IEEE Standards Interpretations for IEEE Std 605™-1998

IEEE Guide for Design of Substation Rigid-Bus Structures

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Interpretation Number: 1
Topic: Conductor Vibration
Clause: 7

Interpretation Request #1

1) Please clarify whether this calculation is also applicable for 765kV ac system? Our live rigid conductor of 765kV is supported at 15M from ground level.

2) For the given current rating, the following are the typical values of rigid bus selected for 765kV ac system:

Conductor	= 4.5” IPS Al. tube (Sch 80)
Conductor diamanter (d)	= 120mm
Wall thickness	= 12mm
Cross sectional area (A)	= 4072 sq.mm
Mass per unit length (m)	= 11kg/m
Moment of inertia (J)	= 59998842 mm4
Modulus of elasticity (E)	= 6700 kg/sq.mm
Maximum span length (L)	= 10m

With the above values, considering 15mi/hr, Aeolian frequency (Fa) calculated using eqn. (6) is around 10Hz; Natural frequency (Fc) calculated using eqn. (5) is around 22Hz. Hence, the natural frequency of oscillations Fc is found to be 2 times higher than the Aeolian frequency calculated even under normal condition. As per 7.2.2, "If twice the natural frequency is greater than Aeolian frequency, then bus span should be changed."

In this connection (referring to the example mentioned above), we interpret in the following manner:

Aeolian frequency calculated is less than (half the) natural frequency of the bus span selected. Hence, the system designed will not resonate with respect to Aeolian frequency as there is significant frequency difference between the Fa and Fc.

Kindly confirm whether our interpretation is correct.

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Interpretation Response #1

1.1 Induced vibrations

For a laminar air flow around a conductor with wind speed less than 72 km/h (45 mph), eddies are shed from the boundaries of the conductor, alternating from edge to edge. The frequency of eddy shedding f_a is given by

(1)

$$f_a = \frac{C \times V}{D_o}$$

where

C is the Strouhal number (a dimensionless number) and is approximately equal to 0.19 for a cylinder shape. It accounts for the oscillatory flow mechanism due to wind.
V is the wind velocity (m/sec) [in/sec]
D_o is the conductor outside diameter (m) [in].

When frequency of eddy shedding f_a
coincides with the natural frequency of the conductor, wind induced vibration of the conductor may occur. It is recommended that an allowance for variations be allowed. This is accomplished by ensuring the ratio of the inducing frequency to the natural frequency is **outside** the range from 0.5 to 2.0 :

(2)

$$\frac{1}{2} \le \frac{f_a}{f_b} \le 2$$

where

f_a is the frequency of eddy shedding, Hz
f_b is the natural frequency of the conductor, Hz (section 12.6)

For wind speeds in excess of 72 km/h (45 mph), the wind tends to be turbulent and steady exciting impulses are less probable. If the natural frequency of the conductor is such that it falls within the range described by Equation (iii), then attenuation measures should be taken as described below.

Another source of vibration for buses is related to alternating current. Current flowing through parallel conductors creates magnetic fields that interact and exert forces on the parallel conductors. This driving force oscillates at twice the power frequency (*2f*). If the calculated frequency of a bus span is found to be greater than half the current-force frequency, that is, greater than the power frequency:

(3)

$$f_b > f$$

then measures should be taken as described below or a dynamic analysis should be made to determine the stresses involved.

1.2 Natural frequency of rigid conductors

A span of rigid conductor has its own natural frequency of vibration. If the conductor is displaced from its equilibrium position and released, it will begin to vibrate at this natural frequency. The magnitude of the oscillations will decay due to damping. If, however, the conductor is subjected to a periodic force whose frequency is near the natural frequency of the span, the bus may continue to vibrate and the amplitude will increase. Such vibration may cause damage to the bus conductor by fatigue or by excessive fiber stress.The natural frequency of a conductor span is dependent upon the manner in which the ends are supported and upon the conductor's length, mass and stiffness. The natural frequency of a conductor span can be calculated as

$$f_b = \frac{\pi K^2}{2L^2}\sqrt{\frac{EJ}{m}}$$

where

f_b is the conductor natural frequency (Hz)
L is the span length (m) [in]
E is the modulus of elasticity of the conductor's material (N/m^2) [lbf/in^2]
J is the moment of inertia of the cross-sectional area (m^4) [in^4]
m is the mass per unit length of the conductor (kg/m) [lbm/in]
K is a dimensionless constant accounting for the boundary conditions at the conductor's ends:
K=1.00 for two pinned ends
K=1.25 for one pinned ends and one fixed (clamped) end
K=1.51 for two fixed (clamped) ends.

NOTE—In the above equation the mass by unit length (m) is required while in calculations we often evaluate the weight by unit length (unit weight). To get mass by unit length in SI units from unit weight in N/m, divide unit weight by 9.81. To get mass by unit length in British units from unit weight in lbf/in, divide unit weight by 386.1.

Ends conditions can range between fixed and pinned. A fixed end is not free to rotate (moment resisting), whereas a pinned end is free to rotate (not moment resisting). Because of structure flexibility and connection friction, the end conditions are not truly fixed or pinned.

The finite element method may also be used to calculate the natural frequency and corresponding mode shapes of a structure; it permits to take account directly of the effect of supports as well as 3D behavior of structures.

1.3 Vibration attenuation

To prevent induced vibrations when the natural frequency of the conductor is in the vicinity of the excitation frequency from wind or from alternating current [Equation (iii) or Equation (iv)], it is preferred that the diameter of the conductor be increased to lower its natural frequencies, taking them out of the critical range. Another possible solution is to increase the bus span length, that is to change the span between supports, which also has the effect of lowering the natural frequencies. Another solution is also to provide damping elements. For tubular conductors, this can be accomplished by two methods:

1) Installing stranded bare cable inside of tubular bus conductor to dissipate vibration energy; or 2) Installing commercially available vibration dampers on the conductor.

Installing stranded bare cable inside the bus conductor requires that the weight of the stranded damping cable used be between 10% and 33% of the bus conductor weight and that the damping cable be the same material as the bus conductor to prevent galvanic corrosion. The designer should also consider the audible noise that can be generated by the stranded damping cable inside of the bus conductor since this may not be acceptable in some locations. Note that the thermal expansion fittings could also act as energy dissipation devices.

Commercially available vibration dampers can also be used on both tubular and non-tubular bus conductors and can be applied in both EHV and non-EHV locations. Spacing of the vibration dampers is based on 1/3 of the span length plus two feet and can be located at either end of the span.

Vibration dampers should be applied when the maximum vibration-free span length is exceeded as listed in the following tables for various bus conductor types.

Table 1 —Maximum vibration-free span length for tubular bus

Nominal Pipe Size	Maximum Safe Span Length
1”	1.5 m [5’-0”]
1-1/4”	1.9 m [6’-3”]
1-1/2”	2.1 m [7’-0”]
2”	2.7 m [9’-0”]
2-1/2”	3.3 m [10’-9”]
3”	4.0 m [13’-3”]
3-1/2”	4.6 m [15’-3”]
4”	5.2 m [17’-0”]
4-1/2”	5.8 m [19’-0”]
5”	6.5 m [21’-3”]
6”	7.7 m [25’-3”]

NOTE—These lengths are based on one cycle of vibration and apply to both schedule 40 and schedule 80 tubular bus. The lengths listed above can be increased approximately 20% with reasonable certainty that there will be no vibration.

Table 2 —Maximum vibration-free span length for universal angle bus conductor (UABC)

UABC Size	Maximum Safe Span Length
3-1/4” x 3-1/4” x ¼”	3.7 m [12’-0”]
4” x 4” x ¼”	4.6 m [15’-0”]
4” x 4” x 3/8”	4.8 m [15’-9”]
4-1/2” x 4-1/2” x 3/8”	5.1 m [16’-9”]
5” x 5” x 3/8”	5.6 m [18’-6”]

NOTE—These lengths are based on one loop of vibration. The lengths listed above can be increased approximately 20% with reasonable certainty that there will be no vibration. However, this table does not apply for double back-to-back configurations.

Table 3 —Maximum vibration-free span length for integral web channel bus (IWCB)

IWCB Size	Maximum Safe Span Length
4” x 4”	4.4 m [14’-6”]
6” x 4”	6.3 m [20’-9”]
6” x 5”	6.5 m [21’-3”]
6” x 6”	6.6 m [21’-9”]
7” x 7”	8.0 m [26’-3”]
8” x 5”	8.8 m [29’-0”]