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DIGITAL CONTROL MODES OF THE SEMI-CONTROLLED THREE-PHASED RECTIFIERS

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ABSTRACT: In this work is presenting an interface circuit between a PC and a semi-controlled three-phsed rectifier. The circuit performs a numerical-analogue conversion using a CAN followed by a current-voltage conversion and a galvanic separation using opto-couplers that enter into a linearity circuit with the operational amplifiers. The output voltage is used to control the impulse forming circuits for the thyristor grids.
KEYWORDS: parallel port, numerical-analogue converter, opto-coupler, process control, power systems control, hybrid systems

❖ INTRODUCTION

The numerical management of the industrial processes acquired today new valencies, both following the evolution of the management concept, and especially following the large scale evolution of the integrated circuits technology (LSI) and on very large scale (VLSI) of the a microprocessors, microcomputers and minicomputers. Thus, the modern concepts regarding the process management, materialized in large classes of adjusting and management algorithms, become operational and efficient following the development of the hardware instructions and the microprocessors on which are implemented with special performances.

The progress obtained in the field of interface systems with the industrial processes, of the data acquisition systems, of conversion and primary processing, as well as of the drive systems allowed the extension of the fields of utilization numerical computation technique in the management of the industrial processes.

Taking into account the processes' diversity, their complexity degree, the performance requirements imposed by the management systems, the knowledge level of them, there have been developped and implemented structures of management systems with different complexity degrees compatible both with relatively simple problems regarding the processes' numeric adjustment and with complex problems of the process management by global performance criteria.

❖ WORK'S PRESENTATION - SEMI-CONTROLLED THREE-PHASED RECTIFYING BRIDGE

The application diagram is presented in fig.1.

The three-phase bridge is formed by the diodes D_1, D_2, D_3 and thyiristors Th_1, Th_2, Th_3. Between phases R, S, T there is a phase difference of 120°. The current through R_L is closing successively by Th_3 and D_2 then by Th_2 and D_1 and, finally, by Th_1 and D_3. The circuits β AA 145 having the terminals 16 connected together and the same control voltage in the terminal 8, they open the thyristors at the same conduction angle (considered against each of the three grid voltages).

The ignition impulses will be identical as duration but dephased in time by 6,66 ms (corresponding to the 120°). Under load, it appears a voltage of which shape is strongly dependent by the value of the conduction angle φ.

The average value of the rectified voltage in case of a rectifier with m phases becomes:

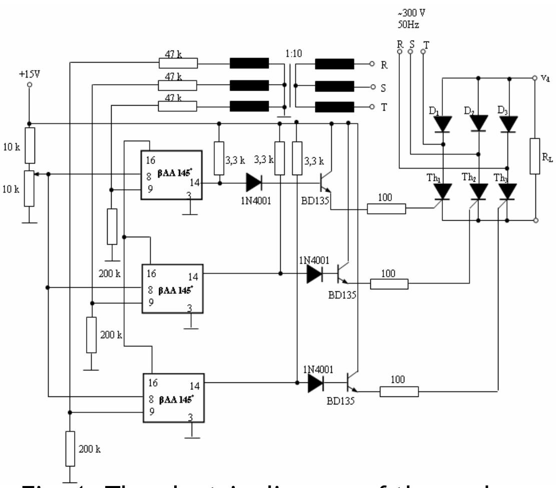

Fig. 1. The electric diagram of three-phase controll of a semi-controlled bridge

$$U_{d0} = 2\frac{m}{2\pi}\int_0^{\pi/m}\sqrt{2}U_2\cos\omega t d(\omega t) = \sqrt{2}U_2\frac{\sin\pi/m}{\pi/m}, \quad (1)$$

where U_2 is the effective value of the voltage in the transformer's secondary; the index ,,0" featuring the situation of an ideal rectifier.

The above relation is valid for m = 2, 3,…..

For $m \to \infty, \lim_{m\to\infty} U_{d0} = \sqrt{2}U_2$.

The effective value of the rectified voltage is calculated as follows:

$$U_{d0ef} = \sqrt{2\frac{m}{\pi}\int_0^{\pi/m}(\sqrt{2}U_2\cos\omega t)^2 d(\omega t)} \quad (2)$$

obtaining the expression:

$$U_{d0ef} = \sqrt{\frac{mU_2^2}{\pi}\left|\omega t + \frac{\sin\omega t}{2}\right|_0^{\pi/m}} = U_2\sqrt{1+\frac{m}{2\pi}\sin\frac{2\pi}{m}}. \quad (3)$$

when $m \to \infty, \lim_{m\to\infty} U_{d0ef} = \sqrt{2}U_2$.

An important issue arisen in case of the power application is to insure the protection of the controlled active element (thyristor, triac) against the possible accidents related to the malfunction of the reaction loop that has to ensure the on-load power stabilization. The integrated circuit β AA 145 that ensures the control can „interpret" this accident as a decrease of the power under load and as consequence to generate ignition impulses with increasing conduction angle, increasing unjustified the on-load power and putting in thermal destruction danger the controlled thyristor or triac.

The same effect can have also an accident in the cooling circuit of the radiator of a power thyristor, of which heat resistance has increased and which, therefore, can not disipate anymore the calculated maximum power.

For such accidents there are protection schemes, separated by the reaction loof of stabilizing the on-load power, that acts at the level of the thyristor's gate, blocking it when the temperature of the controlled active element's radiator decreases a certain value.

In case when the blocking is made directly on the thyristor's gate, then must be manipulaed big currents, which makes that the sensitivity of the protection circuit (in case it'a a circuit not too complex) to be small. Therefore, the thyristors' integrated control circuits are provided with a terminal with blocking priority of the ignition impulses. The circuit has a high sensitivity because it works at small currents (characteristic to an integrated circuit).

Terminal 6 of the circuit β AA 145 is the terminal with blocking priority. When terminal 6 is „put" to the supply voltage (e.g. short-circuited with terminal 7) the impulse generation on both outputs is inhibeted. In normal operation within the time interval passed from the null impulse generation until the appearance of the ignition impulse, the input impedance on terminal 6 is very high (there are only blocked junctions).

Any application diagram that uses terminal 6 for blocking the ignition impluses should respect this condition. If this condition is not taken into account, is possible to appear abbandoned ignition impulses.

The circuit β AA 145 is destined most exclusively to the on-phase control of the thyristors' (triacs') ignition. The increasing complexity of the thyristors' control circuits made that their monolitic achievement to be very attractive, as proven also by the great number of integrated circuits destined to the thyristors' and triacs' cocontrol.

In principle, the priming of a thyristor can be achieved with a circuit extremely simple. Utilization of a complex circuit or an integrated circuit is justified when is desired mot only the thyristor's priming but also the control of the disipated power in the anode circuit.

From the priming achievement's viewpoint, all the existent integrated circuits are identical: they supply current impulses (positive or negative) necessary to the control on the thyristor's grid. Howerever, the circuits are distinguished as regards the control mode of the power disipated in the thyristor's anode circuit's load. As result, hereby the expression „thyristors' control" refers to the control of the power from the load circuit. From this viewpoint, there are three control modes offered by the integrated circuits [1]:

(a) control through phase;
(b) control through zero with constant reference in time;
(c) control through zero with lineary variable reference in time.

❖ THE NUMERICAL-ANALOGUE CONVERSION PRINCIPLE

There will be used balanced codes to present the the numerical information because they have the advantage of a natural expression and are compatible with the numerical calculation circuits. In case of such a code, a figure from a number has both the semnificance of its value itself, and the balance due to the position within the number. The numerical-analogue conversion assumes the transformation of the value and proportion of the number's figures into a corresponding analogue measure. Is considered a binary integer of N bits, as [2]:

$$\overline{B_{N-1}B_{N-2}\ldots B_{i-1}\ldots B_1B_0} = \sum_{i=1}^{N-1} B_i 2^i \tag{4}$$

The figure B_{i-1} has the position i starting with the less significant bit (LSB) and has the balance 2^{i-1}, which means that the balance increases from right to left, the most significant bit (MSB) having the balance 2^{N-1}. The previous remarks are valid also for subunit binary numbers of N bits [2]:

$$\overline{B_1B_2\ldots B_i\ldots B_{N-1}B_N} = \sum_{i=1}^{N} \frac{B_i}{2^i}, \tag{5}$$

One can notice that the numerical-analogue conversion process is similar with the transformation procedure of a number from the binary numeration system, in the decimal numeration system, in this case to each binary figure "1" being associated a certain value of an electric measure (current or voltage) which is summed-up proportionally according to the rank that occupies within the numerical representation (for the figure "0" is associated the value zero of the same electric measure). Modification of the figures' balance with factors under form $1/2^i$ suggests a simple solution to achieve the balancing operation. This would be the utilization of some divisor rezistive grids, with more nodes, having between successive nodes the division ratio of 1/2. The resistances corresponding to the binary figures are introduced in the circuit when the associated binary figure is 1 or are disconnected in contrary case, by means of some electronic switches. The most usual types of grids are the ones with balanced resistances and with resistances R – 2R [3]. The electronic switches can be achieved with bipolar transistors or with transistors with field effect.

In the great converters family, the integrated circuit βDAC-08, 8-bit converter, occupies a position of industrial standard [4]. The circuit has a precision of 0,19% sufficient for the usual industrial applications. Being a speed circuit (set-up time of 100 ns order) can be used for data acquisition for the control of the industrial processes and numerical processing.

The circut has two current outputs noted I_0 and $\bar{I}_0$. These currents have the property that their sum is constant and equal with $\frac{255}{256}I_{REF}$, where I_{REF} is the current imposed from exterior. Thus, depending on the logical configuration, at the inputs $B_1,\ldots,B_8$ is obtained a current I_0 proportional with the numerical value of the binary word formed by the eight bits.

The maximum value at the current output I_0 is obtained when all the currents I_k are switched in this output.

$$I_0 = \sum_{k=1}^{8} I_k = I_{REF}\sum_{k=1}^{8} 1/2^k = \frac{255}{256}I_{REF} \tag{6}$$

The current I_{REF} is supplied from exterior by means of a current generator or from a voltage generator, V_{REF}, and a resistance, R_{REF}, that determines the current's value:

$$I_{REF} = \frac{V_{REF}}{R_{REF}} \tag{7}$$

The output current's conversion into voltage, maintaining a small value for the set-up time is very difficult. The end-scale current for βDAC 08 is set-up in 100 ns [1]. At output can be attached a load resistance in order to obtain an output voltage between 0 and -10 V.

Due to this time constant (RC), the conversion current/voltage is achieved usually with the diagram presented in fig. 2 [1]. The response time is limited now by the set-up time and by the value of the operational amplifier's slew-rate.

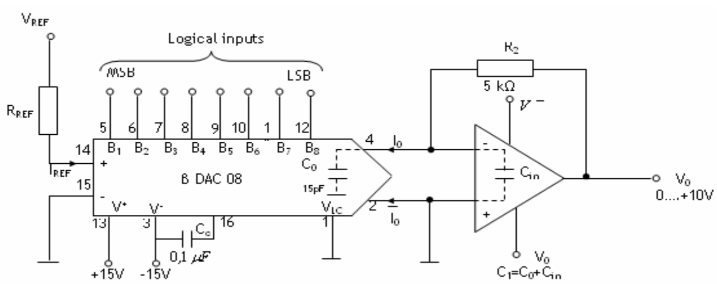

Fig.2. Electric diagram with current-voltage convertor at output

❖ GALVANIC INSULATION CIRCUIT

The process interfaces ensure the junction between the the computing system and the managed process, and as result should be taken safety measures in such way that the damaging of a component of the managed process (including transducers, execution elements) to not cause the damaging of the computing system [3]. Among the protection techniques used in such situations is also the galvanic insulation between the computer's and process' circuits.

The galvanic insulation consists in elimination of any direct electric connection between the computer's circuits and the ones correspond the process. This is achieved usually electromagnetically (with transformers and relays), optically (with opto-couplers or optical insulators) and capacitive (with capacitive barriers).

Utilization of galvanic insulation in the acquisition and management systems ensure the protection of the system and the operator, reducing the noise and rejection of common mode voltages, especially of the ones caused by the mass loops.

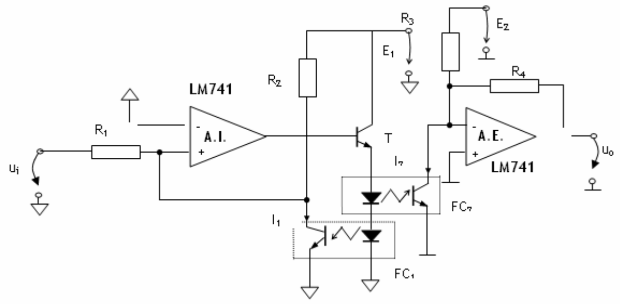

Fig. 3. The galvanic separation circuit

The diagram of the galvanic separation circuit is the one from fig.3.

The transfer function of the insulation amplifier is made based on the hypothesis regarding the identity of the characteristics of the two photo-couplers [3].

$$I_1 = \frac{U_i}{R_1} + \frac{E_1}{R_2} \quad (8)$$

$$I_2 = \frac{U_0}{R_4} + \frac{E_2}{R_3} \quad (9)$$

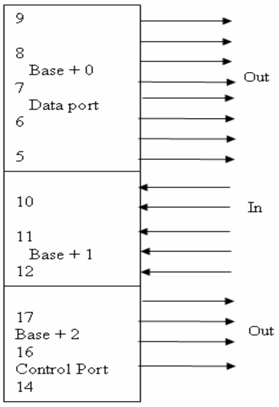

Fig. 4. Parallel Port

where I_1 and I_2 represent the collector currents corresponding to the two photo-transistors. Because the diodes are connected in serial, it results that $I_1 = I_2$ resulting the transfer function of the insulation amplifier:

$$U_0 = \frac{R_4}{R_1} U_i + R_4 \left(\frac{E_1}{R_2} - \frac{E_2}{R_3} \right) \quad (10)$$

It's determined that this transfer function is linear and independent by the photo-couplers' characteristics, with the condition regarding the identity of the two photo-couplers' characteristics.

❖ PROGRAMMING OF THE PARALLEL PORT

The parallel port is used at the computer's communication with the peripheral equipments and for monitoring of different processes by PC [4].

The standardized connector of the parallel port is of D type, mother, with 25 pins [5]. The pin's number is the number inscribed on the connector in front of each pin. "In" represents the data transfer from peripheric to the port, and "Out" from the port to peripheric. At the pins 1, 11, 14, 17 the signal is reversed by the hardware board and the pins from 18 to 25 represent the mass. Presentation of the parallel port's pins (fig. 4).

Table 1. Output voltages CNA and for control of rectifying block

Input	U_{ies1}	U_{ies2}
0	1,1mV	300 mV
10	194 mV	590 mV
25	480 mV	1,15 V
50	969 mV	1,7 V
75	1,45 V	2,54 V
100	1,94 V	3,08 V
125	2,42 V	3,89 V
150	2,91 V	4,49 V
175	3,41 V	5,21 V
200	3,9 V	5,8 V
225	4,38 V	6,52 V
250	4,87 V	7,11 V
255	4,96 V	7,24 V

❖ EXPERIMENTAL RESULTS

Following the experimental verifications, the output voltages from the numerical analogue converter block were noted U_{ies1} and respectively the galvanic separation circuit U_{ies2}, for the input measures between 0 – 255. The measured values are recorded in table 1.

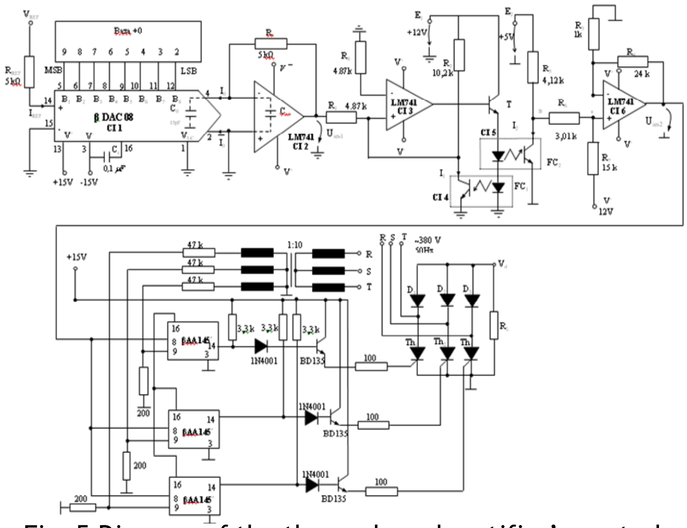

Fig. 5 Diagram of the three-phased rectifier's control interface

The control circuit represents in fact an interface between a computer and a three-phased power rectifier (fig. 5) that operates linearly on the entire variation scale of the numerical sequence on 8 bits (0-255). The program that allows to obtain at the parallel port the numerical sequence is achieved in C^{++} [6][7].

The thyristors of the rectifying bridge are independently controlled each by an integrated circuit βAA 145 specialized in thyristors control, of which synchcronization is achieved trhough a three-phased transformer with the transformation factor 1:10, directly from the voltage of the supply system.

The control impulse is the one related to the positive alternance corresponding to each phase of the supply system.

Further, the obtained impulse is amplified in current by means of the medium power transistors of BD 135 type and which allow the direct connection to the thyristor grids of the rectifying bridge, without being necessary an additional galvanic separation circuit.

❖ CONCLUSIONS

Analyzing the experimental data from table 1 one can notice a linear operation of each block in part, respectively of the conversion circuit, as well as of the galvanic separation circuit. The control circuit allows obtaining at output, directly proportional with a numerical value introduced from the keyboard, a maximum value that does not exceed 8 V, which represents also the maximum input voltage for the circuit ßAA 145 which is the impulse former for the thyristors of the semicontrolled rectifying bridge.

Following the performed experiments was found that for the numerical values 0-10 as input in the control circuit is obtained a neglectable voltage at the rectifying bridge's output, which means that the thyristors are practically not controlled.

By introducing of a reaction loop can be obtained the adjustment of the output voltage automatically by bringing of a part form the output voltage to the computing system which determines the optimal control value.

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