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Research Article

A Novel Improved Stable Power Supply Optimized Model Intended to Industrial Appliances for Low Power Magnetrons

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Abstract

The purpose of this paper investigated a new improved optimized three-phase Magnetic Flux Leakage Transformer (MFLT) comprising a magnetic circuit of the core-type, intended to supply a magnetron. The new system is able to supplying electrical energy to the power circuits of microwave ovens. The advantages of this system are for stabilizing currents in electrical equipment power supplies, especially in the case of high voltage (HV) power supplies. In this paper, a novel proposition to a new iron core structure, which aim to supply many devices in same time, is presented. Thereafter, this new model affords a stabilized changes after a drastic state in the load or the voltage of the supply network. An approach is proposed to model the electric circuit of the Core-Type Transformer (CTT). The duality of the electric circuit and the magnetic circuit gives the model of the design and construction characteristics for the transformer. Therefore, a detailed circuit analysis using a reluctance network method is given, thereby its performance is evaluated for an 800W/2450MHZ magnetron. At last, a developed method describes a method for modeling nonlinear inductances by analytical expressions under the MATLAB SIMULINK® code. It is derived by analytical fitting of a nonlinear B-H curve. As a result, the waveform simulations agree with the experiments in the case of conventional power supplies used in microwave ovens. The following sections describe the detailed design and implementation process, including the design of the new power supply.

Keywords: Microwave ovens, Modelling, Optimization, Magnetron, Power supply

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1. Introduction

The development of domestic microwave ovens has very quickly outstripped, industrial uses for the past thirty years. Recent research [1-5] are thinking about new industrial microwave systems that adopted microwave heat treatment technology [6]. A magnetic leakage flux transformer (MFLT) is often existing in microwave ovens [7-8]. MFLT has a special structure and wide applications, it performs a voltage transformation, stabilize the voltage, it can improve the efficiency, decrease the vibration and noise, and save the energy, unlike the ordinary transformer.

In conventional power supply system [8], a shell-type transformer are often used. The proposed of this study is to develop a new core-type three-phase, which ensure the same function to feed the voltage to the necessary level required by the magnetron load. This model consists of two concentric windings per phase. These windings are mounted on a ferromagnetic core which closes at its ends via cylinder heads generally of circular sections in order to ensure a good channeling of the flow magnetic. In this technology, it is the windings which surround the magnetic circuit. The main advantage of using this proposed design is present an easy design and construction, has low mechanical resistance in reason for the non-bracing of the windings [9-11], the set can be easily removed mounted for repair work, present a better heat dissipation of the windings and best suited for EHV (Extra High Voltage) requirements. Unlike to shell-type transformer, which preset a high mechanical resistance, it cannot be easily disassembled for work repair, the heat does not dissipate easily windings as it is surrounded by core and it is not suitable for EHV (Extra High Tension) [12].

The previous works [13-16] are interested to a shell-type transformer composed of two magnetics stack shunts. The new model are equipped with a single shunt instead of two shunts. Detailed descriptions of transformer construction and operation will present in the following sections.

We are based in this special model on modelling of the simultaneous analysis of both electric-magnetic lumped component equivalents circuits using principle of duality. A precise system model is established to achieve accurate and effective analysis and design. Hence the π model of the MFLT was implemented in MATLAB-Simulink environment. Based on non-linear model with the technical look up table (LUT). It took into account the saturation phenomena. The iron loss due to the hysteresis and eddy currents were not including.

2. Description of System Design

The CTT (Figure 1) is a common structure for stable power applications, first and foremost. The three single-phase transformers are superimposed to create the design, and all three phases cores and windings are combined into a single core structure. The core is SF_{19}, which has an E-I type structure and a nonlinear feature. A line voltage main

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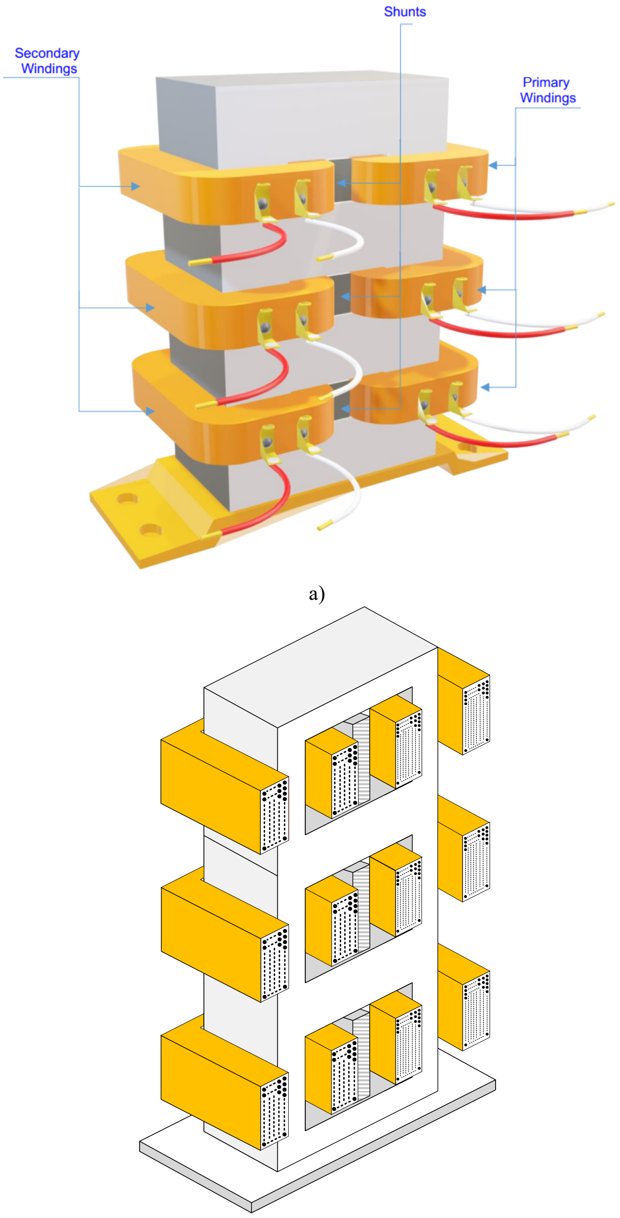
winding, a high voltage secondary winding, and a low voltage filament winding are the three independent windings that typically make up a CTT. The latter winding may be deleted from this operation because it is no longer necessary. The outermost core columns are wound using the primary and secondary windings. Only one shunt made of silicon steel sheets is present for each phase, and there are three vertical shunts in total.



a)

b)

Fig. 1. Investigated shapes of three-phase magnetic flux leakage transformer (a)Geometry and b)dimensions)

2.1. Power generator

Fig. 2 shows a basic power block diagram for the power supply. The primary winding of each phase is directly connected to the AC voltage power. The high voltage capacitor, in conjunction with the diode, forms a voltage doubler rectifier circuit, which boosts the voltage at the magnetron to almost 4000V DC. The design of magnetron consists of the filament supply with low voltage 3.3 V/12A Alternating current (AC) power supply to heat the filament of magnetron by flowing current through it, and a separate high voltage -4kV/0.66A Direct Current (DC) power supply provides bias to the cathode. The secondary winding provides high voltage for the magnetron anode and ensures the stabilization of the average anode current (I_{averg}= 300mA) due to the saturation of its magnetic circuit. The anode voltage must be large enough to activate the magnetron. Moreover, if the anode voltage fluctuates, the anode current changes distinctly, even making the magnetron stop working. Thus, it is clear that the power supply must have some form of regulation that stabilizes the power output of the magnetron.

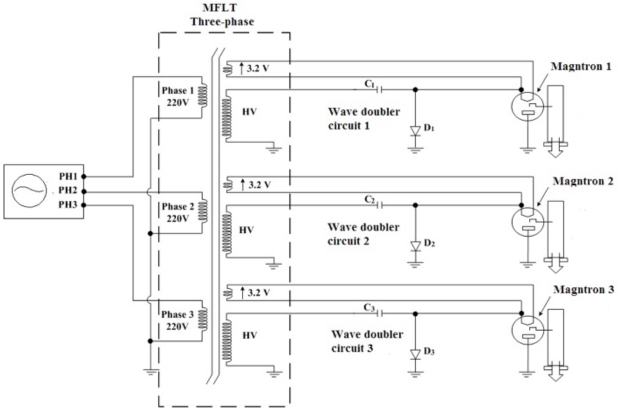


Fig. 2. Scheme of the three-phase HV power supply of a magnetron per phase.

3. MFLT Design Optimization Technique

In this section, we propose an optimization approach [17], it is represented and studied in a very detailed way the optimal design of high voltage transformer with magnetic shunts of the type CTT. It is the most important and expensive component used in microwave power systems. In fact, its optimal design requires the identification of construction variables in order to optimize specific objectives and meet a range of constraints. Good transformer design meets certain functions and requirements, which depend on input and are divided into optimal variables. Then, each variable changes within a certain interval, defining the global search space in which we seek the best solutions. Constraints: The maximum and average current of the magnetic field anode is part of the problem of limiting the global search space. Under parameter constraints, the problem is expressed as follows:

Minimize (or maximize) f(X) $X_j^l < X < X_j^u, \quad i = 1...n$

Where X presents the vector of transformer parameter, f(x) is the objective function to be minimized or maximized, $x_j^l$and x_j^u are lower and upper bound of j-th parameter Xj.

Optimization finds the most economical choice, thus the best possible optimal design. While satisfying any limitations or constraints imposed to his performance. Several techniques have progressed over the centuries to find the optimal solution [18, 19]. Some of them traditionally rely on mathematical formulation [20-25], and others on non-traditional techniques [26–33]. He This results in volume reduction, better material utilization, space saving and waste reduction, thus minimum cost. In the case of our transformer, we looked at several aspects of transformer design, such as core shape, size, copper wire properties and rotation, etc. . .

3.1. Main Steps in Three Phase Transformer Design Process

This section aims to describe the general design approach, which aims to give the dimensions and characteristics of one or more transformers respecting the imposed specifications. The design process can be summarized in the flowchart in Figure 3, presenting the main stages. This method uses different physical models. Other models are also added to this approach, such as price, reliability, mass, losses, etc. . .. The implementation of an optimization loop on this design approach must agree to keep reasonable calculation times. With this in mind, it is preferable to use models of the analytical type..

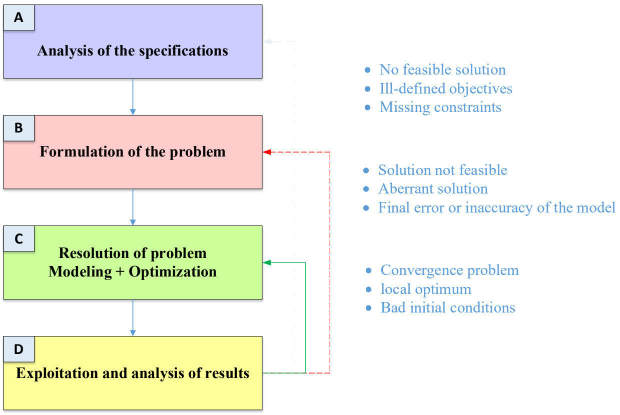


Fig. 3. Flowchart overall optimized transformer design process

The first approach (A and B) consists in formatting the specifications of a specification by means of a mathematical formalism. The objective of optimization is generally expressed by means of an objective function that is sought to minimize or maximize. The constraints of the specifications are expressed as equalities or inequalities, linear or non-linear.

Step (C) consists of solving the optimization problem. The resolution is done using models and optimization methods. A model is a theoretical representation of one or more aspects of the physical behavior of the transformer, or more specifically the electromagnetic phenomena associated with it. The model makes it possible to make the link between the performance (e.g. power, efficiency, . . .) and the geometric dimensions and characteristics (constituent materials, operating point, . . .) of the transformer. An optimization method, associated with the model, makes it possible to iteratively determine the variables of the model which maximize/minimize the objective function of the problem while respecting the constraints of the specifications. To do this, we use optimization algorithms adapted to the model and the problem treated. When an optimal solution has been determined, the exploitation and analysis of the results, the last stage of the process (Stage D), make it possible to check the validity of the solution obtained.

This step (D) is devoted to the exploitation and analysis of the results which can invalidate the solution obtained. The right part of the flowchart in Figure 3 presents the problems generally encountered during the different stages of the design process. The exploitation and analysis of the results can first lead us to return to the step of solving the problem (Step C). It is also possible that the analysis of the results leads to changing the very formulation of the optimization problem. Such a case may arise when obtaining a solution that is not feasible in practice. It may also be necessary to modify the very formulation of the problem to prevent the optimization from exploring search areas in which the models associated with the process are imprecise (return to step B).

Finally, the exploitation of the results may also require a new analysis of the specifications and possibly its modification. It is possible that no solution to the optimization problem exists. You may also need to add missing constraints, modify existing constraints or redefine the optimization objectives (return to step A).

3.2. Geometric parameters

In this part, we recall the cross section of the transformer with a rectangular-shaped ironclad layout (Figure 4), which is a three-phase two-column core structure used for stable power supply applications. The core is manufactured by stacking glazed sheets of SF_{19} silicon steel. Copper is used as a conductive material. The primary and secondary windings are wound at the outer of the columns. There are vertical shunts for each phase made up of silicon steel rolling in the centre with an air space located at each end of the shunts.

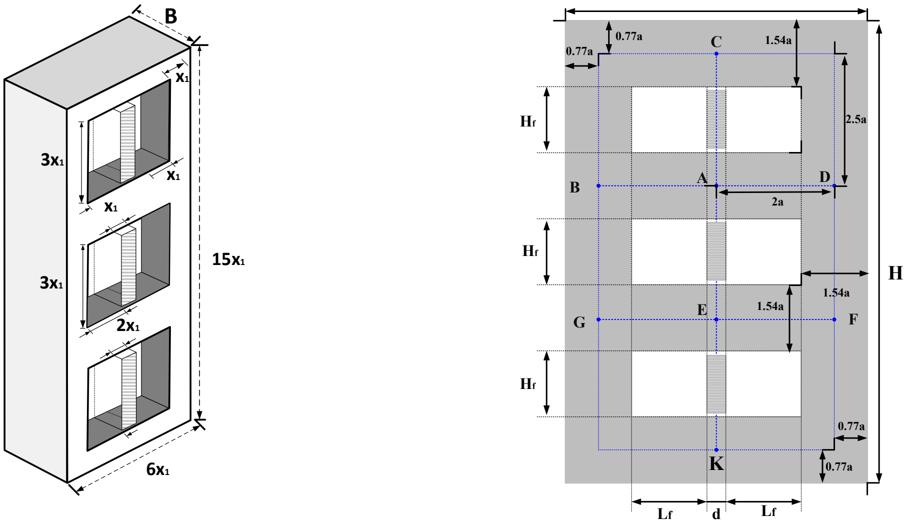


Fig. 4. Designed form of three-phase HV transformer (geometry and dimensions)

The obtained equivalent model nonlinear characteristics were implemented in MATLAB, to simulate the transformer response of the current and voltage waveforms recorded during the simulation. The results obtained [12], confirm that the reference model has been validated and can be used to obtain further satisfactory results and encourage.

Minimizing volume and weight is a function of inputs divided into optimization variables. These variables are the size of the magnetic circuit characterized by the width of the external branch (a), the number of secondary turns (n_2), the size of each space between the two shunts and the magnetic circuit (e) and the number of stacked sheets of the shunt (n_3). Subsequently each of these variables will associate with an unknown variable x which is used to define for each optimal solution, the basic design variables of this optimization method are as follows: $X = [x_1, x_2, x_3, x_4]$.

Where:

- x_1 is the width of the unwound core (a),
- x_2 is the number of turns (n_2) secondary,
- x_3 is the size of the air gap (e),
- x_4 is the number of stacked sheets of the shunt (n_3).

3.3. The objective function formulation

The magnetic circuit of the three-phase transformer with magnetic shunts is symmetrical. It is thus considered to be an association of three single-phase transformers identical. Figure 5 shows the geometric shape of the magnetic circuit equivalent to phase 1 of the three-phase shunt transformer.

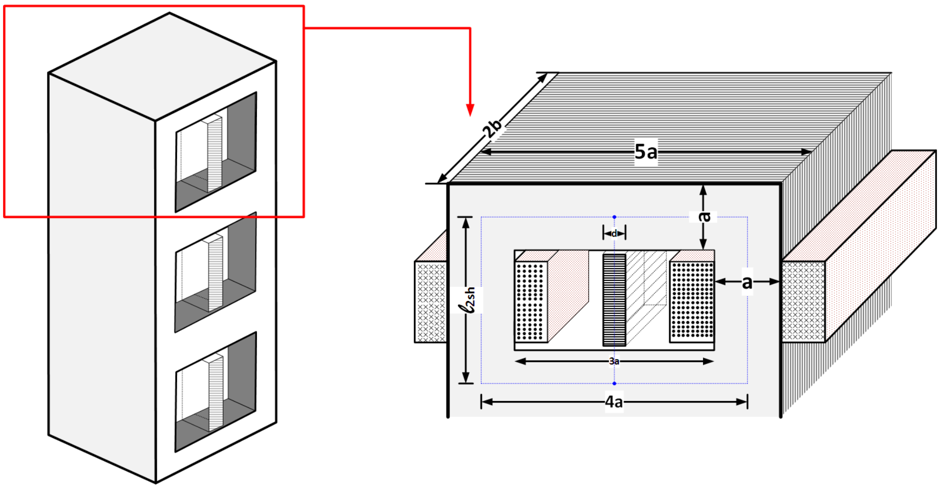


Fig. 5. Designed form of transformer phase 1 (Face View Cut)

Each optimization design variables vary within a boundary condition. In order to fit the objective function in terms of design variables, only solutions which check the defined constraints. This problem can be defined by a triplet (X, D, C) where:

- $X = \{x_1, x_2, x_3, x_4\}$ is the set of variables of the problem, where x_1 represents the width of the unworn core (a), x_2 indicates the number of turns at the secondary (n_2), x_3 is the size of each gap (e) and x_4 corresponds to the number of stacked sheets (n_3)
- The fields of definition: $D = \{D_1, D_2, D_3, D_4\}$ is the set of domains of the variables, for all $k \in [1; 4]$ we have $x_k \in D_k$, thus $D_{x_1} = [30: 2.5: 40]$, $D_{x_2} = [2050: 200: 2450]$, $D_{x_3} = [0.45: 0.25: 1.05]$ and $D_{x_4} = [10: 2: 18]$.

Each of these variables is assumed to be continuous. The following constraints $C = \{C_1, C_2, C_3\}$ are imposed on the design problem:

- $I = f_1(x_1, x_2, x_3, x_4)$
- $I_m = I_{min} = f_2(I)$
- $I_y = I_{aveg} = f_3(I)$
- $Vol = f_4(x_1, x_2, x_4)$
- $C_1 : I_{i_s}^{min} \leq I_m \leq I_{i_s}^{max}$
- $C_2 : I_{y_s}^{min} \leq I_y \leq I_{y_s}^{max}$
- $C_3 : C_1 , C_2$ and $min(Vol)$

With:

- The function f_1 is provided by Simulink of the magnetron current (A) for the equivalent global model.
- The function f_2 calculates the minimum value of the magnetron current in the interval [0.6, 0.64 (s)].
- The function f_3 calculates the average value of the magnetron current in the interval [0.6, 0.64 (s)].
- C_1: Constraint on the minimum current (A) which guarantees the operation of the magnetron at full power and whose values should belong to the interval $[I_m^{min}\ I_m^{max}]$ = [-1.2 -0.80].
- C_2: Constraint on the average current (mA) which guarantees the operation of the magnetron at full power and whose values should belong to the interval $[I_y^{min}\ I_y^{max}]$ = [-300 -200].
- C_3: Compound constraint which imposes the satisfaction of C_1 and C_2 and which seeks the states or the state having the minimal volume.

The optimizing function has been computed and the expression is given below

$$f(X) = \rho_{Fe} \cdot [72x_1^2 + 3x_3 \cdot (x_1 - 2x_4)] \cdot 60 + \rho_{Cu} \cdot [3 \cdot (120 + 8x_1)(424.8 + 0.20x_2)] \qquad (1)$$

Where ρ_Cu=8940 is the mass density of copper in [Kg/m3] and ρ_Fe=7650 is the mass density of core material in [Kg/m3].

3.4. Procedure for optimization

To obtain an optimum solution, the first step is to formulate the problem, select the design variables, define the constraints and specify the objective function. Minimum (or Maximum) bounds are imposed on the design variables.

This subsection describes the method for the optimal design of a three-phase shell-type distribution MFLT using the method of sequential programming (SQP). The use of this method is successful in optimization of dimensioning and shape optimization. This algorithm is powerful and effective in the nonlinear programming, attempts to resolve the program directly instead of transforming it into a sequence problem of minimization without constraints, which makes this algorithm differs compared to other methods (method of optimization without constraints). The advantage of the SQP method is that it can be manipulated in Matlab by using the function "fmincon" in the toolbox of Matlab. This algorithm minimizes a given objective function respecting the constraints determined by the user, where the objective function, defined the total volume of the transformer with shunts, is in the following form. The algorithm can be explained in the form of pseudo-code as follows:

Algorithm:

a. Read transformer data, independent variables, constrain and define of domains of the variables.
b. Set the loop conditions for each variable for all $x_k \in D_k$.
c. Check constraint (C_3) which imposes the constraints of (C_1) and (C_2) and which seeks the states or the state having the minimal volume.
d. Accept or reject each point, check if the C_3 is verifier and go to next step. Otherwise, go to **step (b)**.
e. Formulate of the objective function and calculate the initial volume.

Once this analysis is completed, the decision is making the ability of the computer to get the best solution with respecting the constraints imposed in order to obtain the lower volume and mass. Performance characteristics obtained from the simulation test has been listed in Table 1

4. Optimization results and discussion

The overall results are presented in Table 1, which summarizes the performance characteristics obtained from the simulation test for each design. In addition to these overall results, we will propose more detailed analyses on certain optimal dimensionings (energy balances, comparison between dimensionings, operational analyses, etc.).

Table 1. Comparison of the results obtained using the classical design of the performance of three-phase transformers.

Solution		**S_{data}**	**S_1**	**S_2**	**S_3**	**S_4**
Design variables X [a n_2 n_3 e]	x_1	38.5	36.3	32	31	30.22
	x_2	2400	2400	2750	2050	2400
	x_3	18	18	10	18	18
	x_4	0.75	0.9	0.9	0.45	0.75
I_{max} (A)	Phase 1	1.0418	0.932	0.931	0.829	0.785
	Phase 2	1.0469	0.933	0.932	0.833	0.785
	Phase 3	1,0459	0.931	0.931	0.829	0.788
I_{mean} (mA)	Phase 1	298,1	265.1	280.1	201.3	205.2
	Phase 2	297,9	265.1	280.0	201.5	205.4
	Phase 3	298,3	265.3	280.3	201.5	205.3
P_{mean} (W)	Phase 1	1240,9	1092.9	1157.6	820.4	835.5
	Phase 2	1239,9	1092.8	1157.4	821.3	836.2
	Phase 3	1241,8	1093.6	1158.4	820.7	835.8
Volume (cm^3)	V_{cu}	868.6	814.3	818.8	651.1	651.4
	V_{Fe}	2576.1	2154	1560	1276	1015.54
	V_{Tot}	3644.7	3068.3	2027.9	2027.9	1667.2
Mass (Kg)	m_{cu}	7.54	7.28	7.02	6.82	5.91
	m_{Fe}	21.24	17.24	13.47	10.53	7.78
	f(x)	27	23.5	20.19	17.35	16.19

The results in Table 1 show small differences between the values of the optimized parameters from one model to the next. However, there are few differences. It may therefore be concluded from these observations that these five optimisation designs have converged towards an identical optimum. It is reasonable to assume that the final solutions achieved for each of these models have been taken into account, after performing all the steps of the process described by the algorithm, will also be the same.

It is always assumed that we have a calculation for a 1650 VA three-phase transformer. The input voltage source is a 50Hz, 220V sinusoidal alternating voltage with a regulation range of ±10%. The secondary voltage is 2230V. The transformer has three phases, two columns; the silicon steel used for the iron core material is SF_{19}. A voltage doubling capacitor C = 0.9µF and a high voltage rectifier diode D1. The main program, the calculation of the objective function and the algorithm.

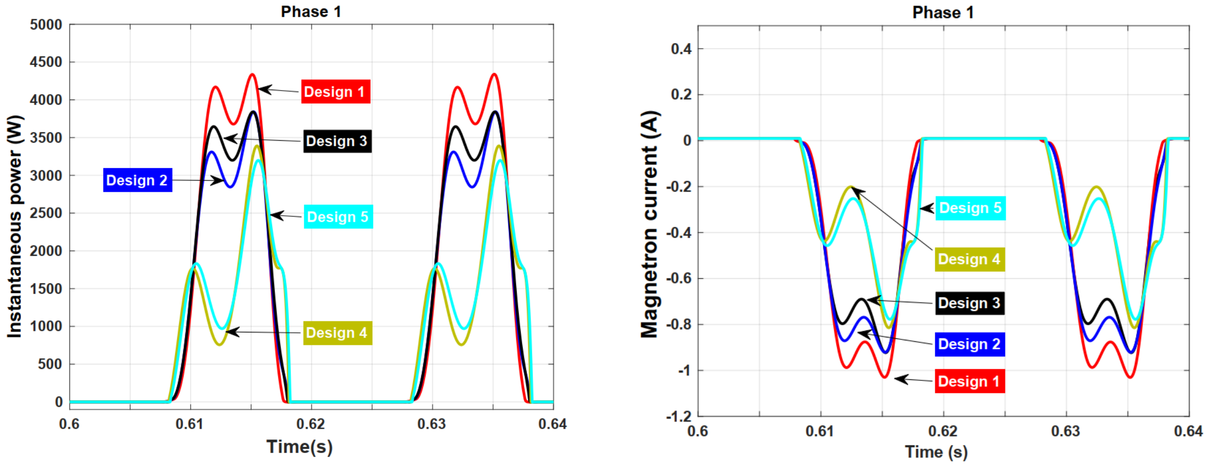
The optimisation methods were encoded in MATLAB 2019a., including the implementation of the equivalent electrical model of the three-phase transformer power supply.

The observation of Figures 6. (a) and 6. (b) shows that the magnetron currents of various optimised solutions reach their maximum value in good operation. The algorithm takes into account many variations in design variables. These variations make it possible to investigate a candidate solution. For each of the candidate solutions, it is checked if the constraints are satisfied and if they are. The volume and mass are calculated and the solutions are acceptable.

Finally, among these solutions, design 3 was selected, which presents the transformer optimal with the minimum manufacturing cost. This optimal design allows the best compromise between the total volume of the transformer and the operation of the magnetron. As a result, the objective function calculations would be reduced by 18.33%. Another loss of 5.41% is obtained for energy units. Based on these variable values, Design 4 has a minimal volume, but it does not allow the magnetron to operate at full power during its lifetime. Finally, a simulation procedure made it possible to verify the optimality of the results obtained with Matlab code.

4.1. Reduced dimensions of the new transformer

During this work, we took the manufacturers' data as a reference (design 1). Table 2 allows to compare graphically the geometric dimensions chosen for each of the two models for the optimised transformer (design 3) and for the reference transformer (design 1).



(a) (b)

Fig. 6. Shape of magnetron current and magnetron power waves across phase 1

Table 2. Comparison with an optimized transformer with manufacturer's data

		Resulted Measurements	
Dimensions		**Manufacturers' data**	**Optimal Design**
Core Design	Width of outer limb (D/2)	19.25 cm	16 cm
	Depth of core (B)	78 cm	78 cm
	Width of central limb (D)	38.5 cm	32 cm
	Central limb cross section (2ab)	3000cm^2	2496 cm^2
Window Design	Height of window (E)	23.8 cm	23 cm
	Width of window F)	24 cm	21.87 cm
	Area of window (Aw)	571.2 cm^2	503.01 cm^2
Overall Frame Design	Overall Width (A)	226 cm	220 cm
	Overall Height (C)	138.5 cm	137 cm
Windings Design	Cross section primary (Sp)	1.77 mm^2	1.77 mm^2
	Cross section secondary (Ss)	0.20 mm^2	0.20 mm^2
	Diameter primary (φ_p)	1.5 mm	1.5 mm
	Diameter secondary (φ_s)	0.5 mm	0.5 mm
	Secondary Resistance (Rs)	65Ω	64.68 Ω
	Primary Resistance (Rp)	100 Ω	89.3 Ω
	Primary Wire Length (Lp)	71.68 m	62.72 m
	Secondary Wire Length (Ls)	768 m	770 m
	Mean Wire Length (L_m)	320 mm	280 mm
	No. of primary turns (np)	224	224
	No. of secondary turns (n_s)	2400	2750
Shunt Design	Height of shunt (h)	9 mm	7 mm
	No. of stacked sheets (n_3)	18	10

4.2. Implementation of the model in the Matlab environment

The global equivalent electrical model obtained (Figure 7) made it possible to implement the optimization method proposed in this work. The model and the method were used to determine the dimensions and characteristics of an optimized three-phase transformer by satisfying the constraints of the specifications. The optimal solution resulting from the process presents a transformer with less mass than that of the initial transformer.

The optimal design was obtained after iterative stages of validation with the calculation for a total duration of the process of approximately 1 hour. The optimality of the solution was also simulated using Matlab simulink.

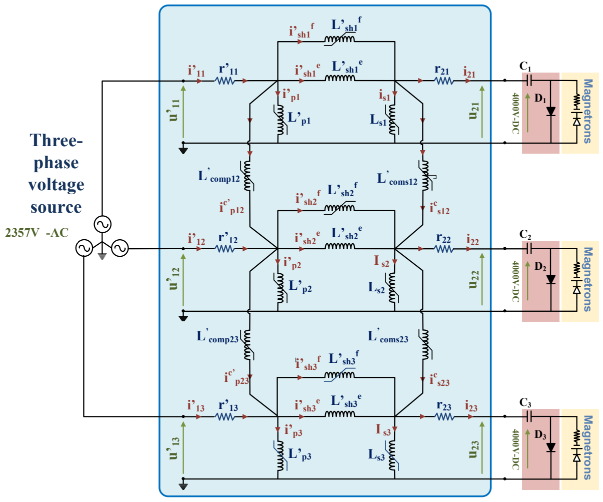


Fig. 7. Global equivalent electrical model of the three-phase HV power supply

To test the feasibility of the proposed model. We used

Matlab/Simulink software. First, a nominal voltage is applied to the primary of the test transformer, the secondary being circuited with a magnetron in each phase. Then, we introduce the curves obtained by simulation. At the end of this study, it will be necessary to determine from the experimental results the parameters of the transformer and the efficiency then to make a comparison [12]. This will validate the behavior of the model on the case of a classical test. In this section, we will simulate our transformer and calculate its efficiency.

4.3. Model diagram and block description

Figure 8 presents the model of the three-phase HV power supply for microwave generators with a single magnetron per phase, uses a three-phase transformer with two-column shunts and four suitably sized yokes.

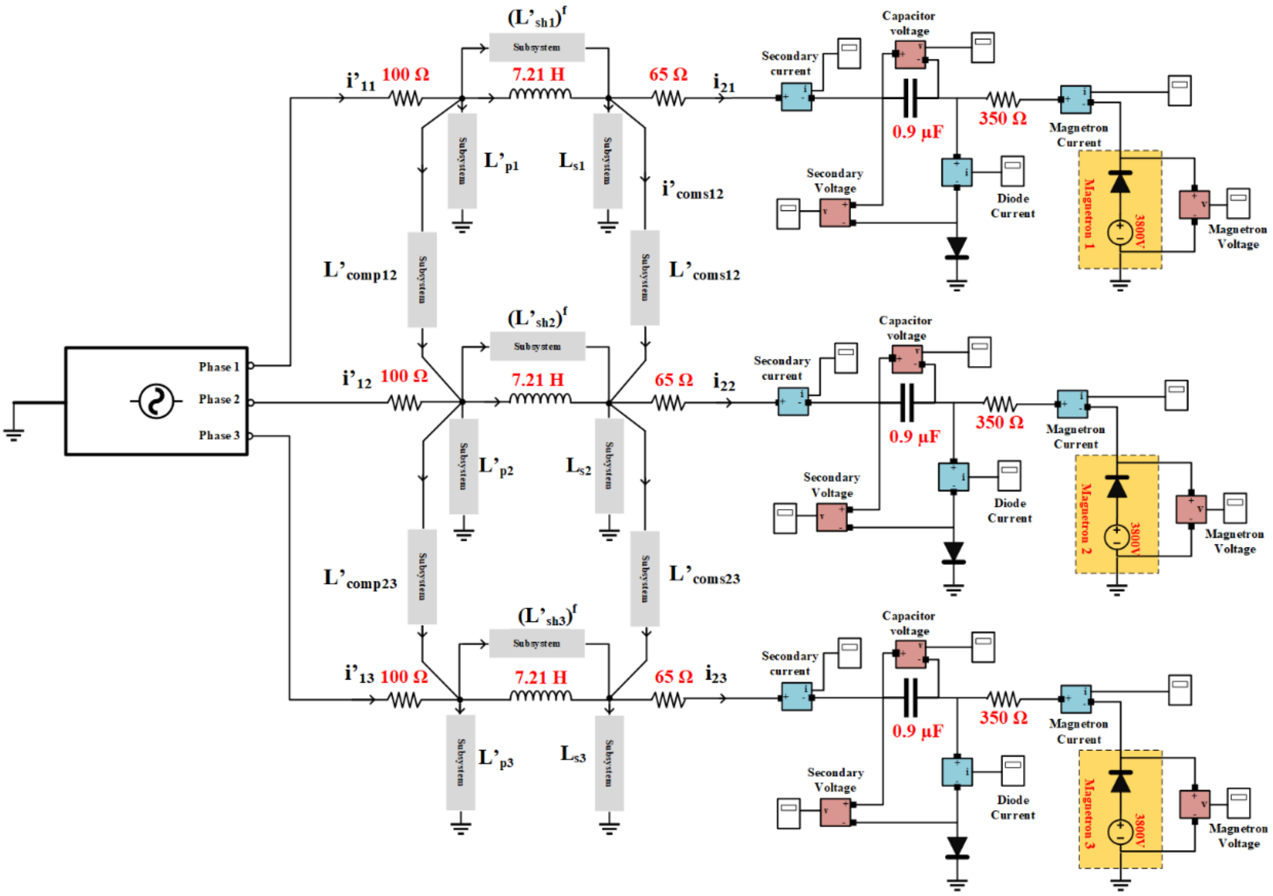


Fig. 8. π-equivalent circuit diagram of the power supply studied for the three-phase transformer designated by n_2 turns.

As mentioned in the Figure 8 above, the complete simulation model consists of some main blocks consisting of:

– A variable voltage source (Power SystemBlockset/Electrical Sources library),

– this library contains direct and alternating current and voltage sources

– which may or may not be ordered. In the window settings fields

– the values of the voltage, the initial phase and the frequency are entered.

– The user block (Powergui).

– The Scope block for observing the shape of the current and voltage curves and the

– powers (Simulink/Sinks library).

– The to workspace block is used to visualize the signal.

– The voltage measurement blocks (Voltage Measurement) and the voltage measurement blocks

– current (Curent Measurement) in the primary and secondary circuits of each

– phase (Power System Blockset/Measurement Library).

– The basic values of the transformer parameters (the resistances for each

– winding).

– The voltage doubler block, circuit comprises only a diode, a capacitor which

– work together to effectively double the voltage.

– The block of a magnetron which consists of a diode with a dynamic resistance of

– 350 ohms and a threshold voltage E of approximately 3800 volts

4.4. Experimental realization of the assembly of the power supply HT to a magnetron

Once the model to be simulated is drawn from the blocks described above. We are passing to the setting of the transformer and the energy source to the load. So, the model of transformer used in the simulation of Figure 9 has for parameters:

- Rated power S = 1650V a,
- The frequency f = 50Hz,
- Rated primary voltage $u_{1j} = 220$V,
- Resistance (primary and secondary) $r_{1j} = 100\Omega$, $r_{2j} = 65\Omega$,
- Windings (primary and secondary) $n_1 = 224$, $n_2 = 2400$,
- A capacitor of capacitance $C = 0.9\mu F$,

- a high voltage DHT diode,
- A 2M229 series magnetron, designed to operate under a voltage of approximately 4000 V,

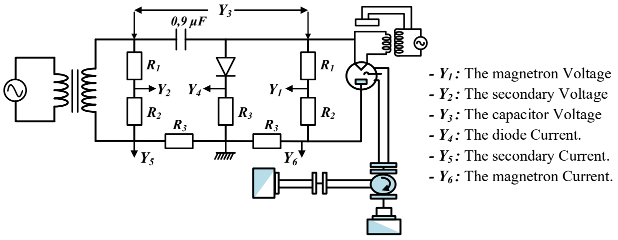


Fig. 9. Experimental configuration to measure characteristics: Magnetron HV supply currents and voltages in nominal mode.

5. Simulation results

In this section, we question the optimal character of the obtained solution. For this purpose, we propose to check the optimality of the determined solution. The simulation procedure applied here does not constitute a mathematical proof of the optimality of the solution obtained with the model and the optimization method proposed [31].

However, it rightly reinforces the credibility of the results obtained by the optimization approach developed. Simulations were carried out in order to verify the proposed optimal transformer model. Observing the curves in Figure 10 provides information on the effectiveness of the method.

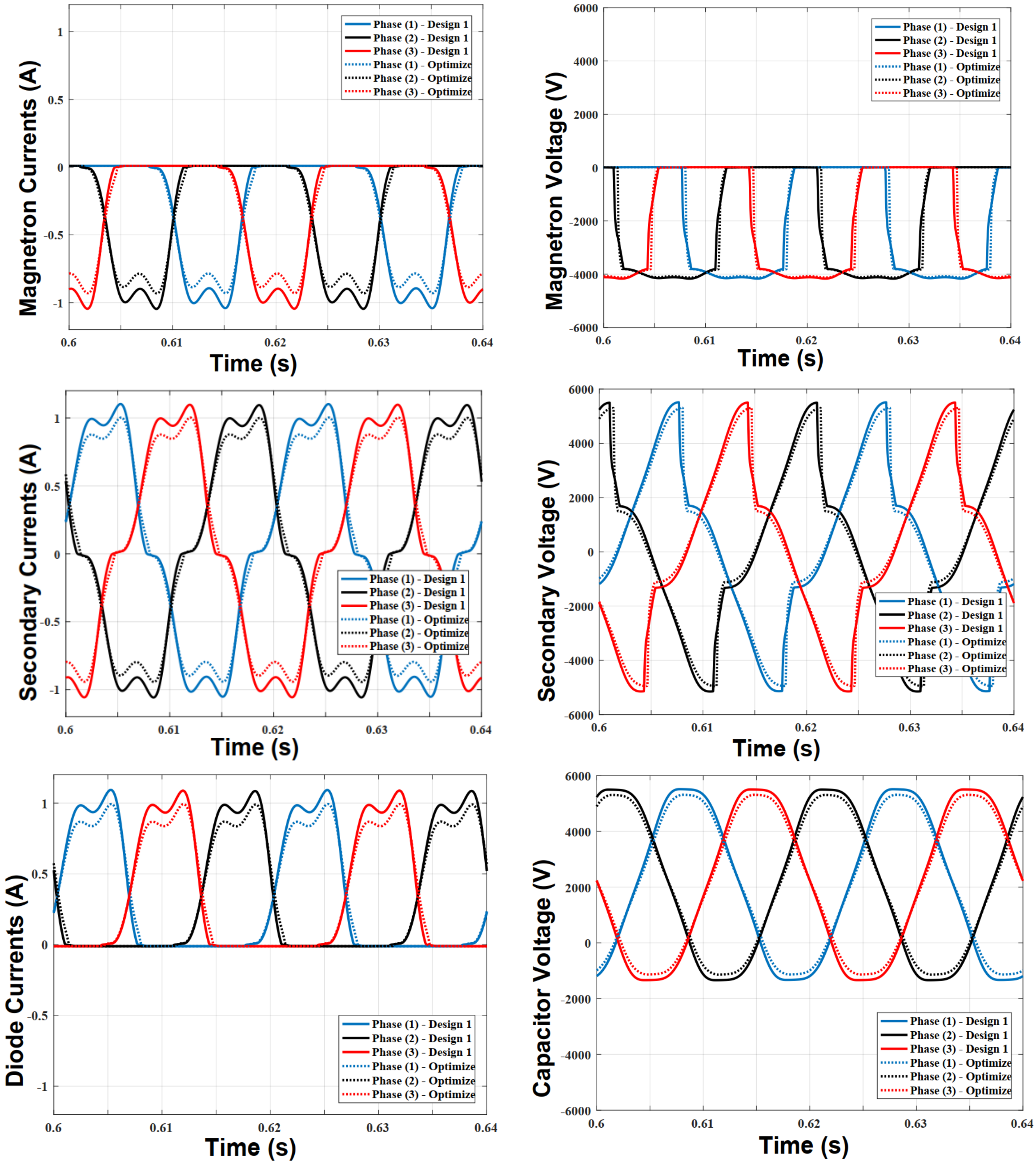


Fig. 10. The simulation curves of the optimised transformer voltages and currents against the manufacturer's data transformer.

By using the design decision variables 3. We simulated under MATLAB Simulink the electrical behavior of the optimal HV transformer. The plots in dotted lines represented on the curves of Figure 10 show the values of the tensions and currents of the optimal transformer, evaluated by simulation, thus the solid lines show the values of the voltages and currents of the reference transformer [33]. The optimal solutions obtained are very similar and show that the method and the model developed work as expected.

The observation of these curves, however, allows us to conclude that the optimal model developed has good sensitivity. Indeed, the waveforms obtained show that these results are in perfect agreement with those obtained by the reference case and respect the criteria recommended by the manufacturer. Each magnetron operates at the rated speed (220V and 50Hz) on the primary side, the electric signals in the diode, capacitor, magnetron and secondary side have the same shape as those of a three-phase power supply conventional for a magnetron [8].

It should be noted that the maximum allowable value of the current amplitude of each magnetron in the optimized transformer does not exceed the limit of the acceptable current (< 1.2A), which complies with the imposed constraints. It guarantees correct operation of the magnetron with a reasonable average current of 300mA without exceeding the recommended peak current. Considering the above, the process of stabilizing the current in each magnetron is completely ensured, which completely protects this microwave tube.

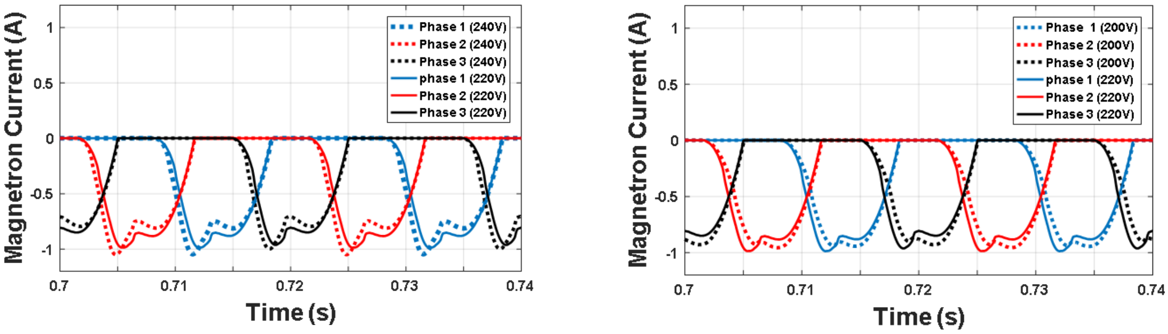


Fig. 11. Magnetron anode voltage and current per phase with different voltage source values.

The currents through the magnetrons regulating the process in each phase of this optimal solution have been verified. While observing the stability of the current variations in each magnetron compared to the variations of the primary voltage of ±10% around the nominal voltage of 220 Volts. Figure 11 shows the waveforms of the current of each magnetron corresponding to the respective values of 200V and 240V of the primary voltage.

6. Conclusion

In this paper, the aspects related to the modeling and the optimal design of the shunt transformer have been presented. Firstly, a review of the basic principles of transformer design made it possible to situate the context and the challenges of the research targeted by this work. The main phases of the design, the notion of model, the different phenomena generally modeled, the types of modeling and the optimization methods generally employed have been described in turn.

The purpose of this paper is started by formulating the objective function, then the study of the sensitivity of various geometrical parameters of the transformer. Then, we observe their influence on the magnetron currents. The proposed algorithm is selected for study. The High voltage transformer response of the chosen solution is shown during the simulation. Therefore, statistical results and values of design variables for the best solutions can be highlighted to exploit it.

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