Study Committee B2

Overhead Lines

10634_2022

Efficacy of Loose Spacers in Mitigating Galloping of Bundled Conductors

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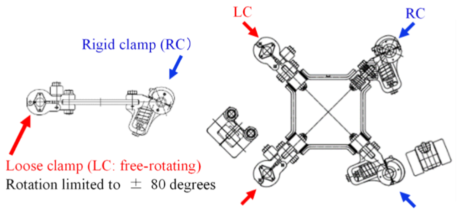
Motivation

- Electrical utilities in Japan had been suffering from conductor galloping. It tends to occur more frequently on bundle conductors.
- Thus, a countermeasure for bundle conductor being effective, less visual impact and also not increasing loads onto support structures was required.
- This motivated us to develop the Loose Spacer (LS) which fulfil all the requirements above.

Method/Approach

- Loose Spacer is a type of bundle-spacer having rotating clamps called "loose clamps" (LCs) and "rigid clamps" (RCs) in one unit. They are expected to suppress galloping aerodynamically by changing the torsional motion between conductors.
- Observations, numerical simulations and wind tunnel tests were performed to investigate the effect of LS and aerodynamics of bundle with LS for suppressing galloping.



Ex. of the configuration of loose spacers

Objects of investigation

a. Actual effect of LSs for suppressing galloping by comparing the motions of bundle conductors with LSs to those with normal spacers (NSs) at multiple full-scale test lines.

b. Reproducibility of the motions of bundle conductors with LSs and NSs by a numerical simulation code "CAFSS" developed by Central Research Institute of Electric Power Industry.

c. Aerodynamical mechanism of the LS for suppressing galloping by performing the wind tunnel test for the model of bundle conductor with LSs.

Experimental setup & test results

a. Observation at three full-scale test lines

- At Mogami test line, where strong local wind blows, motions and tensions of two-, four- and eight-bundle conductors attached with artificial snow for urging galloping were observed, resulting that all the type of LS (LS2, LS4 and LS8) can suppress galloping effectively.
- At Shikoku and Tsuruga test line located in mountainous area where in-cloud icing frequently occurs, motions and tensions of four-bundle conductors with LSs and NSs were observed under natural conditions, resulting in verifying the efficacy of LS under natural icing conditions based on the comparison of them.
- Conductors used for this study was ACSR410mm^2(d=28.5mm) for two- and four-bundles and ACSR610mm^2(d=34.2mm) for eight-bundles.

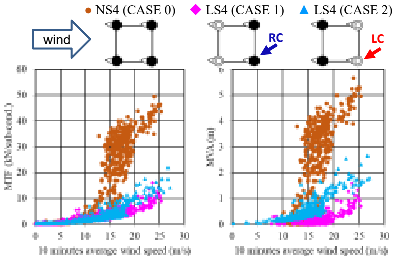
b. Numerical simulation

- Simulations by CAFSS were performed reproducing the wind conditions and bundles with NS4s and LS4s at Mogami, showing that they were roughly the same as the observations.

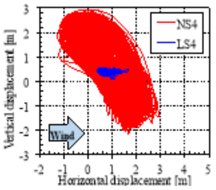
c. Wind tunnel test

- Wind tunnel tests were carried out using section models of four-bundles and the effect of the LC arrangement for suppressing galloping was investigated.
- Consequently, the most effective arrangement is placing LCs windward because the large negative aerodynamic moment acts effectively.

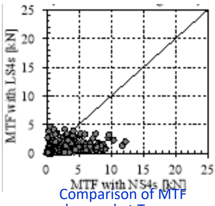
LS4 and artificial snow attached at Mogami test line



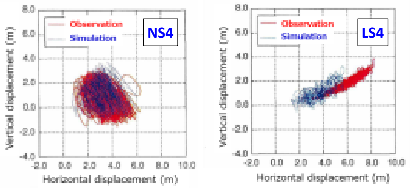
Comparison of MTF(Max. Tension Fluctuation) and MVA(Max. Vertical Amplitude) of four-bundles at Mogami



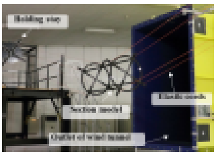
Trajectories observed at Tsuruga



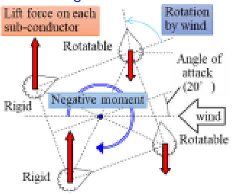
Comparison of MTF observed at Tsuruga



Comparison of trajectories of four bundles between observations and simulations at Mogami Test Line



Experimental setup of wind response measurement tests.



Negative aerodynamic moment acting on four-bundled conductor

Conclusion

- High efficacy of various types of the loose spacer (LS2, LS4 and LS8) for suppressing galloping has been confirmed.
- Locating loose clamps windward is the most effective, however, other arrangements such as diagonal might be adopted when considering wind inversions.

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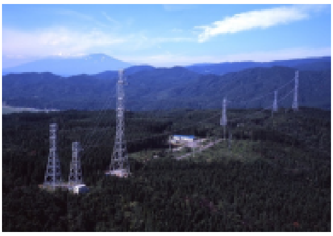
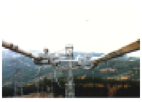
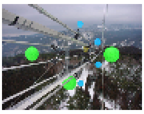
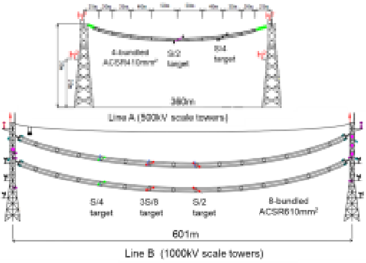
Efficacy of Loose Spacers in Mitigating Galloping of Bundled Conductors continued

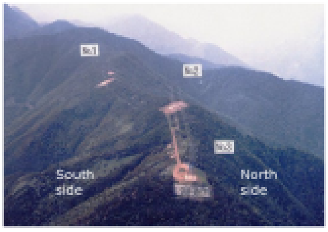
Overview of the full-scale test lines used in this study

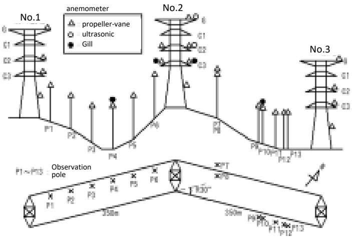
- **Mogami test line** is located in the northern part of Japan, where there is a special local wind. On more than 70 days each year, this wind travels at speeds of 10 m/s or higher from the ESE direction. Due to the strong winds, galloping can easily occur if artificial snow is placed onto the conductors.

Mogami test line

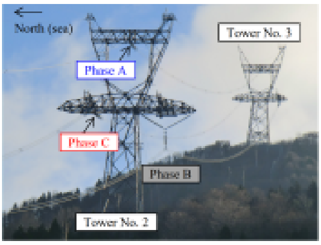
- **Shikoku test line**, constructed at an altitude of 1500 m in the southwest of Japan, consists of three towers and two spans of 350 m each, with two circuits (six phases) of four-bundle ACSR 410 mm^2. In winter, in-cloud icing sometimes occurs here due to its geographical and locational feature.

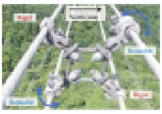
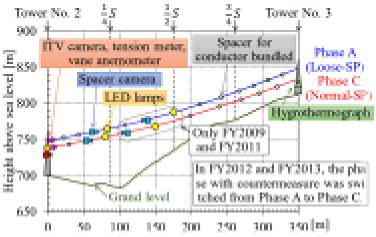


Shikoku test line

- **Tsuruga** test line is located on a ridge at an altitude of 700-800 m in the center of Japan, where in-cloud icing frequently occurs in winter. It has one circuit (three phases) of four-bundle ACSR 410 mm^2 arranged triangularly.



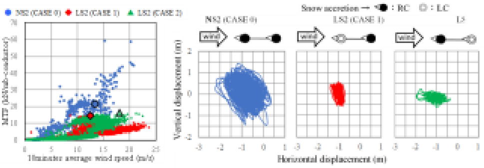
Tsuruga test line

Observation results at test lines

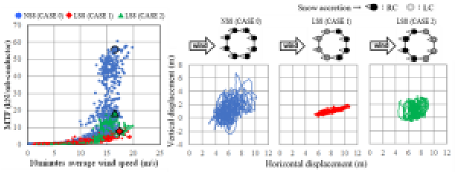
a. Mogami test line

- Below figures show the relationship between 10 min. ave. wind speed and the max. tension fluctuation (MTF) of the 2- and 8-bundles and their trajectories observed. The MTF with loose spacers(LSs) are smaller than with normal spacers(NSs) and trajectories indicate that the displacements with LSs were smaller than with NSs.
- These results are similar to 4-bundle (see right), which proved the effectiveness of the LS regardless of the quantity of sub-conductors.

Motion of four bundle conductors observed at Mogami



Two bundle conductors



Eight bundle conductors

Max. tension fluctuations and trajectiles of two- and four- bundles observed at Mogami.

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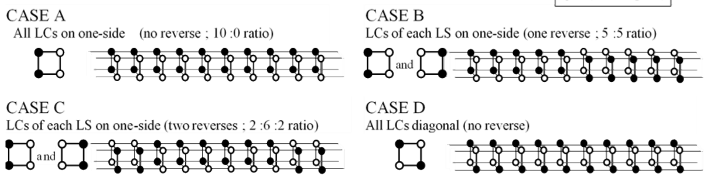
Observation results at test lines

b. Shikoku test line

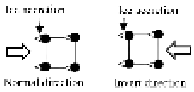
- At Shikoku, conductor motions were observed simultaneously by installing NS4s and four types of arrangements of the LS4s (shown below) onto different phases respectively.
- The lower right table displays the percentage of the cases the ratio of the MTF with LSs to that with NSs during the same 10-min frame was smaller than 1.0 for each arrangement. It was confirmed that the one-side arrangement of 2:6:2 (CASE C) and the diagonal arrangement (CASE D) exhibit somewhat superior performances compared to the other arrangements.



Arrangements of LS4s in the span tested

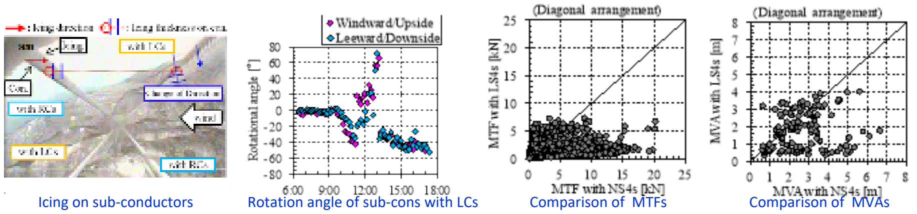
Observation results

Arrangement of LSs		Wind direction	
		Normal	Inverse
One-side	10:0	78	83
	5:5	81	64
	2:6:2	[illegible]	[illegible]
Diagonal		95	75



c. Tsuruga test line

- At Tsuruga, the performance of LS4s was investigated by comparing it to NS4s, using two-phases at the test line. LCs of LS4s had been installed diagonally (CASE D above) first and were replaced with all-one-side arrangement (CASE A above) afterward.
- The directions the icing accumulated to were different between the subconductors with RCs and with LCs and that the sub-conductors with LCs can rotate relatively freely in the presence of natural in-cloud icing.
- Both diagonal and one-side arrangements of LS4s showed good performance.



Icing on sub-conductors | Rotation angle of sub-cons with LCs | Comparison of MTFs | Comparison of MVAs

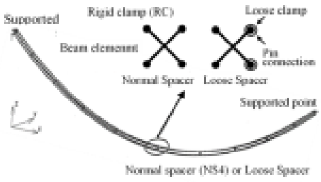
Observation results of the bundle with LS4s and comparison to that with NS4s at Tsuruga test line

Numerical Simulations by CAFSS

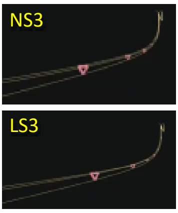
- CAFSS is a time-domain three-dimensional finite element code developed by CRIEPI. The reasonability of the CAFSS has been verified in this study, which means it can be used for presuming conductor motions in various conditions.

Features of the CAFSS

Integration method	Direct integration, Newmark-β method
Elements used	Linear truss elements, Saint-Venant torsion element, linear beam elements (hinge connection can be applied)
Unknowns	Displacement of all nodes, stress and strain of all elements can be calculated
Reference coordinate system	Updated Lagrange system
Large deformation	Takes into account geometric nonlinearity of elements
Convergence calculation method	Newton-Raphson method
Structural damping	Rayleigh damping



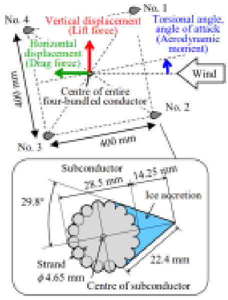
Analysis model



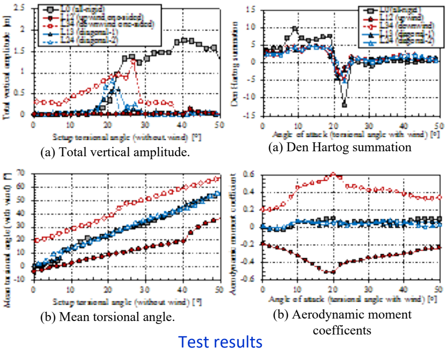
Ex. of simulation for three bundle conductor

Wind tunnel tests

- A serious of wind tunnel tests clarified the aerodynamic characteristics of various types of arrangements of the LS4s.



Four bundle model for the wind tunnel tests

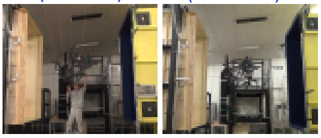


Test results

Model types tested

Model	Arrangement of rotatable subconductors
L0	None (all-rigid)
L12	No. 1, 2 (upwind one-sided)
L34	No. 3, 4 (downwind one-sided)
L13	No. 1, 3 (diagonal-1)
L24	No. 2, 4 (diagonal-2)

NS4(Model L0) LS4(Model L12)



Movement of the model