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Advanced solutions in over-current protection of HVDC of battery-powered electric vehicle

Mitja Koprivšek, Msc, ETI Elektroelement d.o.o. Slovenia, mitja.koprivsek@eti.si

Abstract

This paper shows the new approach for protection of electric energy storage batteries in order to prevent heavy damage in case of sever electrical fault, e.g. direct short circuit on the battery. Existing solutions with Pyroswitches with parallel Fuses has disadvantages. Proposed paper presents battery over-current protection system with specially designed Pyroswitch and melting Fuse in parallel. This connection can be triggered externally and it is able to cover all time-current circumstances. The paper will also show how to extend the rated current and voltage of this device.

Keywords: DC Fuse, Pyro-switch, overcurrent protection, batteries, electric energy storage.

1 Introduction

In last few years, the use of DC voltage and current increased tremendously and with electric energy storage system, especially batteries, they are becoming competitive solution against thermal power plants and conservative 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 battery-operated 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 main electric power-train system. Thus, the short-circuit capacity and expected short-circuit current are getting higher and safety aspects in case of an arc, provoked by the fault on the battery circuit wiring, are becoming more and more important. The following paper will give an information about the different solutions for over-current protection, also for higher rated currents and what is the influence and impact of different time constants in DC electric circuit.

2 Safety issues

Any kind of over-current protection device has to protect the DC circuit against heavy DC fault in case of short-circuit, which can cause heavy fire. On the other hand, it has to break the overload current before the battery gets too hot. Protection device has to protect also the on-off switching device against higher currents, which can cause welding of the contacts. Finally, it has to have a possibility to be triggered externally in case of a crash of the car or any other unexpected event in an electric energy battery storage. Below, there are some examples of such accidents and damages.

Fig.1a shows the electric vehicle in fire because of light accident on the highway. Fig1b. shows the picture of the arc between the DC cables, simulated as being damaged in a car crash.

Fig.1a [1]

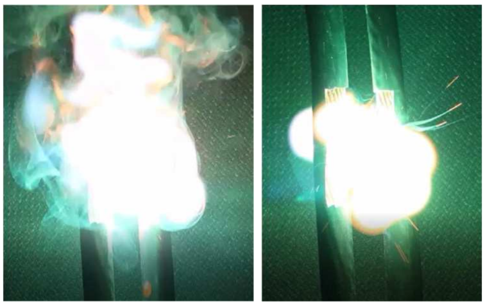

Fig.1b [2]

3 Present solutions

The most common solution in DC overcurrent solution is a melting fuse with extremely high DC breaking capacity capability and high life-time performance. Next to such solution also the so-called pyroswitch has been introduced lately with some good performances and some disadvantages. The modern solution are developing in the way of hybrid solution, using parallel connection of pyro-switch and fuse. Latest solutions are in the form of specially designed 3-contact pyroswitch with parallel fuse. In this section, all these solutions will be shortly described.

3.1. DC Fuses

Melting fuses are excellent solution in DC over-current protection, specialy because of high breaking capacity , also at high DC voltages up to 1500Vdc. On the other hand, also the time-current characteristic is adapted to the electrical behaviour of the battery system. There are several types of fuses, as you can see below on Fig.3[2].

Fig.3

3.2. Pyro-switches

On the Fig.4a ands Fig.4b below we can see the use of pyroswitch and how it works [3].

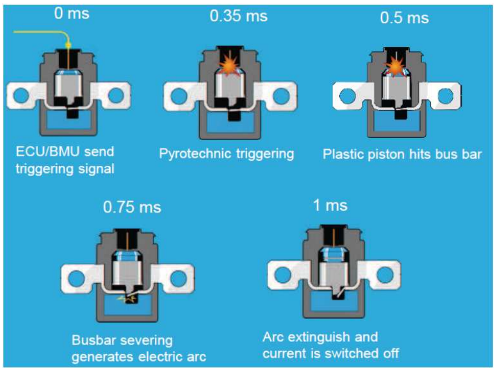

Fig.4a

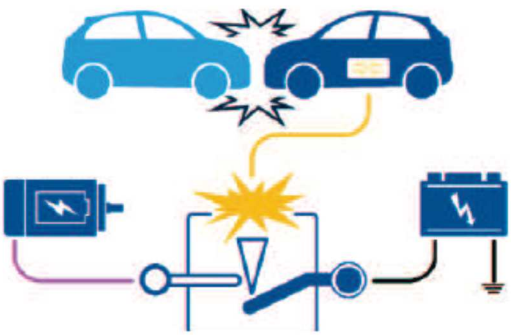

Fig.4b

Such kind of Pyroswitches are very well used in system with the voltages up to 48Vdc, above that voltage they have disadvantage at high breaking capacity if the inductance L is higher than few microHenries, or if the time constant L/R is lower than 1msecond.

3.3. Hybrid connection with pyroswitch and fuse

There are two solutions, shown on the figures below. First one, shown on Fig5, is rather simple parallel connection between pyroswitch an fuse, described in [4].

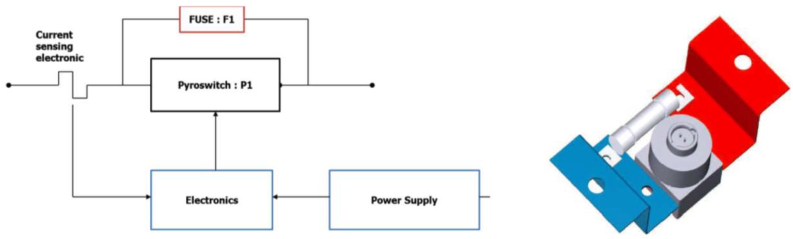

Fig.5

Next one is a combination of two Pyroswitches, one as a type NC (Normaly Closed) and the other NO (Normaly Open). The solution is shown on Fig.6 and described in [5].

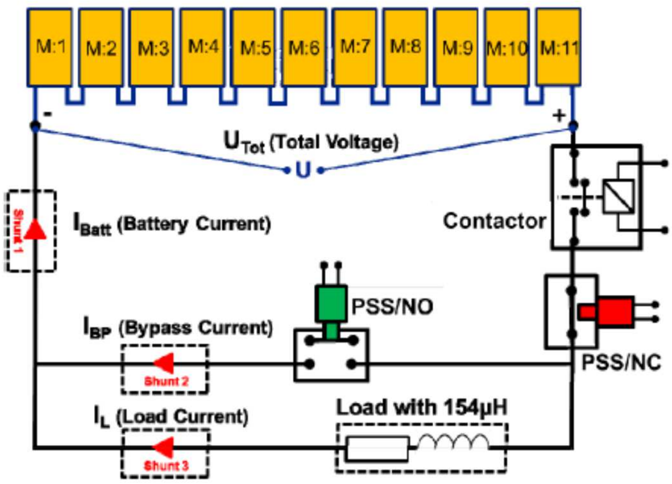

Fig.6

This solution also deals with rather high level of inductivity and gives a clear message, that the battery circuits with high inductive loads cannot be simply switched off only by single pyroswitch solution, there has to be certain bypass available.

3.4. Newest design of 3-contact Pyro-switch and Fuse

This solution is shown on Fig.7 and has been described and presented in [6]. Standard pyro-switch is adapted and third contact is added. In case of a triggering of pyro-switch, the chopped part of the busbar makes the third contact and the short-circuiting of the plus and minus pole happens, as shown below.

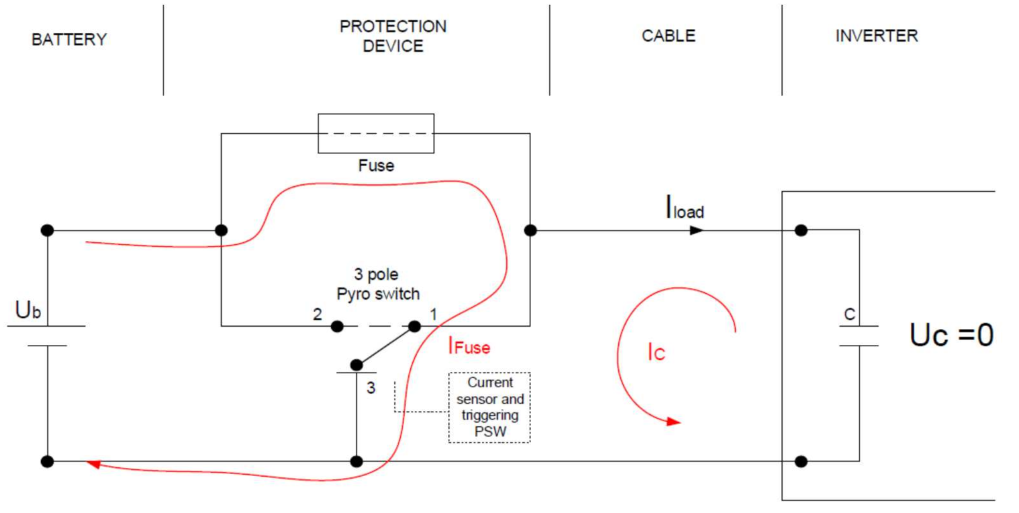

Fig.7

Schematic diagram below on Fig.7 shows the connection of advanced Pyroswitch and Fuse. During the normal operation and before the ignition of Pyro-switch, the main current path between points 1 and 2 is closed. After ignition of Pyroswitch, the main current path is opened and in a very short time less then 1millisecond, the current path between points 1 and 3 is closed.

Under short-circuit current the Fuse operates immediately and safely breaks the main HVDC circuit independently from the value of actual fault current. Due to safe connection between point1 and point 2 of new designed Pyro-switch, the voltage on the power line after the protection device is zero and there is no possibility for arc creation.

3.4. Newest design of 3-contact Pyro-switch, Fuse and integrated over-current sensor

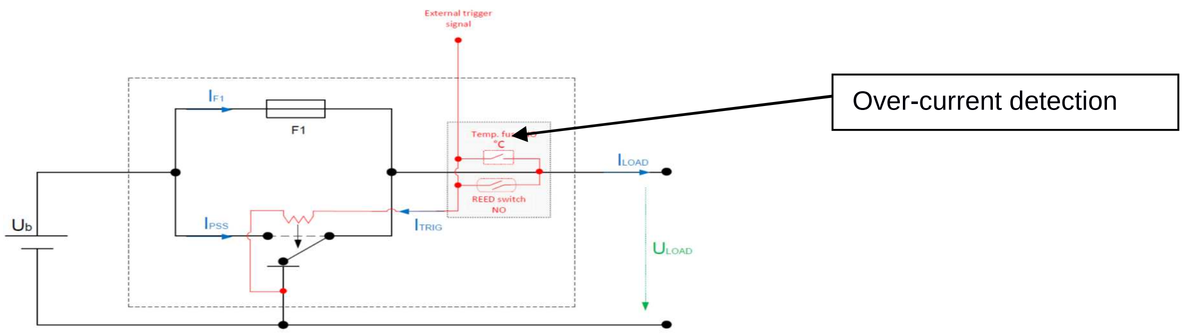

Fig.8

Fig.8 above shows the incorporated over-current detection. The named over-current detection device consists of Thermal Fuse NO (Normaly Open) type and Reed Switch NO type.

Thermal Fuse NO is in thermal contact with the outgoing conductive terminal. In case of a minor overcurrent, the temperature will rise and under specified thermal conditions, the Thermal fuse will react and close the circuit and thus the ignitor in pyro-switch will start the operation, as described in Fig5 and Fig.7. The process of disconnection is closed after the fuse melts and breaks the current.

Reed-Switch NO is in a magnetic connection with the outgoing terminal conductor. It is sensitive to the high short-circuit currents. When such high current appears, the Reed switch closes the ignition circuit and Pyro-switch starts the operation, as described in Fig5. The process of disconnection is closed after the fuse melts.

3.4. Electrical results

In this section are presented results of breaking capacity tests at different value of current, while the test voltage was always 900Vdc. Fig.9 shows the oscilograms of the test at 10kAdc prospective short circuit current. The blue line is the actual current through the pyro and fuse in kA and the red line is voltage on the fuse. We can see that the reaction time of reed relay, ignition of the pyro-switch and the melting phase of the fuse amounts together in timeoh 0,6miliseconds. Than the arcing phase in the fuse starts, which is finished very fast in 0,5miliseconds. The total clearing time is around 1,3 to 1,5 milliseconds.

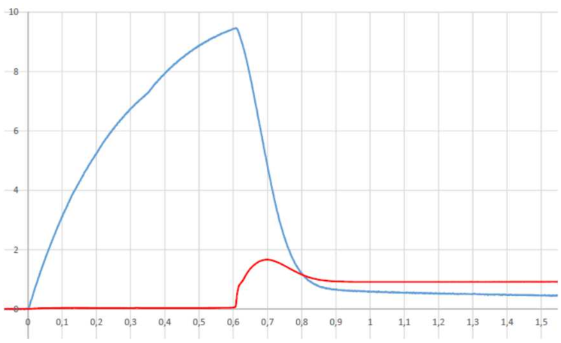

Fig.9

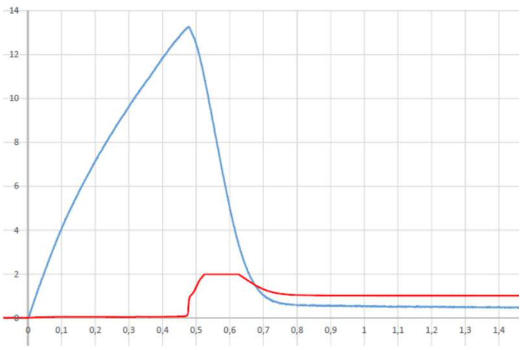

Fig.10

Fig.10 shows the oscilograms of the test at 20kA prospective short-circuit current. We can clearly see even faster process of total clearing and much stronger short-circuit current limitation, caused by the fuse behaviour. The conclusion is that the speed of current sensing is provided by the reed relay. The speed of current opening is given by the pyro-switch and the speed and deepness of current limitation at any kind of DC time constant is given by the fuse.

4 Further development of the hybrid 3-contact pyroswitch with fuse

Previous section are showing us the excellent behaviour of proposed hybrid combination, also called as Triggy Fuse. Further development is dedicated to the goal how to achieve higher rated currents. Namely, standard pyro-switches are usually built for the rated currents until about 300A. To reach double higher rated current, special construction with two pyro-switches has been developed, as shown on Fig.11.

There are two pyro-switches in parallel connection, where the main current path is devided into two main branches, as shown on Fig.11. The speciality is in connection of triggering units of both pyro-switches. Additional explanation of Fig.11 shows the connection of triggering circuit of PSS1 with overcurrent sensor and triggering circuit of PSS2 with the 3rd contact of PSS1.

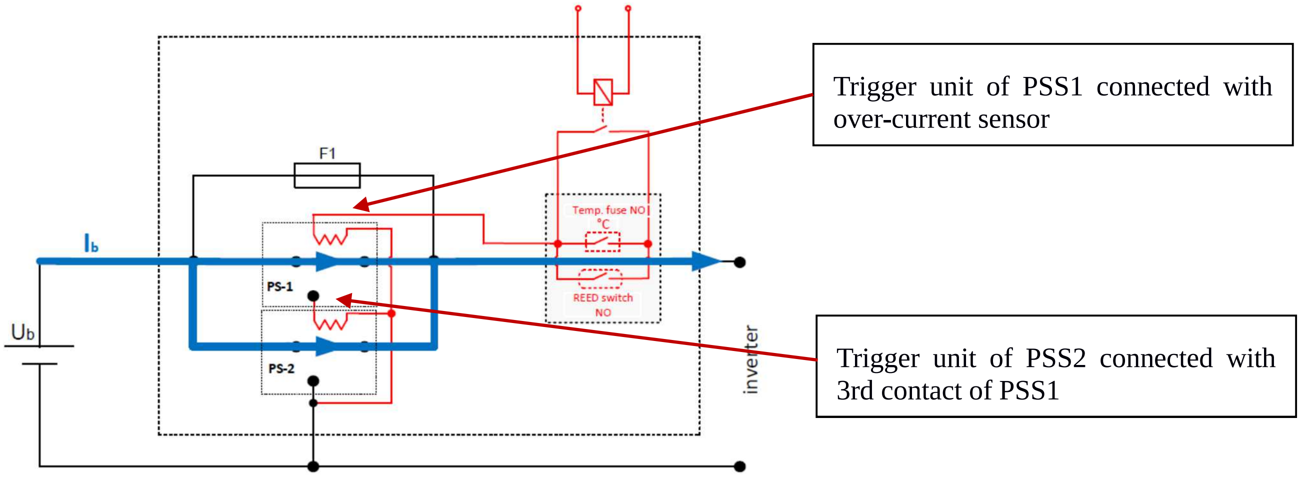

Fig.11

4.1. How does it work?

In case of over-current occurrence, the sensor closes the triggering circuit of PSS1, on the same way as described in [6]. First pyro-switch opens the busbar immediately after opening; the third contact is closed, as shown of Fig.12. Now, the triggering circuit (line in blue colour in Fig.12) for the second pyro-switch is closed and PSS2 is activated.

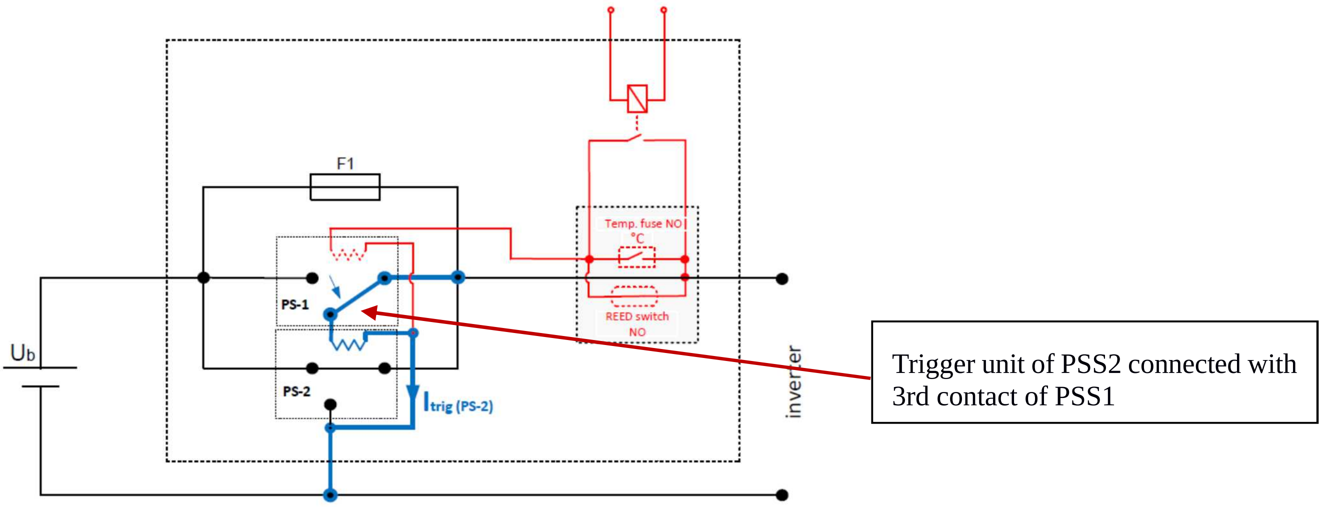

Fig.12

After activating second pyro-switch PSS2, current starts to flow through the fuse, as it is shown on Fig.13. The fuse provides the total clearing of the current in a very short time, because it is expose to the available short-circuit capacity of the battery. Advantage of such solution we can find in a very good behaviour of the fuse also at higher inductivity of the circuit and higher time constants.

The rated voltage and rated breaking capacity of the device is defined with the rated voltage and breaking capacity of the fuse and by choosing the 1500Vdc and e.g. 20kA DC fuse. The rated current of the fuse is not defined and it could be much lower than the rated current of the both pyro-switch. However, the melting time should not be shorter than the PSS opening time.

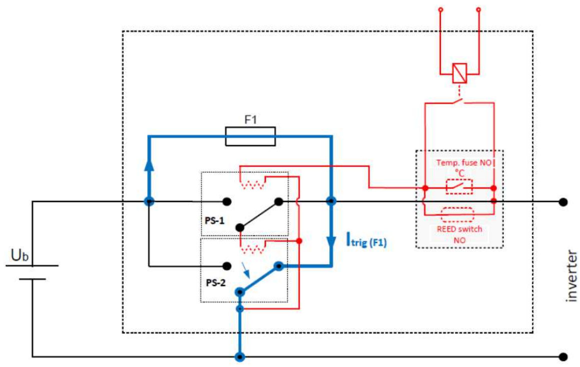

Fig.13

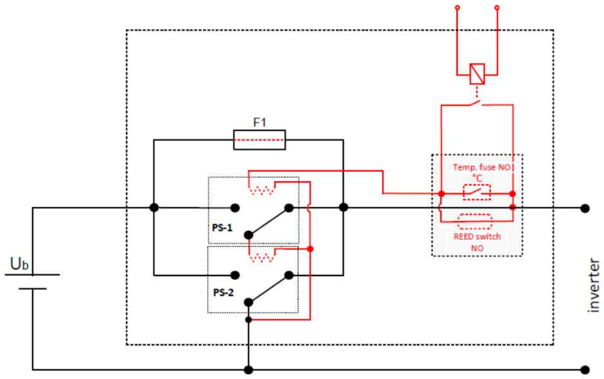

Fig.14

Fig.14.shows the totally opened and cleared protection device, called Triggy Fuse for higher rated currents and DC voltages.

5 Conclusions

Presented paper shows the advanced development of the over-current protection device for battery storage system, which is able to cover whole range of DC voltages up to 1500Vdc and up to 600A rated current, together with very high breaking capacity up to 30kA. Construction of the device is based on the special design of pyro-switch with third contact and parallel connected fuse. To reach higher level of breaking capacity and/or to reach better safety conditions with redundancy, also two fuses in parallel could be used.

Such device, called High Current Triggy Fuse, can obtain the best conditions, providing

- Extremely low power loss,
- High breaking capacity, also at high L/R,
- Good coordination with other switching devices,
- Long lifetime and endurance,
- High level of operability and low costs.

It is suitable to be used in stationary battery storage systems, as well as in battery electric vehicles.

Acknowledgments

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Author

Mitja Koprivšek has a Master Degree of Science in Electrical Engineering from Maribor University, Slovenia. He works with company ETI Elektroelement since 1985 and he occupied several different positions on the field of research and development, product management and strategic product development. He is active in international standardisation in IEC, Cenelec and Slovenian standardisation on protection devices, fuses and breakers. He is active in Slovenian Chamber of commerce and industry and member of several supervisory boards in Slovenian R&D institutions.