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Failures' Diagnosis of High Voltage Power Supply System for Low Power Magnetrons

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ABSTRACT

This paper treats the study of the equivalent magnetic flux leakage transformer core type; it uses three-phase high voltage power supplies for a magnetron in each phase. This special transformer feeds a voltage doubler, a current stabilizer cell in series per phase. It ensures the anodic current stabilization in each magnetron by saturation of its magnetic circuit. It has additional leakage flux, which protects the magnetron against any eventual voltage variation; it is considered the basic element of this power supply.

The simulation results with MATLAB-Simulink environment of the electrical operation of this power supply device were consistent with the experimental laboratory tests in the case of single-phase high voltage for one magnetron. This results obtained shows the feasibility of the proposed simulation model.

Key words: Magnetron, MATLAB-Simulink, MFLT, High-Voltage.

1. INTRODUCTION

The research works that have been done previously regarding the microwave ovens (MWO) including its main components such as high voltage magnetic flux leakage transformer (MFLT), magnetron (MGT) and the doubler circuit. The MFLT is the most important and costly components used in power supply systems.

A good transformer design satisfies certain functions and requirements, such as powering many MGTs by keeping the same transformer with respecting the constraint imposed without damaging them [1]. We can satisfy these requirements with various designs. The aim of this study is to exploit the model developed of three-phase transformer core type to find the most economical choice.

The objective is to treat the performance of power supply system for low power MGTs for each phase using a special transformer with shunt [2]. Based on the modelling of the HV three-phase power supply system, which currently designed to supply in nominal mode.

During this paper, we studied the failure effects in different cases (phase 1 without load and other phases with load), and analyze the possibility of its function without undamaged other MGTs. A Matlab Simulink model of HV supply for MGT presents the different waves of currents and voltage that exist in the whole system of power supply. In order to compare them with those obtained experimentally in case of conventional high voltage power supply for single-phase MGT [3], [4].

Due to peer review of power supply microwave in many works and published paper [1]-[5], this article only is discussed to new modeling and simulation of Matlab-Simulink of three-phase equivalent transformer, in order to realize the exact simulation of behavior and effects in case of broken down in MGT [7]-[9]. This article is organized as follow:

An overview of core type model for three-phase magnetic flux leakage transformer, and its magnetic behavior are presented in II. Suitable Matlab Simulink circuit model for simulation transformers are shown in III, to validate this model by carrying out tests and verification of simulated models is submitted in IV. Comparisons results are presented in VI. Finally, conclusions closed the paper.

2. MODELING OF HIGH VOLTAGE THREE-PHASE POWER SUPPLY FOR MGT

2.1 An Overview of Proposed Model

The cross-section for core type MFLT is a rectangular shape as shown in fig.1, which is a typical high voltage transformer (HVT) core structure used for stable power supply applications.

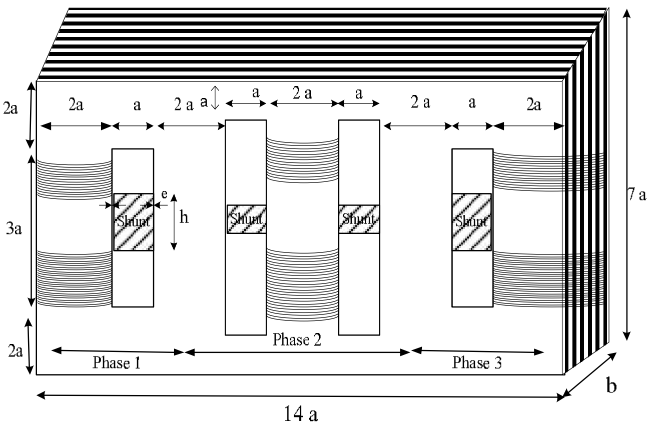

Figure 1: Investigated shapes of three-phase MFLT.

The core is made by stacking varnished laminations of silicon steel SF_{19}. Either copper is used as conductor material.

The primary and secondary windings are wound around the outer of the core legs. The flux leakage flowing in the in three portions (primary, secondary and magnetic shunts). In contrary to the ordinary transformer, the flux flowing in shunt could not be ignored. There is a vertical shunt placed in the middle of each phase, it composed of silicon steel sheets. The importance of shunts is to provide magnetic flux lines, which foliated along the direction to decrease the iron loss. The air identical gaps presents small thickness at each end of the shunts, which provide for different flux densities in the primary and secondary portions of the centre leg.

2.2 Equivalent Electrical of Power Supply of Three-Phase HV system

The graphical of electric representation based on the modelling of each phase using magnetic and electrical equations [2],[4], led to draw the equivalent electric model of HV transformer with magnetic shunts portion referred to the secondary side as presented in figure 2.

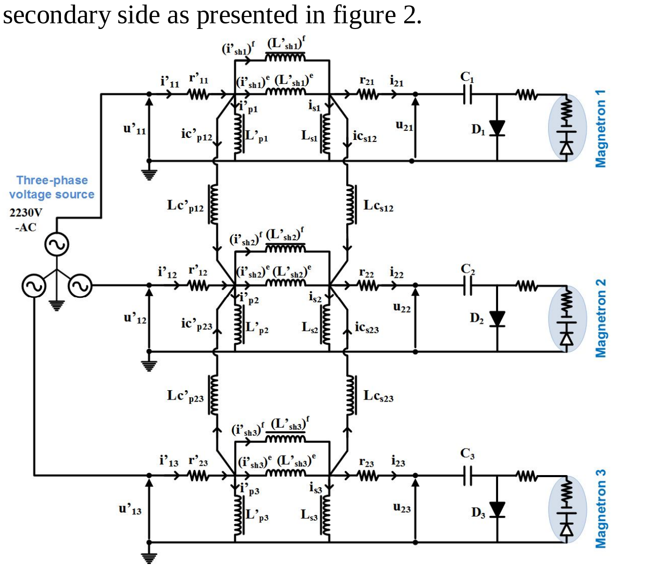

Figure 2: Electrical circuit of π quadruple equivalent of power supply referred to the secondary side.

This model is composed of non-linear inductances with an iron core which related directly to the reluctance (R) of a precise part of the magnetic circuit. The inductances L_{Pj} related to the primary reluctance R_{Pj}, L_{Sj} are related to secondary reluctance R_{Sj} of the magnetic circuit portions, and L_{Shj} is related to the reluctance R_{Shj} of the magnetic circuit including the shunts. The immediate interest of this model is to be able to attribute at each nonlinear inductance a ”flux-current” relation in the form $n_2\varphi(i)$, deduced from the geometrical parameters of a specific magnetic circuit portion of the transformer, thus allow us to reflect its real behavior in nonlinear mode.

3. MATLAB SIMULINK CIRCUIT MODEL

The modeling of the high voltage part is done to check the inputs to the MGT. These parameters should lie within the rated capacity of the MGT. The high voltage supply model has been made by using a Simulink software “MATLAB R2016a”. The Simulink model and the subsystems are shown in figure 3, figure 4, figure 5, figure 6 and figure 7, respectively.

3.1 Nonlinear inductance model

The modelling of the non-linear inductance could be implemented as a controlled current source, where current is a non-linear function of voltage as shown in figure 3.

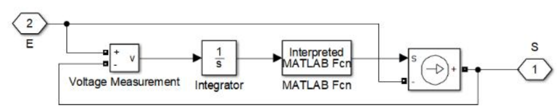

Figure 3: Matlab Simulink circuit of nonlinear inductance.

This model uses two Simulink blocks are a MATLAB Fcn block implementing the saturation characteristic $i = f(\varphi)$. An integrator block computing the flux from the voltage input. All those elements used to establish the π quadruple non-linear model, that have been grouped in a subsystem named magnetic flux leakage transformer as shown in fig.4.

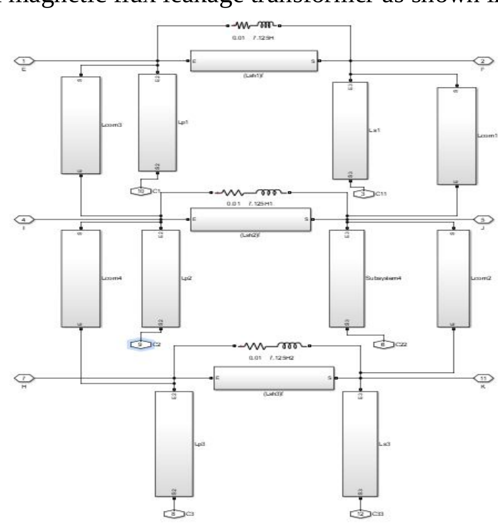

Figure 4: Matlab simulation circuit of π quadruple model triphase nonlinear inductances.

3.2 Curve fitting of BH for SF19 material

In this section, we present a simple mathematical expression, which enables the representation of our magnetization curve for the material used SF19, the problem has been to covering all operation data from the origin to saturation by a single function, with a minimum error over the whole range to obtain more accurate curve fitting.

Curve fitting is a technique of analysing an experimental curve, consisting in constructing a curve from a mathematical function and adjusting the parameters of this function to approximate the measured experimental curve, provided by the manufacturer of magnetic sheets of ferromagnetic materials SF_{19} used in the manufacture of the transformer [1],[2],[4],[7-9].

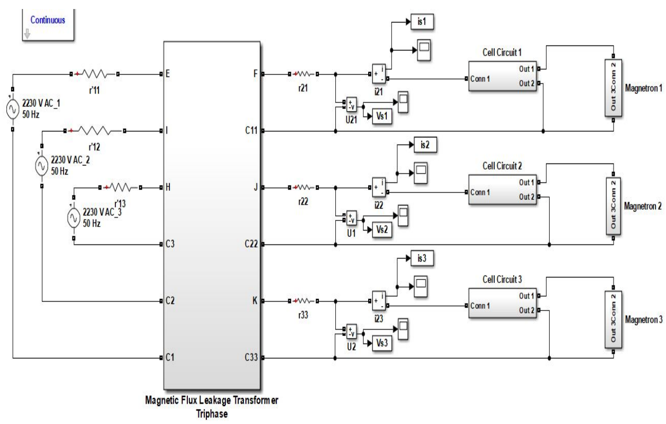

Figure 5: Matlab Simulink model of high voltage supply for the MGT.

Figure 5 shows the Matlab Simulink Model circuit of the microwave oven, which includes voltage doubler circuit as shown and magnetic flux leakage transformer triphase with nonlinear inductances. Nonlinear inductance cell composed of capacitance and diode. A voltage source is used to give supply to the π quadruple model of a non-linear transformer or single-phase leakage flux transformer. The nonlinear inductance of the magnetic circuit is the function of the reluctance.

3.3 Matlab Simulation Circuit of Voltage doubler cell and MGT

Figure 6 shows the Matlab model circuit of the MGT, which includes resistance, a diode, and a DC voltage source.

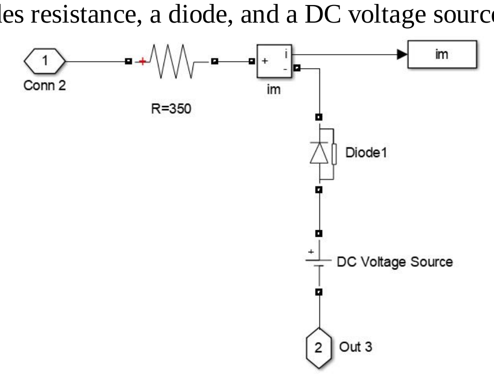

Figure 6: Matlab simulation circuit of MGT.

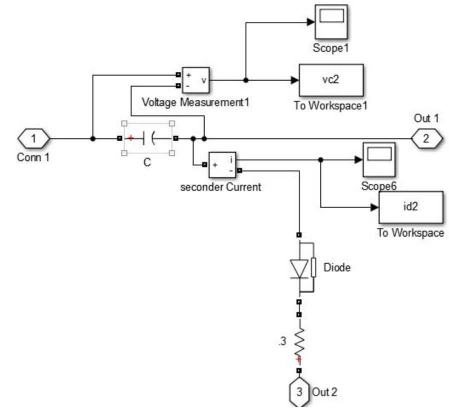

Figure 6: Matlab simulation circuit of voltage doubler cell.

3.3 Simulation waveform's voltages and currents

The simulation with MATLAB-Simulink of the nominal electrical operation of the assembly presented in fig.8. It allows obtaining the time curves of the voltages the currents. The simulation results of transient voltage and current waveforms are compared with the experimental test waveforms obtained from a single-phase power supply for a MGT. We confirm the constraints imposed by the manufactures for full-power operation (I_{avg} = 300mA, and I_{max} = 1A).

Each MGT operates at rated speed (220V and 50Hz from source), the electrical signals in the diode, the capacitor, the MGT, and the secondary side have the same shape as those of obtained from a conventional single-phase power supply for one MGT. These signals are not sinusoidal but periodic and they are phase-shifted 120°.

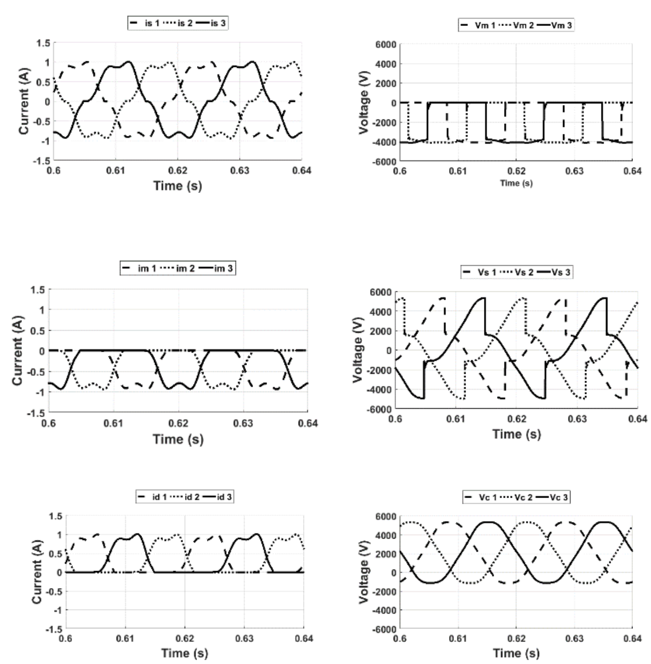

Figure 8: Simulink waveforms of voltages and currents of HV supply for MGT in steady case.

Figure 9 shows the energy balance of the three-phase HV for MGT per phase. It presented the value of the instantaneous power at the terminal of each MGT. It allows to determine the average power curve during a period which equals P_{avg} = 1156.6W.

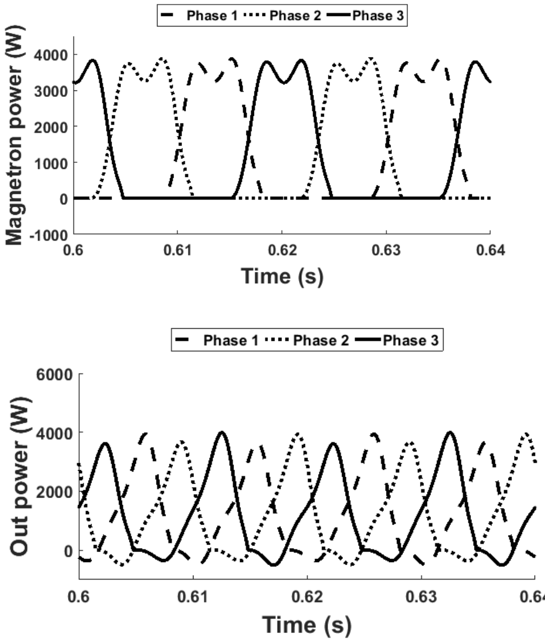

Figure 9: Simulink waveforms of instantaneous power high voltage supply for MGT in steady case.

4. EXPERIMENTAL RESULTS

To validate the aforementioned proposed model, by realize tests that have been set up previously [7-9]. An actual low power MGT is experimented and analyzed, with different load conditions. A generator microwaves supply are composed of the following elements:

- A magnetic flux leakage transformer: f=50 Hz, S=1650 VA, U_1=220 V AC, and, no-load U_2=2330 V, r_1' =100 Ω , r_2=65 Ω, n_1=224 and n_2=2400.
- A voltage doubler capacitor C=0,9μF and a DHV (diode high voltage).
- A MGT, its equivalent circuit is composed in series of dynamic resistance R=ΔU/ΔI, its value is close to 300Ω, cutoff voltage 4000V DC and diode.

Figure 10: Experimental arrangement for the testing of microwave oven.

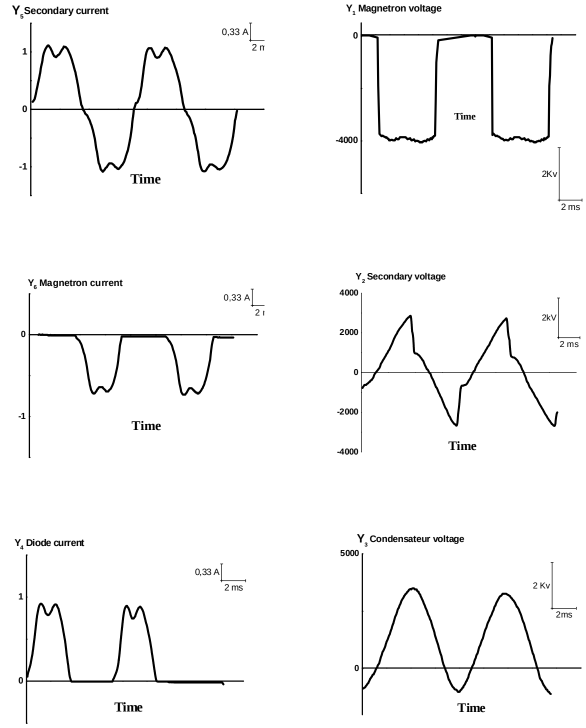

Figure 11: Experimental waveforms curves of the voltages and currents waves of single-phase HV supply for MGT in nominal operating.

5. SIMULATION AND ANALYSIS THE EFFECTS OF THE MGTS FAILURE

This section discusses the simulation under no-load condition, to analyze the performance of the system during the nominal operation of the power supply with three MGTs, using MATLAB-Simulink. The observation of the currents, powers and voltages curves allowed analysing the characteristics of the HV circuit, especially the MGTs current.

The first phase is directly open and not connected with the external circuit, to study the no-load performance of the system.

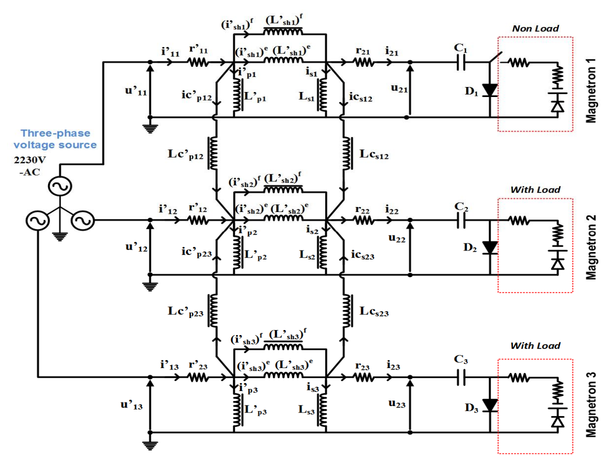

Figure 12: Electrical circuit of π quadruple equivalent of power supply referred to the secondary side under non-load condition.

The results of MATLAB-Simulink simulation of the assembly shows the simulation results from 60ms to 64ms.in fig. 13. It was observed that the faulty MGT decrease the functioning of its voltage doubler cell.

In case of the two phases, the operating point of each of the two functional MGT is not affected. The failure of one MGT does not affect on the operation of the remaining MGTs.

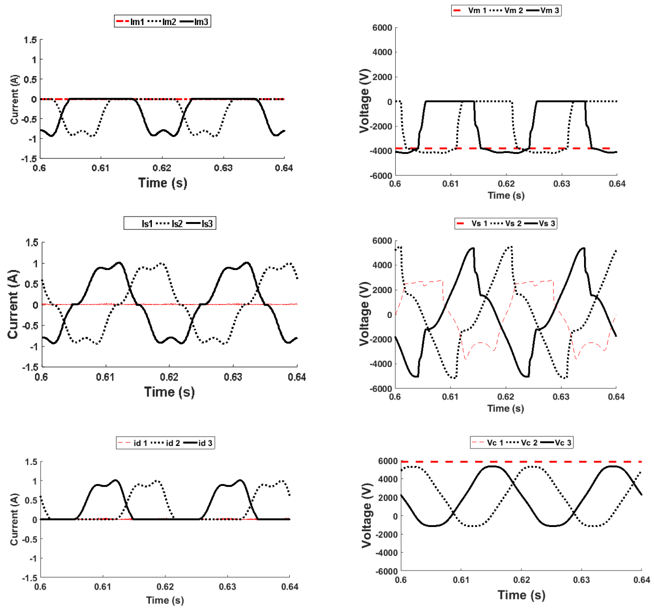

Figure 13: Waveforms of simulation results for voltages and currents of high voltage supply for MGT in non load case.

The results of simulation energy balance present the effects of the faulty MGT on the functioning of its average power and instantaneous power in case of one MGT OFF and the other are ON, we observed that this faulty doesn't have any effect on the other MGTs and are working in normal function.

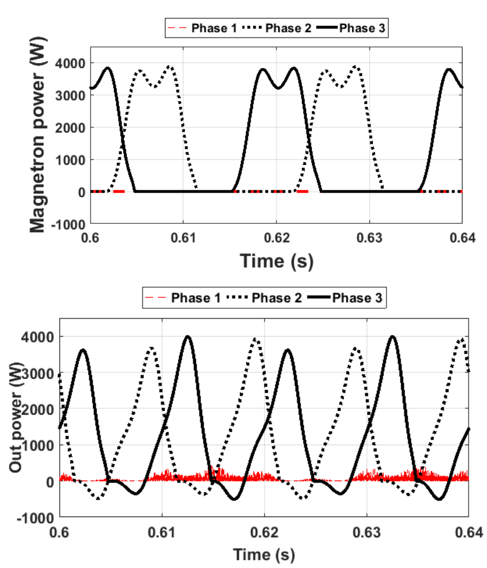

Figure 14: Simulink waveforms of instantaneous power high voltage supply for MGT in non-load case.

6. RESULT AND DISCUSSION

In the previous sections, the correctness of the simulated model is demonstrated. In this section, the obtained simulation results of Matlab Simulink for the proposed model is compared with the single-phase's results model of conventional MFLT of laboratory tests via through simulation of the same condition. In order to perform this comparison, the power supply simulation is done via both conventional and proposed model with a review of the performance of lower MGT s. In order to obtain the maximum flow of microwave power, it suffices to change the defective MGTs with a new one.

The main results of this paper can be illustrated as follow:

1) Modelling a global π quadruple model with Matlab Simulink of HV generator microwave
2) The obtained results of the simulation for power supply are in accordance with the experimental waveforms obtained from a single-phase power supply for one MGT.
3) The failure of one MGT does not affect the operation of the remaining two functional MGTs in the other two phases. The operating point of each of the two functional MGT s is not disrupted.

7. CONCLUSION

This paper described the feasibility study, using MATLAB-Simulink, of the nominal operation of three-phase HV power supply for microwave generators with one MGT 800Watts per phase, so that can deliver 2400 Watts of useful power at 2450 MHz.

The modeling and simulation of high voltage supply to the MGT has been implemented in the MATLAB Simulink environment. to analyze and improve the system performance. It reveals that the input parameters to the MGT are within the limit and the values are verified experimentally.

Experimental data confirmed the simulation results and gave good stability performance. Thus the proposed MFLT model is correct and effective, providing an important aid for the designer. It is also very conducive to optimizing the design of such transformers and power supplies and improves the efficiency of the overall system.

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