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Design optimization of a 138 kV transmission line with optical phase conductors

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SUMMARY

This paper presents the main topics related to the detailed engineering of a 138 kV transmission line near Stewart, British Columbia. This line connects the Long Lake hydroelectric generating station to the BC Hydro network.

The paper addresses the selection process of the innovative optical phase conductor (OPPC) technology and its benefits to optimize the design and minimize the construction cost of this specific project. It is understood that this is the first time this conductor type was installed on a high-voltage transmission line in Canada.

Several firms from the following fields of expertise have joined this project and conducted detailed studies for this particular site. High wind gusts of up to 320 km/hour and radial rime ice of up to 120 mm were considered. Heavy snow creep and avalanche loads were also taken into account for the tower design. To face all these engineering challenges induced by climatic loads, the OPPC selection permits to considerably reduce the structure loads. OPPC allows for an optimization of the number of cables attached to the structures by including the optical fibre inside the conductor. Consequently, it was no longer required to install an optical ground wire (OPGW) cable. As a result, the galloping ellipse interference issue between OPGW and conductors was avoided and both towers heights and foundation sizes were reduced.

In addition, the overhead line location has its own set of constructability challenges. It crosses an 800-metre-wide river, a mountainous terrain (with elevations ranging from 50 m to 1,500 m) and several valleys. Limited access to the structure locations required a construction by helicopter for the entire project. The helicopter constraint was taken into account by a modular and optimized tower design.

Combined with an optimized design methodology, the OPPC selection in this singular project clearly demonstrates the benefits of such innovative technology in the transmission line industry for both design and constructability phases.

KEYWORDS

Optical phase conductor (OPPC), transmission line, design optimization, constructability challenges, rime ice, snow creep, helicopter construction.

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Introduction

This paper presents the main topics related to the detailed engineering of a new 138 kV transmission line near Stewart, British Columbia (Figure 1). This line connects the Long Lake hydroelectric generating station to the BC Hydro network. The overhead line crosses an 800-metre-wide river, a mountainous terrain (with elevations ranging from 50 m to 1,500 m) and several valleys. All structure locations were only accessible by helicopter. It replaced an existing line, which has proven inadequate to withstand the severe climatic conditions prevailing in this area (Figure 2).

Tubular self-supported steel towers were mainly used along the routing. These towers are supported by a steel structure foundation with post tensioned anchors. The structure heights vary from 20 m to 43 m. Two (2) categories of taper and straight stubs were selected. The maximum stub diameter ranges from 1,600 mm to 2,800 mm. The steel foundation base diameter width varies from 3,150 mm to 5,650 mm. Supports were distributed over 33 spans with a span length varying from 130 m to 800 m.

This paper aims to address the selection process of the innovative OPPC technology and its benefits to optimize the design and minimize the construction cost of this specific project compared to the previous solution with three (3) conductors and one (1) OPGW configuration. This is the first time this conductor type was installed on a high-voltage transmission line in Canada.

In this paper, the parameters initiating the deployment of the OPPC solution are first presented. Thereafter, the benefits of the design option are exposed during the design and constructability phases.

Figure 1: Project localization

Figure 2: New transmission line built along the existing line

OPPC definition

An OPPC is a conductor similar to an optical ground wire (OPGW) designed to be energized and to transport both electricity and telecom data. It has the mechanical and electrical properties of a conductor type with added fibres. The OPPC used for this project was made of aluminum-clad steel strands one (1) of which is replaced by a stainless steel tube containing fibres. Unlike OPGW, where the cable is not carrying a continuous current, OPPC is energized along high-voltage power lines. Therefore, adapted insulated splice and termination boxes are required to accommodate the live line conditions. This OPPC section view is presented in Figure 3.

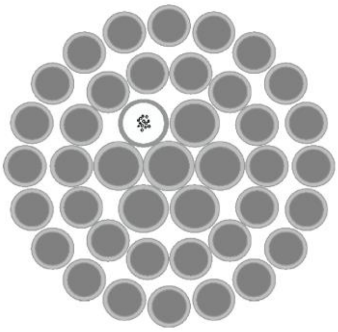
Figure 3: OPPC section view

Climatic conditions

Wind load

The detailed study on wind was provided by the WindEEE Research Institute. To evaluate the extreme wind loads, a scale model of the mountain was made and wind tunnel tests were performed from two (2) dominant wind directions. The wind speeds were measured at the tower locations and along the transmission line inside the wind tunnel. WindEEE provided a summary of the estimated 50-year return wind speed at each tower locations, including gusts and average 10-minute winds. The maximum value of 5-second wind gusts was 320 km/hour [1].

Ice loading

For the ice loading, the Norwegian firm Kjeller Vindteknikk was mandated to characterize the ice loading type and to determine the radial ice thickness and density. Its final report [2] indicates the presence of significant wet snow loads (radial thickness up to 50 mm) in the lowest part of the mountain and severe rime ice loads (radial thickness up to 120 mm) in the top part. This study is supported by on-site observations as shown in Figure 4.

Figure 4: Rime ice accretion on structure and conductor

All these detailed studies were used to establish the design criteria of the project. As the line is located in a mountainous area, the magnitude of loading applied on the transmission line varies all along the routing. In order to optimize the design, data are regrouped by zones as shown in Table 1.

Table 1: Climatic loads and loading zones

Zone	1	2	3	4	5	6
Ice description	Wet snow	Rime ice	Rime ice	Rime ice	Rime ice	Wet snow
Elevations (m)	50 to 500 East	500 to 1,200 East	1,200 to 1,400 East	> 1,400	1,400 to 1,240 West	1,050 to 250 West
Radial ice (mm)	40	60	93	120	110	50
Ice density (kg/m^3)	500	400	400	400	400	500
10-minute wind speed V_R (km/h)	110	160	190	190	190	135

Snow creep

Another factor was the important snow thickness causing significant snow creep and avalanche loads. Based on regional records, helicopter and ground reconnaissance and digital terrain from LiDAR data, Alpine Solutions provided in their report [3] the snow thickness and snow loads to be considered. At some locations, the 50-year-snow thickness was up to 10 m which affects considerably the vertical ground clearance and at the same time the structure heights. According to the specialized study [3], the static snow creep force is in some case accompanied by dynamic forces, which are the avalanche impact force and the avalanche run-up force as shown in Figure 5. Table 2 also shows the magnitude and variability of these forces for the LL-11 to LL-14 tower locations. By considering the indicated values, a maximum value of 10,000 kN.m of induced moment was calculated at the base of the LL-11 structure.

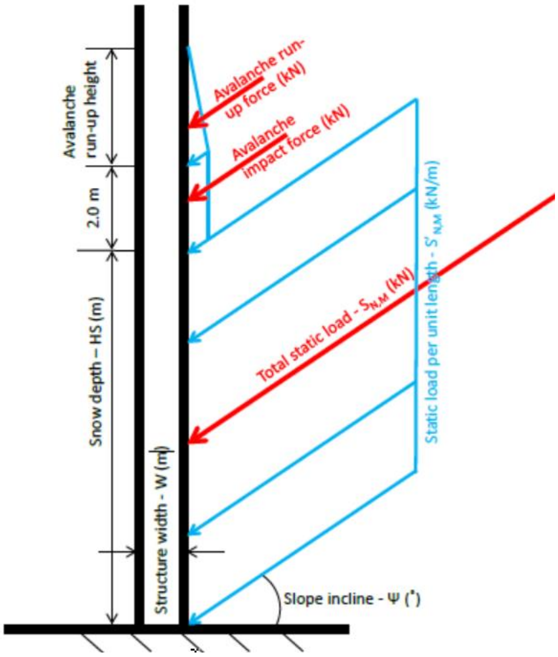

Figure 5: Snow creep and avalanche loads

CSA Standard C22.3 No. 60826 does not address the load combination with snow creep/avalanche loads. It was then decided to combine the 10-year snow creep/avalanche loads with the heavy and light ice and wind loads. The 50-year-snow creep and avalanche load were combined with a medium ice and wind loads in order to optimize the design.

Table 2: Snow creep and avalanche load

Structures	Tower base diameter (m)	Snow thickness (m)	Snow creep (50 years) (kN/m)	Avalanche impact force (kN)	Avalanche run-up force (kN)	Base moment (kN.m)
LL-11	2.8	7.8	224	190	220	10,000
LL-12	2.8	8.7	141	63	24	6,000
LL-13	2.8	7.1	130	-	-	3,300
LL-14	2.0	5.5	46	-	-	700

Galloping

Important galloping events occurred on the previous transmission line and resulted in flashovers and conductor damage. The envelope of galloping motions was then studied for the existing tower geometry. It was concluded that there was not sufficient clearance between the phases and the underlying OPGW on the existing transmission line (Figure 6). This issue was a deciding factor in the improvement of the design as explained in following sections. The new design was performed to ensure enough clearance between the conductor galloping ellipses. The "Institut de Recherche d'Hydro-Québec (IREQ)" was mandated to establish the expected galloping amplitude for each and every span to properly address the issue. The project considers a maximum amplitude of 12.2 m for the 800 m span and amplitudes up to 7.3 m for all the other spans [4].

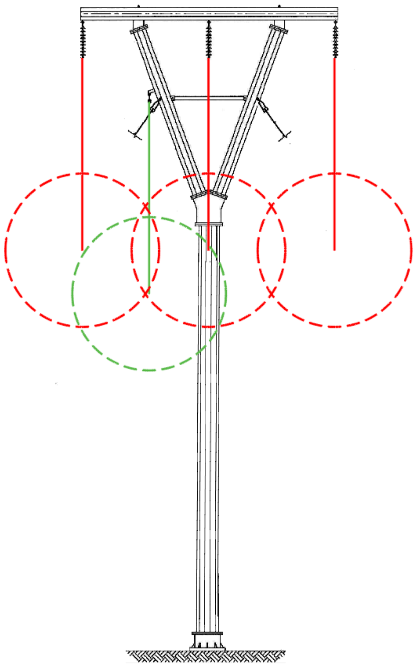

Figure 6: Schematic of the galloping envelope for the previous design tower

OPPC solution

As described in the previous sections, the galloping criteria and the severe climatic loads associated with helicopter construction were considered as primary issues for the design. Additionally, the project required to install a fibre link to connect the Long Lake hydroelectric generating station to the Owner's network and BC Hydro substation. Since the keraunic level in the Stewart area is very low (i.e. less than a 5-day lightning strike per year), the installation of a shield wire was not required for this line. Considering the above and to face all these engineering challenges induced by the severe climatic loads, the OPPC solution was introduced in the design as an optimal alternative. As a result of the aforementioned challenges, the OPPC selection permits to considerably optimize the design. The OPPC had two (2) direct significant impacts. First, the galloping ellipse interference was no longer a concern since the OPPC eliminates the need of an OPGW installation. Secondly, the OPPC solution removes the loads from a fourth conductor and allows the reduction of tower height. This allowed designing shorter, lighter structures and smaller foundations, as explained below.

Figure 7 shows the sequence to initiate this optimal solution considering all the constraints. First, it was considered that the galloping problem could be reduced by installing the OPGW at a lower position. However, this requires a higher structure to respect ground clearance considering up to 10 m of snow thickness, as shown on the left side of the figure. As a result, it was not determined to be the economical solution. Secondly, by introducing the OPPC solution, it was permitted to simultaneously respect the galloping circle required distance and ground clearance with a shorter structure, as shown in the right side of the figure. Consequently, the loads applied to the structure were significantly decreased when eliminating the OPGW and the resulted base moments were significantly reduced. Table 3 shows the comparison between the total moment at the base of a suspension and a dead-end tower used in this project for the two (2) options.

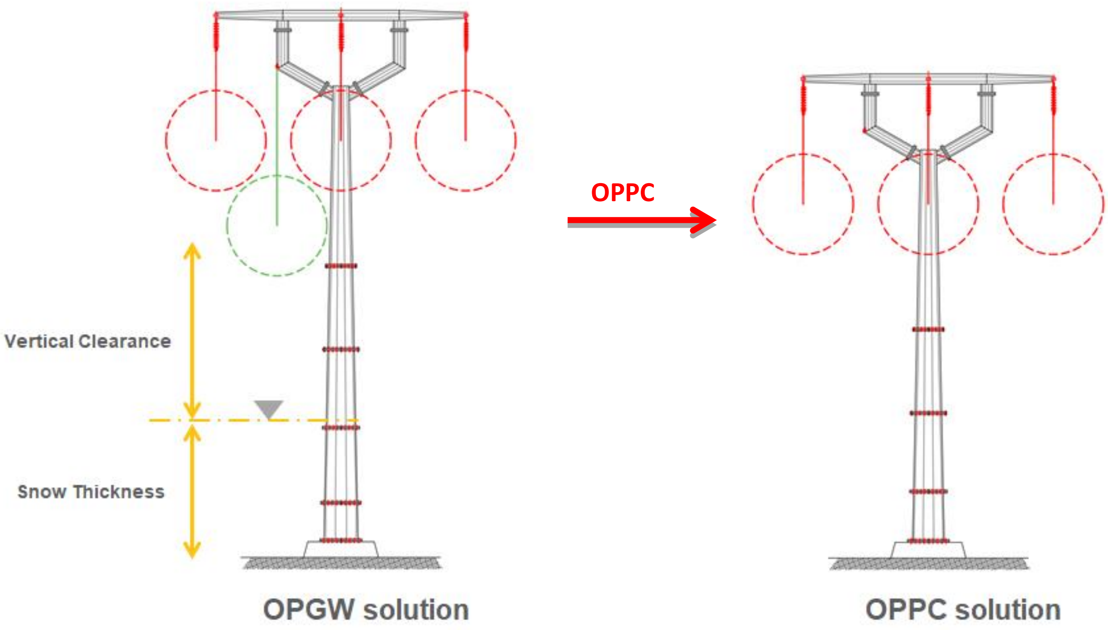

Figure 7: Comparison between the OPGW option and the deployed OPPC solution

Table 3: Tower base moment

Description		Total moment (kN.m)
Dead-end structure	OPGW solution	35,000
	OPPC solution	25,000
Suspension structure	OPGW solution	17,500
	OPPC solution	12,500

The selected OPPC provides other advantages over standard aluminum-conductor steel-reinforced (ACSR) or all aluminum conductor (AAC) types. The cable composition of aluminum-clad steel strands only permits to enhance the mechanical and aeolian vibration behaviour compared to an acceptable reduction of the electrical characteristics. The high steel area of the aluminum-clad steel strands provides remarkable mechanical properties to the OPPC.

Consequently, the OPPC solution permits to optimize the design and therefore the cost of the project by using lighter structures and foundations. Specifically, the foundation base moment was reduced by approximately 30%. In addition to the steel cost optimization, this solution also significantly reduced the cost of helicopter construction, as described in the following section.

Constructability advantages

The optimized design within the OPPC permits more economic structures and foundations, resulting in lower construction cost. It should be noted that all structure locations were only accessible by helicopter, which had been taken into account during the detailed engineering process to limit the weight of the tower sections with the helicopter's lifting capacity. As shown in Figure 8, the structure erection of the entire line was performed by a heavy lift Skycrane-type helicopter. This helicopter has an hourly operation cost of approximately $25,000. Thus, the outcome of this mass reduction minimizes the overall construction cost.

Figure 8: Skycrane transportation

To reduce the transport and installation cost, a modular tubular tower design and prefabricated steel foundation concept was adopted for the project. The design team concluded that the steel ring foundation with post-tension rock anchors was the adequate design choice that offers constructability and capacity advantages (Figure 9).

Figure 9: Prefabricated steel structure foundation

OPPC drawbacks

Despite all the advantages of OPPC, some drawbacks could discourage the use of this innovative technology. Some issues arise during the detailed engineering and the construction stages. As the fibres are inside an energized conductor, specific hardware assembly shall be installed at both ends of the transmission line (terminal unit) and at each junction of conductor reel lengths (straight joint box). The OPPC conductors are bolted on the box of this hardware, as shown in Figure 10. The purpose of these boxes is to allow space for fibre splicing. Unlike an OPGW cable, fibre splicing activity for an OPPC is limited to be performed at the jumper elevation at the top of the tower. This complicated the installation because no heavy lifting equipment was able to reach each straight joint location.

Figure 10: Straight joint box (left and middle) and terminal unit (right) in jumper assemblies

Conclusion

In conclusion, there is still room for innovation in the transmission line design. The OPPC technology was an adequate solution to achieve an optimized design and construction. The solution selected for this project was successfully implemented on site and is operational. Some transmission line areas have specific and significant load issues that should be addressed properly since they could have a major impact on the performance of the asset.

BIBLIOGRAPHY

[1] *Wind effects on Long Lake transmission lines and towers, Phase 1 – Topographic wind study* (WindEEE Research Institute, August 17, 2015)

[2] Report No. KVT/HA/2016/R025 – *Long Lake transmission line, British Columbia, Canada, Calculation of climatic loads* (Kjeller Vindteknikk, March 30, 2016)

[3] *Long Lake project transmission line, Avalanche and snow creep and glide, loading analysis for updated alignment* (Alpine Solutions, avalanche services, August 18, 2017)

[4] *Galloping recommendations, Long Lake Hydro, 138 kV transmission line* (Institut de Recherche d'Hydro-Québec (IREQ), June 1, 2017)