PREBREAKDOWN PHENOMENA IN 20 /80 % N_20/N_2 GAS MIXTURES FOR VFT-VOLTAGE STRESS

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ABSTRACT

Prebreakdown development of 20/80 % N_20/N_2 gas mixtures have been investigated intensively from gas pressure of $p = 0.1 – 1.0$ MPa. This paper gives a detailed overview about valid discharge mechanisms, by means of high speed electro-optical prebreakdown development analysis in 20/80 % N_20/N_2 for said pressures, referring to the individual intrinsic properties of prebreakdown patterns of N_20/N_2. Corona stabilisation processes have been detected as well as high pressure performance of the gas mixture considering dielectric strength. High dielectric strength and presented electro-optical results are in good accordance and are analysed within this paper.

INTRODUCTION

SF_6 is the standard insulation media for gas insulated switchgears (GIS) and gas insulated transmission lines (GITL) because of its excellent insulation properties such as high dielectric strength and arc quenching capabilities. However since SF_6 is a potent greenhouse gas, its use and emission must be decreased due to the large environmental impact. In order the provide a totally SF_6 free insulation gas mixture due to reasons of environmental impact and costs, various N_20/N_2 gas mixtures have been investigated in the recent years at the University of Darmstadt, with the intention to apply these new NO/N_2 gas mixtures in large scale gas insulated lines (GITL). The only but very important specification limitation for these gaseous dielectrics is that such N_20/N_2 gas mixtures don't need to meet enhanced recommendations for arc quenching capabilities.
It was found, that the dielectric strength of these gas mixtures is rather high, even if only small amounts of N_2O are admixed to N_2 [1]. Especially low content gas mixtures seem to be an interesting alternative to replace low content SF_6/N_2 gas mixtures totally.

ELECTRO OPTICAL SETUP

High precision electro-optical analysis of prebreakdown phenomena in insulation gases requires high sophisticated experimental equipment. For this purpose the radiation of the prebreakdown phenomena was sensed by three photomultiplier (**Fig. 1,** (1) PMT) with the according luminous sensitivies for infrared (leader detection, S_{IR}), for ultraviolet (detection of first excitation processes, i.e. corona detection, S_{UV}) and for detection of atomic Oxygen S_O in order to additionally detect total dissociation (leader detection) for the prebreakdown development. Additionally the luminous prebreakdown image was decoupled from the test gap (1) though a ultraviolet transparent glass windows towards a parabolic mirror (2) which was installed at about twice of its focal distance from the test vessel, according to **Fig. 1** From there the image was projected onto a smaller diameter focusing lens (3) of the ultra high speed camera system, which was installed in the inner of a screened chamber (4),(5). A total optical delay for the camera system of t_d =-31 ns was achieved. After passing a ray collecting lens and the beam splitter (6), the luminous radiation is

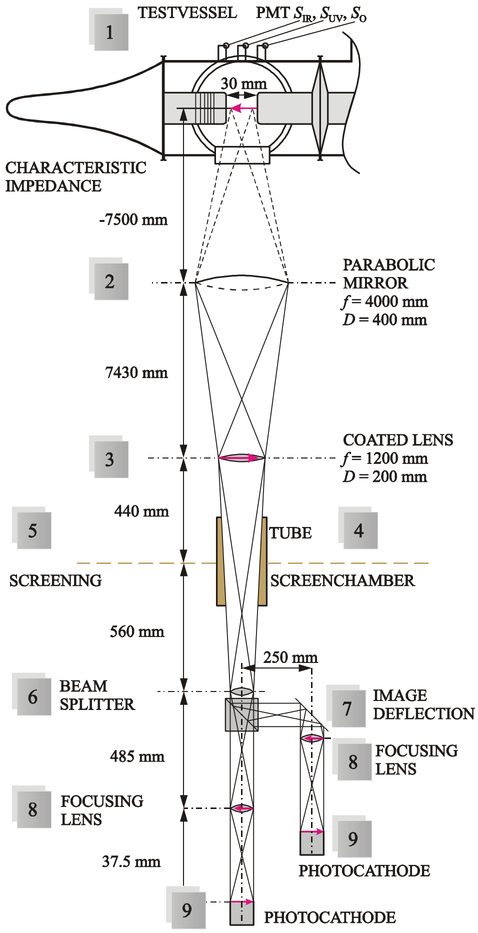
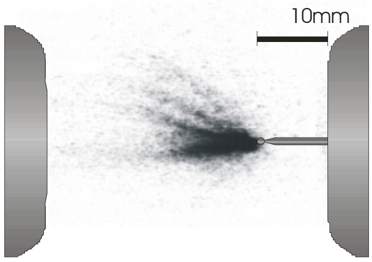
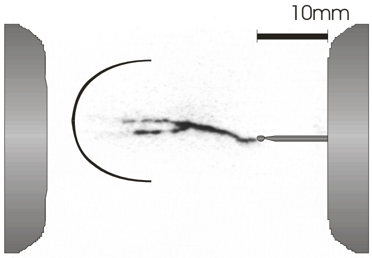


Figure 1: Electro-optical test set up and test vessel.

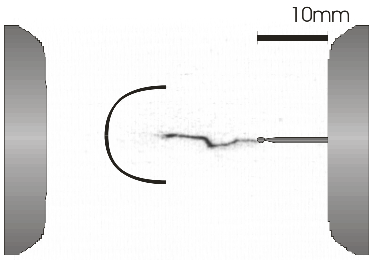
projected (7), (8) onto two separate image intensifier camera systems (9). All lenses and mirrors of the camera system are optically corrected and made of UV transparent and coated glass. Both intensified camera systems are double electronically gated multi micro channel plate intensifier tubes with CCD-Video-Adapter [2]. A detailed description of test voltage generation and the test gap is given in [1]. The applied test gap was homogeneous field configuration with field distortion by a protrusion with a free test gap with of d = 30 mm, see **Fig. 2**.



a) p = 0.1 MPa, t_d=-16 ns t_{ex} = 2.2 ns

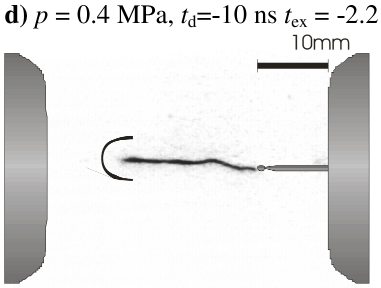


b) p = 0.2 MPa, t_d=-10 ns t_{ex} = 2.2 ns



c) p = 0.3 MPa, t_d=-12 ns t_{ex} = 2.2 ns

d) p = 0.4 MPa, t_d=-10 ns t_{ex} = -2.2 ns



e) p = 0.5 MPa, t_d=-9 ns t_{ex} = -2.2 ns

Figure 2: Pressure dependent prebreakdown development for 20/80 %N_2O/N_2 gas mixtures f_{VFTO} = 1 MHz, gap width d = 30 mm

PREBREAKDOWN PROCESS FOR LOW GAS PRESSURES – CORONA STABILISATION EFFECTS

Fig. 2 shows several very typical prebreakdown phenomena in 20/80 % N_2O/N_2, which have been selected upon a certain amount of pictures at a given gas pressures p. For rather low gas pressure of p = 0.1 – 0.2 MPa the prebreakdown development shows a very significant development of a streamer corona, with up to seven finger like single streamers at p = 0.1 MPa, and still a rather large corona radius (see drawn half-circle) for p = 0.2 MPa, according to **Fig. 2a), 2b)**. For this pressure range the breakdown is mostly induced by only a single streamer, which can be clearly seen by additional means of electro-optical investigational result of the photomultiplier, **Fig. 3**. All photomultiplier indicate no previous discharge activity and show a sudden peak, which clearly indicates a pure streamer discharge, if the test voltage is raised sufficiently. Until p = 0.3 MPa the streamer corona is large, resulting in an increase of the dielectric strength which is a accordance with measurements performed by [1]. At a pressure of p = 0.4 MPa the discharge mechanism obviously changes. **Fig. 2 c)** and **d)** show, that a single streamer step is nearly impossible and for p = 0.4 MPa very often a bright luminous area ahead of a streamer-leader branch was optically detected. These luminous areas, which are typical for pressures from p = 0.3 – 0.6 MPa have been identified as a precursor discharge mechanism. The precursor is a space charge area with space charges of both polarities, whereas the space charges are separated by the applied electrical voltage, respectively the electrical field, and in turn a field enhancement is induced at both space charge bundles, which can be seen as a dissociated gaseous area, e.g. in **Fig. 2d)** [3]. Moreover the electro-optical analysis of the PMT signals from the graph in **Fig. 4** indicates that the UV-PMT S_{UV} is modulated with twice of the frequency of the oscillation frequency f_{VFTO} of the applied test voltage. The free space charges and the application of the very fast transient sinusoidal test voltage shape to the latter, induce a capacitive displacement current, which in turn is able to heat the gaseous volume in the area of the space charge cluster (precursor), which is described as high frequency discharge mechanism in literature [4]. The weak and for the ultra high speed camera system not visible corona discharge, respectively gas discharge activities (starting excitation processes, non dissociated gas corona) near both precursor space charge bundles are fed by the capacitive displacement current and is clearly detected by the UV-PMT,

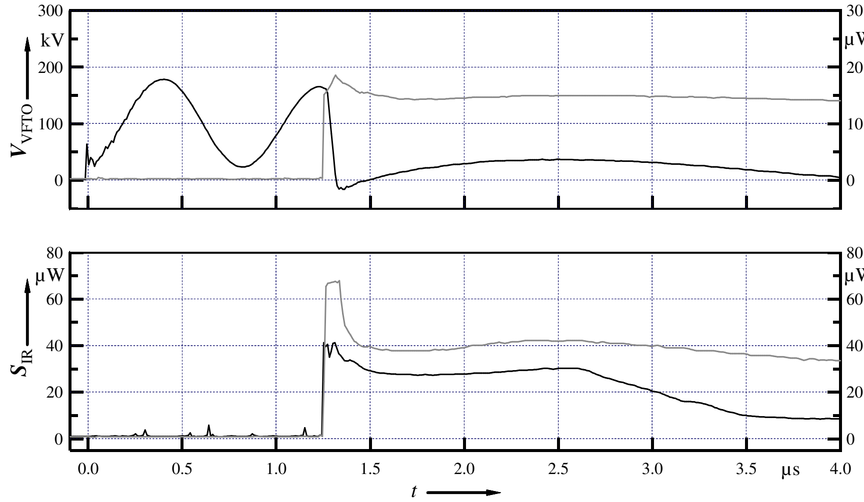


Figure 3: Typical electro-optical prebreakdown development signals (S_{UV}, S_{IR} and S_O) for $p = 0.1 – 0.2$ MPa, 20/80 %N_2O/N_2 gas mixtures, $f_{VFTO} = 1$ MHz.

respectively S_{UV} **Fig. 4**. The IR-sensitive IR-PMT S_{IR} indicates dissociation of the gaseous volume, in particular when reaching a test voltage peak. After producing seed precursor charges S_{IR} **Fig. 4** for pressures of $p = 0.5$ MPa, a multiple streamer-leader step is often detected, growing with enduring application of the low damped oscillatory test voltage. The discharge mechanism for the pressure range from $p = 0.3 – 0.6$ MPa is considered to be a combination of the precursor and the high frequency discharge mechanism. Additionally the presence of a precursor indicates that the a N_2O/N_2 gas mixture is able to produce stable negative NO^- ions as well as (very mobile) positive N^+ ions.

PREBREAKDOWN PROCESS FOR HIGH GAS PRESSURES

For high pressures the discharge mechanism changes significantly while changing the gas pressure from $p = 0.6$ MPa to $p = 0.7$ MPa. For pressures from $p = 0.6 –$ 1.0 MPa all PMT signals are rather silent, indicating neglectable low ultraviolet, infrared and atomic O signals, S_{UV}, S_{IR} and S_O before breakdown of the gas insulated test configuration occurs. Thus obviously no corona stabilisation occurs, the dielectric strength of the 20/80 % N_2O/N_2 gas mixtures considerably rises significantly in between pressures of $p = 0.6$ MPa and $p = 0.8$ MPa [1]. Comparing high pressure discharges for 20/80 % N_2O/N_2 and i.e. for 100 % SF_6, i.e. at $p = 0.8$ MPa (**Fig. 5**) a rather strong branching for 20/80 % N_2O/N_2 has been recognized for the prebreakdown phenomena, which is typically observed in strongly electronegative gases, such as SF_6 and it's mixtures. The discharge mechanism changes from a streamer-leader discharge mechanism at $p = 0.6$ MPa to a pure leader discharge mechanism with strong branching. Transition time from the first detectable prebreakdown phenomena to bridging of the gap, respectively initiation of breakdown is in the range in between $t_d = 16$ ns for $p = 0.6$ MPa and $t_d = 19$ ns for $p = 1.0$ MPa.

HIGH DIELECTRIC PERFORMANCE BASED ON SYNERGETIC EFFECTS FOR HIGH GAS PRESSURES

The prebreakdown development of 20/80 % N_2O/N_2 shows obviously stronger branching, especially above pressures of $p = 0.6$ MPa. Stronger branching and no corona in turn indicate, that electron attachment processes increase significantly above these pressures. This behaviour may only be explained by the special

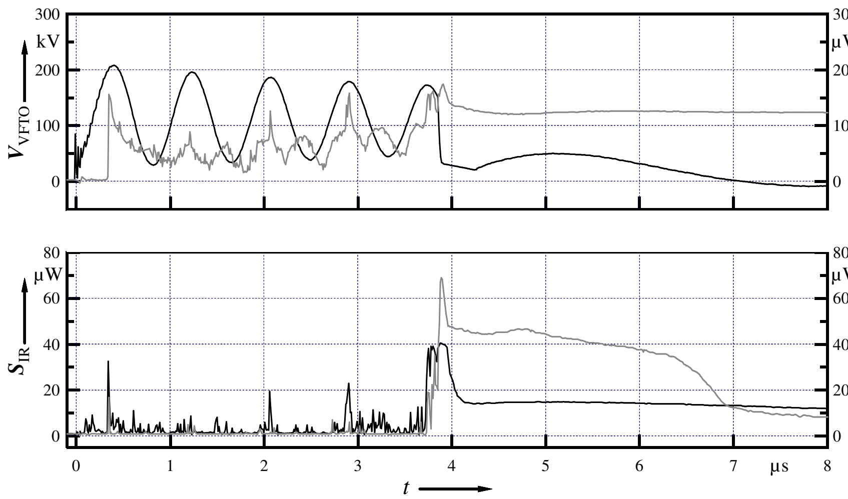


Figure 4: Typical electro-optical prebreakdown development signals (S_{UV}, S_{IR} and S_O) for 20/80 %N_2O/N_2 gas mixtures, $p = 0.3 – 0.5$ MPa, $f_{VFTO} = 1$ MHz. A combined precursor and high frequency mechanism was often observed, as shown in this figure at a pressure of $p = 0.5$ MPa.

properties of N_2O/N_2, whereas both gases are well known as buffer gas, besides the slight electronegative properties of N_2O. Additional the critical pressure reduced field strength E/p_{crit} of N2O is known to rise with pressure [5, 11]. More recently it has become clear, that electron-molecule interactions can strongly influence the collisional behaviour of electrons at energies below $E_{el} < 1$ eV, by so called vibrational feshbach resonances (VFRs) [6], which is only possible for strongly moderated electrons, respectively high gas pressures. Very surprisingly very sharp VFRs have been observed for both, N_2O and CO_2 respectively, in the energy range below $E_{el} < 0.2$ eV [7, 8]. Stable negative ion formation in N_2O (i.e.$(N2O)_2$ or $(N_2O)_9O^-$) due to VFR over a rather large lifetime ($\tau > 100$ µs), compared with the total prebreakdown development (smaller 50 ns) seems to play a decisive role for electron attachment for high pressure gaseous dielectrics. Furthermore it must be considered, that in particular the attachment cross section for vibrational exitation (VE) of N_2 down to electron energies of $E_{el} = 1$ eV [9] is continued by VE of N_2O below $E_{el} = 1$ eV down to $E_{el} = 0.1$ eV [10]. Both properties, electron buffering (VE) and negative ion production due to VFR of low energy electrons, lead to a special high pressure synergetic effect of both gas composites in these N_2O/N_2 gas mixtures. A high pressure synergetic effect which was supposed by [11, 12], was found by means of experimental dielectric [1] and electro-optical tests, the latter showing a strong branching of 20/80 % N_2O/N_2 similar to strongly electronegative gases.

CONCLUSIONS

• Prebreakdown phenomena of 20/80 % N_2O/N_2 gas mixture at pressures between $p = 0.1 - 1.0$ MPa have been investigated and the valid discharge mechanisms have been described.

• Dominating discharge mechanisms in 20/80 % N_2O/N_2 for gas pressures from $p = 0.3 - 0.6$ MPa is a streamer-leader transition incorporating the precursor and the high frequency mechanism. For said pressures strong corona stabilisation can be observed. Above gas pressure of $p = 0.6$ MPa the discharge process changes significantly to a purely leader based discharge mechanism, whereas strong branching of the leader was observed. Additional a strong rise of the dielectric strength occurs [1]. This is characterized as a high pressure dielectric performance of 20/80 % N_2O/N_2 being optimum for gas pressures of $p = 0.8$ MPa and above.

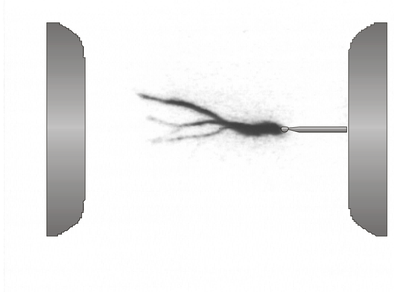
• Increase of the dielectric strength for 20/80 % N_2O/N_2 gas pressures over $p = 0.6$ MPa is characterized by following effects, resulting in a synergy effect:

a) Significant electron moderation effects of both buffer gases N_20 and N_2 respectively.

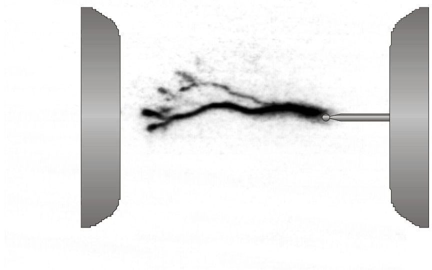
b) Formation of stable negative N_2O ion states induced by very low electron energy attachment processes due to vibrational feshbach resonances (VFR).

c) Effective electron attachment cross sections of N_20 and N_2 supply each other.

Experimental results have shown, that a 20/80 % (to 40/60 % [1]) N_2O/N_2 gas mixture is very advantageous for high pressure large scale applications, especially for GITL.



a) 20/80 % N_2O/N_2 at $p = 0.8$ MPa, t_d=-5 ns $t_{ex} = 2.2$ ns



b) 100 % SF_6 at $p = 0.8$ MPa, t_d=-1.5 ns $t_{ex} = 2.2$ ns

Figure 5: Prebreakdown development for a 20/80 % N_2O/N_2 gas mixture **a)** and for SF_6 **b)** at $p = 0.8$ MPa, $f_{VFTO} = 1$ MHz, gap width $d = 30$ mm

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