ANALYSIS OF CRYOGENICS CABLES ELECTRIC ISOLATION WORKING CONDITIONS

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ABSTRACT

Layer tape paper insulation cables impregnated with liquid nitrogen working condition and as well as theoretical possibility of energy escape at partial discharge in single gas engagement of liquid-nitrogen cable isolation have been studied. The calculations showed that partial discharges existence in single engagement couldn4t lead to avalanche for; boiling of liquid nitrogen in liquid-nitrogen cable isolation and it is not dangerous for these cables.

Keywords: electric isolation, cryogenics cables, partial discharges

I. INTRODUCTION

While transmitting electroenergy along modern high-voltage cables 10 % of the transmitted capacity is spent to the thermal losses in current-carrying veins. Cryogenic cables can serve as perspective efficiency increase of electrotransmission superconducting using phenomena of superconductivity and cryoconducting based on considerable decrease of conductivity materials electro-resistance at temperatures up to *20 K* are related to cryogenic cables. Creation of superconducting cables are connected with great technical difficulties. That's why cryogenic cables can be consider as the stage from usual power to superconducting cables. Losses decrease in veins permits to increase current working density in these cables.

It is known, that the air-lines of electrotransmission demand estrangement of considerable areas in the suburbs of large cities the cost of which continuously grows. Powerful electro inputs application in the cities using cryogenic cables at such conditions can economically be profitable. Cryogenic cables can be also used for currents transmission at considerably not high voltage which is necessary for a member of productions.

One of the important elements of construction is its isolation, the role of which could be carried out by vacuum, cryogenic liquid on impregnated with cryoagent layer isolation.

With temperature decrease dielectrical losses in hard electroisolated materials reduce but electrical strength increases. Together with dielectrical losses reduce at low temperatures dielectric heat conductivity reduces as well which makes heat output conditions worse.

II. MAIN PART

Perspective cryoagent for cryogenductive cables is liquid nitrogen. It should be mentioned that electrical strength of some dielectrics in liquid nitrogen at alternating voltage is considerably more than in liquid helium (table 1) [1].

Table 1

Comparative changes of different dielectrics electrical strength in liquids and gaseous cryoagents

Material	Electro strength change in %					
	Air 293 K	Liquid nitrogen 77 K	Gaseous nitrogen 77 K	Liquid helium 4,2 K	Gaseous helium 4,2 K	Vacuum 10 K
Polyethilenterefto lat	100	144	83	101	71	178
Polyetraftorethilen	″	101	86	118	88	269
Polythilen	″	152	104	90	69	142
Polyamide	″	115	90	101	66	196
Polyvinnichloride	″	97	87	98	67	163
Polimid	″	141	91	116	91	226
Graft paper	″	215	138	292	162	-
Micaceous paper	″	119	97	86	47	

In contradiction to layer isolation impregnated with normal electroisolated liquid, for instance, cable fuel at normal temperature, isolation impregnated with cryogenic liquid will work at temperatures close to liquid boiling temperature. At such situations inconsiderable temperature increase can lead to liquid boiling and intensive ionization occurrence and to breakdown.

Let's consider temperature increase owing to energy escape at partial discharges (pd) in single gas input in layer isolation of liquid-nitrogen cable. The suggested pressure at the further end of liquid- nitrogen cable line will make ap about*1,0 MPa*, at liquid nitrogen temperature of about *90 K*. Saturated steam pressure *0,36 MPa* (table 2) corresponds to this temperature.

Table 2
Nitrogen saturated steam pressure

Pressure P, MPa	0,075	0,101	0,125	0,154	0,246	0,365	0,722	1,105
Temperature T, K	74,83	77,35	79,18	84,21	86,21	90,67	95,56	105,85

Temperature *105 K* corresponds to nitrogen saturated steam pressure*1 MPa*. This suggested nitrogen boiling temperature over its working temperature will make ap approximately *15 K.* At possible temperature and pressure oscillations depending on cable line working regime this excess may be less.

At such situations energy escape in nitrogen layers owing to pd appearing at high voltage tests can lead to local heat which in its turn will lead to nitrogen boiling and the following pd intensification.

Let's consider temperature increase possibility in isolation owing to energy escape at partial discharges in single gas inclusion.

Let's suggest, that gas bubble in the ball form with radius r_0 was formed in the clearances between paper tapes. In this gas inclusion pd occurs which may cause local beat in gas inclusion. If saturated steam pressure in this temperature increase exceeds external pressure over the isolation then gas inclusion will grow. It will cause new escaped energy increase with the following general nitrogen boiling in isolation.

If there is no excess pressure out of example then additional pressure is also created owing to surface tension power stimulation. In this case we'll consider the problem when main mass temperature around the tested sample exactly corresponds to grandeur at which the pressure in the system equals to saturated steam pressure in accordance to table 1. This in the inclusion with radius r_0 additional pressure occurs:

$$\Delta P_H = \frac{2\sigma_a}{r_0} \qquad (1)$$

where $\sigma_a = 9{,}8 \cdot 10^{-3}$ *H/m* - is nitrogen surface tension.

For this additional pressure occurrence the temperature in the gas inclusion area must be so higher than surrounding liquid at which additional steam pressure will be more than determined according to formula (1). In accordance with the table 1 at temperature *77,35K* in not large temperature interval pressure increase owing to additional heat at pd existence equals to:

$$\Delta_{PD} \approx 2{,}5 \cdot 10^4\ \Delta T,\ Pa \qquad (2)$$

where ΔT is temperature increase.

Thus gas bubble growth requirement will be

$$\Delta P_{PD} > \Delta P_н \text{ or } 2{,}5 \cdot 10 \Delta T > \frac{2\sigma_a}{r_0}$$

Otherwise gas bubble sizes will decrease.

Let's calculate temperature increase in inclusion with radius r_0 with pd existence in it. We'll denote $U_{BD} = f(P \cdot \Delta_a)$ Pashen's law for nitrogen in the form of approximated formula (fig. 1)

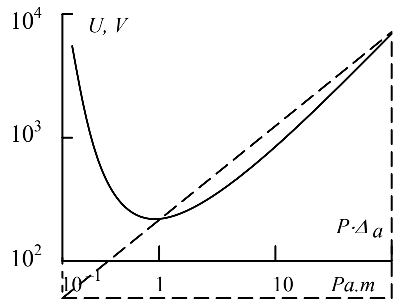

Fig. 1 Pashen's curve for nitrogen

$$lg\ U_{bd} = lgU_0 + blg(P \cdot \Delta_a) \qquad (3)$$

where *P* - pressure, *Pa*; Δ_a - gas layer thickness, *m*;

$$U_0 = 70V,\ b = \frac{2}{3}$$

At pd impulse occurrence field strength in spherical inclusion decreases from field strength pd occurrence (E_H) up to pd damping strength (E_H). Electrical field energy decrease in inclusion will make up:

$$A = \frac{\varepsilon\varepsilon_0}{2}\left(E_H^2 - E_П^2\right)V = \frac{2}{3}\pi\varepsilon\varepsilon_0 r_0^3\left(E_H^2 - E_П^2\right) (4)$$

where ε - dielectrical gas permeability, $\varepsilon_0 = 8{,}85 \cdot 10^{-12}$ *F/m*, *V* - inclusion volume.

This energy is escaped in the gas form. If to take $E_H \approx 0$ in this case we'll gain energy escape wittingly more than real value which will lead to calculated temperature volume increase in comparison with its real value.

As gas inclusion thickness let's take maximum distance on gas cap along electro field vector direction, i.e. $2r_0=\Delta_a$

Energy escaped in time unit will be:

$$W = n A \qquad (5)$$

where n -is the impulse following frequency in time unit.

The number of pd for half period can make up 2 and more. For samples test our dimension was so that the quantity of pd for one half period could not exceed 4 [2]. That's why it is possible to take $n=8f=400$. Consequently taking into account formulas (3) and (4) we'll get for losses capacity in single inclusion with radius the following:

$$lg W = lg\left(\frac{n}{6}\pi\varepsilon\varepsilon_0 r_0\right) + 2 lg U_0 + 2b lg(2r_0 P) \qquad (6)$$

Losses capacity W is taken away through isolation into the environment. Let's consider the sum for set up heat regime. For beat resistance S_{BK} between two concentric spheres with radius r_0 and R we'll get:

$$S_{BK} = \frac{1}{4\pi\lambda}\left(\frac{1}{r_0} - \frac{1}{R}\right) \qquad (7)$$

where λ-is electric isolation heat conductivity impregnated with liquid nitrogen $\lambda = 0,15\ W/mK$.

We'll get more beat resistance at rather large external radius ($R>>r_0$):

$$S_{BK} = \frac{1}{4\pi\lambda r_0} \qquad (8)$$

Thus we'll get more temperature increase. Temperature increase owing to pd will make up:

$$\Delta T = W \cdot S_{BK} \qquad (9)$$

Having substituted S_{BK} from equation (8), W from equation (6) in equations (9) and (2) we'll get saturated steams temperatures and pressure increase owing to pd energy escape:

$$lg\,\Delta T = lg\left(\frac{\varepsilon\varepsilon_0 n U_0^2}{24\lambda}\right) + 2b lg(2r_0 P) \qquad (10)$$

$$lg\,\Delta P_{PD} = lg\left(\frac{2,5\cdot 10^4 \cdot \varepsilon\varepsilon_0 n U_0^2}{24\lambda}\right) + 2b lg(2r_0 P) \qquad (11)$$

Relationships $\Delta P_н$, $\Delta P_{PD} = f(rr_0)$ obtained according to formulas (1) and (11) are expressed in fig. 2.

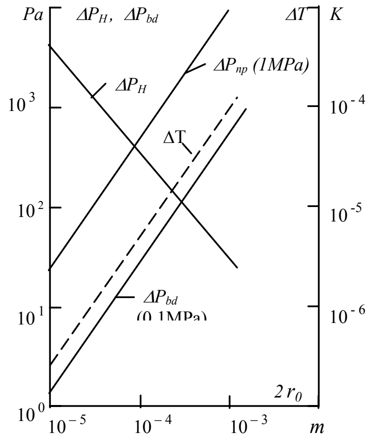

Fig. 2 Pressure and temperature increase relationship in inclusions at partial discharges

From comparison of these relationships it is seen that gas inclusion growth at temperature *0,1 MPa* is possible only in the case if its value ($2r_0$) will exceed $0,5\cdot 10^{-3}m$. If to put the sample into the boiling nitrogen at temperature 1MPa then in this case critical inclusion dimention ($2r_0$) will be less $0,1\cdot 10^{-3}m$. In the paper isolation wrapped with gaps between tapes, the gaps thickness doesn't exceed paper tapes thickness, i.e. $2r_0 \leq 0,1\cdot 10^{-3}m$.

Relationship $\Delta T = (2r_0)$ calculated according to (10) is also expressed in fig. 2. The temperature increase makes up $10^{-3}K$. At excess pressure existence cooling will reach some degrees on Kelvin.

III. CONCLUSION

Thus pd presence in single isolation can't lead to avalanche form growth of nitrogen boiling in isolation and corresponding pd growth and the considered specific requirements of isolation work don't represent serious danger for cryogenic cables.

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