Specific Aspects Regarding Coupled Numerical Modeling of Inverter and Load Equipments in an Induction Heating Installation

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Abstract ***– The most propitious projection of inductive electrothermic installation requires a deep study of coupled electrothermic and circuits problems; therefore the present paper follows the same line. Research in specific literature have emphasized that induction heating has a much higher efficiency if the supply of the charge (inductor – piece) is done at frequencies other that industrial one. [1]. Due to material alter depending on temperature and, implicitly, the variation of the electrical parameters of the heating installation it is necessary to tackle the projection of these inductive electrothermic installation projected through coupled numerical modeling of the inverter circuit and of the heating through induction process. The paper presents the numerical modeling of the continuous current – alternating current conversion bridge (inverter) with elements of static switch – over, the type of command signal (PWM) of elements of static switch of power, the numerical modeling of the heating through electromagnetic induction process and aspects of correlation regarding the functioning/ working of the installation depending on the parameters of the load. The parameters get modified due to material alter depending on temperature during the heating process.***

Keywords: ***invertor, induction, electromagnetic, thermic.***

I. INTRODUCTION

Numerical modeling is extremely useful when we study the heating installation through electromagnetic induction, because it offers/ gives graphic representation/ plotting of the variation in time of electrical parameters of charge supply, the distribution of electromagnetic field, as well as of the thermic filed in the semi-finished product to be heated depending on the electrical parameters of supply, the geometry of the inverter – piece system, and the material properties, [4], [5]. The growth and diversification of product consumption, respectively the decrease of row material reserve, leads to a bitter development of processing technologies of row material and a continuous necessity of quality improvement through optimization methods including the cut in making and functioning costs. The control of heat by electromagnetic induction is done depending especially on the penetration depth oh the electromagnetic field in the semi-finished product. Starting with this relation, the penetration depth will get altered through frequency alteration and, finally, the layer where heat develops in the piece gets altered. The industrial supply of voltage, low, medium or high tension has a 50 Hz frequency. In order for this voltage to be altered according to technological process requirements, different frequency alteration methods are used, such as the ones that use rotative converters, ferromagnetic frequency multipliers and static converters. Technology development imposed in the power electronics field more and more stable and better static commutation elements, leading to lower production costs and higher output of continuous current – alternating current and conversely conversion installation. The power MOSFET static commutation element is an electronic device, very common in the construction of power commutation sources due to developed performances comparing to a bipolar power transistor. These performances can be shortly presented as it follows: high commutation speed, the commutation time is independent from the charge circuit and temperature variations and high value entrance impedance. The inductive electrothermic heating installation is theoretically presented in fig 1, where the following can be observed: the AC-DC converter, the continuous tension filter, the AC-DC converter (the inverter) and the inverter load (inductor – piece) adapted series represented by R-L-C circuit.

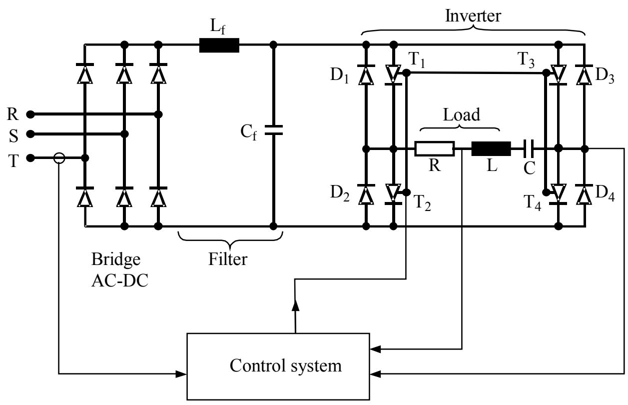

Fig. 1. Electrical scheme of the induction heating installation.

Converters that have a series compensated load are characterized by the simplicity of the command and force circuit. The oscillatory transitory conditions of the inverter imposes the following inequality between R and L parameters of the electrical scheme, equivalent to the load and the C capacity of the condenser:

$$C \le 4 \cdot \frac{L}{R^2} \quad (1)$$

The shape of the electrical power curve through load is influenced by the remaking time of used static commutation elements, meaning the length of the passing through zero lapse of time of the electrical power that crosses the static commutation elements of one part of the inverter bridge. The emergence power can be modified through a PWM command strategy if the commutation frequency is kept constant. This type of modulation is used in order to eliminate the superior order harmonics until a certain order. The higher number of pulses in a longer period, the more harmonics can be eliminated. The breadth of the impulses has to be a sinusoidal function of the position angle of the upper mentioned impulses, measured from the very start of a semi-alternation. The command of static commutation elements is basically done with the help of two functions: an "*f*" frequency sinusoidal function (the frequency of the voltage on heated load) with an adjustable "*A*" amplitude; and a triangular function, of an "A_t' amplitude, that has the frequency:

$$f_t = 2Nf \quad (2)$$

The opening and closing impulses depend on the value of the fundamental that needs to be realized at the inverter emergence, and it has to achieve the canceling of the lower than "*2N*" order harmonics. The maximum number of "*N*" impulses that can be obtained in a semi-period is limited by the maximum frequency switches can work at, considering the fast growth of commutation losses, simultaneous with the frequency growth.

An adequate command of an in bridge type inverter with an R-L-C load has to take into account the power stored in a coil, and to find a convenient way of power leaking. The voltage on the load is formed by PWM impulses, and current shall have sinusoidal form according to the number of PWM impulses and modulation. The PWM technique of command, done through elimination of harmonics until a certain order, also adjusts the power. These are important advantages that justify the use of this technique, although it needs a more complicated command respectively protection device and fast semi conductive devices. The technological progress that has been made regarding the command part (specialized integrated circuits), as well as semi-conductive devices of power turn this technique of command into a more and more attractive one. The working diagram of coupled numerical modeling of the circuit problem with the induction heating process is presented in fig 2. Time period is increased until the final heating time. Every time period means an upgrade the material properties, fact that leads to modification of inverter load parameters.

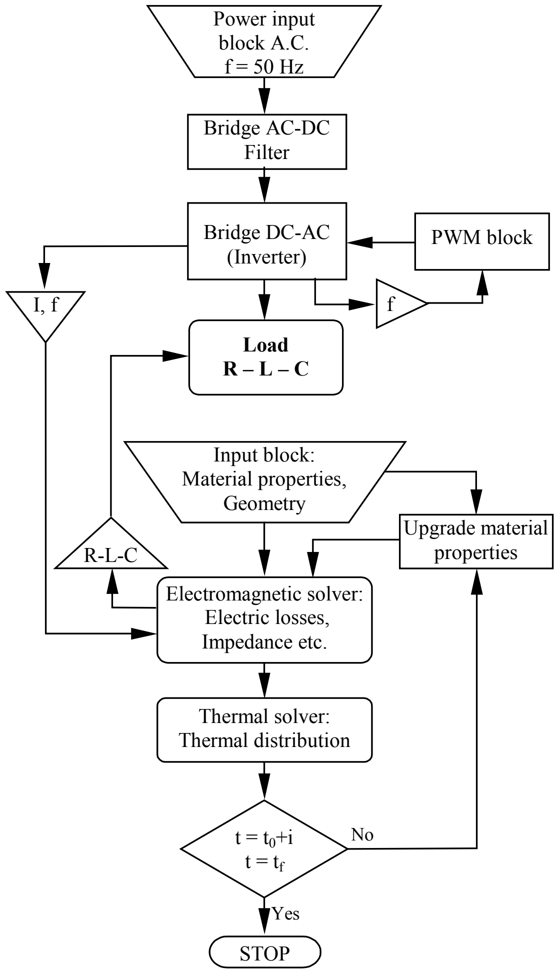

Fig. 2. Working diagram of the induction heating installation.

II. NUMERICAL MODELING AND RESULTS

Numerical modeling is a strong instrument of process and phenomena analysis. Nowadays, using IT technique it is easy to evaluate solutions and to find new ways of adjustment to optimize a phenomenon or process. Numerical modeling for the inverter circuit simulation has been realized using the Matlab-Simulink program, and the numerical modeling of the heating process with the help of special soft programs, dedicated to heating by induction: Elta, Flux.. MATLAB is a high tech program package, dedicated to numerical calculation and plotting in science and engineering.

This program puts together numerical analysis, calculus of matrix, the processing of signal and plotting, in an easy-to use and easy-to-learn environment, where the statement and the result of the problems are expressed as simple and natural as possible, in a mathematical manner, no need of traditional programming.

The straightening of industrial frequency is being realized with the help of a bridge circuit, with four commanded commutation elements – fig 3. Fig 4 presents the form of the signal from the industrial network and rectified continuous voltage.

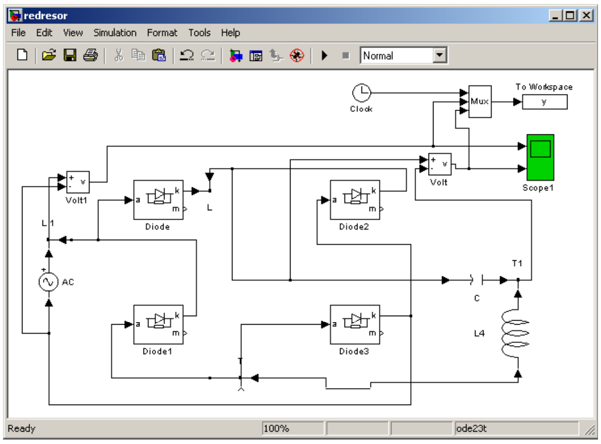

Fig. 3. Scheme of AC-DC bridge and straightening filter.

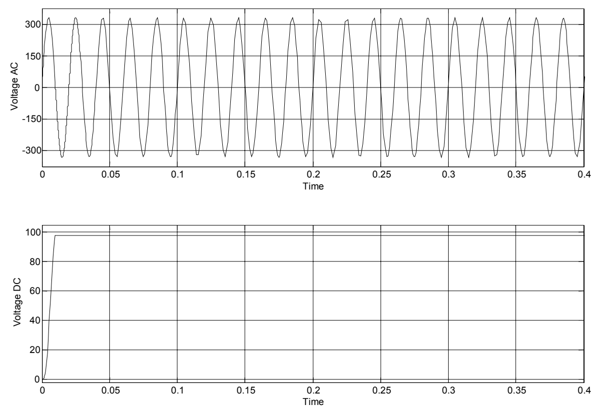

Fig. 4. The input and output form of the signal of AC-DC bridge.

General scheme of the command signals engendering of AC-DC bridge through PWM technique is presented in fig 5. Comparing the straightened sinusoidal alternative voltage in bi-alternation with a triangular voltage does the engendering of PWM command impulses with sinusoidal modulation. The result of the two signals comparison will be a triangular signal, length modulated. – fig 6.

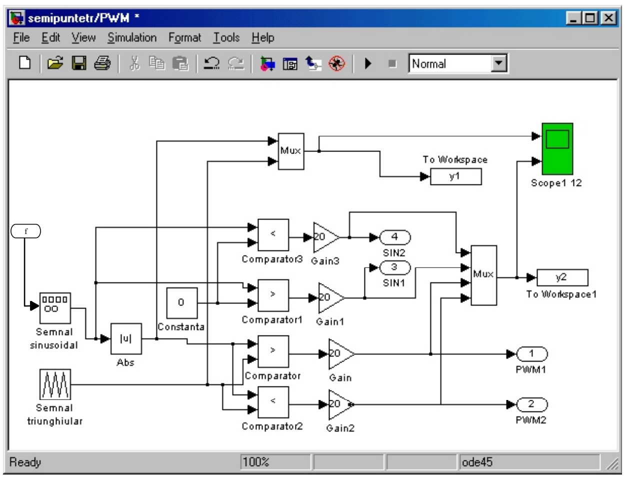

Fig. 5. Scheme of the PWM generator.

Inverter with MOSFET type static commutation elements is presented in fig 7

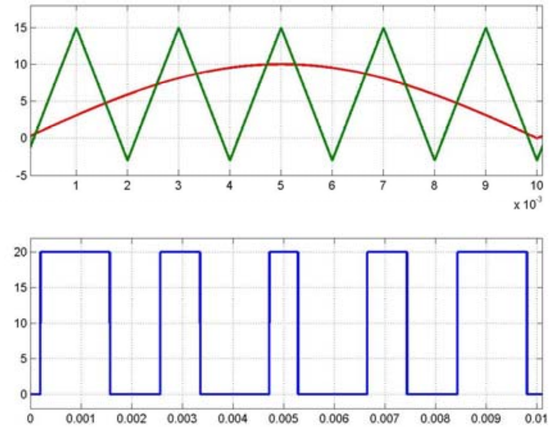

Fig. 6. Pulse width modulation – PWM.

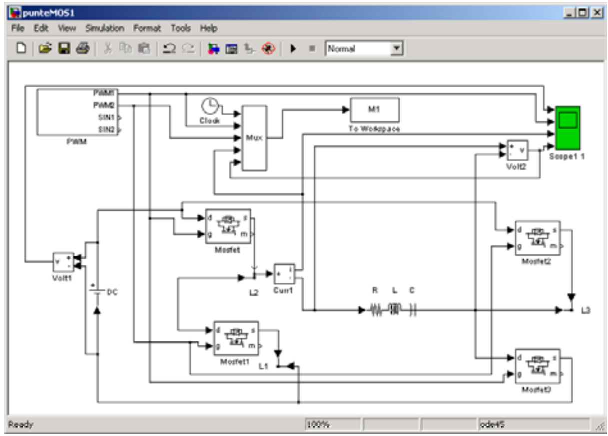

Fig. 7. Scheme of inverter.

The PWM command with sinusoidal modulation used to eliminate the superior order harmonics until a certain order. The fundamental working frequency is f = 1500 [Hz].

The inverter is simulated with MOSFET static commutation elements for two frequencies of the modulator 1000 Hz and 10000 Hz (eliminates harmonics until 1st respectively 12th order) .The results obtained for parameters R-L-C (R = $6{,}01\cdot10^{-3}$ [Ω], L = $5{,}37\cdot10^{-6}$ [H], C = $2088{,}8\cdot10^{-6}$ [F]) at the beginning of the heating process are presented in fig 8 and 9.

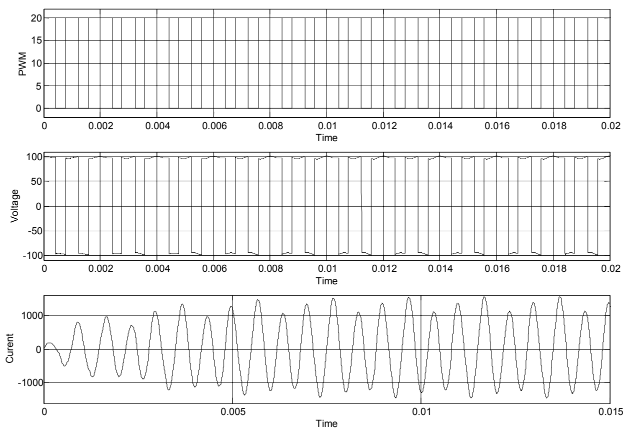

Fig. 8. The form of emergence signals of the inverter for f_t=1000Hz

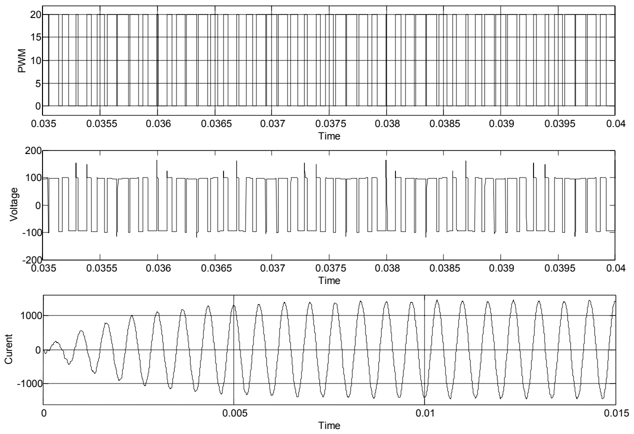

Fig. 9. The form of emergence signals of the inverter for f_t=10000Hz

The form of the current signal with 1500 Hz frequency presented in fig 10, generated by the inverter bridge is introduced in the numerical modeling soft of the induction heating process.

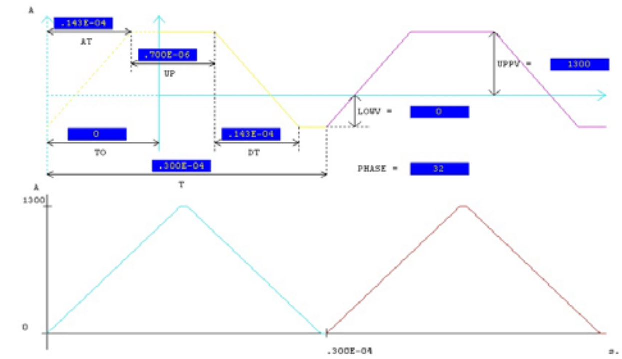

Fig. 10. Current signal, applied to the numerical modeling soft of the heating process.

Through the numerical modeling of the induction heating process results the output depending on time for the case where the PWM command eliminates harmony of order 1, fig 11. In fig 12, is presented the variation of the output depending on time for PWM command that eliminates harmonies until 12th order.

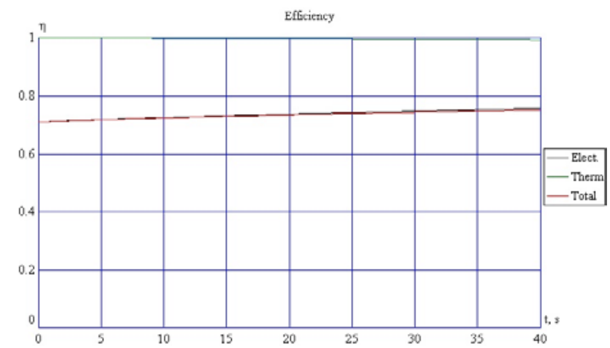

Fig. 11. The efficiency depending on the command PWM with f_t=1000Hz.

Variation depending on time and temperature during the heating process of the inverter load parameters are presented in fig. 13., 14., 15., 16., and 17.

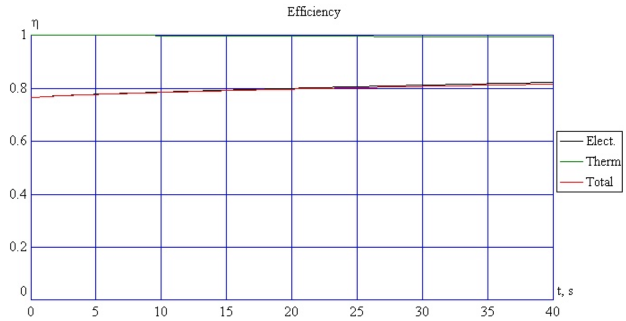

Fig. 12. The efficiency depending on the command PWM with f_t=10000Hz.

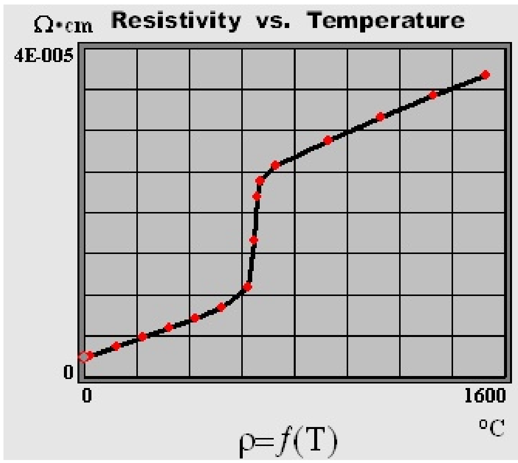

Fig. 13. The variation of resistivity depending on temperature.

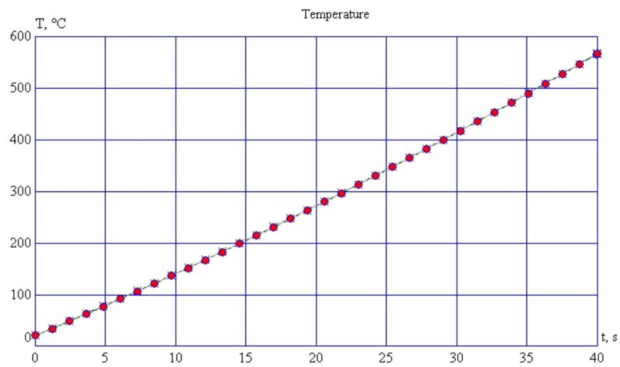

Fig. 14. The variation of temperature depending on time.

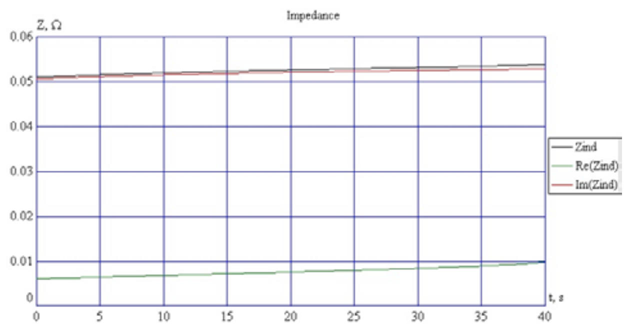

Fig. 15. The variation of impedance depending on time.

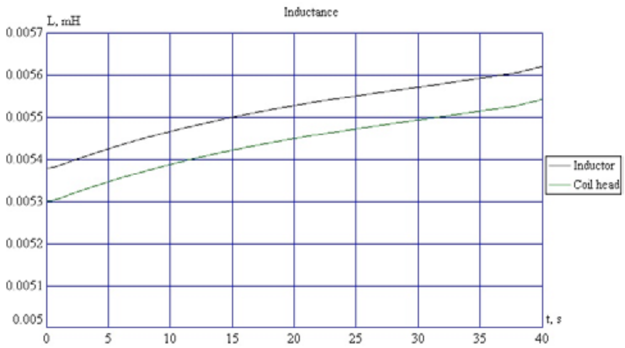

Fig.16. The variation of inductance depending on time.

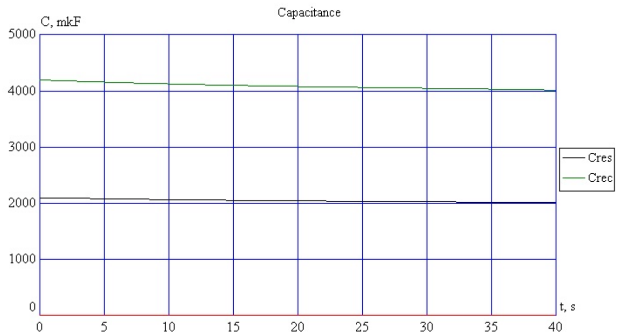

Fig.17. The variation of capacity depending on time.

Because, according to fig 16 and 17, the inductance and the capacity varies, the frequency of the fundamental will be constant for the entire time of heating through induction process. (fig. 18.).

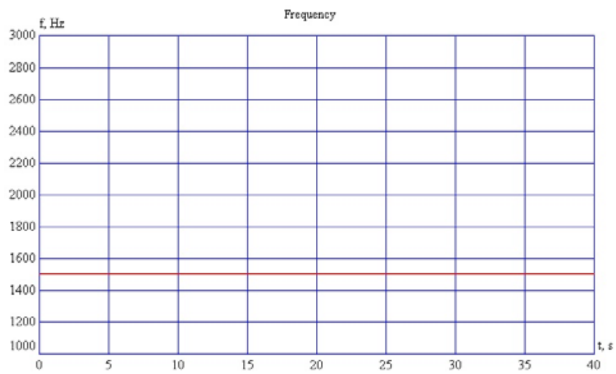

Fig. 18. The variation of frequency depending on time.

In this case of heating of a non ferrous semi-finished product, with material properties with linear variation depending on temperature, the numerical modeling of the load inverter circuit with parameters that alter depending on time and temperature, does not present, during heating process, important modifications of the emergence signal, different from the ones presented in fig 8 and fig 9.

III. CONCLUSIONS

The paper presents aspects of coupled numerical modeling of the inverter circuit, with an inductive electrothermic load. Using this approach technique of the projection of the heating through electromagnetic induction installation, the functioning of the installation can be optimized and we can emphasize certain phenomena that might show up during functioning time and affect the process. Optimizing the functioning of the induction heating installation leads to a growth in efficiency, decrease of production costs by making the right choice in necessary equipments and accessories. Through numerical modeling of the inverter circuit with the help of PWM command technique, the disturbing superior harmonics are reduced and the adjustment of power on the inductive load is done. The numerical modeling of the heating process emphasizes the change of circuit parameters of the load R–L–C) depending on temperature and time, and that is an advantage in numerical modelling of the inverter circuit in as close to reality functioning conditions as possible.

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