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PARALLEL OPERATION OF CONVERTERS FOR INDUCTION HEATING

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ABSTRACT

This article presents an induction heating converter simulation and parametrization. The observed converter is used for induction hardening of different details. It consists of two equal units, supplying power to a common load. Converters' system simulations are performed by using as a load a system inductor-details with certain dimensions. As a result from the simulations the requirements to the converter control system are defined. Driving the converters according to these requirements will help achieving constant power in the load during the heating process. Load parameters are a function of the heated detail's layer temperature.

INTRODUCTION

In the article an induction heating converter operation is investigated. The converter system consists of two identical units, working in parallel. Each unit is a single switch resonant inverter. Inverter's modes of operation are investigated. A simulation model is generated and parametric analyses are performed. Parametrization of the system is the output of the performed simulations and investigations.

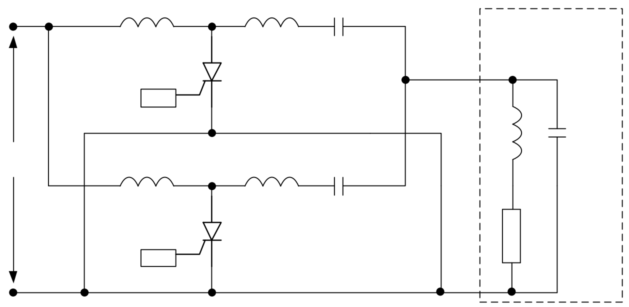

Fig. 1. Resonant converter for induction heating

The converter's schematics is given on figure 1. Two identical converter units are working in parallel and are supplying power with initially defined parameters to a common load.

Different types of resonant converters can be used as power sources [1, 2, 3], each of them having its advantages and disadvantages. Paralleling two or more low frequency induction hardening converters is a possible scenario [4, 5]. The goal is achieving specific load power and ensuring sufficient recovery time to the switching components.

A two unit converter system is under investigation. One of the most critical parameters is the thyristor reverse voltage, which ensures sufficient recovery time. Different modes of operation of the converter are possible. Those regimes are functions of the time that each of the thyristors is turned on. In one of the investigated modes the long recovery time ensured, leads to very high reverse voltage across the component. Respectively, decreasing the recovery time results in lower reverse voltages [6].

As the processes in the converter are very complex, due to the higher number of the reactive components, an LTSpice simulation model of the converter is created and used for performing the investigations.

Another approach to analysis is by reducing to base circuits [7]. Parametric analyses for several modes of operation are performed. Two of them are presented in details, later in the article. Simulations performed use parallel equivalent schematics of the system inductor-load (Lt and Rt). Three different point of operation (Cold detail, close to Curie point and above the Curie point) are present on the following figures. Schematics' components are not tailored, because the goal of the work is to present the basic functions of the converter.

SIMULATION RESULTS

Figure 2 shows the simulation results for the currents via the two inductors Lzar1 and Lzar2, respectively I(Lzar1) and I(Lzar2), the voltage across the thyristor Th1 and the current via the load – I(Lt). One of the selected modes of operation is characterized by load voltage reaching zero value before next thyristor is turned on. This is visible from the I(Lt) graphs. Another observed parameter is the thyristor recovery time. During this interval the positive half wave of the high frequency oscillations have to remain below zero. Simulation results are given on figure 3.

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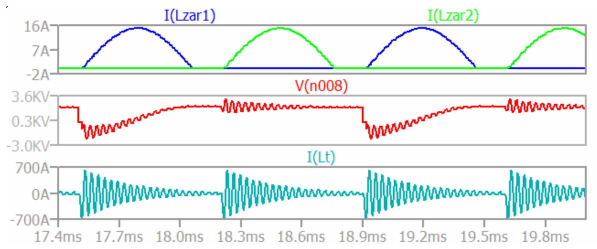

Fig. 2. Simulating results at mode №1

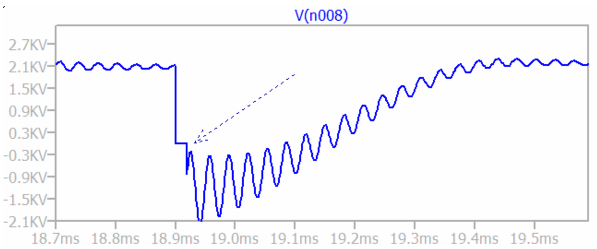

Fig. 3. Voltage across the thyrystor Th1

Figure 4 shows the relations among I(Lzar1), current via the thyristor I(Th1) and the voltage across the load I(Lt).

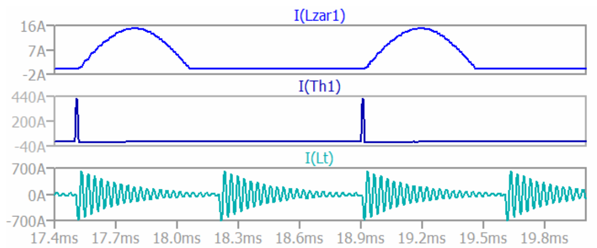

Fig. 4. Simulating results at mode №1

The other mode of operation under investigation presents turning on the following thyristor, before the load voltage reaches zero. Figure 5 shows simulation results, similar to figure 2.

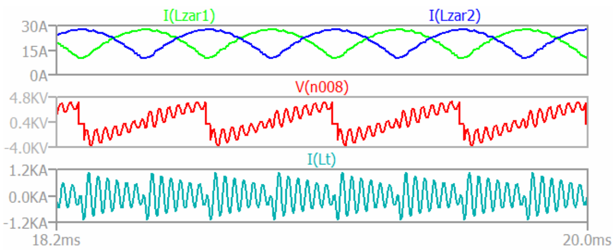

Fig. 5. Simulating results at mode №2

As visible from the graphs of the currents via the inductors Lzar1 and Lzar2, are continuous, having bigger values. This is how the load power can be increased.

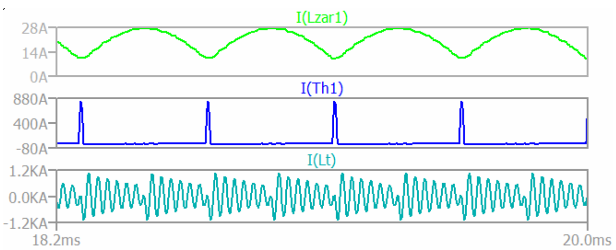

Fig. 6. Simulating results at mode №2

Figure 7 presents the thyristor voltage in this mode of operation (thyristors are switched before the load power reaches zero).

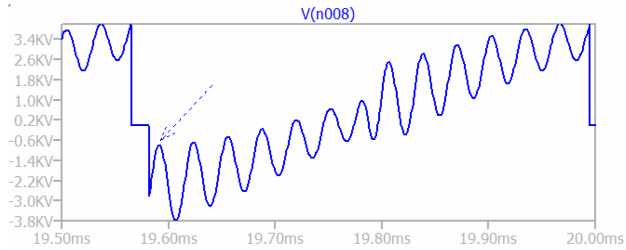

Fig. 7. Voltage across the thyrystor Th1at mode №2

Here the goal again is ensuring sufficient recovery time for the switching element. As visible from the graph both forward and reverse voltages across the thyristors increase.

As mentioned in the Introduction, load parameters change as the temperature of the heated detail increases. By using the LTSpice simulation model the first mode of operation (next thyristor is fired when the load voltage reaches zero) is investigated in more details by adding load variations, in function of the heated detail's temperature.

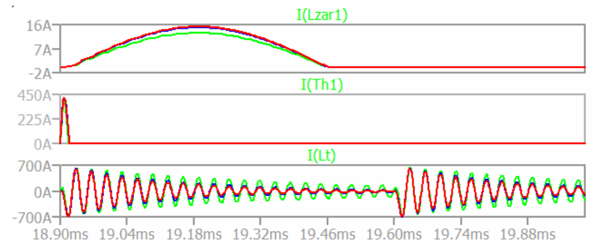

Fig. 8. Results at parametric analysis and mode №1

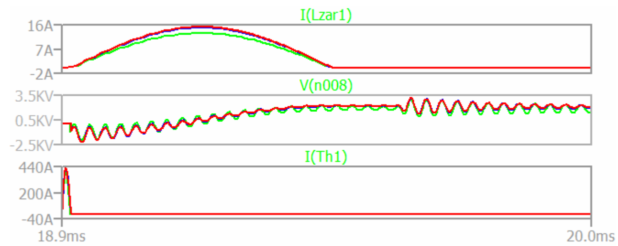

Fig. 9. Results at parametric analysis and mode №1

Figures 8 and 9 show simulation results for the first mode of operation in function of the load parameters for different temperatures of the heated surface. It is visible that increasing the temperature of the treated detail, leads to small parameters' variations.

Same simulations are performed for the second mode of operation (next thyristor is fired before the load voltage reaches zero). Simulation results are presented on figures 10 and 11.

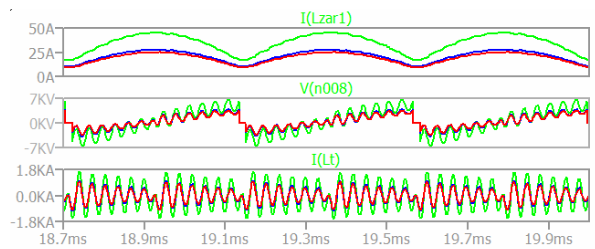

Fig. 10. Results at parametric analysis and mode №2

It is obvious from the graphs on figures 10 and 11 that the power consumed from the source and the voltage across the switching elements increase, unlike some inverters with constant output power [8].

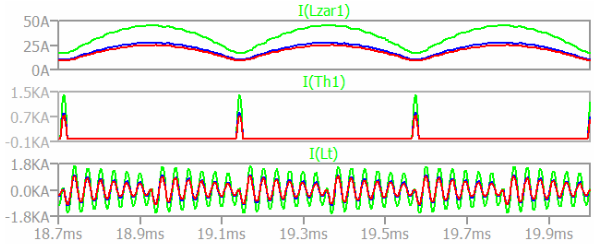

Fig. 11. Results at parametric analysis and mode №2

Figure 12 shows the voltage across the thyristor Th1 in function of the load variations, for three different surface temperature. Load frequency is kept the same.

- cold detail – green graph
- close to Curie point – blue graph
- above the Curie point – red graph

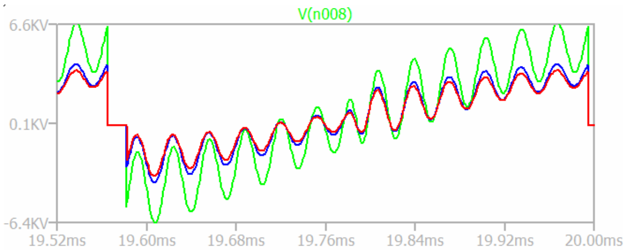

Fig. 12. Voltage across the thyrystor Th1at mode №2 and different load parameters

CONCLUSION

The article presents simulation results for different modes of operation of the schematics shown on figure 1. From the analyses performed it is visible that load parameters are almost constant for the first mode of operation (next thyristor is fired after the load voltage reaches zero). In this mode the energy consumed from the power source has worst parameters.

For the second mode of operation (next thyristor is fired before the load voltage reaches zero) the load parameters have higher influence on the current and voltage variations. To be able to decrease these values and reach the safety operation levels another mode of operation is to be defined. Different values for Lzar, Lp and Cp are to be calculated, as well.

All simulation results are for Eo=500VDC power supply voltage. This voltage is to be decreased for specific intervals of the heating process.

Firing signals' frequency is constant for all modes of operation and no feedback is taken into account during the simulations. Simulation results show that the control system (CS) needs to take into account the voltage across the load when calculating the time of firing the next thyristor.

To ensure thyristors' safe operating voltages it is recommended to calculate and drive the thyristors for the first mode of operation.

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