Study of the stagnation region in HV gas-blast interrupters with synchronous gas injection

N K Kurakina1,2,*, V Ya Frolov1, E N Tonkonogov1
1 Peter the Great Saint-Petersburg Polytechnic University, Polytechnicheskaya, 29, Saint-Petersburg, 195251, Russia
2 Institute for Electrophysics and Electric Power of Russian Academy of Sciences, Dvortsovaya nab, 18, St.-Petersburg, 191186, Russia

* E-mail: nkuriee@gmail.com

Abstract. According to modern trends in the development of HV gas blast circuit breakers GCB (such as increasing of rated voltage per break) a stagnation region in GCB rises and GCB interrupting ability is reduced. The zone of stagnation has the dominant influence on a thermal-dielectric recovery, since some quantity of hot gas medium remains in this region during the transient voltage recovery wave. The paper studies the stagnation region deformation in double-flow gas-blast interrupters with synchronous gas injection. The interaction between gas jet and the stagnation zone in the vicinity of current zero is discussed. Numerical analysis of basic gas flow with synchronous gas injection between arc contacts of the arc quenching chamber is presented.

1. Introduction
The subject for discussion is to improve interrupting capability of GCB. The cognizance of the dynamic characteristics of gas blown in nozzles is the important part of the progress. The thermal-dielectric recovery performance is the determining factor of voltage rated increasing per break.

The synchronous breakers has been known for a long time and widely discussed in scientific community. But by now there is not a significant progress in GCB. First of all there is a problem with drives mechanics. Many researchers pay attention in their investigation to the failure rate reducing of electrical equipment [1-3]. High proportion of circuit breaker failures (52-72% of the overall failure rates [4]) attributed to the drives. Further drives construction complication in GCB contradicts the modern requirements of resource-intensiveness and high criteria for operation according to international standards [5].

The main cause of electrical (thermal) breakdown post current zero period is a very hot remnant of the arc channel in the arc/contact gap [6]. The intensification of cold gas flow removes surplus energy of the decaying arc column. At the same time it is necessary to use the gas mass discharged effectively. The thermal-dielectric recovery starts at the zones of critical nozzles throats, but the stagnation zone of the upstream region reduces recovery processes. Directional synchronous gas injection controls the density and pressure differential of the mass discharged. The pressure differential regulates gas velocity. The maximum effect of turbulent mixing is achieved. Short-time gas impulse allows to use mass flux rate productively. In summary the thermal-dielectric recovery performance after current zero is accelerated by complexity of pressure, mass, velocity interchanges due to the impulse gas injection to the arc-quenching chamber.
The study has determined the influence of synchronous gas injection on gas-dynamics parameters in a research region (see Figure 1) of double-flow GCB. For numerical simulation free open-source package OpenFOAM was used.

2. Model description
A knowledge of the cold gas flow phenomena provides a good basis for a better understanding of the arc-gas interactions [7]. Our prime interest in this paper is restricted in a modern double-flow arc quenching chamber with air as a medium. After the Kioto protocol, agreed in 1997, SF6 using in electric power transmission and distribution systems must to be minimized despite the high efficiency [8, 9]. Search of alternative gases of natural origins and appliance of dry air, CO2, N2 have become actual.

The classical model of modern GCB with single pressure arc-device is presented in Figure 1. The relative dimensions of the system are: \( d_1/d_2=0.5, x/d_2=0.6 \) [10], where \( d_1 \) - diameter of metallic nozzle 1, \( d_2 \) - diameter of teflon nozzle 2, \( x \) - distance between critical sections of nozzles. The working gas (air) of high pressure \( p_0 \) is entered in the upstream area via inlets. Gas flow interaction forms the upstream region. The stagnation zone is developed in the research area and decelerates the process of thermal-dielectric recovery after current zero.

![Figure 1. Model description.](image)

The synchronous commutation requires a special controlled switching system for a fixed command signal to the drive before current zero [11]. However, in this task, the controller has to be updated by additional artificial intelligent technology to control/change the pulse injection time, depending on the short current (short fault \( dI/dt \)), to prevent the current chopping. The gas pulse time duration is taken as 2 ms for a first approximation.
It is suggested to deliver short-time powerful gas impulse of pressure \( p \) at the vicinity of current zero via injectors (imp) on command of the synchronous controller. The injection pressure \( p \) was chosen from a relationship \( p/p_0=3 \). With lower pressure ratio value there is a significant influence of the basic flow. Besides the reduction in the rate of rise of recovery voltage performance \( RRRV \) \( (dU/dt) \) is obtained with pressure ratio equal 3 [12]. It is resulted in more intensive plasma residual breaking and created positive environment for arc extinguish. The investigation is made for various injectors diameter \( d \), where \( k=d/d_1=0.2 \) and 0.33 accordingly.

The articles [13-15] described some details of computational models of arc quenching chamber. Calculated results closely corresponded to experimental data and dependences in [16] in the experimental stand [17, 18]. The stand is intended for investigating of arc quenching processes, erosion of electrodes [19], degradation of insulating materials in various gas environments. In the present research for numerical simulation free open-source package OpenFOAM is used. The modelling is introduced in two-dimensional problem statement and in continuous medium approximation. Conservation laws of mass, momentum and energy complemented by the state equation serve as a basis for the description of the compressed gas flow in similar systems. The fast process is considered adiabatic. The gas pulse is supplied to the computational domain when the basic flow stationary is reached.

3. Discussion of the results
Calculation results for pressure fields with Mach number distribution are given in figure 2: a) without injection, b) - c) using gas injection via injectors with \( k=0.2 \) and 0.33 accordingly. Stagnation points are appeared with increasing of pressure (dark-red region) and velocity reducing. Pressure variations marked by Mach number contours.

![Figure 2. Analysis of stagnation zone (without injection a), with injection b) \( k=0.2 \), c) \( k=0.33 \).](image)

It is demonstrated the gas impulse influence on gas-dynamics parameters (pressure ratio, velocity flow and mass discharged). The pressure fields have evidently reduced with impulse \( k=0.2 \) and Mach numbers were enhanced at the research area (Figure 2b). The stagnation zone was decreased and displaced to a section of metallic nozzle 1 with impulse \( k=0.33 \) (Figure 2c). Values of flow velocity changed their magnitude and direction at the stagnation region for both injectors. The influence of cold
injection on mass flux value is analyzed by Mach number profiles in Figure 2. The axial mass flux profile for stagnation region determines the level of the thermal-dielectric interruption ability.

The calculation results of normalized mass flux ratio \( \frac{\rho v}{\rho_0 w} \) for axial normalized distance \( X=a/d_2 \) without pulse injection in a steady state (green curve) and for various times from pulse beginning (\( t=1\text{ms} \) with maximum pulse amplitude - dashed lines, \( t=2\text{ms} \) at once after the impulse - full lines, \( k=0.2 \) – blue curves, \( k=0.33 \) – red curves) are shown in Figure 3, where \( \rho \) – calculated density of the flow, \( v \) – calculated velocity of the flow, \( \rho_0 \) – density of the air flow with initial basic pressure \( p_0 \), \( w \) – sonic speed under normal conditions, \( a \) – the distance between critical section of nozzle 1 and considered point on axis. It is graphically demonstrated mass discharged fluctuation with the injection contribution. The increasing of the mass flux determines the level of turbulent mixing in the research area.

Normalized pressure distributions \( \frac{p}{p_0} \) of calculated data along the axis for various times from pulse beginning (\( t=1\text{ms} \) with maximum pulse amplitude - dashed lines, \( t=2\text{ms} \) at once after the impulse - full lines, \( k=0.2 \) – blue curves, \( k=0.33 \) – red curves) are presented in Figure 4. The pressure ratio across the throats has a great influence on the interruption performance. The Figure 4 allows to conclude about the positive effect of injection on thermal-dielectric interruption ability in accordance with basic relationship \( \frac{dU}{dt} \approx p^n \) (\( n \approx 1 \) for air GSB, \( n>1 \) for air synchronous GCB).

4. Conclusions
The present investigation has shown that the short-time synchronous gas injection at the vicinity of current zero influences on the stagnation region strongly. It was observed the significant deformation of the stagnation region with \( \frac{p}{p_0} \approx 3 \). The stagnation zone was decreased and displaced depending on time, duration and mass of the injection.

The gas injection does not only enhance the mass discharged at the critical sectors of nozzles but increases upstream pressure in whole. The pressure dissipation at the research area was confirmed by numerical simulation. The maximum effect of turbulent mixing was demonstrated.

The fact of the pressure increasing with gas injection is a confirmation of the thermal-dielectric interruption ability level rising.

Acknowledgments
The results of the work were obtained using computational resources of Peter the Great Saint-Petersburg Polytechnic University Supercomputing Centre (www.spbstu.ru).
References

[1] Zhukovsky Y and Koteleva N 2018 J. of Phys.: Conf. Ser. 1015(4) 042068
[2] Kovalchuk M and Baburin S 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (Saint Petersburg: LETI) 1 566–9
[3] Leonidovich Z and Uriievich V 2015 Int. J. Appl. Eng. Res. 10(20) 41150–5
[4] Thomas R 2004 Controlled switching of high voltage SF6 circuit breakers for fault interruption thesis for the degree of licentiate of engineering (Göteborg: Chalmers University of Technology)
[5] International standard IEC 62271-100 2012 High-voltage switchgear and controlgear - Part 100 Alternating current circuit-breakers (Geneva: International Electrotechnical Commission)
[6] Ragaller K 1981 Current interruption in high voltage networks (Moscow: Energoizdat)
[7] Tonkonogov E and Ugriumov E 2001 Symp. Phys. Switching Arc 14 149
[8] Hama H et al 2014 Electra 299 71
[9] Seeger M et al 2017 Plasma Physics and Technology 4(1) 8–12
[10] Tonkonogov E 2015 HV AC circuit breakers (Saint Petersburg: Polytechnic University Press)
[11] ABB HV technologies Ltd 1996 Circuit breaking with artificial intelligent Technology. Controlled Switching System CAT-INFO 9601/AX-S 12
[12] Briggs A 1982 VII International Conference Gas Discharged (London) 20
[13] Kurakina N, Pinchuk M, Budin A, Smirnovsky A and Frolov V 2018 St Petersburg Polytechnic University Journal of Engineering Science and Technology 24(2) 69–81
[14] Obraztsov N, Frolov V, Popov V, Subbotin D and Surov A 2018 J. of Phys.: Conf. Ser. 1135 012101
[15] Murashov I, Frolov V, Ivanov D and Kvashnin A 2017 Symp. Phys. Switching Arc 22 161
[16] Kurakina N, Pinchuk M, Budin A and Smirnovsky A 2018 J. of Phys.: Conf. Ser. 1135 012094
[17] Budin A, Pinchuk M, Leontev V, Leks A, Kurakina N, Kiselev A, Simakova J and Frolov V 2017 Plasma Physics and Technology 4(2) 120
[18] Budin A, Pinchuk M, Kuznetsov V, Leontev V and Kurakina N 2017 Instrum. Exp. Tech. 60(6) 837
[19] Budin A, Pinchuk M and Kurakina N 2018 Tech. Phys. Lett. 44(9) 808–10