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# PROCEEDINGS

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## VOLUME 1

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## B2. Interaction of vacuum arc with magnetic field

# Investigations of Transient Processes at Vacuum Circuit Breaker Switching and Development of Technical Requirements for 6-35 kV Vacuum Circuit Breakers

A.A. Bazavluk, L.I. Sarin, A.I. Shirkovets, A.V. Telegin

LLC BOLID, PO Box 119, Novosibirsk, 630015, Russia

*Abstract* – **The paper explains the necessity of the development of additional technical requirements for medium voltage vacuum circuit breakers (VCB). Based on experimental investigations, possibility of significant difference in electrical and mechanical characteristics for VCB of various manufacturers is stated.**

**It is shown that associated parameters of electrical and mechanical transient processes at VCB switchings influence on insulation of switched equipment. As an example, results of full-scale tests of vacuum and oil circuit breakers in the operational network of Novosibirsk CHP plant No.4 are presented. Importance of determination of optimal VCB parameters is confirmed.**

## I. Reasons why vacuum circuit breakers are of great interest

Percentage of switching equipment with expired life time in Russian electrical networks is more than 20% [1]. SF6 and vacuum circuit breakers having specific features gradually replace oil and magnetic circuit breakers in 6-35 kV networks [2-4].

Vacuum arc extinguishing medium has special features which cause some negative phenomena during circuit breaker switching. These phenomena may be in the form of switched equipment insulation damages. However, that is not to say that overvoltages ratios at vacuum circuit breaker (VCB) switching significantly exceed overvoltages ratios at SF6 and oil circuit breaker switching. Overvoltage ratios are considerably determined by parameters of a switched circuit and may reach values which are dangerous for equipment insulation with any kind of a circuit breaker (oil, SF6, or vacuum circuit breaker). Both vacuum, and SF6 arc extinguishing media provide stable arc quenching for high-frequency current. According to numerous investigations, vacuum is the hardest arc extinguishing medium where an arc can be quenched for current of higher frequency than in the case of SF6 circuit breaker. Degree of ‘hardness’ for arc extinguishing medium in numeric equivalent can be evaluated by the rate of current zero when it is just possible to quench an arc of high-frequency current. For vacuum, the rate of current zero is in the range of 250-350 A/μs.

The fact that vacuum circuit breakers generate high-frequency overvoltages depends on the possibility of 50Hz current chopping (which values in modern VCB do not exceed relatively safe level of 3-5 A [5]) and on the ability of current interruption at high rates of current zero. High-frequency overvoltages depends on not only parameters of the network, but also characteristics of vacuum interrupters and VCB mechanism. These overvoltages, even at their low levels, are very dangerous for turn insulation of electrical machines and transformers and for solid polymer insulation of cable networks [6-8].

Taking into account that just vacuum circuit breakers are implemented in operational networks and a wide variety of VCB types (more than 15 models in 10 kV class) and of manufacturers of vacuum switching equipment (more than 20 manufacturers in 10 kV class), there is a necessity of evaluation of VCB parameters and development of technical requirements. Undoubtedly, in that case we need to control considered VCB technical requirements during initial inspection (e.g. using special test desks or stands) and during further VCB operation.

## II. Why we are interested in these issues

For the last 5 years, there have been a great amount of Russian [9-11] and foreign [12-16] publications concerning investigations on VCB parameters and transient processes during their switching [including ISDEIV publications 17-19]. This indicates a great interest of operating companies and scientific community in considered issues.

Analysis of foreign normative documents shows that nowadays standards on design and development of high-voltage circuit breakers are being actively developed, For example, for the period of 1996-2011, not less than nine IEC and ANSI/IEEE standards were issued or revised. At present, there is no any similar standards system in Russia.

Since 2003, LLC BOLID within the terms of agreements has been doing investigations on mechanical characteristics and transient processes oscillography at switchings of different high-voltage circuit breakers (i.e. vacuum, SF6, and oil circuit breakers) in operational medium voltage networks. At present, LLC BOLID did investigations in 6-35 kV networks of more than 15 power plants, including Novo-Romanovo substation,

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Chebulinskaya substation, Nikolaevskaya substation (Kuzbassenergo-RES, branch of Interregional Distribution Grid Company of Siberia 2003), Belovskaya GRES power plant (2004), Metallurgic plant named after A.K.Serov (2005, 2008), Gazpromneft – Omsk Refinery (2006), Bogandinskaya compressor station KS-11 (Gazprom transgaz Surgut, 2008), Nizhniy Tagil Iron and Steel Works (2009), Novosibirsk CHP plant No.4 (2010), Volodino compressor station (Gazprom transgaz Tomsk, 2011), Kurakhovskaya CHP plant (Ukraine, DTEK, 2012) and others. 10 kV vacuum circuit breakers of Tavrida Electric, ENEKO (Minusinsk), Kontakt (Saratov), Electroshield Group (Samara), Konstalin (Chelyabinsk), Schneider Electric/MERLIN GERIN (France), ABB were investigated. In different circuits, drive motors up to 12.5 MW, and power and furnace transformers were switched.

Based on the results of investigations on VCB parameters and experimental oscillograms of transient processes during VCB switching, LLC BOLID (sometimes in cooperation with Gazprom) has published papers in special technical journals and conference proceedings [20-23]. The aim of these publications is to draw attention of operating companies to undiscussed issues of VCB operation. Discussions on VCB issues with the participation of Tavrida Electric were organized at production meetings of Interregional Distribution Grid Companies Holding (Kirov, 19-23 September 2011; Yekaterinburg, 14-18 May 2012) and scientific and technical council of Interregional Distribution Grid Company of Urals (Chelyabinsk, 7-8 December 2011).

VCB investigations were continued in the form of research scientific work "Development of technical requirements for 6-35 vacuum circuit breakers and technique of evaluation of VCB technical conditions for increasing of high-voltage equipment reliability" which is now being done by LLC BOLID within the terms of the agreement with Interregional Distribution Grid Company of Volga.

## *III.* Some Results of Experimental Investigations

In June 2010, at Novosibirsk CHP plant No.4 in cooperation with Interregional Distribution Grid Company of Urals we carried out comparison tests of circuit breakers when switching ball mill 800 kW motor which was connected with a circuit breaker by 100m-length mass-impregnated paper insulated cable. The aim of this paper is evaluation of transient processes at circuit breaker switchings and comparative analysis of vacuum circuit breaker (VCB) characteristics made by different Russian manufactures: ELKO Minusinsk (circuit breaker VVTE-M-10-20/630), Tavrida Electric Moscow (BB/TEL-10-20/1000), Kontakt Saratov (VBP-10-20/630). In addition, the oil circuit breaker VMP-10-20/630 was also tested. The following voltages were recorded during testing: at 6 kV KRU, at the beginning of the cable line after the circuit breaker, at the end of the cable line near the motor. Currents through an overvoltage suppressor and load currents were also recorded.

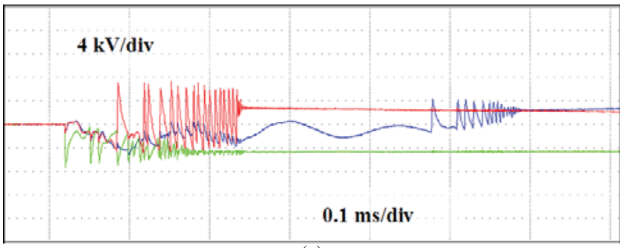
During VCB switchings, high-frequency prestrikes with various durations and amplitudes depending on the VCB type were observed. Oil circuit breaker at its closing is prestrike free which is due to the character of arc extinguishing medium. Overvoltages at the beginning of the cable line at circuit breaker opening do not exceed 1.9 times maximum phase-to-ground voltage, and at circuit breaker closing – 2.0 times maximum phase-to-ground voltage. Overvoltage ratios for different circuit breakers significantly increase at the end of the cable line due to high-frequency component in comparison with overvoltage ratios at the beginning of the cable line. Representative oscillograms of switchings for some tested circuit breakers are presented in Fig. 1, 2.

Along with electromagnetic processes, circuit breaker mechanisms and associated mechanical parts were investigated (e.g. stages of contact moving, contact sticking and bouncing). The change of contact closure velocity for various circuit breakers are presented in Fig. 3 – Fig. 6. Among vacuum circuit breakers, the maximum contact closure velocity is for VVTE-M-10-20/630 by ELKO Minusinsk. The rate of breakdown voltage increases, and prestrike duration decreases. But contact bouncing rises at circuit breaker closing, and numerous high-frequency breakdowns are observed inside a vacuum interrupter.

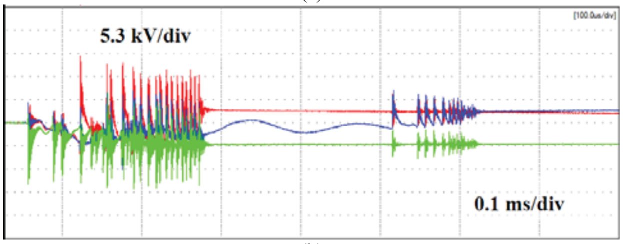
The maximum contact closure velocity for oil circuit breaker VMP-10-20/630 is higher than for tested VCB, thus contact bouncing at VCB closing reaches maximum values (see Fig. 7). BB/TEL-10-20/1000 and VBP-10-20/630 circuit breakers are free of contact bouncing which may lead to arc extinction. It is determined by low contact closure velocity. The quantity of prestrikes rises in this case.

The maximum value of nonsimultaneous contact closure for tested VCB does not exceed 0.5 seconds. The same parameter for oil circuit breaker VMP-10-20/630 is more than 1 ms. This and maximum values of contact bouncing are caused, probably, by long period of its operation (more than 40 years).

Based on the results of experimental and theoretical investigations, some considerations can be done. During switchings, the most important (i.e. considering overvoltage levels) mechanical and electrical transient processes occur in microsecond ranges at the distance between contacts of less than 2 mm. Mechanical transient processes depend on quality of circuit breaker mechanism construction (i.e. absence of backlashes and bounce of contacts) and its quick and smooth operation, and on synchronism and linearity of circuit breaker poles. In turn, mechanical processes and VI characteristics influence on electrical transient processes, i.e. determine their parameters at VCB switching and danger for the equipment. Consequently, mechanical and electrical transient processes should be considered simultaneously.

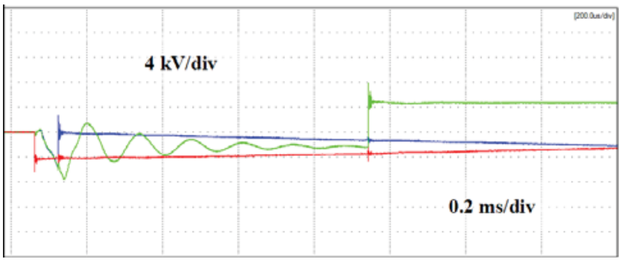



(a)




(b)

Fig. 1. Oscillograms of transient processes for phase-to-ground voltages at the beginning (a) and at the end (b) of the cable line at closing of BB/TEL-10-20/1000 vacuum circuit breaker made by Tavrida Electric Moscow in the 6 kV network




(a)


(b)

Fig. 2. Oscillograms of transient processes for phase-to-ground voltages at the beginning (a) and at the end (b) of the cable line at closing of VMP-10-20/600 oil circuit breaker

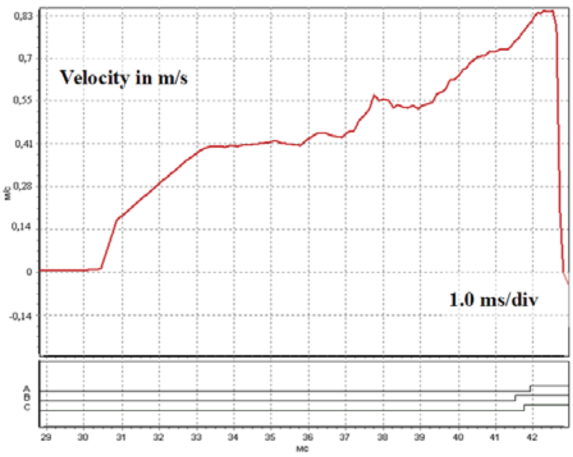



Fig. 3. The change of contact closure velocity for BB/TEL-10-20/1000 vacuum circuit breaker made by Tavrida Electric Moscow

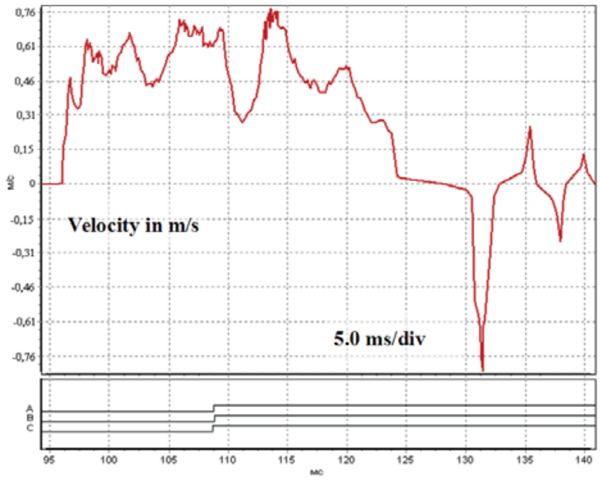



Fig. 4. The change of contact closure velocity for VBP-10-20/630 vacuum circuit breaker made by Kontakt Saratov

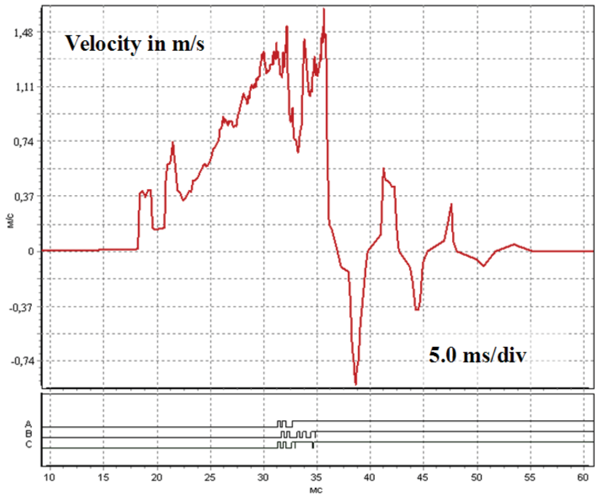



Fig. 5. The change of contact closure velocity for VVTE-M-10-20/630 vacuum circuit breaker made by ENEKO Minusinsk

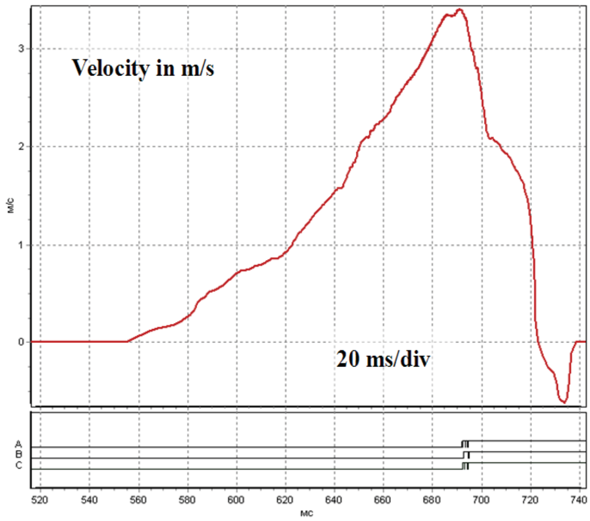



Fig. 6. The change of contact closure velocity for VMP-10-20/630 oil circuit breaker

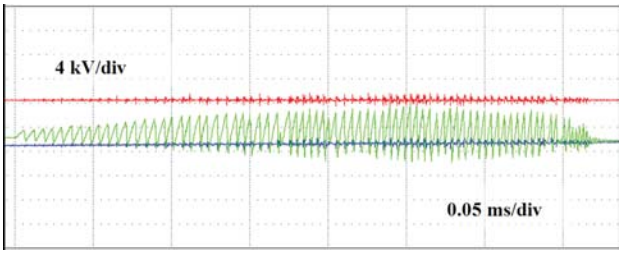



Fig. 7. Oscillograms of transient processes for phase-to-ground voltages at the moment of contact rebound at closing of VVTE-M-10-20/630 vacuum circuit breaker made by ENEKO Minusinsk

## *IV.* Issues we would like to discuss

Depending on the model and quality of manufacture of vacuum interrupters (VI), construction and kinematic configuration of a CB mechanism, type of a switching control system (i.e. three-pole switching or separate switching for each pole), electrical and mechanical characteristics of vacuum circuit breakers of various manufacturers and models may be significantly different. Associated parameters of electrical and mechanical transient processes at VCB switching determine influence on switched equipment. Therefore, determination of optimal and not standardized in Russia now [24-26] VCB parameters is of great interest. These parameters are the following:

- time and velocity characteristics of a VCB mechanism which determine travel speed of a moving contact inside a VI. Mechanical transient processes depend on quality of VCB mechanism construction (i.e. absence of backlashes and bounce of contacts) and its quick and smooth operation, and on synchronism and linearity of circuit breaker poles. In turn, mechanical processes and VI characteristics influence on electrical transient processes, i.e. determine their parameters at VCB switching and danger for the equipment. So mechanical and electrical transient processes should be considered simultaneously.
- electric strength inside a VI at low distances between contacts which is associated with actual degree of contact erosion (i.e. transient resistance) and pressure inside a VI. During VCB switching, mechanical and electrical transient processes (as the most important processes for considering switching overvoltages) occur in microsecond ranges at the distance between contacts of less than 2 mm.
- values of breakdown voltage change rate at VCB switching which influence on prestrike duration at VCB closing and possible development of overvoltage escalation at VCB opening.

Whereas each circuit breaker is an inherent element of an electrical network, VCB periodic inspection and performance evaluation are required for determination of VCB current state and their associated influence on switched network section. For that aim, it is required to determine electrical, time, and velocity characteristics (i.e. parameters) of a circuit breaker according to a special technique which is now being developed. Therefore, in spite of relatively simple construction, VCB requires periodic inspection during its operation.

In connection with the foregoing, we state some issues which should be solve only in cooperation with VCB manufacturers. This allows, on the one hand, increasing VCB reliability (because, unfortunately, VCBs may often cause emergency situations), and, on the other hand, minimizing influence on switched equipment. We suppose for discussion the following issues:

1. Directions of technical documentation development which contains requirements for VCB electrical and mechanical characteristics. It allows operating companies to create valid technical requirements for vacuum circuit breakers and purchase vacuum switching equipment of certified manufacturers.
2. Development of test desks and stands which provide physical models of networks where statistically-valid switching modes can be realized and transient processes in various points of a network can be recorded. It allows comparison testing of different circuit breakers before putting them into operation, determination of rated parameters, and prevention of unsatisfactory VCB implementation into operational networks.
3. Possibility of control of VCB mechanical characteristics using special adapters, modification of VCB mechanism, etc. VI vacuum leakage tests during operation. It allows VCB periodic inspection for conformity with developed requirements and standards and VCB ‘correct adjustment’ during operation.

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**Artem Bazavluk** was born in 1987. He received Dipl.-Ing in electrical engineering from Novosibirsk State Technical University in 2009. He is currently working as Engineer of Research Department at LLC BOLID, Novosibirsk, Russian Federation, since 2009.

**E-mail:** nio_bolid@ngs.ru

**Leonid Sarin** was born in 1959. He received Dipl.-Ing in electrical engineering from Novosibirsk State Technical University in 1981. He is currently working as Director at LLC BOLID, Novosibirsk, Russian Federation, since 1998.

**E-mail:** pnp_bolid@ngs.ru

**Andrey Shirkovets** was born in 1983. He received M.Sc. in electrical engineering from Novosibirsk State Technical University in 2006. He is currently working as Principal Engineer of Research Department at LLC BOLID, Novosibirsk, Russian Federation, since 2006.

**E-mail:** nio_bolid@ngs.ru

**Andrey Telegin** was born in 1987. He received M.Sc. in electrical engineering from Novosibirsk State Technical University in 2010. He is currently working as Engineer of Research Department at LLC BOLID, Novosibirsk, Russian Federation, since 2010.

**E-mail:** nio_bolid@ngs.ru