tts
TECHNIKA TRANSPORTU SZYNOWEGO

Zbigniew SOBCZYK

THE INSTANT FAILURES DETECTION METHODS IN AUTOMOTIVE ELECTRIC LOADS CIRCUITS

Abstract

In the paper has been discussed the instant failures detection methods in automotive electric loads circuits. It has been shown growth of electronic automotive equipment and automotive electric network elements failure frequency. These are the main reasons why failures detection methods in automotive electric circuits has been developed. The instant failures detection methods in automotive electric loads circuits has been particularly described. It has been elaborated the synthesis of the automotive failure electric loads circuits instant detection methods types and their properties. All of the considered method has been assembled in the three main groups and it has been shown their main, most important features.

INTRODUCTION

Equipment level of contemporary vehicles in electrical and electronic devices is already high and still increases. It can be testified by growth of electronic equipment share in vehicles' production costs, shown on fig. 1 [5].

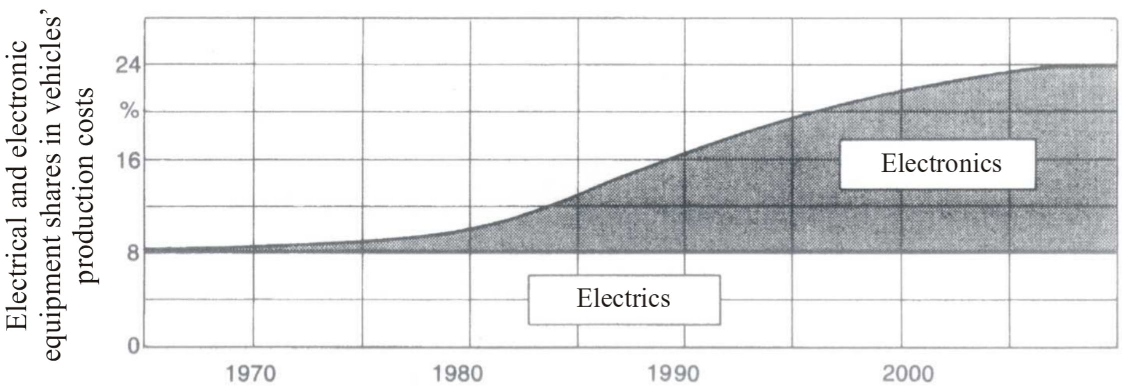

Fig. 1. Growth of electronic equipment share in vehicles' production costs [5]

Electronic devices have enabled widespread use safety systems in vehicles, like ABS, EBD, ASR, ESP, ACC and so on [3, 4, 5, 6, 8, 13, 14, 16, 17, 18, 20]. Engine and driving control processes also are accomplished electronically [4, 5, 6, 7, 9, 10, 11, 12, 13, 16, 18, 28].

It can be noticed significant progress in automotive lights, too [17, 18, 21, 27]. They fulfils important functions. Besides illumination, automotive lights have signalling, warning and inquiry functions. It has direct influence on road safety. For that reason it is important that automotive lights should be reliable and their failure should be signalling, because luminous parts of the car lamps often aren't directly visible for this car driver.

Automotive electrical and electronic equipment gets out of order by reasons' of its lifetime and difficult service conditions, such as: vibrations, temperature, humidity changes and corrosion. That also leads to the others kinds of devices development, like for example LED [1, 19] or xenon high intensity discharge (HID) [17, 18, 21, 27] lamps instead of bulbs, but bulbs are still in common use. Such damages are probably the more so as bulbs' lifetime and so as joints damages are most often defect in the vehicle electric network [5, 26], as shown on fig. 2.

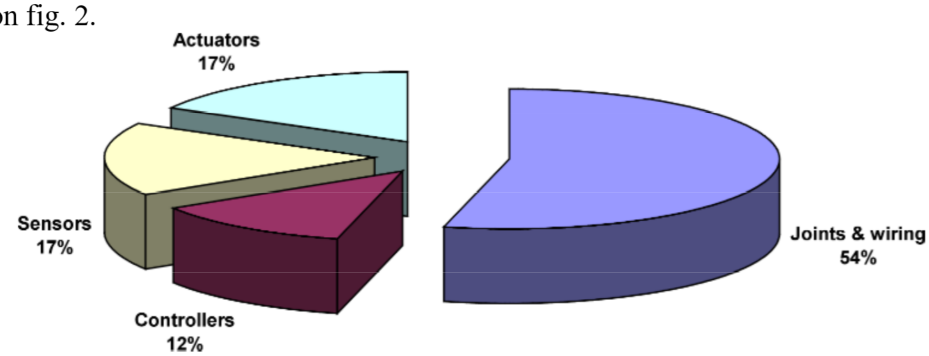

Fig. 2. Automotive electric network elements failure frequency [5, 6]

There are two main electric circuits damages: short-circuit and interruption of electric circuit. Joint damages causes improper work of connected devices like: electric heaters (in air-condition, seats, mirrors, Diesel engine coolant liquid systems [17] and in Diesel fuel filter [4]), glow plugs, electromagnets, electric motors, lights, electronic controllers, sensors' circuits and others.

There are a lot of kinds diagnostic methods, like: instant, prognostic, time-planned, in case of doubts, failures detection and so on. Although instant methods are in some applications less precise, they have undeniable advantages. Immediate signalling allows on sooner, planned action with restricted or eliminated at all possibility of use damaged circuit. Instant methods are easy to use, possible to use with other kinds of diagnostic methods and relative low cost.

On the fig. 3 are shown electric diagrams of basic methods, which are used to failure detection in automotive electric loads circuits [16].

Full load current dropping resistor method (fig. 3a) enables on short-circuit as well as interruption detection. It's applied with individual current sensors [16] and there is a possibility of threshold change during the work. There is a possibility failure detection before turning on when modified to insignificant load current.

Reed relay method can be used with individual load for each one-winding relay or with reed relay which coil has two push-pull windings, each connected to one or two parallel equal each other (symmetric) loads (fig. 3b). Individual solution allows on circuit interruption without short-circuit detection. It seems that with symmetric diagram can be possible both, short-circuit and interruption detection. But when loads voltage supply disappears then circuit interruption detection fails. There isn't possibility either failure detection before turning on or threshold change during the work.

Shown on the fig. 3c scheme with transformer sensor is able to detect short-circuit as well as circuit interruption but can be applied only for symmetric, binate, equal loads. Additionally such solution needs a transformer with relatively big, heavy core [16]. There isn't possibility either failure detection before turning on or threshold change during the work.

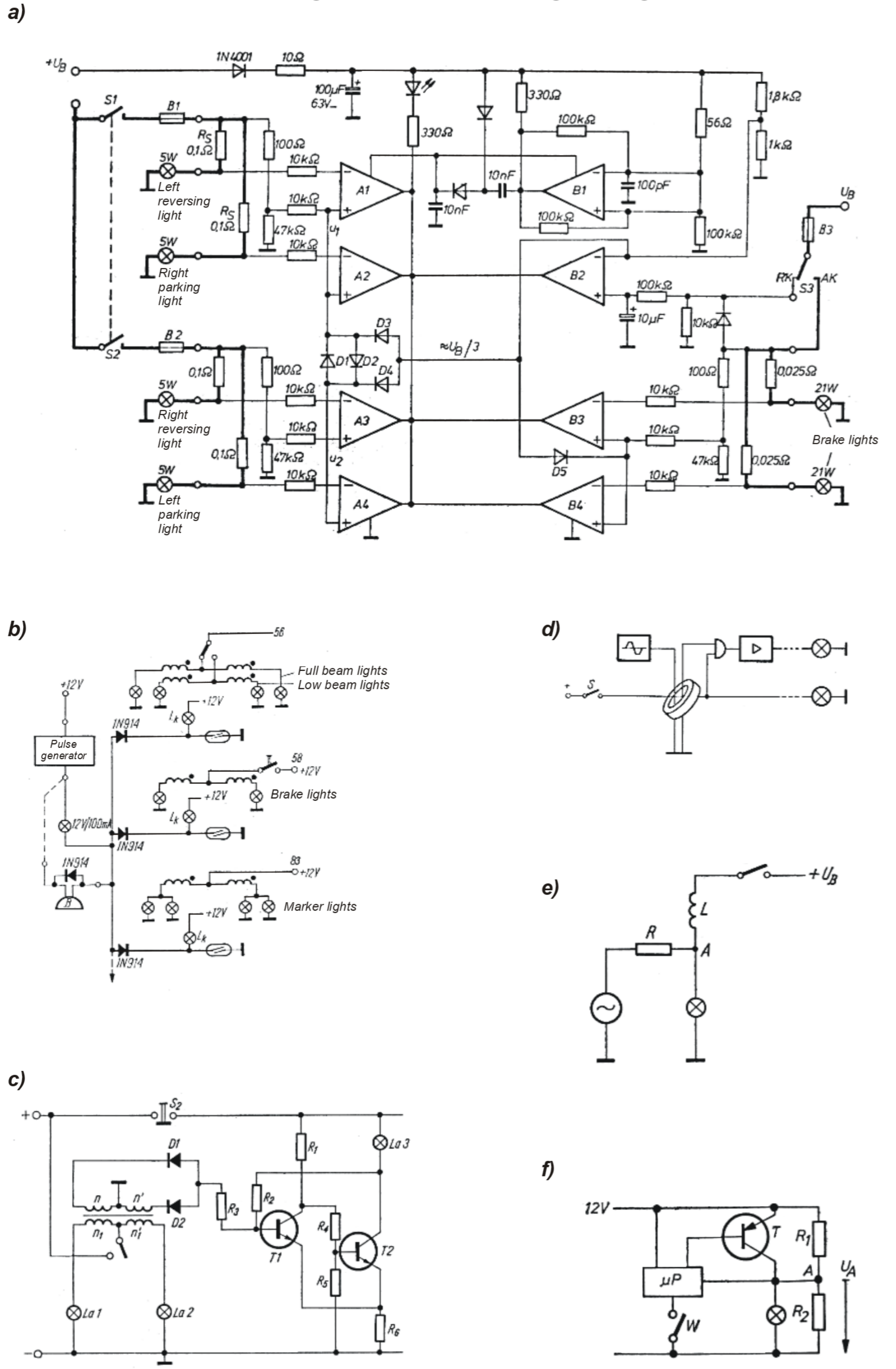

Fig. 3. Electric diagrams of basic failure detection methods in automotive electric loads circuits [16]
a) full load current dropping resistor; b) reed relay; c) transformer sensor; d) saturated magnetic core;
e) alternative voltage on choke's reactance; f) computer pulses

Saturated magnetic core method shows diagram on the fig. 3d. It enables only on interruption detection without short-circuit. One sensor can be applied to individual or more loads. As previously, there isn't possibility either failure detection before turning on or threshold change during the work.

Alternative voltage on choke's reactance method (fig. 3e) also enables only on interruption detection without short-circuit. This method allows to detect failure only for individual load. There is possibility interruption detection before turning on as well as threshold change during the work.

As in previous method, the computer pulse method needs individual sensor for every load, but it allows to detect short-circuit as well as circuit interruption. Similarly to the previous method there is possibility interruption detection before turning on as well as threshold change during the work. The main disanvantage of the computer pulse method is the transistor T exposure on the load's short-circuit. For that reason transistor's nominal collector's current shuold be many times larger than nominal load's current.

1. SHORT-CIRCUIT DETECTION METHODS

Voltage supply sources with enough current efficiency demands fuse protection against short-circuit. Thus short-circuit signalling can be obtained by signalling lamp mating with fuse, as shown on the fig. 4. The ability signalling lamp turns on and off simultaneously with loads when everything is in order. If the switch of the considered load is on and short-circuit occurs, the fuse blows and voltage on the load as well as ability signalling lamp turns off. The same effect for a load is caused by electromechanical or electronic cut-out, which schemes are shown on the fig. 5 and fig. 6.

In the electromechanical cut-out example shown on the fig. 5 the contacts are manually closed and contact's spring is tense. If the coil's current is too much, the electromagnetic attractive force exceeds tensile force of the armature spring. The armature moves and releases the pawl. The contact's spring causes opening the contacts. The voltage on the load and ability signalling lamp turn off.

On the fig. 6 is shown an example scheme of the electronic cut-out. When the battery's voltage is applied through the closed switch to the elements of the cut-out, the thyristor *Th* is off, then the base of the transistor *Tr* is polarised through resistor R_B . The emitter-collector resistance is low and transistor is on. The load and ability signalling lamp currents (I_L and I_S) flow through resistor R_S , diode *D* and transistor *Tr*. The bigger load current the bigger voltage drop on the resistor R_S. This voltage is applied to the thyristor's *Th* gate. When overloaded, voltage drop rises and turns the thyristor on, thus causes transistor's base current decay and the emitter-collector resistance increases, then voltage on the load as well as ability signalling lamp turn off.

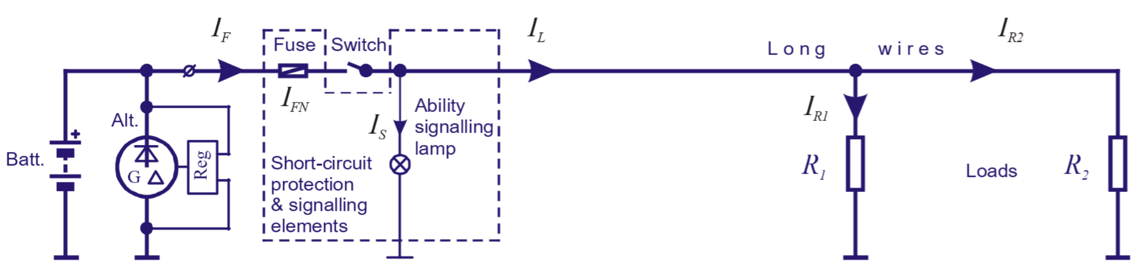

Fig. 4. Short-circuit protection and signalling realized by ability signalling lamp mating with fuse

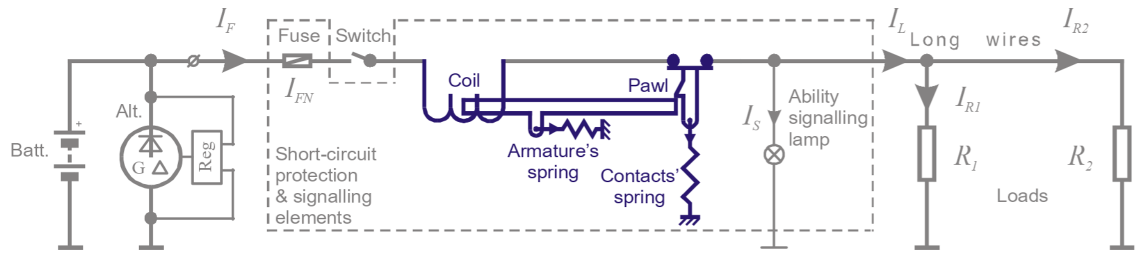

Fig. 5. An example of short-circuit protection and signalling realized by ability signalling lamp mating with electromechanical cut-out

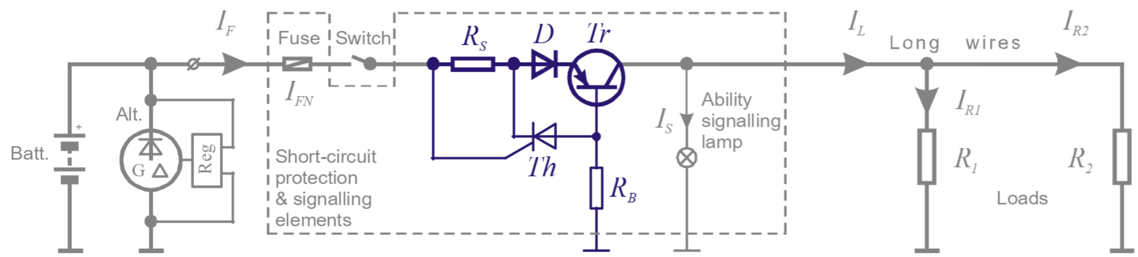

Fig. 6. An example of short-circuit protection and signalling realized by ability signalling lamp mating with electronic cut-out

More sophisticated electronic and electromechanical cut-outs are described in [2, 22].

Such instant short circuit detection methods, which encloses an ability signalling lamp, are able to detect the voltage source failure as well.

To the advantages of the electronic or electromechanical cut-outs belong possibility of repeated operation, then they don't need spare parts (reserve fuses).

Usually, with electronic or electromechanical cut-out is additionally applied fuse protection. Such situation is caused by its reliability. Damage of the correct exploited fuse protection can cause only groundless operation. Failure of the other, more developed protections can result in groundless as well as lack of operation. Besides better reliability, fuse protection is the simplest and cheapest.

For that reasons the fuse protection possibilities should be considered in detail.

On the fig. 4÷6 are applied the following designations:

I_F – actual fuse current;

I_{FN} – nominal fuse current;

I_S – ability signalling lamp current;

I_L – load current;

I_{R1} – load R_1 current;

I_{R2} – load R_2 current.

It can be stated following dependences between some of mentioned on the fig. 4÷6 quantities:

$$I_{R1} + I_{R2} = I_L \ , \tag{1}$$

$$I_L + I_S = I_F \ , \tag{2}$$

and usually:

$$I_S << I_L \ . \tag{3}$$

Beyond safety, the fuse fulfils information role that has happen overcurrent described approximately by condition:

$$I_F > I_{FN} \ . \tag{4}$$

Nominal value of the fuse current is usually chosen from 1,2 to 5 and even 10 or more times larger than nominal current of the secured device. Besides actual value of the current, fuse reacts on the duration of the overcurrent (fig. 7), especially in range of time from $1x10^{-3}$ s [15] to even $7{,}2x10^{3}$ s [2]. Long-term blowing current is about 1,4÷1,8 times larger than nominal value of the fuse [2, 15, 25]. Many devices have greater starting than nominal current. The fuse should withstand starting current and react only on short-circuit or long time overcurrent. Starting current value and its duration depends on the load properties. Then there are different types of fuses, with different nominal current and speed reaction. There are generally produced quick-break, normal and slow-blow automotive fuses. In compliance with IEC standard there are very fast, fast, middle (normal), slow-blow, very slow-blow types of fuses. Popular fuses' nominal current values are from 1 to 60 A [15]. In automotive circuits usually are applied fuses from range 5÷30 A [4, 17, 23].

An interesting matter is the protection possibility a lot of loads by one fuse. On the fig. 8 are shown *n* loads R_1, R_2 …R_n protected by one fuse.

Adequately to the first Kirchhoff's law and equal (1) it can be obtained:

$$I_{R1} + I_{R2} + \ldots + I_{Rn} = \sum_{i=1}^{n} I_{Ri} = I_L \ , \tag{4}$$

The number of these loads can be increased if the short circuit current is much more than nominal current. Loads' currents should be similar each other as well as them current-time characteristics. It should be distinctly emphasized that loads' number increasing protected by one fuse decreases efficiency of that protection. Then the protections should be individualised. The short circuit current can be about ten times larger than load's nominal current I_N . If one fuse protects for example ten similar loads and only one of them gets short-circuit, then total current will increase from ten nominal current to (9 I_N +10 I_N)=19 I_N . This means that fuse current will increase only 1,9 times. Such could be not enough to reliable action of the fuse. Reliability diminution of the fuse with the loads' number increasing excludes in principle such protection operation when the overcurrent occurs. To this two negative effects joins another. It can increase a number of groundless operations, too. A lot of devices have greater starting than nominal current. It can cause blowing the fuse immediately after switching on. If the loads can change drawn current, like for example electrical motors with it torque change, then the efficiency and reliability of that protection worsens. The fuse can blows not only immediately after switching on loaded motors but even after that, when the load torques simultaneously increase on the shafts of several motors. When the motors are working with small load then short-circuit one of them can not to result blowing of the fuse.

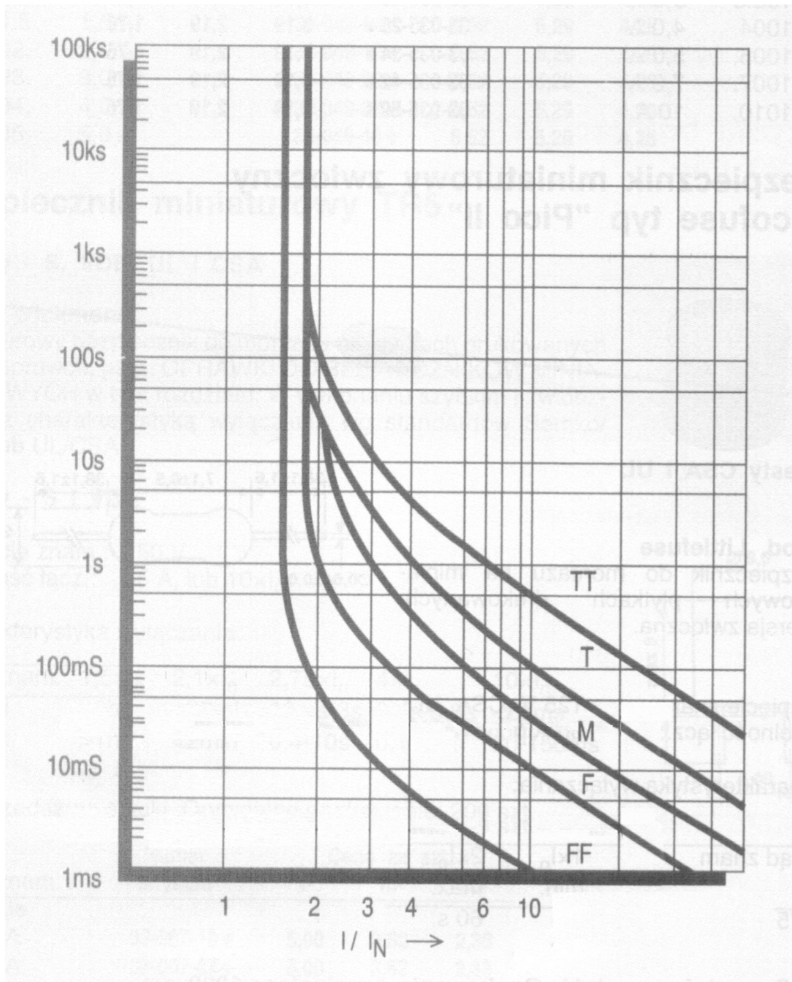

Fig. 7. Response time versus nominal current multiplication factor for different types of fuses [7]: FF – very fast, F – fast, M – middle (normal), T – slow-blow, TT – very slow-blow

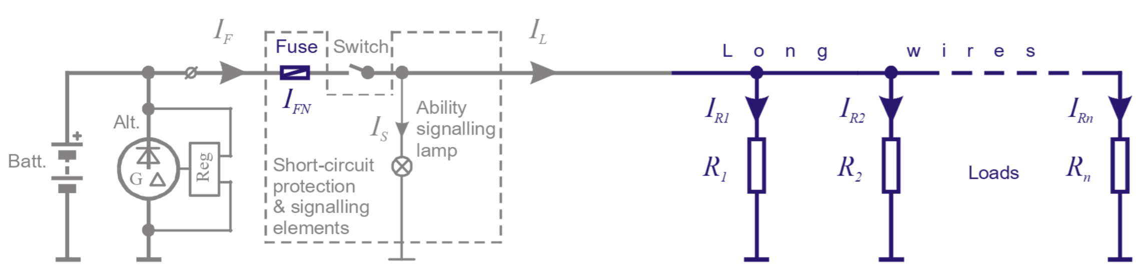

Fig. 8. Short-circuit protection and signalling of n loads

For that reasons the number protected by one fuse loads should be minimized. When the loads number to protect by one fuse is too much, it should be increased the number of fuses. In practice one fuse protects more than one load. Load number assignation and protection choice demands analysis of the specific case and honest engineer's knowledge, supported by deep experience. Loads with very various drawn currents and even with different starting current characteristics should be protected by separate fuses. From above considerations also ensues that use of ability signalling lamp is risky and unconsistent because usually is fulfilled the condition (3). Then the ability signalling lamp circuit is in fact unprotected.

The failure detection information which driver gets by ability signalling lamp mating with fuse as shown on fig. 4, is incomplete. Even if lamp lights, he isn't sure if load is supplied too. It's because of electric interruption only in load circuit possibility, as can be seen on the fig. 9.

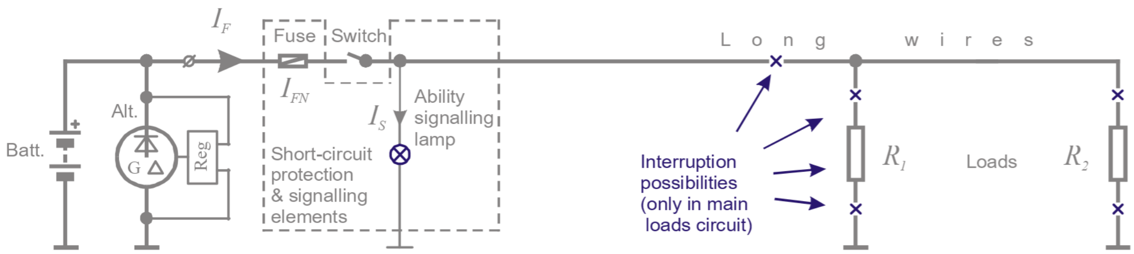

Fig. 9. An example of incorrect signalling in simple electric circuit

2. CIRCUIT INTERRUPTION DETECTION METHODS

More general method of loads circuits failure detection can be load's surroundings temperature monitoring [16], as, for example, shown on the fig. 10. Usually powerful load emits some warm. It is obvious for electric heaters and glow plugs. Other devices, like bulbs, electromagnets, electric motors emits warm adequatly to their power losses described by their efficiences. Every load should have individual temperature sensor and there is the same reaction on short-circuit and interruption bulb's circuit in this method. Obviously this method causes increase of wires and is also sensitive to ambient temperature changes. This method usually has essential response time lag caused its thermal inertia in comparison to short-circuit response requirements.

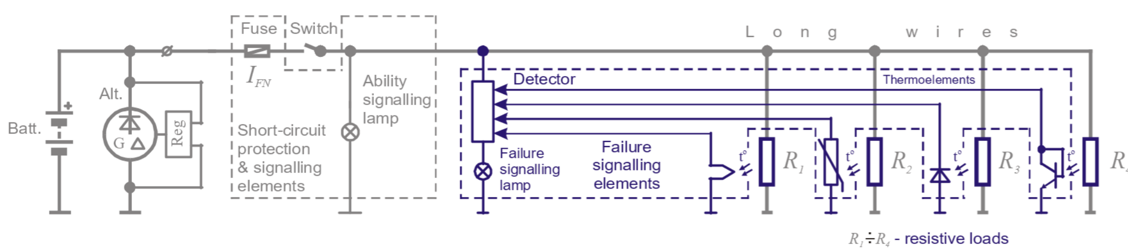

Fig. 10. Interruption's of electric circuit signalling with thermoelements

For loads which emits light can be applied luminous flux density measurement method [16]. It consists in attachment a photoelement reacting on the every source's light as shown on the fig. 11. As a photoelement can be applied a photodiode, phototransistor or photoresistor. One of the main advantages seems direct reaction on the most essential parameter. It makes possible bulb's glass internal dimming, inside lamp's dirty or reflector's mirror fading detection. Other advantage can be the same reaction on short-circuit and interruption bulb's circuit. However that method causes increase of wires. It is also imperative that assembly place should be well-chosen to avoid inappropriate operation on account of external lights, from other light sources like vehicles, street lights, sunlight etc.

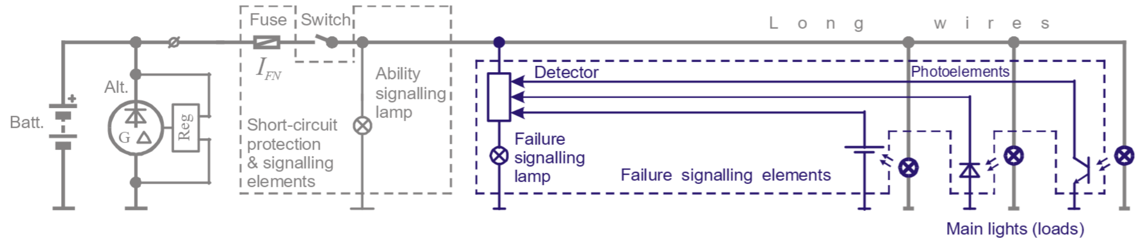

Fig. 11. Interruption's of electric circuit signalling with photoelements

Other method interruption's of electric circuit signalling can be inspected circuit resistance measurement method. There is achieved by frequency or computer generated pulses measurements [16].

More profitable in mass production is the total current measurement method, shown on fig.12 [24]. On account of less connections, such solution, in compliance with fig. 1, is more reliable too.

Another method of bulbs circuits failure detection can be bulb's circuit electric current measurement. It consists in put current sensors in bulb's circuit, as shown on the fig. 13. As current sensors can be applied: resistors, relays, reed relays, magnetic cores saturated by measured current by which additional generator's signal is obstructed, coils and magnetic cores mating with Hall generators or magnetoresistors, transformer sensors. According to specific application bulb's circuit electric current measurement method needs from one to four additional wires and joints.

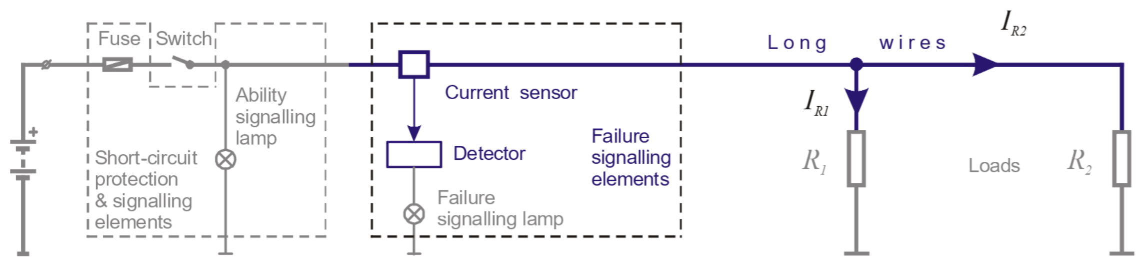

Fig. 12. Interruption's of electric circuit signalling with total current sensor

3. SYNTHESIS OF THE AUTOMOTIVE FAILURE CIRCUIT INSTANT DETECTION METHODS TYPES AND THEIR PROPERTIES

The recapitulation of the above considerations can be presented on the fig. 14. There are located all of the mentioned methods. As can be seen all of these method has been assembled in the three main groups, like: work parameter's inspection, load's circuit electric current measurement and inspected circuit resistance measurement group.

There is shown that almost all of them are able to detect circuit interruption and some of them can be applied to short-circuit detection.

Almost all of the methods (except transformer sensor and reed relay with symmetric load methods) can work with individual sensors but there are significantly less methods which can be applied with more loads for one sensor.

In a lot of the methods there is a possibility to change threshold during the work, but such important feature like failure detection possibility before turning on can be found only in a few methods.

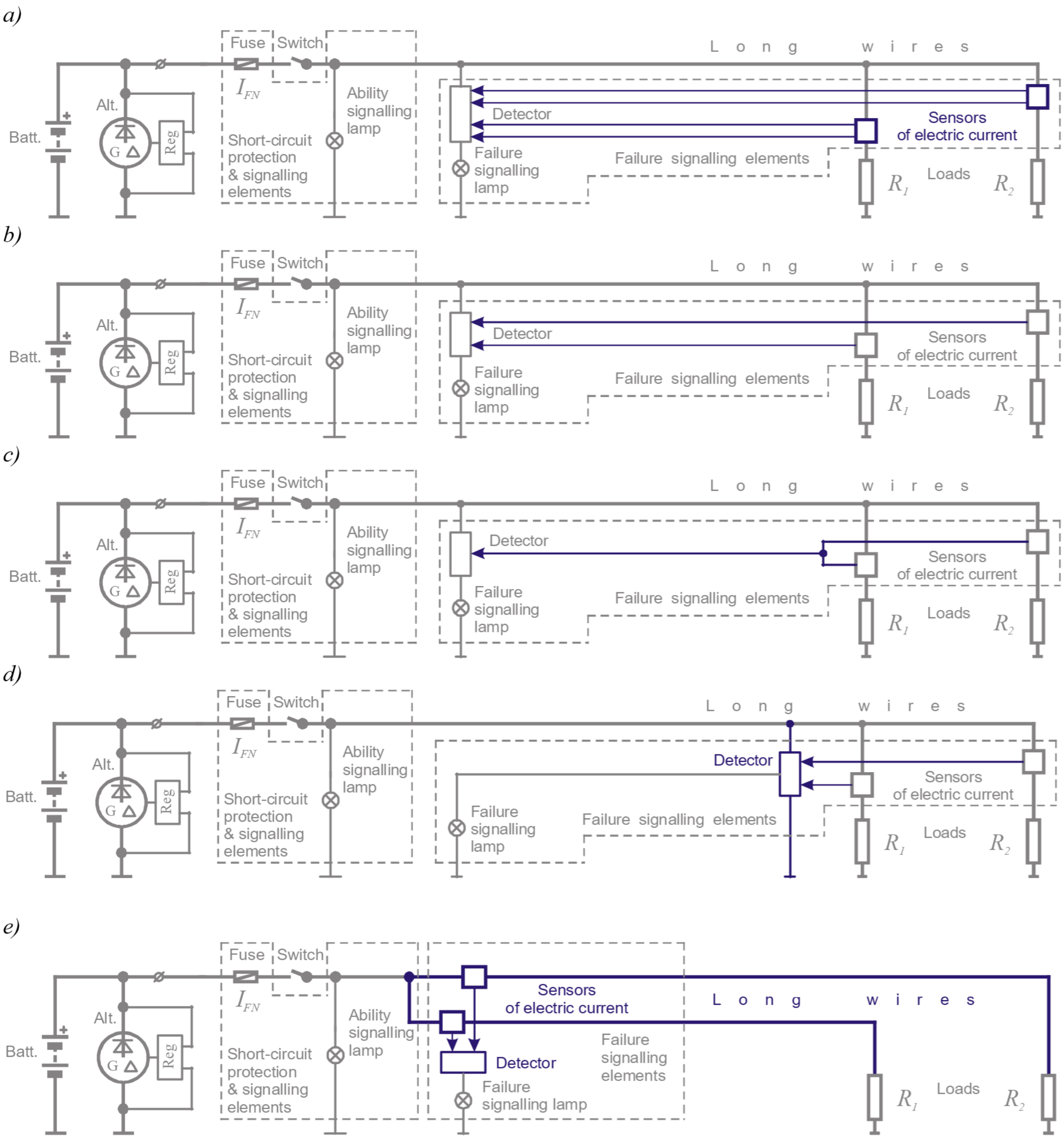

Fig. 13. Interruption's of electric circuit signalling with individual current sensors:
a) general diagram, for all sensors' types; b) diagram for sensors except resistors; c) diagram only for relays and reed relays; d) diagram for detector located near main loads; e) diagram for sensors located near driver's dashboard

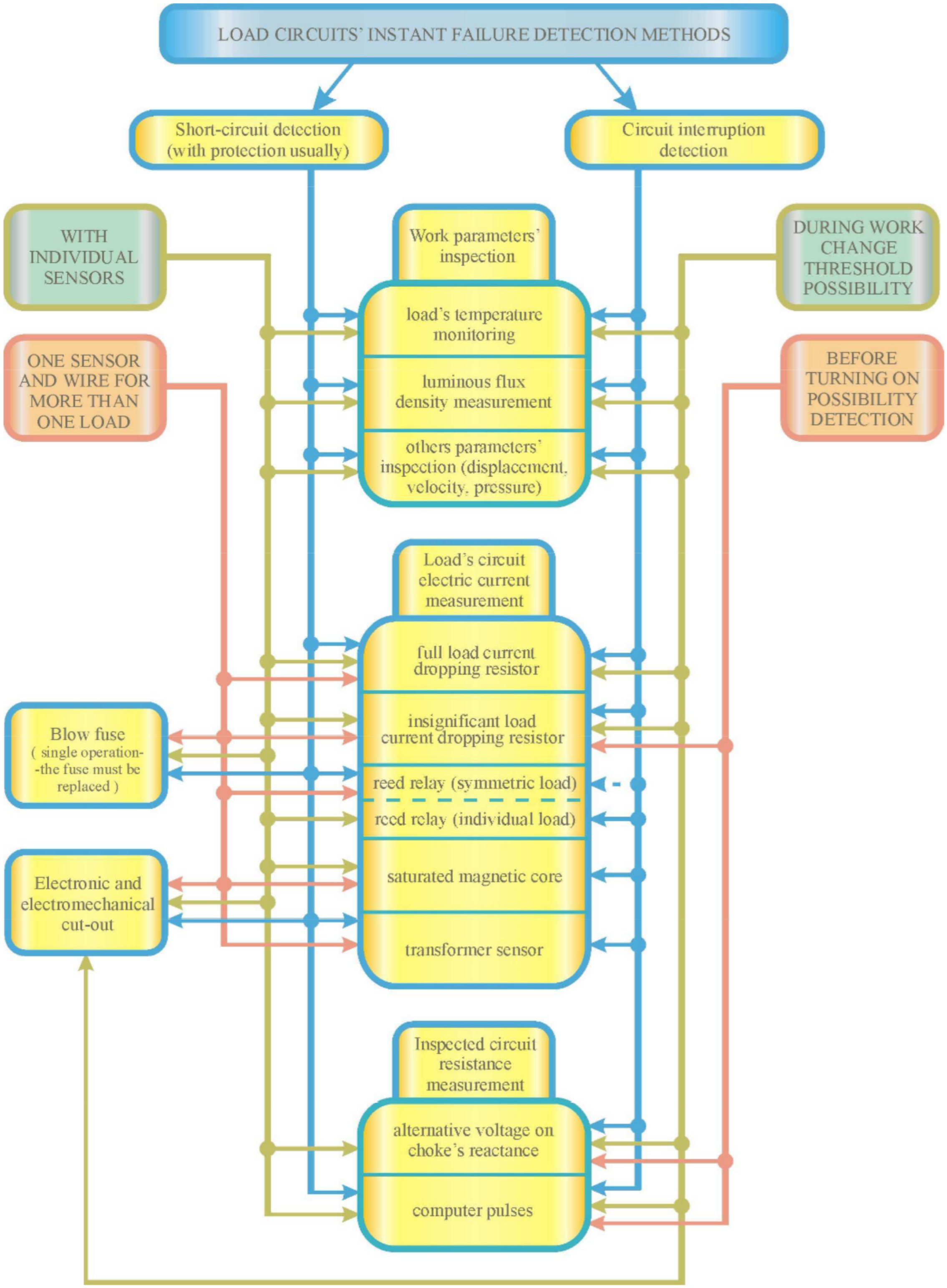

Fig. 14. Load circuits' instant failure detection methods types and their properties diagram

METODY NATYCHMIASTOWEGO WYKRYWANIA USZKODZEŃ W OBWODACH ELEKTRYCZNYCH ODBIORNIKÓW SAMOCHODOWYCH

Streszczenie

W artykule przedstawiono metody natychmiastowego wykrywania uszkodzeń w obwodach elektrycznych odbiorników samochodowych. Pokazano wzrost udziału wyposażenia elektronicznego w pojazdach, a także częstotliwość uszkodzeń elementów samochodowych sieci elektrycznych. Należą one do głównych przyczyn rozwoju metod diagnozowania usterek samochodowych obwodów elektrycznych. Szczegółowo opisano metody natychmiastowego wykrywania uszkodzeń w obwodach elektrycznych odbiorników samochodowych. Opracowano syntezę rodzajów i własności metod natychmiastowego wykrywania uszkodzeń w obwodach elektrycznych odbiorników samochodowych. Wszystkie rozważane metody zostały podzielone na trzy główne grupy oraz przedstawiono ich główne, najważniejsze cechy.

REFERENCES

1. Automotive LED Lighting, Home > LED Drivers & LED Lighting Design > Automotive LED Lighting, http://www.national.com/en/led/automotive_lighting.html;
2. Bartodziej G., Kałuża E., *Aparaty i urządzenia elektryczne*, WSiP, Warszawa, 1984;
3. Berger K.-J. i inni, *Budowa pojazdów samochodowych cz. I i II*, Wydawnictwo REA,Warszawa, 2003;
4. Etzold H.R., *Opel Astra II i Zafira. Sam naprawiam swój samochód*, WKŁ, Warszawa, 2005;
5. Herner A., Riehl H.-J., *Elektrotechnika i elektronika w pojazdach samochodowych*, WKŁ, Warszawa, 2006;
6. Informator techniczny Bosch, *Adaptacyjna regulacja prędkości jazdy ACC*, WKŁ, Warszawa, 2005;
7. Informator techniczny Bosch, *Elektroniczne sterowanie skrzynką biegów EGS*, WKŁ, Warszawa, 2004;
8. Informator techniczny Bosch, *Konwencjonalne i elektroniczne układy hamulcowe*, WKŁ, Warszawa, 2006;
9. Informator techniczny Bosch, *Napędy hybrydowe, ogniwa paliwowe i paliwa alternatywne*, WKŁ, Warszawa, 2010;
10. Informator techniczny Bosch, *Sieci wymiany danych w pojazdach samochodowych*, WKŁ, Warszawa, 2008;
11. Informator techniczny Bosch, *Sterowanie silników o zapłonie iskrowym. Zasada działania. Podzespoły*, WKŁ, Warszawa, 2002;
12. Informator techniczny Bosch, *Sterowanie silników o zapłonie samoczynnym*, WKŁ, Warszawa, 2004;
13. Informator techniczny Bosch, *Układ stabilizacji toru jazdy ESP*, WKŁ, Warszawa, 2000;
14. Informator techniczny Bosch, *Układy bezpieczeństwa i komfortu jazdy*, WKŁ, Warszawa, 2000;
15. *Katalog ELFA 55*, ELFA Polska, sp. z o.o., Warszawa, 2007;
16. Konopiński M., *Elektronika w technice motoryzacyjnej*, WKŁ, Warszawa, 1987;
17. Korp D., *Volkswagen Golf IV i Bora. Poradnik użytkownika*, WKŁ, Warszawa, 2003;
18. *Lighting Programme 2011. Automotive lamps*, OSRAM GmbH, Head Office, Hellabrunner Strasse 1, 81543 Munich, www.osram.com,

http://www.osram.cz/osram_cz/KATALOG/27060_Automotive_gb_klein2575250577746035482.pdf
19. Łęgiewicz J., Systemy doświetlania zakrętów, Auto Moto Serwis 10/2005;
20. Poradnik techniki samochodowej, Wydawnictwo REA, Warszawa, 2010;
21. Regulation No. 37, *Uniform provisions concerning the approval of filament lamps for use in approved lamp units on power-driven vehicles and of their trailers***,** United Nations Economic Commission for Europe, E/ECE/324, E/ECE/TRANS/505, Rev.1/Add.36/Rev.5, 19 September 2008;
22. Rusek A., Podstawy elektroniki, WSiP, Warszawa, 1982;
23. Schwarz J., *Skoda Octavia II*, WKŁ, Warszawa, 2007;
24. Sobczyk Z., *Total current measurement interrupts detection method in automotive bulbs circuits*, Journal of KONES Powertrain and Transport, Vol.18, No. 1 2011, European Society of Powertrain and Transport Publication,Warsaw, 2011;
25. Świrkowski E., *Instalacje elektryczne*, PWN, Warszawa, 1978;
26. Widerski T., *Samochodowe sieci informatyczne*, Poradnik Serwisowy Nr 5/2005, Wydawnictwo INSTALATOR POLSKI, Warszawa.
27. www.osrammiddleeast.com/osram_com: *OSRAM/News/Trade Press/Automotive Lighting*, 2008;
28. W. Zimmermann, R. Schmidgall, *Magistrale danych w pojazdach. Protokoły i standardy*, WKŁ, Warszawa, 2008;

Autor:
dr inż. Zbigniew SOBCZYK – Wojskowa Akademia Techniczna