Device with Analogical Circuits for Protection to the Lack of the Pulse for the Three-Phase Rectifiers in Electrical Drive

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Abstract— In this paper is proposed a device for protection at the lack of pulse for the three-phase rectifiers in bridge with load inductive resistive (dc motors).

Keywords — protection, device, no pulse, three-phase rectifiers.

I. INTRODUCTION

DEVELOPMENT, of automation and robotics in a series of important industrial branches as the car making industry, metallurgy, transportations etc, has been and still is tightly related to the development, generalization and perfecting of the driving system and electric measurement as the most efficient form to obtain necessary mechanic energy, on the basis of electric energy conversion.

The use at a larger scale of the electrical motors imposed making some electric driving systems as performant and reliable as it is possible, with a reduced energy consume and low sizes.

For example, in the case of d.c. current motors, ranges of 1÷10.000, 1÷30.000 and even more for revolution adjustment have been reached, at short periods of the transitory regime of 30-50ms in the whole variation range of the revolution, at high precisions and the time constant of the adjusted quantity of the 0,1% order, or even more restrictive at the extension of the range power up to driving of 10MW.

These progresses and achievements have been determined by the higher requirements for performance imposed to the driving systems in a series of applications: driving on machines-tools, industrial robots, industrial driving, individual driving or for technological lines in metallurgy, paper industry, fibers or wires strings.

A factor that produced important mutations in the control and measuring of electric driving has been the development of microelectronics which effectively created the possibility of extensive application of the modern control and measurement strategies whose implementation in the analogical technique was forbidden.

The development of some performant microprocessors on 16 and 32 bits (8086, 80386 şi 80486) and of some arithmetic coprocessors (8087, 80287 şi 80387) which execute multiplication operations on 32 bits in less than 10μs, of the interface circuits (for example Analogical to Digital Converter of 10–12 bits with conversion time 100ns – AD7520), is the base of the implementations of the structures and modern strategies to control in the domain of electric driving systems.

In industrial processes the driver electrical are very often used. In the last few years it has been ascertained the tendency for development of the action systems as numerical exclusive variant, based on a singular microcontroller which insures all command and setup functions.

The electrical actions are used in this moment because of following advantages:

- the availability of electrical energy;
- the possibility of a simple connection to an energy source;
- very good dynamic performances (a good time answer between the moment of the application command and the execution);
- high efficiency of the energy (more than 90 %);
- high reliability;
- the acquisition and maintenance cost very low;
- the possibility of changing revolution in larges limits;
- compatibility between the command systems and the electrical machine.

In most cases, the mechanic processes which are of interest from the point of view of the automated control refers to adjustment of a force or of a couple which moves any load,

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linear or rotated. The movement is made with the help of a motor coupled into any kind of transmission with the load.

The continuous current motor is often found in the automated adjustment theory as an execution element in an adjustment system, and also as a process which is automated. Mostly, the continuous current motors are found within the automated adjustment systems under the shape of the processes which are automated.

The d.c. motor was not so long time ago the most used motor in electric control systems. Even now it is preferred in most applications which presume variable revolution and couple control.

The d.c. motors run at optimum capacity in a field of revolution between 5% and 100% from the nominal revolution. These performances are better than a.c. machines and because of the projecting are capable to eliminate efficient the casual heat in rotating coiling and operate at small revolution.

The advantages using the d.c. motors are:

- the adjusting field of large revolution from 5% to 100% of the nominal revolution;
- the command circuits are simple
- the force circuits are also simple; in most applications are used the pulse width modulation (PWM).

Despite of all this advantages compared to the a.c machines these motors have disadvantages:

- they are bigger and cost much more for the same developed power;
- they need high maintenance costs due to the presence of brushes and collector lamellas which wear out in time and must be changed.

This device makes the object of a demand of license of invention. The invention refers to a method and a device for the protection of rectifiers when the semiconductor element is not working and overload.

When a semiconductor element is not working they can be shown because of the defection of the command circuit (does not receive the command signal) or because of his defection.

The idea of making this kind of device has appeared as a necessity for the predictive maintenance [4] of drive system with the DC motors.

II. PROBLEM FORMULATION

There are known various circuits for the protection of rectifiers: at the lack of phase, at overload, over voltage, etc. The most recent follow the voltage between the force terminals of electronic devices, interfering when this voltage is higher than the saturation voltage, protecting at the exceeding of normal current.

These circuited present the disadvantages that they don't detect when the semiconductor device is not working, when he must be in conduction (when receives the command).

III. PROBLEM SOLUTION

The purpose of the device is to determine when the semiconductor devices of rectifiers are not working to the following to the form of current through load and the lack of pulse.

The diagram of the protection device for a three-phased rectifier in bridge is presented in the figure 1 where you can see clearly the following components:

- CT1 and CT2 -current transformers (current transducer) for the measurement of current for 2 phases of the rectifiers;
- RP1, RP2, RP3-rectifiers of precision made of operational amplifiers;

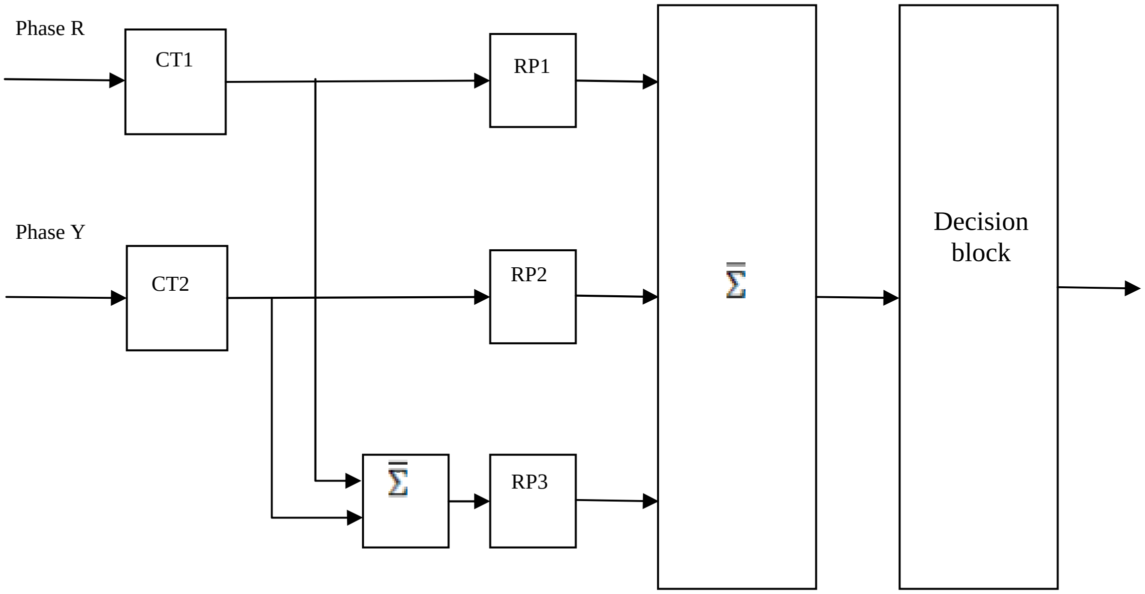


Fig.1. Block scheme

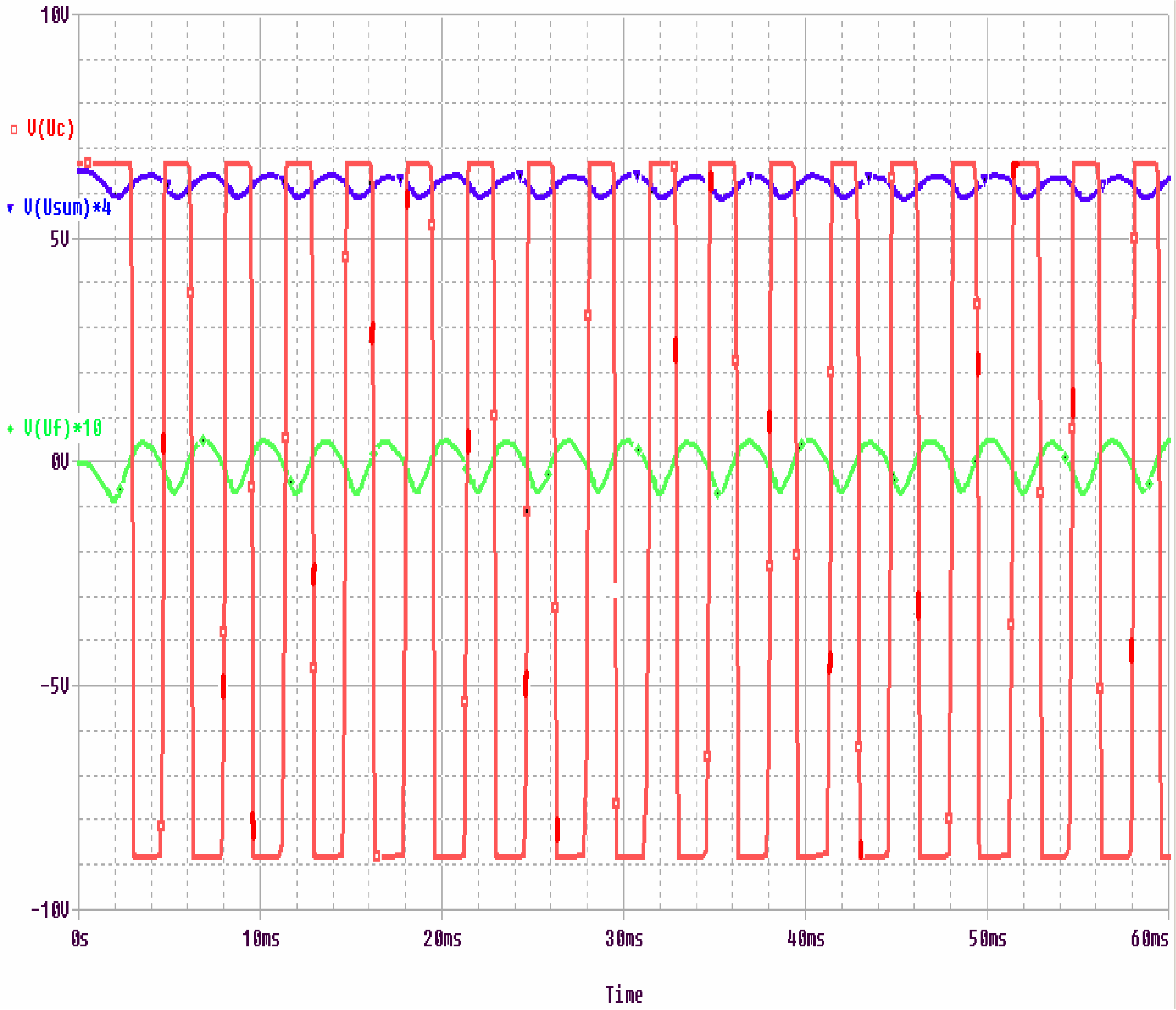


Fig. 2. The signal u_f, u_c and u_{sum} when the pulses are not missing.

- $\overline{\Sigma}$ adder change-over switch for the remaking of the current of the 3 phase for the sum of the received signals for precision rectifiers;
- Decision block.

At the output of the rectifier circuit and adder, made with OA [1] is obtained the signal u_{sum}, which has the same form of variation with the current through the DC motors.

The decision bloc can be made using the analogical circuit, logical circuit or both [2].

If the decision bloc is made using the analogical and logical circuit, this must contain: the filtration circuit, comparing, timing, counting the lack of pulse.

The filtering circuit doesn't leave the continuous current component. The inferior limit of the frequency of the amplification band is determined by the passive elements from the entrance circuit that are obtained from the relation for pulsation:

$$\omega_j = 1/(RC) \Rightarrow 2\pi f_j = 1/(RC) \Rightarrow f_j = 1/(2\pi RC)$$

Being only six pulse in a period of 20 ms (for the frequency of 50 Hz) it must be used the condition that the inferior limit of frequency of the filtration circuit is smaller then the frequency of the pulse: $fu_{SUM} = 6 \times 50Hz = 300Hz$

Choosing $f_j = 200$ Hz and C=0.1 μF will result the standard value for R=8.2 kΩ. The filtering circuit also has the comparison function; the operational amplifier is working in an open loop, without reaction, so that the signal from the output of the comparator will change at every passing through zero of the signal from the output of the filter.

The signal from the output of the filter, u_f, together with the signal u_{sum} and the signal u_c from the output of the comparator are exposed in the figure 2, when pulses are not missing, also in the figure 3, when the pulses are missing.

The signal from the output of the filter is transformed into rectangular impulses with the help of a comparator, after that it rectifies after which it applies the timing circuit made with

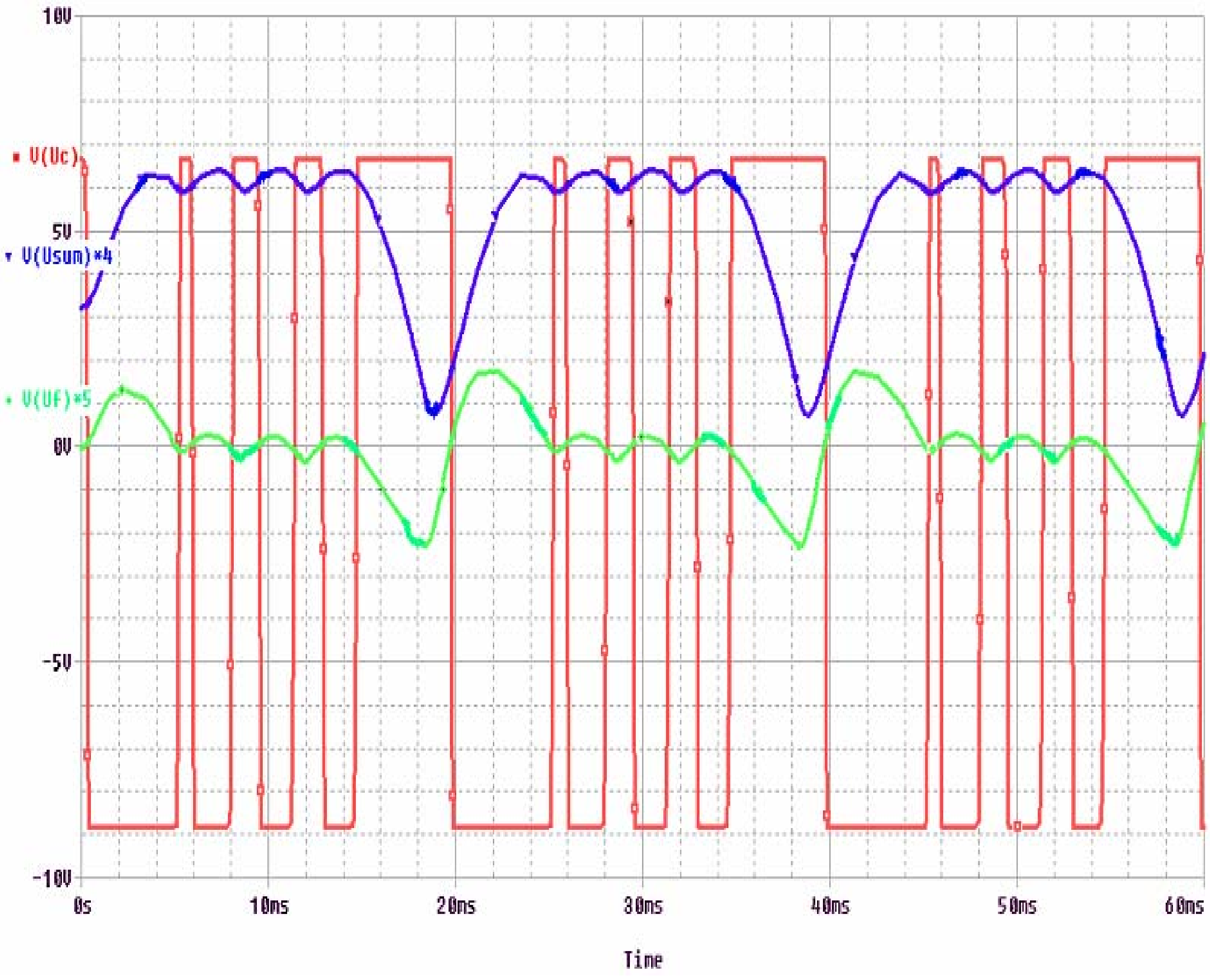


Fig. 3. The signal u_f, u_c and u_{sum} when the pulses are missing.

the retriggerable monostable circuit.

The monostable period is chosen at 5 ms, so that these being bigger than the duration of the pulse (20ms/6 pulses=3.3ms) and smaller than the duration of the two pulses missing (2*3.3ms=6.6ms).

Because the monostable is configured retriggerable according to those shown earlier the output signal from the monostable if no pulses are missing, they should be at level one logical. Then when no pulses are missing these signals will change between one and zero logical.

There is a possibility to appear the situation when the sporadic pulses are missing (for example the sudden modification of the prescribed tension at the commanded rectifiers), this is why we used a counter which will count the missing pulse in an interval of time after which it will reset.

If the decision bloc is made using the logical circuit reporting to the analogical and logical circuit, the distinction consist in the excluding of the bialternance precision rectifiers and the adders, whose functions are being implemented in the digital processing circuit.

To measure the current we can use current transformers or current transducers with Hall Effect, LTS 6-NP type, in closed loop, named and with zero flux. These have an integrated compensation circuit through which the transducer's performances are being improved.

Closed loop transducers give a secondary current, which acts as a reaction to compensate the induction created by the primary current.

They are characterized by an excelent precision, very good liniarity, drift decreased with temperature, reduced response time, wide frequency band, they don't introduce losses in the circuit for measurement and suffer current exceeds without getting deteriorated. Also, these transducers offer the possibility to measure three nominal values for the primary current I_p: 2A, 3A or 6A.

The digital processing circuit may be a performant microcontroller (of at least 16 bits) or a DSP processor. The MSP430 microcontroller family and the digital signal processors from the C2000 family produced by Texas Instruments may be successfully used. They contain analog to digital converters on 12 bits with the variation domain of the input measurement 0-3V and the value of a quantum of $3V/2^{12}=3V/4096=0.73$ mV.

The analog to digital converter will give a value of x = n(Vref/4096)=n(3/4096), where n is the number of quantums. It results that the adaptation circuit must give at the output a signal equal to 0.5V for a measurement current $-I_{pSN}=-1A$; 1.5V for a null measurement current $I_{pS}=0$ and 2.5V for a $+I_{pSN}=1A$ measurement current, where I_{pSN} is the nominal current of the load which passes through the transducer's primary. The value of the current through load will be $I=I_{pSN}(x-1.5)$.

Due to the small variation domain, the signal given by the transducer is amplified after the continuous current component of 2.5V is eliminated, and because of this reason, we can use the operational amplifier OPA2228PA with the following characteristics: low offset voltage (+/-75µV max), high frequency band (33MHz), high speed variation of the output (10V/µs). Then, a continuous current component of 1,5V is added to the amplified signal, so that the variation domain to be between 0-3V, according to the requirements of the analog to digital converter from the microcontroller or from the DSP.

If the decision bloc is made using the analogical circuit, this must contain: a peak detector circuit, a filter Bessel circuit and comparators.

It must work the signal received from the adder, in the purpose of verifying the lack of pulse and/or verifying the rise above the admissible current through the load.

The report between the medium value and the maximum value of the u_{sum} signal will be:

$$\frac{U_{SUM}}{U_{SUMM}} = \frac{6}{\pi}U_m \frac{1}{2U_m} = \frac{3}{\pi} = 0,95 \qquad (1)$$

In this way, the u_{sum} signal is applied to a circuit which detects the peak value made with OA [3], to obtain the U_{SUMM}, figure 4.a, and to a filter circuit Bessel type, 4 order, with the upper limit frequency of 40Hz, at its output we obtain U_{SUM}, figure 4.b.

The unload time constant of the capacitor which detects the peak is:

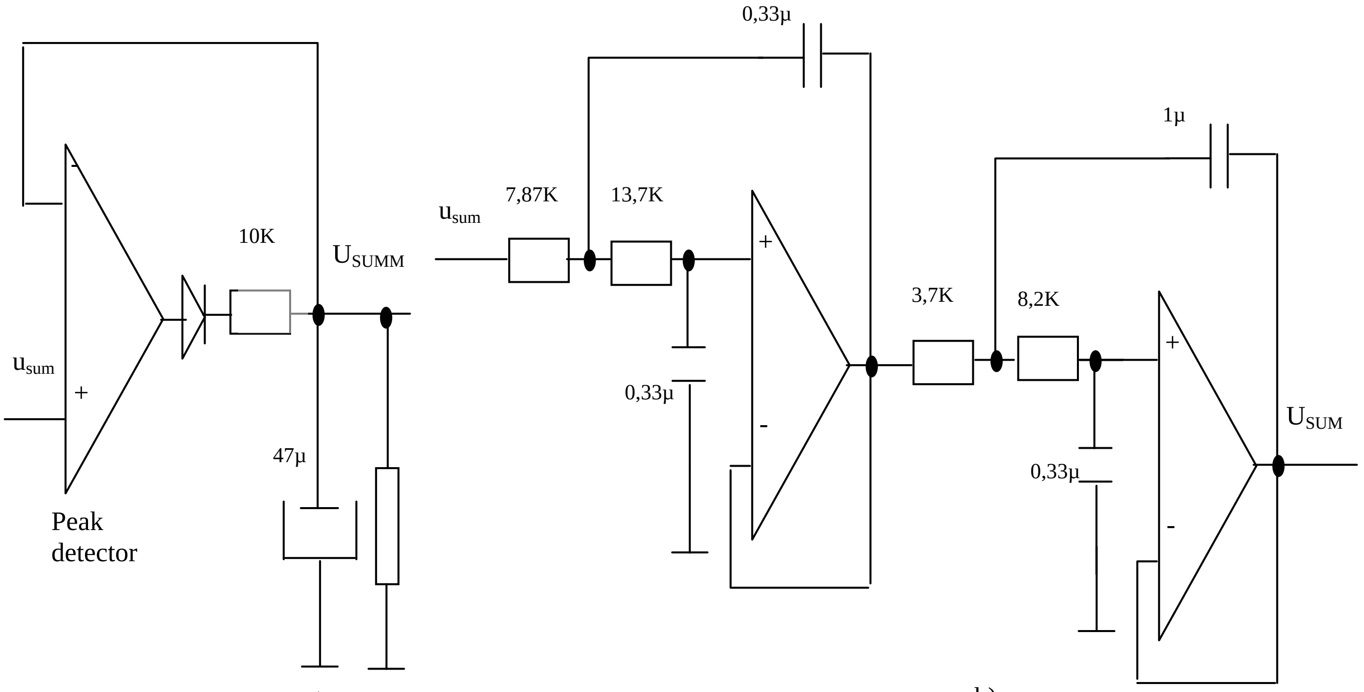
$$t_d = RC = 47\mu F * 47k\Omega =$$
$$= 47*10^{-6}*47*10^3 s = 2209ms \qquad (2)$$

In figures 5 and 6 are presented the u_{sum}, U_{SUMM} (noted with U_{max}) and U_{SUM} (noted with U_{med}) of the input and output of the peak detector circuit, and also from the output and input of the Bessel filter, when no pulses are missing, respectively when pulses are missing, as a result of the PSpice simulation.

In figure 7 the report between the medium and maximum value of the u_{sum} signal is:

$$U_{SUM} / U_{SUMM} = U_{med} / U_{max} =$$
$$= 310mV / 325mV = 0.953 \qquad (3)$$

meaning a value which is equal to the one calculated above.



a) b)

Fig. 4. a) Circuit which detects peak. b) Filtering circuit.

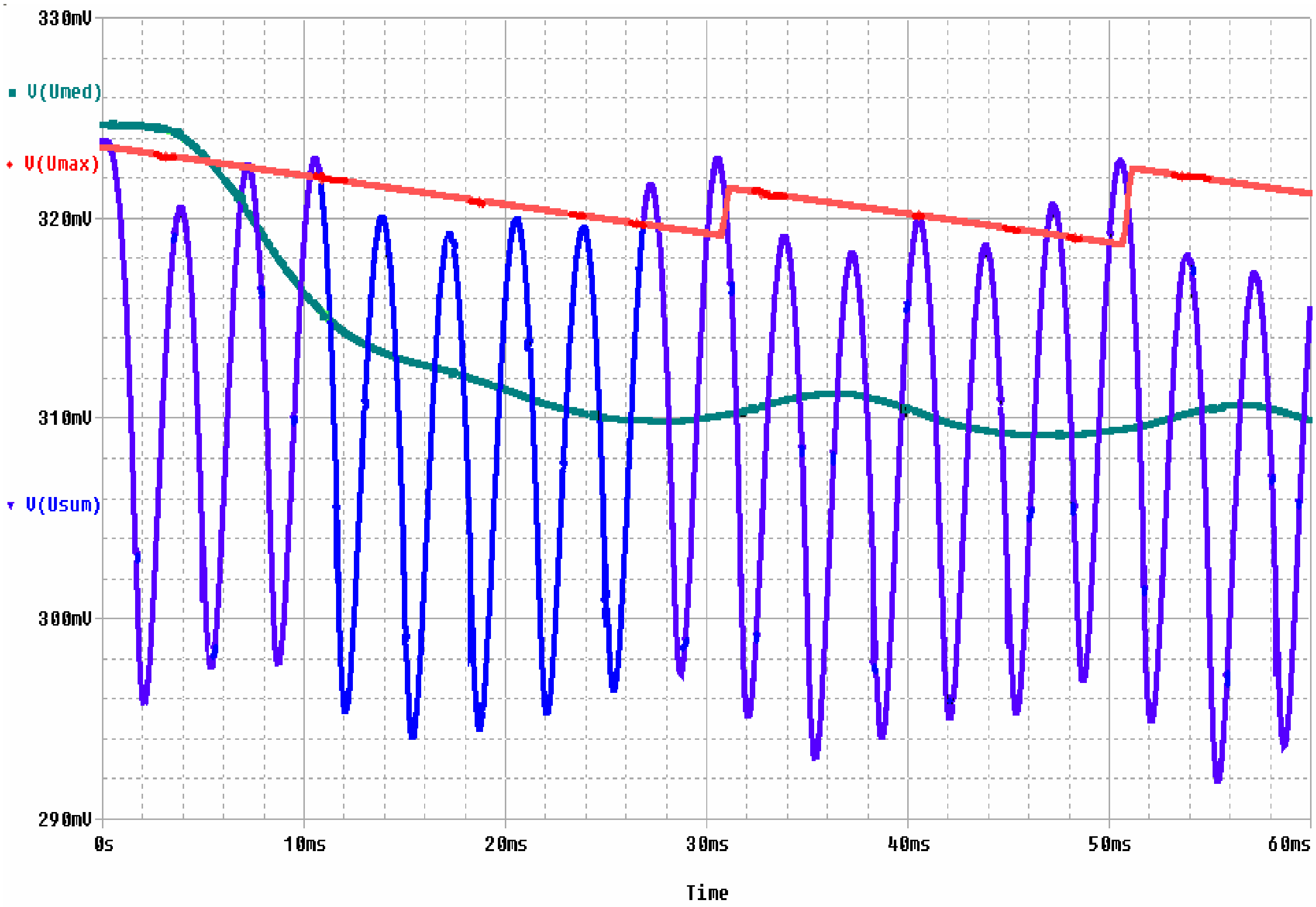


Fig.5. The signals at the output of the filter and the peak detector when no pulses are missing

The signal obtained at the output of the Bessel filter is applied to the analog-digital current converter (if we wish other processing with a digital signal) and in the same time to a reverse amplifier, obtaining thus the signal – U_{SUM}.

This signal is summed with the signal at the output of the peak detector U_{SUMM}, and the result is applied to the reverse input of the C_1 comparer, as in figure 7.

When a semiconductor element is not working, two pulses are missing, because a semiconductor element leads a semiconductor element of opposite polarity at a time and on different phases. In this case, the medium value should be:

$$U'_{SUM} = U_{SUMM}\frac{2}{3} = \frac{2}{3}*2U_m = \frac{4}{3}U_m \qquad (4)$$

So the medium value will decrease with $\frac{1}{3}$ if a force electronic device isn't working (when two pulses are missing) and with $\frac{2}{3}$ if a secondary electronic device of the same polarity isn't working (when four pulses are missing, remaining in two).

But the medium value is with 5% lower than the maximum value for a normal functioning when no pulses are missing, and if an electronic device isn't working, the medium value should decrease with 33%.

In this case we can consider an abnormal functioning regime if the medium value decreases with 20% below the maximum value, which leads to the existence of a potential VA = 0.

If no pulses are missing, the potential VA will be approximately – $0.75U_{SUMM}$, and the output of the C1 comparer will have a value close to – Vc, because the potential of the point B is positive (aprox. 1/9.2Vc), and the potential of the point C is negative (-1/11Vc).

The diode D_1 and the transistor T will not be in conduction, and the coil of the relay will not be supplied.

In diagram from figure 6, the signal u_{sum} has a positive polarity and the medium value is 250mV, and the report between the minimum medium value (closest to zero) and the maximum value is:

$$U_{SUM}/U_{SUMM}=U_{med}/U_{max}= 220mV/325mV=0.61, \qquad (5)$$

meaning a value which is between the limit imposed above for an abnormal functioning, when pulses are missing.

If the medium value decreases with more than 20%, the potential of the point A, increases to positive values, and the output of the comparer C will have a value close to $-V_c$.

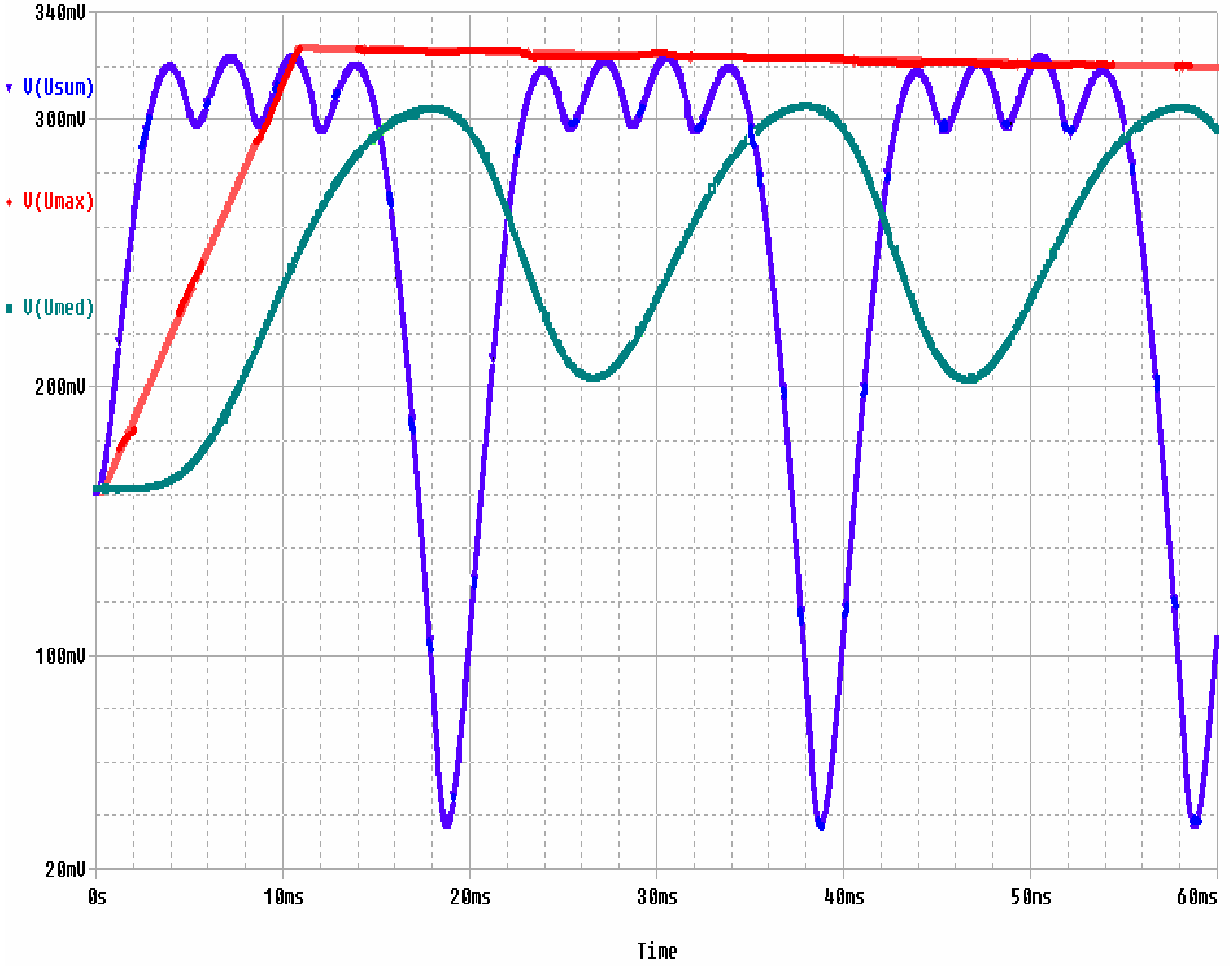


Fig.6. The signals at the output of the filter and the peak detector when pulses are missing

As a consequence, the output of the comparer C_2 will commutate into a value close to $+V_c$, because the potential of the point B is negative (aprox. $-1/9.2V_c$), and the potential of the point C is also negative ($-1/11V_c$), but $|V_B|>|V_C|$.

The diode D_1 and the transistor T will be in conduction, and the coil of the relay will be supplied. The LED 1 will be on and will indicate “LACK OF PULSES”.

The diode D_2 of the relay will enter in conduction, closing the reaction and ensuring a potential V_C of aprox. $1/8V_C$, while V_B will be of aprox.$1/9.2V_C$ for a normal functioning.

We may say that after detection of the lack of pulses, the circuit gives a damage alarm and keeps this state (memorizes it) even if meanwhile the functioning comes to normal, because $V_C>V_B$.

The output from the damage state is done by pressing the “RESET” button, when the potential V_C will be aprox. $-4/31V_C$, forcing the output of the comparer C_2 to go into a close value to $-V_C$.

In order to detect the overflow of the nominal value of the current (of overload) is used the comparer C_3.

The medium value of the current is applied on the reverse input, and on the normal input is applied a value which corresponds to the overload current for the circuit where the protection device is connected, which is fixed with the potentiometer of 22kΩ.

When the current gets over the prescribed value of overload, the output of the comparer commutates into a high positive potential which polarized directly the LED 2 “OVERLOAD” which visualizes the appearance of an over current.

In this case, the diode D_5 gets into conduction, being directly polarized, bringing a part of the positive potential from the normal outputs, which force the output to remain at a high positive potential (memorizing the defect).

To get out of this state, the same “RESET” button should be pushed.

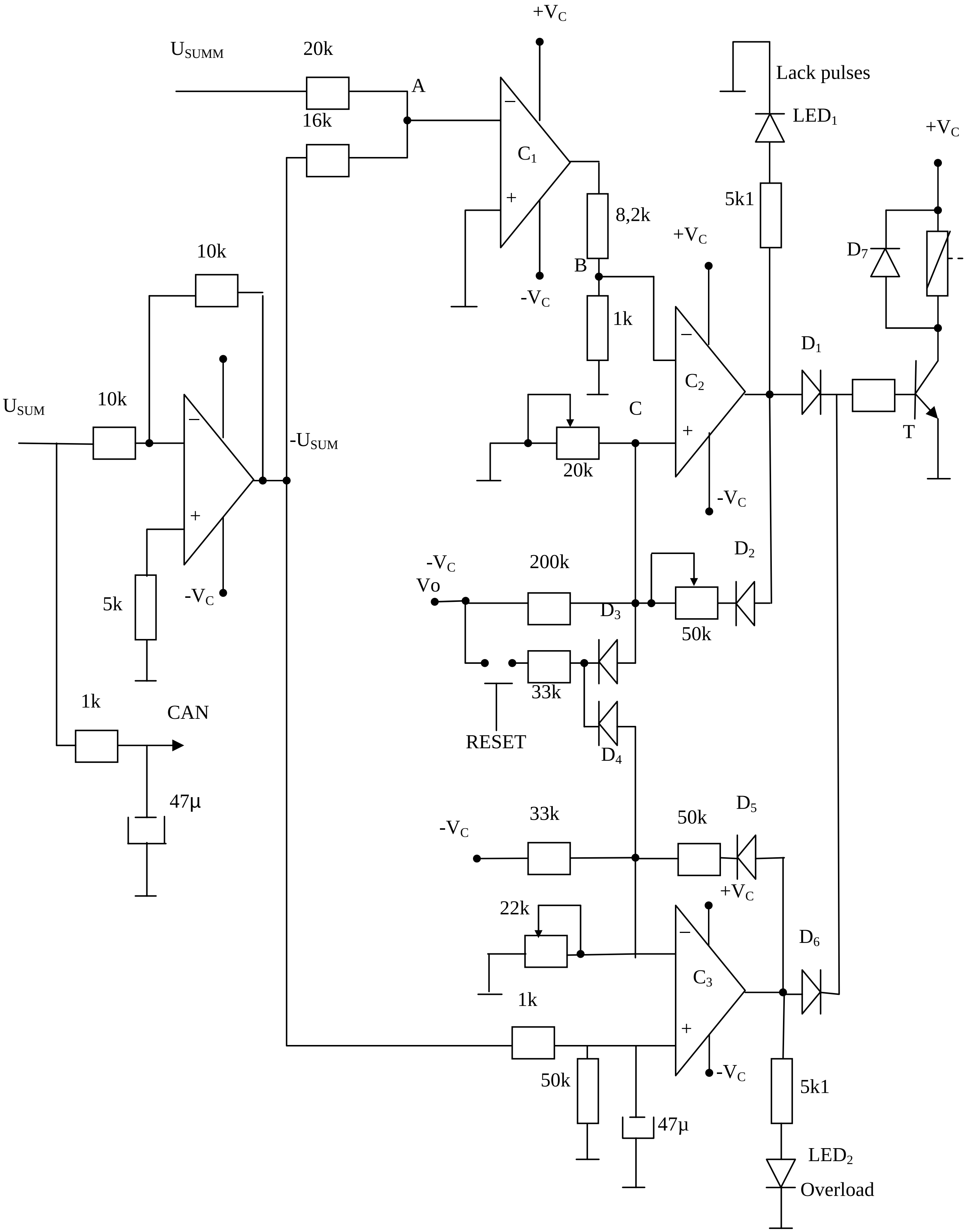


Fig. 7. The decision block made with analog circuits.

IV. CONCLUSION

The application and use of the device has the following advantages:

- is basically easy;
- it eliminates the protection circuit and no phase and overload;
- it ensures the protection at no pulse (the semi conductor element of the redresser not working);
- it can be used for wanted rectifiers and but also for unwanted;
- also, it can use any type of mono or try phased rectifier, with the exception of the monophased monoalternance rectifier, modifying only the monostables duration;
- it can also be used as a current transducer, giving the information about the medium value of the current trough the load;
- the biggest advantage is represented in the case when the rectifier is a part of a automated relation system of revolutions, of a DC motors (in the industry, robotics,…) [5]…[10].

In this situation if the pulses are missing, by the diminution of the medium value of the output voltage from the rectifier and in the same time the charge voltage of DC motors and revolutions.

But by not being modified the revolutions is maintained constant, by increasing the remaining pulses (the medium value is being kept constant) which leads to the increase of the current amplitude above the admissible value (especially if 4 pulse are missing).

The actual circuits don't make this protection when there is no pulse.

In most cases, the increase of the current over the admissible value, leads to the motor's deterioration, thus it leads to the stop of a whole production system.

This probably means the stop for at least half an hour of the electric energy supply and replacing the motor and the afferent defect circuits.

The losses occurred in the cost of production can vary function of the industry and the fabrication process, but in most cases, an interruption of half an hour of the production may be very expensive, as I explained above.

The device can only to alert if the pulses are missing, and in a short time, when possible, the operator to stop the installation and to ask for the technical intervention team.

The three methods presented have each advantages and disadvantages.

The simplest one is with digital decision block, but needs programming knowledge.

If microcontrollers from the MSP430 are used, some of these, for example M430F436, have a driver integrated for the command of the displays and may show the value of the current, or, if a voltage transducer is used, they may measure and show the energetic parameters.

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