Investigation of the electrical strength of a contact gap of the high voltage live tank circuit breaker 126 kV class using an intelligent controlled switching system

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Abstract

Uncontrolled switching of reactive elements of power networks may create electrical transients which cause equipment damage and system disturbances. The high frequency, high current transients, associated with uncontrolled energisation of capacitors can inductively couple voltage transients into control equipment and protective relays via the switchyard cabling. These transients may cause misoperation or failure of the control equipment. Controlling the point in the electrical cycle at which switching takes place is a possible method for minimising these negative effects. Controlled switching requires knowledge of electrical strength of contact gap. This paper is associated with investigating the electrical strength of a contact gap of a high voltage SF_6 circuit breaker 126 kV voltage class with sulfur hexafluoride gas – SF_6 for development of the smart-designed controlled switching system via investigation of the rate of decrease of dielectric strength. In this paper, a new approach to solve the problem of controlled switching is proposed.
Keywords: SF_6 gas-insulated circuit breaker, electric arc, zero current, burning arc, shunt reactor, capacitor bank, rate of decrease of dielectric strength.

1 Introduction

Modern high-voltage substation equipment Unified Energy Systems of Russia requires increased reliability of its elements. Special attention to improving the stability should be given to aspects of high-voltage switching, which are

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subjected to considerable stress in the various switching modes. The use of intelligent controlled systems is a more effective and functional means in comparison with pre-insertion resistors: allow control switching in the desired phase of the reference voltage and polarity, can eliminate the harmful effects caused by surges, inrush current, re-ignition and breakdowns.

2 Electrical endurance analysis

The initial value of intension discharge at full lightning impulse among the insulating gas at a pressure of $0,1 \leq p \leq 0,6$ MPa is given by: [1, equation 3-54]

$$E = 89 \cdot p^{0.88} \cdot (1 + \frac{0,180}{(p \cdot r_0)^{0.5}})$$

where l – contact distance, p – pressure, Pa, r_0 – the radius of curvature of the electrode with the maximum field strength, m; a and m – coefficients depending on the nature of the change of the field in the gap.

With the chosen design parameters of live tank SF_6 gas circuit breaker the guaranteed value of the pulse voltage at which there is no breakdown of the insulating gap is given by:

$$U^{\text{guar}}_{\text{discharge.imp}} = 467\text{kV}$$

The selected value of the insulating gap is more than the rated standard value – 450 kV by Russian National Standard 1516.3-96 [2] and provides the necessary dielectric strength of the gap by lightning impulse at the fully open position.

The package ELCUT was used for numerical simulation of the electric field in the distance between the contacts. Obtained results of electric field simulation [3] are in good accordance with data, presented in [4].

3 The principle of operation

In this study an intelligent integrated controlled switching system (CSS) is considered as a means of contact closing near the peak of the reference voltage to plot the breakdown voltage curve in pure sulfur hexafluoride gas according to its electrophysical duration.

The main principle of the controlled switching system is that the controller monitors the waveform of the reference voltage when the command to actuate the breaker, registers ideal point, and taking into account the opening time and other adaptive operating factors, forms on time delay so that the closing or opening of arcing contacts would occur in the required time, the required phase and polarity of the voltage reference. Control of switching moment of contacts with the process of electro pre-strike voltage relative to a reference system, which occurs when the reactive elements are an effective means for significantly reducing of inrush currents and surges that occur during switching of capacitor banks, shunt reactors, unloaded lines [4].

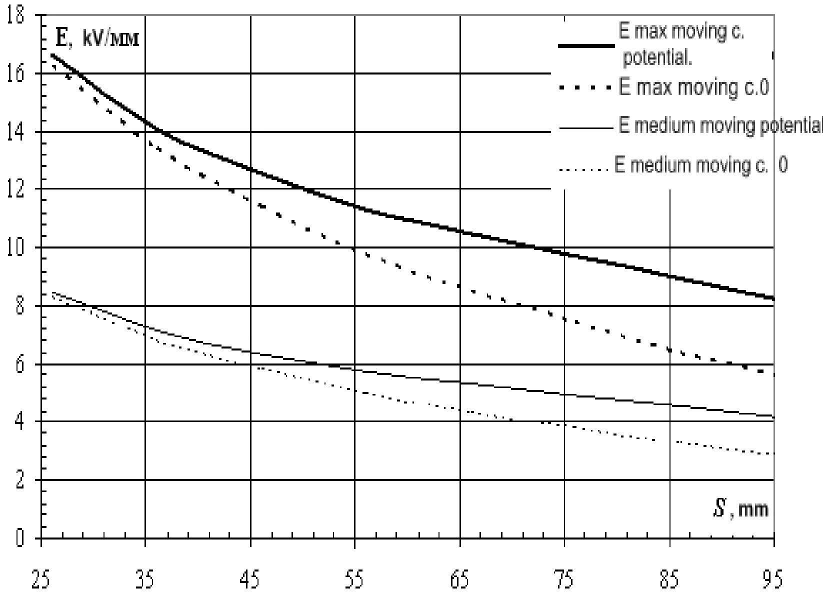

Figure 1: Electric field intension of the contact gap made in ELCUT package simulation – moving contact case [3].

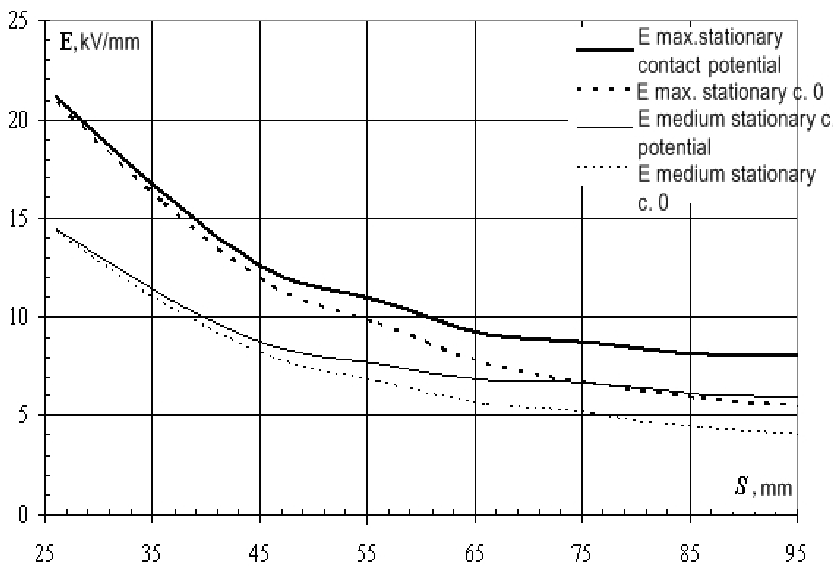

Figure 2: Electric field intension of the contact gap made in ELCUT package simulation – stationary contact case [3].

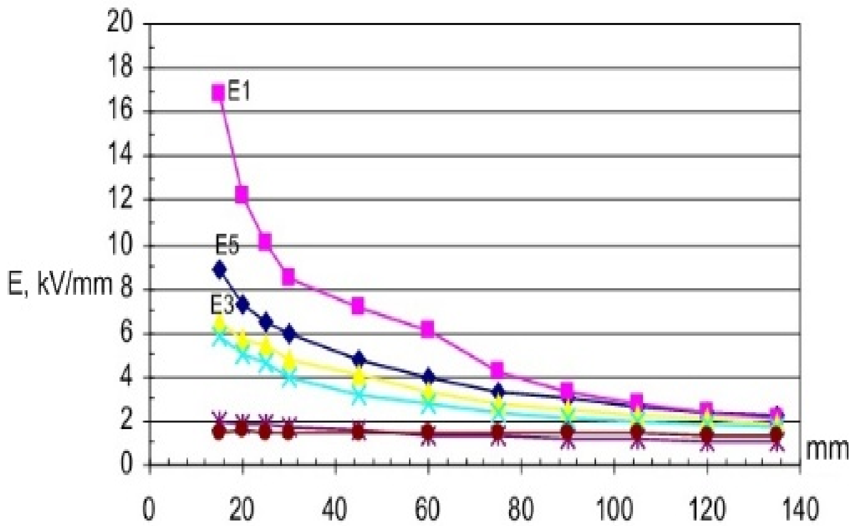

Figure 3: Electric field intension of the HGF 1014/63 kA SF_6 circuit breaker's contact gap [4].

Figure 5 shows the principle of operation of the controlled switching system.

In the case of a synchronous switching on the circuit breaker (controller input – "synchronous closing"), or synchronous breaking (controller input – "synchronous opening") system for each pole switch counts $\Delta t_{command}$ from the time of the next reference voltage crossing zero to the delivery of closing/opening command to operating drive of the corresponding pole considering its opening/making time ($t_{opening}/t_{closing}$), so that the beginning of closing (or opening) of the arcing contacts pole had at the time of the transition sine wave voltage reference through a natural zero, then the timing is calculated as follows:

$$\Delta t_{total} = \Delta t_{command} + t_{opening} + t_{delay}$$

where Δt_{total} – total time of operation for synchronous performance of breaker's poles from the moment of the first corresponding phase sine wave voltage reference natural crossing zero after receipt the controller commands for synchronous operation to the start switching (opening or closing) the arcing contacts of this pole;

$\Delta t_{command}$ – delay of the control command (closing or opening) of the operating drive of circuit breaker's pole generated by the controller to perform switching (opening or closing) the arcing contacts of the circuit-breaker pole to the desired point of the associated phase of the reference voltage ($\Delta t_{command}$ value is calculated depending on the programmed settings);

$t_{opening}/t_{closing}$ – programmed into the controller closing or opening time;

t_{delay} – additional time delay in solenoid control command (closing/opening) to operating drive, that determines the phase of reference voltage at switching poles of CB (user selectable in milliseconds, between 0 and 20 ms during programming synchronization module).

Research tests have been performed to determine the electrical strength of a contact gap of SF_6 gas live tank circuit breaker VGT – 110 class 126 kV using a controlled switching system in high-voltage laboratory of JSC "Uralelectrotyazhmash". This intelligent system provided a contact closing (pre-strike) near the peak of the reference voltage during capacitive load switching (1000 pF). The pre-strike voltage was obtained by smooth voltage rise and changing of time delay for switching operation so that the time of pre-strike took place at the voltage maximum. The curve of contact travel curve was recorded by resistive travel sensor, electromagnetic interference during switching process have been corrected by processing filter programs by two methods. Recording of instantaneous values of analog and digital electrical signals was realized by recorder RES-03 with 15 kHz sampling frequency.

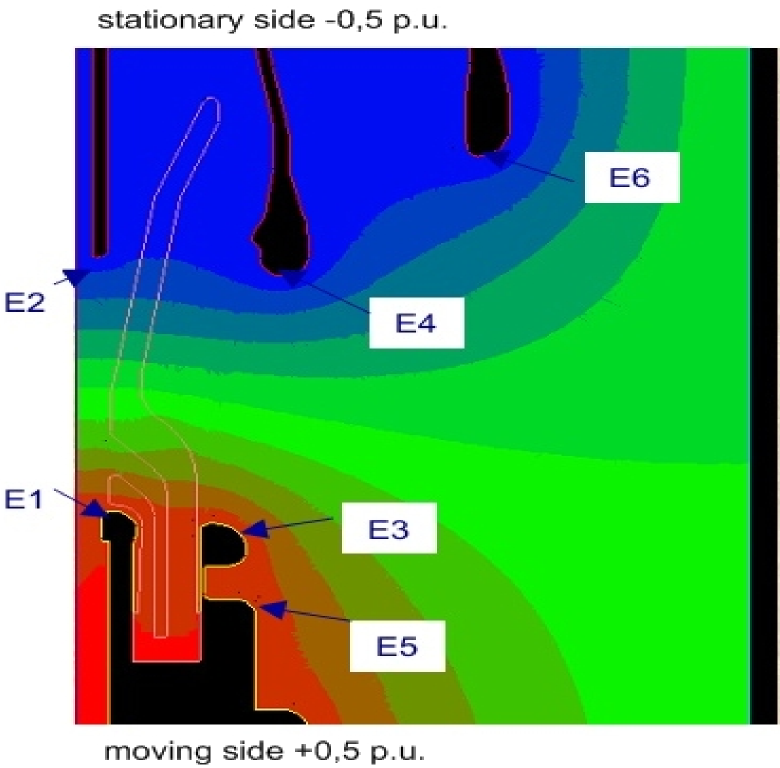

Figure 4: Distribution of electric field intensity of the HGF 1014 /63 kA SF_6 circuit breaker's contact gap [4].

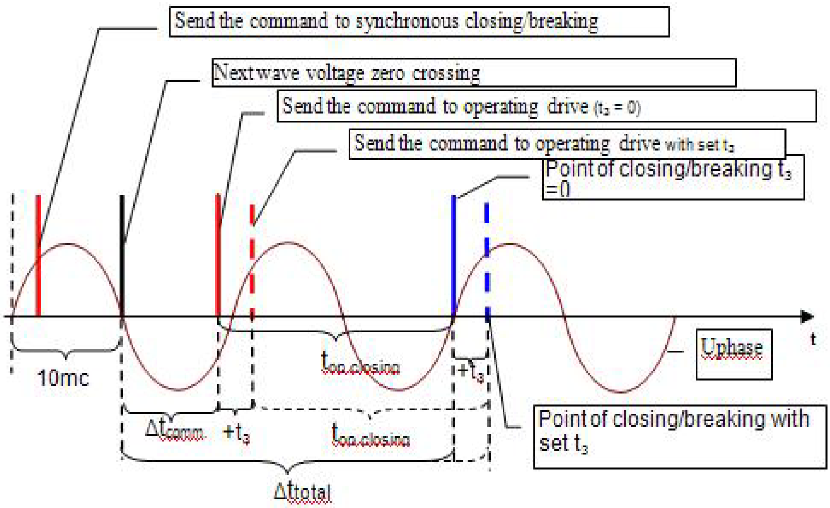

Figure 5: The algorithm of the subsystem clock synchronous operation of intelligent control switch system (independent single pole operation).

The relation of pre-strike voltage according to duration at different reference voltages was determined. Angle characteristics of electrical breakdown at nominal pressure – 0,5 MPa and a minimum – 0,42 MPa operating pressures of pure sulfur hexafluoride, that define RDDS were defined by two methods of filtering electromagnetic interference. In Figures 6–9 trendlines are shown with coefficients that characterize the dielectric strength (RDDS) of a contact gap during pre-strike at nominal pressure – 0,5 MPa and minimum – 0,42 MPa accordingly.

The main goal of the controlled switching system in the present study was to provide closing of arcing contacts (providing pre-strike as they touch) close to voltage peak for registration and subsequent plotting pre-strike voltage graph according to duration (that characterizes the rate of decrease of dielectric strength – RDDS).

4 Experimental results

The lines representing the RDDS were determined by linear interpolation. The kind of interpolation which best fits a given set of points might be dependent on the circuit-breaker design.

It is quite evident that duration of the pre-strike in SF_6 is directly proportional to the pre-strike (breakdown) voltage, the experimental data results obtained by two filter methods in this research differ slightly. CIGRE'S angle characteristics of RDDS are shown in p.u. without reference to rated voltage class of circuit breaker under test [5, I p.38]. However differences of obtained RDDS angle characteristics with CIGRE'S characteristics of RDDS are in good accordance.

Angle characteristics of RDDS obtained in this research are slightly steeper than RDDS presented in [5, I p.38]. Some differences may be explained by design features of test circuit breakers (mechanical scatter – beginning of the contact movement, variation of contact speed, filling pressure, SF_6 quality, etc.) Two methods of filtering of electromagnetic interference have shown about the same results.

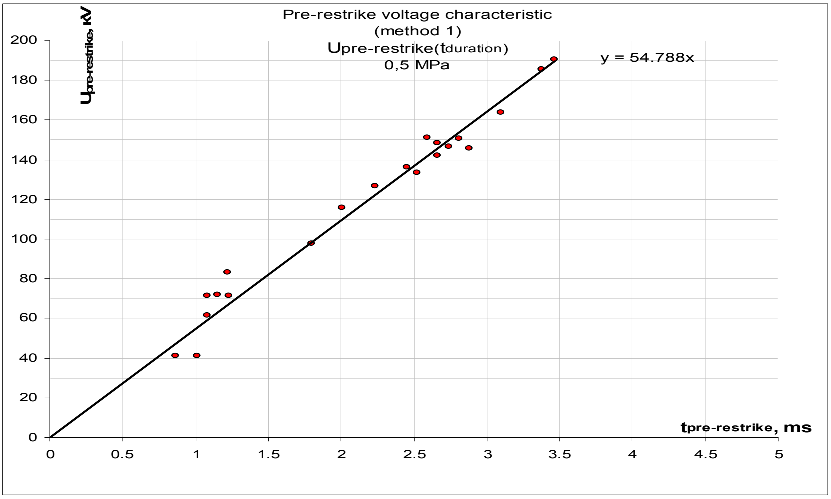

Figure 6: Pre-strike voltage (voltage breakdown) characteristic – (RDDS) according to duration (method 1) at the filling pressure of 0.5 MPa.

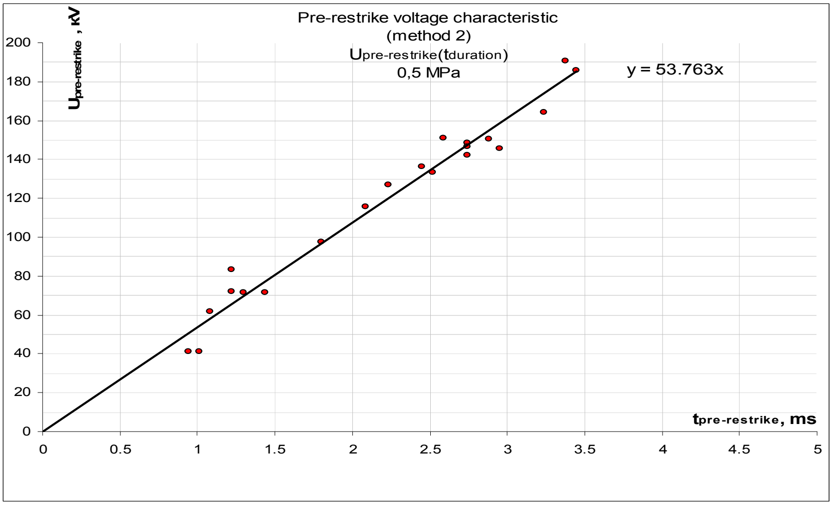

Figure 7: Pre-strike voltage (voltage breakdown) characteristic (RDDS) according to duration (method 2) at the filling pressure of 0.5 MPa.

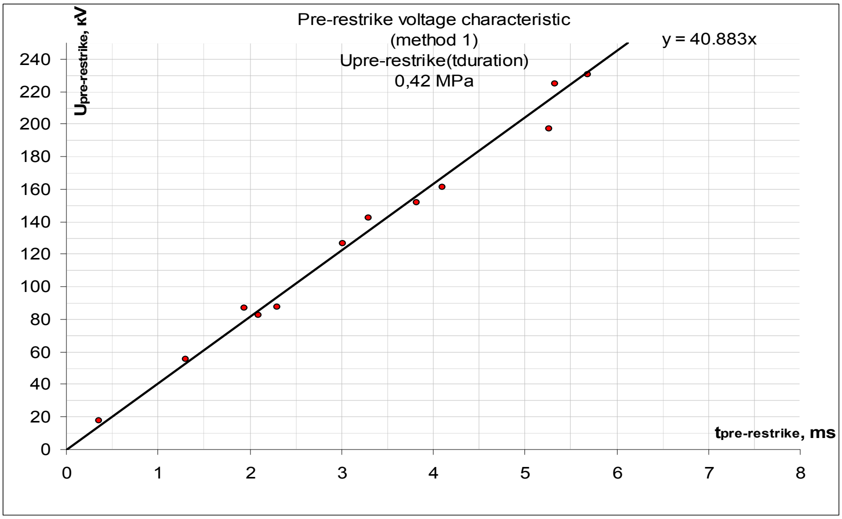

Figure 8: Pre-strike voltage (voltage breakdown) characteristic (RDDS) according to duration (method 1) at the filling pressure of 0.42 MPa.

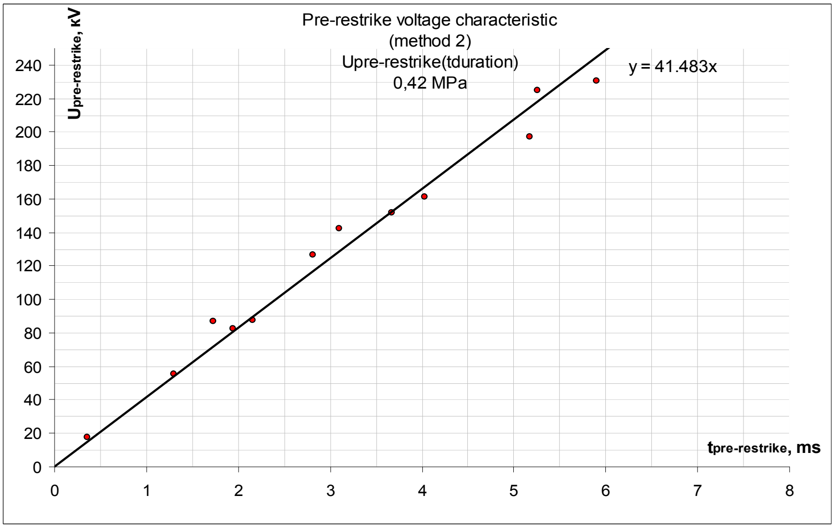

Figure 9: Pre-restrike voltage characteristic – RDDS according to duration (method 2) at the filling pressure of 0.42 MPa.

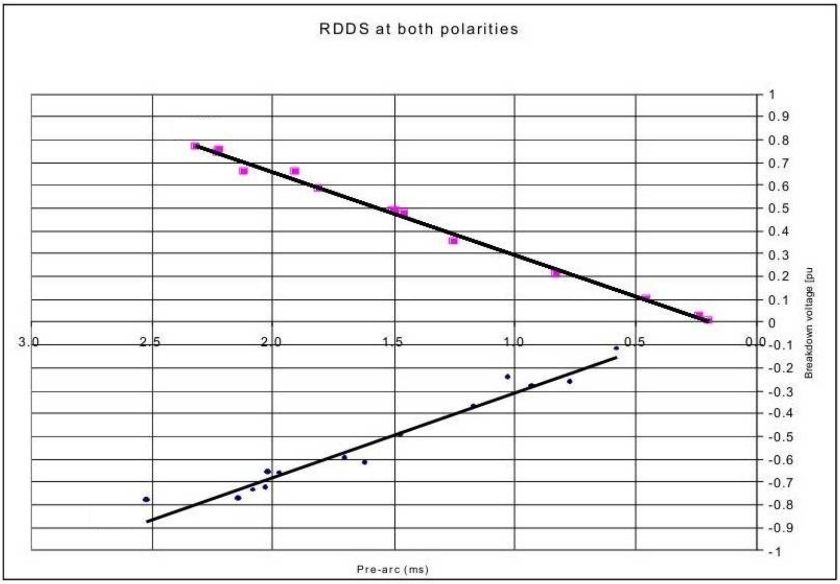

Figure 10: Pre-restrike voltage (voltage breakdown) characteristics – RDDS in p.u. according to duration CIGRE A3.07 WG data [5, I p.38].

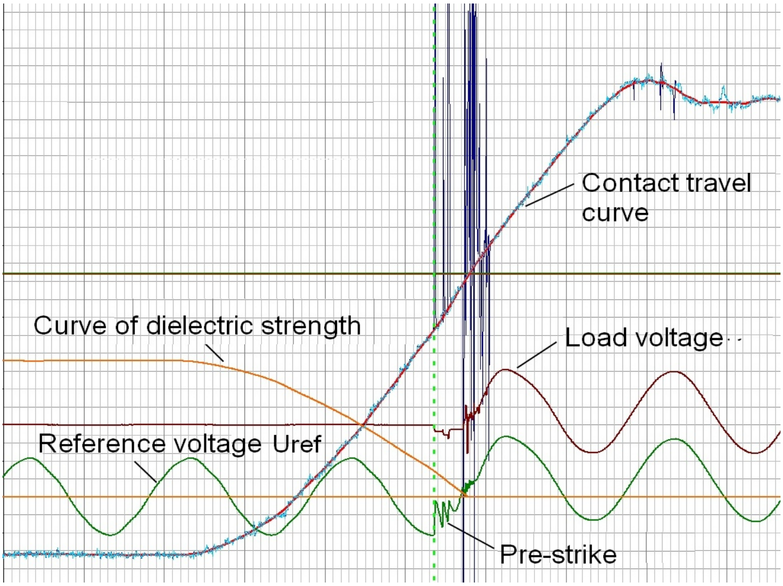

Figure 11: The obtained curve of the dielectric strength according to contact travel, reference voltage and load voltage, obtained during capacitive load switching.

Table 1: Pre-strike voltage values and durations – at filling pressure of 0.42 Mpa.

№ test	Pre-strike voltage, kV	Pre-restrike voltage (abs.), kV	Duration, msec	
			Approach № 1	Approach №2
1	41.4	41.4	0.86	0.94
2	41.4	41.4	1.01	1.01
3	-61.74	61.74	1.08	1.08
4	71.5	71.5	1.08	1.44
5	-71.7	71.7	1.23	1.3
6	-72.14	72.14	1.15	1.22
7	83.14	83.14	1.22	1.22
8	97.6	97.6	1.8	1.8
9	-115.9	115.9	2.01	2.09
10	126.9	126.9	2.23	2.23
11	133.4	133.4	2.52	2.52
12	-136.22	136.22	2.45	2.45
13	-141.94	141.94	2.66	2.66
14	145.6	145.6	2.88	2.95
15	-146.6	146.6	2.74	2.74
16	148.5	148.5	2.66	2.74
17	150.55	150.55	2.81	2.88
18	151.03	151.03	2.59	2.59
19	-164	164	3.1	3.24
20	185.7	185.7	3.38	3.45
21	190.59	190.59	3.46	3.38

5 Conclusions

With all the variety of controlled switching system's advantages this article is devoted only for investigation of the electrical strength of a contact gap of High Voltage SF_6 Circuit Breaker. The curve of dielectric strength according to the contact stroke and reference voltage was obtained. Electric field analysis, made by numerical simulation in ELCUT package, allowed us to optimize the configuration of stationary and moving contact assemblies, significantly reducing the amount of research tests. The data, obtained from this study, formed the basis, required for development of smart-designed controlled switching system and provide necessary time delays for successful circuit breaker's operation. Controlled switching system will eventually increase switching performance of the circuit breaker, degree of protection and reliability of substation equipment. With increasing of power consumption and innovative direction of the replacement and upgrading of substation's equipment such intellectual systems will find an active application in smart grids.

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