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STUDIES ON THE ELECTROMAGNETIC DISTURBANCES PRODUCED BY A.C. ELECTRIC ARC

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Abstract: *Lately, more and more fires were caused by faults in electrical installations. In intelligent networks, the role of the integrated microcontroller devices with surge protection, overcurrent, electrocution and electric arc, as well as the transmission of information with remote possibility is central. The paper presents the simulations and the experimental determination on the A.C. electric arc, in order to analyze the electromagnetic disturbances caused when arching is produced, and to provide the necessary information to establish a universal algorithm of detection for all types of arcs, based on a dedicated microcontroller.*

Key words: *electromagnetic disturbances, electric arc, simulations, measurement.*

1. Introduction

The electric arc is considered as a source of electromagnetic radiated and conducted disturbance of wide band spectrum [5].

For the low voltage installations many causes of fires have been induced by the presence of the electric arc, due to abnormal operating conditions (overvoltages, shortcircuits). Thereby the present paper considers these cases as an important study related to conducted and radiated disturbances.

Simulations were made in MATLAB/ Simulink considering the intermittent commutation of the low voltage electric circuit (230 V A.C. voltage supply and resistive load).

The experimental determinations were in accordance with the simulations and from the electromagnetic compatibility point of view the current variations in the circuit $i(t)$ and the frequency spectrum for the radiated disturbances were obtained. This is a start for generating an algorithm which eventually will be implemented using dedicated microcontroller.

There are many concerns related to the design and achieve of devices that interrupt the circuit at the time of arcing. Electric arc can be detected by light generated [8], [11] or by analyzing the current flowing through the circuit. The current analysis and load circuit interruption can be performed by microcontroller control [6], [7].

Reference [12] mentions that a number of fire scenarios involve a sequence of two steps: overheating followed by arcing and ignition. For example, a wire may become heated either due to excessive current or due to a poor connection. This may soften the insulation sufficiently, so that a short

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circuit occurs at a place where the wire is bent or passes a metal edge. A number of fires occur either at the junction between a cord and the male plug, or at another place along the cord where repeated bending has taken place.

Electric arc is two types: switching arc and arc due to the leakage of an electrical current across the surface of an insulator. Switching arc occurs between the contacts of the circuit breakers, and depends on the interrupted current and the second type is defined as an accidental discharge that occurs as a result of an abnormal operation.

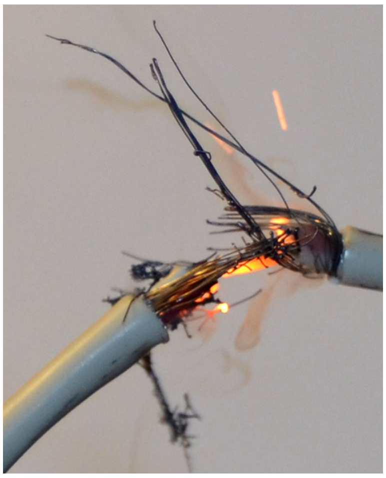
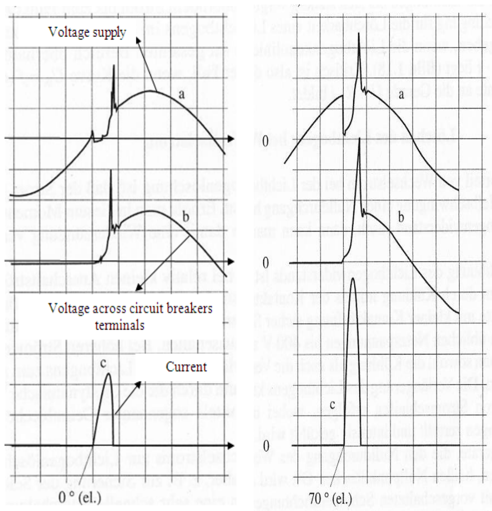


Fig. 1. *Arc due to the leakage of an electrical current across the surface of a stranded cable*

A picture of the arc due to the leakage of an electrical current across the surface of a stranded cable, at a current of 1-2 A, was taken by the author, for a domestic low voltage installation (Figure 1). Cable wires are partially broken and make random contact, and portions of the wires are melted.

2. Theoretical Background

The voltage across circuit breaker terminal has a variation at a shortcircuit current interruption Figure 2a is the case of shortcircuit occurring at zero voltage crossing.



a) b)

Fig. 2. *Oscillogram of shortcircuit current interruption, 10 kA (cos φ = 0.97); a) Shortcircuit at 0º el of the voltage supply; b) Shortcircuit at 70º el of the voltage supply (time: 2 ms/division; voltage 200 V/division; current 1000 A/division)* [3]

Overvoltage has a moderate value, and the maximum value of the shortcircuit current is not very high. If shortcircuit occurs at 70 ºel (Figure 2b), the arc does limit the current and the overvoltage becomes twice the amplitude of the voltage supply.

For a RLC circuit (Figure 3a), at the instant of the shortcircuit occurrence between a and b points of the circuit, the oscillating recovery voltage u_r is determined considering that the shortcircuit current breaking takes place the instant current naturally crosses zero.

The differential equations of the circuit the moment after the disconnection of the *K* breaker, and considering that due to the shortcircuit current, at the moment $t = 0$ the capacitor was not charged, can be solved taking into account the following simplified hypothesis [4], [10]:

- Shortcircuit current disconnection takes place the instant current naturally crosses zero;

- Phase shift between voltage and current is π/2 (Figure 3b);
- The self-oscillation frequency f_e is much higher than the supply voltage frequency *f*;
- The AC supply voltage is considered constant and equal to the maximum value (amplitude) of the supply voltage;
- The influence of the electric arc is not considered, the recovery voltage being independent recovery voltage.

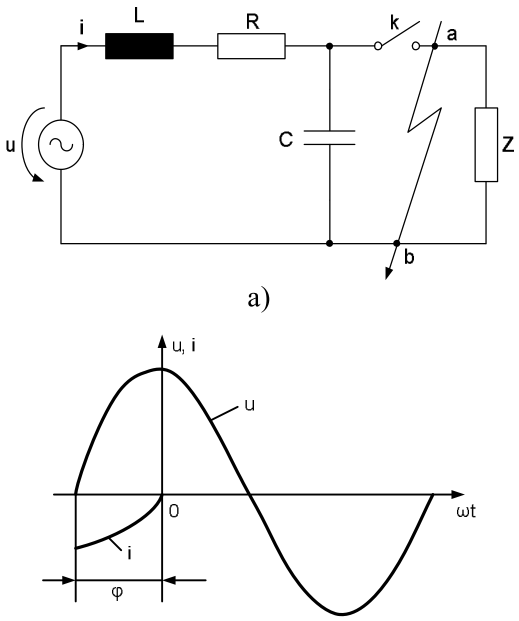


Fig. 3. *Explanation related to the recovery voltage process* [9]

If the damping factor δ is much smaller than the self-angular frequency of the recovery voltage ω_e ($\delta << \omega_e$), the expression for the recovery voltage is [4]:

$$u_R = \sqrt{2}\,U\left[1 - e^{-\delta t}(\cos \omega_e t)\right]. \quad (1)$$

The variation for the recovery voltage for the general solution of the differential equation of the RLC series circuit and the simplified solution are represented in Figure 4.

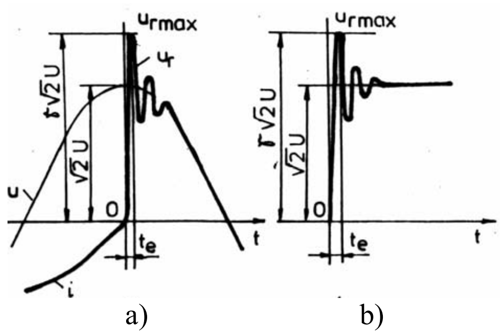


Fig. 4. *Recovery voltage variation* [9]

Arc may occur in the circuit in two configurations: in parallel or in series with the load, as shown in Figure 5.

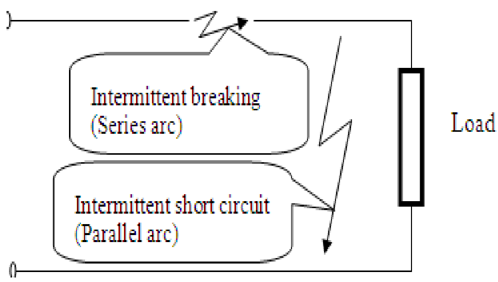


Fig. 5. *Series and parallel arc*

The series configuration appears when the conductor is interrupted unintentionally, where the wire breakage occurred and causing localized heating. The current's amplitude is limited by the load and its value is usually much smaller than the conventional over current or short circuit protection devices. Overheating may occur, and that could cause a fire.

Cases that may lead to electric arc -serial connections can be weak connections, a repeated flexing conductor or due to a conductor cable which was cut accidentally.

The parallel arc is limited only by the maximum current generated by the source and the source impedance. If the faulty circuit has low impedance, the short circuit protection device may disconnect the load. But if the impedance is high, it may not be enough energy to open the over-current protection device. Particles of molten metal are spread around and this can be a cause a fire A short circuit caused by intermittent contact between conductors can cause an electrical arc parallel. Parallel arc can also occur between phase and earth.

3. Simulink Simulations of the A.C. Electric Arc

In order to determine an algorithm for detection of the electric arc, it was used a MATLAB/Simulink model: simulating harmonic current with a sine-wave generator (1 A amplitude) and the variation of the current due to the arc with a random signal of 1 A. The results are represented in Figure 6.

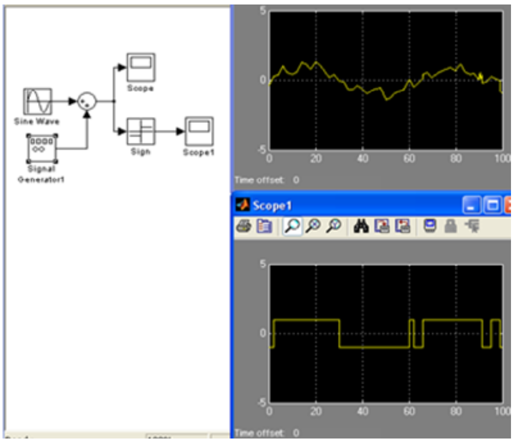


Fig. 6. *Arc simulation at 1 A current*

Then it was increased the current amplitude at 5 A in simulation, like before arching. The variations are represented in Figure 7. It can be observed that are much more changes in polarity. Based on this idea, it can be developed a detection algorithm for the arc that analyzes these passing through zero of the current and also the value of the current amplitude.

These conditions are necessary because the cutoff of the supply must be done only if a dangerous arc appears.

Two types of arc were simulated:

- Case A - arc occurring after intermittent short circuits;
- Case B - arc caused by intermittent breaking.

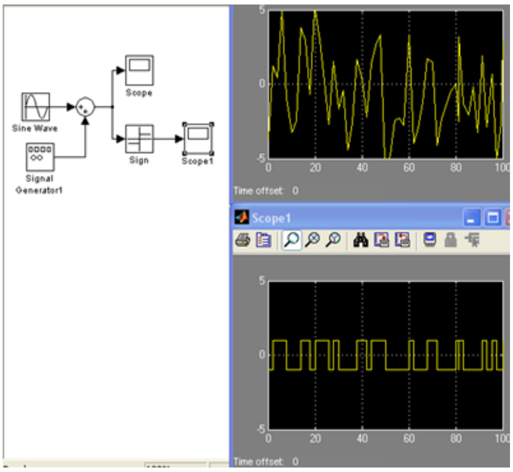


Fig. 7. *Arc simulation at 5A current*

To simulate case A, we assumed that the intermittent overcurrent is due to a bad contact and the current value does not attain the shortcircuit value to melt the fuse wire. The block configuration is represented in Figure 8.

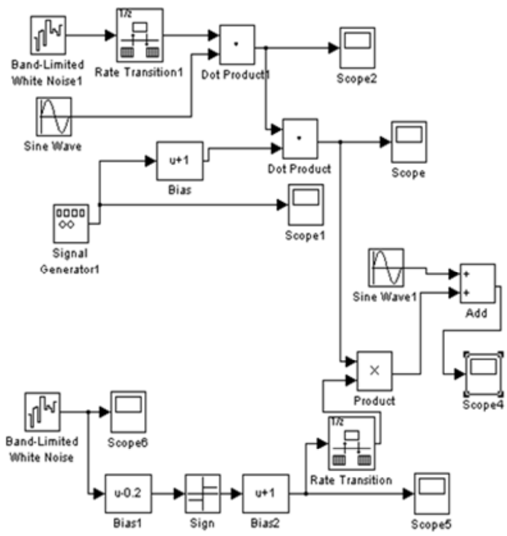


Fig. 8. *Block diagram for the simulation of an intermittent short circuit (case A)*

Arching appears at random moments and the current amplitude is also random. The current form is generated with the Sine Wave block and the amplitude was modulated with Band Limited White Noise generator. The results are represented in Figure 9.

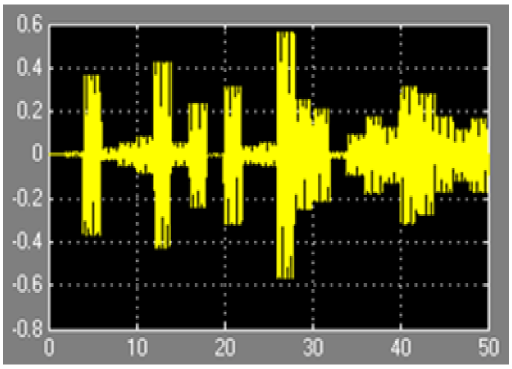


Fig. 9. *Modulated sine-wave signal*

Signal Generator block generates a triangle signal to create a decrease form of the random current sequences (Figure 10).

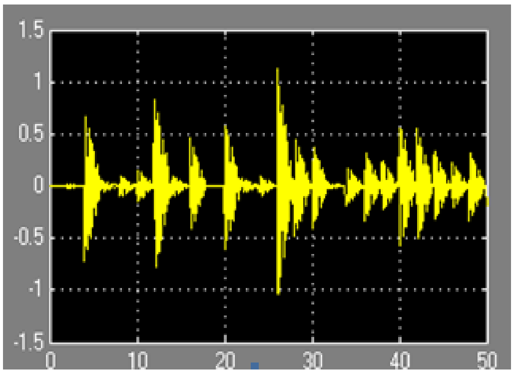
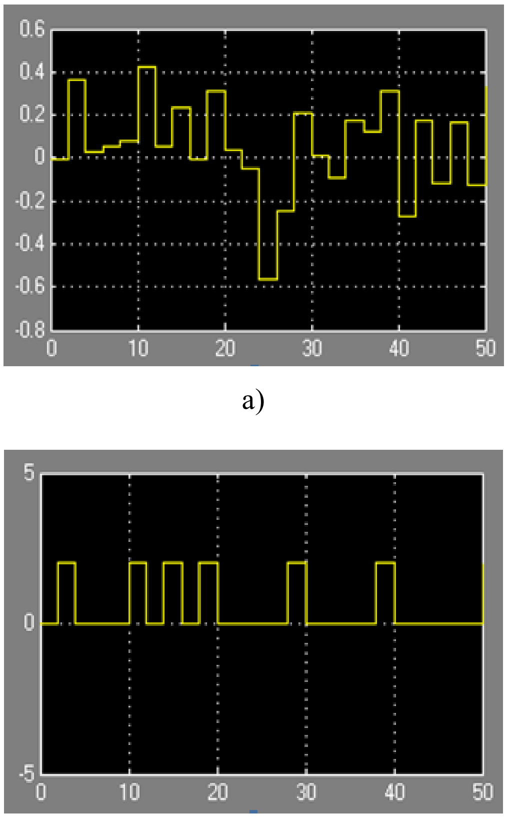


Fig. 10. *Signal form after adding the triangle signal*

Band Limited White Noise block creates a random sequence to a random decrease of the numbers of the increase of the current (Figure 11a).

From this signal is created a rectangular signal with a time random sequence (Figure 11b).



b)

Fig. 11. *Rectangular resulted signal*

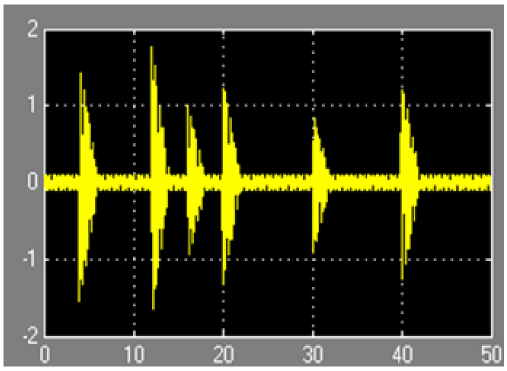


Fig. 12. *Current variation for intermittent short circuit simulation*

The final signal contains also a permanent sine-wave signal (simulating the load current, created with Sine Wave block (Figure 12).

Case B. The Simulink model was similar with the one represented in Figure 8.

It should be noted that in comparison with the arc appeared on an intermittent short circuit - that produces the increase of the current- the absorbed current by the load in the network decreases. The results are represented in Figure 13. The signal for simulation has the same characteristics as in Case A, the moments of arching being random.

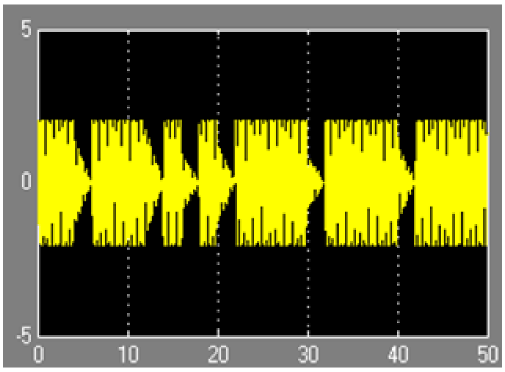


Fig. 13. *Current variation for intermittent interruption simulation*

The simulations show that the arc both for case A and case B is characterized by variations in the magnitude of the absorbed current in the network. The variations are of a higher value and are more frequencies than those appearing in the normal operation.

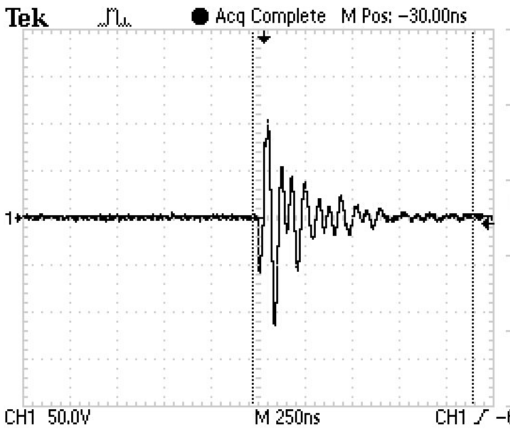
Based on these simulations, a form for the signal variation, when the arc appears, was obtained and it will be used to develop a detection algorithm of the electric arc.

4. Experimental Determinations

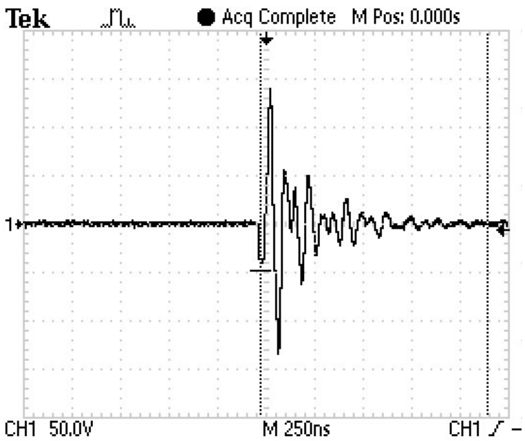
All electric arcs emit radiation, the amount and character of which depends on the atomic mass and chemical composition of gaseous medium, the temperature and the pressure. As energy input to an arc increases, higher states of ionization occur and higher level of radiation result. By emitting radiation, the energy of arc gets lower [1]. In the paper is studied the electromagnetic radiation.

4.1. Time Domain Determinations

The arc was realized by the contact of two stranded cables, the circuit been closed with a serial resistor for the current limitation.



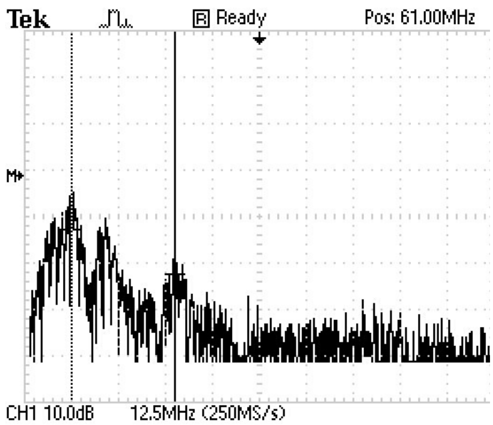
a)



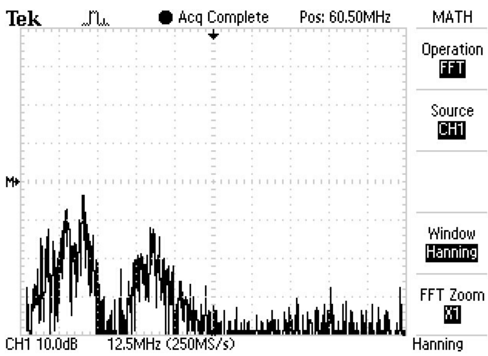
b)

Fig. 14. *Current variation for the A.C. arc*

The load in the circuit had different values (0, 330 Ω, 680 Ω, 1162 Ω) Measurements were done to determine the shape of the current. For the discharge spectrum were used two types of oscilloscope using the FFT function and were compared the obtained results. The results for are represented in Figure 14 (a - for $R = 0$, and b - for R = 330 Ω) and the arc discharge spectrum is in Figure 15.



a)



b)

Fig. 15. *Arc discharge spectrum for a.c. arc: a) for R = 680 Ω; b) for R = 1162 Ω on a 12.5 MHz frequency spectrum*

4.2. Frequency Domain Determinations

Measurements for electromagnetic radiations were made at the R&D Institute of the *Transilvania* University of Braşov, in the shielded room.

For radiated spectrum determinations was used the Handheld Spectrum Analyzer R&S FSH3 with the isotropic antenna, in the frequency range 0-3 GHz.

For accuracy, it has been also determined the radiation without electric arc (Figure 16).

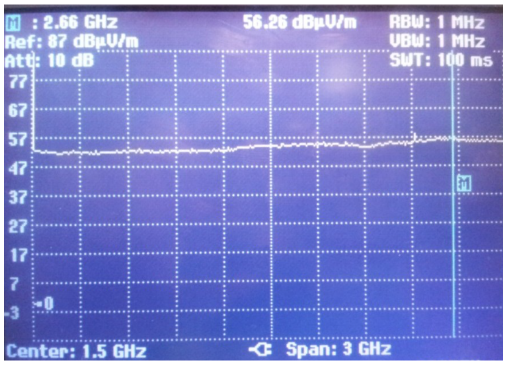


Fig. 16. *Radiated electromagnetic disturbances without arc on the spectrum 0-3 GHz*

Brief results of the radiated spectrum when arching are represented in Figure 17.

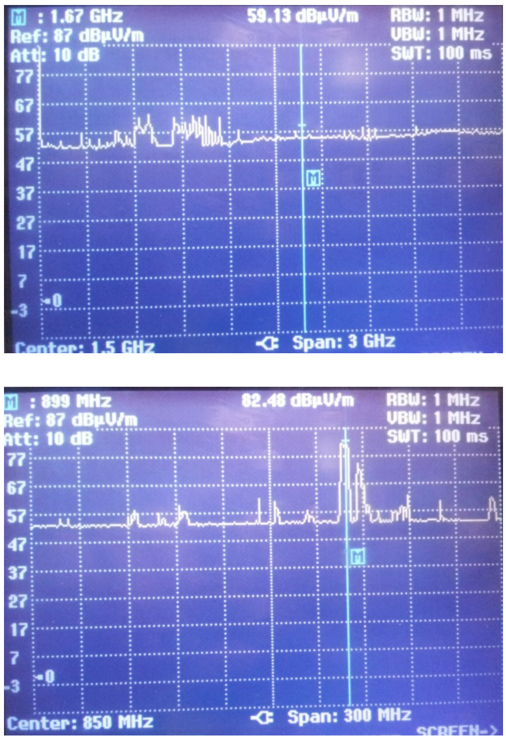


Fig. 17. *Radiated electromagnetic disturbances produced by low voltage successive arc on the spectrum 0-3 GHz*

5. Conclusions

In the smart networks, integrated microcontroller devices ensuring surge protection, overcurrent, electrocution and electric arc, as well as the transmission of information with remote control and data transmission have an important role.

The differences between the dangerous or non-dangerous arc can be achieved of the current interruptions that are not synchronous to the moments of zero crossing [2].

The electric arc does not have a fixed form, having different shapes, intensities and features depending on the environment in which appears and the occurring way. An algorithm of detection, universal, which can detect all types of electric arcs is difficult to achieve and deploy, being necessary a vast research in this field and a multitude of tests performed in the laboratory with the different parameters of the environment, different types of cables and types of arcing.

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