

# Optimization of a New Three-Phase High Voltage Power Supply for Industrial Microwaves Generators with N Magnetrons by Phase (Treated Case N=1)

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**Abstract**—Currently, the High voltage power supply for microwave generators with one magnetron uses a single-phase transformer with magnetic shunt. To contribute in the development of technological innovation in industry of manufacturing of power supplies of magnetrons for microwaves, ovens for domestic or industrial use, this original work treats the optimization of a new three-phase high voltage power supply for industrial microwaves generators with N magnetrons by phase (Treated case N=1), from its modeling with Matlab-Simulink. The design of this power supply uses three  $\pi$  quadruple models equivalents of new three-phase transformer with magnetic shunt of each phase. Every one supplies at its output a voltage doubler cell composed of a capacitor and a diode that in its output supplies only one magnetron.

In this work we will define a strategy that aims to reduce the volume of the transformer and the weight and cost of the entire system of the high voltage power supply, while respecting the conditions recommended by the manufacturer, concerning the current flowing in each magnetron: ( $I_{max} < 1.2$  A,  $I_{Av} \approx 300$  mA).

**Keywords**—Optimization, Three-phase transformer, Modeling, power supply, magnetrons, Matlab Simulink, High Voltage

## I. INTRODUCTION

**B**UILDING on previous studies on the modeling and optimization [3], [5], [6], [9] of high voltage power supply for microwave generators with several magnetrons, this work treats the optimization of a new three phase high voltage power supply for industrial microwaves generators with one magnetron 800 Watts-2450 MHz by phase, this optimization is based essentially to study the modeling of the three-phase transformer with magnetic shunt.

This work is divided in two parts. In the first one we will present the equivalent model [13], [14] of this new three-phase transformer with magnetic shunts. This model will be integrated into the overall scheme of the power supply, to be suitable for the modeling and optimization of the whole

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device, using numerical simulation software MATLAB SIMULINK.

In a second part, we will define a strategy that aims to minimize the volume of transformer; it's based on the study of the influence of each geometric parameter on the electric functioning of the power supply. Then we will validate the nominal functioning of the new transformer, on the basis of the selected solution from optimization.

## II. MODELING OF THE NEW THREE-PHASE HIGH VOLTAGE POWER SUPPLY FOR ONE MAGNETRON BY PHASE

### A. Description of the Model

The modeling of this new generation of power for magnetrons is already developed [13]-[15]; its passes necessarily by the modeling and dimensioning of its own new three-phase HV power transformer with magnetic shunts. This transformer is an assembly of three single-phase transformers (Fig. 1). Each column represents a transformer having  $n_1$  turns in primary and  $n_2$  turns in secondary.

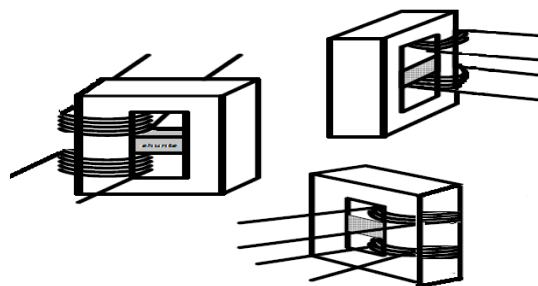


Fig. 1 Equivalent circuit of three-phase transformers with magnetic shunts

These three single-phase transformers can be combined in order to create a single central column consequently (Fig. 2). Each phase of the three-phase transformer behaves as a single-phase transformer.

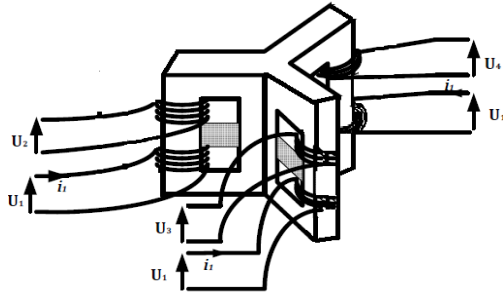


Fig. 2 Form of magnetic circuit diagram tetrahedron type of the new three-phase transformer with magnetic shunts

The three-phase HV transformer is presented by its equivalent scheme referred to secondary. Everything happens as if each phases of the new three-phase HV transformer with magnetic shunts, is composed of three ideal transformers; each one supplying a quadruple  $\pi$  [7], [8] composed of inductive elements  $L_p$  et  $L_{COM}$  on the primary side, and  $L_S$  et  $L_{com}$  on the secondary side and  $L_{Sh}$  on the shunts side. Fig. 3 shows the integration of the equivalent scheme in  $\pi$  of the new three-phase transformer in the power supply from the source to the magnetron.

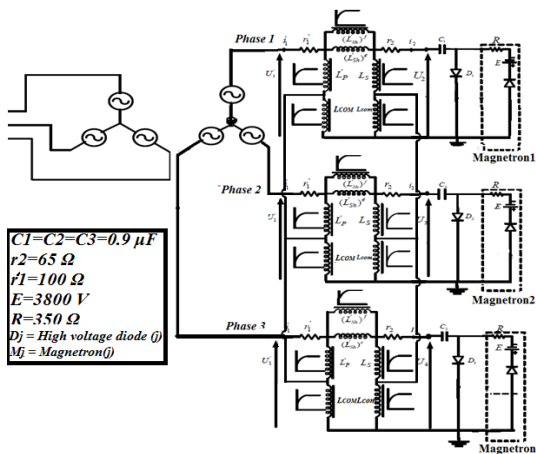


Fig. 3 New quadruple model of three-phase transformer supplying one magnetron by phase

The five non linear inductive elements [1], [2], [4]  $L_p$ ,  $L_{COM}$ ,  $L_S$ ,  $L_{com}$  and  $L_{Sh}$  of the studied model in Fig. 2 are function of the magnetic circuit portion, with a section  $S$  and average length  $l$ . Each one is represented by its characteristic  $\Phi(i)$  according to the relation  $L(i) = n^2\Phi(i) / i$  where the quantity  $n^2\Phi(i)$  and its currents  $i$  can be determined from the curve  $B(H)$  of the material used and the geometrical dimensions of the transformer used as reference(see Appendix) using the relation:  $n^2*\Phi(i)=n^2*B*S$  and  $i=(H*l)/n^2$ .

*B. Simulation Results of the Nominal Functioning of the New Three-Phase Power Supply One Magnetron by Phase*

In this new three-phase high voltage power with one magnetron by phase, we have connected in star three identical

quadruple models of three identical single phase transformer with magnetic shunts and supplied respectively by three-phase Voltages dephasing by  $(2\pi/3)$  between them. By using Matlab Simulink code, we have simulated the nominal electrical behavior of this New Three-Phase Power Supply circuit with one Magnetron by Phase used as reference. Figs. 4 (a) and (b) show the oscillograms obtained from this simulation.

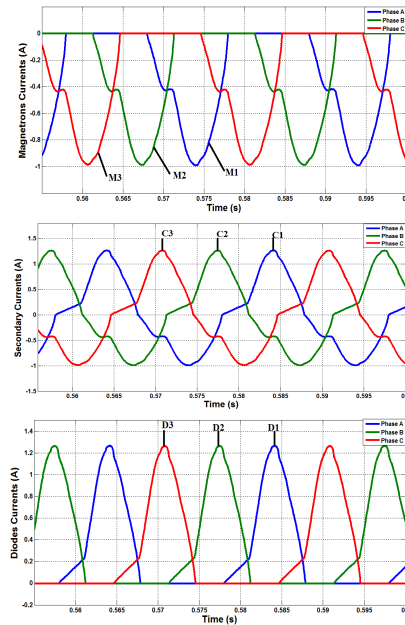


Fig 4 (a) Simulation with Matlab-Simulink: Forms of currents waves

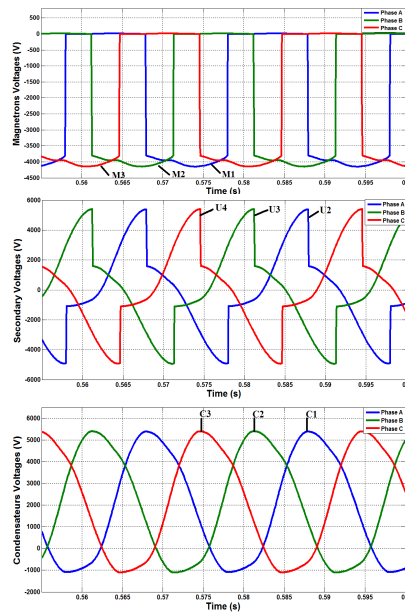


Fig 4 (b) Simulation with Matlab simulink: Forms of voltages waves

The electrical signals obtained (current in magnetrons ( $M_1$ ,  $M_2$ ,  $M_3$ ), voltages across each magnetron ( $M_1$ ,  $M_2$ ,  $M_3$ ),

current in the capacitors ( $C_1$ ,  $C_2$ ,  $C_3$ ), voltages across the secondary of the model of the transformer ( $U_2$ ,  $U_3$ ,  $U_4$ ), voltages across each capacitors ( $C_1$ ,  $C_2$ ,  $C_3$ ) and currents in the diodes ( $D_1$ ,  $D_2$ ,  $D_3$ ), are curves of various sizes, periodic and non-sinusoidal dephasing of ( $2\pi/3$ ) between them. These signals have the same form as those of a conventional power supply using a single phase transformer for one magnetron. We note that the maximum current in each magnetron does not exceed limit imposed by manufacturer ( $I_{max} < 1.2A$ ).

Unlike research done in this topic, the stabilizing effect of the current in each magnetron has been conclusively verified (Fig. 5), by observing, with Matlab-Simulink code, the evolution of the current in each magnetron relative to the variations of primary voltage of  $\pm 20V$ .

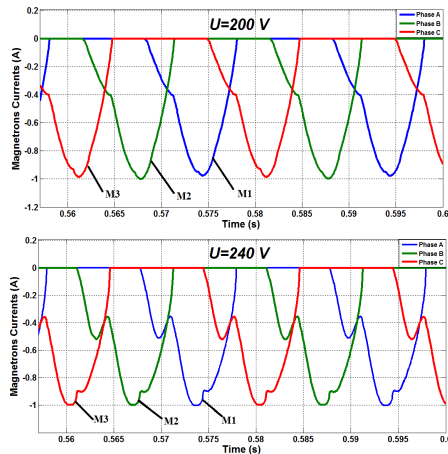


Fig. 5 Stabilization of the magnetron current relative to the variation of section voltage of  $\pm 20V$  of the nominal voltage

### III. OPTIMIZATION OF THE NEW THREE-PHASE HIGH VOLTAGE POWER SUPPLY FOR ONE MAGNETRON BY PHASE

#### A. Principle of Optimization

Based on previous studies concerning the optimization of single phase power supply for several magnetrons [10]-[12], our principle of optimization is to use essentially the equivalent model quadruple in  $\pi$ , of the new three-phase transformer; by using Matlab Simulink code to highlight compared to the reference case (see appendix) the sensitivity of the magnetron current, due to variations of one or more geometric parameters. To do this, we perform a set of simulations in which we seek the following objectives:

The first is to show the influence of the variation of a single geometric parameter of the transformer on the magnetron current; other parameters remaining unchanged. The geometric parameters of the transformer considered variables are:

- The size of the magnetic circuit  $a$  (mm).
- The number of secondary turns  $n_2$
- The size of the shunts materialized by  $n_3$
- The width of the air gap  $e$  (mm).

- The quality of magnetic plates

The second objective is to define a strategy that aims to reduce the volume of transformer, based on the simultaneous variation of the geometrical parameters.

#### B. Influence of Different Geometric Parameters

Table I shows the variation range of each parameter of the three-phase transformer.

TABLE I  
VARIATION RANGE OF THE PARAMETER

Name of the parameter	Rating values
$a$ : width of the core unwound(mm)	$15 < a < 25$
$n_2$ : number of secondary turns	$2300 < n_2 < 2500$
$n_3$ : number of stacked sheets of each shunt	$10 < n_3 < 18$
$e$ : thickness of the air-gap(mm)	$0.55 < e < 0.95$
$B(H)$ : magnetic quality of the material	SF19,S91,AFK502

By using the Matlab Simulink code and varying the reference parameters in the ranges indicated in the Table I. In each simulation, we observe the waveforms of different electrical parameters of the circuit HT especially those giving the shape of the current magnetrons, noting each time the maximum and average values. Fig. 6 shows the results of variation of the average and maximum current values according to the parameter of the transformer.

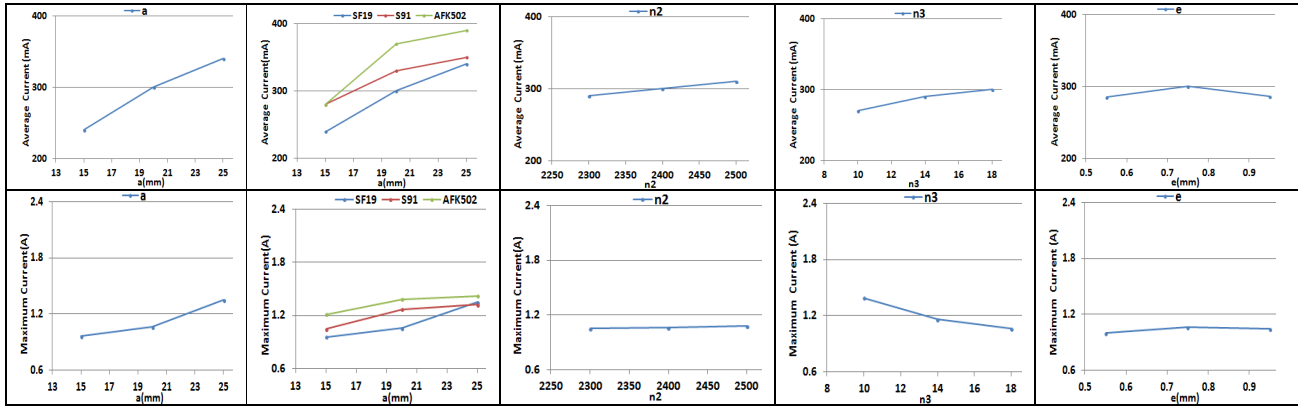


Fig. 6 Simulation results of the magnetron current according to geometric parameters of the transformer

From the results obtained, we note that the variation of the geometric parameters changes the behavior of the circuit high voltage power, which allows as defining a strategy to reducing the volume of iron and copper of the transformer, so that of the entire system respecting the conditions imposed by the manufacturer.

*C. Optimization of Three-Phase Transformer with Magnetic Shunts*

From the results obtained in the previous paragraph which show the sensitivity of the magnetron current, towards the variations of the different geometric parameters of the new

transformer. We defined a strategy based on the study of the simultaneous influence of more than one parameter, by minimizing in the same time the width of the core unwound 'a', number of secondary turns 'n2', number of stacked sheets of each shunt 'n3' and thickness of the air-gap 'e'. This leads to a minimum of the volume of the transformer.

Using Matlab Simulink code and the equivalent model quadruple in  $\pi$ , of the new three-phase transformer, we simulated the behavior of the HV circuit of different possible configuration of parameters (Fig. 7).

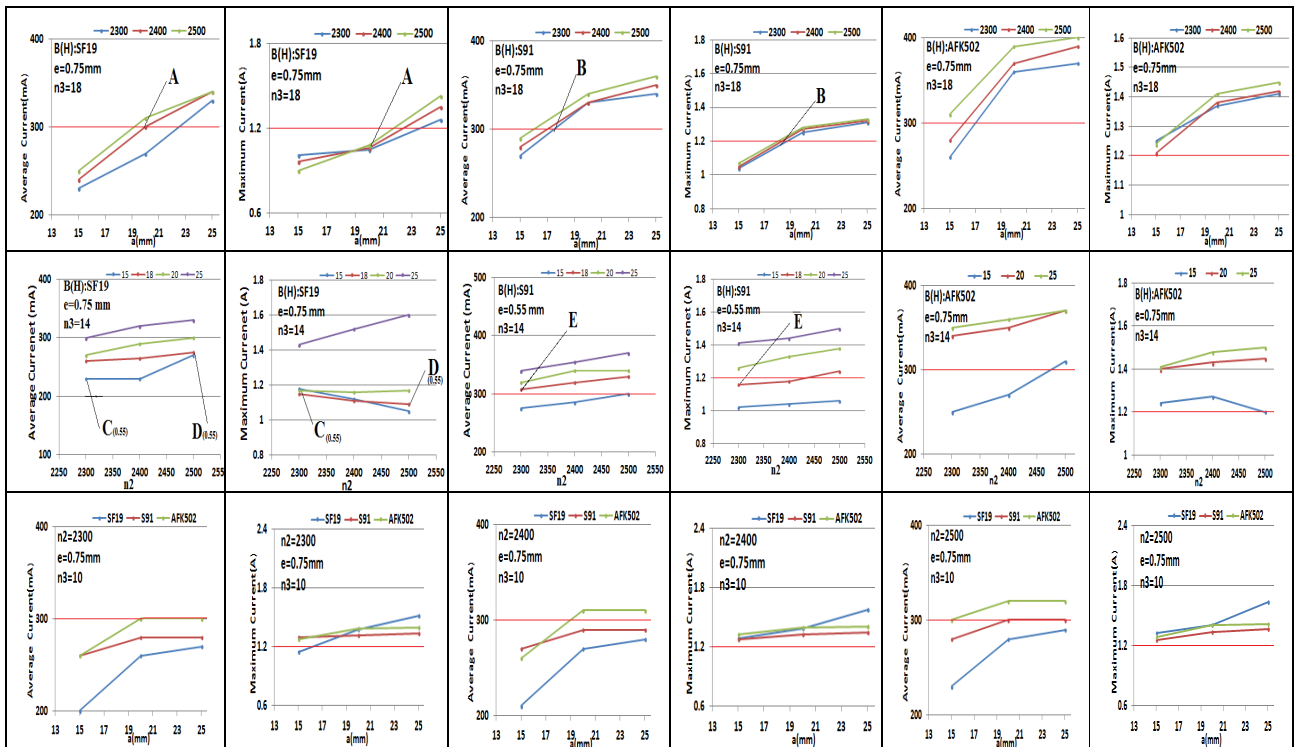


Fig. 7 Network of obtained curves

Fig. 7 presents the different selected solutions that meet the criteria imposed by the manufacturer. The choice of the optimal solution must be validated by calculating the volume

of the total volume (Iron + Copper). Table II summarizes the selected solutions from the network curves obtained.

TABLE II  
POSSIBLE SOLUTIONS OF PARAMETER SETTINGS THAT RESPECT THE NORMS IMPOSED BY MANUFACTURER

Name of solution	B(H)	a (mm)	$n_2$	$n_3$	e (mm)	$I_{av}$ (mA)	$I_{max}$ (A)	V (cm <sup>3</sup> )
A(Ref)	SF19	20	2400	18	0.75	228	0.99	1509
B	SF19	20	2300	14	0.75	280	1.17	1487
C	SF19	15	2300	14	0.55	230	0.98	879.6
D	SF19	18	2500	14	0.55	280	1.02	1235
E	S91	18	2500	14	0.55	308	1.16	1235

From the table we find that the D solution simultaneously, presents the best compromise between the operation of the magnetron ( $I_{max}=1.02(A)$  and  $I_{av}=280mA$ ) and the volume of iron and copper of the transformer. We note that the solution C presents a minimum volume but it does not allow a functioning of the magnetron in full power ( $I_{max}=0.98(A)$  and  $I_{av}=230(mA)$ ).

By using the geometric parameters of the transformer of the adapted D solution, we simulated under Matlab Simulink code the electrical behavior of the new three-phase high voltage power. Figs. 8 (a) and (b) show the waveforms of voltages and currents obtained.

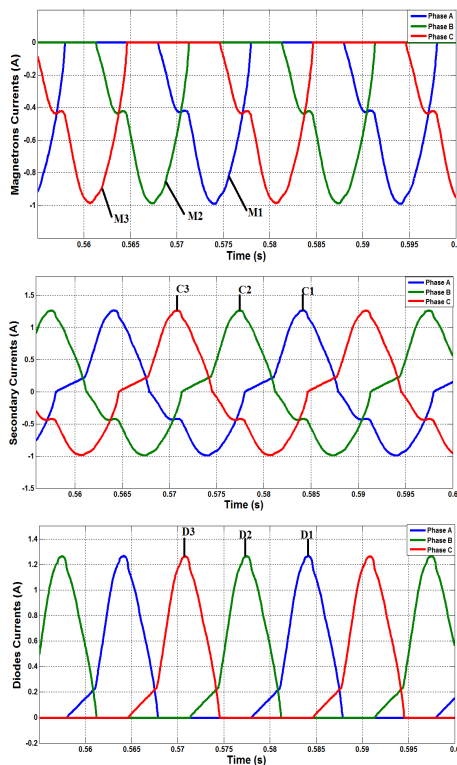


Fig. 8 (a) Waveforms of currents corresponding to the chosen solution D

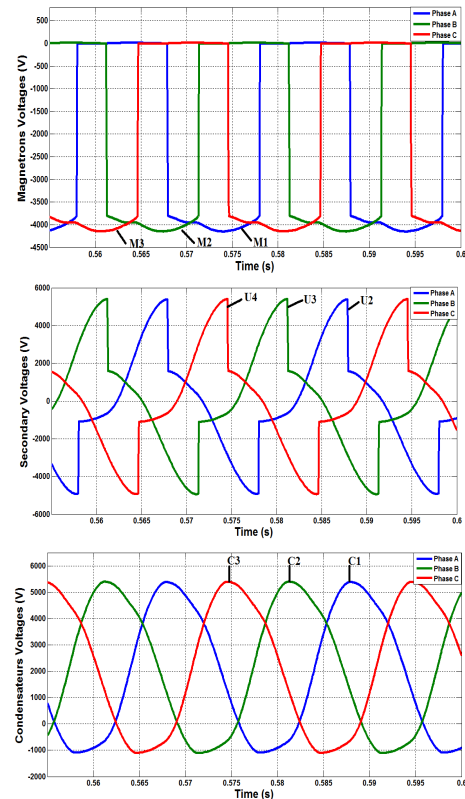


Fig. 8 (b) Waveforms of voltages corresponding to the chosen solution D

From Figs. 8 (a) and (b) we observe that the waveforms corresponding to the solution D are in perfect accordance with those obtained by the reference case.

Fig. 9 shows the evolution of the magnetron currents relative to variations of primary effective voltage of 20V, we observe that the stabilizing effect is checked up for D solution.

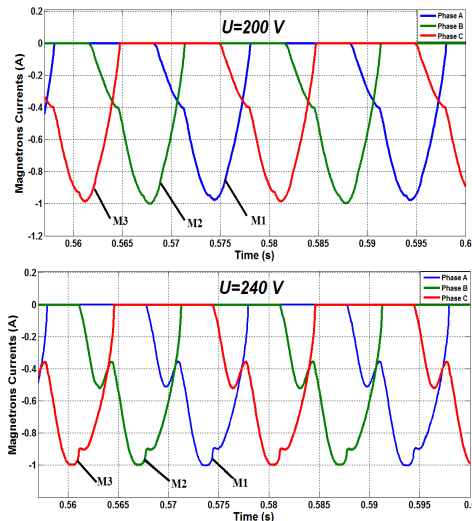


Fig. 9 Stabilization of the magnetrons currents relative to variation 10% of the nominal voltage in primary corresponding to D solution

#### IV. CONCLUSION

We have defined a strategy for optimizing the geometry of the new three-phase transformer using MATLAB SIMULINK code. This strategy allows as reducing the volume of the transformer and the weight and cost of the entire system of the HV power supply.

From this optimization, we can therefore make the new three-phase transformer with magnetic shunts for a new HV optimized power for Industrial Microwaves Generators with one Magnetron by Phase.

As perspectives, this work can be extended for modeling and optimization of new three-phase or six-phase power supply for several magnetrons by phase.

#### APPENDIX

In this work, we have taken as reference the following geometrical dimensions of the three-phase transformer HV with magnetic shunts:

- The width of the non-wound core:  $a = 20\text{mm}$
- The width of the magnetic circuit:  $b = 120\text{mm}$
- Number of stacked sheets of the shunt:  $n_3 = 18$
- Number of turns in the primary:  $n_1 = 224$
- Number of secondary turns:  $n_2 = 2400$
- Height of the sheet stack of shunts:  $h = 0.5 n_3$ .
- Surface of the core:  $S_1 = S_2 = a \cdot b$
- Surface of shunt:  $S_3 = b \cdot h$
- Thickness of the air gap:  $e = 0.75\text{mm}$

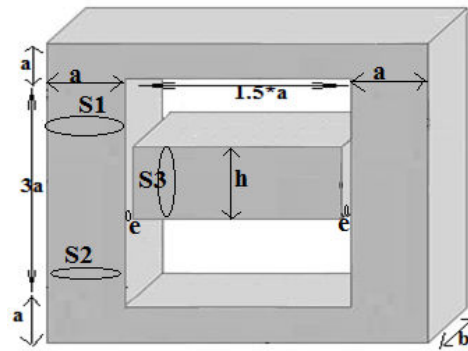


Fig. 10 geometry of transformer with magnetic shunt (Phase 1 as example)

#### ACKNOWLEDGMENT

B: Magnetic flux density

H: Magnetic field

HV: High voltage

L'P: Primary inductance referred to secondary

LS: Secondary inductance

(L'Sh): Equivalent inductance in the shunts referred to secondary

LCOM, Lcom: the common inductances between the three phase.

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His research is interested in the " Study of the energy balance of a new high voltage power supply N magnetrons per phase 800 Watts - 2450 MHz for microwave generators used in industrial applications".

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