Method to Protect from no Pulse for a Three-Phase Rectifier Bridge

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Abstract— In this paper we will propose a way to detect if the electronic valves aren't working (diodes, thyristors and transistors) of the commanded or not three-phase rectifiers with resistive load or resistive-inductive load.

Keywords— three-phase rectifiers, pulses, resistive and resistive-inductive load

I. INTRODUCTION

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, 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 most wanted continuous current motors for automated adjustment systems are the ones with separate or independent excitation. Because the two circuits (of the induced and of the excitation) are separate, they can even have separate supply sources.

The continuous current motors, seen from the point of view of the load of a rectifier, may be resembled with a resistive-

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inductive load.

For powers which exceed 2-3kW, power disposed in load, the monophased rectifiers become inefficient. In these situations poliphased rectifiers are used, with the following advantages:

-charge in a symmetric way the phases of the supply network (so we have an equilibrated consumption on each phase);

-the level of undulations is more reduced compared to the monophased situation, thus the filtering circuits are simpler;

-the factor of use of the network transformer is improved.

The study of the rectifiers is made in the following ipothesis:

-the supply network is symmetric, giving equal voltages;

-the network transformer has no losses in the core;

-the power electronic circuits that are used are considered to be ideal (the resistance to direct polarization is zero and the resistance to inverse polarization is infinite and has no parasite capacities);

-the resistances, the inductivities and capacities are linear, concentrated and equal on the phases of the rectifier;

-all the phases have the same functioning;

-the network has an infinite power of short-circuit, thus zero impedance, not deformed sinusoidal voltages, symmetrical in the case of three-phase network;

-the functioning intervals are identical for diverse ways of the commutation one;

-in each moment, the sum of the line currents in the primary of the transformer is zero.

From the category of the poliphase rectifiers, the most used is the three-phased rectifiers, for which the factor of use of the transformer is optimal. The three-phase rectifier in bridge is obtained by putting two rectifiers in series with the secondary of the transformer in star position.

The supply of the continuous current motor is made from a three-phase rectifier with thyristors, transistors, or triacs.

Generally, three-phase rectifiers have circuits that do the protection for going over the medium current that is permitted in load, when the synchronization voltage of the three phases is missing, and for going over the nominal voltage [1].

In figure 1 is presented a protection circuit which observes the lack of synchronization voltages for a three phase rectifier. The synchronization voltages are used at the circuits which form impulses to command in phase the semiconductor

elements of the rectifiers. These voltages, according to figure 1, are rectified, and then compared with two fixed values of +5V and -5V (if the effective value of the synchronization voltage is 24V) with the help of some comparison blocks. If a synchronization voltage is missing (corresponding to one of the R, Y or B), then the two comparison blocks observe the decrease of the medium values of the voltages at the rectifier's output, under +5V and -5V, commanding the blockage of the rectifier.

In figure 2 is presented another protection circuit, which observes the lack of synchronization voltages, for a three phase rectifier. This circuit allows the detection of phase succession by adding the voltages of the R and Y phases. The RC circuit makes a phase difference of 180^0 between the voltage of the R phase and the voltage of the Y phase, resulting 0V by adding for a correct succession of the phases (normal functioning). This determines the blocking of the T_1 transistor.
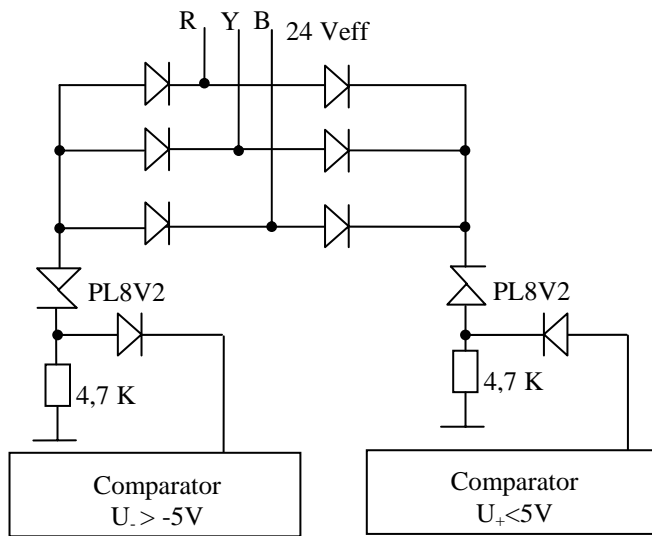

Fig.1 Observing the lack of synchronization

The synchronization voltages of the three phases are monoalternance rectified, and normally, when no voltage is missing, a negative voltage will be obtained after rectification in the high level mode. This thing determines the blocking of T_2 transistor. The T_2 transistor goes into conduction (is saturated) when one of the synchronization voltages (from one phase) is missing and when the level of the negative voltage from the rectifier's output decreases in module (gets close to zero). In this case, the T_3 transistor gets into conduction, the Th thiristor is blocked and the relay is no longer supplied and blocks the impulses transmitted to the force semiconductor elements of the rectifier.

II. PROBLEM FORMULATION

Sometimes it is possible to have all the above conditions fulfilled, for protection, and not to have all the electric components working from various reasons (the elements are defective or they are not commanded). The rectifier will function normally if there will be installed a circuit that can detect the fact that not all the electronic valves are working (missing pulses). This fact has a great importance if the load of the rectifier is represented by a motor of continuous current at which we want to control the rotation speed. In this case, if we don't have an electronic switch (semiconductor element) working, two pulses from six will be missing from the current wave form for a three-phase rectifier in bridge fig. 6, because every semiconductor element conduction one at a time with two semiconductor elements from the other two phases and the

opposite branch [2] [3], referring to polarity. Having this said, the medium exit current (through load) will drop, and will lead to the drop of the active couple according to the resistant couple and the drop of rotation speed. The negative reaction will oppose to the fall of the rotation speed by keeping the medium exit voltage of the rectifier, this also meaning the current, all because of the increase of the maximum value of the current (of the amplitude).

When two semiconductor elements from the same branch (same polarity) are not working, to keep the rotation speed constant, the maximum current value (amplitude) must be increased a couple of times.

This is possible, because, if the resistant couple of the motor is bigger than the active couple, the current in the motor will increase very much if it is not limited.

But this limitation is made according to the medium value of the current in the motor, that is being kept constant if pulses are missing or not.

If the instant current value in the motor is not looked for, the motor can get itself wrecked, because the medium value can remain constant and the maximum value can increase if the pulses are missing.

III. PROBLEM SOLUTION

We resolve the problem presented above using the device of figure 3.

We used as current transducer the current transformer type ASM10. In primary it has more reeled coils to increase the sensitivity so that at a value of the current of 0.3A through the primary, tying into the secondary a load of 50Ω, we get a voltage of 60mV.

To measure the current of the two phases we use two current transformers of type CT1 and CT2, and for the third phase the current is reestablished by putting together the first two phases with a reverse adder. If it is considered that the current transformers are on R and Y phases, we will have these voltages [4]:

$$u_R = U_m \sin\omega t \quad \text{and} \quad u_Y = U_m \sin(\omega t - \frac{2\pi}{3}) \quad (1)$$

Adding the two voltages together we get:

$$u_R+u_Y=U_m\left[\sin\omega t+\sin(\omega t-\frac{2\pi}{3})\right]=$$

$$U_m\left[\sin\omega t-\sin(\frac{2\pi}{3}-\omega t)\right]=$$

$$=2U_m\cos\frac{\omega t+2\frac{\pi}{3}-\omega t}{2}\sin\frac{\omega t-2\frac{\pi}{3}+\omega t}{2}=$$

$$=2U_m\cos\frac{\pi}{3}\sin(\omega t-\frac{\pi}{3})=-U_m\sin(\omega t-\pi-\frac{\pi}{3})=$$

$$=-U_m\sin(\omega t-\frac{4\pi}{3})\qquad(2)$$

The sinusoidal signals from the current transformer outputs are getting rectified with the help of the double alternation precision rectifiers PR1, PR2 and PR3 (fig. 3). On the outputs of the precision rectifiers we get the signals u'R, u'Y, u'B (the negative semi-alternation of signals uR, uY, uB), which are added together with a reverse adder made with an operational amplifier, ∑ (fig. 4).

To calculate the level of the signal from the output of the reverse adder ∑, we start from these relations:

$$u'_R=-U_m\left|\sin\omega t\right|$$

$$u'_Y=-U_m\left|\sin\left(\omega t-\frac{2\pi}{3}\right)\right|$$

$$u'_B=-U_m\left|\sin\left(\omega t-\frac{4\pi}{3}\right)\right|$$

In this situation:

$$u_{SUM}=-(u'_R+u'_Y+u'_B)\qquad(3)$$

If ωt=α, then we are interested in the next function:

$$f(\alpha)=\left|\sin\alpha\right|+\left|\sin(\alpha-\frac{2\pi}{3})\right|+\left|\sin\left(\alpha-\frac{4\pi}{3}\right)\right|\qquad(4)$$

If we know that the electronic valves conduct two at the same time it results that on a 2π period, there are six pulses. It is easy to demonstrate that the function has the period 2π/6=π/3:

$$f(\alpha)=f(\alpha+\frac{\pi}{3}),\ (\forall)\alpha\qquad(5)$$

In consequence it's sufficient to study the function on the interval [0,π/3].

On the other hand,

$$f(\alpha)=\left|\sin\alpha\right|+\left|\sin(\alpha-\frac{2\pi}{3})\right|+\left|\sin\left(\alpha-\frac{4\pi}{3}\right)\right|=$$

$$=\left|\sin\alpha\right|+\left|\sin(\alpha-\frac{2\pi}{3}+\pi)\right|+\left|\sin\left(\alpha-\frac{4\pi}{3}+\pi\right)\right|=$$

$$=\left|\sin\alpha\right|+\left|\sin(\alpha+\frac{\pi}{3})\right|+\left|\sin(\alpha-\frac{\pi}{3})\right|=$$

$$=\left|\sin\alpha\right|+\left|\sin(\alpha+\frac{\pi}{3})\right|+\left|\cos(\alpha-\frac{\pi}{3}+\frac{\pi}{2})\right|=$$

$$=\left|\sin\alpha\right|+\left|\sin(\alpha+\frac{\pi}{3})\right|+\left|\cos(\alpha+\frac{\pi}{6})\right|$$

For $0\leq\alpha<\frac{\pi}{3}\Rightarrow$ sinα>0 and cosα>0

$$0\leq\alpha<\frac{\pi}{3}\Rightarrow\sin\alpha>0\qquad(6)$$

$$\frac{\pi}{3}\leq\alpha+\frac{\pi}{3}<\frac{2\pi}{3}\Rightarrow\sin(\alpha+\frac{\pi}{3})>0\qquad(7)$$

$$\frac{\pi}{6}\leq\alpha+\frac{\pi}{6}<\frac{\pi}{2}\Rightarrow\cos(\alpha+\frac{\pi}{6})>0\qquad(8)$$

So for $\alpha\in[0,\frac{\pi}{3}]$ we will get:

$$f(\alpha)=\sin\alpha+\sin(\alpha+\frac{\pi}{3})+\cos(\alpha+\frac{\pi}{6})==2\sin(\alpha+\frac{\pi}{6})\cos\frac{\pi}{6}+$$

$$\cos(\alpha+\frac{\pi}{6})=2[\sin(\alpha+\frac{\pi}{6})\cos\frac{\pi}{6}++\cos(\alpha+\frac{\pi}{6})\frac{1}{2}]=$$

$$=2[\sin(\alpha+\frac{\pi}{6})\cos\frac{\pi}{6}+$$

$$+\cos(\alpha+\frac{\pi}{6})\sin\frac{\pi}{6}]=2\sin(\alpha+\frac{\pi}{6}+\frac{\pi}{6})=$$

$$=2\sin(\alpha+\frac{\pi}{3})\qquad(9)$$

Then we get :

$$u_{SUM}=\left|U_m\sin\omega t\right|+\left|U_m\sin(\omega t-\frac{2\pi}{3})\right|$$

$$+\left|U_m\sin(\omega t-\frac{4\pi}{3})\right|=2U_m\sin(\omega t+\frac{\pi}{3})(10)$$

for $0\leq\omega t<\frac{\pi}{3}$

with the maximum value $U_{SUMM}=2U_m$
for $\omega t=\frac{\pi}{6}$.

The medium value will be:

$$U_{SUM}=\frac{1}{T}\int_0^T u_{SUM}(\omega t)=\frac{6}{\pi}U_m(-\cos)=$$

$$=\frac{6}{\pi}U_m\left[-\frac{1}{2}-\left(-\frac{1}{2}\right)\right]=\frac{6}{\pi}U_m\qquad(11)$$
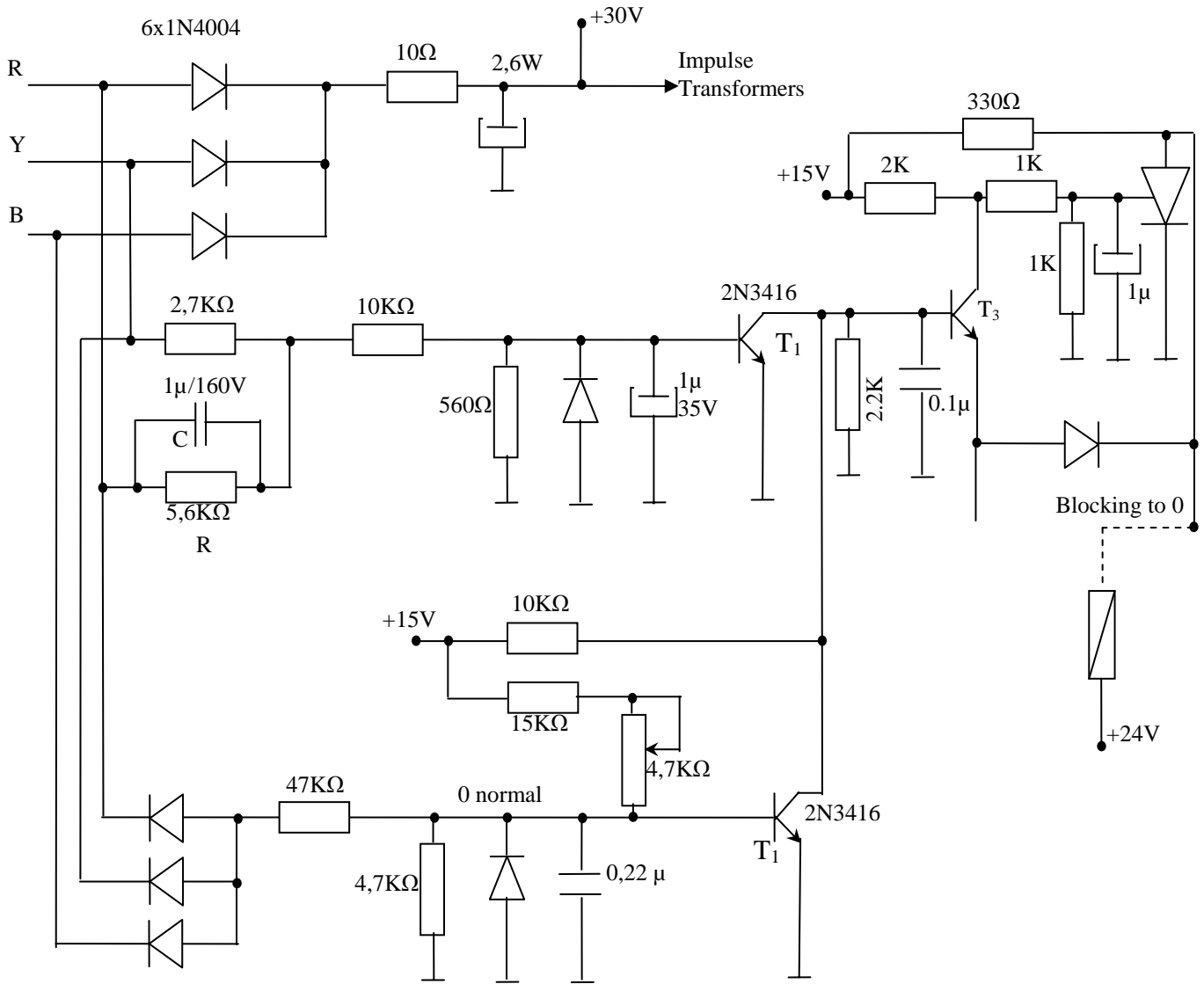
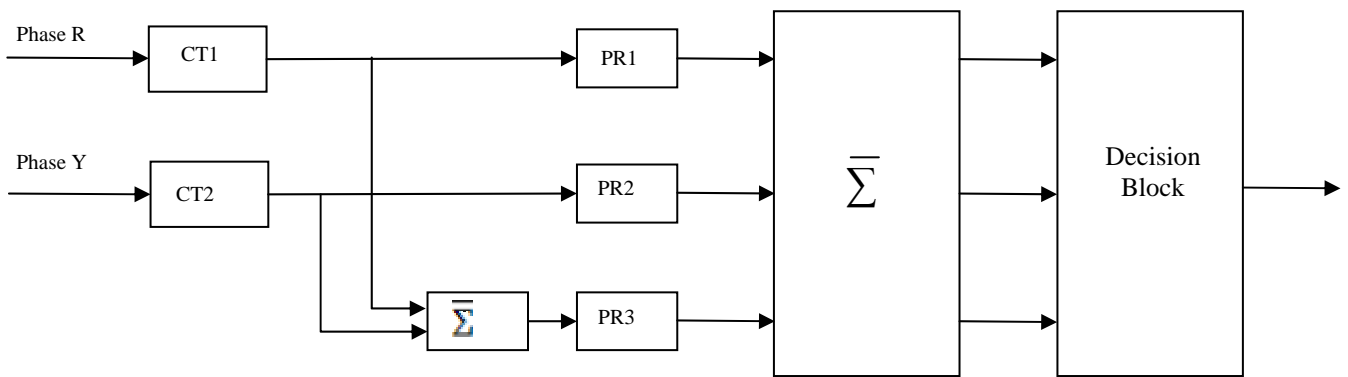Fig.2 Protection circuit rectifier.
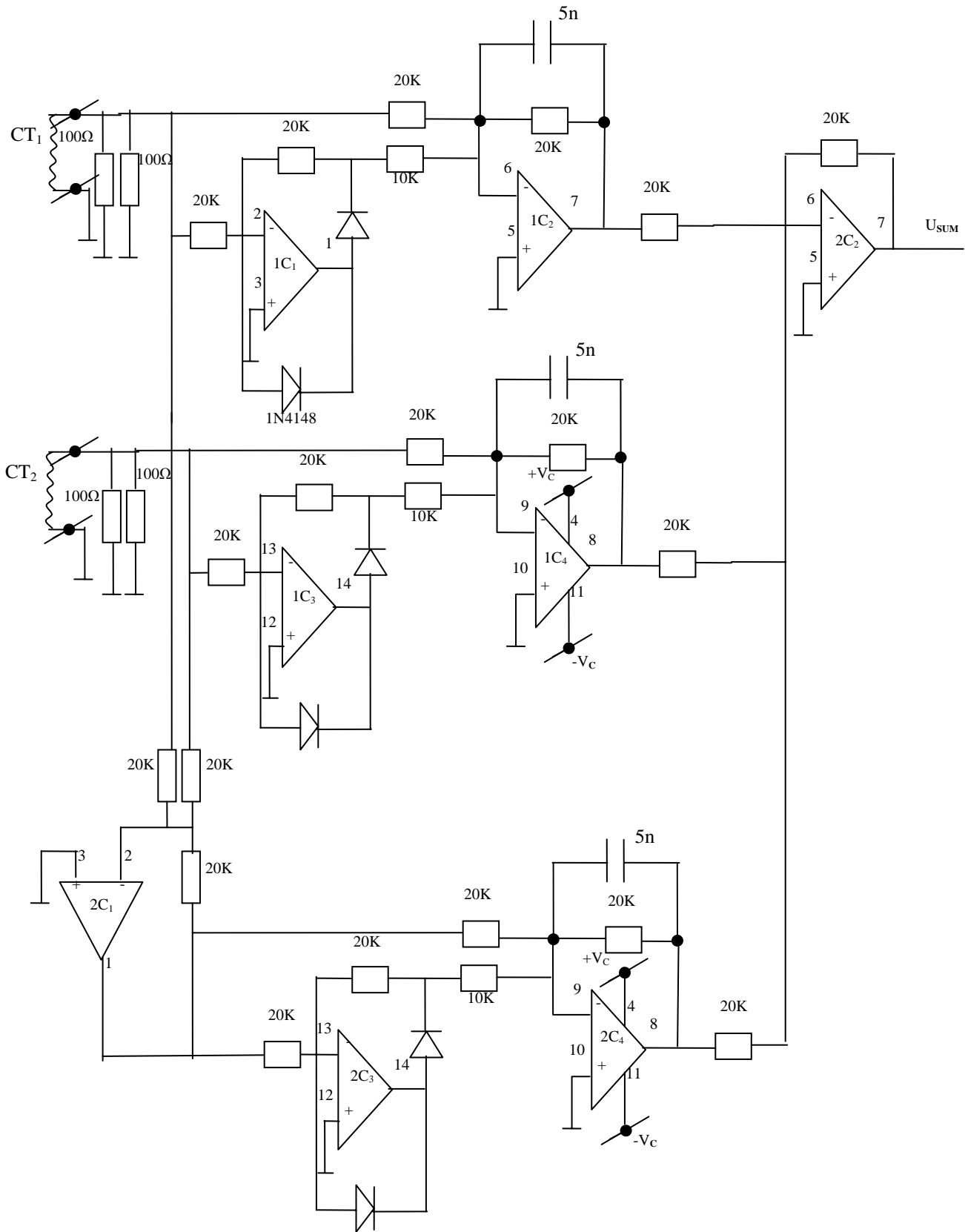

Fig.3. The Block scheme

Fig. 4. The precision rectifier and adder

The relation between the medium and the maximum value will be :

$$\frac{U_{SUM}}{U_{SUMA}} = \frac{6}{\pi} U_m \frac{1}{2U_m} = \frac{3}{\pi} = 0.95 \quad (12)$$

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

If the decision block is made using analogical circuit, the maximum value U_{SUMM} is compared with the medium value – U_{SUM} of the u_{sum} signal obtained at the output of the reverse summator.

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

If the decision block is made using the analogical and logical circuit, it must contain: the filtering 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.

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.

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.

Taking over the functions of the precision bialternance rectifiers and of the inverse adders by the digital processing circuit is done with a program which must follow the steps:

-to obtain the current information of the B phase, the corresponding negated signals of the R and Y phases are added (as I proved before), or, to reduce the number of operations, first we add the signals and then negate the result;

-if the signals from the current transducers (from the adapting circuits which they are used for ADC with the domain 0-3V) are higher than 1.5V, the situation corresponds to positive values of the signals;

-if the signals from the current transducers are less than 1,5V, the situation corresponds to the negative values of the signals, and these will be negated;

-to obtain the current information through the load of the three-phase rectifier, the signals corresponding to the three phases , R, Y, B, are added;

The digital processing circuit makes the detection of the lack of pulses in the following way:

-the minimum and maximum values of the current through load are detected on a time interval equal to the period of the current when no pulses are missing (3,3ms);

-the two values are compared, the report between them, when no pulses are missing should't be smaller than 0.9. This results from the calculus at point b, where we obtained the report between the medium value and maximum value as being equal to $U_{SUM} / U_{SUMM} = 0.95$.

Considering that the signal has a symmetric trip compared to the medium value and results an estimated report between the minimum and maximum value of 0.9.
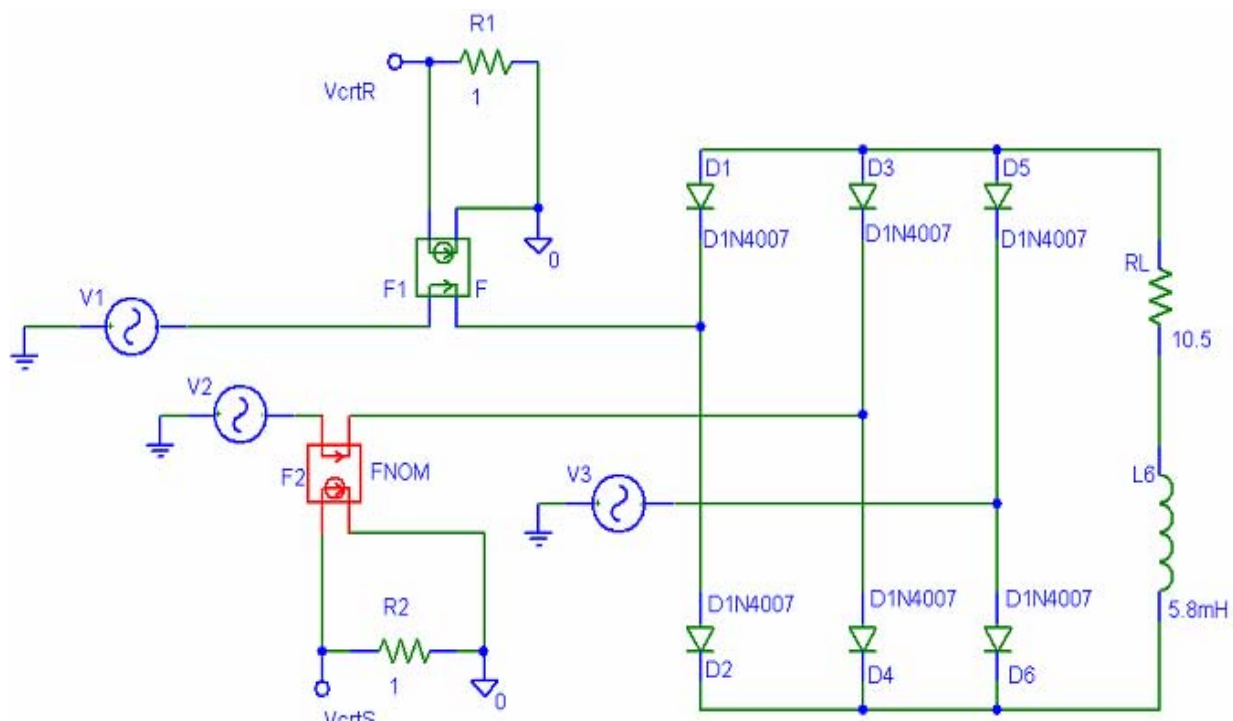

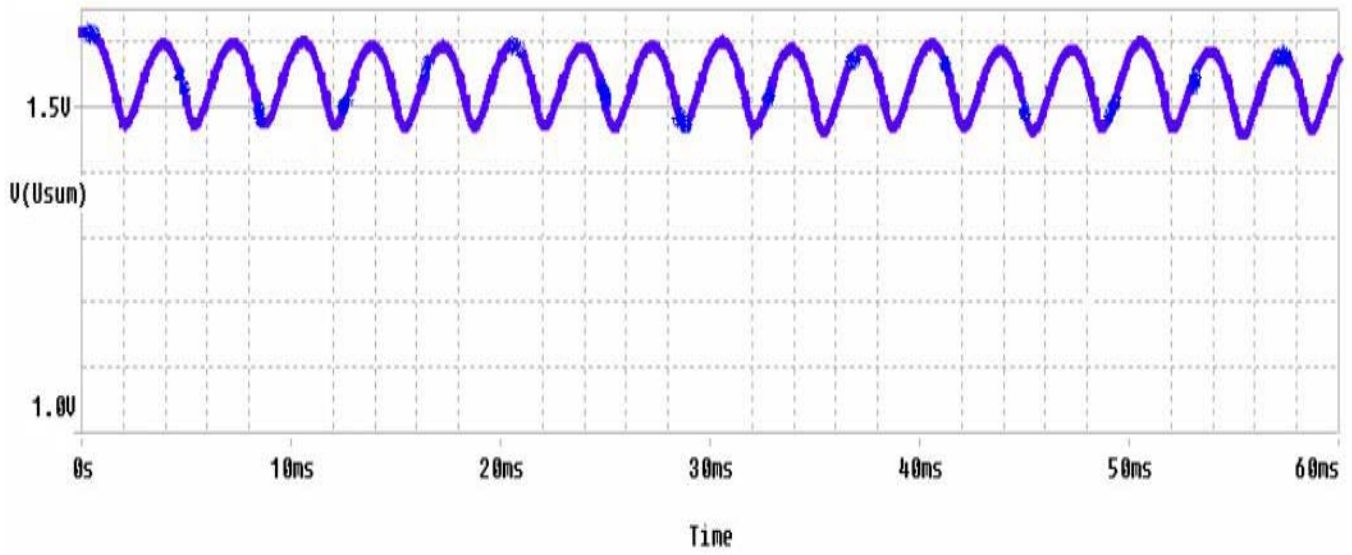Fig 5. The power electric diagram when the pulses are not missing.

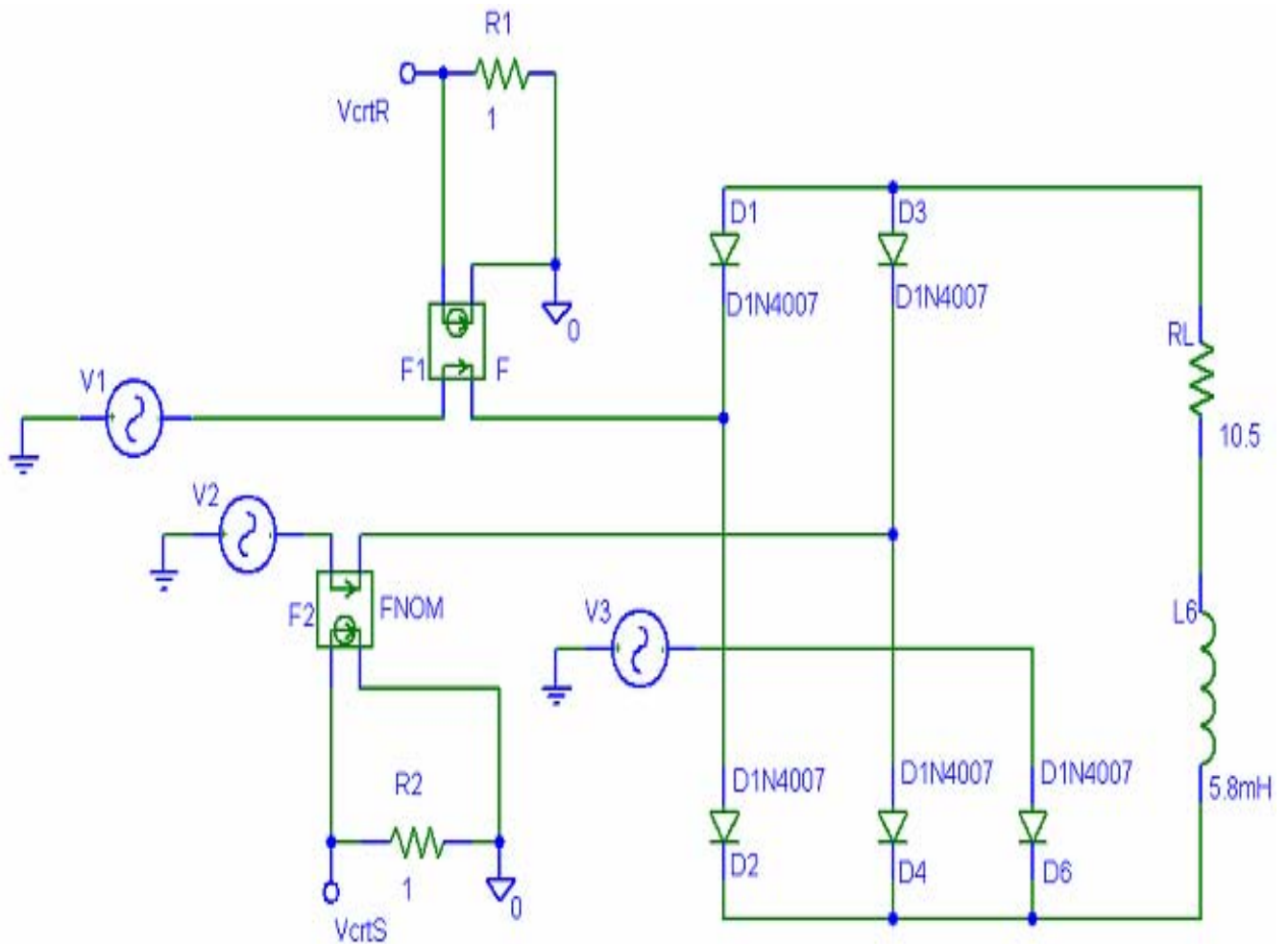Fig 6. The signal u$_{sum}$ when the pulses are not missing.

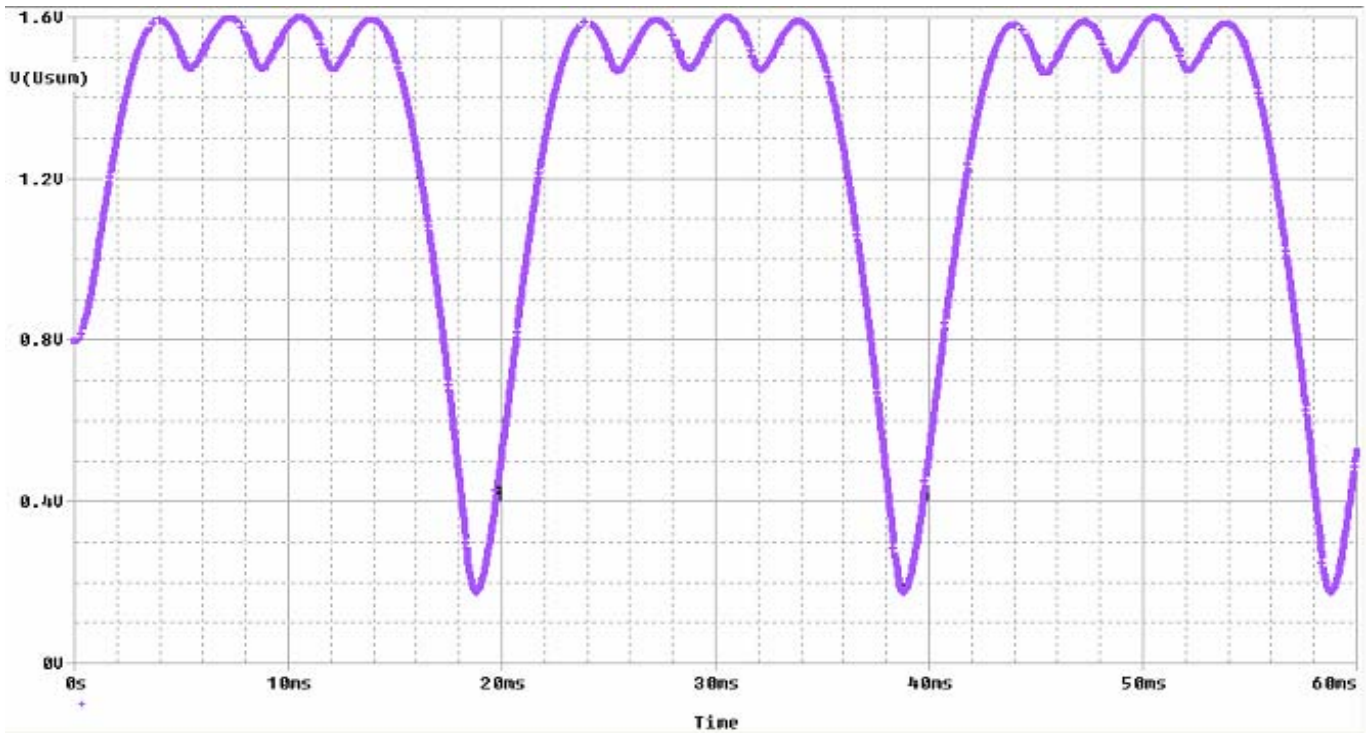Fig 7. The power electric diagram when two pulses are missing.

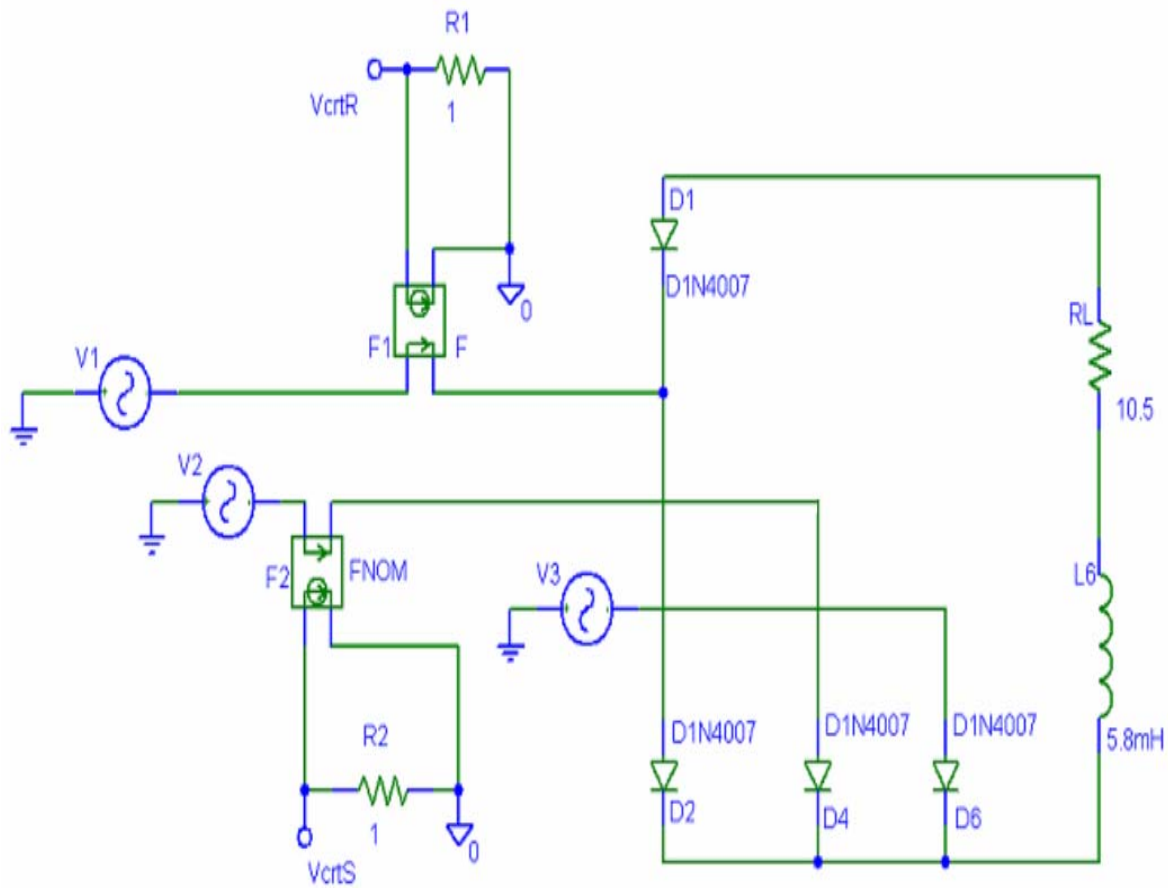Fig 8. The signal u_{sum} when two pulses are missing.

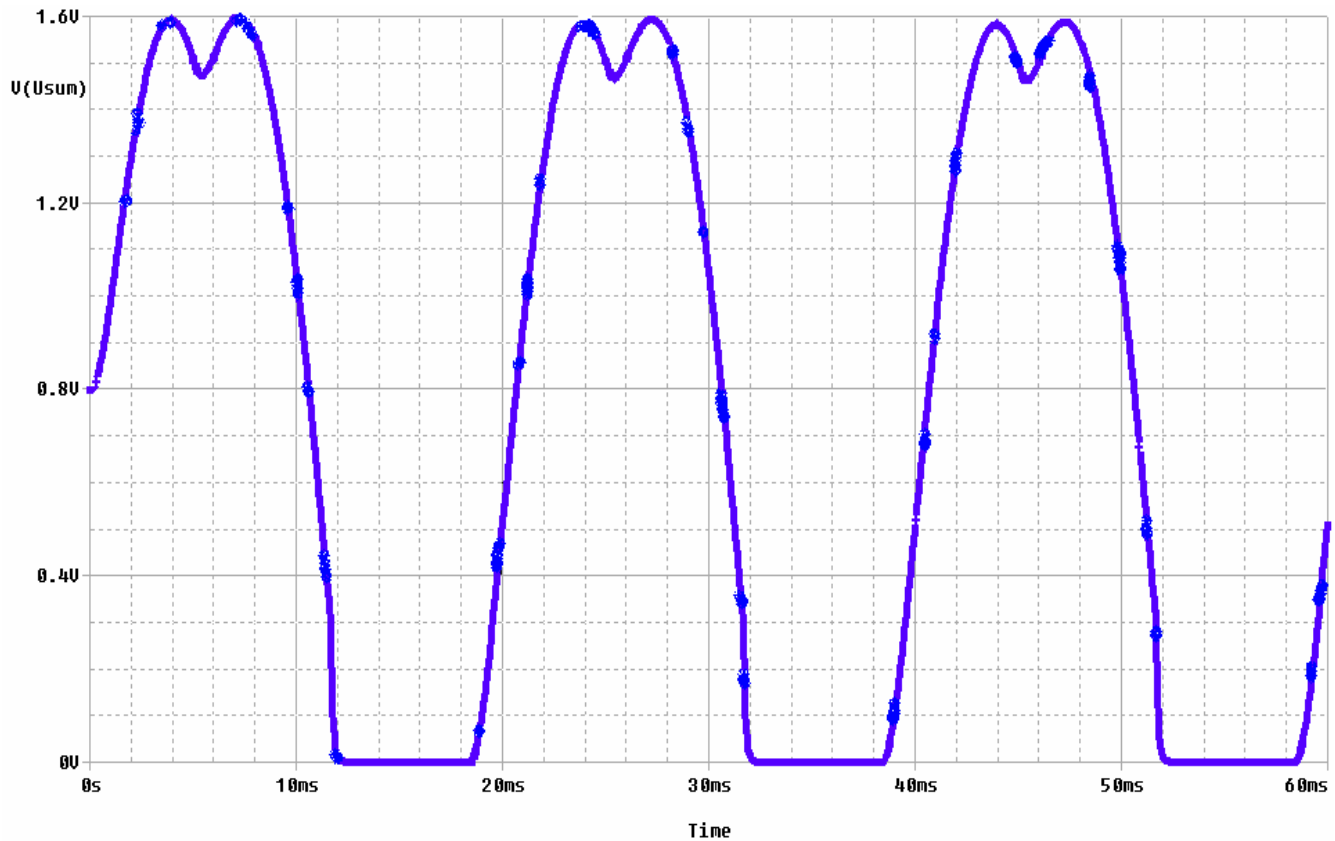Fig 9. The power electric diagram when four pulses are missing.

Fig.10. The signal u_{sum} when the pulses are missing (4 pulses).

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.

In figure 5 we present the power electric diagram [2], [3] used for obtaining the signal u_{SUM} when pulses aren't missing (all the electronic elements are working).

If we simulate in PSpice the circuit of the figure 4 we will obtain the waveform of the figure 6. In the figure 7 we present the power electric diagram used for obtaining the signal u_{SUM} when pulses are missing (all the electronic elements aren't working). If we simulate in PSpice the circuit of the figure 4 we will obtain the waveform of the figure 8.

In the figure 9 we present the power electric diagram used for obtaining the signal u_{SUM} when four pulses are missing (two electronic elements aren't working).

If we simulate in PSpice the circuit of the figure 4 we will

obtain the waveform of the figure 10.

Therefore the Decision block from fig. 3 can be made using analog circuits, combinational logic or mixed. Also, we can use a microcontroller to reduce the sizes of the circuit.

It must process the received signal from the adder $\overline{\Sigma}$, to verify the missing of pulses and/or verifying if the admissible current through load is not passed.

IV. CONCLUSION

The proposed method can be used with success to verify the functioning of all the semiconductor elements of the three-phase rectifiers in bridge with resistive load or inductive load, commanded or not.

The circuits with detection of missing phase (missing synchronizing voltage) and ultra fast fuses with "percutor" and switch can only detect the missing of the power voltage, but using this method the lack of pulses can be detected.

The biggest advantage is represented in the case when the rectifier is a part of an automat relation system of revolutions, of a DC motors (in the industry, robotics,…) [5]…[8].

Using a microcontroller we can reduce the physical sizes of the element from figure 3, by eliminating the adders, the precision rectifiers and the decision block.

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