Temperature and Current Density Simulation in Overhead Ground-Wire Cable with Fiber Cable (OPGW) under Short-Circuit Current Passage

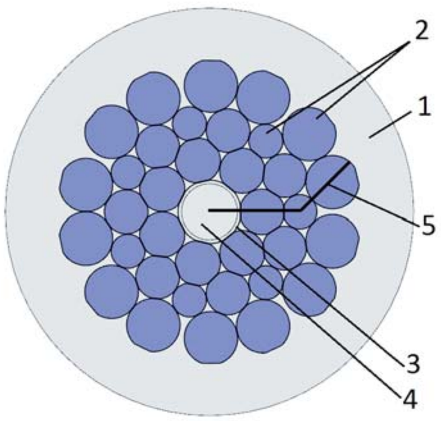
Leonid GUREVICH (Леонид ГУРЕВИЧ),
Vladimir DANENKO (Владимир ДАНЕНКО),
Dmitry Pronichev (Дмитрий ПРОНИЧЕВ),
Mikhail TRUNOV (Михаил ТРУНОВ),
Volgograd State Technical University

Along with the standard information fiber-optic cables (FOC), made with dielectric self supporting cables, overhead ground-wire cables made of steel wires with different coatings containing stainless steel module which comprises optical fibers in hydrophobic semi-liquid gel are widely used (OPGW). This design provides necessary mechanical strength and is a product of dual purpose: it performs the traditional role of protecting power lines from lightning strikes and used as communication and data transfer cable.

OPGW must satisfy JSC FGC UES traditional requirements to overhead ground-wire cables: mechanical strength, corrosion resistance, resistance to lightning discharges, Aeolian vibrations, Galloping, as well as short circuit withstand capability.

Steel wire used in OPGW layers must be protected against corrosion, therefore zinc or aluminum coatings, significantly more resistant to oxidation than steel core, are used. Resistance to corrosion and specific conductivity of aluminum coating is slightly higher than zinc, however, such coatings have a number of disadvantages. Outdoor contact of stainless steel and aluminum causes active corrosion: atmospheric salt and chemical contaminations on the surface of the metal act as the electrolyte and lead to accelerated destruction of aluminum. Therefore the international standard IEEE-1138-2009 for zones with high corrosive activity, which include all industrial and

Fig. 1. OPGW thermal withstand capability design diagram: 1 — air; 2 — steel wire; 3 — central tube; 4 — optical fibers in hydrophobic gel; 5 — the line along which data is presented in Fig. 2.



densely populated areas, prohibits the usage of OPGW optical module made of stainless steel and aluminum coated wires.

Moreover, the comparative tests to withstand lightning charge up to 110 coulomb carried out on "Four-part lightning current generator" (GTM-4) test bench in Moscow Power Engineering Institute under the same tension revealed that shield wire made of aluminum-clad steel wire suffered the greatest damage.

OPGW usage requires to calculate thermal resistance, provided that not only residual mechanical strength of the cable, but also effective heat removal from the optical module are considered. Regulations for design of fiber-optic communication lines on OHL require thermal stability analysis of optical cable when subjected to fault currents.

OPGW thermal withstand analysis included the following calculations:

- dynamic magnetic field caused by the AC pulse frequency of 50 Hz and a duration of up to 1 s in order to obtain the current density distribution in each of the cable conductors, depending on the time;
- unsteady temperature field using Joule losses as the heat source.

The simulation used Magnetic Fields and Heat Transfer in Solids modules license software package COMSOL Multiphysics, capable of solving partial differential equations.

For simulation diagram of ground wire with grade OPGW 11,0/E1(12)-MZ (ground wire with diameter 11.0 mm with built-in optical communication cable) made according to the technical conditions enterprise standard 71915393-TU 113-2013 (Fig. 1) was used.

While thermal analysis four possible variants of steel wire surface coating were compared:

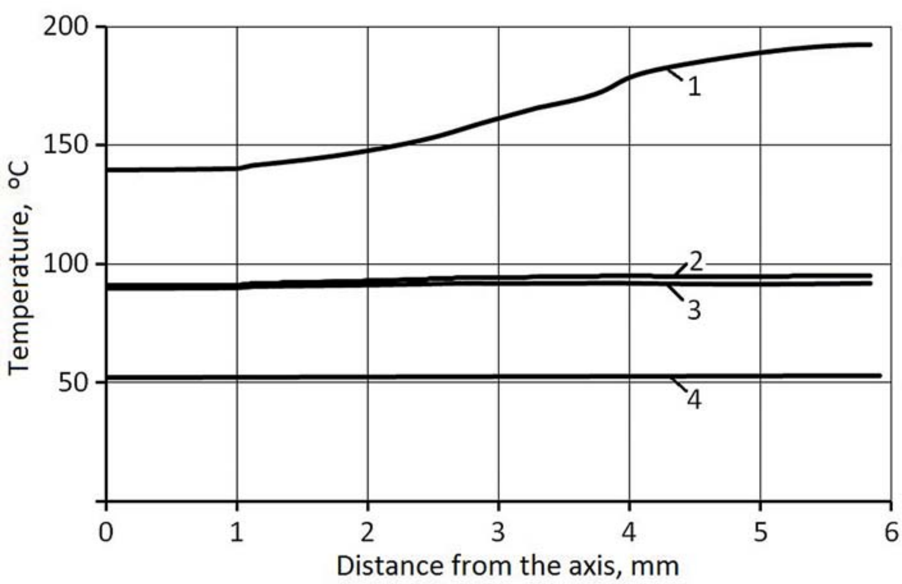
- steel rods with zinc coating for particularly harsh environment operation (corresponds to OPGW really made by Severstal-Metiz JAC according to enterprise standard 71915393-TU 113-2013);
- steel rods without coating;
- steel rods with aluminium coating which thickness corresponds to zinc coating of first variant (20 µm);
- steel rods with aluminium coating with volume aluminium content up to 25%.

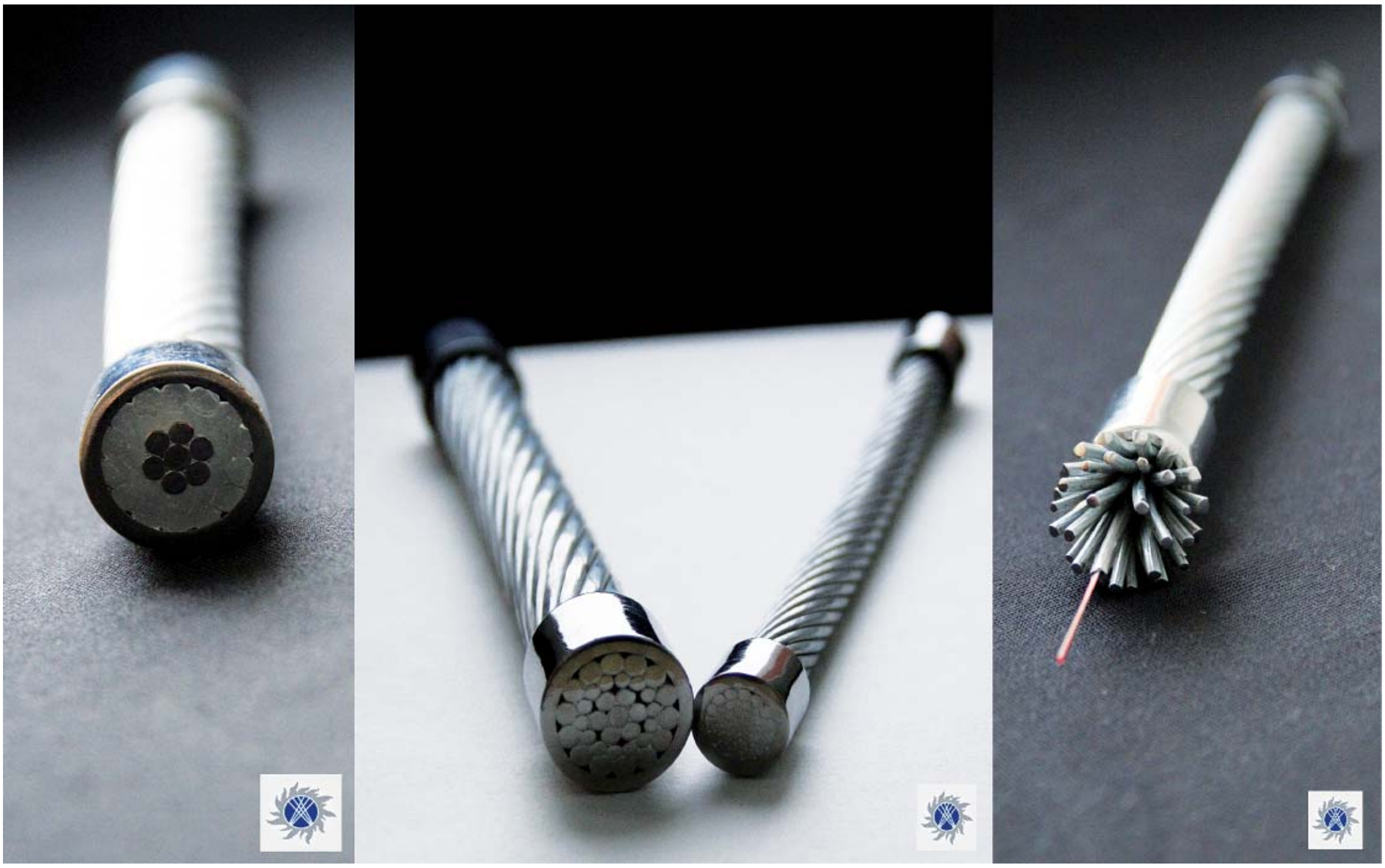
The simulation results were verified by experimental data of field tests in OPGW high voltage equipment test center of JSC NTC FGC UES showing that 1 second passage of 4.3 kA short circuit current increased cable temperature by an average of 88°C.

It was found that current density in uncoated steel wire increases with distance from the axis of the cable, which leads to substantial increase in temperature in the outer wire layers (Fig. 2).

The use of zinc or aluminum coating results in predominant current flow in them (current density in these coatings respectively is 4 and 9 times the current density in the carbon steel core). The difference in current density in external and internal layers is not significant. Under 1 second fault current J_{fc} = 4.3 kA the use of coating zinc reduced the temperature in optical module area by 35° C and in the outer layer — by 83° C. The use of 20 µm aluminum coating with increased electrical conductivity allows to further reduce the temperature in the optical

Fig. 2. Temperature distribution in OPGW along the line shown in Fig. 1 at J_{fc} = 4.3 kA current through 1 s: 1 — uncoated steel wires, 2 — zinc coating, 3 and 4 — aluminum coating, thickness 20 and 260 µm respectively 1.0 s.





module by 15° C, however, in the case of both zinc and aluminum coatings temperatures lie in the safe range and do not lead to degradation of optical properties of optical fiber. During simulation the increase of aluminum coating thicknesses to 25% volumetric content provided under selected current value of J_{fc} = 4.3 kA temperature increase only up to 52°C. This aluminum content is too high with respect to temperature stability at current J_{fc} = 4.3 kA and is appropriate only at J_{fc} = 6.2—6.3 kA currents.

Specific resistance/cable coating dependence is often not analyzed in choosing OPGW wire coating material. For OPGW under consideration when using uncoated steel wires DC resistance value R = 3.1 ohm/km, with zinc coating R = 2.2 ohm/km, with 20 µm thick aluminum coating R = 1.9 ohm/km.

Shield wire DC resistance reduction when replacing zinc coating for aluminum will inevitably lead to an increase in forced and active components of fault current that can neutralize determined by laboratory testing and modeling the lower values of temperature fields in ground steel wires with aluminum coating over wires with zinc coating.

Change in strength characteristics and critical deflection for OPGW made by Volgograd Affiliate of Severstal-Metiz when replacing steel galvanized rod of 1770 MPa marking group with steel aluminized one with aluminium volume content 25% was evaluated. Cross-sectional area of all wires in OPGW of existing construction is 83.59 mm^2, approximate weight of 1000 m lubricated ground cable is 695 kg and actual aggregate breaking strength is at least 147 kN. OPGW coating changed, the weight is reduced to 515 kg. Aluminum-coated steel wire tensile strength σ_{bim} calculated according to the additivity concept is 1342 MPa and actual aggregate breaking strength of all wires is less than 112 kN.

Table 1. Calculation of linear and specific loads in OPGW under its own weight, the weight of ice and wind pressure

Load Designation	OPGW with Galvanized Rods		OPGW with Aluminized Rods	
	Linear Load, N/m	Specific Load, MPa/m	Linear Load, N/m	Specific Load, MPa/m
from proper weight	6.82	0.0815	5.05	0.0604
from glaze ice weight	19.11	—	19.11	—
from wind pressure while glaze ice	24.72	—	24.72	—
resultant from proper weight, glaze ice weight and wind pressure while glaze ice	40.22	0.6415	39.11	0.6238

When using OPGW in Russian area of the third groups by wind pressure (1 time per 25 years wind pressure up to 0.67 kPa) and by glaze ice (1 time per 25 years standard thickness of glaze ice layer up to 20 mm) calculation according to EIC-7 results in the following values of linear and specific loads (Table 1).

With a span length of l=300 m minimum allowable sag under the action of wind and ice loads at permissible stresses in ground wire equal to 50% of ultimate tensile strength of the wire being used is 8.15 m for OPGW of galvanized steel wires and 10.46 m for OPGW of aluminum-coated steel wire.

Thus, the use of aluminized wire with high aluminium content in OPGW manufacture leads to considerable reduce in bearing capacity of the cable not compensated by the decrease of mass per unit length.

CONCLUSIONS

1. A method for modeling the distribution of current density and temperature over OPGW cross-section manufactured by the TU STO 71915393-TU 113-2013 and verified by the results of environmental tests in HV EC of JSC FGC UES was developed.

2. Use of galvanized steel wire in the plastically deformed OPGW outer layer under 1-second 4.3 kA max fault current passage allowed to reduce the temperature on the surface of the optical module by 35°C compared with an uncoated steel wire rope.

3. Aluminum coating allows to make additional reduction of temperature but its use is associated with a number of negative factors: the low corrosion resistance of aluminium coating in the contact area with the optical module stainless tube; low lightning strike withstandability of aluminum wire.

When it comes to choosing which type of protective coating to use for steel wires it should be taken into account not only the possible change of temperature fields in OPGW under the same values of fault current, but also dependence of its size on specific resistivity of the shield wire, as well as lightning current withstandability, corrosion resistance and carrying capacity of the shield wire.

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