The study and modelling of power failure in a new generation of three-phase high-voltage power supplies for industrial microwave generators.

H. elkhatat, M.DERRHI, O.FILALI

Electrical Engineering Department, University of AbdelmalekEssaadi, ENSAT
Ancienne Route de l'Aéroport, Km 10, Ziaten.BP : 416. Tangier - Morocco
hayat.elkhatat@gmail.com

mderrhi@yahoo.fr

Abstract—**This work dealsthe failure study of a load of a new generation of three-phase high-voltage power supplies.**
In each phase of this three-phase power supply, a voltage doubler and a stabilizer current cell are supplied, which in turn feeds our load according to this study, which is the magnetron.

The simulation, with MATLAB-Simulink, of the electrical operation of this power supply device, under rated conditions, gave theoretical results close to those obtained experimentally in the case of single phase high voltage power supply for one magnetron
Keywords—Modelling, Breakdowns' diagnosis Magnetron, MATLAB, Regulation

I. INTRODUCTION

To contribute to the development of technological innovation in the manufacturing industry for microwave generators for domestic or industrial use, this work is part of the development of a new generation of the three-phase high voltage power supplies for one magnetron per phase.

The first part of this work presents a global equivalent circuit diagram of this power supply. The figure 1 shows the electric schematic of the new three-phase high voltage power supply for one magnetron per phase [1][2][3][4], which corresponds to a star coupler of the three phases' equivalent electric model, each one supplying one magnetron. The electrical diagram of each phase consists of an equivalent electrical model of its own magnetic circuit [5][6][7][8] feeding a voltage doubler and a stabilizer current's cell that in turn supplies one magnetron.

The simulation, with MATLAB-Simulink, [9][10][11] of the electrical operation of this new power supply device allows observing the time curves of its different signals, currents and voltages, and to compare them with those obtained experimentally in the case of single phase high voltage power supply for one magnetron [12][13][14].

The second part of this article is devoted to the magnetron failure's study in the new three-phase high voltage power supply. We will examine the influence of the faulty magnetrons on the electric operation of the other functional magnetron. In this failure's study, we are considering:

- ➤ The case of one faulty magnetron and two functional magnetrons.
- ➤ The case of two faulty magnetrons and one functional magnetron.
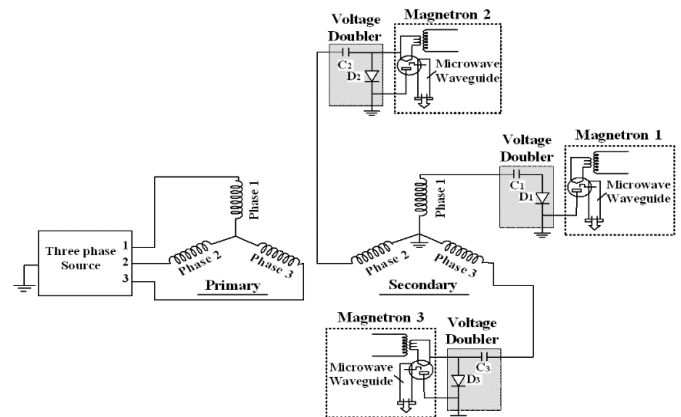- ➤ The case of all three magnetrons failed.

Figure 1: High voltage power for one magnetron by phase.

II. THE ELECTRIC MODELLING OF THE HIGH VOLTAGE POWER SUPPLY FOR MICROWAVE GENERATORS WITH ONE MAGNETRON PER PHASE.

The new three-phase high voltage power supply for microwave generators with one magnetron per phase uses a new form-type transformer with magnetic shunt (five limbs and two yokes). The figure 1 presents the geometric shape of the magnetic circuit of the three-phase high voltage transformer with magnetic shunt, each phase contains two windings (primary and secondary) successively placed limb 1, limb 3 and limb 5. Shunts in the form of stacked sheets are inserted between the primary and the secondary of each phase as shown in Figure 1, they are used to deflect a part of the magnetic flux, which regulates the anode current in the magnetron [12].
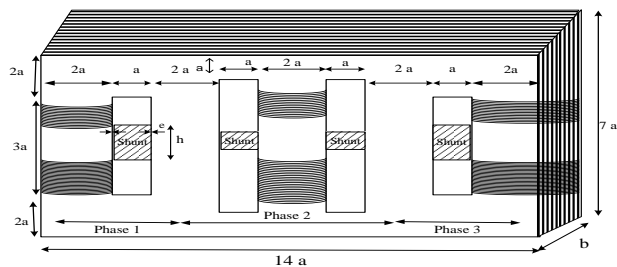
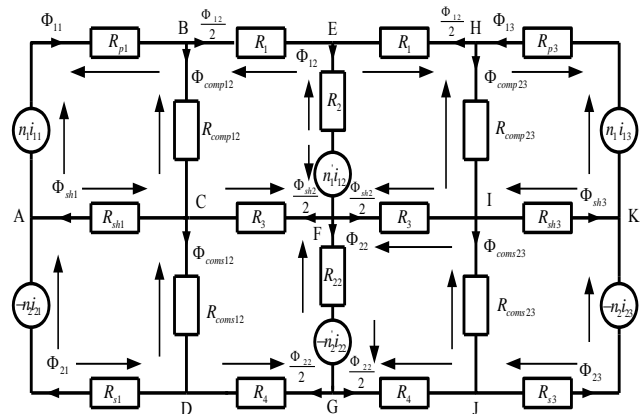Figure 2: Magnetic circuit of the three-phase transformer.

Figure 3: Equivalent electrical diagram of the magnetic circuit.

The graphical representation of electric and magnetic equations, obtained during the modelling of the phases 1, 2 and 3, led to find the equivalent electric model rooted to the secondary side. The global equivalent electric diagram of the new high voltage transformer with magnetic shunts (presented in figure 3) brings together the three previous electric assemblies while verifying the equations expressing the relationship between the different phases.
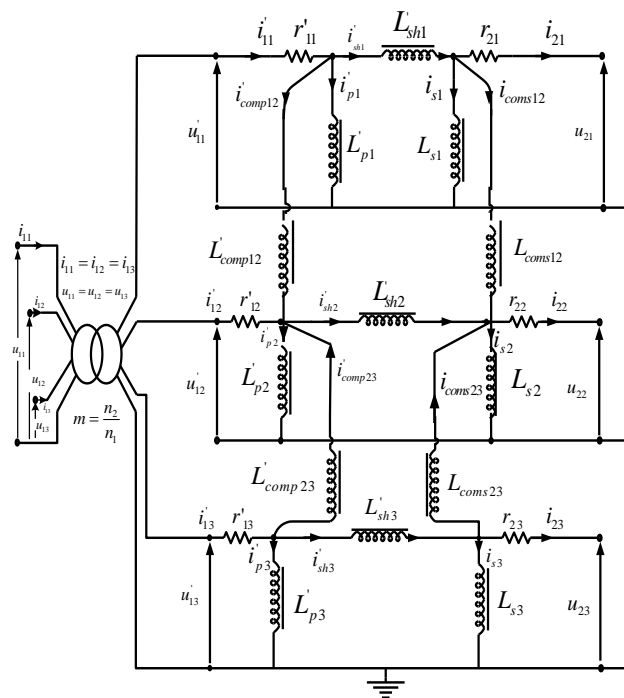

Figure 4: Global electrical diagram of the new three-phase transformer with magnetic shunt.

III. Simulation, With MATLAB-Simulink, Of The New Three-Phase High Voltage Power Supply For One Magnetron Per Phase.

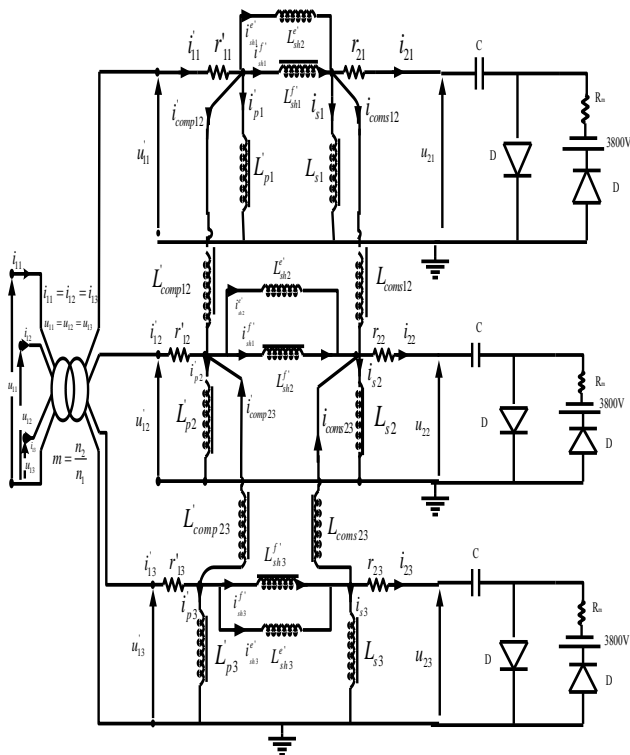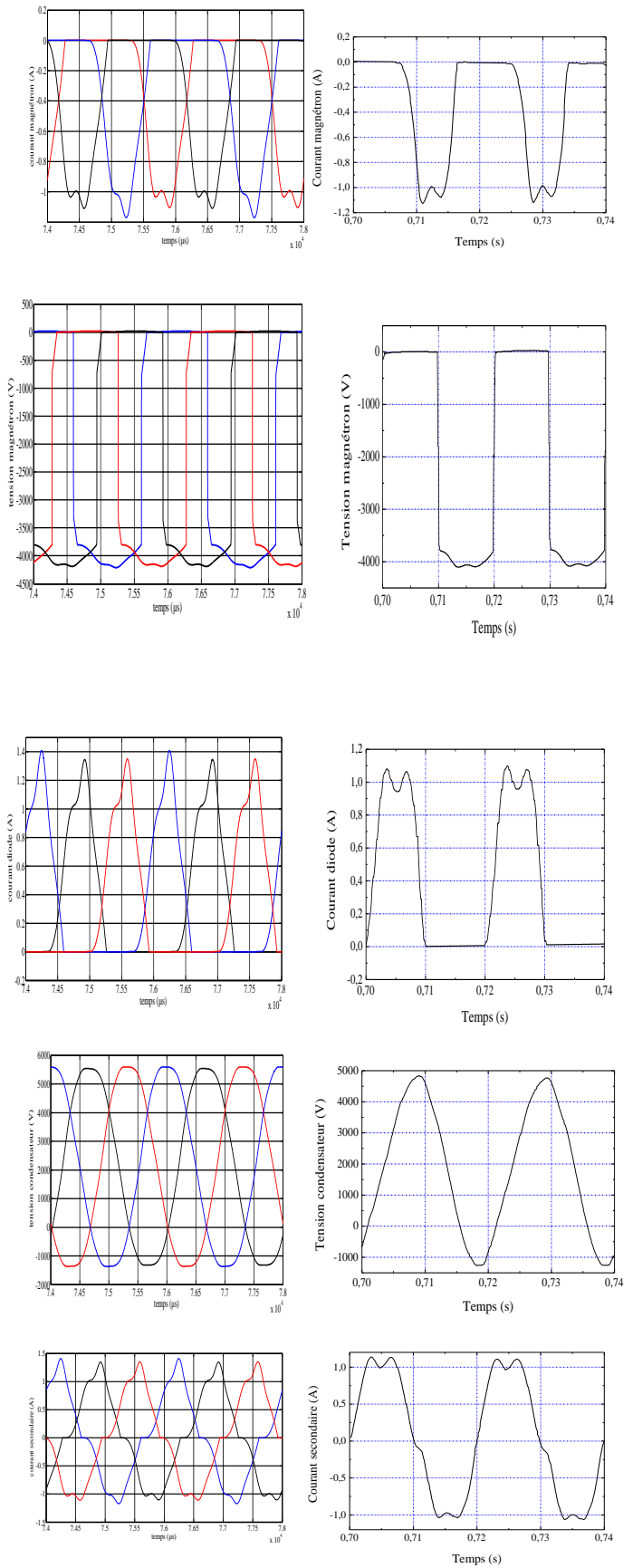Figure 5: The three-phase high voltage power supply for one magnetron per phase (equivalent electrical diagram).

The simulation, with MATLAB-Simulink[16][17][18], of the nominal electrical operation of the assembly in figure 3 allows obtaining the time curves of the voltages (capacitor, diode, magnetron) and the currents (diode, magnetron, transformer's secondary side) as presented in figure 6A.
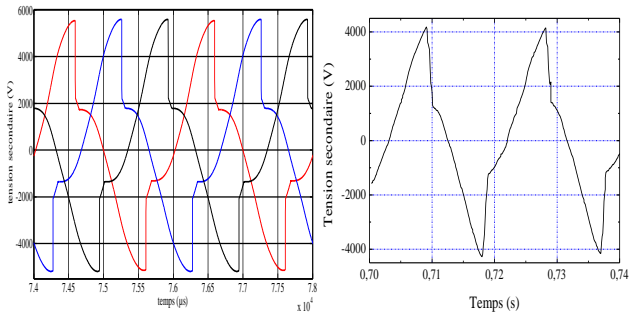
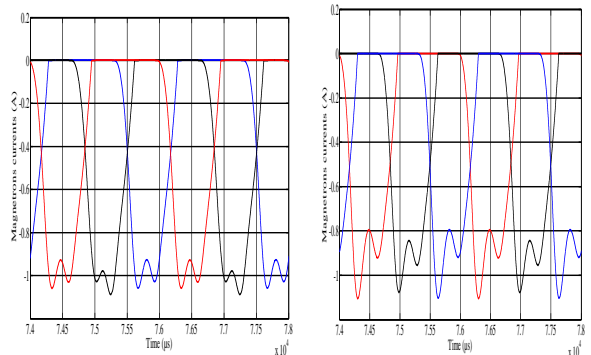| Figure6A: The simulation results with MATLAB of a three-phase high voltage power supply for one magnetron per phase | Figure 6B: Experimental curves of currents and voltages in a single phase high voltage power supply for one magnetron per phase |

For each magnetron into a phase that operate at rated speed (220V and 50Hz in the primary side), the electrical signals in the diode, the capacitor, the magnetron and the secondary side have the same shape as those of a conventional single-phase power supply for one magnetron. These signals are periodic but not sinusoidal and they are phase shifted 120°.

We can affirm that the curves obtained by simulation using Matlab-Simulink of the new three-phase power supply device, in nonlinear regime, are in accordance with the experimental waveforms obtained from a single-phase power supply for one magnetron (figure 6B).

Finally, the allure of each magnetron's current reflects the flow of its full output power, therefore the phase shift 120° between the three magnetron's currents confirms the absence of any interaction between the magnetron of a phase and that of the next phase. The operating point of all magnetrons is no longer disturbed.

During the simulation, with MATLAB-Simulink [12][13][14], of this new three-phase high voltage power supply for one magnetron per phase, the current regulating process in all three magnetrons was verified while observing the stability of the current's variations in each magnetron with respect to the variations of the primary voltage of ±10% around the nominal voltage of 220 Volts. The figure 5 shows the waveforms of each magnetron's current corresponding to the respective values of 200V and 240V on the primary voltage.

Figure7: Stabilization of the anode current in each magnetron compared to the variations of ±10% around the nominal voltage

It is noted that the maximum value of the amplitude of each magnetron's current in the three phases remains below the acceptable limit (<1.2A), which complies with the constraints imposed by the manufacturer and ensures the correct functioning of the magnetron with a reasonable average current of 300mA without exceeding the recommended peak current. Given the above, the current stabilization process in each magnetron is completely ensured, which completely protects this microwave tube.

IV. NEW POWER SUPPLY STUDIED: STUDY OF THE MAGNETRONS FAILURE

Table1 gives the possible cases of failures that can occur during the nominal operation of the microwave generator with three magnetrons.

TABLE I. The possible states of the three magnetrons failure

Type of failure	Phase 1	Phase 2	Phase 3
One faulty magnetron and two functional magnetrons	Faulty magnetron	Functional magnetron	Functional magnetron
Two faulty magnetrons and one functional magnetron	Faulty magnetron	Faulty magnetron	Functional magnetron
Three faulty magnetrons	Faulty magnetron	Faulty magnetron	Faulty magnetron

The simulation, using MATLAB-Simulink [5][6][8][10], of the electrical behavior of the power supply for one magnetron per phase was performed for each case of failure as shown in table 1. The observation of the currents and voltages' waveforms allowed analyzing the different characteristics of the high voltage circuit, and particularly that of the magnetron's current.

A. *Case of one faulty magnetron and two functional magnetrons.*

The simulation's results, with MATLAB-Simulink [22][23][24], of the assembly in figure 8A are presented in figure 8B. We observe that the faulty magnetron reduces the functioning of its corresponding voltage doubler, which consists of one diode and one capacitor of 0.9 µF.

For each of the other two phases, the operating point of each of the two functional magnetrons is not disrupted. The failure of one magnetron does not affect the operation of the remaining two functional magnetrons in the other two phases.
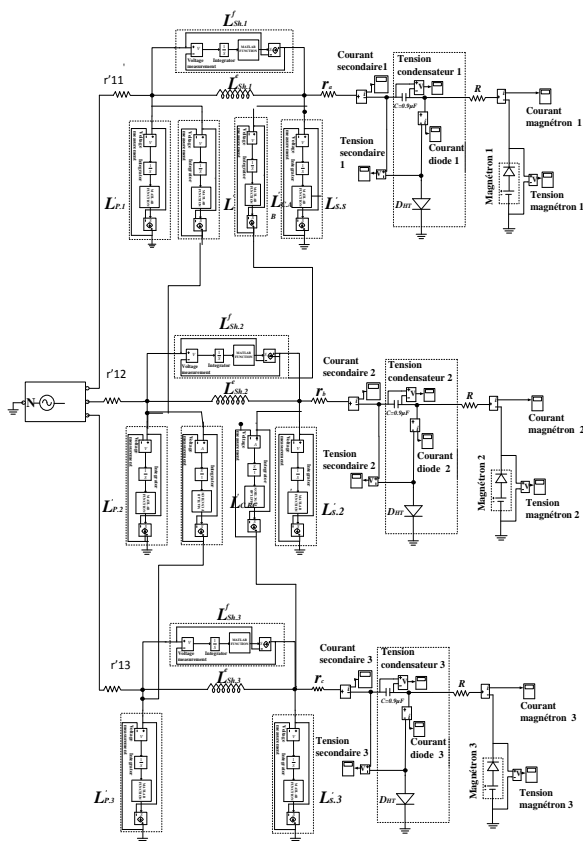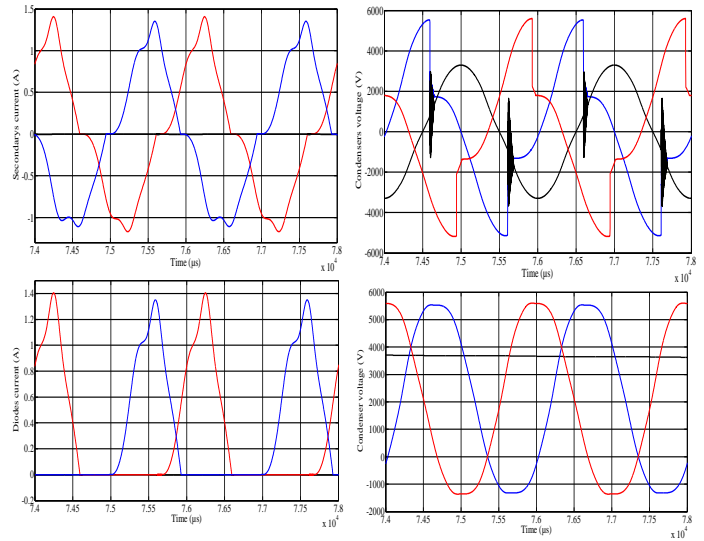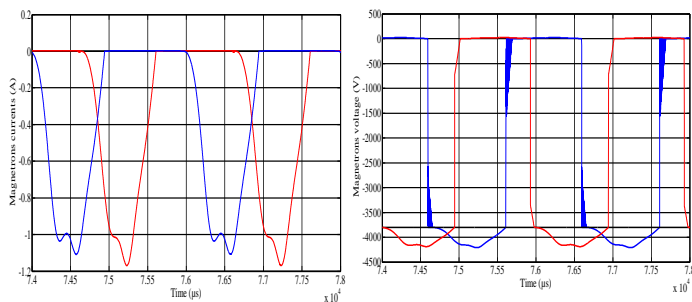

Figure 8B: The voltages and the currents' forms of the assembly in figure 8A in the case of one faulty magnetron

The faulty magnetron in phase 1 has no interaction's effect on the operation of the two other functional magnetrons (in phase 2 and 3) taking into account that their operating point is not disrupted.

The current regulating process in each of the two functional magnetrons was verified through simulation using MATLAB-Simulink [9][12][6], while observing the stability of the current's variations in each magnetron with respect to changes in the primary side voltage (±10% of the nominal voltage as in figure 9).
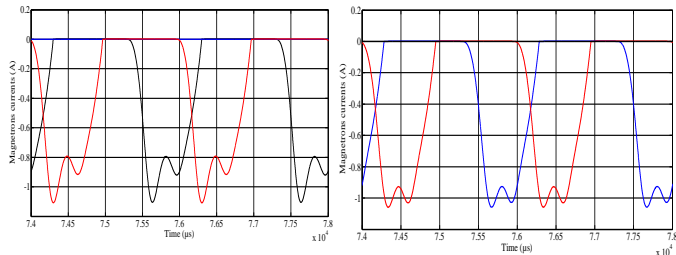

Figure9: The stabilization of the anode current in each magnetron relative to the primary voltage's variations of ±10% of the nominal value.

It is noted that the maximum value of the current's amplitude in each of the two identical magnetrons remains below the acceptable limit (<1.2A), which complies with the constraints imposed by the manufacturer and ensures the correct functioning of the magnetron with a reasonable average current of 300mA without exceeding the recommended peak current.

B. Case of two faulty magnetrons and one functional magnetron.

Figure 8A: Electric diagram of the three-phase high voltage power supply for one magnetron per phase. Case of one faulty magnetron

The simulation's results, with MATLAB-Simulink [1][3][8], of the assembly in figure 10A are presented in figure 10B. We notice that each of the two faulty magnetrons, in phase 1 and 2, reduces the functioning of its corresponding voltage doubler, which consists of one diode and one capacitor of 0.9 µF. Each of the two faulty magnetrons does not disturb the operation of the other magnetron remaining in service.
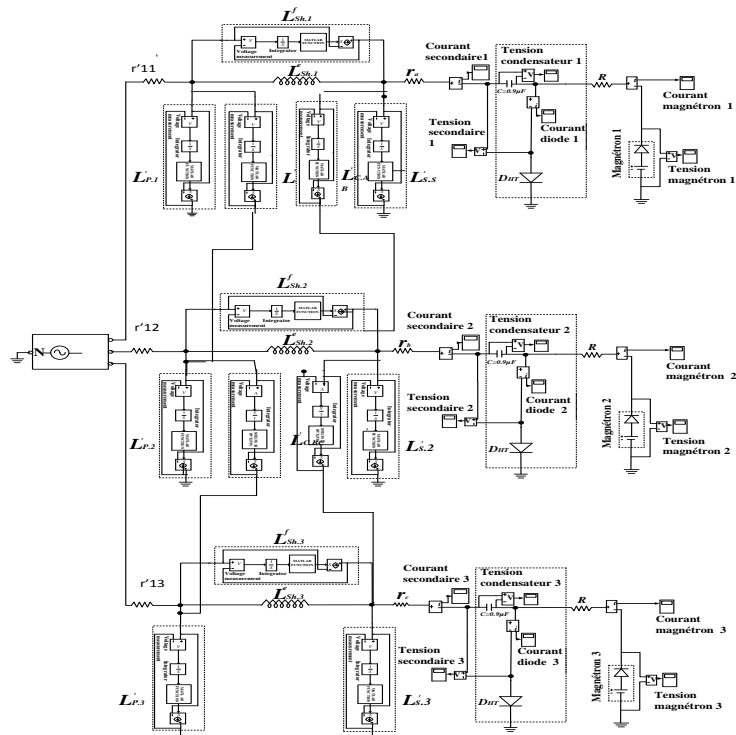

Figure10A: Electric diagram of the three-phase high voltage power supply for one magnetron per phase. Case of two faulty magnetrons
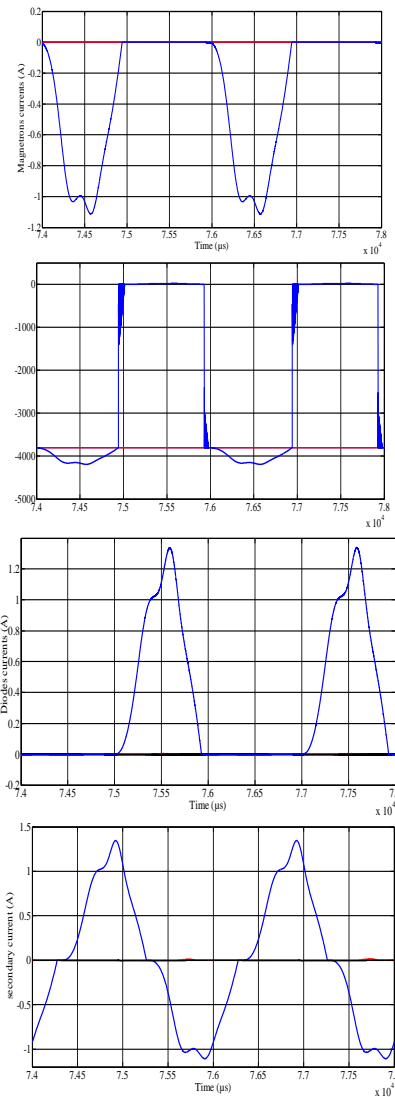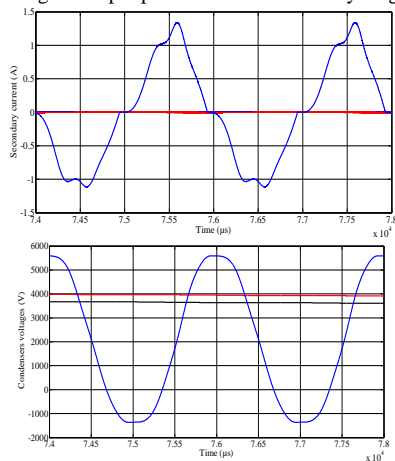

Figure10B: The voltages and the currents' forms of the assembly in figure 10A in the case of two faulty magnetrons

The current regulating process in the functional magnetron was verified through simulation using MATLAB-Simulink [2][5][6], while observing the stability of the current's variations in the functional magnetron with respect to changes in the primary side voltage of the corresponding phase (±10% of the nominal). The figure 11 shows the current's waveforms, obtained in each magnetron, corresponding to the respective values of 200 Volts and 240 Volts in the primary voltages of the three-phase power supply.
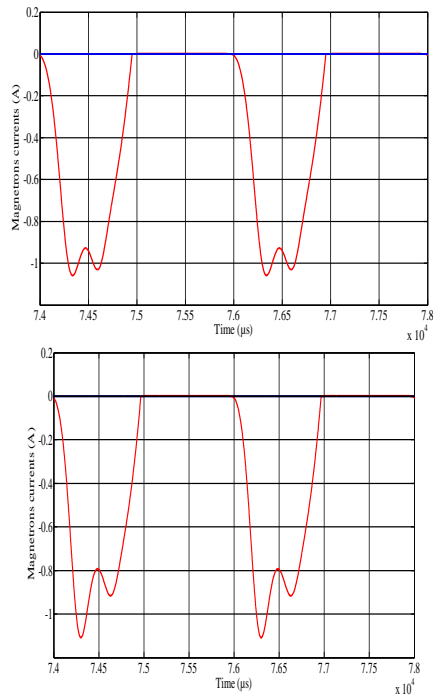
Figure11: The stabilization of the anode current in each magnetron relative to the primary voltage's variations of ±10% of the nominal value.

It is noted that the maximum value of the current's amplitude in the functional magnetron, in phase 3, remains below the acceptable limit (<1.2A), which complies with the constraints imposed by the manufacturer and ensures the correct functioning of the magnetron with a reasonable average current of 300mA without exceeding the recommended peak current.
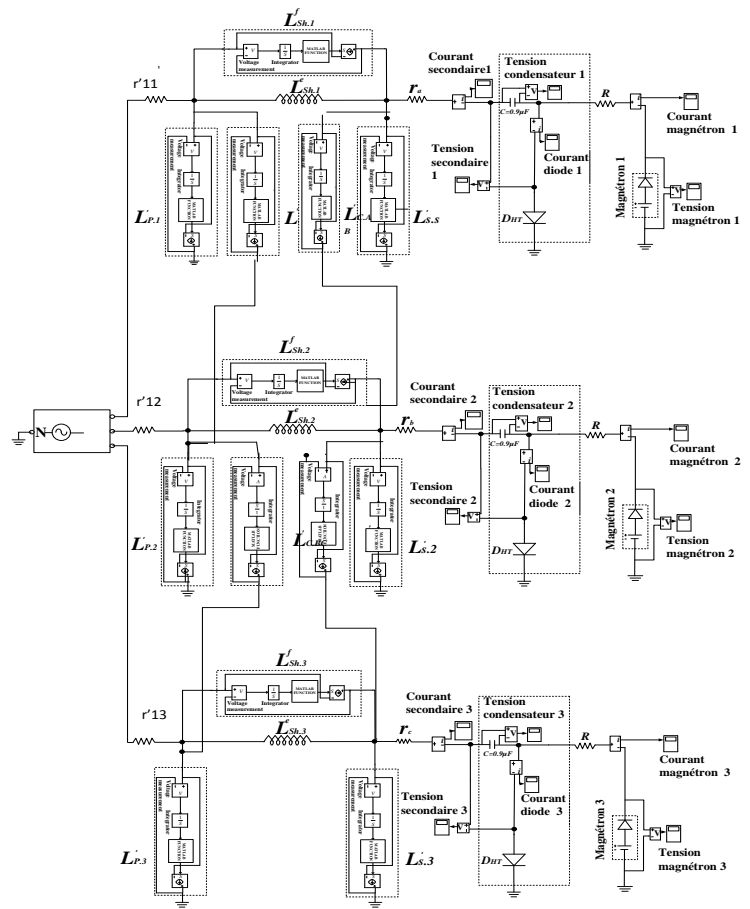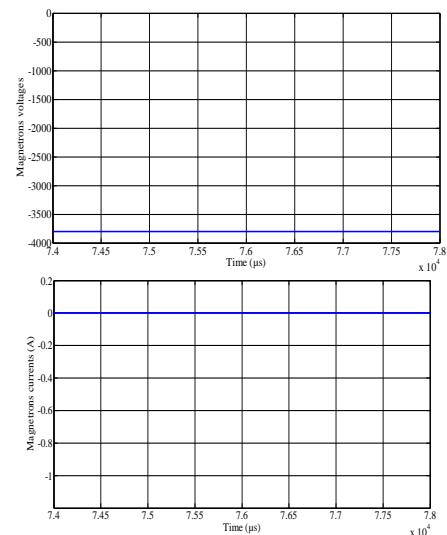
C. Case of three faulty magnetrons

Figure12A: Electric diagram of the three-phase high voltage power supply for one magnetron per phase. Case of three faulty magnetrons
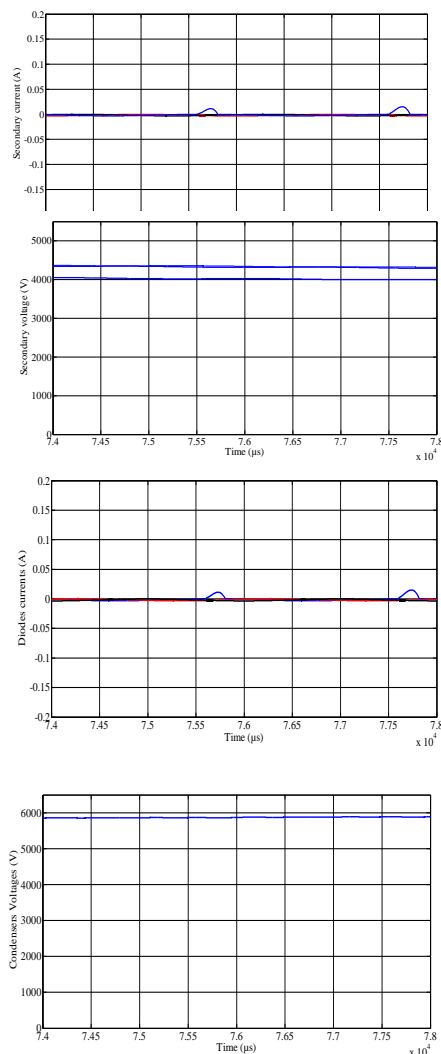
Figure12B:The voltages and the currents' forms of the assembly in figure 12A in the case of three faulty magnetrons.

The simulation's results, with MATLAB-Simulink [2][5][6], of the assembly in figure 12A are indicated in figure 10B. We note that each faulty magnetron, in each phase, reduces the functioning of its corresponding voltage doubler, which contains one diode and one capacitor of 0.9 µF. In order to obtain the maximum flow of microwave power, it suffices to replace the defective magnetrons with new ones.

V. CONCLUSION

In this study, we have been able to describe the nominal operation of a new three-phase high-voltage power supply for microwave generators with an 800Watts magnetron per phase, so that 2400 Watts of useful power can be supplied at 2450 MHz.

MATLAB-Simulink code was used to present the electrical operation of this new power supply, after which the results of the simulation could be compared with those obtained experimentally in the case of a single-phase high-voltage power supply for a magnetron. Then, the magnetron failure study was initiated in the new three-phase high-voltage power supply, where the influence of the defective magnetrons on the electrical operation of the other functional magnetron was seen. In order to verify the process of regulating the current in each magnetron, which ensures the protection of all magnetrons against any variation of the input voltage of the three-phase power supply network

On the one hand, the feasibility test of the electrical operation, under nominal conditions, of the new three-phase supply system for one magnetron per phase has been conclusive. It can be extended without problem by providing N = 2, 3 ... 10 magnetrons per phase at rated speed.

On the other hand, the failure of M among the N magnetrons supplied (in our case N = 3 and M≤N) does not affect the electrical operation of the remaining functional magnetrons (N-M magnetrons). By replacing all faulty magnetrons with functional magnets, the electrical operation of their power supply will find its nominal state.

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