Microprocessor Control of Inductive Cumulation Inverter

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Abstract – **To achieve an optimal operation mode of a class of inductive cumulation inverters in the low frequency range the control need to be done in real time. Automatic regulation of the cumulation time duration is necessary to maintain an optimal mode, as the load parameters change dynamically (the object temperature). A variant of a microprocessor control maintaining an optimal mode is presented in the paper. Structure variants for the various blocks and criteria for selecting proper circuits are defined.**

Keywords – **microprocessor control, inductive cumulation, real time operation, time estimating.**

I. Introduction

In many workings out dealing with inverter operation control, various circuits are suggested, using specialized integrated circuits working as PWM regulators. These circuits do not have the needed flexibility; they do not react to the inverter mode changes in real time.

In order to achieve an optimal control mode, it is necessary to gather data about the inverter operation modes from suitable sensors in strictly defined control points in every moment.

It is necessary to measure the values of the controlled parameters [1], [3], to estimate them and to generate such control signals for the cumulation time in order not to exceed the admissible voltages and currents for the elements building up the inverter.

The real load parameters Z_T (R_T, L_T) must be taken into consideration, having in mind, that with increasing the temperature of the processed part (material) in real time, these parameters change fulfilling a certain law [1], [2].

At low temperatures the active load component has low values tending to increase. The reactive component remains constant in a considerably wide temperature range. That is why the quality factor of the inverter at the beginning of the technological process has big values:

$$Q_e = \frac{\rho_e}{R_e} = \frac{\sqrt{\frac{L_e}{C}}}{R_e} \qquad (1)$$

which can result in considerable increasing the voltage amplitude across the inverter reactive components, respectively across the transistor implementing cumulation.

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The major aim in the report is to develop an architecture of an inductive cumulation inverter microprocessor control.

Major problems solved in the report:

- To estimate the maximum time values for measurement, conversion and generating the control signals;
- To suggest proper ideas for gathering information about the inverter operation modes and for generating a control signal for the cumulation time;
- To coordinate the transient inverter processes with the control device operation in real time;
- To develop the structure of the inductive cumulation inverter control microprocessor device.

II. Formulation of the Task for Inductive Cumulation Inverter Control in Real Time

The basic circuit of an inductive cumulation inverter is shown in Fig. 1.

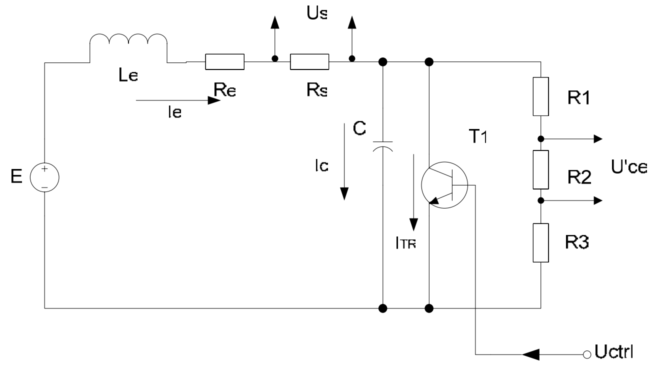

Fig. 1. Inductive cumulation inverter circuit

L_e equivalent inductance of the inverter resonant circuit (Eq. 2):

$$L_e = L_1 - L_{imp} \qquad (2)$$

R_e equivalent active resistance of he inverter resonant circuit (Eq. 3):

$$R_e = R_1 + R_{imp} \qquad (3)$$

R_s a resistor giving information about the value of the current in the primary circuit of the inverter;

C capacitance in the primary circuit;

T_1 transistor defining the energy cumulation in L_e;

U_{ctrl} control signal with duration τ , intended to switch on the transistor T_1;

U'_{ce} voltage, proportional on the voltage across the capacitor U_c.(Eq. 4):

$$U'_{ce} = U_c \frac{R_2}{R_1 + R_2 + R_3} \qquad (4)$$

The period of the inverter with cumulation is defined by two components (Eq. 5):

$$T = \tau + \tau_s \qquad (5)$$

Where:

τ is the time for cumulation;

τ_s time for inverter free oscillations.

The illustration of the transient process in the inductive cumulation inverter operation is shown in Fig. 2.

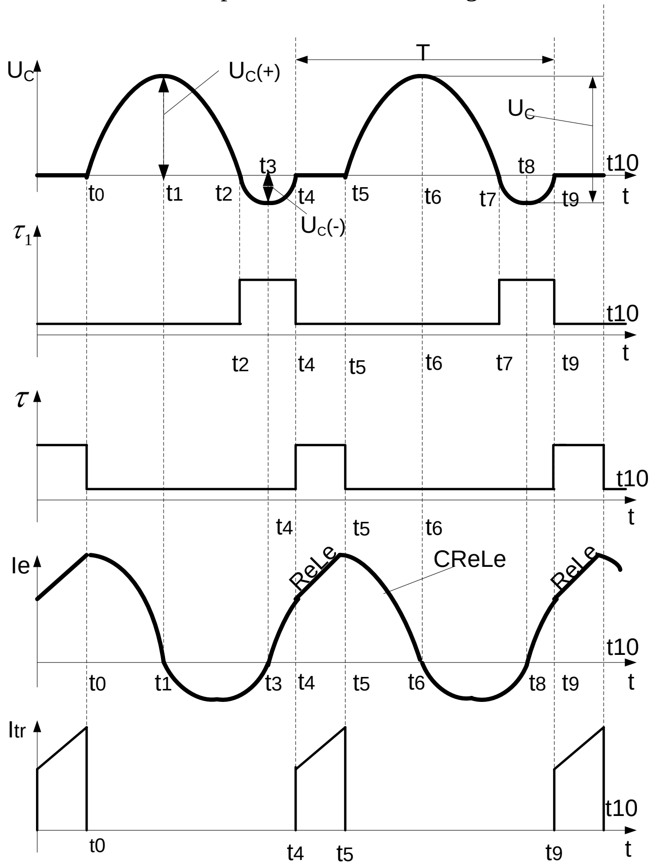

Fig. 2. Waveforms illustrating the typical moments of the transient process of the inverter

On the waveform for U_c the moment t_1 and t_6 from the transient process define the maximum voltage values, and the moment t_3 and t_8 define the minimum voltage values.

The inverter current trough the inductivity L_e and R_s for the above mentioned moments (t_1, t_3, t_6, t_8) becomes zero.

That is why the hardware defining of those moments has been made with zero current comparator, using the information from the resistor R_s.

It is necessary to start a fast ADC at those moments to define the value of the voltage across the capacitor (transistor) (Eq. 6):

$$U_c = U_{c(+)} + |U_{c(-)}| \qquad (6)$$

Thereby it is necessary to estimate whether the condition (Eq. 7) is fulfilled:

$$U_c \le k(U_c)_{\partial on} \qquad (7)$$

Where $0{,}9 \le k \le 0{,}95$ is a reliability coefficient;

$(U_c)_{\partial on}$ – the maximum admissible value of the voltage across the capacitor (transistor).

The moment t_4 and t_9 form the transient process set the beginning of the cumulation process (switching on the transistor) and the time constant of the circuit becomes *ReLe*. The hardware defining of those moments has been made by a zero voltage comparator basing on the information, got from the resistive divider *R1*, *R2*, *R3*.

The duration of the cumulation time τ has been determined automatically by software. The object function in the algorithm is emission of maximum power through the load without breaking the maximum admissible voltage and current values through the transistor.

The transistor current gains its maximum value at the end of the time intervals for the cumulation (the moment t_0, t_5, t_{10}).

As the current I_e through L_e and R_s and the current through the transistor I_{tr} during the cumulation time $(t_4 \div t_5), (t_9 \div t_{10})$ have got approximately one and the same value (Eq. 8):

$$I_e \approx I_{tr} \qquad (8)$$

and after (t_0, t_5, t_{10}) free oscillations through L_e, R_s and C begin, we can get information about the maximum value of the current through the transistor by single measurement of the current I_e at that moment. Therefore at the moment t_0, t_5, t_{10} the microcontroller will generate a signal to stop the cumulation and to start the measurement of I_{tr} by the second channel of the ADC, using the information from R_s.

III. Architecture of a Microprocessor Device Controlling an Inductive Cumulation Inverter

The control signal generated by the PWM (OUT 2) of the microcontroller has been connected to the input of the block, shown in Fig. 3.

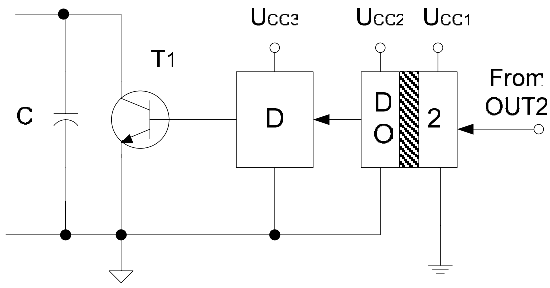

Fig. 3. Cumulation control signal block

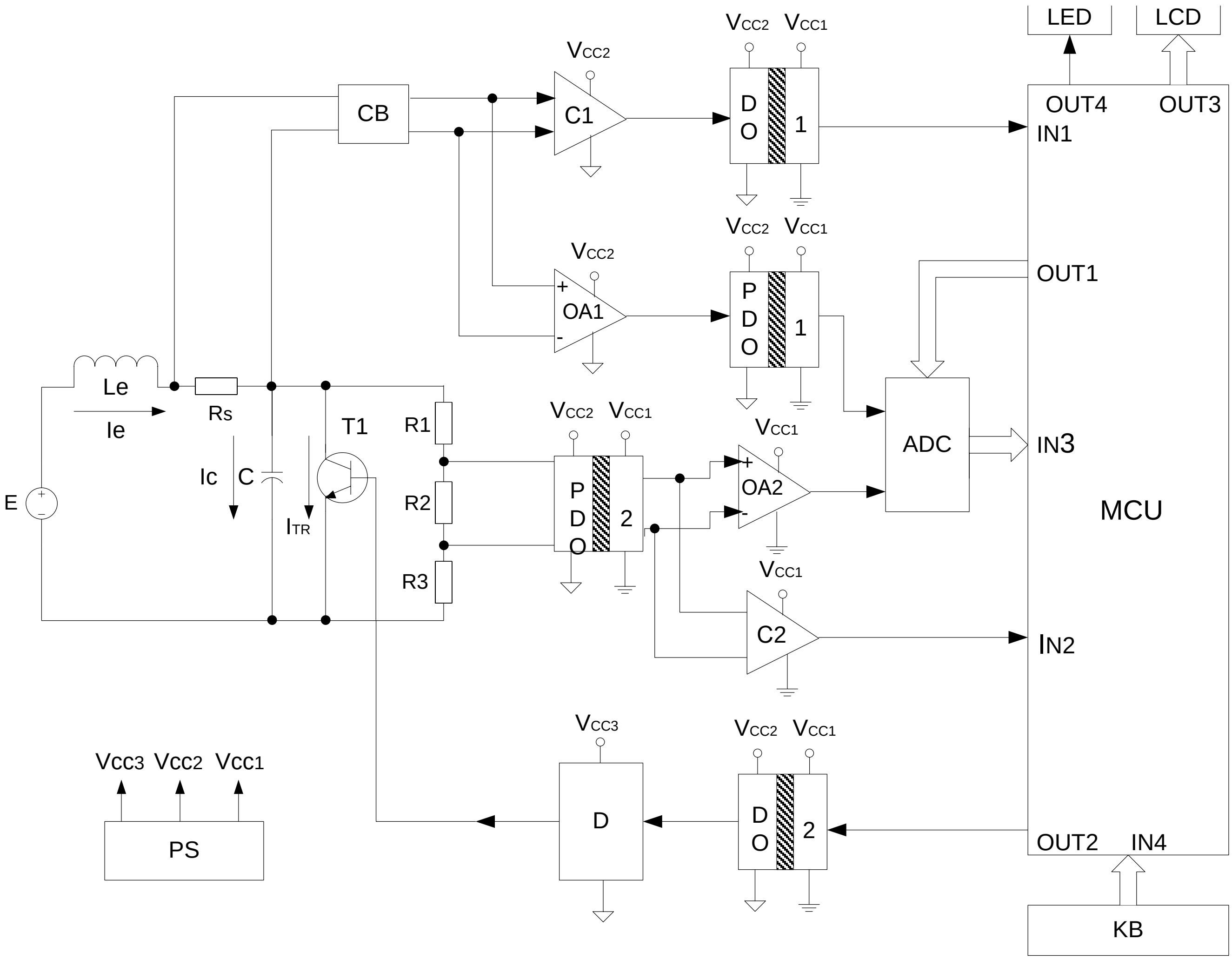

Fig. 4. MCU control device architecture of an inductive cumulation inverter

Using the results from the simulation in [1] for the transistor T_1 it is evident that $(U_{ce})_{0on} \leq 1200\ V$ and the current through the transistor is $(I_{tr})_{max} \leq 50\ A$. Hence BUP314 can be used.

As a driver, forming the signal for the transistor can be used the standard IC IR2113.

As a digital opto-coupler (*DO2*) making the galvanic isolation of the control signal, generated by the microcontroller, IC IL710 can be used.

The common time delay of the signal τ_{del1} can be calculated using the datasheets of the IC, used in Fig. 3, and the maximum time durations $(t_{on})_{max}$ and $(t_r)_{max}$.

The signal, formed at the moments t_1, t_3, t_6 and t_8 (Fig. 2), will generate an interrupt request on the input *IN1* of the microcontroller. The source of the signal is the voltage U_s across the resistor R_s (Eq. 9):

$$U_s = I_e \, . \, R_s \tag{9}$$

The time delay of that signal is due to the following blocks: Co-ordination Block (CB), Comparator 1(C1) and DO1, and its value is τ_{del2} (Fig. 4, Eq. 10):

$$\tau_{del2} = \tau_{CB} + \tau_{C1} + \tau_{DO1} \tag{10}$$

The digital values for the signal about the voltage U_{ce} across the transistor at the moment t_1 and t_3 will be received with delay τ_{del3} due to the blocks *PDO2*, Op-Amp 2 (*OA2*), *ADC* and the software delay for calculating the actual value (Eq. 11).

$$\tau_{del3} = \tau_{PDO2} + \tau_{OA2} + \tau_{ADC} + \tau_{sw} \tag{11}$$

That is why the voltage U_{ce} will be measured at the moments $t_1 + \Delta t$, $t_3 + \Delta t$, $t_6 + \Delta t$ and $t_8 + \Delta t$ instead of t_1, t_3, t_6 and t_8, where:

$$\Delta t = \tau_{del2} + \tau_{del3} \tag{12}$$

In order not to allow a flagrant measuring error it is necessary to select the elements, forming τ_{del2} and τ_{del3}, to be with proper parameters so that the Eq. 13 to be fulfilled.

$$\Delta t < \frac{1}{2}(t_4 - t_2) = \frac{1}{2}(t_9 - t_7) \tag{13}$$

The digital signal values of the current through the transistor I_{tr} at the moment t_0, t_5 and t_{10} will be formed with a delay τ_{del4} due to the blocks *CB*, *OA1*, *PDO1*, *ADC* and the program delay for calculating the actual value (Eq. 14):

$$\tau_{del4} = \tau_{CB} + \tau_{OA1} + \tau_{PDO1} + \tau_{ADC} + \tau_{SW} \quad (14)$$

So the current through the transistor I_{tr} will be measured in the moments $t_5 + \tau_{del4}, t_{10} + \tau_{del4}$ instead of t_5, t_{10}.

In order not to allow a big error when measuring the current through the transistor I_{tr} , it is necessary the elements forming τ_{del4} to be faster if it is possible.

The signal on the input *IN2* of the MCU will be late in relation to the moment t_2 and t_7 with τ_{del5} , due to the blocks *PDO2* and *C2*,

$$\tau_{del5} = \tau_{PDO2} + \tau_{C2} \quad (15)$$

so the actual moments are (Eqs. 16):

$$t_2' = t_2 + \tau_{del5}$$
$$t_7' = t_7 + \tau_{del5} \quad (16)$$

The inverter cumulation time $\tau = t_5 - t_4 = t_{10} - t_9$ is a function of the operation mode and will be discussed in another paper.

VIII. Conclusions

In this paper the following results are presented and systematized:

- An attempt is made to harmonize the transient processes in an inverter, operating in an inductive cumulation mode, with the operation of a control device working in real time;
- The maximum values of the times for measuring, conversion and generating control signals are estimated;
- An architecture of a microprocessor device controlling the operation of an inductive cumulation inverter is designed;
- Preconditions for making an algorithm of the inverter control process by regulating the cumulation time are found.

References

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