

## Improved Model of New Six-Phase High Voltage Power Supply for Industrial Microwave Generators with A Single Magnetron By Phase

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### Abstract-

This original work treats the feasibility study of new type of high voltage power supply with a character six-phase for a magnetron 800 Watts-2450 MHz per phase for industrial microwave generators. The design of this new power supply uses a new sex identical single-phase high voltage transformer with magnetic leakage flux, coupled in star. Each single phase supply a cells which multiples the voltage, stabilizes the current and supplies in its turn a single magnetron. The  $\pi$  equivalent model of the transformer is developed, taking into account the saturation phenomenon and the stabilization process of each magnetron current. This model is based on the determination of the analytical expressions of its non-linear inductances, that can be determined from the establishment of the B(H) magnetization curve of the used material (SF19). This new power supply presents a multiple benefits in terms of reducing of weight, volume, electrical wiring and cost during of the implementation and maintenance of such a new device. The simulation results, upbraided by Matlab-SIMULINK code, are in good agreement with those found by experimental measurement for one magnetron, while respecting the conditions recommended by the manufacturer of magnetron:  $I_{peak} < 1.2$  A,  $I_{mean} \approx 300$  mA.

**Keywords:** Modelling; New power supply; regulation; magnetron; Microwave; Matlab-SIMULINK.

### I. INTRODUCTION

For supplying currently one magnetron, the single phase power supply with a single magnetron for generator microwave uses a HV transformer with magnetic shunt [2][3][4][7][17][18][19][20]. this work develops a new type of HV power supply with character six-phase for microwave generators supplying several magnetrons of type 800 watts, 2450 MHz (case treated  $N=1$ ). This new power supply presents a multiple benefits in terms of reducing of weight, volume, electrical wiring and cost during of the implementation and maintenance of such a new device.

The tendency to the HV power supply with a character sex-phase will be therefore a different version of the model single-phase currently made by the manufacturers of microwave in domestic ovens or industrial applications [10]-[16]. The Modelling of this new generation of power supply for magnetrons pass obligatory by the modelling and dimensioning of its own new HV transformer with shunt. Otherwise, in our previous work we participated in a preliminary study treating the feasibility studies of nominal

functioning for a new HV power supply with a character six-phase for one magnetron by phase (6x800 Watts to 2450 MHz) uses in industrial microwave generators under Matlab-SIMULINK code [1].

This work present in the first time, the hybrid method of adjustment of pre-bend portion and the post-bend portion of the magnetization curve B-H respectively with a series of non-integer power [12] and with a polynomial representation based on the least squares method [12] - [11].

In the second time, the new model in  $\pi$  of the transformer is integrated, with the analytical expressions of inductances in the circuit of the HV power supply from the source to the magnetron, this model is validated by comparing simulation results with those obtained from tests already carried [2].

In the third time, feasibility study of the nominal functioning of a new high voltage power supply with a character six-phase for one magnetron by phase is treated, by using the single-phase model of HV power supply with shunts for one magnetron.

Finally we use the Matlab-SIMULINK code to study the process of regulation of this power supply. the stability of magnetron current is verified, overlooked the change of voltage ( $\pm 10\%$ ), [1][5][6][8][9] and the value recommended by the manufacturer of the magnetron current  $I_{peak} < 1.2A$  and  $I_{mean} \approx 300mA$ .

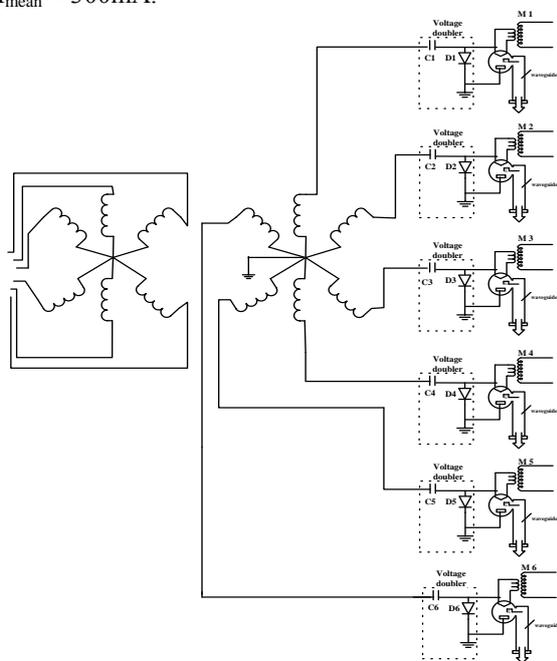


Fig. 1. Six-phase power supply for one magnetron by phase (AMPEREX technology)

## II. ANALYTICAL REPRESENTATION OF B-H MAGNETIZATION CURVE

The solution of the problems in the field of ferromagnetic materials is complicated due to the nonlinear relations between B and H. One of the problems is the absence of a simple mathematical expression, Two parts of this curve is considered for this analytical representation: The linear region is adjusted by a series of non-integer power [12], whereas the saturation region is represented by a polynomial function [11][13][14][15].

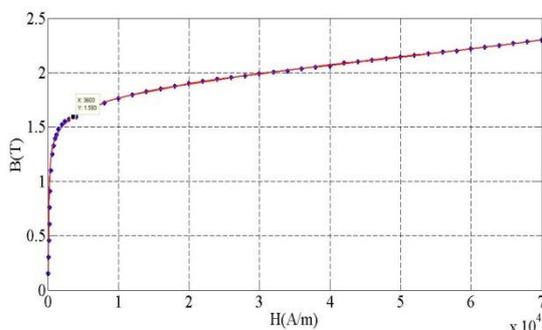


Fig2. magnetization curve (SF19): — measurement data,  $\circ \circ \circ$  curve represented by the series of non-integer power, +++ curve represented by the polynomial function.

The superposition of the simulated BH curve obtained by the two analytical expressions and from the real data shows that these two curves are combined. It illustrates the accuracy of this procedure for modelling the non-linear characteristic of the ferromagnetic material (SF19).

## III. MODELLING OF SINGLE PHASE HV POWER SUPPLY WITH SHUNTS FOR MAGNETRON

The modelling already developed [2]-[19] of a HV single-phase power supply for a magnetron 800 Watts-2450 MHz (Figure 3) consists essentially to model its HV special transformer with leakage flux which ensures the stabilization of the anodic mean current in the magnetron.

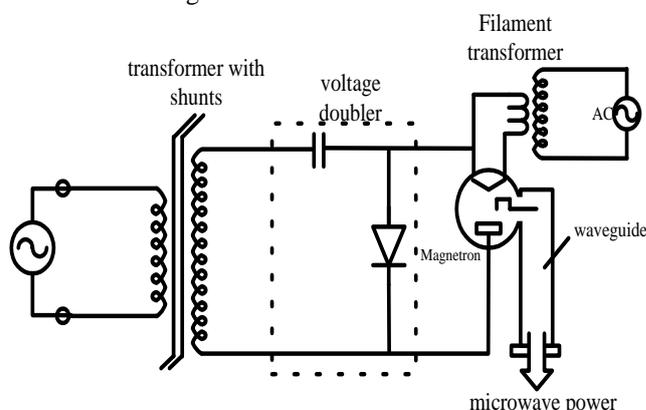


Fig. 3 Current power supply for magnetron (AMPEREX Technology)

The equivalent model obtained of this transformer will be integrate into the overall schema of the power supply to be adapted at the modelling of entire system with Matlab-SIMULINK which able to take into account of the geometry and non-linear magnetic properties of materials.

The equivalent circuit must translate the behaviour of the all power including the magnetron and transformer with shunt. The simultaneous resolution of the electric and magnetic equations of all system is too complex and the solution can be only digital (Matlab-SIMULINK) that analytical with the possibility to study the choice of materials and dimensions of the transformer with a view to a possible optimization.

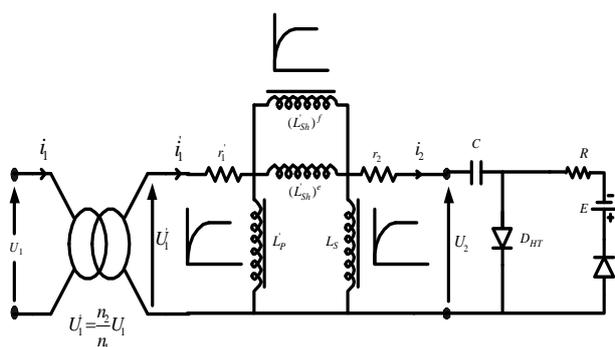


Fig. 4 global model of supply studied for a magnetron

The figure 4 shows the incorporation of the equivalent circuit in  $\pi$  of the transformer in the power supply from the electric and magnetic equations of its operation. The advantage of this model is presented in its single-phase equivalent circuit reduced to the secondary which seems more convenient to study the operation of the transformer with Matlab-SIMULINK. The immediate relevance of this model is to assign at each inductance a relation non-linear "flux-current" of the H from the geometric parameters of a precise portion of the magnetic circuit of the transformer, allowing so of translate its real operation in non-linear regime.

To perform this modelling [1], [3], [4] we sought to integrate the model of the transformer in the circuit of power supply from the source to the magnetron (Figure 4), where we represented the microwave tube by its equivalent circuit deduced from its electrical characteristic that is formally similar to that of a diode of dynamic resistance  $R = \Delta U / \Delta I$  near of  $350 \Omega$  and the threshold voltage  $E \approx 3800$  volts.

The elements of the model including the non-linear inductances were determined from the magnetic sheet and the geometrical dimensions of the transformer. Each element of a storable portion magnetic circuit, the section S, of medium length l, is represented by its inductance  $L = \frac{n_2 \Phi_p}{i_p} = \frac{n_2^2 s_1}{l_p} \frac{B}{H(B)}$  where the quantity  $H(B)$  can be determined from magnetization curve of the material used and geometric elements using the following relations:

- For  $B < 1.7225$ :  $H = \sum K_i B^{n_i}$
- For  $B > 1.7225$ :  $H = a_{2p+1} B^{2p+1}$

Each inductance is represented under matlab-SIMULINK by a block diagram (figure 5) constituted of its elements follow:

- An integrator allows us to deduce the flux from the voltage.
- The *MATLAB Fuction* block applies the specified MATLAB function or expression to the input. The output of the function must match the output dimensions of the block or an error occurs.

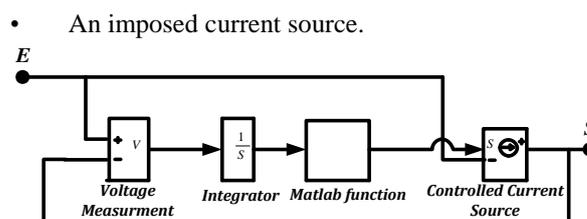
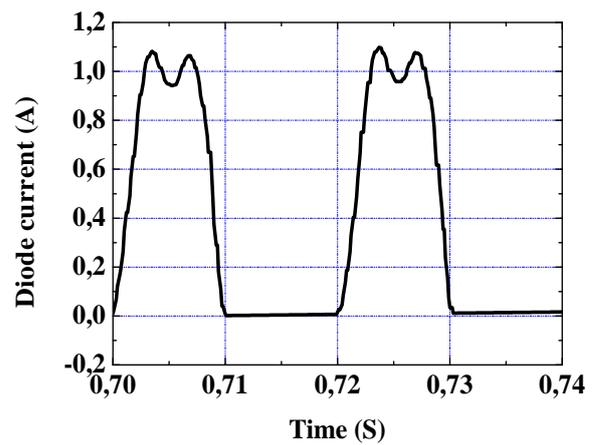
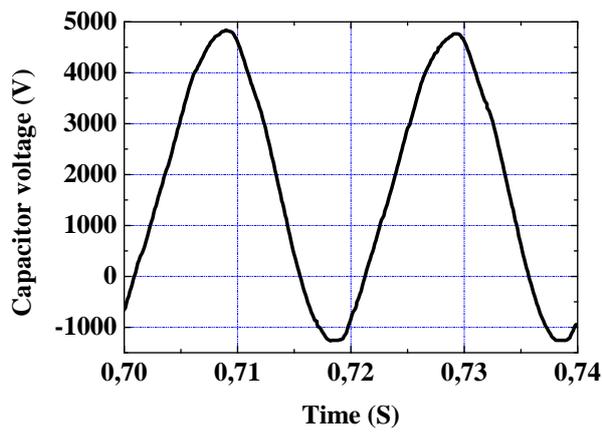
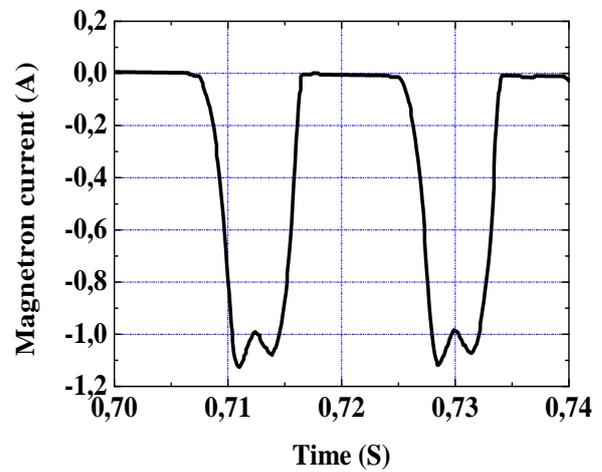
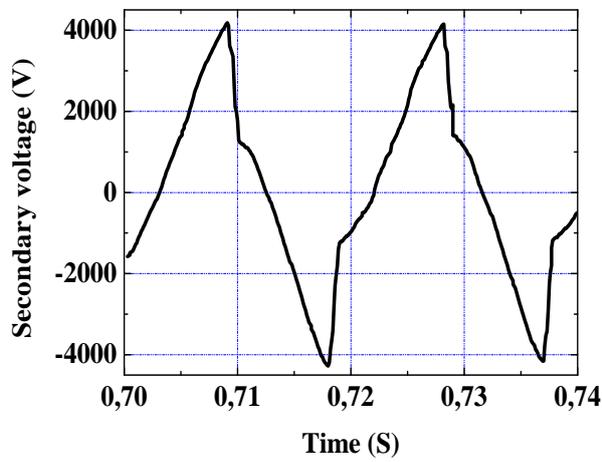
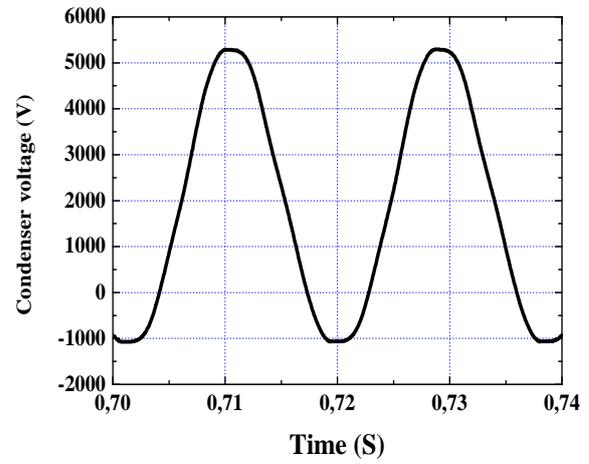
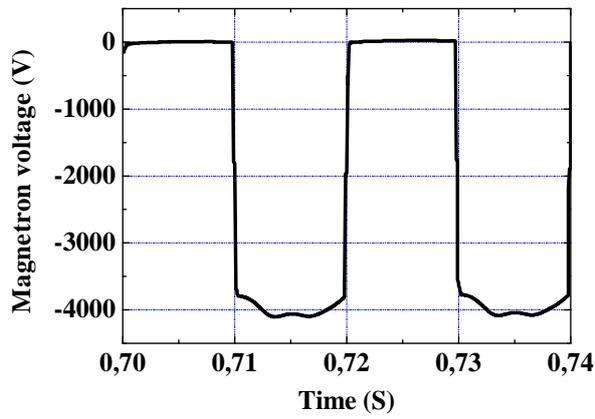


Figure 5. Block Diagram of a non-linear inductance under Matlab-Simulink.

To validate this model, we carried out tests on a microwaves generator made up of the following elements:

- A HV transformer with magnetic shunt of nominal characteristics:  $f=50$  Hz,  $S=1650$  VA,  $U_1=220$  V, and  $U_2=2330$  V (resistance of the primary back to the secondary  $r'_1=100 \Omega$ , secondary resistance  $r_2=65 \Omega$ , number of primary turns:  $n_1=224$ , number of turns in the secondary  $n_2 = 2400$ ).
- A condenser with a capacity  $C=0,9 \mu F$  and a high voltage diode DHT ;
- A magnetron designed to function under an approximately voltage  $\approx 4000$  V, To obtain its nominal power, it needs an average intensity  $I_{mean} = 300$  mA, but without exceeding the peak value of its current ( $I_{peak} < 1,2$  A).



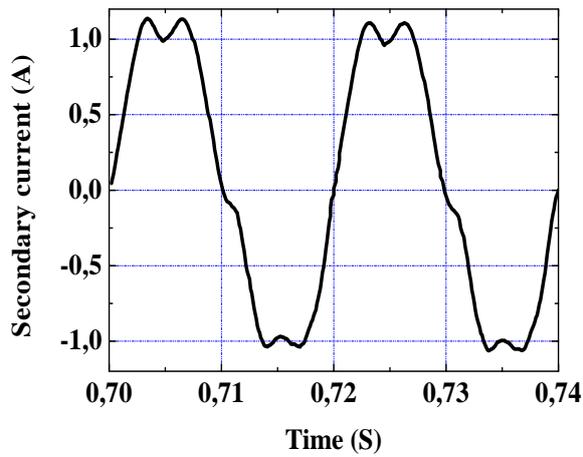


Fig. 5A Concordance of the experimental waveforms of currents and voltages (nominal regime)

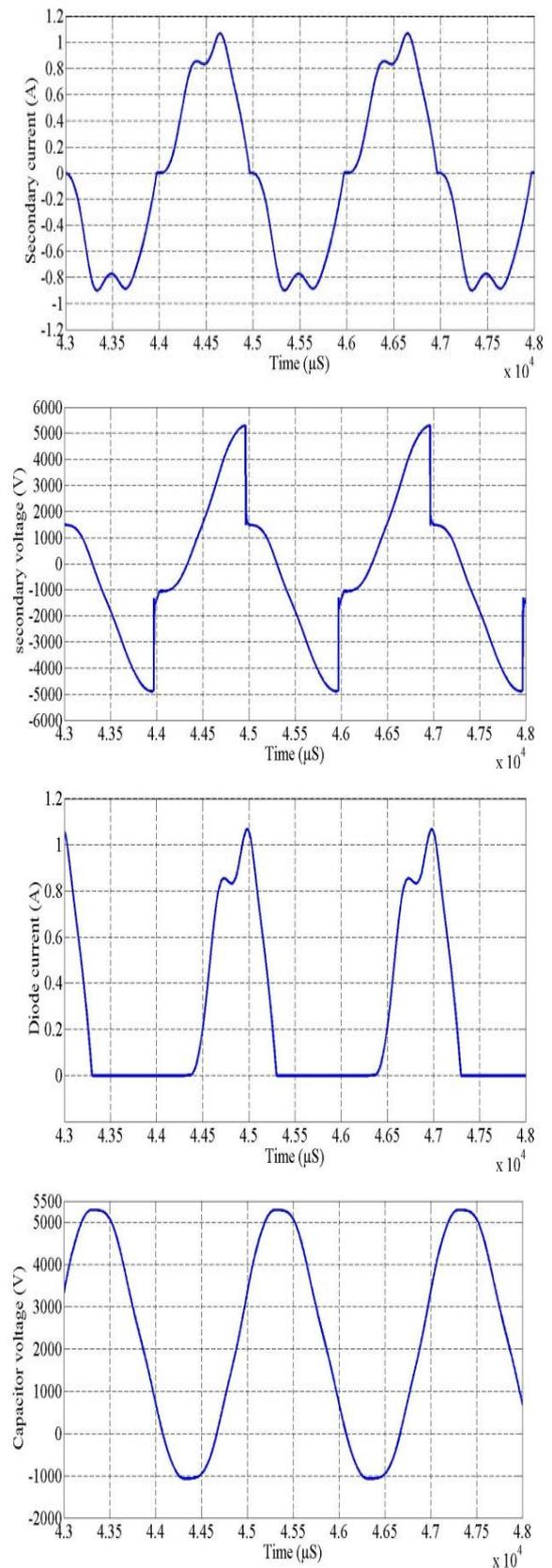
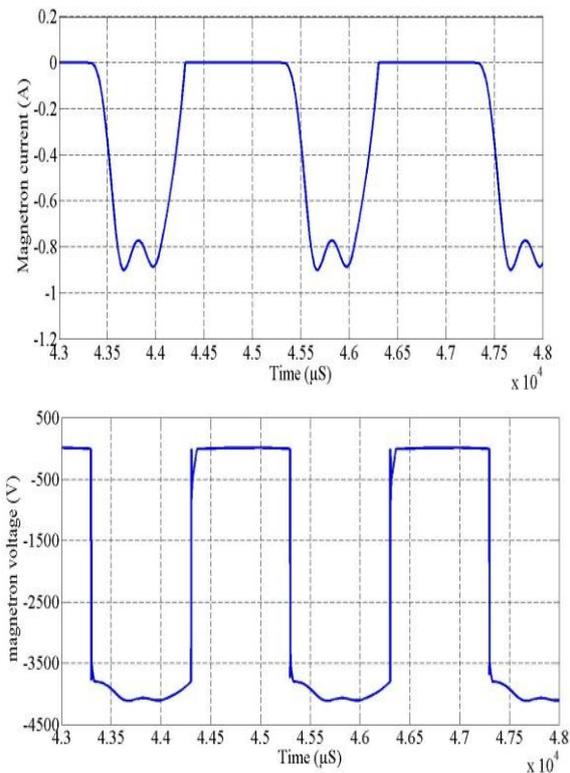


Fig. 6B Concordance of theoretical waveforms of currents and voltages (nominal regime)

The figures 6 and 7 indicates that in nominal functioning ( $U_1=220$  V and  $f=50$  Hz) the results of simulation by matlab-SIMULINK of the device, in non-linear mode, are in concordance with the experimental waveforms observed in these same conditions. Indeed, between peak to peak values, the variations relative never exceed 6%. Taking into account the precision the various data and acceptable tolerances on operation of the magnetron, the validity of modelling was considered to be satisfactory. On the other hand, the stabilizing effect of the current magnetron has been checked with respect to the variations of the voltage primary for  $\pm 10\%$  of the nominal voltage ( $\pm 20$  V).

#### IV. MODELLING OF HV POWER SUPPLY WITH A CHARACTER SIX-PHASE FOR A MAGNETRON BY PHASE

The feasibility study of operating in nominal regime of this new system (Figure 8) was undertaken. It consist to highlight the feasibility of supplying several magnetrons by phase (case treated  $N=1$ ) using single-phase model of a HV power supply for a single magnetron 800 Watts- 2450MHz.

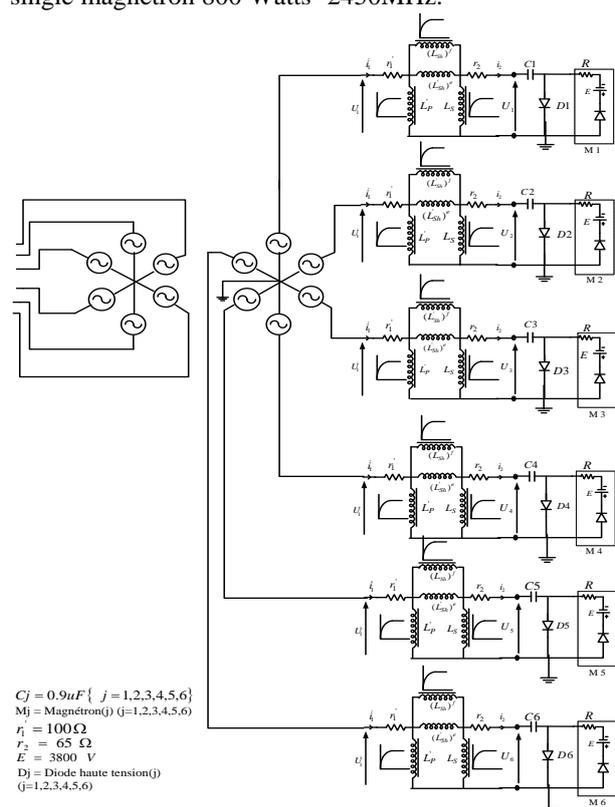


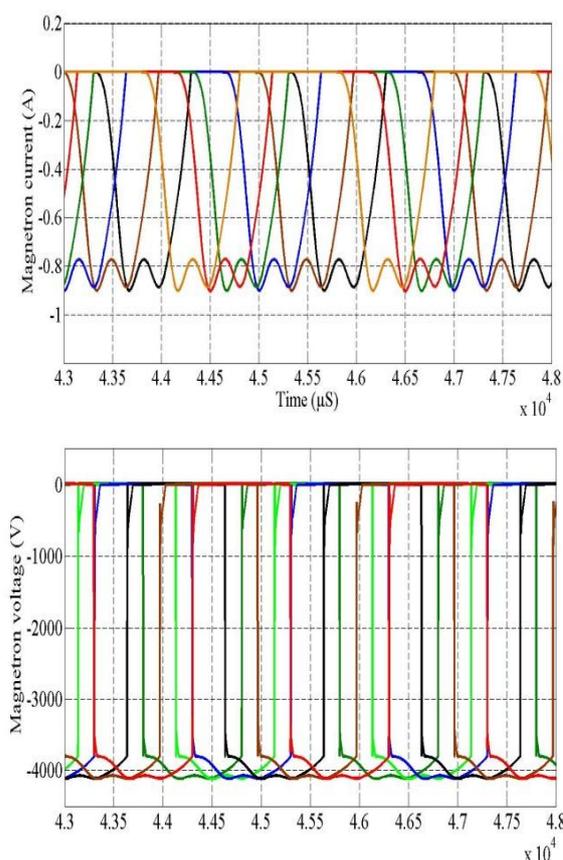
Fig. 5 the diagram of a mounting Six-phase simulated by matlab-SIMULINK (a magnetron by phase)

The six-phase transformer, not yet so far modelled or made, is represented by six identical models of power supply for magnetron coupled in

star and supplied respectively by the six-phases voltages system out of phase  $2\pi/6$  between them. The output of each model supplies its own voltage doubler and voltage stabilizer, composed of a capacitor and a diode which in his turn supplies a single magnetron.

The mounting in figure 8 was simulated to account for the operation of a six-phase power supply of microwave generator for a magnetron by phase, able to delivering, each one, under 220 V in the full power of 800 Watts useful to 2450MHz. Each of the six identical models corresponds to that of a single-phase power supply designed currently for supply normally in nominal regime an only magnetron which is of Moulinex mark, bearing on the nameplate the characteristics 220V, 50Hz, 1650VA.

By powering the primary connected in star the new power system studied (Figure 8) at the nominal voltage of 220V, 50 Hz, the simulations with matlab-SIMULINK have allows of raise the time curves of voltages and currents (Figure 9). In the first remark, we note that the electrical signals obtained (currents in the diodes ( $D_1, D_2, D_3, D_4, D_5, D_6$ ), currents in the magnetrons ( $M_1, M_2, M_3, M_4, M_5, M_6$ ) current in the capacitors ( $C_1, C_2, C_3, C_4, C_5, C_6$ ), the voltages ( $U_1, U_2, U_3, U_4, U_5, U_6$ ) across the secondary of the model of transformer and the voltages across each magnetron ( $M_1, M_2, M_3, M_4, M_5, M_6$ ) are the curves of various sizes periodic and non sinusoidal shifted relative to each 60 degrees.



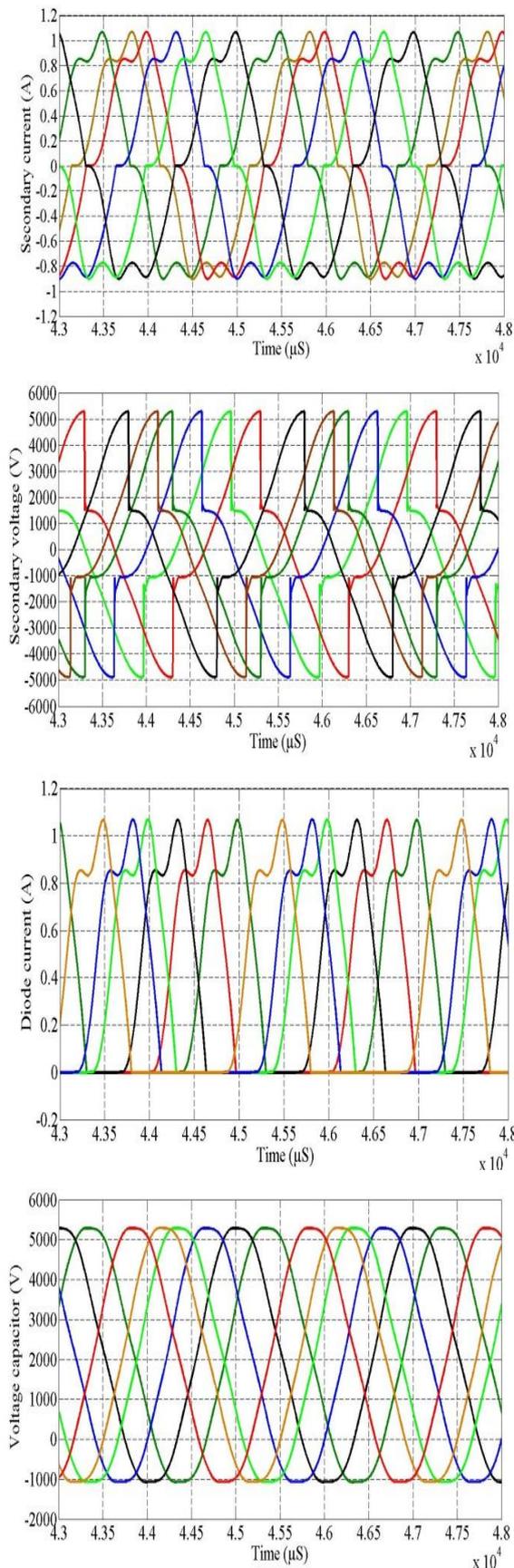
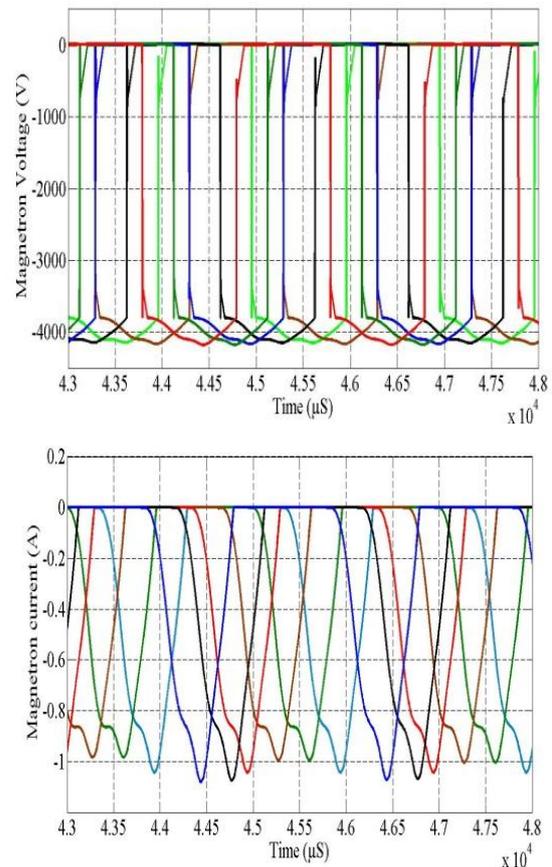


Fig. 6 Simulation results of the new power system

These signals have the same form as those of a classical power supply with a single transformer by magnetron. The phase shift between them of 60 degrees confirms the absence of interaction between magnetrons. The operating points of these magnetrons are not longer disrupted, which important for a stabilized current of the power supply. Moreover, the breakdown of each magnetron does not affect the operation of other remaining magnetrons. Just replace the magnetron off service by a new magnetron.

### V. VERIFICATION OF PROCESS REGULATION OF VOLTAGE AND CURRENT MAGNETRON

The stability of the variation of the magnetron current compared with variation of the voltage is observed, during the simulation of the model using Matlab-SIMULINK.



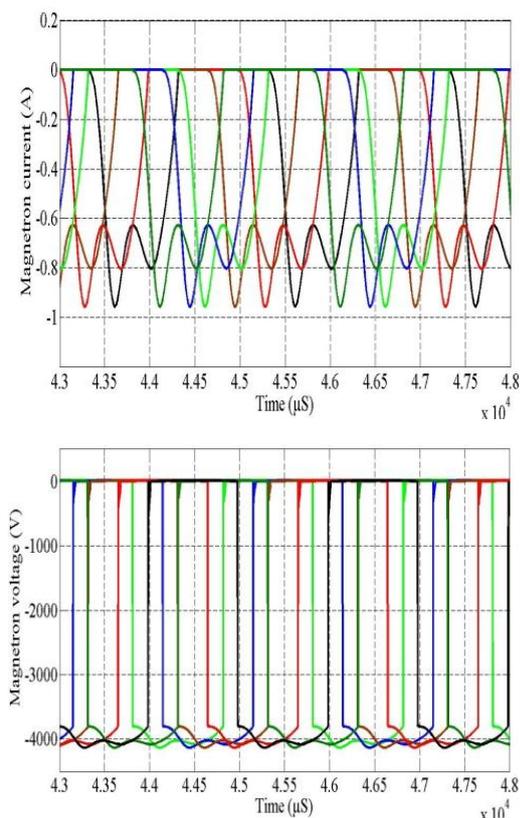


Figure 7. The stabilization of the anode current of the magnetrons with respect to variations of supply voltage ( $\pm 10\%$ ) of the rated voltage.

These figures show the waveform of the magnetron current in case 200V and 240V ( $\pm 10\%$ ) of the rated voltage. We find that the maximum amplitude of the current is not exceeded the permissible value recommended by the constructor ( $I_{max} = 1.2A$ ). The stabilization of the magnetron current is completely recovered in this model.

## VI. CONCLUSION

The feasibility study conclusive of the new power supply with a style six-phase for magnetron by phase will certainly lead us to undertake the actual study of the real new systems three-phase or six-phase supplying several magnetrons (800 Watts, 1000 Watts or 1200 Watts to 2450 MHz) by phase, for microwave generators for industrial applications, by modelling and in properly sizing its own transformer six-phase with shunts.

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