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Modeling Under MATLAB by ANFIS of Three-Phase Tetrahedral Transformer Using in Microwave Generator for Three Magnetrons Per Phase

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Abstract

This work deals with the modeling of a new three-phase tetrahedral transformer of HV power supply, which feeds three magnetrons per phase. The design of this new power supply is composed of three single-phase with magnetic shunt transformers coupling in star; each one is size to feed voltage-doubling cells, thereby feeds a magnetron. In order to validate the functionality of this power supply, we simulate it under Matlab-Simulink environment. Thus, we modeled nonlinear inductance using a new approach of neuro-fuzzy (ANFIS); this method based on the interpolation of the curve B(H) of ferromagnetic material, the results obtained gives forms of both voltages and currents, which shows that they are in accordance with those of experimental tests, respecting the conditions recommended by the magnetron manufacturer

Keywords: *modeling, tetrahedral, three magnetrons, matlab-simulink, neuro-fuzzy (ANFIS)*

1. Introduction

Current power supply systems for microwave application use a single-phase transformer to feed one magnetron, so to meet certain high energy needs, it is necessary to have several single-phase power supplies; The development and innovation of these systems consists tofinding more efficient and optimized solutions that can feed several magnetrons at a time, to reduce cost, volume and ease of maintenance.

In order to provide these criteria, in this article we modeled a new Three-phase HV power supply, for three magnetrons per phase as shown in Figure 1. This model is a design of tetrahedral magnetic shunt type transformer, which sized to feed three double cells each one is composed of a capacitor and a diode; the doublers feed their turns a single magnetron [1-6]. The advantage of this coupling is to assure the stability of the current in each magnetron respecting the characteristics imposed by the manufacturer. Unlike the ordinary transformer, the leakage flux in the shunts is the same order as that in primary and secondary core.

The modeling of this power supply is essentially to model its own special shunt transformer. It seems necessary to develop a new model in appropriate π-model, formed of non-linear passive electrical components (inductance) [7-9]. We take into account the actual state of saturation of the transformer, during its nominal operation in the supply circuit magnetron HV 800 Watts at 2450 MHz.

This work is divided into two parts; first part presents the equivalent model, and in the second part, we implemente and simulate this model, based on fuzzy logic network (ANFIS) available in library of Matlab-Simulink [15-19], which interpolate the curve B(H) of material used SF19 to model the different non-linear inductances. Thus, the simulation results obtained were comparing with those of the experimental tests by checking the regulation process of the current in each magnetron.

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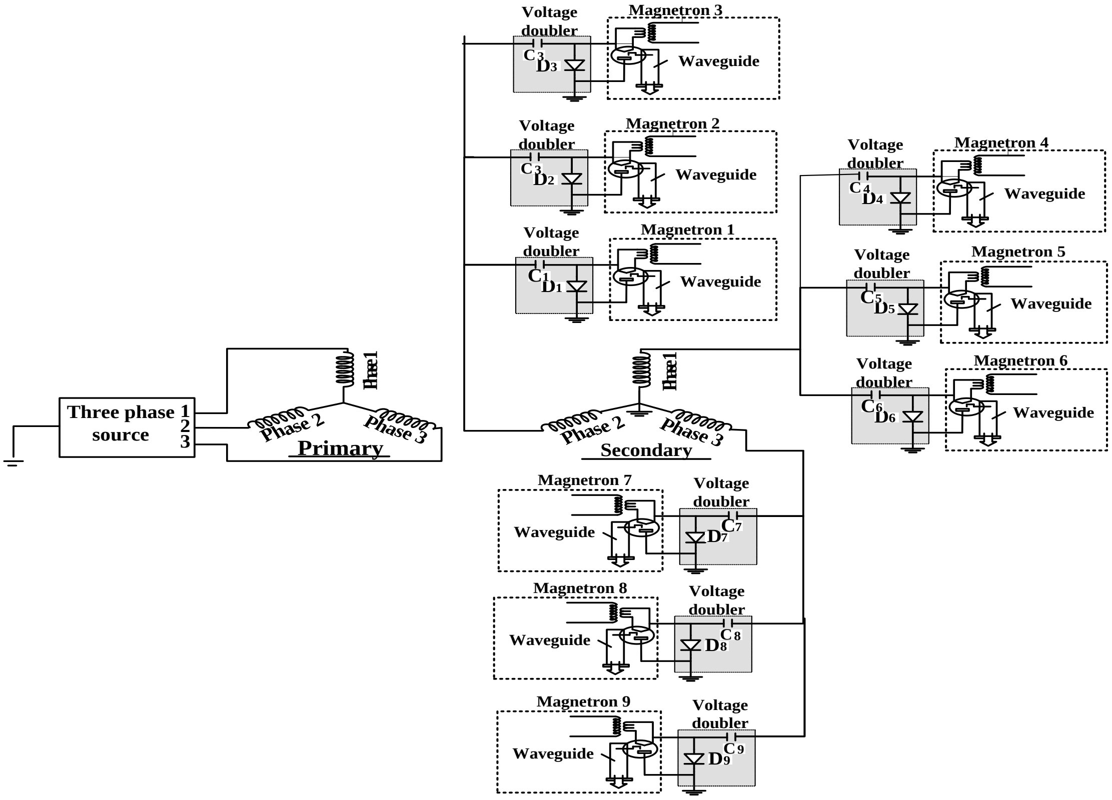


Figure 1. Three-phase transformer HV power supply for three magnetrons per phase

2. Modeling of Three-Phase Transformer Power Supply for Three Magnetrons per Phase used in Industrial Microwave

Figure 2 shows the structure of a three-phase tetrahedral shunt transformer, which consists in modeling a magnetic shunt transformer adapted to the constraints imposed by the manufacturer for the operation of these magnetrons.

The aim of this section is to model each transformer composed of three-limb, the windings (primary and secondary) wound around the midlle limb, and the outer limb used to close the magnetic circuit. Magnetic shunts integrated to deflect a portion of the flow between the two windings, in order to adjust the anode current in the magnetron.

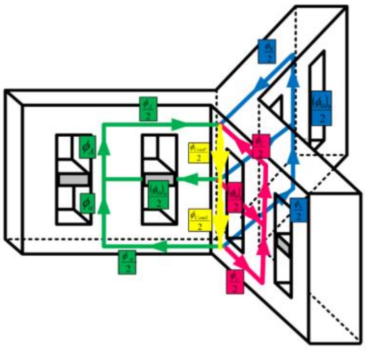
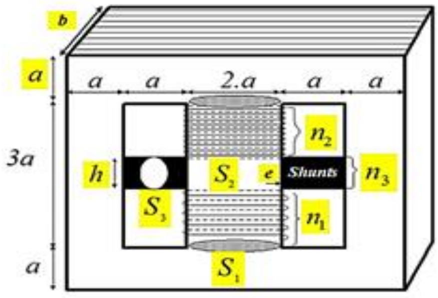


Figure 2. Three-phase magnetic tetrahedral shunt transformer structure

Here are the different dimensions of a phase the tetrahedral transformer.



- The width of the non-wound core: $a = 75mm$
- The width of the magnetic circuit: $b = 20mm$
- 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: $h = 0.5 \cdot n_3$
- Surface of the core: $S_1 = S_2 = a \cdot b$
- Thickness of the air gap: $e = 0.75mm$

Figure 3. Geometry of a phase the tetrahedral transformer

Taking into account the saturation of the material in the modeling, we consider that the leakage flux in gap air is negligible compared to the flow in the shunts. We apply the two-ohm's law and Hopkinson to define different electrical and magnetic equations of each phase:

$$u_{1i} = n_2 \frac{d\phi_{1i}}{dt} + r_{1i} i_{1i} \tag{1}$$

$$u_{2i} = n_2 \frac{d\phi_{2i}}{dt} - r_{2i} i_{2i} \tag{2}$$

$$R_{pi}\phi_{1i} + R_{si}\phi_{2i} = n_1 i_{1i} - n_2 i_{2i} \tag{3}$$

$$R_{pi}\phi_{1i} + R_{shi}\phi_{3i} = n_1 i_{1i} \tag{4}$$

$$R_{si}\phi_{2i} - R_{shi}\phi_{3i} = -n_2 i_{2i} \tag{5}$$

$$\phi_{1i} = \phi_{2i} + \phi_{3i} \tag{6}$$

The equations obtained present a model of a quadruple in π-model referred to the secondary, by multiplying the equations (1) (4) (5) (6) in a transformation ratio (m). The advantage of this model, which contains non-linear inductances (primary, secondary and shunts) for each phase presented in Figure 4, is to model each of the inductances associated with each portion of the transformer, which is impossible in case of a T-model [7].

$$u'_{1i} = r'_{1i} i'_{1i} + \frac{d(L'_{pi} i'_{pi})}{dt} \tag{7}$$

$$u_{2i} = - r_{2i} i_{2i} + \frac{d(L_{si} i_{si})}{dt} \tag{8}$$

$$i'_{shi} = i_{2i} + i_{si} \tag{9}$$

$$i'_{1i} = i'_{pi} + i'_{shi} \tag{10}$$

$$\frac{d(L'_{pi} i'_{pi})}{dt} = \frac{d(L_{si} i_{si})}{dt} + \frac{d(L'_{shi} i'_{shi})}{dt} \tag{11}$$

3. Simulation and Expermental Results

We integrate under Matlab-Simulink the equivalent electric model of tetrahedral transformer in the global circuit of the Three-phase HV power supply. Figure 4 present the three magnetrons of each phase by its equivalent diagram, composed by a diode connected in series with a dynamic resistance of 350 ohms, and a voltage source of a threshold E of 3800 volts.

The different nonlinear inductances studied are represented by the characteristic $\phi(i)$ resulting from the relation, $L(i) = (n_2 \cdot \phi(i)/i)$ that can be determined from the magnetization curve B(H) of the material, and the geometrical dimensions of the transformer [11-14]. The relations characterizing these inductances are:

$$n_2 \cdot \phi(i) = n_2 \cdot B \cdot S$$

$$i = \frac{(H \cdot \ell)}{n_2}$$

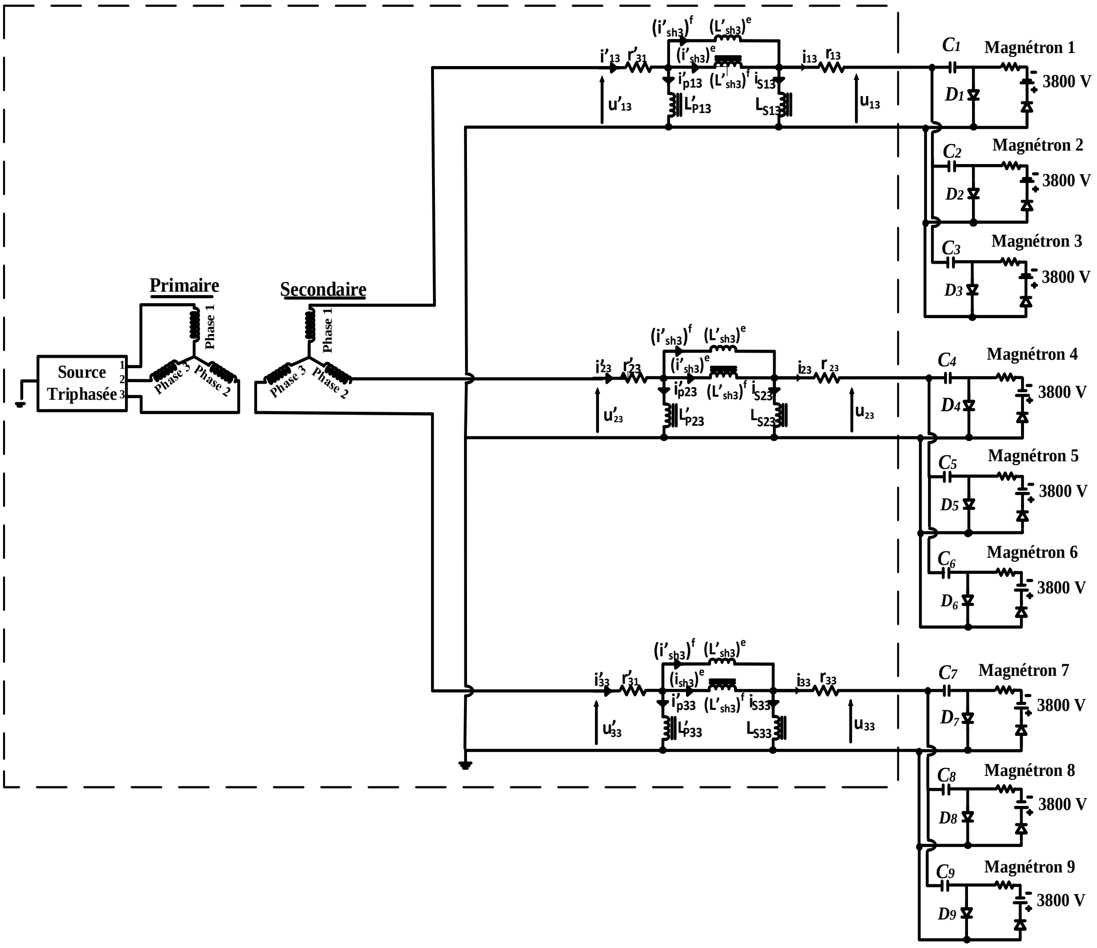


Figure 4. Global equivalent model of eletrical circuit for three-phase transformer power supply three magnetron per phase

These relations allowing obtaining a subsystem as shown in Figure 5 contain:

1. A voltage integrator to derive the flow ϕ as a function of time to deduce the magnetic field B using the relation $n_2 \cdot \phi(i) = n_2 \cdot B \cdot S$
2. A Simulink block called Fuzzy Logic Controller Block that implements a fuzzy inference system (FIS) in Simulink, to interpolate the B(H) curve.

3. A current source imposed to derive the current from the relation $i = \frac{(H.\ell)}{n_2}$

Applying a method based on using of neurofuzzy inference (ANFIS) to interpolate the B(H) curve, taking into account the saturation phenomenon. We give the architecture in five layers (fuzzification, Multiplication of the entries between them, Normalization of the input data, Adaptive layer with modulation of the weights, recombination of the outputs) of the ANFIS model presented in Figure 6, making it possible to build a fuzzy system thanks to neural networks.

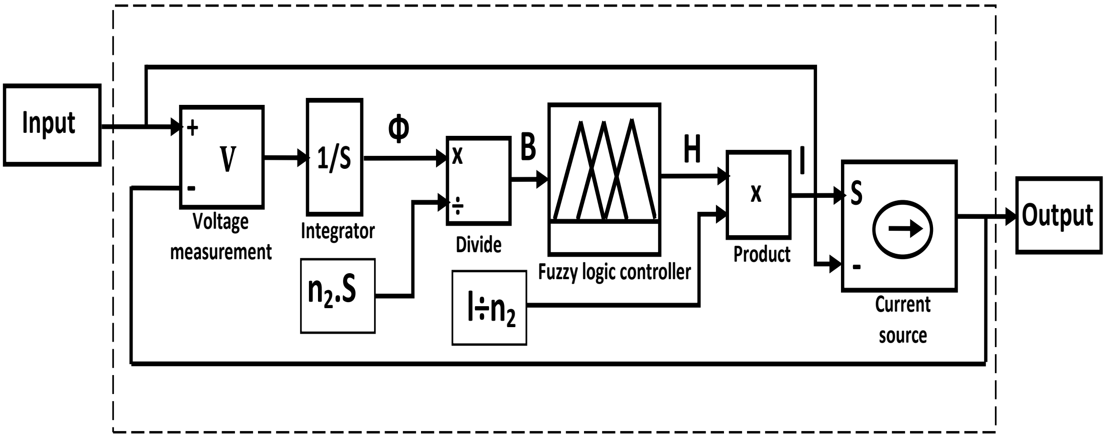


Figure 5. Subsystem of a nonlinear inductance

To develop the ANFIS model, we follow these steps [17].

a. Step 1: The definition of the inputs/outputs of the ANFIS model, which are the parameters B_n and H_n of the material used for the construction of our transformer.
b. Step 2: Find fuzzy partitions of input data by ANFIS In this step; we choose the Grid partition technique to generate the initial model in which we define the number and type of membership function for the entrees.
c. Step 3: Training input/output data via the neural network, choosing a hybrid algorithm with the following conditions, an interaction number of 300 and an error (tolerance) of 0.005. Once the network is traine, we test the system by different data values to check its good functionality. The Figure 7 shows the fuzzy neuro network setup and training window (ANFIS) in which we visualize the interpolation results of the B(H) curve.

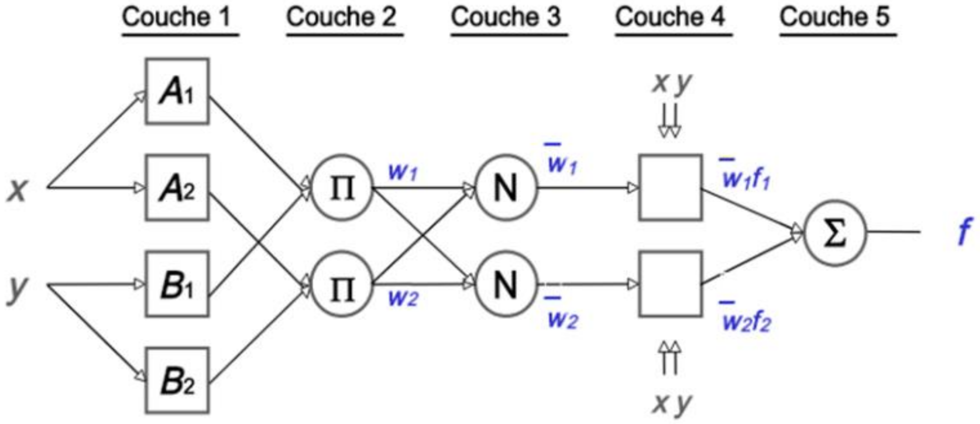
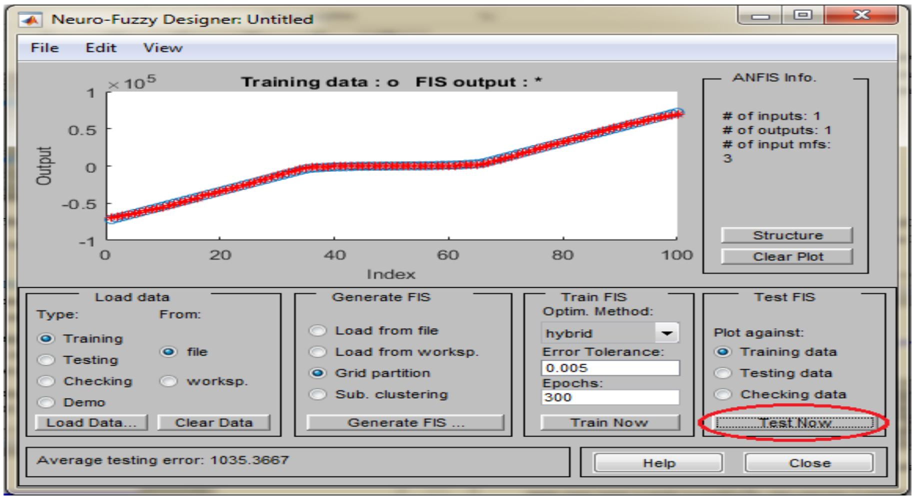


Figure 6. Architecture of the ANFIS model



ANFIS Info.
# of inputs: 1
# of outputs: 1
# of input mfs:
3

Type: ● Training ○ Testing ○ Checking ○ Demo

From: ● file ○ worksp.

○ Load from file ○ Load from worksp. ● Grid partition ○ Sub. clustering

Optim. Method: hybrid

Error Tolerance: 0.005

Epochs: 300

Plot against: ● Training data ○ Testing data ○ Checking data

Average testing error: 1035.3667

Figure 7. Setup and training window of neuro-fuzzy network

After having executed and tested the ANFIS model, we load the results obtained under the "fuzzy logic controller" block present in the model of the non-linear inductance in Figure 5. To simulate our power supply under Matlab-Simulink.

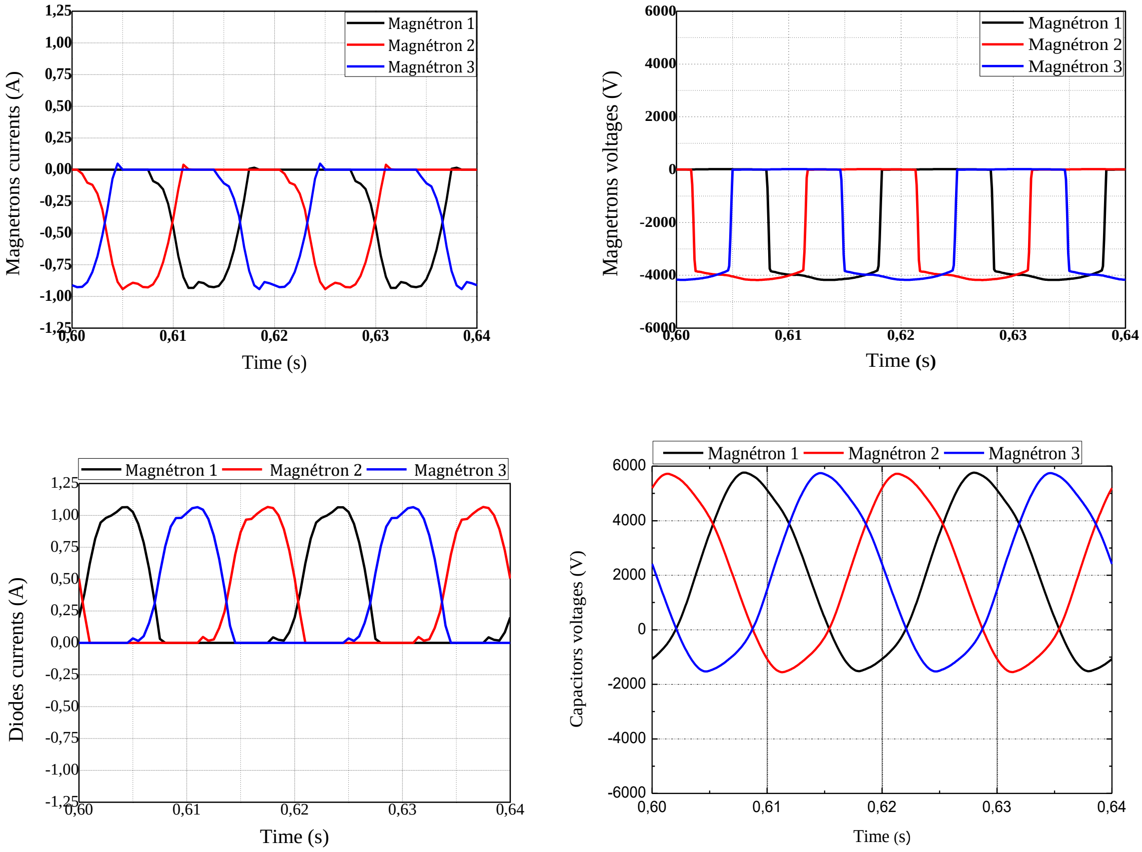
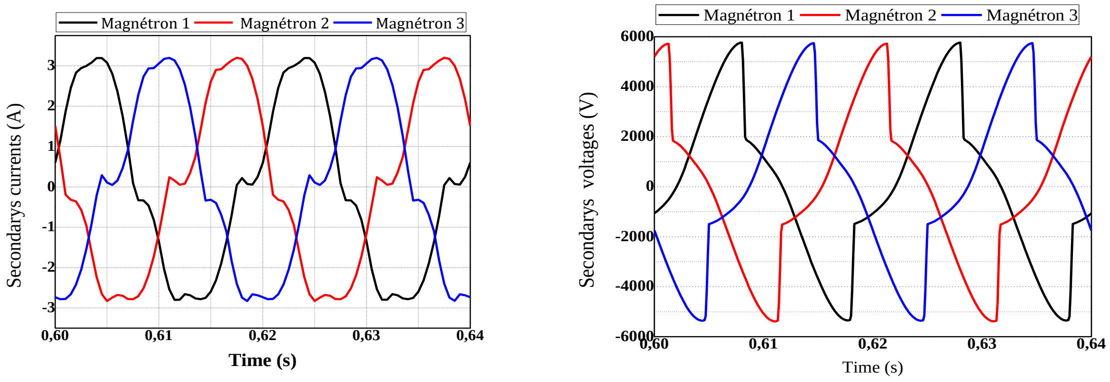


Figure 8. Simulation waveforms of theoretical currents and voltages obtained



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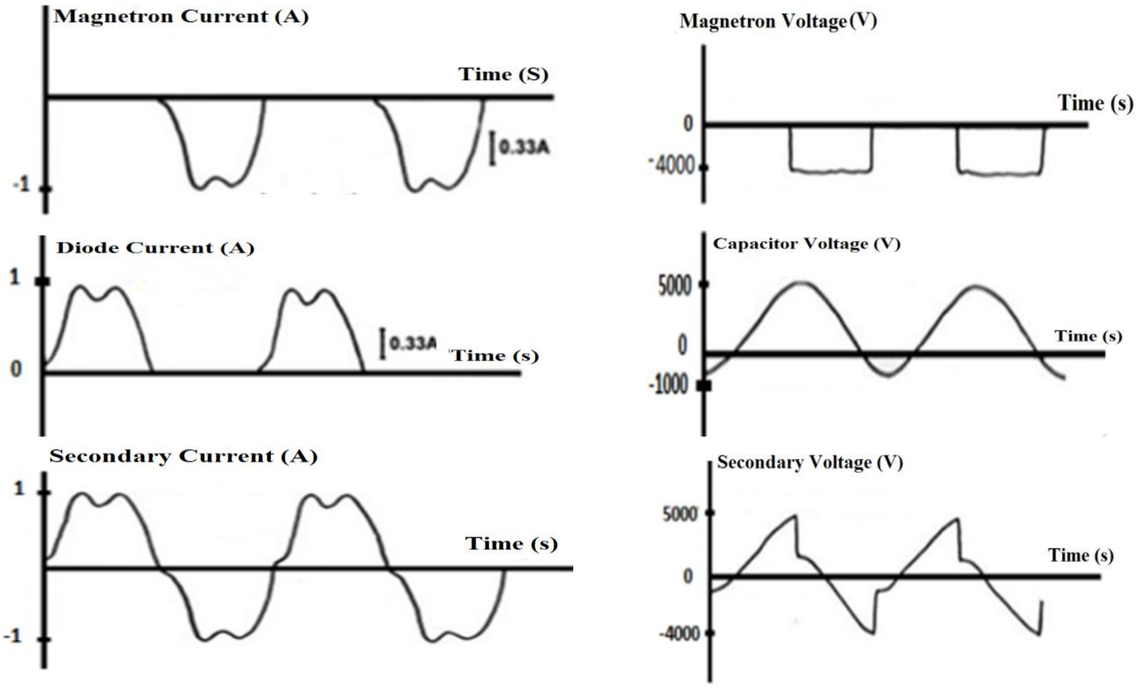

Figure 9. Experimental curves of the voltage and current waveforms of the magnetron HV supply

4. Results and Discussions

After having simulated our model under Matlab-Simulink, the time curves of currents and voltages (secondary, magnetrons and capacitor) represented in Figure 8 are in agreement with those obtained by experimental test Figure 9 of a single-phase power supply [2-5], which presents a phase among the Three-phase of our model. The error rate between the theory and the experiment is of the order of 6%.

To validate the operation of the model under Matlab-Simulink with respecting the maximum current 1.2A and an average current of 300mA, for the nominal operation of magnetron. During this simulation, we checked the current stabilizing effect in each magnetron for a variation of ± 10% of the primary voltage around its nominal value 220V as shown in Figure 10. As a result, for both 200V and 240V cases, the maximum amplitude and the average value of the current in each magnetron do not exceed the imposed limit.

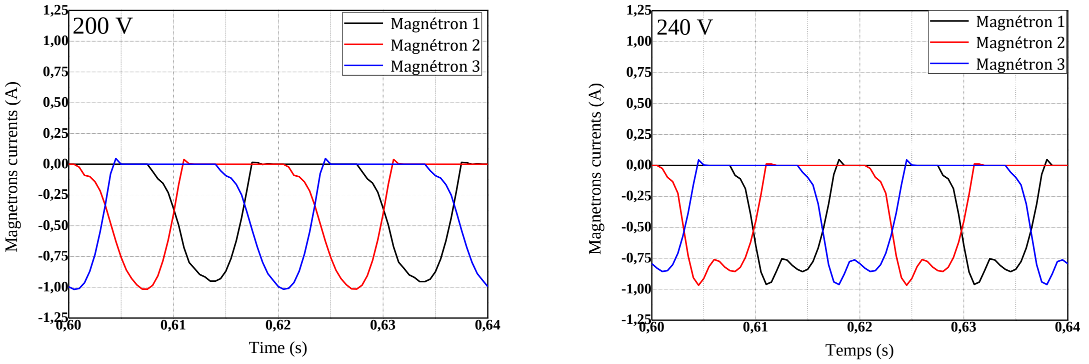

Figure 10. Stabilization of the anode current in each of the three magnetrons with respect to the variations of the source voltage (± 10%)

5. Conclusion

In this article we studied the validity of a new three-phase HV power supply with tetrahedral transformer feeding three magnetrons per phase, this study was simulated using a new method of interpolation of the curve B(H) based on fuzzy standards (ANFIS) to model the nonlinear inductance under Matlab-Simulink. The different curves (voltages, currents) obtained compared with those of experimental shows a coordination between them.

The modeling of the power supply makes it possible to validate the constraints imposed by the manufacturer on the level of the magnetron current due to the effect of saturation of the transformer, which ensures the protection of the magnetron against any variation of the input voltage. For perspective of this work, we study the optimization in order to reduce the volume of this transformer, and consequently gain of cost and congestion.

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