NEW CURRENT- LIMITING AND INTERRUPTING DEVICE CONTRA CURRENT- LIMITING FUSES

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Abstract: Advent of new era in the overcurrent protection of both l. v. and h. v. power electric system which is going to offer a new current interrupting possibility, is a good opportunity to compare the classical current limiting fuses (CLF) and the new hybrid current- limiting and interrupting devices (H-CLID). The last, also developed in the Technical University of Gdansk (TU Gdansk), in a comparison given in the paper, show their advantages and disadvantages and their preferential fields of applications. Despite their costs the H-CLIDs are promising devices to apply in those systems, where, generally speaking, the capitalised costs (installation and maintenance costs) are lower or comparable with CLFs. It denotes that H-CLIDs shall be used in the systems from which one requires a high degree of reliability, super very quick operation resulting in practically negligible let- through integral and peak let-through current and generally the CLFs elimination.

I. INTRODUCTION

Most recent developments to overcurrent protection in both l. v. and h. v. electric systems are so- called intelligent circuit breakers (CB). This tendency has been pushed forward as the preferential subjects of CIGRÉ and CIRED Conferences. Among intelligent CBs the current - limiting (CL) l. v. and h. v. CBs are one of the promising apparatus which are able not only to a considerable limitation of the current but also to its final interruption. Beside these devices there are also such ones which limit the current only, whereas an additional apparatus serves to final current interruption. This reason makes possible, for the purpose of the paper, to distinct:

- current- limiting and interrupting devices (CLID) and
- current- limiting devices (CLD).

The advantages of mechanical (contact) CBs and semiconductor CBs (usually based on thyristors and GTOs) led to so- called hybrid circuit breakers (HCB)s and to hybrid current limiting interrupting devices (H-CLID)s. On the contrary to HCBs, as concerns their operation, their counterpart, which is H-CLID, usually possesses more or less developed electric schemes those obviously shall not resemble a mechanical CB operation. Hybrid solution makes possible to exploit the advantages of both, semiconductor and mechanical CB principles of operation.

Recently, the Chair of Electrical Apparatus of the TU Gdansk made several new developments to achieve an effective and reliable H-CLID for AC and DC purposes, which demonstrate a number of benefits. On these background a question arose how far the new H-CLID can be a challenge to the classical current limiting fuses (CLFs). The paper is going to make a comparison between mentioned H-CLID and CLFs and to point out the preferential fields of their applications.

II. PRINCIPLES OF H-CLID OPERATION

Obviously, there is no need to describe here the principles of CLFs operation. But the basis of H-CLID operation is worth to a summary to get a better acquaintance with this modern device.

Hybrid circuit breaker (HCB) being discussed in this paper, comprises a mechanical contact in the main current path, counter current injection circuit for forced commutation in the main contact and ultra rapid electrodynamic drive, Fig. 1. The DC HCB, type DHR, was worked out by Collart and Pellichero [1].

The HCB enables current limitation and interruption as fast as a contactless circuit breaker, e.g., thyristor circuit breaker (TCB) but without TCB's drawbacks as big dimensions, power losses in the ON state, etc. There is no upper limit on the prospective current that the DHR circuit breaker is capable to break. A limiting factor for DHR operation is the initial value of di/dt but it may be greater than 15 A/μs. On the other hand, a sophisticated mechanical system is a drawback of that HCB. It is due to the requirements on the very short pre- arcing time that needs very high contact opening speed. An initial acceleration of order of (20,000÷40,000) g must be applied to give the moving contact a speed of 10÷50 m/s on the way 1÷5 mm and to obtain the pre-arcing time of order 100 μs [1]. The kinetic energy of the fast moving system must be absorbed by a breaking system that complicates the design of HCB and makes it very expensive.

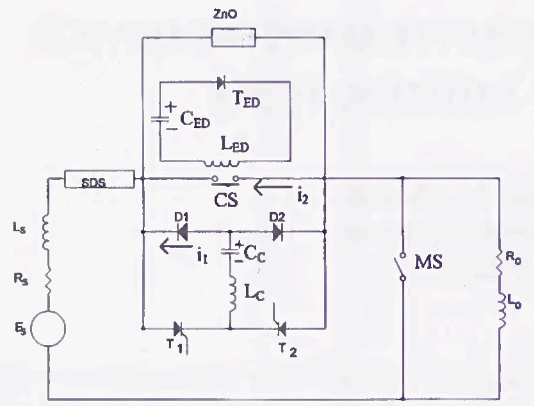

Fig.1 Schematic circuit diagram of AC-HCLID

E_s, R_s, L_s – source parameters; R_o, L_o – load parameters; CS - contact switch; MS - short-circuit making switch; L_c, C_c, T_1, T_2, D_1, D_2 - elements of commutation circuit; SDS - short-circuit detection system; ZnO - varistor suppressor; L_{ED}, C_{ED}, T_{ED} - elements of electrodynamic drive circuit; i_2 - counter current; i_1 - diode D_1 current

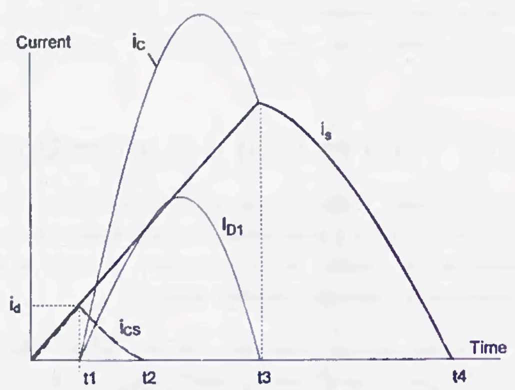

Fig.2 Current wave forms of AC-HCLID

i_{CB} – contact switch current; i_{D1}, i_{D2} - diode currents; i_c - commutation capacitor current; I_d - discrimination current; t_1 - commutation starts; t_2 - contact CS separation starts, final current interruption in CS; t_3 - recovery voltage starts; t_4 - final fault current interruption

That is why a simplified, inexpensive device named H-CLID (hybrid current limiting and interrupting device) was worked out and tested by the authors [2 ÷ 5]. A "one shot" contact is used in the H-CLID. Normally, the contact is kept in closed position by a clamping arrangement so the device is in the ON state. The contact can be opened by tear down due to the repulsion force developed by the electrodynamic drive circuit. The contact itself (or a damping element in the contact assembly) must be replaced after each operation. Please notice an analogy to fuse element that is also a "one shot" device.

The operation of H-CLID is shown in Fig. 2, at the assumption that the forced current commutation is ideal, it means the contact S is open exactly at zero current. The H-CLID operates very fast so in AC circuit the line voltage can be considered as almost constant during current breaking. Thus the basic waveforms of current and voltage at H-CLID operation are essentially the same in DC and AC circuit.

The research carried by the authors on the H-CLID has shown that the following fields of application can be taken into account:

• short-circuit protection for diode and thyristor converters, then the semiconductor fuses can be entirely eliminated [3, 5];
• disturbance arc protection in l. v. systems [4].

Further discussions have shown that the H-CLID could also be used as a protection against:

• explosion of high power transistors;
• earth faults in converter circuits (ability to interrupt fault currents with DC component).

III. FEATURES OF CLF AND H-CLID

Amongst the features of CLF and HCLID there are recognised in the paper 3 groups of them, juxtaposed in the Tables 1, 2 and 3.

The information given in Table 1 need more extensive comments, whereas given in Tables 2 and 3 do not.

IV. COMMENTS TO TABLE 1

No. 1. From the obvious reasons there is a practically unlimited bottom boundary as concerns the fuses' rated voltages. To get very small rated voltages it is enough to limit the fuse-element length. But the voltage upper limit is limited because of the service reasons. The electricity utility company as a protection means for the line voltage, say 36 kV, usually has not accepted the use of CLF. Namely, the power outage costs due to the time required to fuse-links replacement become so significant that the circuit breakers be used instead. Moreover, DC CLF are needed up to 3 kV only, usually to railway purposes.

No. 2. For the time being even sub-miniature (micro and pico) fuses for few mA are available. The only limitation is to manufacture a very small, in cross-sectional area, fuse-element within an acceptable reproducibility level. On the other hand, fuses of several kA, for protection of heavy power semiconductor inverters (e.g. American „Amp-trap" fuses) can be relatively easy designed and manufactured.

Table 1. Electric features of CLF and H-CLID

No.	Feature	CLF	H-CLID
1.	Rated voltages U_n	Few volts up to 36 kV	Up to 3 kV DC
2.	Rated currents I_n	Few mA up to several kA	Few A up to several kA
3.	Rated breaking capacity	Unlimited	Almost unlimited, e.g.,150 kA DC, 100 kA_{RMS} AC
4.	Minimum breaking current I_m	Depends on fuse type: back- up - several rated currents general purpose- 1 h current full range- rated current	Unlimited small current
5.	Total Joule integral I^2t	Depends on rated current I_n (for given short circuit conditions)	Depends on discriminated current level I_d but the I^2t parameter is always lower than for fuse of equivalent I_n
6.	Peak let- through (cut-off) current i_0	Depends on rated current I_n (for given short circuit conditions)	Depends on discriminated current level I_d but the peak let- through current is always much lower than for fuse of equivalent I_n
7.	Total operating time at rated breaking capacity	Depends on rated current I_n (for given short circuit conditions)	Depends on discriminated current level I_d but the total operating time is always shorter than for fuse of equivalent I_n
8.	t-I characteristics	Common, time-lag, transformer, high-speed, back-up and any other needed for special purposes, e.g., for coal mine	Depends on t-I characteristics of electronic short circuit current detection system (SDS) those can be designed to meet customer's requirements; however, for fast rising fault currents the operation of SDS must be instantaneous
9.	Permissible di/dt	No limits	Depends on HCB's design; di/dt > 50 A/μs seems to be an available limit
10.	Overvoltages U_0	Not higher than permissible for given rated voltage of installation	Level of overvoltages is dependent upon commutation capacitance and/or Z_nO voltage clamping varistor
11.	Discrimination	Between neighboring fuses of nearest network distribution nodes not less than 1.6 of ratio of their rated currents	Depends on SDS design. For simple electronic overcurrent trip there is possible discrimination overload currents only; for fast rising fault currents the operation of SDS must be instantaneous. However, for advanced SDS a precise discrimination is possible
12.	Ability of operation at DC	Special fuses for DC purposes	No problem with breaking DC currents, however, for highly inductive DC loads a free- wheel diode (thyristor) may be required
13.	Rated power losses P_n	Depend on rated voltage, rated current and fuse type	Negligible as in conventional mechanical circuit breaker of similar rated current

Table 2 Service features of CLF and H-CLID

No.	Feature	CLF	H-CLID
1.	High breaking capacity	No need for complex short- circuit calculations. No concerns about costly future upgrades due to system expansion with increased fault currents	Need complex verification (computer simulation) of breaking capability for increased fault currents
2.	Reset-ability	Fuses can not be reset thus forcing the user to identify and correct the over-current condition before energizing the circuit	H-CLID with expandable contact can be easily reset
3.	Reliability	No moving parts to wear out or become contaminated by dust, oil or corrosion. Fuse replacement ensures protection is restored to its original state of integrity	No problems with contact erosion or wear of arc chambers. Line test and device revision after breaking heavy faults is not required before next making. H-CLID with expandable contact needs very low maintenance.
4.	Safety	No emission of gas, flames, arcs and other materials when clearing currents. The speed of operation limits the flash hazard at fault condition. Quiet operation.	Similar features as fuses and in addition no acoustic effects at current interruption, however, noise is caused by the electrodynamic drive
5.	Power supply dips	Minimum voltage dips in power system at clearing high fault currents	Duration of voltage dip is almost negligible, e.g., 1 ms
6.	Tamperproof	Fuses can not be modified or adjusted to change their level performance once installed, thus avoiding improper adjustment and malfunctions	Setting of short circuit current detection system (SDS) can be adjusted according to customer requirements, in limits of device breaking capability
7.	Life security	Limited to large overcurrents. At overload, particularly low, due to fault to earth too long time existence, no security for human being	Can be easily incorporated phase- to-earth fault protection at any fault current
8.	Possibility of 1- or 2-phase failure in system supply	Exists but can be eliminated by use of fuse- switch combination	Can be eliminated by simultaneous activation current breaking in three phases
9.	Impulse ageing	Due to fuse-element oxidation, its pulsed ageing in constrictions and M.-effect, -ageing exists. It leads to unexpected operation, hence supply system expensive outage	Unexpected operation at impulse loads does not exist, contacts ageing is possible as in conventional CB
10.	Influence of environment	Relatively high influence of the ambient temperature	The influence of environment on electronic control system can be eliminated by proper design of electronic circuits
11.	Electromagnetic compatibility	During arcing in CLF modest electromagnetic field radiates. But it is a very seldom case	Emission of high electromagnetic field at operation of electrodynamic drive. Both electrodynamic drive and electronic control system must comply EMC standards
12.	User qualifications	Simplest among possible	Qualified technician electrician

Table 3. Economical features of CLF and H-CLID

No.	Feature	CLF	H-CLID
1.	Cost of system supply outages	Considerable due to time needed for fuse- link replacement	H-CLID - similar cost as for fuses
2.	Investment costs	Very small. Fuses are so-called installment overcurent protection	Relatively high in comparison to fuses
3.	Dimensions	Very small	Medium
4.	Weight	Very small	Medium

No. 3. Due to the current- limiting ability, which is based upon the pre- arcing Joule integral and then due to the effective and quick forced current diminishing to the artificial zero, the CLF's rated breaking capacity normally is unlimited. But a problem may arise with the current interruption of so- called critical (test duty 2) which usually is in the range of three to four times of one-half cycle current taken from a CLF t-I characteristic.

No. 4. A serious problem within CLFs is the minimum breaking current. With exception of the special fuses, i.e. so-called the full range fuses, all other types possess this breaking current boundary. The majority of the CLFs show this current as equal to several times of their rated current. It seriously limits their application as a sole overcurrent protective device. Thus in many applications it is necessary to apply an additional apparatus, very often a load switch

No. 5. Pre-arcing and in a consequence also arcing and hence also operating I^2t of CLFs strongly depend on their rated current because the fuse-element cross-sectional area is related to this current. Larger rated current, larger that area; hence larger is pre-arcing I^2t. In turn, larger pre-arcing I^2t, larger is the cut- off current and greater are both arcing and operating I^2t, because the energy to dissipate in a CLF strongly relate to $Li_0^2/2$ (where: L- the circuit inductance, i_0- the cut-off current).

To illustrate the differences between I^2t of CLF and H-CLID let us compare these values for a typical 660 V h.r.c. fuse of 100 A & 1000 A rated current and of H-CLID for 100 kA(RMS) prospective current, Table 4.

No. 6. The cut- off current i_0 for conditions as above, Table 5 and Fig. 3.

No. 7. Supremacy of the H-CLID is also very distinct as concerns the time t_0.

No. 8. In respect of t-I characteristics both compared apparatus can meet the users specific requirements. In the case of CLF an appropriate shaping of the fuse- element that can not be modified past manufacturing, can do it. On the contrary, in the case H-CLID its t-I characteristics can be adjusted and controlled in service.

Table 4. Operating I^2t for typical CLF and H- CLID

CLFs				H-CLID	
common h.r.c.		for semiconductors			
I_n	I^2t	I_n	I^2t	I_n	I^2t
[A]	[A^2s]	[A]	[A^2s]	[A]	[A^2s]
100	80,000	100	9,000	100	6,000
1,000	$25x10^6$	1,000	650,000	1,000	15,000

Table 5. The cut-off current i_0 for typical CLFs and H-CLID

CLFs				H-CLID	
common h.r.c.		for semiconductors			
I_n	i_0	I_n	i_0	I_n	i_0
[A]	[kA]	[A]	[kA]	[A]	[kA]
100	20	100	7	100	6
1,000	80	1,000	25	1,000	7

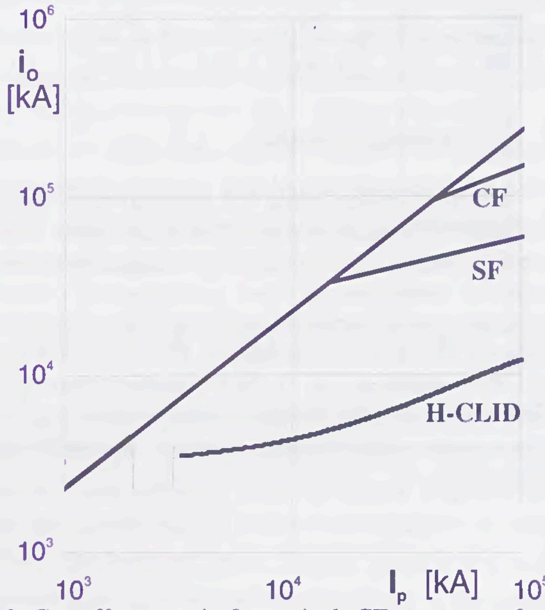

Fig.3. Cut-off current i_0 for typical: CF - common fuse, SF – semiconductor fuse, and H-CLID of I_n= 3,000A

No. 9. Fuses prevail H-CLID in respect of the permissible di/dt. They are not susceptible on this parameter, whereas H-CLID is.

No. 10. For both apparatuses in question there is no hard obstacles to keep the overvoltages on a required level, however, absolutely different designing means are used to achieve this. It should be remembered that for CLFs the overvoltages could be practically the same at lower rated voltages. That is why this problem should be a subject of careful considerations before their use in the systems of rated voltages lower than the rated voltage.

No. 11. In respect of discrimination the CLFs are devices which relatively easy can be selected along a feeding grid to ensure their proper co-ordination. Similarly, the H-CLIDs can do that, if an advanced electronic SDS is applied.

No. 12. For DC applications often entirely different fuses' design is needed. On the contrary, there is no problem with breaking DC currents by the H-CLID. Its design becomes simpler and less expensive than at AC applications.

No. 13. Unfortunately the power losses P_n of CLFs are very large as compared with H-CLID. For example, in conditions gives in No. 5 above approximate values of P_n are given in Table 6.

Table 6. Power losses P_n for typical CLFs and H- CLID

CLFs				H-CLID	
Common h.r.c.		for semiconductors			
I_n	P_n	I_n	P_n	I_n	P_n
[A]	[W]	[A]	[W]	[A]	[W
100	10	100	35	100	1
1,000	100	1,000	180	1,000	10

V. CONCLUSIONS

Current limiting fuses will probably ever dominate the field of overcurrent protection as a simplest amongst possible means of overcurrent protection. However, the physical principles of fuse performance decide on available parameters characterising fuse operation at clearing faults, as the operational I^2t and cut- off current i_0. The research on hybrid current limiting and interrupting circuit breakers and devices has shown a new way towards improvement of short circuit protection.

The available parameters of H-CLID as operational I^2t and cut- off current i_0 are now a technical challenge to current limiting fuses. Therefore it may be expected that the H-CLID at least will soon:

- replace fuses in power converter protection,
- enable effective arcing fault protection for l. v. switchgear.

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