PROTECTION OF DISTURBANCE ARC ON BUS-BARS BY MEANS OF L.V. FUSES

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Abstract: Carried out experimental investigations of the disturbance arc in 3-phase l.v. switchboards show that it is possible to interrupt this fault by means of 1-phase interrupting apparatus. A proof of this was made using a flat 3-phase bus-bars system within lumen distance d=70 mm and 90 mm between bars. The prospective metal short-circuit currents were up to ab. 43 kA (RMS) at 3x460 V, p.f.=0.25, 50 Hz. As a protective apparatus a fuse placed only in one central bar has been used. After switching off of the feeding by this fuse of this bar the short-circuit undergoes into 2-phase arcing fault between utmost bars. Then this open arc is interrupted finally by the quenching at its nearest natural current zero. As a result the disturbance arc energy is less than the maximum value 100 kJ permissible for the l.v. switchboards. The conclusion is that 1-phase interrupting apparatus installed in the central bar can prevent such switchboards against destruction due to 3-phase disturbance arc.

I. INTRODUCTION

The investigations of disturbance arc on switchboards bus-bars have been carried out since several decades and by many authors. The major effort was laid down on medium voltage systems [1] [2] [3] [4] [5]. On the other hand the investigations of disturbance arc in low-voltage (l.v.) switchboards practically were carried out by one, Prof. Stade's, group from TU Ilmenau, Germany, in cooperation with Klöckner Moeller Co [6] [7]. According to Prof. Stade's idea, the protection has an aim to minimize the destructive effects of the disturbance arc by a very quick deenergisation of the whole switchboard, irrespective of the place of that arc appearance. The protective system consists of a number of optoelectronic gauges in a combination with a making-switch and main circuit-breaker. The gauges, tuned to sense the arc light, are placed in several selected spaces of the switchboard. If a disturbance arc will ignite, the gauges, throughout the light- fiber connections, activate the tripping mechanism of the making-switch. As a consequence arise a metal short-circuit on the bus-bars terminals. Thus, the arcing fault will disappear. But still existing metal short-circuit is then finally switched off by the main circuit-breaker.

Described protective system shows several drawbacks:

- The gauges are working with interlinked electronic relays in a system connected by light-fiber network. Hence exists some additional time delay between the arc ignition instant and the instant of making-switch tripping. It should be underlined that each hundred of microseconds of such delay can considerably enlarge the arc destructive effects.
- The gauges should sense relatively narrow light waves bandwidth. On the other hand they should be not sensitive to arc light in the arc-quenching chambers, light of welding arc, light of flash, day light and other light sources. In addition to that, there is a wide range of prospective short-circuit currents in disturbing arcs and places of their ignition in the switchboards. That's why the gauges, tuned on a narrow waves bandwidth, should be selected rather individually to the given switchboard type and number of the gauges should be rather large. Hence the protective system become sophisticated one.
- To get the disturbance arc liquidation there are necessary two special heavy current commutating devices: the making-switch and the main circuit-breaker. Their time of operation should be of order of few ms.
- However , temporary, but appearance, of the metallic short-circuit, between the making-switch contacts closing and final interruption of the fault by the main circuit-breaker. This time should be of order not longer than few ms too.

To note is, that already in 1960 Siemens Co [1] had been suggested an arc disturbance protective system based on a making-switch and a main circuit-breaker, which resembled above sketchy described system of prof. Stade. But at that time the system had no practical implementation. The possible reasons of this were not yet appropriate quality of the optoelectronic gauges at that time and possibility of an unexpected faild making-switch operation which could led to unwanted metallic short-circuit on bus-bars.

Much better solution to the problem under considerations offers a high speed 3-phase hybrid current-limiting and interrupting device (H-CLID) [9].

Using H-CLID, now it means one heavy current device only, one can get similar results, as described above, as concerns the protection of a l.v. switchboard against disturbance arc destruction. Investigations, for example described in [8] [9], show that H-CLID limits the time of disturbance arc duration and its energy to the permissible level suggested by Prof. Stade, which should be not larger than 100 kJ.

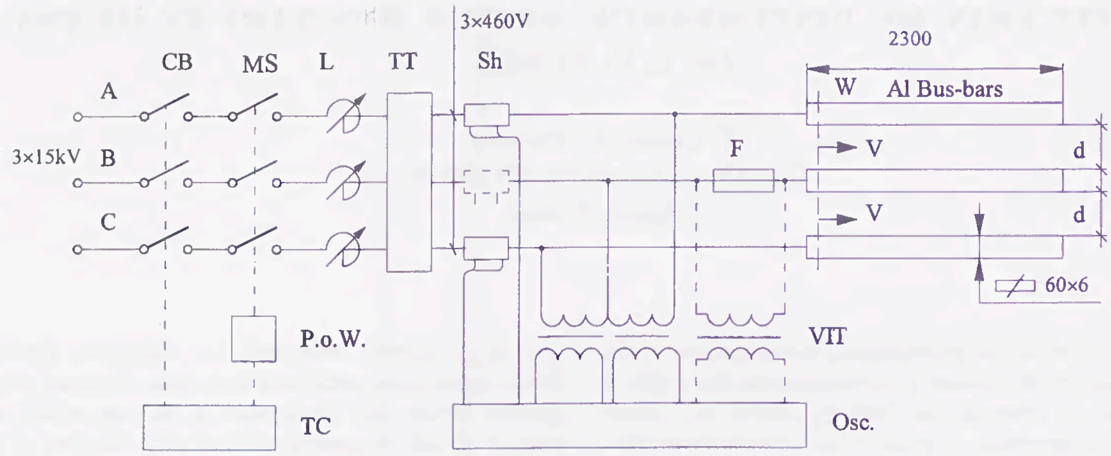

Fig.1 Test's scheme
CB- circuit-breaker, MS- making switch, L- chokes, TT- test transformer, Sh- shunts, VIT- voltage instrument transformers, F- fuse, W- wire for disturbance arc ignition, P.o.W.- point on wave control, TC- time control, Osc.- oscilloscope, d- distance in lumen between individual bus-bars, v- direction of arc-motion

Recently, in doing some experimental research on the disturbance arc in the Chair of Electrical Apparatus of TU Gdańsk, there had been observed a new aspect of that arc behaviour. The aspect pertains to 3-phase l.v. switchboard bus-bars placed in one plane, i.e. flat bus-bars system. It appeared, that if a lumen distance between individual bars is not less than a defined one but still acceptable from practical point of view, a 3-phase arcing fault can be effective switched off by breaking it in one phase only! But the condition is that the switched off phase is the central bus-bar.
To get such a result a l.v. high breaking capacity fuse provided to switch off only central phase was used. In this stage of investigations the use of mentioned fuse insted e.g. of 1-phase H-CLID was dictated by the simplicity of the tests. Such an approach gave an easy control of the interrupting time, by given fault current, by selecting the fuse's rated current.
The paper is going on to describe mentioned protection aspect.

II. DETAILS OF EXPERIMENT AND RESULTS

In this stage only an experimental approach in real short-circuit conditions was possible.
The investigations were carried out in the 3-phase system (Fig.1) at the prospective short-circuit current ab. 43 kA (RMS), p.f.=0.25 and voltages 3x460 V, 50 Hz. According to preliminary tests for this prospective current the arc disturbance current was ab. 27 kA (RMS) (Fig.2). All below described, with some exceptions, tests were carried out in the current conditions corresponding to the point A in Fig.2.
The bus-bars system was placed in horizontal plane within d=70 mm or 90 mm. It was recognised that such distance should be still acceptable by the switchboards designers. Majority of the shots were made using a h.b.c. fuse (F in Fig.1) of the rated current 400 A. This current is large enough to get reasonably good continuous rated power of the bus-bar system, i.e. ab. 320 kVA. Some additional tests using fuses of the rated current 80 A and 125 A were performed to simulate action of a protective device quicker than 400 A fuses. In mind was a possibility of the future application of a 1-phase H-CLID [9], which is a super fast acting apparatus.
To get the disturbance arc-ignition a ϕ 0.2 mm Cu-wire had been used, clamped by bolts to each bar in the place W (Fig.1). According to authors experience, selected kind of arc-ignition should have no practical influence on the test results.
Digital oscilloscope in a combination with computer was sufficient to get trustworthy results illustrating the disturbance arc behaviour (Table 1, Fig.3).
In addition to that, to illustrate the influence of an interrupting apparatus switch off time on the time duration of disturbance arc, three different fuse's rated currents were used: 80 A, 125 A and 400 A. All remaining parameters were these same, as mentioned above with one

Table I. Test's results for h.b.c. fuse rated current 400 A

p.o.w. °el	d mm	E_a kJ	t_a ms
90		77.6	10.2
		79.2	10.9
120		57.2	9.0
		63.3	8.9
150		45.3	11.2
		48.2	11.6
180	70	45.7	6.3
		46.6	6.3
210		38.0	5.3
		34.9	5.0
240		53.1	10.6
		31.8	5.0
270		80.4	10.6
		64.9	10.6
90		63.3	10.0
		52.3	9.4
150		45.4	11.5
	90	42.8	12.0
210		38.8	5.6
		38.5	5.4
270		39.2	7.6
		40.1	5.4

Note:
p.o.w.- point on wave of circuit making, d-distance in lumen between individual bus-bars, E_a- arc energy, t_a- arcing time

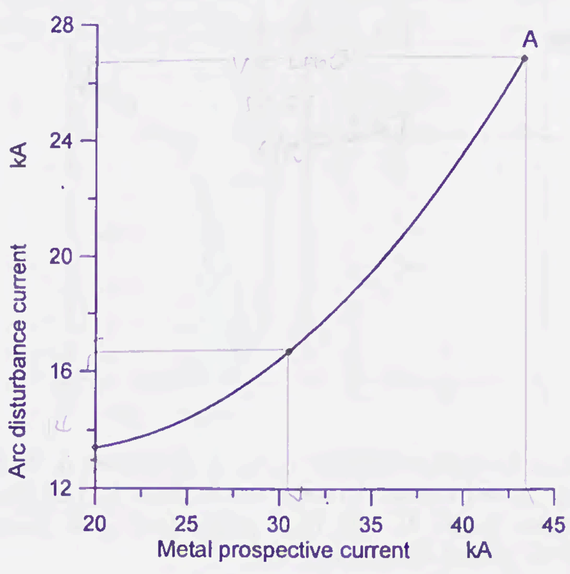

Fig.2 Arc disturbance current versus metal prospective current for d=70 mm (see details in text).

43 27
31 16.5
20 13.5

exception. Namely, the distance d=90 for 400 A fuses was chosen. The reason was that at 90 mm easier is to interrupt an open disturbance arc between utmost bars by the natural current zero, after switching off the feeding in the central bar. The results showed that even in such conditions the disturbance arc time for 80 A and 125 A fuses was ab. 15 % shorter than for 400 A fuses.
All above results should be considered in a comparison with the arc destruction energy for the case without a quick feeding interrupting of the central bar, by a fuse.

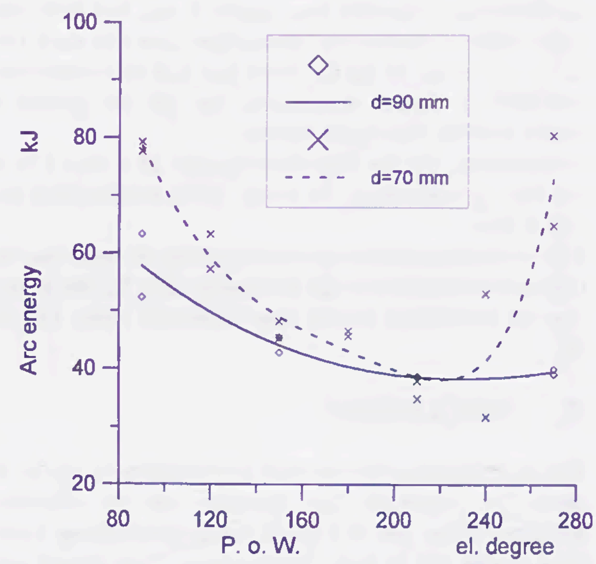

Fig. 3 Disturbance arc energy versus point on wave

That is why also the shots were made without mentioned fuse. I this case for d=70 mm the disturbance arc duration was ab. 19 ms and its energy ab. 190 kJ.
Fig.4 shows two typical records.

III. DISCUSSION

The investigations of Prof. Stade's group [6] at 65...100 kA prospective current led to the statement that, at the time duration of disturbing arc up to 5 ms and liberated arc energy up to 100 kJ, the destruction of a l.v. switchboard is practically negligible. Thus, after small cleaning of the insulating elements and checking of the dielectric withstand the switchboard can be reclosed into service. But the condition is the switchboard compartment should be equiped within a pressure relief reductors.
From records for d=70 mm (Fig.4a), in the instant 1 the feeding of the central bar B become interrupted by the fuse. The 3-phase short-circuit undergoes into 2-phase arcing fault between utmost bars. From this moment the current in both phases is this same, but after several ms also the open arc is finally quenched due to natural current zero.
A different behaviour shows a disturbing arc in the case

of d=90 mm (Fig.4b). Now in the instant 1 the 3-phase arc short-circuit undergoes into 2-phase one, between the phases B and C. The reason is a natural quenching of one arc only, burning between the phase C and outstanding phases. It happens due to large enough distance d, in this case 90 mm instead 70 mm. So now beyond the instant 1 already a 2-phase (between phases A and B) arcing exists only, which finally has been interrupted by a fuse placed in the central bar B.
The results given in par. II of this paper, in view of Prof. Stade's statement, are very promising. However, the disturbing arc duration was above 5 ms, but their energy, which is crucial for destruction, was less than 100 kJ, i.e. up to ab. 81 kJ for d=70 mm and fuse rated current 400 A. Better results one can get for greater d and/or smaller fuse rated current.
For example, for the fuse rated current 80 A and 125 A the time of disturbing arc is ab. 15 % smaller than for 400 A fuse.
The investigations also shows that point on wave has an important influence on the arc energy (Fig.3), but in any case its magnitude is less than threshold value 100 kJ [6].

IV. CONCLUSIONS

The investigations proves that the disturbance arc in 3-phase l.v. bus-bars flat systems can be effective switched off by use of a quick acting interrupting apparatus placed just in one, central phase. This feature was pointed out by the experiments, for simplicity using h.b.c. fuses as that interrupting device.
Obviously in practical applications the use of one fuse in the central bus-bar is not acceptable. But the results of the investigations show clear that is possible to apply, for example, 1-phase H-CLID instead of a 3-phase one. This conclusion is an important direction how in a cheapest way to protect the bus-bars by a very rapid disturbance arc liquidation without or with a very slight destruction of the l.v. switchboards by means of 1-phase protective apparatus. Of course, the gauges and the whole sensing arc disturbance system will remain as it is in Prof. Stade's solution.

ACKNOWLEDGEMENT

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a)

b)

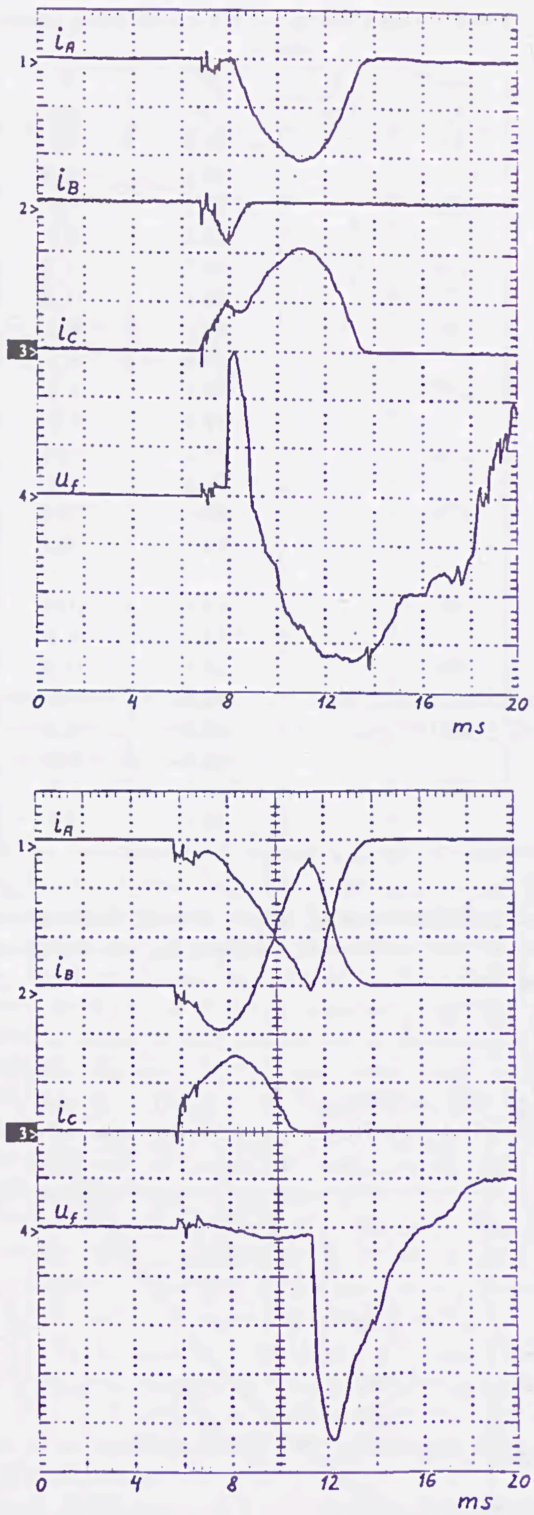

Fig. 4 Records of currents i_A, i_B, i_C (in phases A, B, C Fig. 1), and voltage u_f on the fuse in phase B. Test conditions: 3x460 V, 50 Hz, prospective metal short-circuit current ab. 43 kA (RMS);
a- fuse rated current 80 A, d=70 mm
b- fuse rated current 400 A, d=90 mm
amplitude factors:
- currents k_i=9 kA/div.
- voltage k_u=150 V/div.

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