Modeling of a new Three-phase High Voltage Power Supply for Industrial Microwave Generators with a Single Magnetron per Phase

A. Belhaiba[1], M. Chraygane[1], N. Elghazal[1], M. Ferfra[2], B. Bahani[1]

Abstract – **In this article, a new model of a new three phase transformer with shunts will be evaluated. This special type of transformer with shunt is used in industrial microwave power supply. This original work is part of the development of new microwaves power supplies generation for several magnetrons. The trend towards the new three phase power supply device will thus be a different version of the single-phase model currently used by microwave ovens manufacturers. The new device has multiple advantages regarding the reduction of weight, volume, electrical wiring and the cost of the production and maintenance. The theoretical model obtained from electric and magnetic equations has allowed to simulate with MATLAB-SIMULINK the electrical operation of the new three-phase transformer with shunt, the obtained results are compared to those obtained experimentally for single phase power supply.**

Keywords – **Magnetron, Three-phase, Magnetic flux, Modeling, Matlab-Simulink.**

I. Introduction

In this paper, we will study the design of a new three phase High Voltage (HV) power supply of one magnetron 800 Watts -2450 Mhz per phase for industrial microwave generators. This new device then includes one new three-phase HV transformer with magnetic shunts, supplying by phase one voltage doublers and current stabilizer, each consisting of a capacitor and a diode which in turn supplies a single magnetron. At the level of realization of the new power system, this new technology provides, for the same microwave power, a less space, weight and electrical wiring, which reduce thus the costs of implementation and maintenance device of magnetrons. This article is proceeds as follow:

In the first part, we will present the description of the new three phase transformer with shunts. After that we will develop the systems of electric and magnetic equations for each phase, the obtained equations system will allow to establish the electric equivalent model of the new three phase transformer with shunts in nonlinear regime.

The second part will be devoted to the simulation of the established model, from this new original model of three-phase transformer we will simulate the electrical functioning of the three phase power supply. The results of currents and voltages waveforms for each phase of the modeled three-phase assembly will be compared with those obtained experimentally of classical single phase system. In the end of this part, we will check the current regulation process in the magnetron of each phase [1-6].

[1]MSTI team Higher School of Technology, Ibnou Zohr University, 80000, Morocco, E-mail: a.belhaiba@gmail.com

[2]Power Electronics Laboratory, EMI, Mohammadia Engineering School (Mohamed V University), Agdal, Morocco.

II. Description of the new Three-Phase Transformer with Shunts

A. Magnetic Circuit

Figure 1 shows the geometric form of the new three phase transformer with shunts having magnetic circuit with 3 columns and 4 yokes (Shell form). Its magnetic circuit, which is supposed laminated to reduce eddy current losses and supposed realized with type of sheets SF_{19} with tackiness (0,5 mm), isolated from each other.

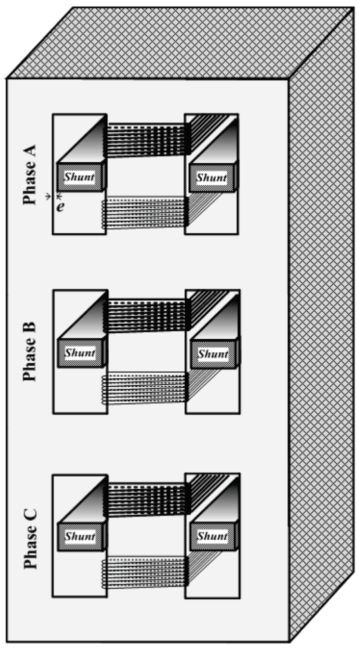


Fig. 1. Schema of the new three-phase transformer with shunts

B. The Winging

The six coils presented in the figure 1 of the new three phase transformer with shunts are placed on the central core. The primary windings connected to the source of balanced three-phase alternating voltage, are powered by the mains voltage. They receive a power close debited by the secondary windings which deliver the high voltage to the three receivers each consisting of a voltage doublers and magnetron. In each phase, we have a primary winding (n_1 turns) and a secondary winding (n_2 turns).

C. The Shunts

The shunts are inserted between the primary and the secondary of each phase as shown in the figure 1, are used to deviate an important portion of the flux its role is to ensure regulation of the current in the magnetron of each phase [36]. Each phase has two shunts with sizes *h* composed each of n_3 sheets with overall gap thickness *e*.

III. Modeling of the new Three-phase Power Supply for one Magnetron per Phase

During the modeling of an ordinary three-phase block, it is sufficient to develop the model one phase between the three and then to generalize for remaining two. Contrary to the new HV three phase transformer with shunts, its new structure leads us to study the modeling of each phase taking into account the common circuit between the phases (A-B) and (B-C).

III.1. Modeling Principle

The new transformer cannot be separated from the external circuits, including each of the three magnetrons, because the equivalent diagram must reflects the real functioning of the whole device. It is therefore necessary to find a formulation that will allow to the simultaneous resolution of the electric and magnetic equations of the entire system. The obtained equivalent model from the electric and magnetic equations should take into account the non-linearity of the system. The construction under SIMULINK code of the no-linear inductance using the predefined functions in the SIMULINK library will finally allow establish the overall model of the three phase transformer.

III.2. Notation

The three phases are named A, B and C. The capital letters are reserved for primary quantities (A, B and C) while for lowercase letters for secondary values (*a, b* and *c*). Notations and sign conventions used during the modeling are shown in the Fig. 2.

The flux distribution in the magnetic circuit of the new three-phase transformer with shunts is done according to the following ordinary configuration:

- Primary – Secondary
- Primary – Secondary
- Primary – Secondary

Designate by:

- r_A, r_B and r_C : Primary resistances windings of the phases (A, B and C).
- n_1 : Number of primary winding turns in the phase (A, B and C).
- i_A, i_B and i_C : Primary currents coils of the phases (A, B and C).
- u_A, u_B and u_C : Supply voltages of primary coils of the phases (A, B and C).
- r_a, r_b and r_c : Resistances of secondary windings of the phases (A, B and C).
- n_2 : Number of secondary winding turns in each phase (A, B and C).
- i_a, i_b and i_c : Secondary currents coils of the phases (A, B and C).
- u_a, u_b and u_c : Supply voltages of secondary coils of the phases (A, B and C).

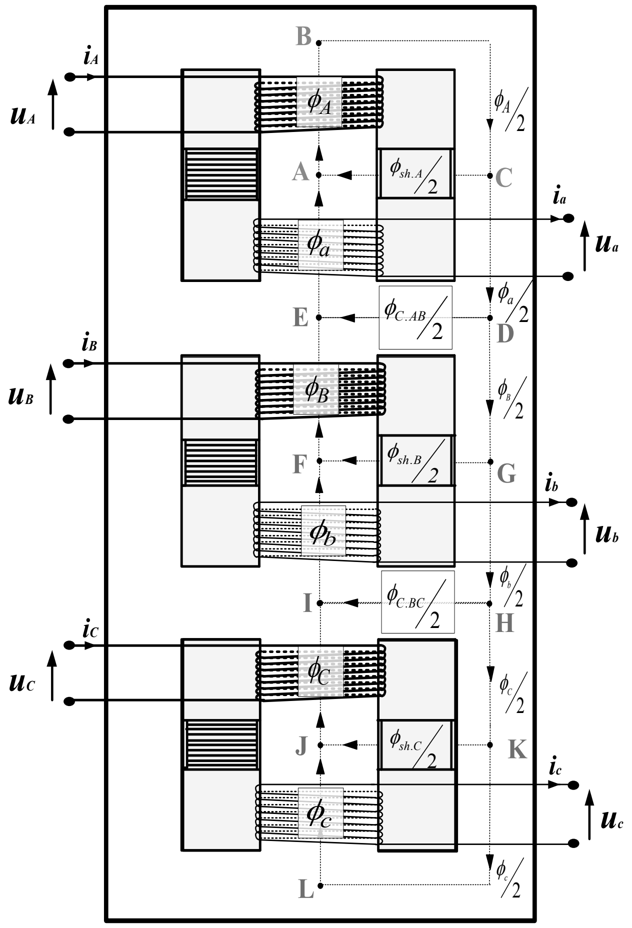


Fig. 2. Magnetic circuit of the new three phase transformer with shunts

In the proposed study, we consider the new three phase transformer without iron losses (hysteresis losses and eddy current) and we assume the leaks that exist are only channeled into the shunts of each phase. The dispersion leaks in the air are negligible.

III.3. MODELING OF THE PHASE A

A.Magnetic Equations (phase A)

We consider the magnetic circuit of Fig. 2 which the millimeter dimensions are identified by the letters A, B, C, D and E which are relative to the mean force line of the flux in the different portions of the circuit, the numerical values of various geometric quantities are listed in the appendix.

According to Hopkinson law, we obtain for the different contours of the phase A (Fig. 2):

- For the contour **ABCA**

$$R_A\phi_A + R_{AA}\frac{\phi_A}{2} + R_{CA}\frac{\phi_{sh.A}}{2} = n_1 i_A$$

with:

$R_A = R_{AB} = \dfrac{l_A}{\mu_A S_A}$: Reluctance of the path AB traversed by the flux ϕ_A (Fig. 2).

$R_{AA} = R_{BC} = \dfrac{l_{AA}}{\mu_{AA} S_{AA}}$: Reluctance of the path BC traversed by the flux $\dfrac{\phi_A}{2}$ (Fig. 2)

$R_{AC} = \dfrac{l_{sh.A}}{\mu_{sh.A} S_{sh.A}}$: Reluctance of the path AC traversed by the flux $\dfrac{\phi_{sh.A}}{2}$ (Fig. 2).

$$\left(R_A + \frac{R_{AA}}{2}\right)\phi_A + \phi_{sh.A}\frac{R_{AC}}{2} = n_1 i_A$$

We put $R_{P.A} = R_A + \dfrac{R_{AA}}{2}$ and $R_{sh.A} = \dfrac{R_{AC}}{2}$, we get:

$$R_{P.A}\phi_A + R_{sh.A}\phi_{sh.A} = n_1 i_A$$

Multiplying the last equation by $1/n_2$

$$\left(\frac{R_{P.A}\phi_A}{n_2}\right) + \left(\frac{R_{sh.A}\phi_{sh.A}}{n_2}\right) = \left(\frac{n_1}{n_2}\right) i_A$$

According to the relation $ni = R\phi$ the quantities $\left(\dfrac{R_{P.A}\phi_A}{n_2}\right)$ and $\left(\dfrac{R_{sh.A}\phi_{sh.A}}{n_2}\right)$ correspond respectively to the following electric currents

$$i'_{P.A} = \left(\frac{R_{P.A}\phi_A}{n_2}\right) \text{ and } i'_{sh.A} = \left(\frac{R_{sh.A}\phi_{sh.A}}{n_2}\right)$$

Thus we obtain the equation (1)

$$i'_{P.A} + i'_{sh.A} = i'_A \tag{1}$$

- For the contour **ACDEA**

$$R_a\phi_a + R_{aa}\frac{\phi_a}{2} - R_{CA}\frac{\phi_{sh.A}}{2} + R_{DE}\frac{\phi_{C.AB}}{2} = -n_2 i_a$$

with :

$R_a = R_{EA} = \dfrac{l_a}{\mu_a S_a}$: Reluctance of the path EA traversed by the flux ϕ_a (Fig. 2).

$R_{aa} = R_{CD} = \dfrac{l_{aa}}{\mu_{aa} S_{aa}}$: Reluctance of the path CD traversed by the flux $\dfrac{\phi_a}{2}$ (Fig. 2).

$R_{DE} = \dfrac{l_{C.AB}}{\mu_{C.AB} S_{C.AB}}$: Reluctance of the path DE traversed by the flux $\dfrac{\phi_{C.AB}}{2}$ (Fig. 2).

$$\left(R_a + \frac{R_{aa}}{2}\right)\phi_a - \frac{R_{AC}}{2}\phi_{sh.A} + \frac{R_{DE}}{2}\phi_{C.AB} = -n_2 i_a$$

We put $R_{s.a} = R_a + \dfrac{R_{aa}}{2}$ and $R_{C.AB} = \dfrac{R_{DE}}{2}$, we get:

$$R_{s.a}\phi_a - R_{sh.A}\phi_{sh.A} + R_{C.AB}\phi_{C.AB} = -n_2 i_a$$

Multiplying the last equation by $1/n_2$

$$\left(\frac{R_{s.a}\phi_a}{n_2}\right) - \left(\frac{R_{sh.A}\phi_{sh.A}}{n_2}\right) + \left(\frac{R_{C.AB}\phi_{C.AB}}{n_2}\right) = -i_a$$

Thus we obtain

$$i'_{sh.A} = i_{s.a} + i_a + i'_{C.AB} \tag{2}$$

with

$$i_{s.a} = \left(\frac{R_{s.a}\phi_a}{n_2}\right),\ i'_{sh.A} = \left(\frac{R_{sh.A}\phi_{sh.A}}{n_2}\right) \text{ and } i'_{C.AB}\left(\frac{R_{C.AB}\phi_{C.AB}}{n_2}\right)$$

Equations (1) and (2) and are complemented by the additional relation reflecting the flux conservation in the phase A, namely:

$$\phi_A = \phi_a + \phi_{sh.A}$$

Putting the last expression in the form

$$\frac{d}{dt}(n_2\phi_A) = \frac{d}{dt}(n_2\phi_a) + \frac{d}{dt}(n_2\phi_{sh.A})$$

and writing

$$n_2\phi_A = \left(\frac{n_2^2}{R_{P.A}}\frac{R_{P.A}\phi_A}{n_2}\right) = L'_{P.A} i'_{P.A}$$

$$n_2\phi_a = \left(\frac{n_2^2}{R_{s.a}}\frac{R_{s.a}\phi_a}{n_2}\right) = L_{s.a} i_{s.a}$$

$$n_2\phi_{sh.A} = \left(\frac{n_2^2}{R_{sh.A}}\frac{R_{sh.A}\phi_{sh.A}}{n_2}\right) = L'_{sh.A} i'_{sh.A}$$

we have thus

$$\frac{d}{dt}(L'_{P.A} i'_{P.A}) = \frac{d}{dt}(L_{s.a} i_{s.a}) + \frac{d}{dt}(L'_{sh.A} i'_{sh.A}) \tag{3}$$

B.Electrical Equations (phase A)

The application of Ohm's law to the primary of the phase A lead to the following electrical equation

$$u_A = r_A i_A + n_1 \frac{d\phi_A}{dt}$$

we obtain thus

$$u'_A = r'_A i'_A + \frac{d}{dt}(L'_{P.A} i'_{P.A}) \quad (4)$$

$r'_A = \left(\frac{n_2}{n_1}\right)^2 r_A$, $i'_A = \left(\frac{n_1}{n_2}\right) i_A$ and $u'_A = \left(\frac{n_2}{n_1}\right) u_A$

We apply Ohm's law to the secondary of the phase A, we get the following equation:

$$u_a = -r_a i_a + n_2 \frac{d\phi_a}{dt}$$

and we get

$$u_a = -r_a i_a + \frac{d}{dt}(L_{s.a} i_{s.a}) \quad (5)$$

III.4. Modeling of the Phase B

A.Magnetic Equations (phase B)

We consider the same magnetic circuit of Fig. 2 which the millimeter dimensions are identified by the letters F, E, D, G, H, I which are relative to the mean force line of the flux in the different portions of the circuit, The numerical values of various geometric quantities are listed in the appendix.

The application of Hopkinson law to the different contours of the magnetic circuit of phase B (Fig. 2) gives the following equations:

- For the contour **FEDGF**

$$R_B\phi_B + R_{BB}\frac{\phi_B}{2} + R_{GF}\frac{\phi_{sh.B}}{2} - R_{DE}\frac{\phi_{C.AB}}{2} = n_1 i_B$$

with

$R_B = R_{FE} = \frac{l_B}{\mu_B S_B}$: Reluctance of the path FE traversed by the flux ϕ_B (Fig. 2).

$R_{BB} = R_{DG} = \frac{l_{BB}}{\mu_{BB} S_{BB}}$: Reluctance of the path DG traversed by the flux $\frac{\phi_B}{2}$ (Fig. 2).

$R_{GF} = \frac{l_{sh.B}}{\mu_{sh.B} S_{sh.B}}$: Reluctance of the path FG traversed by the flux $\frac{\phi_{sh.B}}{2}$ (Fig. 2).

This allows writing directly:

$$i'_B + i'_{C.AB} = i'_{P.B} + i'_{sh.B} \quad (6)$$

with

$i'_{P.B} = \frac{R_{P.B}\phi_B}{n_2}$, $i'_{sh.B} = \frac{R_{sh.B}\phi_{sh.B}}{n_2}$ and $i'_{C.AB} = \frac{R_{C.AB}\phi_{C.AB}}{n_2}$

- For the contour **FGHIF**

$$R_b\phi_b + R_{bb}\frac{\phi_b}{2} - R_{GF}\frac{\phi_{sh.B}}{2} + R_{HI}\frac{\phi_{C.BC}}{2} = -n_2 i_b$$

with

$R_b = R_{IF} = \frac{l_b}{\mu_b S_b}$: Reluctance of the path IF traversed by the flux ϕ_b (Fig. 2).

$R_{FG} = \frac{l_{sh.B}}{\mu_{sh.B} S_{sh.B}}$: Reluctance of the path FG traversed by the flux $\frac{\phi_{sh.B}}{2}$ (Fig. 2)

$R_{bb} = R_{GH} = \frac{l_{bb}}{\mu_{bb} S_{bb}}$: Reluctance of the path GH traversed by the flux $\frac{\phi_b}{2}$ (Fig. 2),

$R_{HI} = \frac{l_{C.BC}}{\mu_{C.BC} S_{C.BC}}$: Reluctance of the path FG traversed by the flux $\frac{\phi_{C.BC}}{2}$ (Fig. 2).

Similarly

$$i'_{sh.B} = i_{s.b} + i_b + i'_{C.BC} \quad (7)$$

with

$i_{s.b} = \frac{R_{s.b}\phi_b}{n_2}$, $i'_{sh.B} = \frac{R_{sh.B}\phi_{sh.B}}{n_2}$ and $i'_{C.BC} = \frac{R_{C.BC}\phi_{C.BC}}{n_2}$

Equations (6) and (7) are complemented by the additional relation reflecting the flux conservation in the phase B, namely:

$$\phi_B = \phi_b + \phi_{sh.B}$$

$$\frac{d}{dt}(n_2\phi_B) = \frac{d}{dt}(n_2\phi_b) + \frac{d}{dt}(n_2\phi_{sh.B})$$

posing

$$n_2\phi_B = \left(\frac{n_2^2}{R_{P.B}}\right)\left(\frac{R_{P.B}\phi_B}{n_2}\right) = L'_{P.B} i'_{P.B}$$

$$n_2\phi_b = \left(\frac{n_2^2}{R_{s.b}}\right)\left(\frac{R_{s.b}\phi_b}{n_2}\right) = L_{s.b} i_{s.b}$$

$$n_2\phi_{sh.B} = \left(\frac{n_2^2}{R_{sh.B}}\right)\left(\frac{R_{sh.B}\phi_{sh.B}}{n_2}\right) = L'_{sh.B} i'_{sh.B}$$

replacing

$$\frac{d}{dt}(L'_{P.B} i'_{P.B}) = \frac{d}{dt}(L_{s.b} i_{s.b}) + \frac{d}{dt}(L'_{sh.B} i'_{sh.B}) \quad (8)$$

B.Electrical Equations (phase B)

The application of Ohm's law to the primary of the phase B gives the following electrical equation:

$$u_B = r_B i_B + n_1 \frac{d\phi_B}{dt}$$

we obtain thus

$$u_B^{'} = r_B^{'} i_B^{'} + \frac{d}{dt}(L_{P.B}^{'} i_{P.B}^{'}) \quad (9)$$

with

$r_B^{'} = \left(\frac{n_2}{n_1}\right)^2 r_B$, $i_B^{'} = \left(\frac{n_1}{n_2}\right) i_B$ and $u_B^{'} = \left(\frac{n_2}{n_1}\right) u_B$

We apply Ohm's law to the secondary of the phase B, we get the following equation:

$$u_b = -r_b i_b + n_2 \frac{d\phi_b}{dt}$$

and we get

$$u_b = -r_b i_b + \frac{d}{dt}(L_{s.b} i_{s.b}) \quad (10)$$

III.5. Modeling of the Phase C

A. Magnetic Equations (phase C)

We consider the magnetic circuit of the same Fig. 2 which the millimeter dimensions are identified by the letters J, I, H, K, L which are relative to the mean force line of the flux in the different portions of the circuit, The numerical values of various geometric quantities are listed in the appendix.

The application of Hopkinson law to the different contours of the magnetic circuit of phase C (Fig. 2):

- For the contour **JIHKJ**

$$R_C \phi_C + R_{CC} \frac{\phi_C}{2} + R_{KJ} \frac{\phi_{sh.C}}{2} - R_{HI} \frac{\phi_{C.BC}}{2} = n_1 i_C$$

with

$R_C = R_{JI} = \frac{l_C}{\mu_C S_C}$: Reluctance of the path JI traversed by the flux ϕ_C (Fig. 2).

$R_{CC} = R_{HK} = \frac{l_{CC}}{\mu_{CC} S_{CC}}$: Reluctance of the path HK traversed by the flux $\frac{\phi_C}{2}$ (Fig. 2).

$R_{KJ} = \frac{l_{sh.C}}{\mu_{sh.C} S_{sh.C}}$: Reluctance of the path KJ traversed by the flux $\frac{\phi_{sh.C}}{2}$ (Fig. 2).

which allow directly to the following equation

$$i_C^{'} + i_{C.BC}^{'} = i_{P.C}^{'} + i_{sh.C}^{'} \quad (11)$$

with

$i_{P.C}^{'} = \frac{R_{P.C}\phi_C}{n_2}$, $i_{sh.C}^{'} = \frac{R_{sh.C}\phi_{sh.C}}{n_2}$ and $i_{C.BC}^{'} = \frac{R_{C.BC}\phi_{C.BC}}{n_2}$

- For the contour **JKLJ**

$$R_c \phi_c + R_{cc} \frac{\phi_c}{2} - R_{KJ} \frac{\phi_{sh.C}}{2} = -n_2 i_c$$

with

$R_c = R_{LJ} = \frac{l_c}{\mu_c S_c}$: Reluctance of the path IF traversed by the flux ϕ_c (Fig. 2).

$R_{cc} = R_{KL} = \frac{l_{cc}}{\mu_{cc} S_{cc}}$: Reluctance of the path KL traversed by the flux $\frac{\phi_c}{2}$ (Fig. 2).

which allow to the following the equation

$$i_{sh.C}^{'} = i_{s.c} + i_c \quad (12)$$

with : $i_{s.c} = \frac{R_{s.c}\phi_c}{n_2}$

On the other hand, the flux conservation in phase C gives:

$$\phi_C = \phi_c + \phi_{sh.C}$$

We obtain by development the following equation

$$\frac{d}{dt}(L_{P.C}^{'} i_{P.C}^{'}) = \frac{d}{dt}(L_{s.c} i_{s.c}) + \frac{d}{dt}(L_{sh.C}^{'} i_{sh.C}^{'}) \quad (13)$$

B. Electrical Equations (phase C)

The application of Ohm's law to the primary phase C gives the following electrical equation:

$$u_C = r_C i_C + n_1 \frac{d\phi_C}{dt}$$

we obtain thus

$$u_C^{'} = r_C^{'} i_C^{'} + \frac{d}{dt}(L_{P.C}^{'} i_{P.C}^{'}) \quad (14)$$

We apply Ohm's law to the secondary of the phase C, we get the following equation:

$$u_c = -r_c i_c + n_2 \frac{d\phi_c}{dt}$$

thus

$$u_c = -r_c i_c + \frac{d}{dt}(L_{s.c} i_{s.c}) \quad (15)$$

III.6. Connecting equations

- Nodes law in the point D (Fig. 2)

$$\frac{\phi_a}{2} = \frac{\phi_{C.AB}}{2} + \frac{\phi_B}{2}$$

we thus obtain

$$\frac{d}{dt}(L_{s.a} i_{s.a}) = \frac{d}{dt}(L_{C.AB}^{'} i_{C.AB}^{'}) + \frac{d}{dt}(L_{P.B}^{'} i_{P.B}^{'}) \quad (16)$$

- Nodes law in the point H (Fig. 2)

$$\frac{\phi_b}{2} = \frac{\phi_{C.BC}}{2} + \frac{\phi_C}{2}$$

$$\frac{d}{dt}(L_{s.b} i_{s.b}) = \frac{d}{dt}(L_{C.BC}^{'} i_{C.BC}^{'}) + \frac{d}{dt}(L_{P.C}^{'} i_{P.C}^{'}) \quad (17)$$

III.7. Electrical Equivalent Circuit of the new Three-Phase Transformer with Shunts

The electric and magnetic obtained equations during the modeling of phases A, B and C (1:17) allowed to find the global electrical model referred to secondary of the new three phase transformer with shunts (Fig. 3).

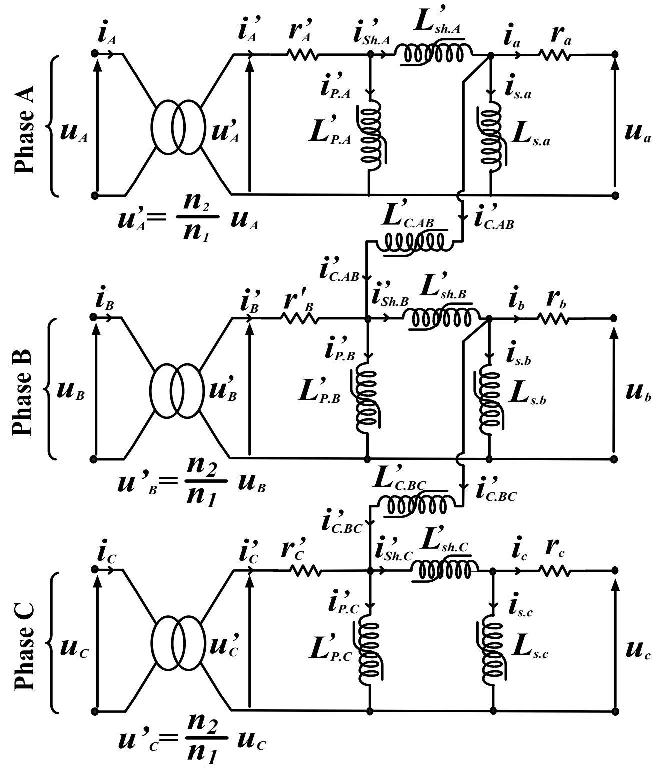


Fig. 3. Global electrical model referred to secondary of the new three phase transformer with shunts

The shunt of each phase consists of an iron part and a air gap part, therefore the equivalent inductance is given by:

$$L'_{sh.A} = \frac{\left(L'_{sh.A}\right)^f \left(L'_{sh.A}\right)^e}{\left(L'_{sh.A}\right)^f + \left(L'_{sh.A}\right)^e}$$

$$L'_{sh.B} = \frac{\left(L'_{sh.B}\right)^f \left(L'_{sh.B}\right)^e}{\left(L'_{sh.B}\right)^f + \left(L'_{sh.B}\right)^e}$$

$$L'_{sh.A} = \frac{\left(L'_{sh.C}\right)^f \left(L'_{sh.C}\right)^e}{\left(L'_{sh.C}\right)^f + \left(L'_{sh.C}\right)^e}$$

Similarly we get for the currents:

$$i'_{sh.A} = \left(i'_{sh.A}\right)^e + \left(i'_{sh.A}\right)^f$$

$$i'_{sh.B} = \left(i'_{sh.B}\right)^e + \left(i'_{sh.B}\right)^f$$

$$i'_{sh.C} = \left(i'_{sh.C}\right)^e + \left(i'_{sh.C}\right)^f$$

Thus the model of Fig. 3 is slightly changed it is replaced with that presented of Fig. 4 in which we have integrated the model of the new three-phase transformer in the power supply circuit from the source to the magnetrons.

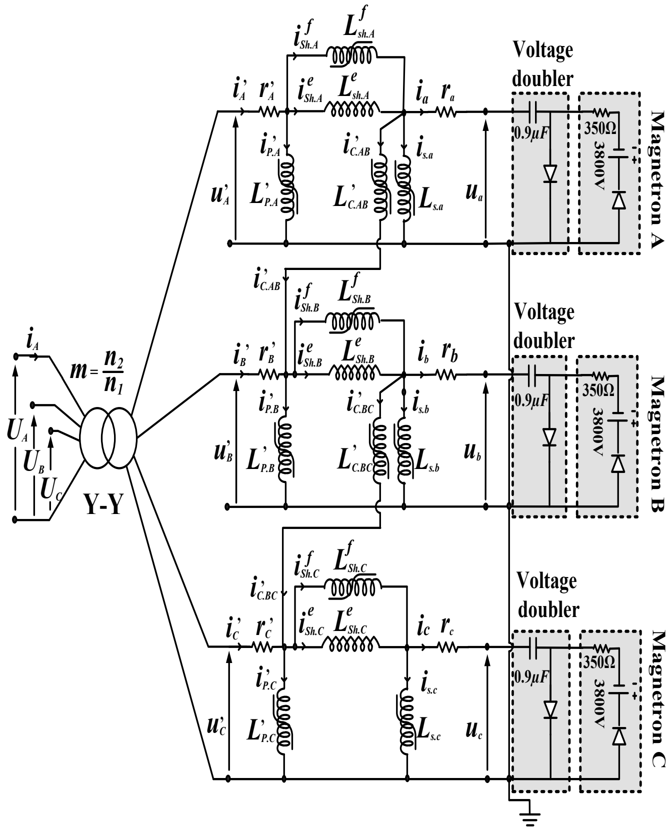


Fig. 4. Global electrical model of the new three phase power supply for one magnetron per phase (star-star connection)

IV. Simulation of the Model of the new Three-Phase Power Supply

The simulation study of electrical functioning of this new device was performed with a new three-phase transformer correctly sized (appendix) supposedly on its nameplate characteristics *Y V/Y V* : 220/2200, f = 50*Hz*/3*ph.*, 3 × 1650 = 9450*V A*.

The nonlinear inductances are depending to the flux and current [7], [8]. The implementation of each nonlinear inductance (Fig. 5) with its polynomial expressions under Matlab Simulink-code was presented in Fig. 6.

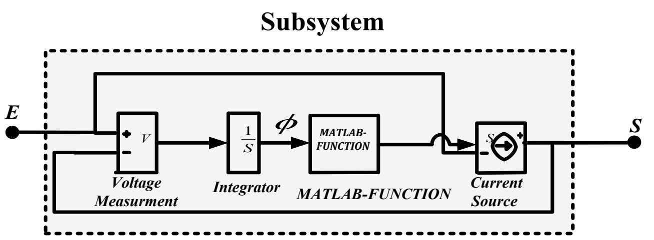


Fig. 5. Block diagram of a nonlinear inductance under Matlab-Simulink code

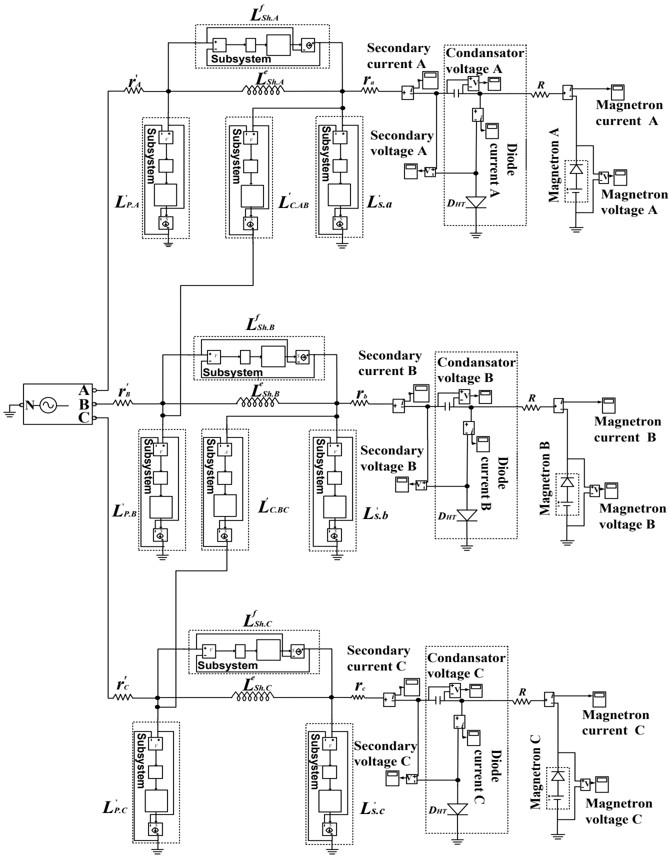


Fig. 6. Global electrical model of the new three phase power supply for one magnetron per phase under Matlab-simulink

The simulation with Matlab-Simulink of the new three-phase transformer model (Fig. 6) allowed finding the waveforms of currents and voltages of each phase (A, B and C), the simulation results are shown in the Figs. 7.A and 7.B) [9-13].

The obtained results by simulation with Matlab-simulink are in perfect agreement with the experimental results for a classic single-phase power supply with single magnetron [4]. We see that the maximum amplitude value of the magnetron current in each phase remains less than an acceptable limit (I_{max} < 1.2A). Moreover, we see from Fig. 7.A that the forms of the currents in the magnetrons (A, B and C) respects the constraints imposed by the manufacturers for full-power operation (I_{avg} = 300mA and I_{max}=1A). The operating points of these magnetrons are therefore not disturbed which is essential for a current stabilized power supply [14-20].

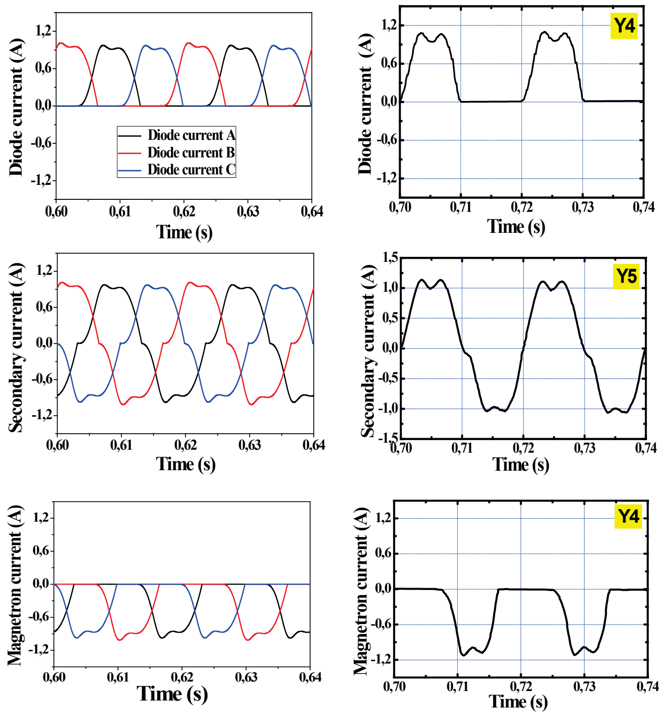


Fig 7.A. Theoretical and experimental waveforms of currents New three phase power supply for one magnetron per phase

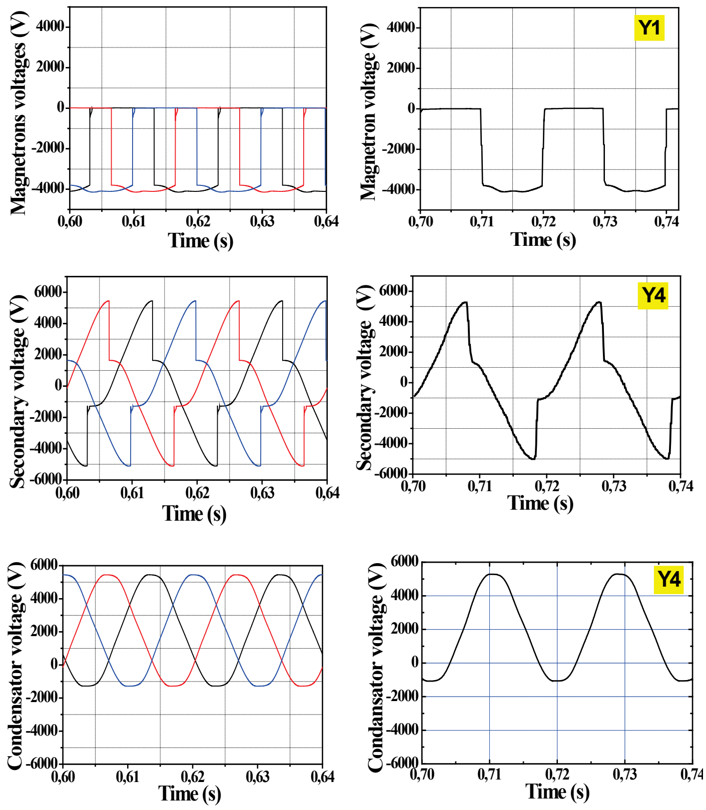


Fig. 7.B. Theoretical and experimental waveforms of voltages New three phase power supply for one magnetron per phase

V. Verification of the Current Control Process in the Magnetrons

During the simulation of the new three-phase power supply for one magnetron per phase, we have successfully observed the stability of the current variations in each magnetron according to the line voltage variation. The figure 8 shows the same waveform of the current in each magnetron for the respective cases of 200V and 240V (± 10% of the supply voltage).

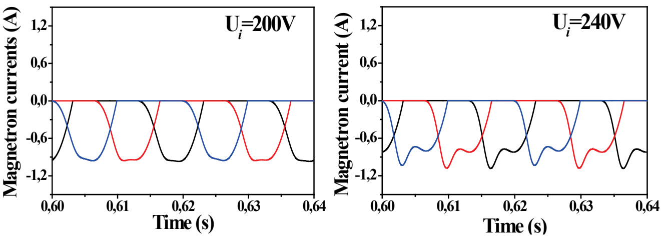


Fig. 8. Current stabilization in each magnetron according to the variations of line voltage (± 10% of nominal voltage)

We see that the maximum amplitude of the current has never exceeds the permissible limit recommended by the manufacturer. We can confirm that with this model of the new three-phase transformer with shunt, the current stabilization process in each magnetron is completely checked .

VI. Conclusion

The modeling study of the new three phase power supply for one magnetron per phase was successfully completed. The simulation results showed good superposition with those obtained for the classical single phase power supply currently used in microwave ovens. For each magnetron, the current regulatory process is completely assured as recommended by the manufacturer of the tube generating microwaves.

Finally, this work will significantly contribute to the development of technological innovation in the industrial manufacturing supplies, and understanding the physical phenomena related to the complex electrical operation of these power circuits types.

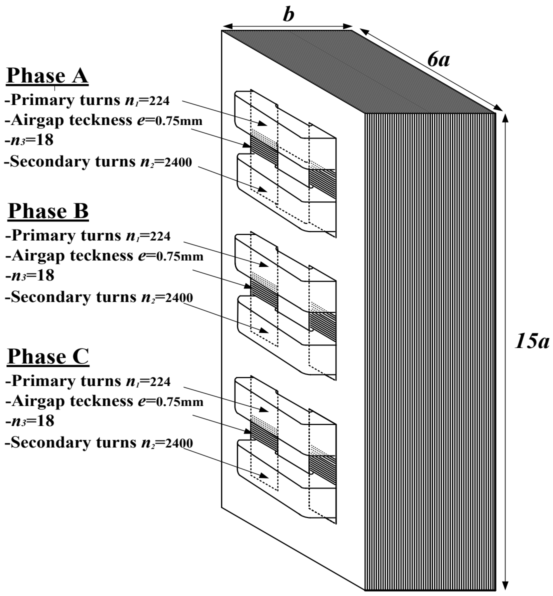
Appendix

The geometric characteristics of each of magnetic circuit portion of a three phase transformer with shunt.

In the figure below we present the following parameter values.

a : Width of unwound core.
b : Width of magnetic circuit
n_1 : Number of primary windings in each phase.
n_2: Number of secondary windings in each phase.
n_3: Number of stacked sheets of a shunt in each phase.
e : Thickness of the air gap in each phase.

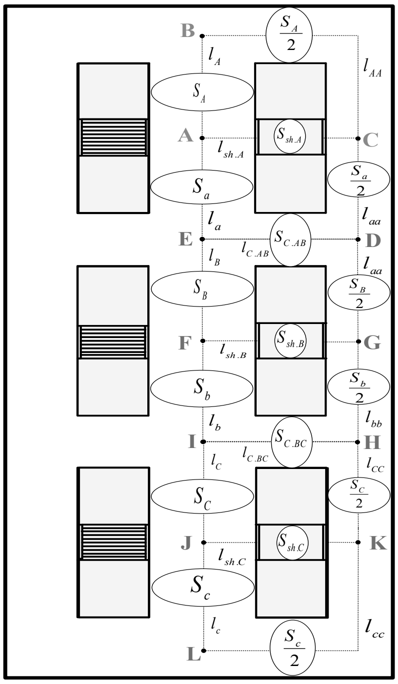
We consider the magnetic circuit of Figure below which millimeter dimensions are identified by the letters A, B, C, D, ..., L as:



- AB=JL=l_A=l_c=2a=50mm
- BC=KL=l_{AA}=l_{cc}=4.5a=112.5mm
- AE=CD=l_{AA}=l_{aa}=2.5a=62.5mm
- EF=DG=l_B=l_{BB}=2.5a=62.5mm
- FI=GH=l_b=l_{bb}=2.5a=62.5mm
- IJ=HK=l_C=l_{CC}=2.5a=62.5mm
- AC=FG=JK=$l_{sh.A}$=$l_{sh.B}$=$l_{sh.C}$=2.5a=62.5mm
- ED=IH=$l_{C.AB}$=$l_{C.BC}$=2.5a=62.5mm
- $l_{P.A}$=l_A+l_{AA} =6.5a=162.5mm
- $l_{s.a}$=l_a+l_{aa}=5a=125mm
- $l_{P.B}$=l_B+l_{BB}=5a=125mm
- $l_{s.b}$=l_b=l_{bb}=5a=125mm
- $l_{P.C}$=l_C+l_{CC}=5a=125mm
- $l_{s.c}$=l_c+l_{cc}=6.5a=162.5mm

The values of the areas of different magnetic circuit parts are :

- $S_A=S_a=2*a*b=3000mm^2$
- $S_B=S_b=2*a*b=3000mm^2$
- $S_C=S_c=2*a*b=3000mm^2$
- $S_{sh.A}=S_{sh.B}=S_{sh.C}=0.5*n_3*b=540mm^2$
- $S_{C.AB}=S_{C.BC}=2*a*b=3000mm^2$



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