

ELECTRICAL NETWORK INFLUENCED BY OVERLOAD, BROKEN PHASE AND SHORT-CIRCUIT

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Abstract: This work evaluates the impact of short-circuit, broken phase, and overload in a transmission network. The chosen network is modelled in Matlab Simulink software. Further, the network currents and voltages undergo abnormal behavior when short-circuit, broken phase and overload come into play. Moreover, some interesting phenomena are investigated such as symmetrical and asymmetrical short-circuit, current troughs, voltage fluctuations or Flicker effect. The paper also presents a review of some electrical faults, the effects of those electrical faults, and some devices of some protection devices.

Keywords: Short-circuit; broken phase; overload; current troughs; voltage fluctuations; symmetrical fault; asymmetrical fault.

1. INTRODUCTION

It is well known that a power system can be seen as a huge electrical transmission network which connects a part of a country or the whole country [1,2]. Further, such system can also connect more than one country. The power system is composed by much electrical equipment such as generators, transformers, transmission line, relays and circuit breakers [1,2]. The generators transform the mechanical energy into electrical energy leading to the electrical power. The transformers increase or decrease the level of the produced voltage following the needed application. The transmission lines allow the electrical energy transmission from one place of the system to another. The relays and circuit breakers are employed for the protection of the power system against faults [1,2].

The phenomena that occur between two different conductors leading sometimes to serious damages are called faults. Those electrical faults are induced by abnormal conditions due to equipment failures, human errors, and weather phenomena. This situation often leads to equipment damages, electrical flow interruptions, and sometimes to the human or animal deaths [2, 3].

The equipment failures occur when the performance of electrical equipment is reduced with age. In this case, the insulation failures are often introduced. This situation often leads to the short-circuit faults in the system. Further, short-circuit fault induces through the network the abnormal current flow leading to the equipment damages [1, 2]. Besides, the human errors are often occurred when

inaccurate calculations provoke the improper selection of electrical equipment. The inappropriate maintenance can also influence the equipment performance leading to the power system faults [1, 2]. Another abnormal condition leading to electrical faults concerns weather conditions such as rain, snow and lightning. Those environmental conditions disturb the network operations leading to power system faults [1, 2]. Further, next to the weather conditions, we can also have the smoke of fires. In fact, the ionization of air comes from the smoke particles surrounding the overhead lines. The smoke of fires is originated to the spark between the lines or between conductors to insulator. Consequently, according to these fires, the insulators lose their insulating capacity due to high voltages.

We can classify electrical faults into different types. Among those types, we have the short circuits. The short circuit fault in the power system stands for an unwanted connection between two elements. This electrical perturbation occurs between one phase and ground, two phases, or three phases. This situation can induce lines and equipment damages and sometimes human beings [4, 5]. Moreover, short circuit fault can be symmetrical or asymmetrical. Besides, symmetrical fault affects all the three phases equally. It induced in the network an abnormal current flow with the same magnitude, but different phase angle with a shift of 120 degrees. It is also called balanced three phase fault [1, 6]. The asymmetrical short circuit fault does not affect all three phases equally. So, there are three different types of asymmetrical faults that can occur in the power system. Among them, we have the phase to phase fault, the

phase to phase to ground fault, and single phase to ground fault [6, 7].

It appears that each kind of faults act on the transmission network in a different way. Some of them can provoke blackout and others can induce equipment damages [1]. Among those fault effects we can list the over current flow, the loss of equipment, danger to employees, and the electrical fires. The over current flow occurs when short circuit fault comes into play. So, it generates a very low impedance path for current flow leading to huge current coming from the supply. This situation can damage equipment insulations [3]. The loss of equipment occurs when high current damages the insulation, windings of motors and transformers. This situation leads to improper working of such equipment [3, 6, 8]. Moreover, the loss of equipment can induce the interruption of some operations of the network leading to the modification of the power system parameters. Consequently, this situation changes the power transmission capabilities [6]. Besides, it is also well known that disturbs interconnected active circuits, contribute in the fault current [3, 9]. The danger to employees corresponds to faults that can provoke shocks to workers leading sometimes to death [3].

It clearly appears that the power system undergoes abnormal currents due to electrical fault. So, such system should be protected to reduce or avoid harmful effects. Consequently, the faulted zone should be isolated in power system by circuit breakers or relays selected following the estimated calculations [2, 6, 10]. The relay is an electrical device often seen as the brain of the protection system. In fact, the relay compares the input voltage or current with a preset value and then takes action. Further, the action taken by the relay corresponds to send a trip signal to the associated circuit breaker to either open or close, to isolate a faulted area [2, 6]. Besides, those relays often use some parameters such as directional overcurrent protection and distance protection to improve their function [11].

The paper presents the impact of some power system faults such as short-circuit, broken phase and overload. The manifestations of those electrical faults are presented in detail in the cases of one-, two- and three-phases perturbations. Some specific phenomena related to those faults are also presented. Among them, we have power surges, voltage fluctuations or Flicker effect, current troughs, symmetric short-circuit and asymmetric short-circuit. The rest of the paper is organized as follows. Section 2 presents the model of the transmission network and the initial conditions leading to the parameters at the beginning of the investigation. In section 3, we introduce the fault (short-circuit, broken phase and overload) in the transmission network. The network voltages and currents are presented to evaluate the impact of each fault. The results presented here, can improve the comprehension electrical fault action in the transmission network. This investigation can also improve the network stability. In section 4, we conclude.

2. TRANSMISSION LINE MODEL

2.1. Initial conditions without perturbation

The chosen network is located in the south division of Cameroon (Central Africa). This transmission network is included in a whole structure called in Cameroon the south interconnected network (SIN). This network is limited by two towns in south region of Cameroon called “Songloulou” and “Logbaba”. The parameters of the line at the beginning of the investigation are given in Tab.(1). So, those parameters are known as the voltage V , the frequency F , the inductance L , the resistance R , the reactance X , the active power P , the reactive power Q , the apparent power S and the phase angle δ or the transport angle ϕ . Some other assumptions are made to perform our investigation. (i) The generator and the phase-shifting transformer are assumed ideal. (ii) The line balanced, the voltage drops across the line represented by the reactance X and the inductance L . The distance related to the network is given L_0 . The characteristics of the network are given in Tab.(1).

Table 1: Characteristics of the chosen network (Songloulou-Logbaba)

I(kA)	V(kv)	F(Hz)	L_0 (km)	R(Ω)	X(Ω)	P(Mw)	Q(Mvar)	S(Mva)	$\phi(^{\circ})$
2.8	225	50	93	8.17	38.6	228.8	48.65	234	12

2.2. Transmission line representation

The electrical fault stands for the deviation of voltages and currents from nominal values or states. Under normal operating conditions, power system equipment or lines carry normal voltages and currents which result in a safer operation of the system.

This investigation concerns the damage coming from some electrical fault on transmission line. In this work, three types of faults are studied known as the short circuit, the broken phase and the overload. Consequently, we begin by showing a model of the transmission network in the Matlab Simulink software as illustrated in the Fig.(1).

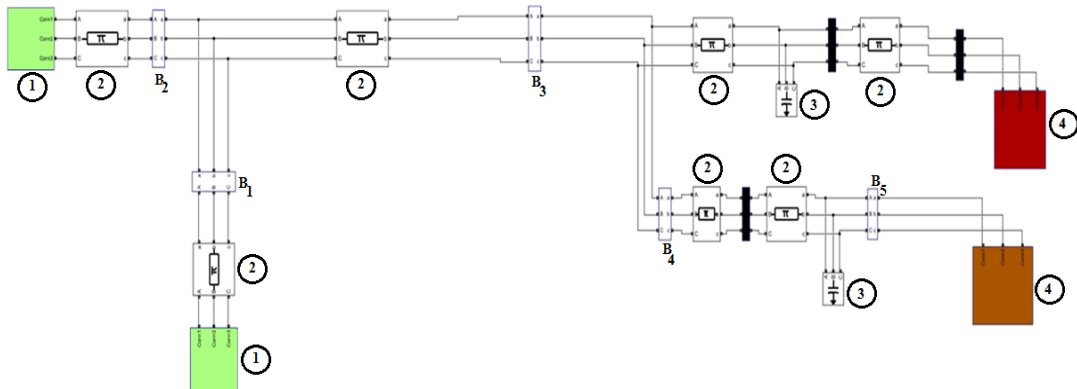


Figure 1: Network without perturbation

The network contains the following elements. (1) Source 1 and Source 2 which provide energy to the system. (2) The phase-shifting transformers. (3) The phase-shifting transformers. (4) Loads at the end of the network. This network will be submitted to different tests corresponding to overload, broken phase and short-circuit. The measured quantities during this work are the network voltages and currents.

3. NUMERICAL SIMULATIONS

3.1. Network voltages and currents without perturbation

During the pre-fault phase, the network is generally in a stable steady state. This step of network operation is characterized by a synchronization of network parameters, such as a harmonization of voltages and currents. So, they are equalized in amplitude and frequency and shifted by 120 degrees as shown in Figs.2(a) and 2(b). The observation of Figs.2(a) and 2(b) shows that the voltages and the currents exhibit sinusoidal behaviors. This oscillating behavior corresponds to a normal behavior for alternative voltage and alternative current. The three curves depicted in Figs.2(a) and 2(b) are three-phase voltages and currents, respectively.

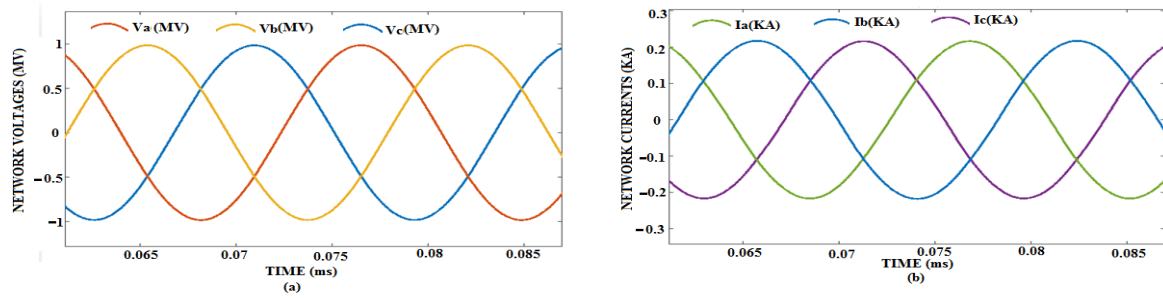


Figure 2: Network voltages and currents without perturbation

Moreover, the voltages vary between -1kV and +1kV as seen in Fig.2(a). In addition, the corresponding currents vary between -0.3 kA and +0.3 kA. It appears that the amplitudes of currents are least important compared to those of the corresponding voltages as depicted in Fig.2(a) and 2(b).

3.2. Short-circuit impact in the transmission network

We now introduce in the network a device able to induce short-circuit as seen in Fig.(3). This device corresponds to (1) as depicted in Fig.(3).

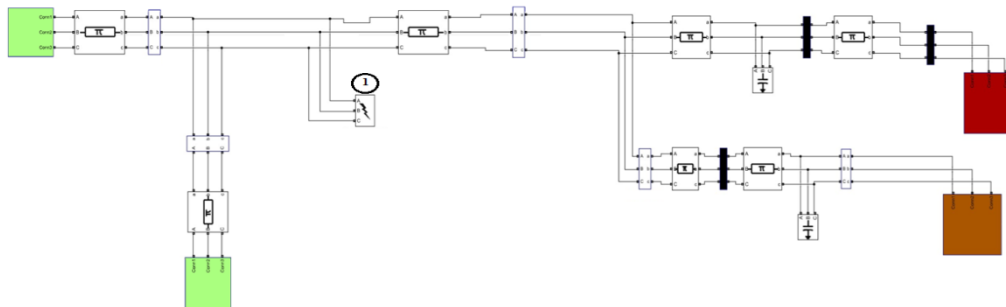


Figure 3: Transmission network influenced by short-circuit

In the next section, we will evaluate the impact of short-circuit in the network parameters.

3.2.1. Network voltages and currents with one phase short-circuit

As soon as a perturbation comes into play, the network exhibits short-circuit conditions. In fact, we obtain this short circuit conditions with phase to ground [1]. The modifications which occur on the network voltages are depicted in Fig.(4).

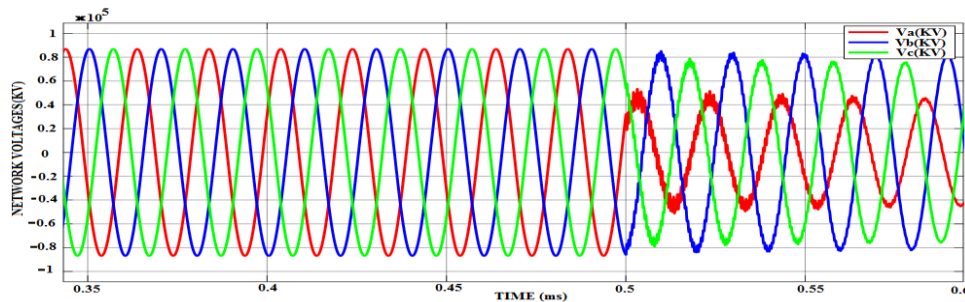


Figure 4: Network voltages influenced by single one phase short-circuit

A rigorous observation of Fig.(4) shows the evolution of three phase voltages V_a , V_b and V_c . Considering the temporal range $0 < t < 0.5$ ms, the red, green and blue curve voltages appear alternatively. Those three curves present sinusoidal behavior corresponding to an oscillating behavior

which varies between -0.9×10^5 kV and $+0.9 \times 10^5$ kV as depicted in Fig.(4). If $t > 0.5$ ms, the blue and green curve voltages maintain their amplitude and their oscillating behavior. This behavior is normal compared to that illustrated in Fig.2(a). Further, the red curve voltage decreases its amplitude from $+0.9 \times 10^5$ kV to $+0.5 \times 10^5$ kV for $t > 0.5$ ms as seen in Fig.(4). It appears that the voltage V_a undergoes short-circuit since it maintains low voltage values compared to V_b and V_c .

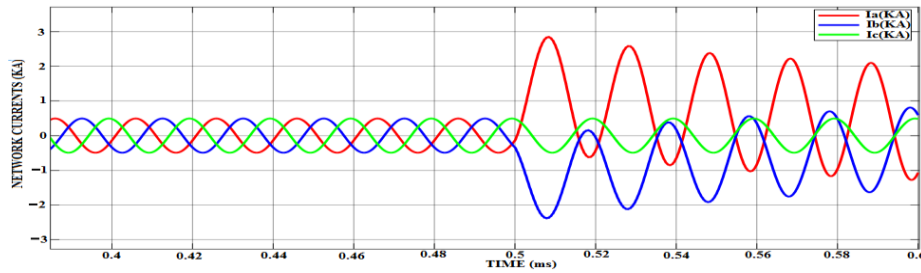


Figure 5: Network currents influenced by one phase short-circuit

According to currents, the corresponding curves present for $0 < t < 0.5$ ms the conventional behavior of three AC currents as depicted in Fig.(5). They vary between -0.5 KA and $+0.5$ KA. However, the red and the blue curve currents undergo high perturbations and act in opposite sense. The red curve I_a varies between -0.5 KA and 2.8 KA and the blue curve varies between -2.5 KA and $+0.2$ KA as seen in Fig.(5). We observe that the red curve progressively loses its amplitude from $+2.8$ KA to ≈ 2.1 KA and the blue curve increases its amplitude from $+0.2$ KA to $+0.8$ KA as seen in Fig.(5). It is important to note that the green curve maintains its conventional behavior.

3.2.2. Network voltages and currents with two-phases short-circuit

We now introduce the perturbation on the two phases. This perturbation corresponds to two phases short-circuit obtained by phase to phase or double phase to ground [1]. The corresponding network voltages are depicted in Fig.(6).

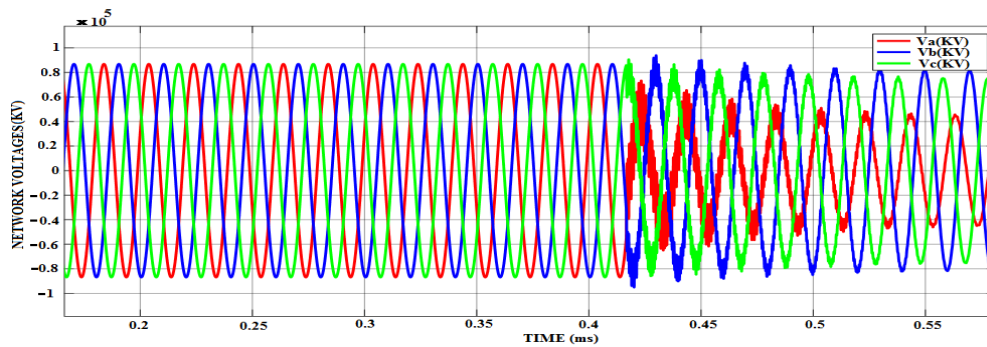


Figure 6: Network voltages influenced by two phases short-circuit

The observation of Fig.(6) reveals that the conventional behavior of the system is maintained for the temporal range $0 < t < 0.425$ ms. Those three curves vary between -0.9×10^5 KV and $+0.9 \times 10^5$ KV. Further, two of the three network voltages are influenced by this perturbation for the temporal range $t > 0.425$ ms as seen in Fig.(6). The amplitude of the green curve varies between -0.8×10^5 KV and $+0.8 \times 10^5$ KV as seen in Fig.(6). Furthermore, the red curve varies between -0.4×10^5 KV and $+0.4 \times 10^5$ KV. So, those two phases are significantly affected by short-circuit. This is the manifestation of two phases short-circuit as depicted in Fig.(6).

After the observation of the network voltages, we now see the impact of the two phases short-circuit on network currents as seen in Fig.(7).

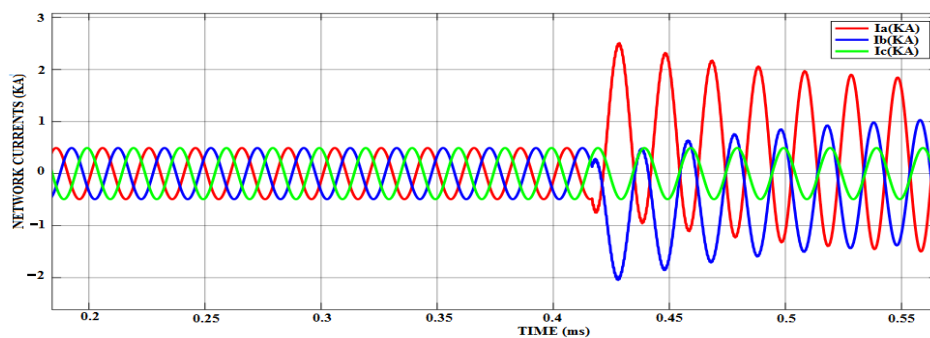


Figure 7: Network currents influenced by two-phase short-circuit

It appears that the conventional behavior previously observed in Fig. 2(b) is maintained in Fig. (7) for the temporal range $0 < t < 0.425$ ms. Besides, the green curve I_c maintains its behavior for the temporal range $t > 0.425$ ms. However, the red curve I_a suddenly increases from 0.5 KA to 2.5 KA for the positive values. This red curve progressively decreases from 2.5 KA to 1.8 KA as seen in Fig.(7). The curve corresponding to I_a acts in opposite sense for negative values. The quantity I_a gradually increases from 0.5 KA to 1.5 KA for negative values of amplitudes as seen in

Fig.(7). The quantity I_b suddenly decreases from 0.5 KA to -2.1 KA. Thereafter, the blue curve gradually increases from -2.1 KA to -1.4 KA as depicted in Fig.(7). It appears that the quantity I_b progressively increases from 0.5 KA to 1.1 KA as seen in Fig.(7).

3.2.3. Network voltages and currents with three-phases short-circuit

We now introduce the perturbation on the three phases. The three phases short-circuit can be obtained by phase to phase to phase or phase to phase to ground [1]. So, we obtain Fig.(8). So, the network voltages subjected to three phase short-circuit are illustrated in Fig.(8). In fact, the traditional behavior of the three curves is safeguarded for $0 < t < 0.425\text{ms}$. Moreover, this behavior is changed for $t > 0.425\text{ms}$ as depicted in Fig.(8). It appears that the amplitudes of three curves are significantly decreases from $0.9 \times 10^5 \text{KV}$ to $0.6 \times 10^5 \text{KV}$. These three curves become large at the beginning of the perturbation and narrow at the end as depicted in Fig.(8). Besides, the amplitudes of those three perturbed curves progressively decrease as observed in Fig.(8).

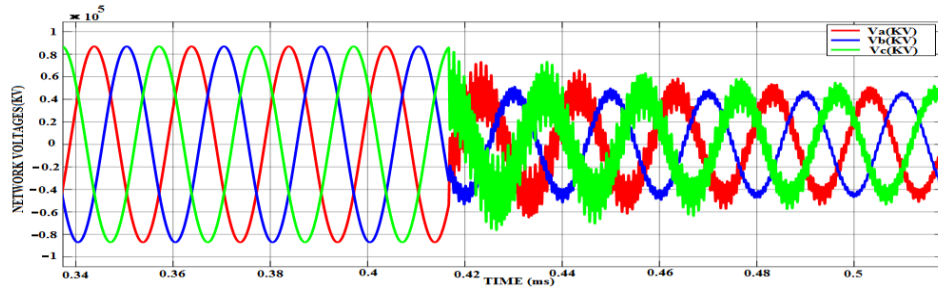


Figure 8: Network voltages influenced by three-phase short-circuit

The corresponding network currents are illustrated in Fig.(9). It appears that the system safeguards its traditional behavior for the temporal range $0 < t < 0.425\text{ms}$. Thereafter, the perturbation occurs and introduces an important temporal shift between the three curves. At the beginning of the perturbation the temporal shift is introduced with high amplitudes for $t > 0.425\text{ms}$. Those amplitudes progressively decrease as the time increases as seen in Fig.(9). The temporal shift also decreases as the time increases. However, the three curves adopt alternative behaviors at the end of the perturbation. Besides, those curves exhibit different amplitudes due to the three-phases short-circuit.

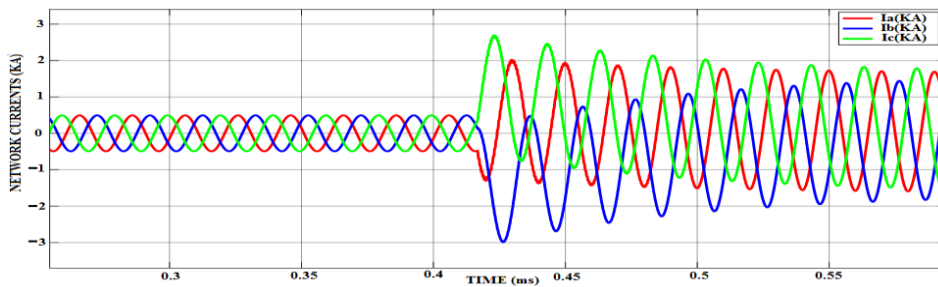


Figure 9: Network currents influenced by three-phase short-circuit

The strange behaviors presented in Figs.(8) and (9) correspond to the signature of the three phases short-circuit.

3.2.4. Symmetric and asymmetric short-circuit phenomena

The observation of Fig.(9) shows two types of short-circuits. In fact, the green, red and blue curves illustrate a symmetric behavior of short-circuit as seen in Fig.(9). It appears that the three phases short-circuit modifies the network currents such as it induces the generation of the symmetric behavior as illustrated in Fig.(9). Moreover, Figs.(5) and (7) present the red and blue curves subjected to an asymmetric behavior. This behavior corresponds to an asymmetric short-circuit fault. The situations depicted in Figs.(5), (7) and (9) respectively correspond to the signatures of one-, two- and three- phases short-circuits. Those results have been also investigated in [1] where a rigorous review of electrical faults is presented.

3.2.5. Voltage fluctuations or Flicker effect

The observation of Figs.(11), (13) and (15) presents network voltages subjected to single, two and three phases short-circuits. Those network voltages exhibit several perturbations similar to small distortions called voltage fluctuations. The voltage fluctuations' phenomenon is also called Flicker effect. This phenomenon corresponds to rapid and random variations of the voltage coming from the absorbed or produced powers of electrical installations.

3.3. Network influenced by broken phase

3.3.1. Network representation with broken phase

The network is now modified to introduce a device able to induce phase break and we obtain Fig.(10).

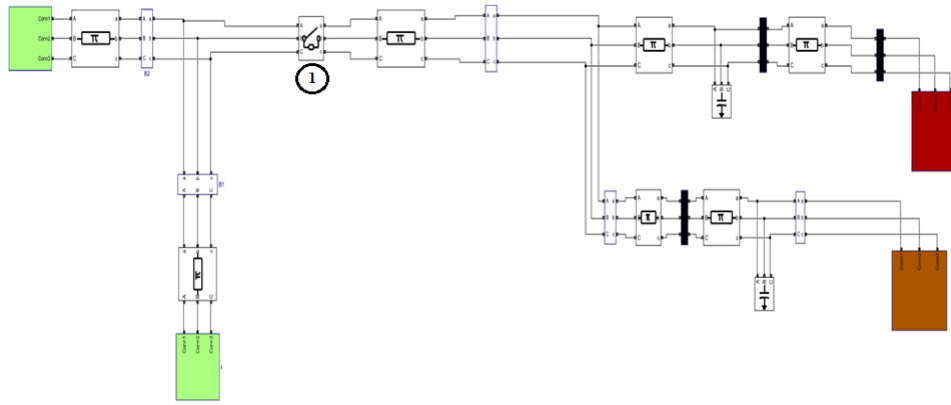


Figure 10: Network influenced by the broken phase perturbation

We now consider the network influenced by a broken phase perturbation. The added element in the network corresponds to (1) the broken phase generator as seen in Fig.(10).

3.3.2. Network voltages and currents influenced by the single broken phase

The broken phase device introduces at the first time the single broken phase perturbation which only acts on one phase. The transformations which occur on the network voltages and currents are illustrated in Figs.(11) and (12).

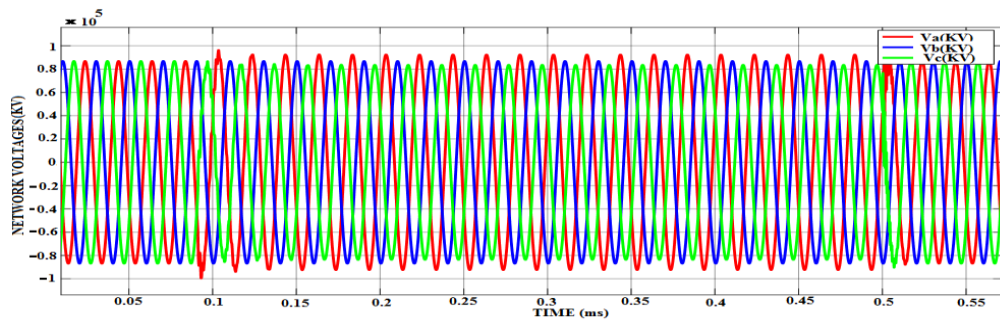


Figure 11: Network voltages influenced by single broken phase

The network voltages obtained after the introduction of the single broken phase leads to Fig.(11). We observe three temporal ranges. The first and third temporal ranges $0 < t < 0.1\text{ms}$ and $t > 0.5\text{ms}$ present three curves with conventional behaviors. Those conventional behaviors correspond to the periodical oscillating behavior presented in Fig.(11). The different curves vary between $0.9 \times 10^5\text{KV}$ and $-0.9 \times 10^5\text{KV}$ for the first and the third temporal ranges. However, the second temporal range $0 < t < 0.5\text{ms}$ presents three curves where the blue and the green curves safeguards their conventional behaviors similar to those exhibited in the first and third temporal ranges. Besides, the red curve V_a has increased its amplitude from $0.95 \times 10^5\text{KV}$. It appears that the red curve V_a is affected by the single broken phase justifying this increase in amplitude as depicted in Fig.(11).

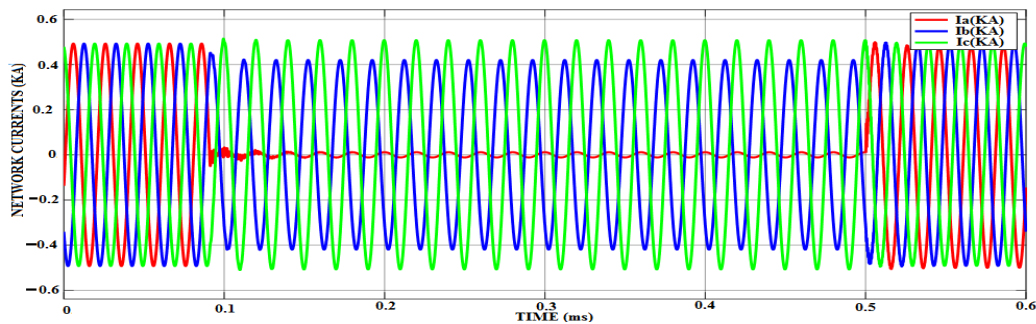


Figure 12: Network currents influenced by single broken phase

After the analysis of the network voltages, we now observe the impact of the single broken phase on network currents depicted in Fig.(12). The first and the third temporal ranges present three currents with similar behaviors. Those curves vary between -0.5KA and 0.5KA . However, the red curve I_a is practically closed to zero corresponding to the phase affected by the perturbation for $0.1 < t < 0.5\text{ms}$. the broken phase introduces some modifications on the two other phases for the intermediate temporal range as seen in Fig.(12). The blue curve amplitude decreases from 0.5KA to 0.4KA and the green curve one increases from 0.5KA to 0.55KA . This behavior constitutes the main signature of the single broken phase on the network currents as seen in Fig.(12).

3.3.3. Network voltages and currents influenced by two broken phases

The perturbation now affects two phase on the network. So, the network voltages are modified as illustrated in Fig.(13).

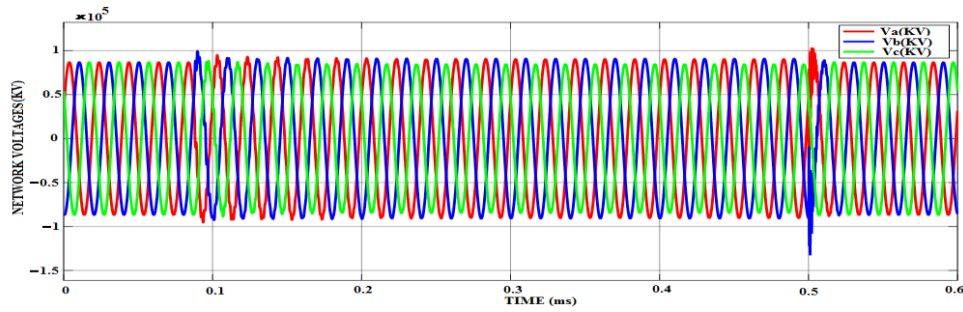


Figure 13: Network voltages influenced by two broken phases

The observation of Fig.(13) shows that the traditional behavior of the network voltages are safeguarded for the first and third temporal ranges $0 < t < 0.1 \text{ ms}$ and $t > 0.5 \text{ ms}$. However, the red and the blue curves present high amplitudes compared to that of the green curve which conserves its original behavior as seen Fig.(13).

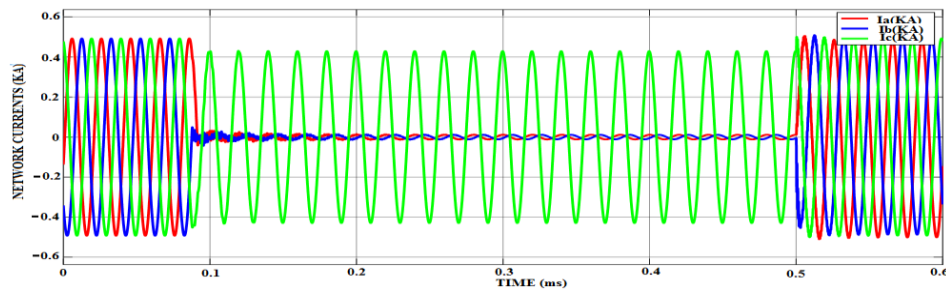


Figure 14: Network currents influenced by two broken phases

The corresponding network currents are illustrated in Fig. (14). It appears that the original behaviors of currents are safeguarded for the first and third temporal ranges $0 < t < 0.1 \text{ ms}$ and $t > 0.5 \text{ ms}$. Further, the red and the blue curves are closed to zero at the second temporal range as depicted in Fig.(14). Moreover, the green curve amplitude decreases from 0.5 KA to 0.4 KA. This situation which appears in the second temporal range $0.1 < t < 0.5 \text{ ms}$ constitutes the signature of the two broken phases.

3.3.4. Current trough phenomena due to broken phase perturbations

The observation of the broken phase phenomenon depicted in Figs.(12) and (14) shows another strange behavior of network currents. This behavior can be related to the voltage troughs and can be called current troughs as illustrated in Figs.(12) and (14). This current trough phenomenon can induce the degradation of some materials on the transmission network.

3.3.5. Power surge phenomena due to broken phase perturbations

We consider the broken phase perturbations illustrated in Figs.(11) and (13) which present specific behaviors of the network voltages. In fact, we observe sudden increase in voltage amplitudes at the beginning and at the end of the broken phase perturbation as seen in Figs.(11) and (13). Those sudden voltage peaks correspond to the power surges' phenomenon. This strange phenomenon occurs for few seconds and disappears as seen in Figs.(11) and (13). It well known that the power surge phenomenon induces the destruction of computer materials.

3.4. Network representation influenced by overload

We now introduce in the network a device able to induce an overload perturbation (1) as seen in Fig.(15). Those devices (1) can induce an overload perturbation anywhere in the transmission network.

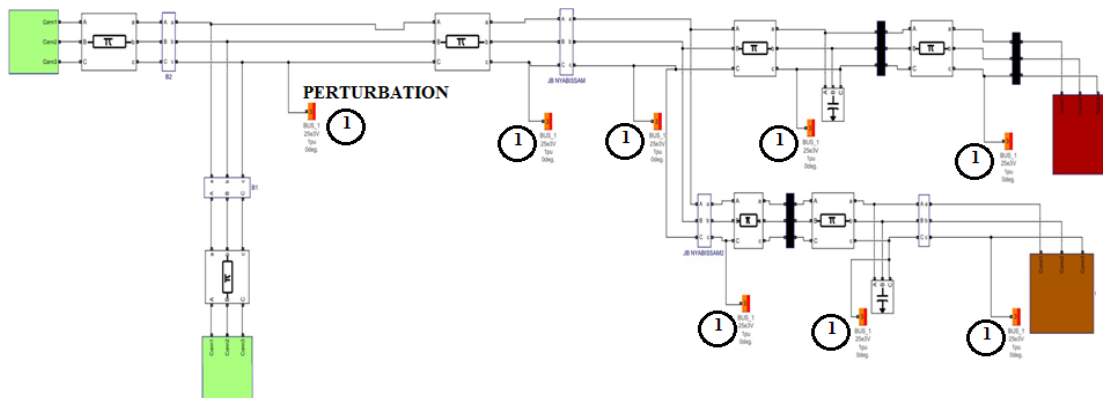
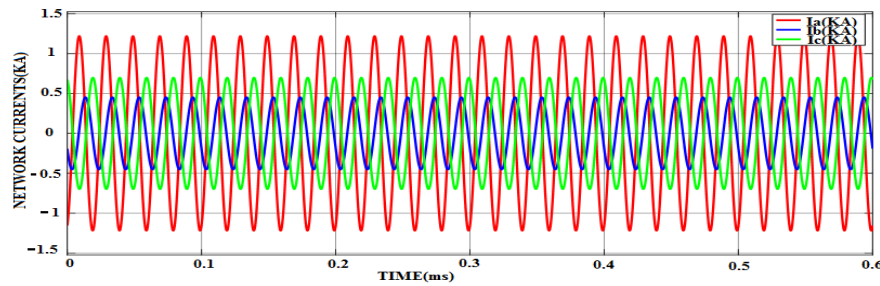


Figure 15: Network representation influenced by overload on single phase

3.4.1. Network currents influenced by single phase overload

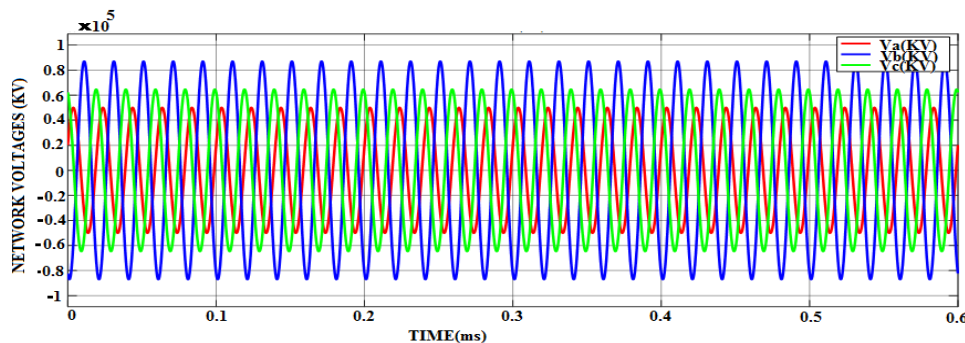
We provoke on the network a single phase overload. We obtain Fig.(16) where the impact of the single phase overload is presented on network currents.



The introduction of the overload perturbation on the red phase leads to a significant increase in amplitude as seen in Fig.(16). The red curve therefore varies between -1.25 KA and $+1.25$ KA and maintains the oscillating behavior as illustrated in Fig.(16). However, the green and the blue curves maintain their original behaviors with small amplitudes. The blue curve safeguards its original behavior and acts between -0.5 KA and 0.5 KA. Further, the introduction of the single phase overload induces on the green curve another shift which provokes a small increase in amplitude as seen in Fig.(16). This small growth in amplitude corresponds to an increase from 0.5 KA to 0.75 KA. This situation reveals the generation of internal disturbances due to the introduction of the single phase overload in the network. Those internal disturbances induce the growth in amplitude of the red and the green curves previously observed in the system. Besides, this internal excitation also induces the strange shift located between the green and the blue curves as depicted in Fig.(16). The modifications presented in Fig.(16) correspond to the signature of single phase overload on the transmission network.

3.4.2. Network voltages influenced by single phase overload

The corresponding network voltages influenced by single phase overload are illustrated in Fig.(17). The introduction of the single phase overload perturbation has previously increased the red current I_a as seen in Fig.(17). This situation leads to the decrease in amplitude of corresponding network voltage V_a as seen in Fig.(17). In fact, red curve acts between -0.5×10^5 KV and $+0.5 \times 10^5$ KV. The other network voltages are modified by the single phase overload. Besides, the blue curve exhibits amplitude which acts between -0.9×10^5 KV and $+0.9 \times 10^5$ KV.



We observe that the green curve present amplitude which acts between -0.62×10^5 KV and $+0.62 \times 10^5$ KV as seen in Fig.(17). The general observation reveals that the currents act in opposite sense compared to the voltages as depicted in Figs.(16) and (17). The modifications which occur in Fig.(17) correspond to the signature of the single phase overload on the transmission network..

CONCLUSION

In summary, the paper has investigated the impact of short-circuit, broken phase and overload in a transmission network. First of all, using Matlab Simulink software, we have modelled the transmission network without fault (short-circuit, broken phase or overload), and the transmission network with fault. Secondly, we have presented the behavior of the network voltages and currents when one-, two-, and three- phases faults come into play. It appears that each electrical fault acts in a particular way on network voltages and currents. Moreover, some interesting phenomena have been also presented such as current troughs, power surges, symmetrical and asymmetrical faults, and voltage fluctuations or Flicker effect.

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