Energy Balance of Three-Phase High Voltage Power Supply for Microwave Generators

A. Belhaiba, N. Elghazal, B. Bahani

Abstract – **The objective of this work was to study the energy balance of new three phase power supply for one magnetron per phase. The current model of the new three-phase transformer has not been energetically validated. In this study, different powers (primary power of the transformer, output power of the transformer and input power of the magnetron) were investigated. Each of these powers was compared to its experimental power obtained for a single-phase power supply. The obtained results allowed the validation of the functioning power of the developed model at three phase power supply for one magnetron per phase.**

Keywords – **Magnetron, Energy balance, Matlab-Simulink, Microwaves, Power supply.**

I. Introduction

The energetic characteristics of the magnetron require an average input power of 1200 W, which is given in the technical characteristics of the manufacturer. At this power, the magnetron can deliver a full useful power of 800W [1-3]. This study was carried out using Matlab-Simulink simulation to determine the energy balance of the new three phase power supply for one magnetron per phase. The novel model will allow to energetically validate the three-phase transformer for the correct energy operation of each magnetron. This aims to develop a prototype design of the new three-phase transformer for one magnetron per phase. This later offers advantages in terms of space, weight, volume and electrical wiring, thus reducing production costs.

This paper is divided into two parts. The first part is dedicated to classical single-phase power supply model, which is currently used in most microwaves ovens, and presents the different powers (instantaneous and average powers). Afterwards the equivalent electric model of the new three-phase power supply based on a system of electrical and magnetic equations will be recalled. This will allow establishing an electrical equivalent model. The simulation with Matlab-Simulink will validate the correct electrical operation of this new three-phase power supply.

Secondly, different electrical parameters will be investigated by using Matlab-Simulink code to study the energy balance of the new three phase power supply. The results for currents and voltages in each phase, obtained by simulation, allow calculating the different powers. The obtained power curves were compared with those obtained experimentally for the single-phase power supply in the same conditions [4].

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II. Energy Balance of the Single-Phase Power Supply for Microwave Generator

Figs. 1 and 2 show a basic setup and an electrical model of high voltage power supply for one magnetron of a microwave generator used by almost all manufacturers of microwave ovens (Moulinex, Phillips, Toshiba, etc.). In the majority of domestic and industrial applications, this setup uses a single-phase high voltage transformer supplying a cell doubler of voltage, composed of a capacitor and a diode. This cell supplies one magnetron. A comparative study between the powers obtained using the equivalent electrical model of the single-phase transformer (Fig. 1) and those obtained by the experimental setup (Fig. 2) was performed. The obtained results will allow to validate the energetic operation of the new three-phase power supply.

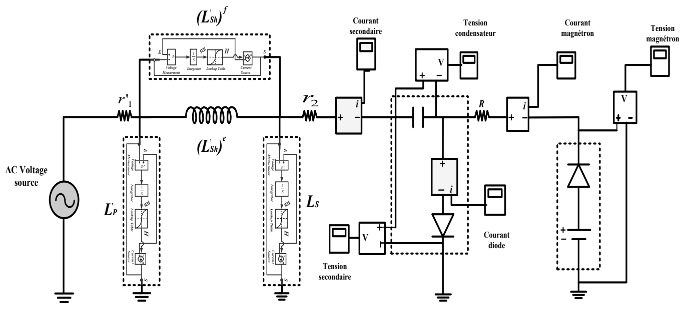

Fig. 1. Power supply model under Matlab-Simulink [5]

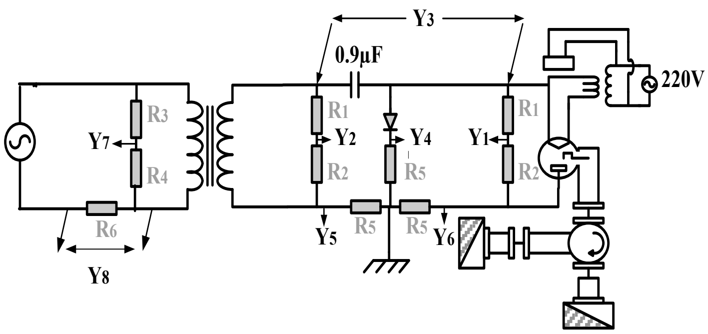

Fig. 2. Experimental setup used for voltage and currents measurements

The theoretical and experimental values of voltages and currents were used to calculate the following powers:

- Input power of the transformer.
- Output power of the transformer.
- Input power of the magnetron or anodic power.

The power measurements were performed according to the setup from the Fig. 1. The voltage measurement was performed using a digital oscilloscope. The obtained results have been compared with those obtained by simulation for the setup presented in Fig. 2. Those results are shown in Fig. 3.

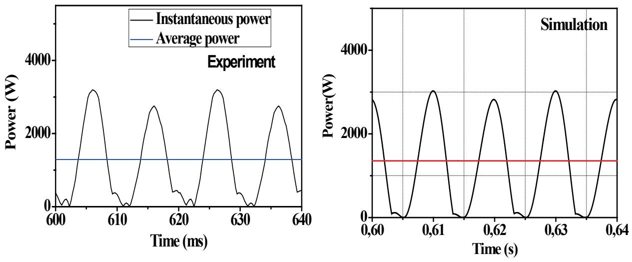

Fig. 3. Input power of the transformer

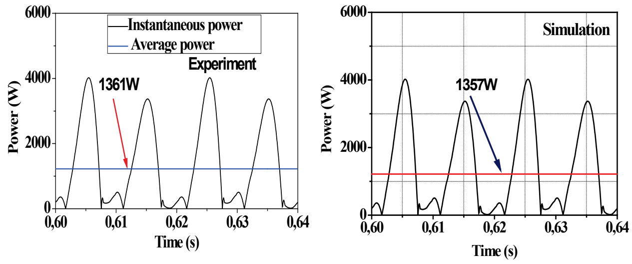

Fig. 4. Output power of the transformer

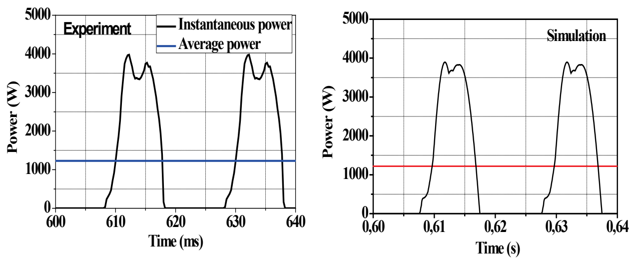

Fig. 5. Input anodic power of the magnetron

The power values (Figs. 3, 4 and 5) obtained by simulation using Matlab-Simulnk and the experimental setup showed a good correlation. This confirms the validity of the electric model of the single-phase power supply used for microwave generator. The average power at the input of the magnetron is 1200 W. This value is in accordance with the recommendations indicated in the data sheet for a full power magnetron operation [6-8].

The experimental and simulation powers values obtained for the classical single-phase power supply will be used to calculate the efficiencies:

$$\eta_{Experiment} = \frac{1200+40}{1360} = \frac{1260}{1360} = 0{,}91$$

$$\eta_{Simulation} = \frac{1198+40}{1357} = \frac{1238}{1357} = 0{,}911$$

The value of 40 W is added to the average power because of the magnetron cathode filament heating.

III. Modeling of the new Three-Phase Power Supply for one Magnetron per Phase (Remind)

During the modeling of an ordinary three-phase block, it was sufficient to develop a model of just one phase and then to generalize results for the remaining two. For the new high voltage (HV) three phase transformer with shunts, it is necessary that each phase be modeled taking into account the common circuit between the phases (A-B) and (B-C), [9-10].

A. Magnetic Circuit of the Three-Phase Transformer with Shunt

The Fig. 6 shows the magnetic circuit of the transformer, the three phases are named A, B and C. The capital letters (A, B and C) are used for primary parameters, while the secondary values are denoted with lowercase letters (a, b and c).

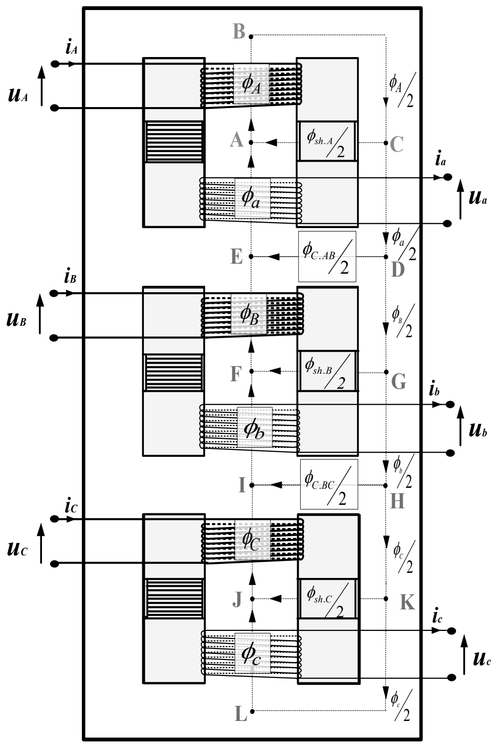

Fig. 6. Magnetic circuit of the new three phase transformer with shunts

The circuit parameters are:

- 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).

B. Modeling of the Three-Phase Transformer with Shunt

Magnetic equations (phase A, B and C)

Applying the Hopkinson law on the different contours for all three phases A, B, and C, the following system of equations is obtained:

$$i'_{P.A} + i'_{sh.A} = i'_A \quad (1)$$

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

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

$$i'_B + i'_{C.AB} = i'_{P.B} + i'_{sh.B} \quad (4)$$

$$i'_{sh.B} = i_{s.b} + i_b + i'_{C.BC} \quad (5)$$

$$\frac{d}{dt}(L'_{P.B} i'_{P.B}) = \frac{d}{dt}(L_{s.b} i_{s.b}) + \frac{d}{dt}(L'_{sh.B} i'_{sh.B}) \quad (6)$$

$$i'_C + i'_{C.BC} = i'_{P.C} + i'_{sh.C} \quad (7)$$

$$i'_{sh.C} = i_{s.c} + i_c \quad (8)$$

$$\frac{d}{dt}(L'_{P.C} i'_{P.C}) = \frac{d}{dt}(L_{s.c} i_{s.c}) + \frac{d}{dt}(L'_{sh.C} i'_{sh.C}) \quad (9)$$

Electrical equations (phases A, B and C)

Using Ohm's law to the primary and secondary of each phase A, B and C lead to the following electrical equations [11-14]:

$$u'_A = r'_A i'_A + \frac{d}{dt}(L'_{P.A} i'_{P.A}) \quad (10)$$

$$u_a = -r_a i_a + \frac{d}{dt}(L_{s.a} i_{s.a}) \quad (11)$$

$$u'_B = r'_B i'_B + \frac{d}{dt}(L'_{P.B} i'_{P.B}) \quad (12)$$

$$u_b = -r_b i_b + \frac{d}{dt}(L_{s.b} i_{s.b}) \quad (13)$$

$$u'_C = r'_C i'_C + \frac{d}{dt}(L'_{P.C} i'_{P.C}) \quad (14)$$

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

Using those equations and applying the nodes law in the points D and H from Fig. 6, the following system of equations is formed:

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

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

The electric and magnetic equations (1-17) obtained during the modelling of phases A, B and C, allowed us to find a global electrical model referred to the secondary of the new three phase transformer with shunts (Fig. 7), [11-16].

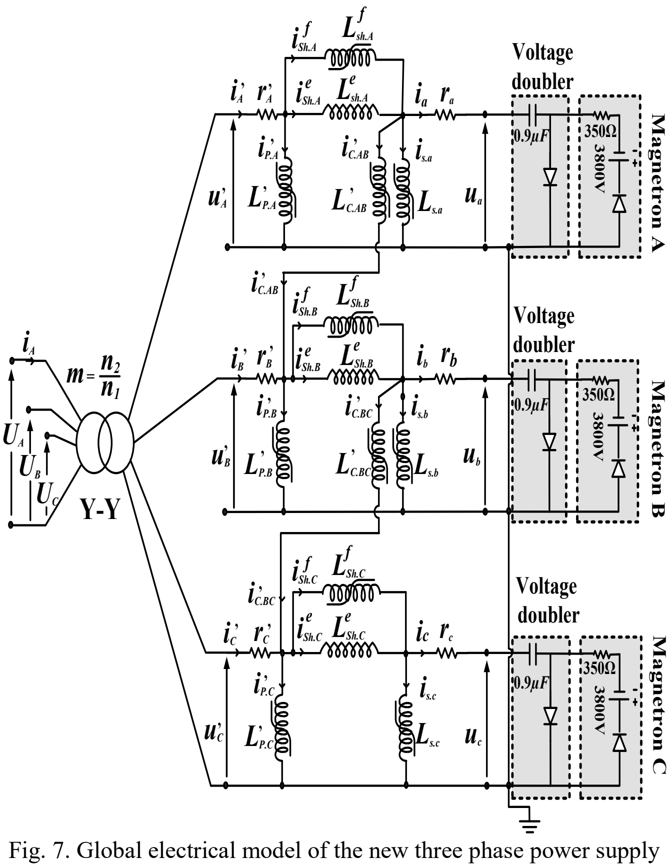

Fig. 7. Global electrical model of the new three phase power supply for one magnetron per phase (star-star connection)

C. *Equivalent Model under Matlab-Simulink*

The simulation study of electrical functioning of this new device (Fig. 8) was performed with a new three-phase transformer, which is correctly sized and supposed to be shown on its nameplate characteristics Y V/Y V : 220/2200, f= 50Hz/3ph., 3 × 1650 = 4950V A.

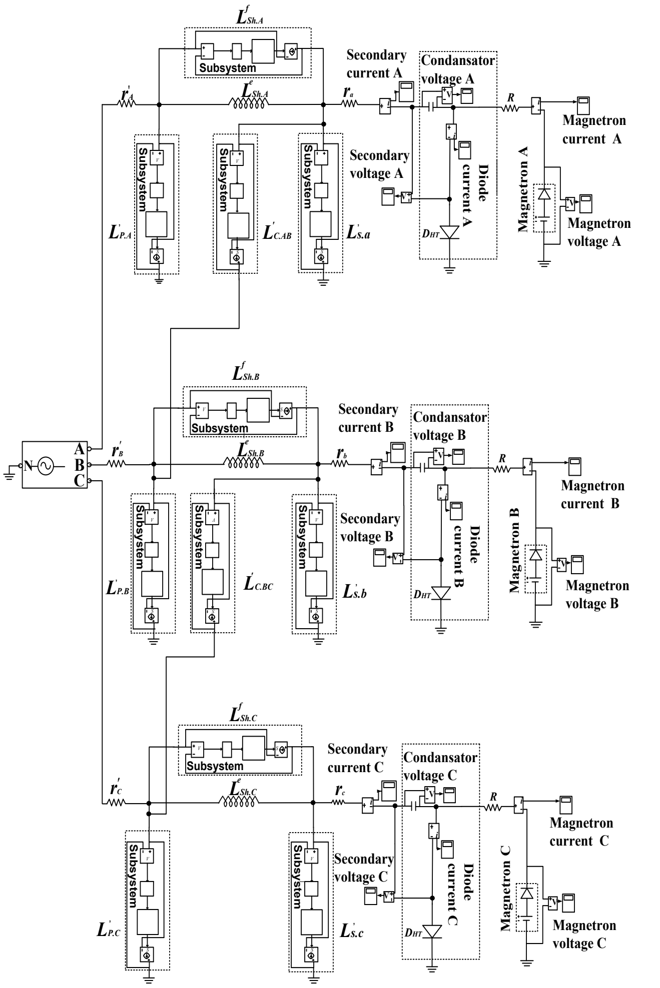

Fig. 8. Global electrical model of the new three phase power supply for one magnetron per phase under Matlab-Simulink

IV. Energy Balance of the new Three Phase High Voltage Power Supply for one Magnetron per Phase

The established model of the new three-phase power supply (Fig 8), allowed to extend an energy study of each phase (A, B and C).

The input and output powers for each phase are determined as follow:

- Input power curves of three-phase power supply are shown in Fig. 9 for each phase (A, B and C) using values for primary current and primary voltage.

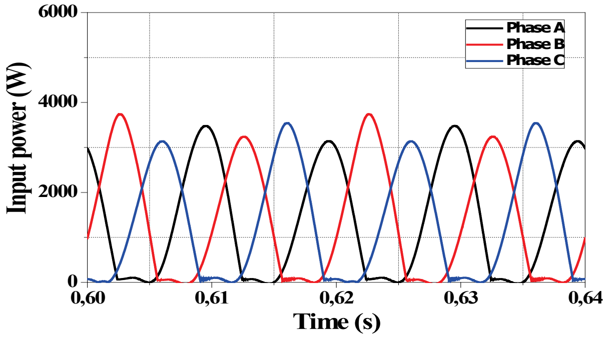

Fig. 9. Instantaneous powers on the input transformer for each phase A, B and C

- Output power curves of three-phase transformer are presented in Fig. 10 following the same procedure. The curves for the secondary voltage and secondary current are obtained by simulation. That enables to find the instantaneous output power of the three-phase transformer, as given in Fig. 10.

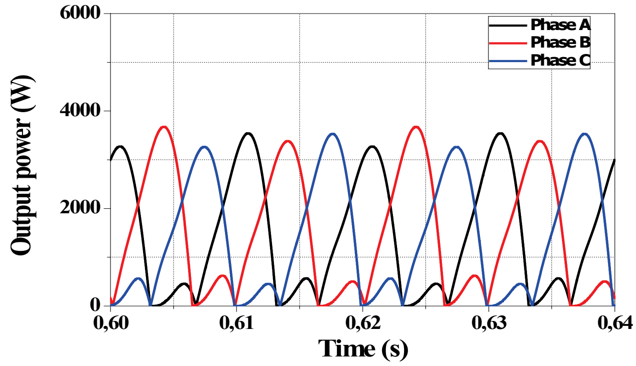

Fig. 10. Instantaneous power of the output three phase transformer

- Input power of each magnetron or anode power can be calculated using the point-by-point product of the current and voltage of magnetron input. In that way it is possible to determine an instantaneous power and average power of the magnetron in each phase (A, B and C), as shown in Fig. 11.

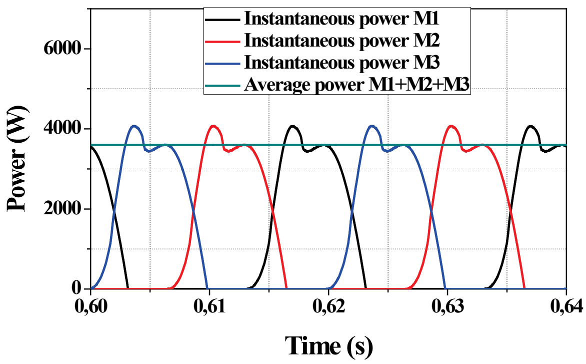

Fig. 11. Input power of the magnetron or anodic power

The power curves results obtained by Matlab-Simulink and presented in Figs. 9-11 show that the powers of the phases A, B and C, obtained using theoretical approach, are in close agreement with those obtained by experimental setup from the Fig. 2. This confirms that the operation of a three-phase power supply of one magnetron per phase is similar to that of a conventional single-phase power supply of a magnetron. This proves that the two systems (single-phase and three-phase) work well in nominal mode and proving that each magnetron delivers its full useful microwave power.

Table 1 shows the values of the different average powers found during the simulation of the electrical operation of the new three-phase power supply studied by one magnetron per phase. For the output power of the secondary side of the transformer, was added 40 W for the heating of magnetron cathode filament (13A at 3.15V).

TABLE 1
POWERS PRESENTATION OF EACH PHASE A, B AND C

	Phase A	Phase B	Phase C
Input power of the transformer - primary	1364W	1365 W	1363 W
Output power of the secondary transformer, + 40W	1290 W	1292W	1285 W
Overall power at the transformer output	1330 W	1332 W	1325 W
Magnetron power	1260 W	1266 W	1264 W
Performance η	0,923	0,927	0,927
Average performance	0,925		

The average performances are 0,925 and 0,911 for the new three phase power supply for each phase and the single-phase power supply, respectively. So, the error rate ε between these two parameters can be calculated as:

$$\varepsilon(\%) = \frac{\eta_{three} - \eta_{\sin g-ph}}{\left(\frac{\eta_{three} + \eta_{\sin g-ph}}{2}\right)}$$

$$\varepsilon(\%) = \frac{0{,}925 - 0{,}911}{\left(\frac{0{,}925 + 0{,}911}{2}\right)} = 0{,}015(1{,}5\%)$$

This confirms that the operation of this new three-phase power supply is identical to the classical single-phase power supply of a magnetron. This justify that both systems (single and three-phase power supplies) operate well in nominal mode providing that each magnetron delivers its full microwave power output.

V. CONCLUSION

In this paper, the developed single-phase system allowed a comparative study of electrical operation for magnetron power supply. The Matlab results are successfully validated with those obtained experimentally. This will make it possible to understanding the complex operating of this special transformer with shunts.

In this study, the energetic operation of the new three phase power supply was successfully verified. The obtained curves for the different powers of each phase showed that each magnetron can operate with the full power. These results lead to the prototype realization of this new three-phase transformer with shunt.

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