# Triggered Fuse

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Keywords: Triggered Fuse, batteries, DC Fuse, safety, e-mobility

**Introduction**

In last few years, the use of DC voltage and current has been tremendously increased. This increased trend started with the use of Photovoltaic power plants as one of the most important renewable recourses of electric energy. Together with electric energy storage system, especially batteries, they are becoming competitive solution against traditional power plants and centralized electric energy distribution systems. On the other hand the use of DC current is even more significant in electric vehicles. The batteries are becoming more efficient and the range of e-cars is getting longer. The efficiency of electric cars also depends on the capacity of the batteries, which depends, among others on the value of the DC voltage of the whole system. Thus, the short-circuit capacity and expected short-circuit current are getting higher. It is also known that traditional fuses, like gG or gPV, are not very suitable for battery protection, because of unique electrical behavior of batteries.

**The problem**

We should say not only one problem, but several problems. First of them is dedicated to the already mentioned electrical behavior of the batteries. To adapt the fuse to these electrical circumstances, a new fuse characteristic has been introduced, so called “battery fuse”.  Next Figure1 (1) is showing the reason why the new time-current characteristics should be involved in order to provide good short-current and good endurance in case of cyclic loads.

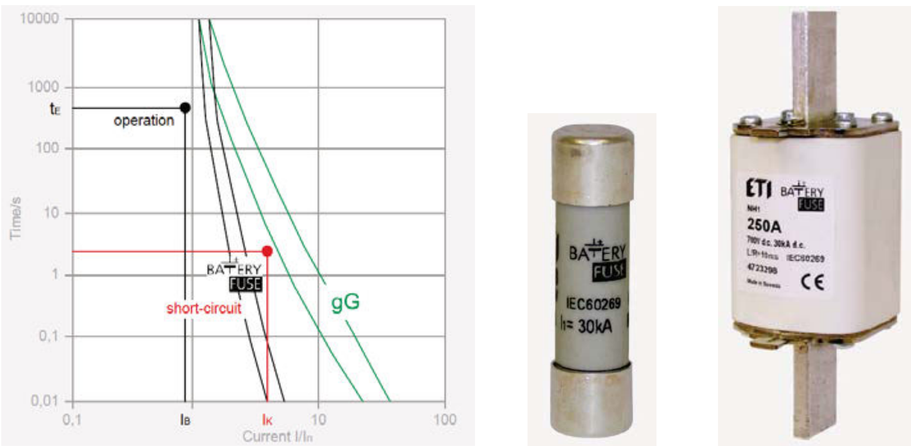


Figure 1

It is clearly seen that the steepness of the curve is much stronger comparing to gG fuse in order to gain good operation behavior and short-circuit protection. But on the other hand, there is always the question, could we somehow influence on the behavior of the fuse, namely how to break the fuse also in the case when the actual current is not high enough to melt the melting element. This could be of special importance in case of urgent or critical situations inside of energy storage battery bank. When the Li-ion batteries are used, the so-called "thermal run-away" could happen and heavy fire-breakout is not excluded. Next source (2) (Figure 2) is showing the Wind power plant combined with battery energy storage and the situation where the fire caught the whole building with battery banks.

Figure 2

It has been reported that firefighters had the problem with heavy fumes and therefore the fire spread all over the building. One of the solutions, how to minimize the damage would be in a reliable system which would be able to secure electrically cut the particular parts of the battery banks from the rest of the system. DC contactors are usually used, but it is known that the welding of the contacts can occur and the reliability of these products is questionably in case of higher DC voltages and currents.

**Next problem**

Next problem is even more problematic, because effects the safety of electric cars. Electric cars are more and more used in public and personal transportation and the capability of battery banks in cars is getting higher and higher. Also the possibility of heavy electric arc in the battery system is increasing after the crash of the car is getting higher. And this heavy arc can cause the flames and the whole car could ablaze. Below we can find some more information from different sources. One of the sources is showing the Tesla S car in flames (3) (Figure 3).

Figure 3

The source does not clearly unveil the real cause of the fire, whether there was the “thermal run away” of the Li-ion battery, or an arc in powertrain caused by the crash. Nevertheless, it is obviously crucial to disconnect the battery from the rest of the system, when any irregular situation is happening.

Next situation is unveiled in (4) (Figure 4) and there is more clearly given the information that the BYD e6 car has been caught by fire after a crash with another vehicle and that the main cause of death of persons in the car was lack of the system which would be able to automatically disconnect the battery immediately after the crash.

The cause of the massive fire engulfing the e6 was traced to short circuits in the battery pack and wiring, which became highly deformed under strong impact.

Figure 4

It is very much obvious that modern electric cars need a reliable battery disconnection system, which will safely disconnect the battery from the rest of the vehicle in order to prevent an arc as a cause of fire.

**Previous known proposals for solution**

In this paragraph, existing solution is presented by the source (5). In Figure5 below we can see the working principle of so-called Pyroswitch which works as a physical cut of a conductor and where the cutting edge is propelled by special initiator, most probably a sort of combustion material, triggered by external trigger pulse coming from air-bag control unit.

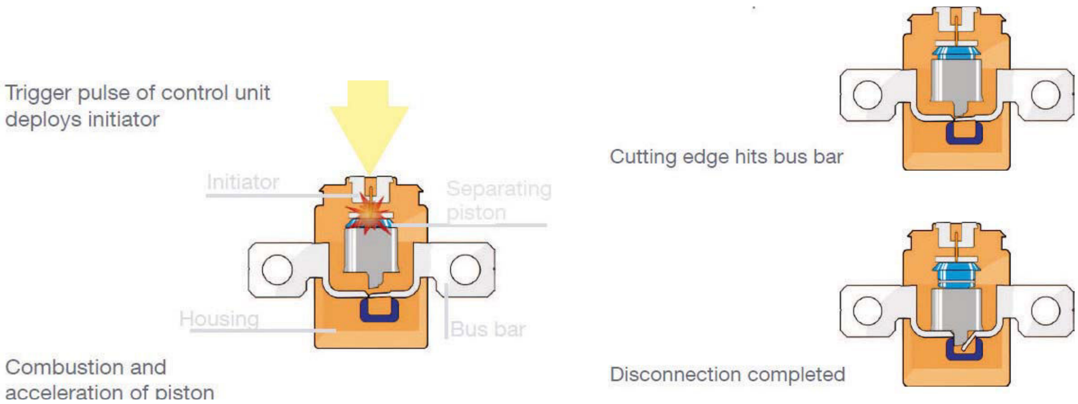


Figure 5

At a first glance, such solution sounds very good because of high speed and reliability. But on the other hand there are several disadvantages. Firstly, the breaking capacity at 400V DC is only 250A, therefore there is a strong need for back-up fuse which can reliably break the short-circuit current up to 10kA DC at 400V and even higher voltages. Such fuse is usually available in main battery circuit; another component which is also inevitable in main circuit is a DC contactor, which is used as a main switch enabling/disabling the battery to be connected with the powertrain. So, the second disadvantage of this solution is too many components in the main circuit.

Another, already in the past proposed solution, is presented by the source (6), shown in the Figure 6.

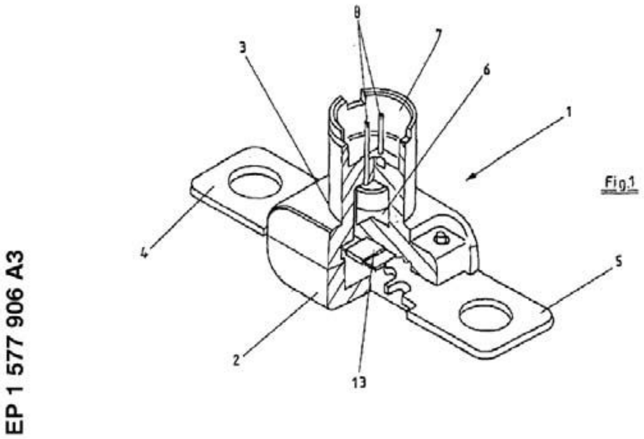


Figure 6

Such solution contains a melting element with a special triggering part which is triggered by external electric pulse, which ignites special chemical substance and thus providing thermal energy to melt the melting element. The disadvantage of such solution is obviously the fact that the added part influences on the normal behavior of the fuse.

The third already known solution is proposed by the source (7). The solution is based on power electronic and schematically shown on the Figure 7.

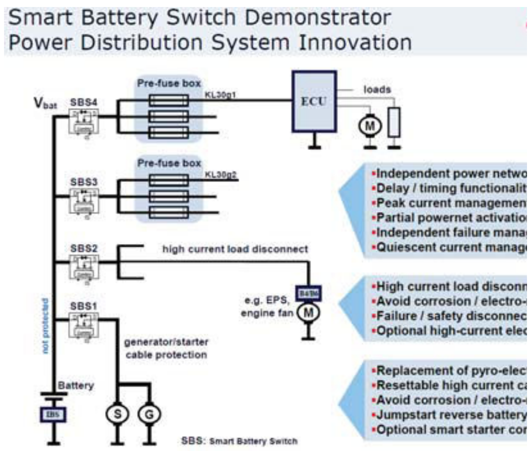


Figure 7

## Conclusion about existing situation

I believe that we all agree about the fact that there is the problem of an arc in the main battery circuit which can cause a fire in electric car. This threat will even increase with higher DC voltages, needed for better range efficiency. Some existing solutions are using special chemical substance which thermal behavior is triggered by electric pulse and the consequence is a melted or mechanically broken conductor. It means the energy for breaking the conductor or melting element is stored in thermally sensitive material. Other solutions are more close to the power electronics and/or classical contact systems.

## Proposal for triggered fuse

The basic intention of the proposal, presented in this article, is to fulfill some basic requirement which should be, to my opinion, listed as follows:

- Do not increase the number of components in the main battery circuit,
- Keep the lightweight of the vehicle on the lowest level possible,
- Keep the system simple, reliable and manageable,
- For breaking the main current, use already available energy sources

Basic functional principle is shown on the Figure 8 and described below.

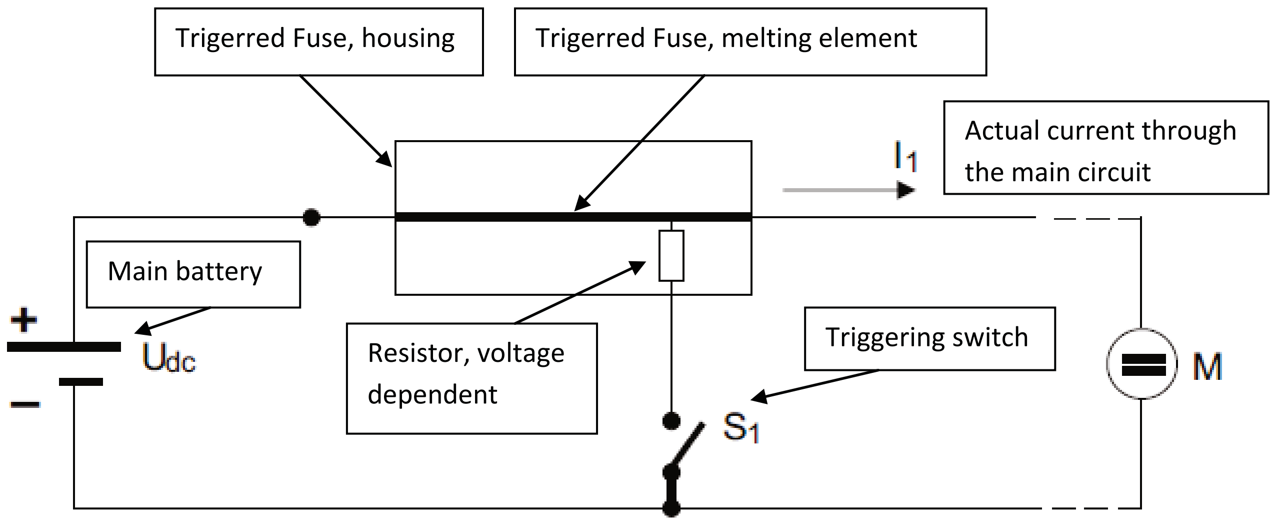


Figure 8

To proof the concept of Triggered Fuse a prototype was built on the base of NV DC fuse link where a special voltage dependent resistor was added as shown on Fig.8. The outlook of the Triggered fuse is shown on Fig.9. We can clearly see the third contact in a form of additional wire where the switch S1 should be connected.

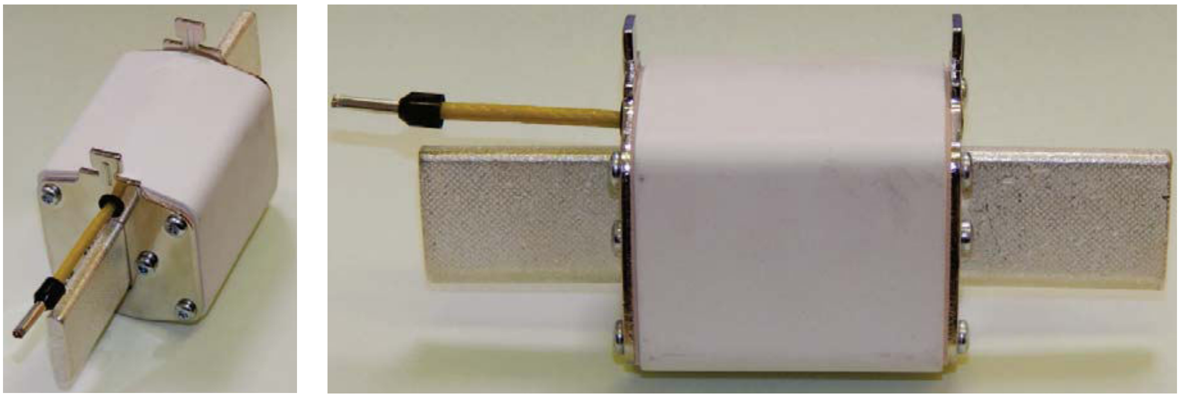

Figure 9

In normal situation the triggering switch S1 is open and the voltage dependent resistor has no effect on regular function of the fuse. Thus, Triggered fuse provides all functions as normal fuse, namely protection against over-current, corresponding to time-current characteristics. Physically and electrically, Triggered Fuse should be placed as close as possible to the main battery in order to provide the best protection for main circuit from the battery to main consumer powertrain M.

**How Triggered Fuse works in case of vehicle crash?**

In every today's vehicle there is an airbag electronic logic which triggers airbag initiators and thus passengers are protected against impact forces. The very same airbag signal would be used to close the switch S1, as it is shown on Figure 10.

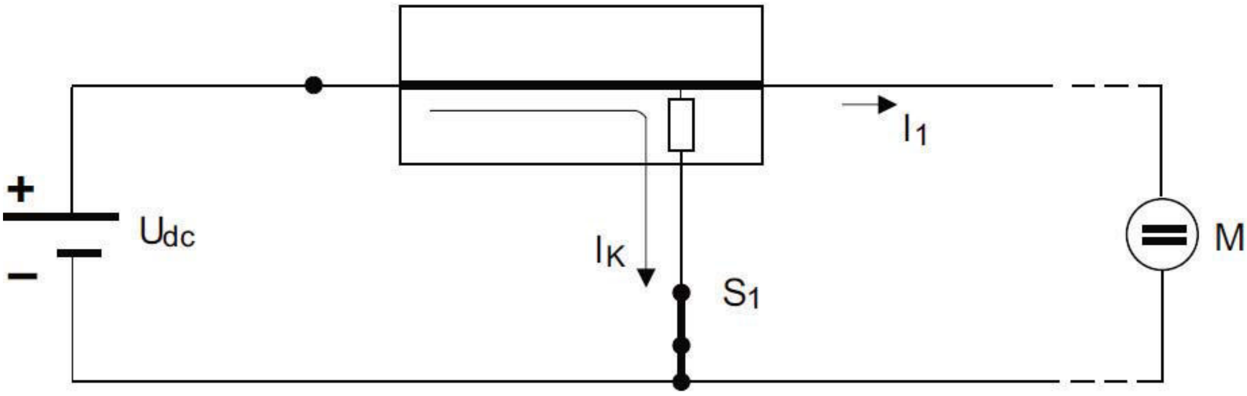


Figure 10

When the Triggering switch S1 is closed, the voltage dependent resistor gets the voltage which causes the change of his resistivity form very high level to very low level. Short circuit current Ik starts to flow and because of high capacity of a battery, it is high enough that the melting element is melted in a very short time. The question is what is the function use voltage dependent resistor? The reason is that the real start of short circuit current is when the resistor changes his resistivity and not when the switch S1 is closed. We assume that the time gap is around few microseconds or less, but anyway enough that the current making moment happens in the voltage dependent resistor and not on switch S1. This fact prevents occurrence of an arc on the switch S1.

**Electrical tests and measurements on prototypes**

A test setup was created which electrically corresponds to the circuit on Figure 8. Following tests were carried out

1. Test:
   a. Parameters defined:
      - Rated current of Triggered Fuse: In = 100A
      - Test Voltage Up = 459Vdc
      - Main current I1 = 51,46Adc
      - Time constant of main circuit t1 = 2,1msec
      - Prospective short-circuit current Ik = 2,059kA
      - Time constant of triggered circuit tk = 2,05msec

   b. Results measured:
      - Let-through current id = 1,36kA
      - Melting time tmelt = 5,02msec
      - Melting integral $I^2t$ $I^2t_{melt}$ = 4,59kA$^2$s
      - Breaking time tc = 51.99 msec
      - Total integral $I^2t$ $I^2t_{tot}$ = 16,34 kA$^2$s

   c. Current and Voltage behavior over time: see Figure11 below

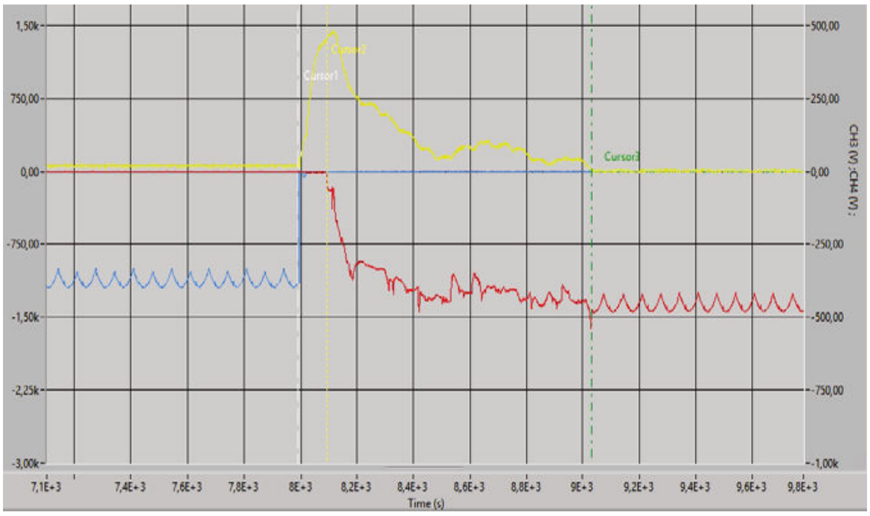

Figure 11

2. Test:
   a. Parameters defined:
      - Rated current of Triggered Fuse: In = 100A
      - Test Voltage Up = 459Vdc
      - Main current I1 = 51,46Adc
      - Time constant of main circuit t1 = 2,1msec
      - Prospective short-circuit current Ik = 6,095kA
      - Time constant of triggered circuit tk = 1,96msec
   b. Results measured:
      - Let-through current id = 2,22kA
      - Melting time tmelt = 1,41msec
      - Melting integral $I^2t$ $I^2t_{melt}$ = 2,43k$A^2$s
      - Breaking time tc = 19.68 msec
      - Total integral $I^2t$ $I^2t_{tot}$ = 14,56 k$A^2$s
   c. Current and Voltage behavior over time: see Figure12 below

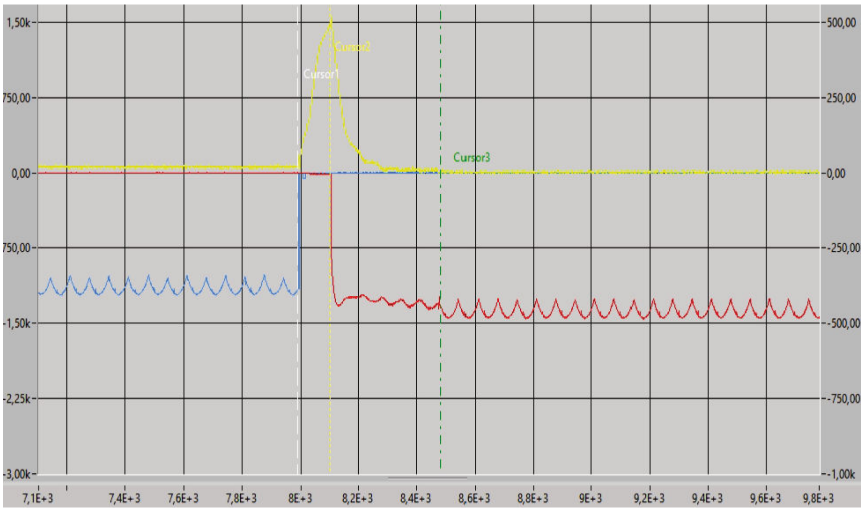

Figure 12

3. Test:
   a. Parameters defined:
      - Rated current of Triggered Fuse: In = 100A
      - Test Voltage Up = 459Vdc
      - Main current I1 = 51,46Adc
      - Time constant of main circuit t1 = 2,1msec
      - Prospective short-circuit current Ik = 10,456kA
      - Time constant of triggered circuit tk = 2,24msec

b. Results measured:

- Let-through current — id = 2,55kA
- Melting time — tmelt = 1,32msec
- Melting integral $I^2t$ — $I^2t_{melt}$ = 2,38kA$^2$s
- Breaking time — tc = 7.53 msec
- Total integral $I^2t$ — $I^2t_{tot}$ = 8,38 kA$^2$s

c. Current and Voltage behavior over time: see Figure13 below:

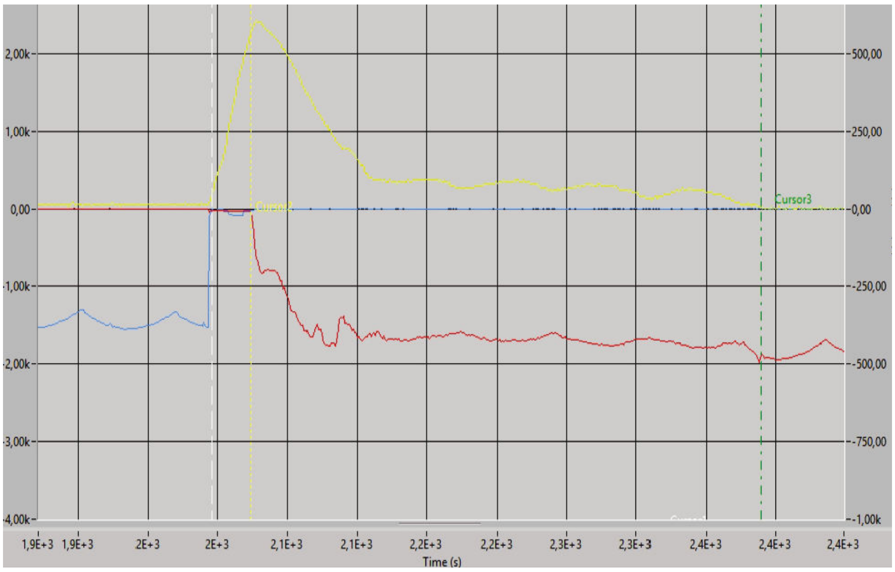


Figure 13

**Conclusions**

Prototype of Triggered Fuse in a today's presented form cannot be directly used in e-vehicle, because of his weight. However, the test results presented in this article are showing a good chance for future work. Important advantage of this Triggered Fuse is that the making process happens inside of the fuse by means of voltage dependent resistor. Therefore, no arc occurs outside of the fuse link. Second advantages is that only one protection device, namely fuse, is used for standard over-current protection, as well as device which could be remotely triggered to break the current also at conditions below the value of rated current. And finally, energy for melting the element is taken from the battery itself. If the battery is so discharged, that there is no energy for melting the Triggered Fuse, then there is no danger for arc followed by the crash of vehicle and current breaking process can be easily made by DC contactor in the main circuit.

**Literature and sources**


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Conference: 10th International Conference on Electric Fuses and their Applications

Organized by: Dresden University of Technology
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Frankfurt am Main, Germany
September, 2015