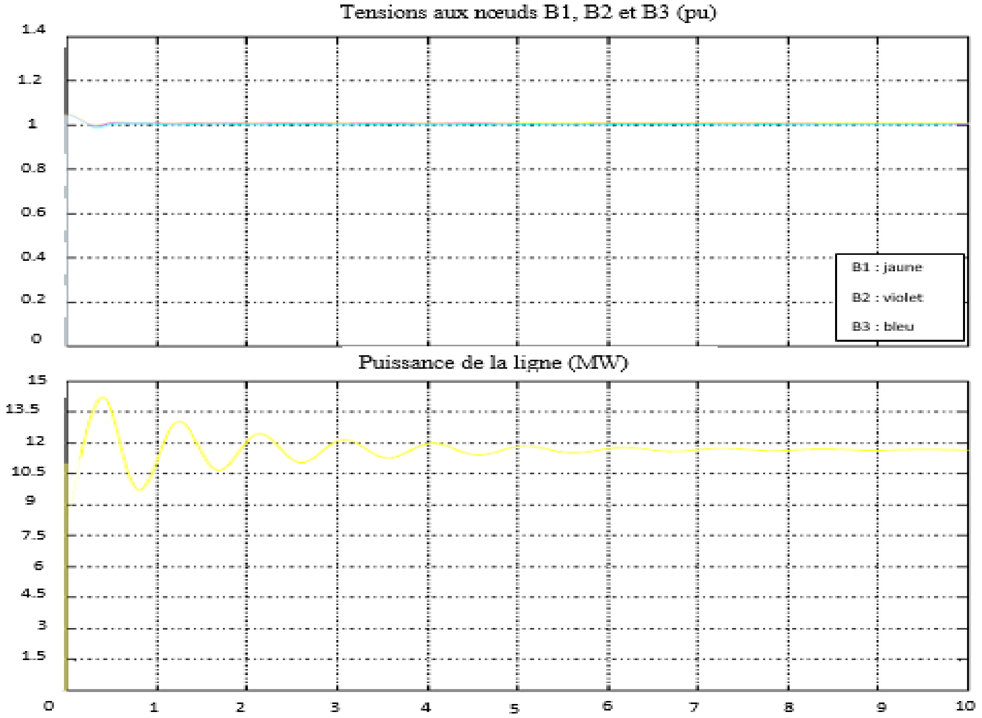


Figure 14: (V, P) reduced load half

Case 3: Charge coupled

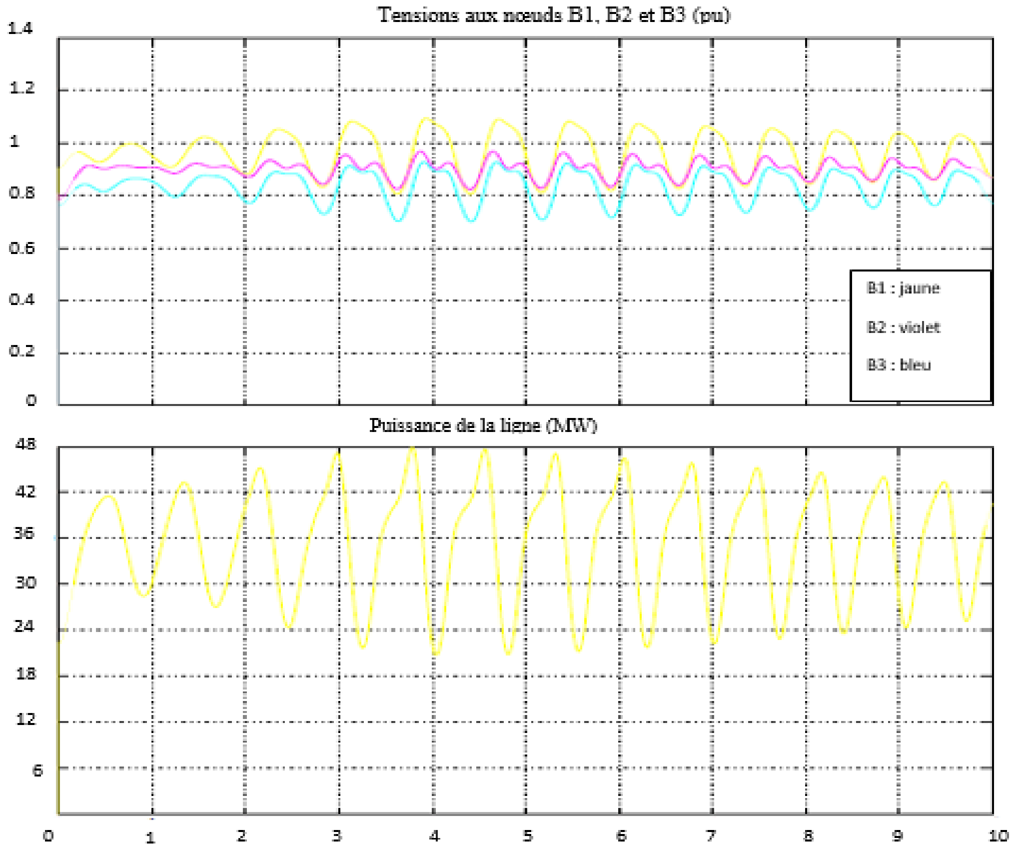


Figure 15: (V, P) coupled load

- **Cleavage of two phases**

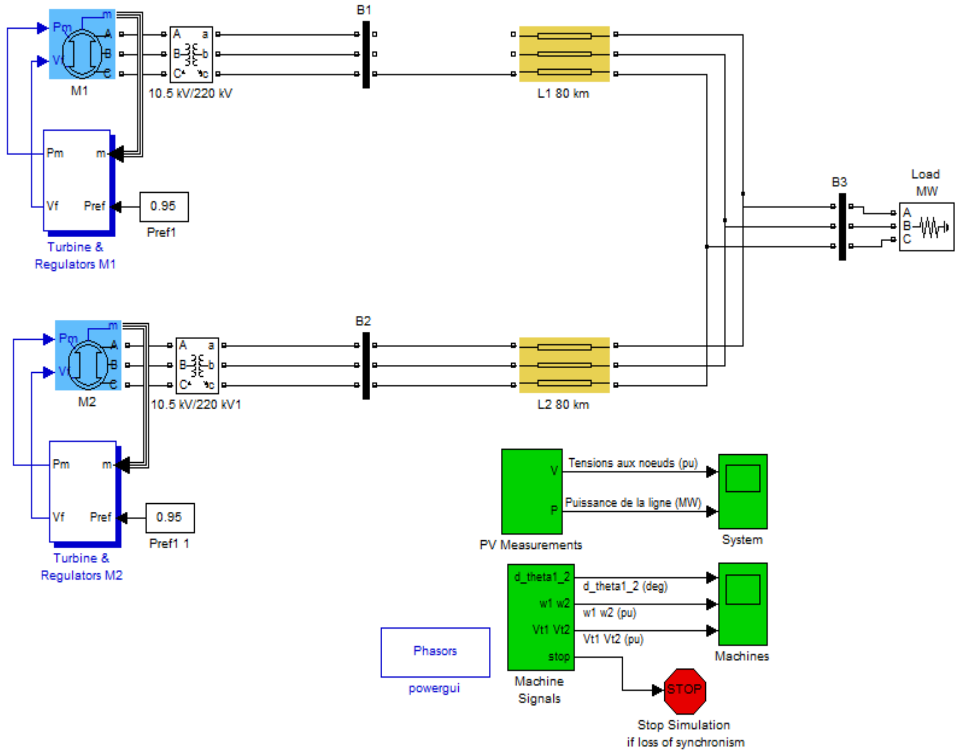


Figure 16: Operation with two phases cutoff

Case 1: the normal load

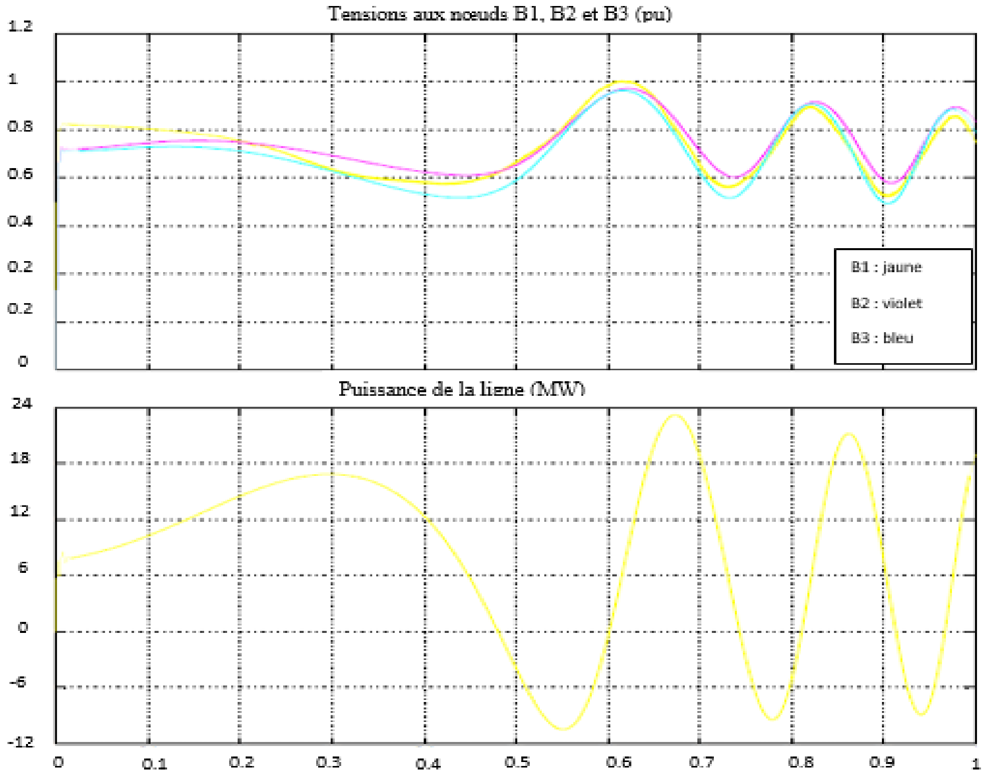


Figure 17: (V, P) normal load (1 test)

Case 2: reduced load power by half

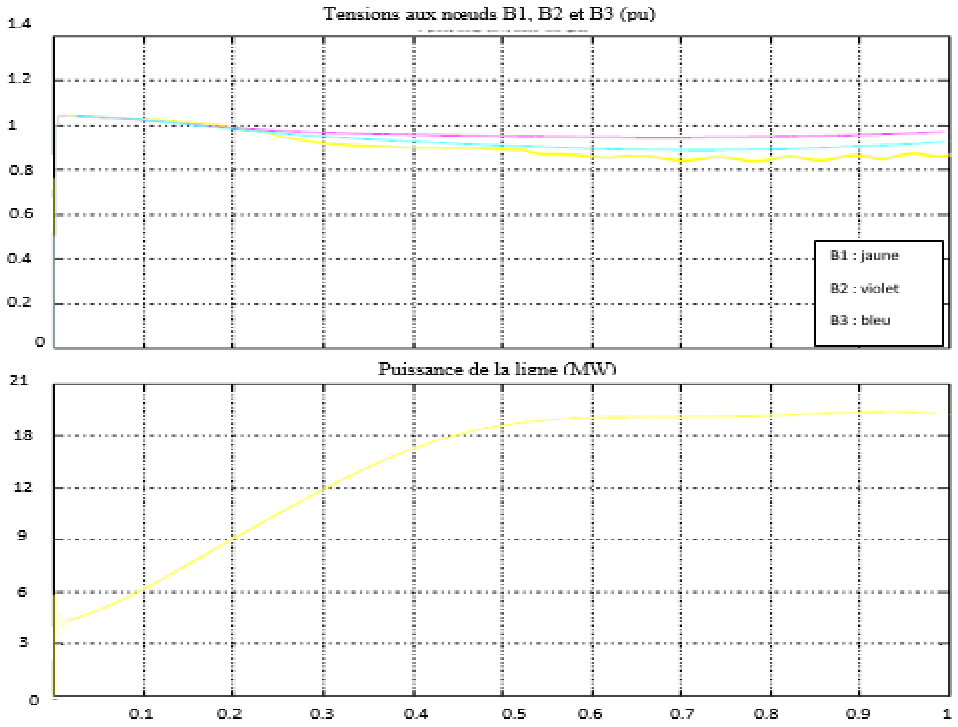


Figure 18: (V, P) reduced load half (second test)

Case 3: Power of the doubled load

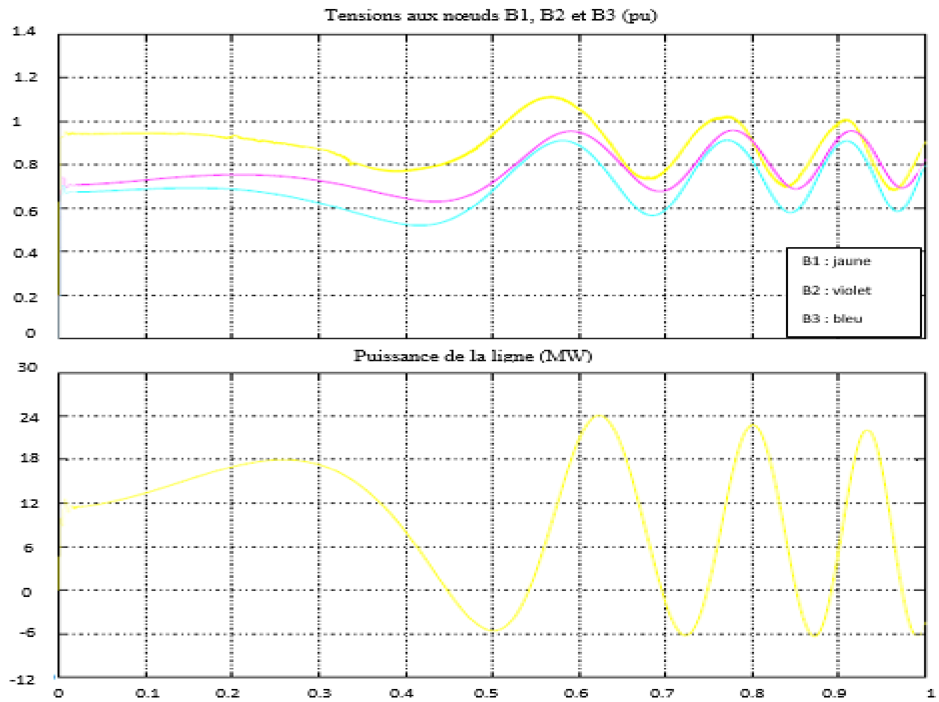


Figure 19: (V, P) coupled load (third test)

7. Discussion

For this study Imboulou online - Ngo, we performed several simulations using Matlab Simulink normal load P_{ch} = 40MW When the load is halved and finally when the load is doubled.

1st operation without breaking phase: in this operation, for the three cases of the load the system remains stable. Note for normal charging voltages are 1pu and power of the line $P_L = 27MW$. When the load is reduced, at $t = 0s$, the tensions are 1.2pu fall before stabilizing at 1.09 and power of 18MW line fall and stabilize at 15MW. Finally, when the power of the load is doubled the voltages are constant, the maximum value is 0.99pu and the power line remains constant at a relatively higher value to 30MW.

2nd operation with a phase failure: In three cases of the load, it is noted that when the power of the load is normal voltages are normal to a 1pu value and line power is disturbed until $t = 8s$ then stabilizes. When the load is reduced tensions are stable at 1pu, the transmitted power stabilizes. $t = 5s$. By cons when the load is doubled the system loses its stability, voltage fluctuations are observed between 0.8 and 1.05pu. The power ranges from 20 to 48MW

3rd operation out of two phases: In this unbalanced operation the system is disturbed and can not find a stable value of the load. When the load is normal, tensions at $t = 0s$ are at 0.7pu and fluctuations are between 0.5 and 0.9pu. The power of the line at $t = 0s$ is equal to 6MW, it oscillates between $-11MW$ and 24MW.

When the load is halved tensions at $t = 0s$ are at 1pu then fall to 0.8pu and the power line is to 3MW, rises to a relatively higher value to 18MW.

Finally for double load, voltages are unstable and values vary between A.5 and 1.05pu. At $t = 0s$ the power line is equal 12MW. This oscillating power and reaches extreme values ranging between $-6MW$ and $24MW$.

8. Conclusion

The importance of online Imboulou - Ngo (220kv - 207km) requires operators to avoid cuts that can increase the risk of instability. In this study we carried out the analysis of this in the case unbalanced diet. To do this we conducted a mathematical development for solving the equations of the different areas using the methods of symmetrical components in the case of a ruptured and two phases. This mathematical approach is supported by simulations using Matlab Simulink, the results allow us to conclude for the line Imboulou - Ngo, the risk of instability is almost zero in the case of operation without phase loss for three scenarios of load. In the case of operation with a phase failure the system remains stable when the load is normal or when halved. by Note against it loses stability when the load is doubled. Operation with break of two phases described unstable operation regardless of the value of the load.

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