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Voltage dips reduction with a hybrid contactless short-circuit limiter

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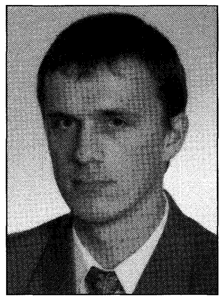

Abstract

The paper presents operation of a hybrid contactless short-circuit current limiter on the basis of computer simulation. Special attention was paid to the possibility of improving of the quality of the delivered electrical energy, through limiting of the voltage dips duration in the power grid owing to the application of a hybrid circuit breaker. The calculations were performed using the PSPICE and MATLAB software.

Streszczenie

W artykule przedstawiono działanie bezstykowego ogranicznika prądów zwarciowych w oparciu o symulację komputerową. Szczególną uwagę zwrócono na możliwość poprawy jakości dostarczanej energii elektrycznej, poprzez ograniczenia trwania zapadów napięcia w sieci elektroenergetycznej, dzięki zastosowaniu wyłącznika hybrydowego. Modelowanie matematyczne wykonano w programie MATLAB i PSPICE.

Keywords: hybrid circuit breaker, voltage dip, contactless current limiter
Słowa kluczowe: łącznik hybrydowy, zapady napięcia, bezstykowy ogranicznik prądu

1. Introduction

In distribution systems the power quality is of increasing importance as the low voltage consumers use microelectronic components for control and operation, which are sensitive to voltage dips and power supply interruptions. Voltage dips can be defined as follows: a voltage dip is a sudden voltage reduction ranging from 1% to 90% of the nominal voltage and with a short circuit duration from 10 ms up to one minute [1]. In the US a short-duration reduction (up to a few seconds) in the voltage amplitude is termed a voltage sag [2].

Typically, voltage dips are due to short circuit faults in the power system. The time of disturbance elimination by classical contact circuit breakers is of several dozens milliseconds. It is too long to limit fault currents, and to reduce the duration of the voltage dip. Effective limitation of voltage dips can be achieved, among other means, by the application of hybrid circuit breakers [2].

One of the first hybrid circuit breakers put in the practice was designed by Collard and Pellichero [3]. Later on Żyborski [4] and Bartosik [5] significantly developed their idea. A modified approach was presented by Wolny [6] who applied a special ultra short fuse in the place of the contact switch. This way the need for a fast electrodynamic drive was eliminated, which allowed to considerably reduce dimensions and costs of the hybrid current limiter. The new device is called the contactless hybrid current limiter (CHCL).

Design of the analyzed CHCL

In fig. 1 the structure of the analyzed CHCL is presented. It consists of the following basic elements: the ultra short fuse (USF) shunted by the semiconductor device (SD), controlled by a special control system (CS), and the metal oxide varistor (MOV) absorbing the magnetic field energy of the switched-off circuit. The triggering impulses may be controlled by the voltage across the USF.

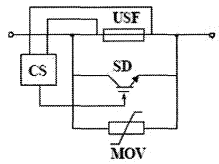

Fig. 1. The model of a hybrid DC switch [6]
Rys. 1. Model łącznika hybrydowego prądu stałego [6]

In fig. 2 the voltage and current traces of the CHCL operation are shown. The experiments were carried out in the oscillatory LC circuit at the frequency of 480 Hz and the prospective short-circuit current of 1.2 kA. The used frequency higher then 50 Hz increased the rate of current rise, essential for current limitation devices.

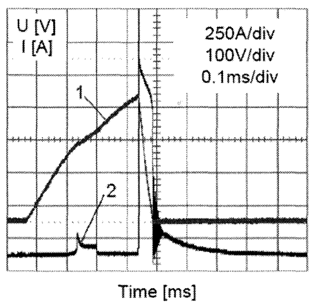

Fig. 2. The oscillograph records of the CHCL operation with an IGBT transistor; 1- the CHCL current, 2 - the voltage
Rys. 2. Oscylogram działania CHCL z tranzystorem IGBT; 1 - prąd CHCL, 2 - napięcie

Modelling of CHCL operation

Due to the simulation of operation of a hybrid circuit breaker, a complex analysis of the components of a given assembly and its parameters is possible. In numerical experiments, a very important role is played by the proper selection of models of the components [7], of the analysed circuit. In simulations of the operation of a CHCL, the selection of the ultra short fuse arc model is a difficult and important issue, since due to the prevailing axial cooling no existing arc model can be directly applied. The calculations were performed using the PSPICE and MATLAB software.

In regard to the PSPICE simulations, the arc model was founded on a voltage-controlled switch modified by the application of a nonlinear resistance connected in parallel to the opening contacts.

With regard to the MATLAB a ready-to-use model based on the Cassie's concept is offered [8]. However such a rough model did not work properly. Hence modification had to be introduced consisted in the addition of energy-absorbing elements connected in parallel to the arc. The resistance and capacitance were used.

Commercial programs offer a large selection of models of the semiconductor devices available on the market. The list is amended every time when a new device is developed. Different approaches of model selection are adopted in the MATLAB and the PSPICE. In the former case, parameters of a generic model of the device are modified in accordance to the actual catalogue data. In the case of the PSPICE ready-to-use models are only available.

The results of the numerical experiments, obtained with the PSPICE software are presented in fig. 3. The calculations were carried out in the oscillatory LC circuit at the frequency of 480 Hz and the prospective short-circuit current of 1.2 kA

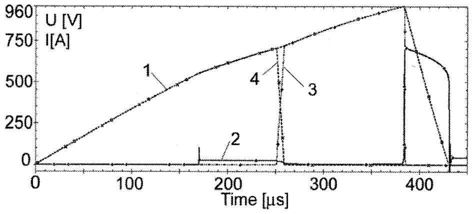

Fig. 3. The record of CHCL operation (PSPICE): 1-the switch current, 2- the switch voltage, 3 - the IGBT current, 5 - the fuse current

Rys. 3. Działanie CHCL (PSPICE): 1-prąd łącznika, 2 - napięcie, 3 - prąd tranzystora IGBT, 4 - prąd bezpiecznika

Similar results obtained in physical and numerical experiments (fig. 2 and fig. 3) allow for an analysis of the operation of a hybrid circuit breaker in an AC circuit with a frequency of 50 Hz.

The numerical experiment was performed with the MATLAB software. The simulation was performed for the circuit presented in fig. 4.

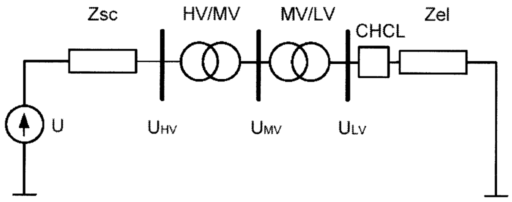

Fig. 4. The modelled power-system grid segment: U - the voltage source, Z_{SC} - the system impedance, HV/WV, MV/LV - the transformer, Z_{el} - the load impedance

Rys. 4. Modelowany fragment systemu elektroenergetycznego Modelowany fragment systemu elektroenergetycznego: U - źródło napięcia, Z_{SC} - impedancja systemu, HV/WV, MV/LV - transformator, Z_{el} - impedancja obciążenia

2. Effect of the semiconductor device control on the operation of a hybrid circuit breaker

In the operation of a hybrid circuit breaker an important problem is the proper control of the semiconductor device. Delayed turn-off causes an increase in the cut-off current, while in the case of an early turn-off, there is the possibility that the gap in the molten fuse element will be too short and will not withstand the recovery voltage. In fig. 5 the relationship between the shortest permissible IGBT time on and the arcing time of the short fuse are shown [9].

Durations of the fuse element melting and the increase in the recovery dielectric strength are associated with the cut-off current, while the recovery voltage, which must be withstood by the limiter, depends on the actual state of the power system. Any delay in the cut-off process is detrimental, as it increases the limited current, fault clearing time and the energy allowed through by the hybrid circuit breaker.

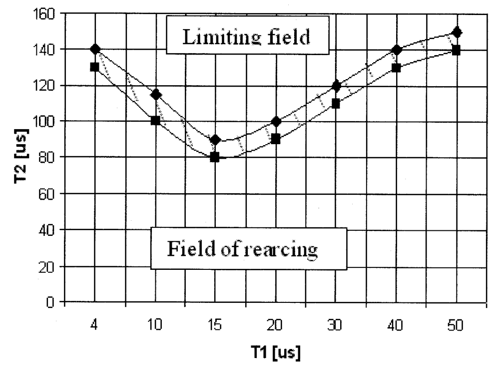

Fig. 5. The relationship between the shortest permissible IGBT time on and the arcing time of the short fuse; T1- arcing time, T2 - recovery time of the fuse dielectric strength [9]

Rys. 5. Zależność między czasem odbudowy wytrzymałości przerwy a czasem łukowym bezpiecznika; T1- czas łukowy, T2 - czas odbudowy wytrzymałości dielektrycznej przerwy [9]

Selection of the optimal making and cut-off moment of the semiconductor device is of great significance for the quality of the power supply. The shorter the duration of the short circuit fault, the sorter the duration of the voltage disturbance in the power system will be. However, selection of very short turn-on and let-through times of the IGBT will cause the arc reignition, and this way an increase in the duration of disturbance in the power delivery and the possibility of current limiter damage. In fig. 6 the elimination of a short circuit fault in the power system is presented, using a classical switch (1). The duration of the voltage dip is Δt=31 ms.

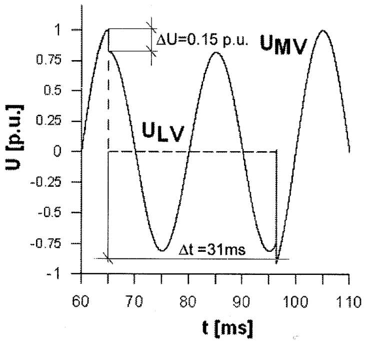

Fig. 6. Fault clearing time with a contact switch (simulation)

Rys. 6. Czas trwania zakłócenia w przypadku łącznika zestykowego (symulacja)

A considerable limitation of the disturbance duration is achieved using a hybrid circuit breaker. In this case, the time necessary to eliminate a disturbance depends, to a great degree, on the IGBT control delay. In fig. 7 the short circuit cut-off time using a hybrid circuit breaker is shown. In this case, the time necessary to eliminate a disturbance is Δt = 0.9 ms.

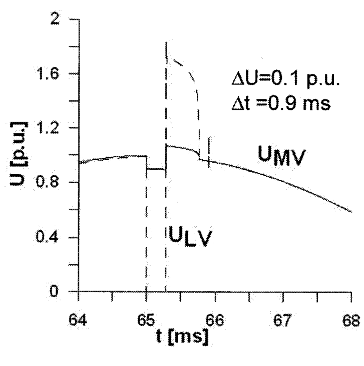

Fig. 7. Fault clearing time with the CHCL (simulation)

Rys. 7. Czas trwania zakłócenia w przypadku łącznika hybrydowego (symulacja)

However, the selection of the optimum current let-through time of the semiconductor device is a very complex issue. It should be as short as possible from the point of view of the quality of the supplied power. On the other hand, taking into consideration the current transfer requirements it must be long enough to allow for the disintegration of the fuse element and the recovery of dielectric strength of the fuse, in order to prevent the reignition.

3. Summary

The voltage dips disturb high quality power supply. They can cause identical results, as total interruption in the electrical energy supply, particularly dangerous for electronic devices, which are very sensitive to rapid voltage changes.

The voltage dips, due to short circuit faults in power system, can be reduced, by the application of the hybrid circuit breaker, whose fault-clearing time is merely a few hundreds of μs.

The optimum control of the hybrid circuit breaker should consider:

- maximum limitation of the disturbance duration,
- minimization of the energy let-through by the current limiter during any fault occurrence.

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Tytuł: Ograniczenie zapadów napięcia za pomocą bezstykowego ogranicznika prądu

Artykuł recenzowany