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Risk simulation of having direct contact with electric urban networks

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Abstract

To know the electric risks for the human health having electric discharges on low and medium voltage urban networks helps people to make aware about doing actions of prevention and safety, which reach to prevent injuries and/or accidental deaths. In this paper, simulations on ATP-Draw software over three different specific risk cases were done, based on the concurrent problem presented in the central region of Colombia between August and October when people use to fly kites. The first case analyzed is an individual who has an indirect contact with medium voltage transmission lines by means on a conventional kite, presenting no serious effects on its health. In the second and in the third case, the individual generates a direct contact both low and medium voltage lines, when tries to recover a stuck kite, receiving high health effects even producing death. The main goal of this work is to show the different consequences and effects in the human body which are presented over a person when receiving an electric discharge by direct contact, in order to prevent accidents.

Keywords: *electric discharge, electric risk, urban electric networks, ventricular fibrillation*

1. Introduction

Electric energy is present in the daily life of people, due to most of the common activities are performed involving secondarily electric energy which indirectly implies electric risk. It is possible to use an electric risk analysis as tool to evaluate the possibility of happening incidents which can produce effects on the public welfare, the safety, the environment and the individual health [1, 2]. The flow of electric current through the human body no matter its origin, is defined as electrocution, which can produce as a fibrillation as the death of the individual [3]. The electric failures mainly happened on the transmission or distribution systems due to atmospheric discharges that collide against structures near them [4], as well as failures on the electric system that affect its safety and indirectly put in risk the physical integrity of people. Some countries present significantly more cases of death by electrocution, in which retrospective statistical studies have been done [5-9], even in cases of death by exposure to low voltaje networks [10, 11].

Most of the electric discharges are generated due to the people have not the knowledge and/or respective caution to avoid accidents [12], for example when someone touch an electric wire with its hand, it is produced a common symptom of the electrocution which is pain due to the sensorial fibers are activated, also producing unconscious spasms in the forearm muscles, stimulating the grip of the conductive element that produce the discharge, intensifying the symptoms due to an extended exposition to the electric current [13].

One of consequences of the low voltage electrocution is the ventricular fibrillation, which implies ventricular fibrillation by direct induction, cardiac T wave with shock and in long term reduction of the ventricular fibrillation threshold due to cardiac capture of high frequency [14]. The media of electric risk prevention have tried to make aware to the people both in jobs and in homes, about the risk involved in the use of the electricity and its possible effects on the health. For this some implementation projects have been developed, such as simulation trainings on VR (Virtual Reality), developed for Android Smartphones, which through simulation of specific electric discharges cases on different environments, train the person to prevent and act correctly on the different sceneries of electric risk [15].

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On the other hand, for an adequate analysis of the impacts or alteration factors on distributed generation systems and distribution networks, the ATP-Draw software is usually utilized, with which it is possible to do an adequate behavior analysis once the electric model of each of the electric system elements is done [16-18]. Also, ATP-Draw software is used to make analysis of impact overvoltage on towers by lightnings. In the characteristics as voltage, current and transitory time, ATP-Draw generates confident responses for the design of protections against atmospheric discharges for cell-phone towers and speed control for wind energy centrals, among others [19, 20]. In this paper ATP-Draw is used for analyzing the electric risk over humans on three different case of electric discharges by direct and indirect contact with electric networks of low and medium voltage, and thus can infer the possible effects on the human health.

2. Research Method

2.1. Effects in the Human Body

In spite of existing strict procedures for a safety manipulation of the electric energy, people use to ignore them producing injuries and deaths due to certain degree of wrong confidence when people manipulate elements that use electric energy [21]. An important aspect in the cases of electric risk is the attention time elapsed from de accident, due to the person is not rapidly attended there is a high probability to have big complications for the human body, such as tachycardia, sinus bradycardia, Severe late arrhythmia, effect ventricular extrasystole and alterations of the wave ST-T [22]. There are different types of electric injuries which mainly affect the nervous system, an electric discharge can produce cardiac arrhythmias potentially deathly, transient myocardial ischemia and enzymatic changes and myocardial infarction [21].

In addition, there are another type of injuries less frequent, like shoulder dislocation posterior which can be associated with concomitant fractures of the humerus, that is produced by having a violent muscular contraction due to the electrocution of the arm by electric discharge [23]. From the 78% to the 92% of the electrocution cases correspond to men in ages of 28.9±12.5 years in average, as well as the upper limbs are the most usually to do contact with the electric source [24-26], most of the accidents are generated in the work environment especially in factories and also in the streets, additionally most of them occur in the summer season from June to August [25].

Depending on the current intensity and the exposition time, the human body presents effects over the skin, which are classified in different affectation zones [27], as shown in Figure 1. In the zone 0, there are no alteration on the skin, if there is a longer exposition it is evident a gray color and roughness in the skin. In the zone 1, the skin presents redness, in the zone 2 the skin turns into brown and swells and in the zone 3 the skin presents carbonization. Also, the physiological effects can be analyzed depending on the specific energy received by the person as shown in Table 1.

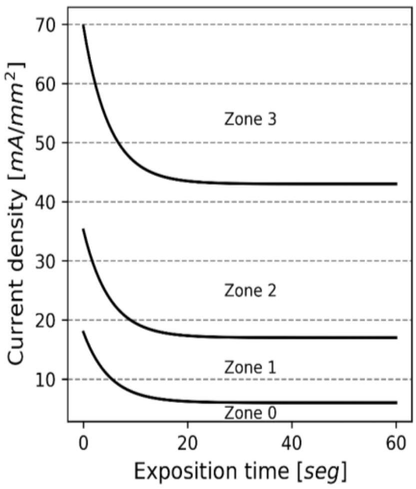

Figure 1. Skin effect zones [27]

Table 1. Specific Energy and Physiological Effects Relationship [28]

Specific energy I^2t [$A^2s * 10^{-6}$]	Physical effects
4 to 8	Low sensation in the fingers and in the tendons of the feet.
10 to 30	Soft muscular stiffness in the fingers, wrists and elbows.
15 to 45	Soft muscular stiffness in the fingers, wrists, elbows and shoulders. Some sensation in the legs.
40 to 80	Muscular stiffness and pain in arms and legs.
70 to 120	Muscular stiffness, pain and burning in arms, shoulders and legs.

2.2. Electric Model of the Human Body

The different body parts such as muscles, blood, skin, etc., represent an impedance compound by resistive and capacitive elements, due to it behaves as the sum of the input impedance of the skin, the inner impedance of the body and the output impedance of the skin [27]. The impedance of the human body could be considered mainly resistive, where the trunk has less magnitude than the limbs; depending on the way of the electric discharge in the human body, there are different impedance values in the body, for instance from a hand to the another one, from a hand to a foot, and all the posible combinations, taking as reference an impedance value of 100% in the cases of hand-hand or hand-feet [27]. Also, the impedance values established for the human body in alternate current, in the hand-hand trajectory, in dry skin conditions and frequency of 50-60 Hz and 125V could be change from 1125 to 2875 Ω.

2.3. Electric Risk zones

The Figure 2 from the NTC (Colombian Technical Standard), specifically the NTC 4120, which in part is based on the International Technical Commission IEC 60479-2, describes the zones that represent the effects of exposing to alternate current compared with the exposition time changing the frequency from 15 Hz to 100 Hz [28]. For the protections design the curve C1 of the Figure 2 is used as design limit for current shutdowns avoiding the death by electrocution, according to previous research done by Dalziel. For doing a correct analysis of the Figure 2, which is composed by a time axis in milliseconds against a current axis in milliamperes, it is necessary to know that each zone is represented as a closed area in the graph, where a lot of different combinations of current and exposition time can belong to the same area or zone. The Figure 2 shows the 6 established effects Zones. The zones that present less effect over the human body are the 1st, 2nd and 3th ones, where usually any dangerous physiologic or pathologic effect occurs, not even any fibrillation risk. Those zones have maximum currents of 0.3 mA for the 1st one, 200 mA for the 2nd one and 500 mA for the 3th one, depending on the exposition time to the electric discharge. It is necessary to take into account that if this time increases near the current limits of a zone, it is very probable to overpass it to the next one.

The zone 4, which is defined from 500 mA to 1000 mA, presents effects on the human body like 5% of fibrillation risk, it is important to highlight that for exposition times higher than 1000 mS, the lower current limit of this zone is reduced to approximately 50 mA. The zone 5, which is defined from 1000 mA to 1500 mA, presents a risk of 50% of fibrillation, considered very dangerous for the human body. For exposition times higher than 2000 mS, the lower current limit of this zone is reduced to approximately 40 mA. The most dangerous zone is the 6th one, which is defined from 1500 mA onwards. It is considered the zone that presents more effects and risk on the human body, due to it can produce heart attack, respiratory failure, high grade burns and fibrillation risk higher than 50%. For exposition times higher than 2000 mS, the lower current limit of this zone is reduced to approximately 50 mA.

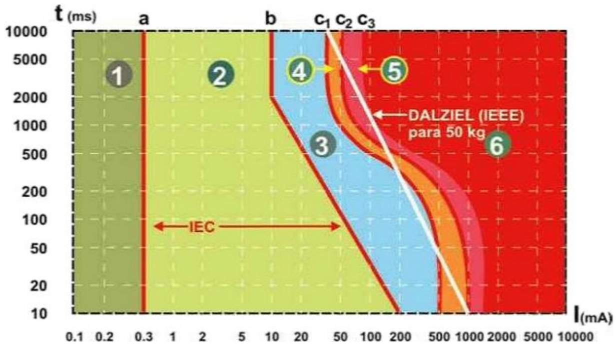

Figure 2. Effects zones of exposing a human being to alternate current [28]

3. Results and Analysis

In Colombia, August is considered as the windiest month in the year, for that reason, most of people go out from their homes to practice the most typical activity of the that season, which is flying kites. This activity produces annually a lot of accidents. This paper shows the analysis of two specific cases, the first one is when a person tangles the rope of its kite on an electric wire which belongs to an urban low or medium voltage network, analyzing a possible electric discharge to the person. In the second case, the same person climbs directly to the medium-voltage network in order to recover its kite directly through the pole or a tree [29], analyzing the voltages and the currents induced to the person and what are the risks on its health.

3.1. Electric Risk by Indirect Contact through a Kite Rope with a Medium Voltage Network

A simulation, where a person tangles its kite on a wire is done. The wire belongs to a medium voltage network of 11.4 kV rms and it is located in a pole 10.2 m high. The person receives an electric discharge as shown in the schematic of the Figure 3 and in the electric model (using ATP-Draw software) shown in Figure 4. A three-phase system of medium voltage (11.4 kV) is modeled, with a height of 11.2 m, taking into account a medium voltage line of 20 km and 40 m of conductor (Centelsa ACSR (6/1) Sparrow caliber 2 AWG de configuration LA 204), using a pole-type transformer of 45 kVA with Delta–Y configuration of 11.4 kV/ 208 V/120 V, having 2 domestic electric supply connections.

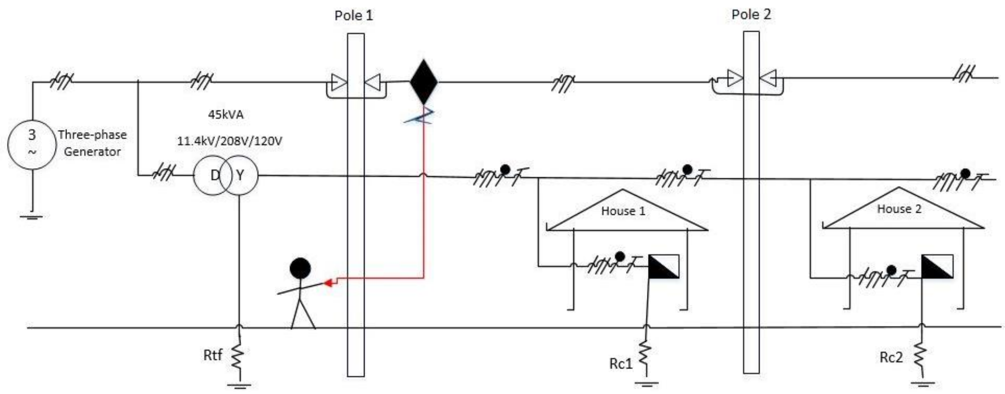

Figure 3. Schematic of the case of electric discharge in medium voltage through a kite rope

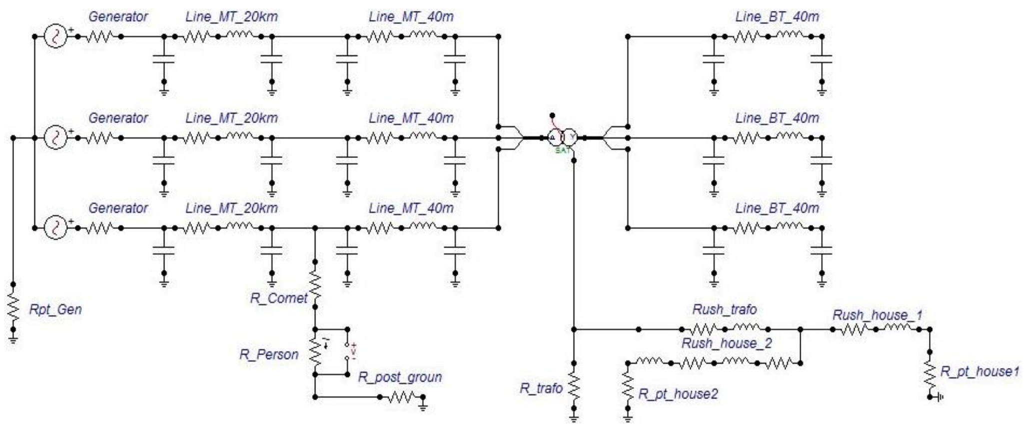

Figure 4. Electric model of the case of electric discharge in medium voltage through a kite rope

The failure is generated by the contact of the kite rope with the electric components of the electric system, so it is necessary to know the electric model of that rope. The building material of the rope use to be organic, like cotton or agave fiber, then its electric behavior is consider highly resistive alike wood. Taking the resistivity coefficient of wood (10^8), a length of 15 m and a radius of 0.75 mm, the resistive behavior of the kite rope is found, it is shown in (1) and (2). When the electric failure is generated, the person behaves as an electric load for the system, which has a generated voltage and current shown both in the Figure 5.

$$Rc = \frac{\rho * l}{\pi r^2} \quad (1)$$

$$Rc = 10^8 \frac{\frac{\Omega mm^2}{m} * 15m}{1.767mm^2} = 8.849M\Omega \quad (2)$$

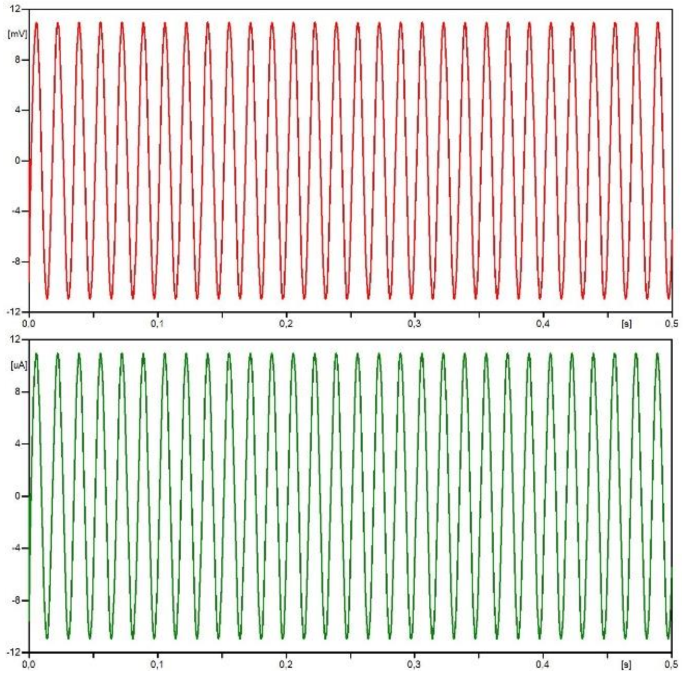

Figure 5. Voltage (left) and current (right) generated on the person in medium voltage through the kite rope

3.2. Electric Risk by Direct Contact with a Medium Voltage Network

For the second case, a simulation of a person taking direct contact with a medium voltage line is done. For this case the person tries to recover its tangled kite, climbing to the pole of a medium voltage network of 11.4 kV rms, generating an electric discharge by direct contact with the wire as shown in the Figure 6, as well as its electric schematic in the ATP-Draw software in the Figure 7. The system has the same features of the first case, but here the person climbs the pole where the medium voltage network is installed, generating an electric failure by direct contact. On the person, a generated voltage and current are presented as shown in the Figure 8.

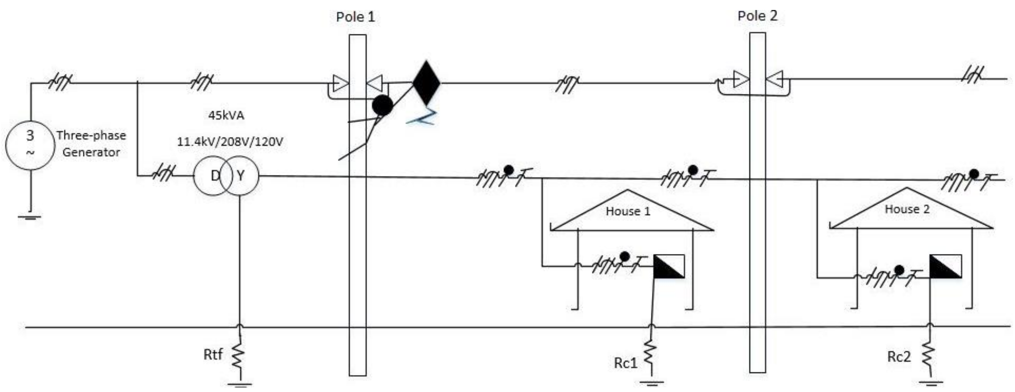

Figure 6. Schematic of the case of electric discharge in medium voltage by direct contact

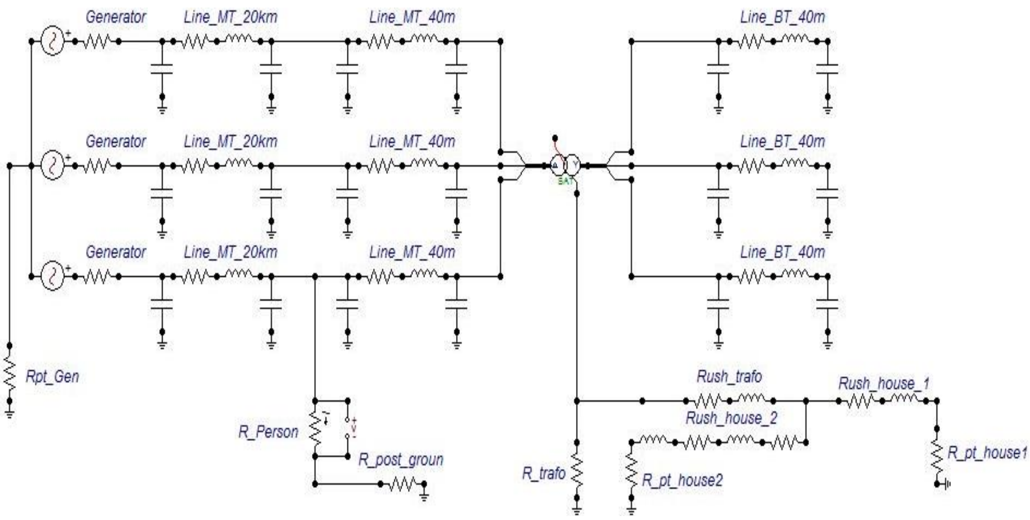

Figure 7. Electric model of the case of electric discharge in medium voltage by direct contact

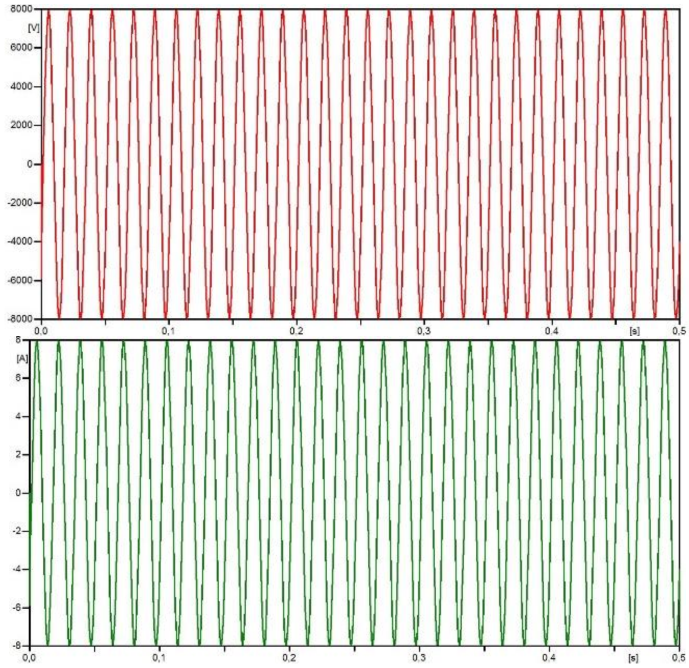

Figure 8. Voltage (left) and current (right) generated on the person in medium voltage by direct contact

3.3. Electric Risk by Direct Contact with a Low Voltage Network

For the third case, a simulation of a person taking direct contact with a low voltage line is done. In this study case, the person tries to recover its tangled kite, climbing to the pole until reach a wire of a low voltage network of 120 V rms, generating an electric discharge by direct contact with the wire. This discharge is shown in the Figure 9 and its electric schematic made in ATP-Draw in the Figure 10. The system has the same features of the one of the first case, and it is modeled using a low voltage three-phase conductor caliber 8 AWG with neutral line. When the electric failure is generated, the person behaves as an electric load for the system, which has a generated voltage and current shown both in the Figure 11.

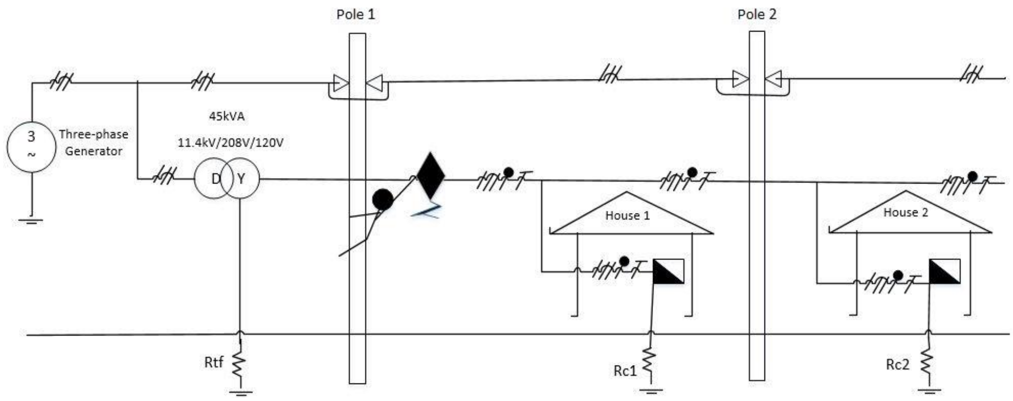

Figure 9. Schematic of the case of electric discharge in low voltage by direct contact

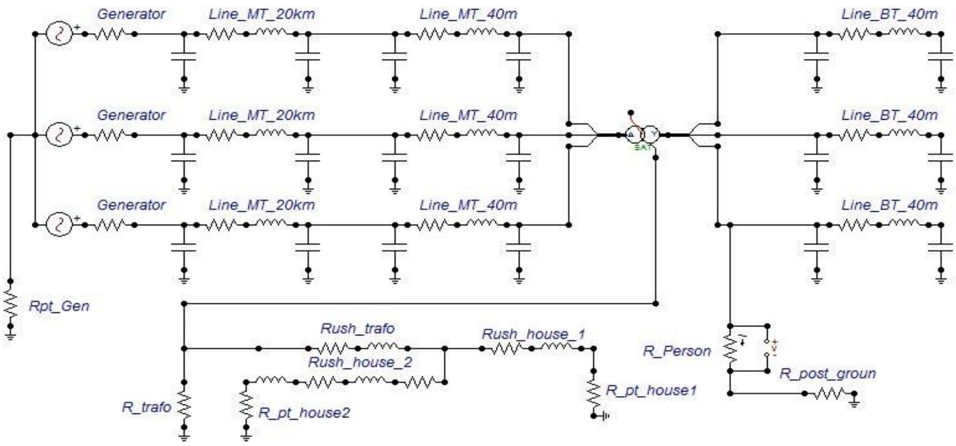

Figure 10. Electric model of the case of electric discharge in low voltage by direct contact

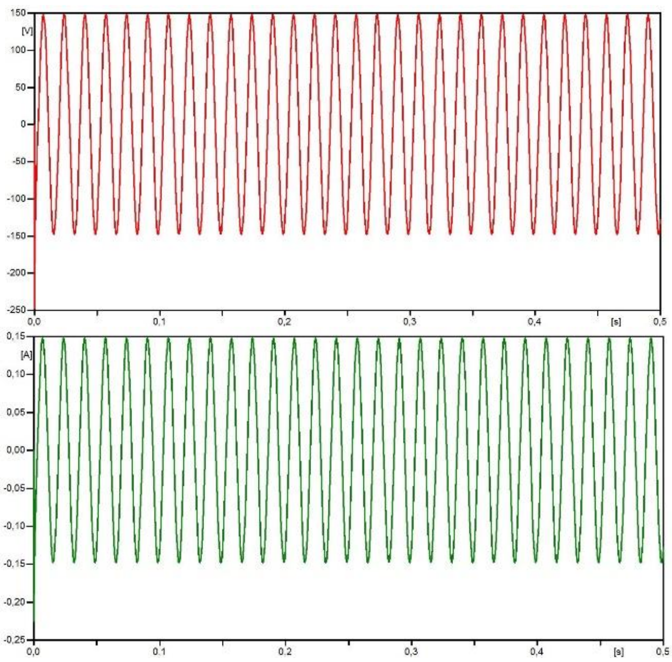

Figure 11. Voltage (left) and current (right) generated on the person in low voltage by direct contact

4. Conclusion

The physical effects by the electric energy on the human body, can present serious implications against the health even reaching the death or permanent injuries, which in some cases could be irreversible. One of the main features to analyze in cases of electric risk is the circulating electric current in the human body, as well as the stay time of the electric failure, because they are determinant factors to define the real effects on the human body. In the first proposed case, the electrocution is presented in an urban medium voltage network of 11.4 kV rms through a kite rope, which represents a high impedance to the electric failure, due to it is a high-resistivity element and additional is 15m long. In this case, the person presents an average transferred voltage of 12 mV and a current of 11 μA, which do not represent any kind of risk for the person. It is very important to highlight, the conductive element is modeled over ideal weather conditions, with low humidity and sun. If the model includes high humidity in the air or raining, its resistive is highly reduced, increasing the electric current pass on the person. In the central region of Colombia, August is not only the windiest month but the driest, for that reason it was not necessary to consider another humidity condition in the model.

For the second case, the person has direct contact with a medium voltage lines, generating on it a transferred peak voltage of 8 kV and a peak electric current of 8 A, which according with the risk zones defined in the NTC 4120 produce heart attack, respiratory failure, serious burns and risk fibrillation over 50%, having almost 100% of probability that the person dies. For the third case, in a low voltage urban network of 120 V rms, a peak voltage is transferred to the person of approximately 150 V and a peak current of 150 mA, which can produce different effects according to the defined risk zones, depending on the exposition time. If the person is exposed less than 400 ms, it keeps in the zone 3, where there are no serious effects on the human body. When the exposition time is from 400 ms to 600 ms it gets into the zone 4, where there is a fibrillation risk of 5%, but if the time overpasses 600 ms it gets into the zones 5 and 6, which the can produces the death of the person.

In order to prevent fatal accidents in the community, it is important to make aware all the people about the risk of exposing directly to a medium and low voltage line. Most people especially children, could think that climbing a pole to reach a tangled kite is easy and safe, ignoring that only a trained person with the appropriate equipment could manipulated those electric lines, making that just children are most of the victims of the death by electrocution in August. Additionally, not only the medium voltage network lines can produce the death of a person but the low voltage ones too, sometimes people consider that a regular home electric input connection is harmless, but its low voltage can produce serious injuries even the death depending on the conditions. Finally, to make aware the people, especially children about all the possible electric risks is imperative, with the purpose of avoiding possible deaths or serious injuries, that is so important in the context of the month of August in Colombia, in order to quietly enjoy flying kites in family.

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