Required safety component of automotive cyber-physical systems

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***Abstract*—This identification of possible hazardous events is a task for the risk assessment procedure. Current practices for risk characterization is based on known threats, their consequences and damage expectance.**

Modern technologies, such as electric, electronic, cyber-physical systems etc. have proven the existence of many challenges related to their practice and there is potential for improvements in how the hazard characterization can be conducted.

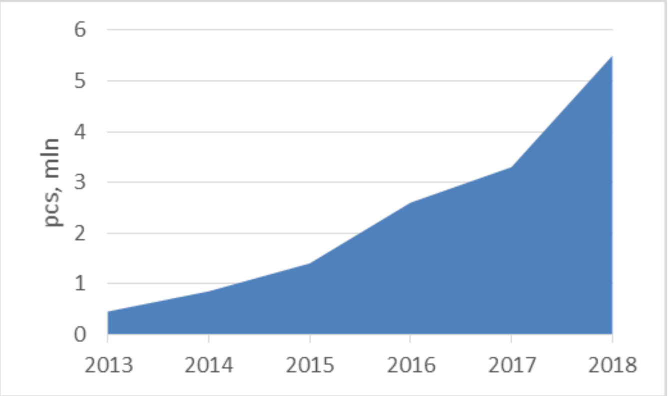
Our purpose is to present practical methods that should be applied for hazardous events' evaluation. Features of electric vehicles fire safety studies are highlighted. These approaches include furthering studies regarding rankings of risk factors and assumptions supporting the analysis. Focusing on events not included in existing studies. A simple example is used to illustrate how efficiency is reduced, due to a lack of a proper risk assessment perception from a safety standpoint. For the wires with polyvinylchloride insulating material with a most widespread cross-sectional areas the temperature and the time of the reaches the point of self-ignition was established.

Keywords*—*assessment; failure; cyber-physical component; hazard, efficiency; safety; measurement; wiring

I. Introduction

Fusion of physical component and computer processing is more than signal compatibility. This process integrate smart material, intelligent composition of subsystems, and composition at multiple levels. Modern vehicles are equipped with a variety of cyber-physical systems (CPS) that are designed to meet the needs of consumers. They include electronic traffic safety systems, in particular: traffic restraint system, automatic emergency stop, emergency braking system, driver fatigue and drowsiness monitoring system, emergency recorder, drunk driver's car lock system and several others [1]. Most of conducted research [2 - 4] focused on challenges of automotive design, security CPS software, but less about hardware safety. The quality and reliability those systems directly affect the safety not only of the passengers of such vehicles but also of those around them. However, the implementation of these systems requires the introduction of various sensors, creation of additional electrical systems and units [5]. They are expanding, modifying and complicating the on-board power supply of vehicles. This reduces their reliability as a whole and increases the likelihood of accidents. This is concerning, given how widespread is the use of vehicles has become [6].

We are considering equipping automotive CPS with wired hardware components. We would like to focus on vehicles operating on alternative fuels, most of which are represented by electrical vehicles (EVs). The number of electronic and electrical systems in them is higher compared to their fossil-fueled counterparts [7 - 9]. Enormous emissions of exhaust gas produced by vehicles with internal combustion engines (ICE) into the atmosphere, which has worsened the environmental situation; noise generation, limited resources of petroleum products, etc. [7, 9] have led to EV's growth in numbers. The development dynamics for electric vehicles and their share in the world transport fleet today can be seen in Figure 1.



a)

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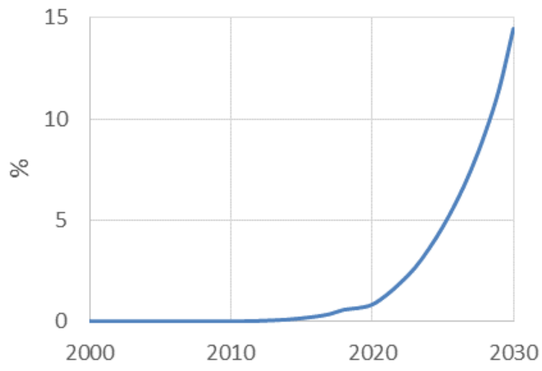


b)

Fig. 1. Number (a) and percentage (b) of electric vehicles and their share in the world fleet today and projected [4]

The hazard these vehicles pose lies in their rechargeable batteries, where lithium-ion batteries are widely used [10]. This type of power source is capable of discharging or even exploding when mechanically damaged or overcharged. Lithium contained in batteries reacts with water on a chemical level, releasing hydrogen. Hydrogen can form a so-called "rattlesnake" explosive mixture [11].

II. Assessment Component of Hazardous Event

A. Choosing an area of focus

By analyzing scientific documents [6]-[18], we have concluded that the unreliable operation of electronic vehicle systems can engage their emergency operation modes and cause a fire. Electronic vehicle system malfunction caused more than 20% of EV fires. In particular, [19] we can see that incorrect design and installation of the on-board power supply of the vehicle is being pinpointed as a common cause of fire. It is apparent that all types of vehicles suffer malfunctions in electric and information wired systems. In turn, they cause ignition. We distinguish three types of fire hazardous vehicle electrical equipment malfunction by their cause: current overload, short circuit (SC) and increased transient resistance [20].

Under normal conditions, the measure of the short-circuit current will depend on the parameters of the DC generator, which can supply the on-board car power supply independently or in parallel with the battery. In case of a parallel supply, the short circuit current value will be much greater, since the internal resistance of parallel-connected sources will be at least two times less than the internal resistance of individual parts. In addition, transient resistances in contact points, with normal values being in range of 0.05 - 0.1 Ohm [21], the resistance of wires, which depends on the cross-sectional area and length, as well as the resistance in the short circuit arc will limit the current of the short circuit.

The most dangerous area where a short circuit can occur is the engine compartment where there high temperature and the presence of flammable and combustible liquids are common. This, including the lining and trim of the car interior, built by using large amounts of synthetic and polymeric materials, creates a large fire load [22].

B. Modelling failures by Numerical Estimation

The lengths of wires where the short circuit can occur range from 1 to 4 m. Therefore, we deem it necessary to evaluate the current value during a short circuit, provided that it will flow from the power source through the wire and return through the elements of the body of the vehicle. Given that the vehicle body elements are made of steel and wires are made from copper, we approximate that the resistance of the reverse current path is much higher than the resistance of the wire, so they can be neglected.

The magnitude of the short-circuit current occurrence in the vehicle on-board power supply is determined by the following:

$$I_{sc} = \frac{U_{ab}}{R_{in} + R_{tr} + R_{sca} + R_{scc}} \qquad (1),$$

where I_{sc} is the current of SC, A; U_{ab} is the battery voltage, V; R_{in} is the internal resistance of the battery, Ohm; R_{tr} is the transient resistance of contacts, Ohm; R_{sca} is the resistance of the SC arc, Ohm; R_{scc} is the resistance of the circuit, Ohm;

$$R_{scc} = \rho \cdot \frac{l}{S} \qquad (2).$$

Documentation indicates that the voltage of the serviceable battery is in the range of 12 to 14 V; the sum of the resistances of the transient contacts is 0.1-0.5 Ohms; the resistance of the SC arc lies in the range of 0.03-0.07 Ohms.

The cross-sectional area of the most typical vehicle's on-board wires is 1 mm2, 1.5 mm2 and 2.5 mm2. Given that the short circuit occurs in the engine compartment, we will be using the (2) the resistance of the wires of the above sections; that will be 0.035 Ohms, 0.023 Ohms and 0.014 Ohms, respectively.

III. Battery Experimental Testing

A. Conducting Experimental Study of a Battery Short Circuit Event

We determined the internal resistance of the battery by carrying out an experimental study on a schematic diagram shown in Figure 1. The study was based on batteries of both domestic and foreign brands of cars.

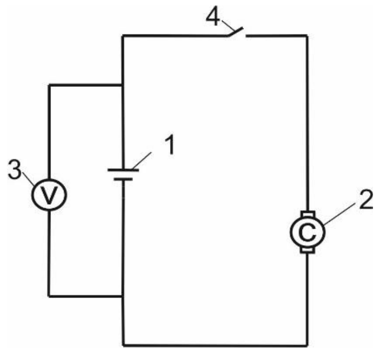


Fig. 2. Schematic diagram of research scheme: 1 is battery; 2 is starter; 3 is voltmeter; 4 is key.

The battery voltage was measured up until the ignition switch was closed U_0, and then is U_1, when the starter current was applied. In this case, the voltage drop on the battery was $\Delta U = U_0 - U_1$. By knowing the consumption current of the starter I_1, the internal resistance of the battery was determined with

$$R_{in} = \frac{\Delta U}{I_1} \quad (3).$$

The results of the experimental study are provided in table 1.

TABLE I. RESULTS OF THE EXPERIMENTAL STUDY OF BATTERY SHORT CIRCUIT EVENT.

N	Parameters in Experimental Circuit Study			
	U_0, V	U_1, V	ΔU, V	R_{in}, Ω
1.	13,5	11,8	1,7	0,017
2.	13,2	11,5	1,7	0,017
3.	12,9	11,0	1,9	0,019
4.	12,6	10,8	1,4	0,014
5.	12,8	11,1	1,7	0,017
Average	13,0	10,84	1,7	0,017

B. *Evaluation of a Short Circuit On Board Event*

The scheme of a short circuit current caused by damage to the insulation material of the wires of the onboard power supply is shown in Figure 3:

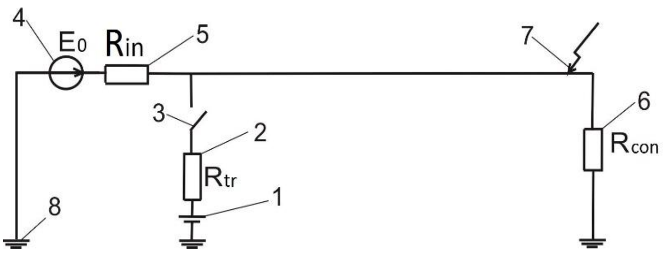


Fig. 3. Scheme of short circuit current in case of damage to the wires insulation material of the onboard mains: 1 is battery; 2 is the internal resistance of the battery; 3 is key; 4 is the eelectromotive force of the generator; 5 is the internal resistance of the generator; 6 is consumer resistance; 7 is the place of occurrence of the short circuit; 8 is housing.

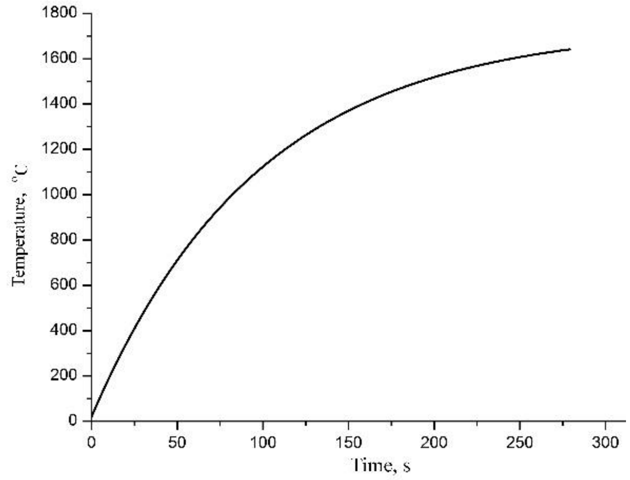
The short-circuit current of use (1) for copper PVC wires within a vehicle electrical network with a cross-sectional area of 1 mm2, 1.5 mm2 and 2.5 mm2 will be 59 A, 62 A and 65 A, respectively.

C. *Graphical Presentation and Comparison of Results*

Current arising from the short circuit will heat the wire along its entire length. The change of the wire's temperature over time in relation to the flow of short circuit current is shown in the form of a graph in Figures 4, 5, 6, for cross-sectional areas of wires 1 mm2, 1.5 mm2, and 2.5 mm2.

For the PVC wire with a cross-sectional area of 1 mm2, the steady-state mode occurs after 300 s (Fig. 4a). The ignition temperature of commonly used insulation materials of the vehicle onboard power grids had been experimentally established in the range of 290 - 370 ºC [23], so in Figure 5 the increase of temperature of the insulated wire over time during the flow of short circuit current is given. On 25 second`s the temperature of the insulating material reaches the point of self-ignition.

At a cross-sectional area of 1.5 mm2 of PVC wire with a current of SC 62 A, the steady-state mode occurs at a temperature close to 1000 ºC after 400 s from the beginning of the occurrence of the SC (Fig. 5a) and the temperature of self-ignition of the insulating material is reached by 55 s.



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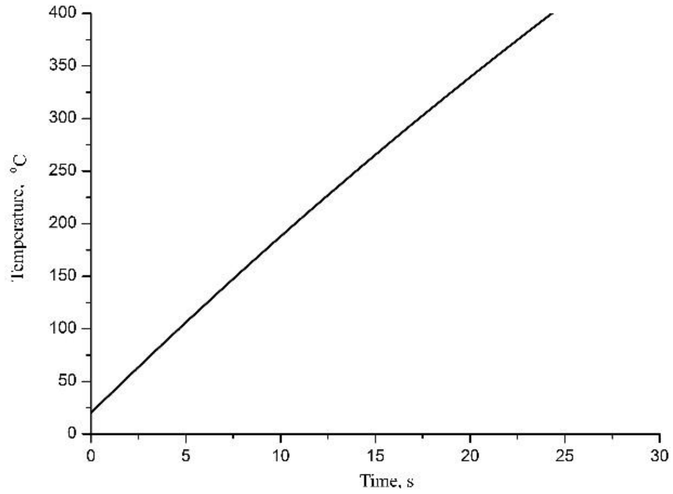

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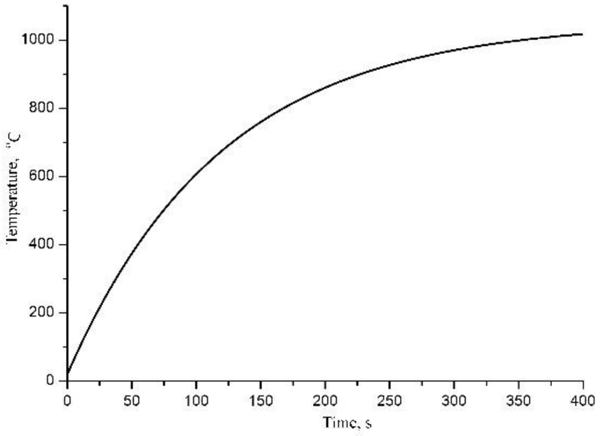
Fig. 4. Change of temperature of heating by current of the wire with cross-section 1 mm2 with time



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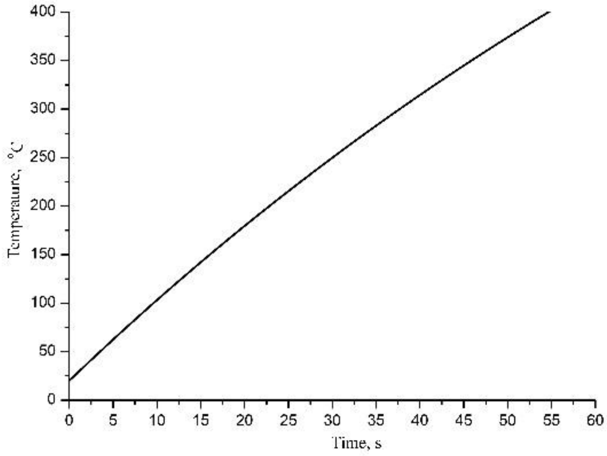

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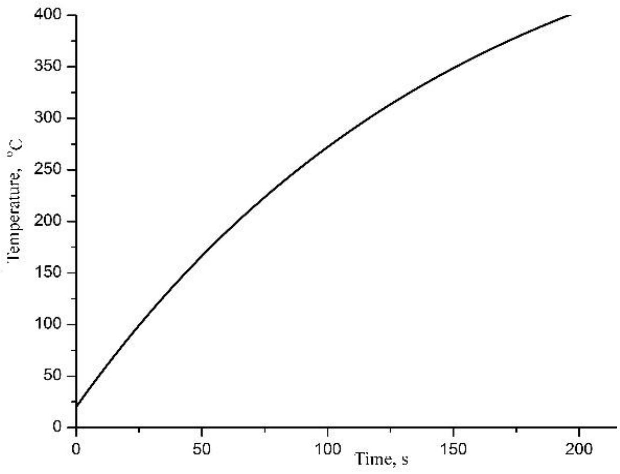
Fig. 5. Change of temperature of heating by current of the wire with cross-section 1.5 mm2 with time.

For a PVC wire with a cross-sectional area of 2.5 mm2, the short-circuit current is 65 A, which heats the conductor to the temperature of self-ignition of the insulating material for 180 s, and the steady-state mode comes after 500 s.



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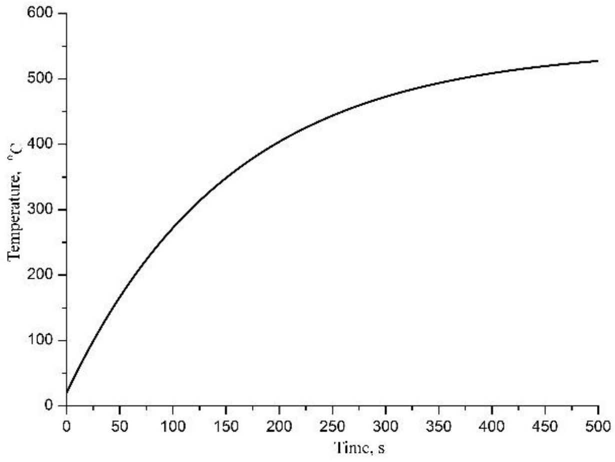

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Fig. 6. Change of temperature of heating by current of the wire with cross-section 2.5 mm2 with time.

Numerical experiments have shown that, provided that the rated current of the fuse is set incorrectly or it is absent, and its place is shorted, the short circuit current that flows through the onboard power supply of the EVs is able to heat the insulated wire to the temperature of self-ignition and cause fire.

D. Some Efficiency Assessment

Identifying possible hazardous events is a task for the risk assessment procedure [24]. They provide accurate forecasts for models of the system based on data regarding specific functions and separate tests of the system's components. In physics and engineering efficiency is the correlation between the amount of energy a machine needs to make it work, and the amount it produces. In the case of this paper, efficiency is the ratio of the useful work performed by a machine or a process to the total energy expended or heat taken in.

Modern technologies as electric, electronic, IT etc. have been disseminated through the higher efficiency of commands and signal, sharing and processing, better overall dimensions compared to chemical, mechanical systems [25]. However, from a safety standpoint, this efficiency is far from peak values due to the lack of perception of risk assessment. Issues in this area had illustrated with concrete examples. Risk assessments include the evaluation of the effectiveness of prevailing and alternative coping capacities with respect to likely risk scenarios. An excellent example of research on this topic is [26].

The future research study in this direction must be provide by complex composition of controllers with power and data lines, routers and receivers, which complete the car cyber-physical system.

IV. CONCLUSION

1. In emergency modes of operation of the automotive cyber-physical systems, onboard car power supply network, a short circuit current may occur. These modes of operation are a result of violation of the fastening of the wires, loss of dialectical ability of the insulating material

due to mechanical and temperature damage, the use of fuses with high rated current of the fusible insert.

2. The mode of heating of an insulated wire by the current of the short circuit is determined by the total circuit resistance and the magnitude of the electromotive power source. The results of the numerical experiment of changing the heating temperature of the wire by the current of the short circuit over time are shown in the form of graphical dependencies.

3. Short circuit current heats the insulated wire with PVC insulation to the temperature of self-ignition of the insulating material with a core cross-sectional area of 1 mm2 for 25s, a core cross-sectional area of 1.5 mm2 for 55s and 2.5 mm2 for 180s.

4. Safety efficiency is lowered due to the lack of perception of risk assessment, which must include the evaluation of the effectiveness of prevailing and alternative coping capacities with respect to likely risk scenarios.

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