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# ELECTRODYNAMIC STABILITY OF ISOLATORSAND BUS BARS IN A SHORT CIRCUIT

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*The results of research of the electrodynamic stability in a short circuit for isolators and bus bars are considered. The tensions in the material of buses with a rectangular cross-section and isolators loads are calculated.*

***Key words:*** *electrodynamic stability, isolator, bus bar, short circuit, tension, isolator load.*

**Statement of the problem.** At present, the problem of testing the stability of high-voltage switchgear equipment, especially isolators and bus bars, becomes critical due to a lack of testing facilities.

The calculation of bus bars structures on rigid supports is sufficiently consuming process. Therefore, for simplifying we will investigate only the middle spans of a long straight section of the bus line without a line tap with equal distances between the isolators. The bus bar's spans examined are in the same conditions, so it is sufficient to consider only one span.

**Analysis of last researches and publications.** Some of the most interesting researches of electrodynamic stability are in the following published works [1-9] and etc.

The aim of the article is to publish the results of the research of electrodynamic stability of isolators and bus bars in a short circuit for switchgear equipment with voltage up to 35 kV.

Statement of the main material.

Isolators (pillars) of the switchgear equipment up to 35 kV can be considered as absolutely rigid. In this case, the bus in the span between isolators can be considered as a rod (beam) with a uniformly distributed mass along the length and substituted ends (Fig. 1, a).

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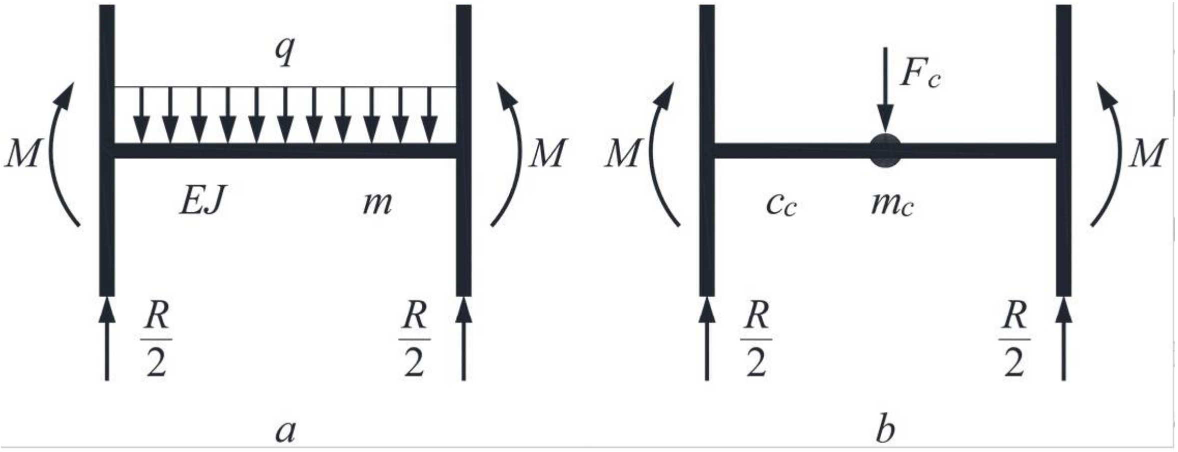

Fig. 1. The shame of bus bars in the span between isolators (beam with supports): a – mass is evenly distributed along the length; b – mass is concentrated in the middle of the span

It is known that the beam is a system with an infinite number of degrees of freedom, and that is has an infinite number of own vibration frequencies. However, fluctuations in the rods are mainly determined by the first form of own vibrations. Therefore, for simplify we replace the rod with a distributed mass by the rod with the concentrated mass in the middle of the span (Fig. 1, b). This rod has one degree of freedom and only one own frequency. If to ignore the scattering of energy from bus oscillation the motion of the system with one degree of freedom will be described by the following differential equation:

$$m_c \frac{d^2 y_c}{dt^2} + c_c y_c = F_c, \qquad (1)$$

$m_c$ – mass of system with one degree of freedom, kg;
$y_c$ – deflection of system (beam deflection), m;
$c_c$ – rigidity of system (beam rigidity), N/m,
$t$ – time, s;
$F_c$ – concentrated force, N.

The solution of this differential equation (1) is the following:

$$f_c = f_1 = \frac{r_1^2}{2\pi l^2}\sqrt{\frac{EJ}{m}}; \qquad (2)$$

$$F_c = ql = \frac{\alpha l}{a} I_{m1}^2 \sum_{n=1}^{6} D_n T_n; \qquad (3)$$

$$c_c = c_b\ , \qquad (4)$$

$q$ – electrodynamic load, *N/m*;

$E$ – elastic modulus of bus bar, *Pa*;

$J$ – moment of inertia of the bus bar relative to the axis that is perpendicular to the plane of bending, $m^4$;

$f_c$ – natural frequency of the system with one degree of freedom, *Hz*;

$f_1$ – first (primary) frequency of bus bar oscillation, *Hz*;

$r_1$ – frequency parameter (with absolutely rigid isolators equal 4,73);

$c_b = \frac{EJ}{l^3}$ – rigidity of the bus bar, *N/m*.

The frequency, rigidity and mass are associated by dependency:

$$\Omega^2 = (2\pi f)^2 = c/m, \qquad (5)$$

$\Omega$ – the angular frequency of the system oscillation, *rad/s*.

If bus bars were at rest before a short circuit than the solutions of the differential equation (1) has the form:

$$y = \frac{1}{m\Omega}\int_0^t F(\theta)\sin\Omega(t-\theta)d\theta, \qquad (6)$$

$\theta$ – variable that characterizes the time varying in process from $0$ to $t$ .

Substitute the expression (6) the value of force (2) and multiply the numerator and denominator at Ω. Taking into account relation (5), we obtain:

$$y = \frac{\alpha l}{ac} I_m^2 \Omega \sum_{n=1}^{6} D_n \int_0^t T_n(\theta)\sin\Omega(t-\theta)d\theta. \qquad (7)$$

Introduce the notation:

$$y(t) = \sum_{n=1}^{6} D_n y_n(t) = \sum_{n=q}^{6} D_n \Omega \int_0^t T_n(\theta)\sin\Omega(t-\theta)d\theta, \qquad (8)$$

$y_n$ – relative deflection *(n=1,2...6)*, caused by the action of the individual components Tn of electrodynamic load;

$y$ – full relative deflection of system.

In this way:

$$y(t) = \frac{\alpha l}{ac} I_m^2 \sum_{n=1}^{6} D_n y_n(t) = \frac{\alpha l}{ac} y(t). \qquad (9)$$

The principal types of cross-sections for bus bars are shown in Fig. 2.

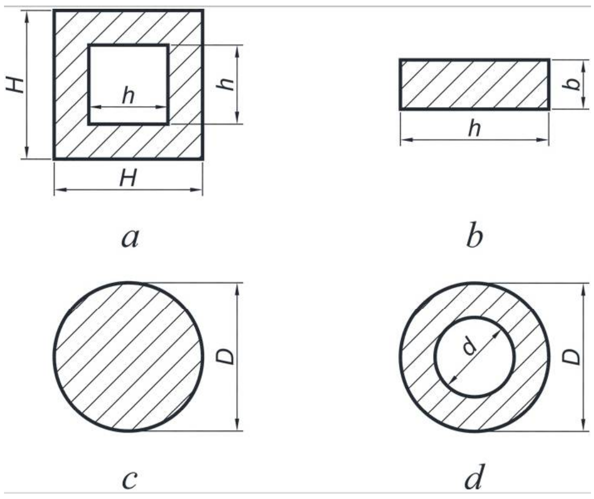

Fig. 2. The principal types of cross-section for bus bars: *a* – square with a square hole; *b* – rectangular; *c* – circular; *d* – circular with a circular hole

The forces acting on the same isolators structures with the same span are equal:

$$R(t) = cy(t) = \frac{\alpha l}{a} I_{m1}^2 \sum_{n=1}^{6} D_n y_n(t) = \frac{\alpha l}{a} I_{me}^2 y(t) \qquad (10)$$

The maximal tension in the material of the bus bar occurs at the point of the bus bar section most remote from its axis:

$$\sigma(t) = M(t)\,/\,W\,,$$

$M$ – bending moment, N·m;

$W$ – resistance moment of the cross-section of the bus bar, m$^4$ (shown in Table 1).

The bending moment is defined by the formula:

$$M = \frac{cl}{12} y \; .$$

Therefore,

$$\sigma(t) = \frac{cl}{12W} y(t) = \frac{\alpha l^2}{12aW} I_{m1}^2 \sum_{n=1}^{6} D_n y_n = \frac{\alpha l^2}{12aW} I_{me}^2 y. \qquad (11)$$

Moments of inertia and resistance of bus bars with a different type of cross-sections are shown in Table 1.

*Table 1*

**Moments of inertia and resistance of bus bars with a different type of cross-section**

| Type of cross-section | Moment of inertia $J$ | Resisting moment $W$ |
|---|---|---|
| Square with a square hole | $\frac{H^4 - h^4}{12}$ | $\frac{H^4 - h^4}{6H}$ |
| Rectangular | $\frac{bh^3}{12}$ | $\frac{bh^2}{6}$ |
| Circular | $\frac{\pi D^4}{64}$ | $\frac{\pi D^3}{32}$ |
| Circular with a circular hole | $\frac{\pi\left(D^4 - d^4\right)}{64}$ | $\frac{\pi\left(D^4 - d^4\right)}{32D}$ |

As an example, it was calculated maximum tension in the material of rectangular bus bars $10\times0,6$ cm (aluminum alloy with elasticity modulus $E = 7\cdot10^{10}$ Pa) and isolators loads. Metal bus bars were placed next to each other by narrow sides, the span's length is $l = 1,6$ m, the distance between bus bars is $a = 0,7$ m. The three-phase short-circuit current is $i_{yn} = 87$ kA, time constant is $T_a = 0,05$ s. The value of a switchgears voltage examined does not exceed $35$ kV.

As a result, the following parameters were calculated: moment of inertia is $J = 18\cdot10^{-8}$ m$^4$, moment of bus bars resistance is $W = 6\cdot10^{-6}$ m$^3$, own bus frequency $f = 119$ Hz. Maximal tension in bus bar is $\sigma_{max} = 86,6$ MPa and isolator load is $R_{max} = 4500\ N$.

Maximal tension in bus bar and isolator load are less of permissible one: $\sigma_{critical} = 89,2$ MPa, $R_{critical} = 4500\ N$. Therefore, selected bus bars satisfy the conditions of electrodynamic stability

Resume

1. The peculiarities of calculating of maximal tension in bus bars and of isolator load for switchgears equipment with voltages up to $35$ kV are considered.

2. Maximal tension in bus bar is $\sigma_{max} = 86,6$ MPa and isolator load is $R_{max} = 3896$ N.

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*О. С. Кіріченко.* ***Електродинамічна стійкість ізоляторів і струмопровідних шин при короткому замиканні***

*У роботі розглянуто результати дослідження ізоляторів і струмопровідних шин на електродинамічну стійкість при короткому замиканні. Розраховано максимальне напруження в матеріалі шин з прямокутним поперечним перерізом і навантаження на ізолятори.*

***Ключові слова:*** *електродинамічна стійкість, ізолятор, струмопровідна шина, коротке замикання, максимальне напруження, навантаження.*

*А. С. Кириченко.* ***Электродинамическая устойчивость изоляторов и токопроводящих шин при коротком замыкании***

*В работе рассмотрены результаты исследования изоляторов и токопроводящих шин на электродинамическую устойчивость при коротком замыкании. Рассчитано максимальное напряжение в материале шин с прямоугольным поперечным сечением и нагрузка на изоляторы.*

***Ключевые слова:*** *электродинамическая устойчивость, изолятор, токопроводящая шина, короткое замыкание, максимальное напряжение, нагрузка*