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BY EMAIL AND RESS

September 19, 2022

Ms. Nancy Marconi
Registrar
Ontario Energy Board
Suite 2700, 2300 Yonge Street
P.O. Box 2319
Toronto, ON M4P 1E4

Dear Ms. Marconi,

EB-2022-0140 - Hydro One Networks Inc. Chatham x Lakeshore Leave to Construct Application – Supplementary Interrogatory Responses

In accordance with Procedural Order 3, issued August 30, 2022, please find attached an electronic copy of responses provided by Hydro One Networks Inc. ("Hydro One") to supplemental interrogatory questions posed by Environmental Defence ("ED"), Haudenosaunee Development Institute ("HDI"), Pollution Probe ("PP"), Three Fires Group ("TFG"), the Ross Professional Corporation Firm ("TRPCF") and Ontario Energy Board ("OEB") Staff.

The table below is provided to assist in referencing how each individual intervenor supplemental interrogatory has been filed in this document.

Intervenor Posed Supplemental Interrogatory Naming Convention		**Hydro One Interrogatory Response Reference**		
Intervenor	Interrogatory	Exhibit	Tab	Schedule
OEB Staff	OEB Staff-18	I	01	18
ED	1-ED1	I	02	10
HDI	1-HDI-1	I	03	05
HDI	1-HDI-2	I	03	06
HDI	1-HDI-5	I	03	07
TFG	1-Three Fires-1	I	04	08
TFG	1-Three Fires-2	I	04	09
TFG	1-Three Fires-3	I	04	10
PP	Pollution Probe #1	I	06	09
PP	Pollution Probe #2	I	06	10
PP	Pollution Probe #3	I	06	11
PP	Pollution Probe #4	I	06	12
PP	Pollution Probe #5	I	06	13

PP	Pollution Probe #6	I	06	14
PP	Pollution Probe #7	I	06	15
TRPCF	1	I	07	02
TRPCF	2	I	07	03
TRPCF	3	I	07	04

An electronic copy of these responses has been submitted using the Board's Regulatory Electronic Submission System.

Sincerely,

Joanne Richardson

c/ Intervenors of record in EB-2022-0140

OEB STAFF INTERROGATORY - 18

Reference:

Exhibit B-2-1, Attachment 1, Page 2

The Chatham to Lakeshore 230 kV Transmission Line Class Environmental Assessment: Draft Environmental Study Report

Preamble:

Procedural Order No. 2 established that parties may seek information related to the pricing and reliability impacts of Hydro One's proposed route. OEB Staff-18 is asked from this context.

The first reference illustrates Hydro One's preferred route for the project. It also illustrates the route of the four existing transmission circuits connecting Chatham SS to Lakeshore TS.

The Environmental Assessment (EA) indicates that three route alternatives were considered. The EA concludes that "…Route Alternative 2A is preferred because it minimizes the overall impact to the natural and socio-economic environments compared to the other Route Alternatives and minimizes impacts to agricultural lands by utilizing an existing idle transmission corridor for nearly 1/3 its length."

Interrogatory:

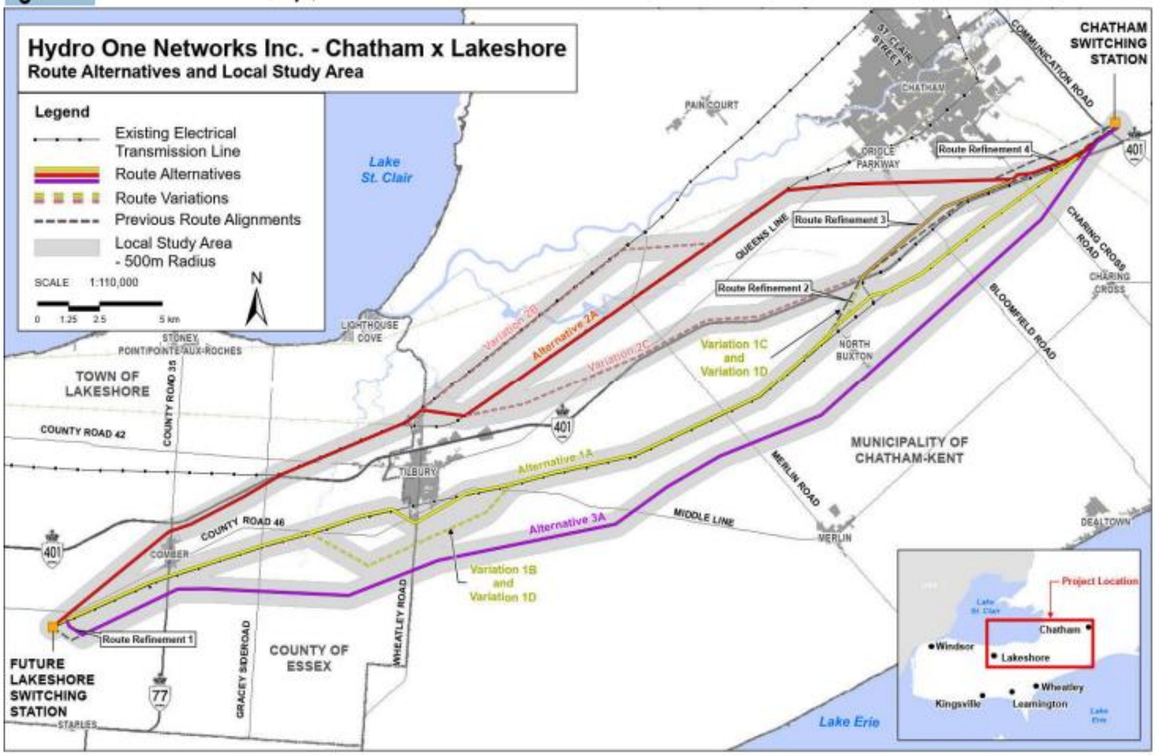
a) Please briefly describe each route option considered during the EA process, including identifying the advantages and disadvantages of each.
   - When responding, please specifically identify the reasons for why expanding the existing 230 kV corridor between Chatham SS and Lakeshore TS was not determined to be the preferred route.

b) Please briefly describe Hydro One's route selection process. As part of the description, please clearly articulate the reasons for why the preferred route was selected.
   - When responding, please specifically identify the steps Hydro One has taken to ensure that a cost-effective route is selected.

Response:

a) The identification and evaluation of route alternatives is described in detail in Chapter 5 of the draft Environmental Study Report (ESR) for the Chatham x Lakeshore Project. A map of the routes considered, as provided in Figure 5-2 at page 5-5 of the draft ESR, is provided below for ease of reference.

Figure 5-2: Route Alternatives, Variations and Refinements



The Class EA process that was undertaken for the Chatham to Lakeshore Project is in accordance with the Class Environmental Assessment for Minor Transmission Facilities (2016) which is approved under the *Ontario Environmental Assessment Act*. The draft ESR is available on Hydro One's website[1] and was available for public review and comment for 60 days from June 11, 2021 to August 10, 2021. Table 5-6 of the draft ESR presents the detailed results of the route evaluation, including the advantages and disadvantages of each. For ease of reference, that table is provided as Attachment 1 of this response.

Route Alternative 1 largely parallels an existing 230 kV transmission line. Route Alternative 1 contains a total of four variations (1A, 1B, 1C and 1D). The variations include different combinations of changes to the route, one around the south end of Tilbury and another closer to the City of Chatham, which parallels the Highway 401 corridor. For reference, Route Alternative 1 is akin to the alternative mentioned in OEB Staff's sub-bullet to this question and further information on why this alternative was not the preferred alternative is provided after explaining the other route alternatives considered as requested.

[1] https://www.hydroone.com/about/corporate-information/major-projects/chatham-to-lakeshore

Route Alternative 2, shown in red in Figure 5-2, largely parallels two existing 115 kV transmission lines (including a portion of one of the lines which is an idle 115 kV transmission line between Tilbury and Chatham). Route Alternative 2 and its variations also parallel portions of the Highway 401 corridor. There are a total of three variations (2A, 2B and 2C) associated with Route Alternative 2.

Route Alternative 3, shown in purple in Figure 5-2, is a greenfield option. While it does not parallel any existing transmission lines or other linear infrastructure for any significant distance, this was determined to be a feasible Route Alternative for the new 230 kV transmission line. As a result, it was prudent to include for consideration during the Class EA. There are no variations associated with Route Alternative 3.

Route 1 variations generally scored lower on Natural Environment, Socio-Economic Environment, and First Nations Culture, Values and Land Use categories.

Despite largely paralleling an existing 230 kV transmission line corridor, Route 1 scored poorly on Natural Environment criteria as this existing corridor traverses several natural features such as woodlots and other areas of incompatible vegetation, watercourse crossings, potential species at risk habitats and would directly affect the Big O conservation area, which the existing 230 kV corridor traverses. While variations 1A and 1B parallel the existing 230 kV line for most of their distance, landowners affected by this route alternative raised concerns regarding the construction of more transmission towers adjacent to existing ones and how this outcome would negatively impact farming operations. Route 1 therefore scored lower on the Effects to Agricultural Operations criterion.

Route 1 traversed a large number of features associated with archaeological potential, the North Buxton National Historic Site of Canada and Cultural Heritage Landscape, and a property listed on the Lakeshore Municipal Heritage Register. These factors contributed to Route 1 scoring lower on the Archaeological Resources and Built and Cultural Heritage route evaluation criteria.

Route 1 also scored lower in the First Nations and Haudenosaunee Culture, Values and Land Use category, as many of the criteria in this category relate to natural environmental features and habitats of importance identified by First Nations communities.

b) The identification and evaluation of route alternatives is described in detail in Chapter 5 of the draft Environmental Study Report (ESR) for the Chatham x Lakeshore project. Table 5-6 of the draft ESR presents the detailed results of the route evaluation, which again, for ease of reference, has been provided as Attachment 1 of this response.

To determine the viable routes for the new transmission line, Hydro One mapped out known technical and environmental features such as waterbodies, dense residential areas, environmentally significant areas, areas in close proximity to conflicts with existing infrastructure, amongst others, and looked for opportunities to parallel linear infrastructure and utilize existing easements. Based on that information, our design team developed three viable route alternatives and associated variations that respected the above-noted constraints and opportunities, while also minimizing potential project effects and costs by considering total line length, line angles required, and avoidance of transmission line crossings where feasible

To evaluate each of the routes, a weighted Multi-Criteria Decision Making analysis method, a typical decision making tool, was used, which included the following key steps:

- Collecting feedback from First Nations and Haudenosaunee communities, community members and stakeholders, as well as collecting available information across four categories: Natural Environment, Socio-Economic Environment, Technical and Cost and First Nations and Haudenosaunee Culture, Values and Traditions

- Using the feedback and information collected to build an evaluation framework by: i) Identifying a wide variety of evaluation criteria under each category, ii) Assigning weighting (importance) to each evaluation criterion (e.g., we heard very loud and clear from the community the importance of considering effects to agricultural operations, and this was therefore included as a criterion we evaluated and weighed to be of most importance within the socio-economic category), and iii) Assessing each route alternative based on the framework to select the preferred route.

Through this objective process, Hydro One holistically evaluated each route. A key component of the Class EA process was ensuring that the evaluation of each route, incorporated feedback received and weighing that feedback over the entire length of the proposed route.

Overall, Route Alternative 2A was selected as the preferred route because it minimizes the overall impact to the natural and socio-economic environments compared to the other Route Alternatives and minimizes impacts to agricultural lands by utilizing an existing idle transmission corridor for nearly 1/3 of its total length. Selection of Route Alternative 2A thus minimizes new land requirements as 1/3 of its length makes use of an existing transmission corridor. From a technical perspective, Route Alternative

2A is more complex to construct (soil conditions, line angles, etc.) but crosses the fewest number of property parcels and makes use of the existing idle line corridor. From an Anishnawbek and Haudenosaunee Culture, Values and Land Use perspective, Route Alternative 2A minimizes impacts to the natural environment while balancing opportunities to co-locate with existing infrastructure and proximity from identified areas of historical significance to Anishnawbek communities.

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Table 5-6: Comparative Evaluation Results

Criteria	Metric of Measurement/Scoring	Criteria Weight	Scoring Scale: 1 = Most Effect 3 = Neutral 5 = Least Effect	Alternative Routes							
				Alternative 1A	Alternative 1B	Alternative 1C	Alternative 1D	Alternative 2A	Alternative 2B	Alternative 2C	Alternative 3
Natural Environment			Natural Environment Factor								
Effects to Fish and Aquatic Habitat	Effects to aquatic habitat including total number of watercourse crossings, effects to bank riparian vegetation, potential effects to surface flows	15	Reasoned Argument	Traverses 2.11 km of watercourse (surface flow), crossing 43 watercourses in total, with potential to affect fish and fish habitat and riparian vegetation.	Traverses 2.21 km of watercourse (surface flow), crossing 46 watercourses in total, with potential to affect fish and fish habitat and riparian vegetation.	Traverses 1.89 km of watercourse (surface flow), crossing 42 watercourses in total, with potential to affect fish and fish habitat and riparian vegetation. .	Traverses 1.99 km of watercourse (surface flow), crossing 43 watercourses in total, with potential to affect fish and fish habitat and riparian vegetation.	Traverses 1.57 km of watercourse (surface flow), crossing 26 watercourses in total, with potential to affect fish and fish habitat and riparian vegetation.	Traverses 1.63 km of watercourse (surface flow), crossing 28 watercourses in total, with potential to affect fish and fish habitat and riparian vegetation.	Traverses 1.94 km of watercourse (surface flow), crossing 32 watercourses in total, with potential to affect fish and fish habitat and riparian vegetation.	Traverses 2.59 km of watercourse (surface flow), crossing 46 watercourses in total, with potential to affect fish and fish habitat and riparian vegetation.
			Score	2	2	3	2	5	5	4	1
Effects to Vegetation	Effects to vegetation including potential effects to incompatible vegetation communities and disturbance/alteration/destruction of existing windbreaks	15	Reasoned Argument	Traverses 6.92 ha of vegetation communities including hedgerows (e.g. windbreaks). 4.05 ha (59%) are incompatible with tranmision lines (long term effects) while 2.87 ha (or 41%) are compatible (short term effects).	Traverses 6.99 ha of vegetation communities including hedgerows (e.g. windbreaks). 4.20 ha (or 60%) are incompatible (long term effects) with transmission lines, while 2.79 ha (or 40%) are compatible (short term effects).	Traverses 6.29 ha of vegetation communities including hedgerows (e.g. windbreaks). 3.79 ha (or 60%) are incompatible (long term effects) with transmission lines, while 2.50 ha (or 40%) are compatible (short term effects).	Traverses 6.37 ha of vegetation communities including hedgerows (e.g. windbreaks). 3.95 ha (or 62%) are incompatible (long term effects) with transmission lines, while 2.41 ha (or 38%) are compatible (short term effects).	Traverses 6.18 ha of vegetation communities including hedgerows (e.g. windbreaks). 3.05 ha (49%) are incompatible (long term effects) with transmission lines, while 3.13 ha (or 51%) are compatible (short term effects).	Traverses 5.51 ha of vegetation communities including hedgerows (e.g. windbreaks). 2.88 ha (52%) are incompatible (long term effects) with transmission lines, while 2.64 ha (or 48%) are compatible (short term effects).	Traverses 6.92 ha of vegetation communities including hedgerows (e.g. windbreaks). 3.41 ha (or 49%) are incompatible (long term effects) with transmission lines, while 3.51 ha (or 51%) are compatible (short term effects).	Traverses 6.73 ha of vegetation communities including hedgerows (e.g. windbreaks). 4.02 ha (or 60%) are incompatible (long term effects) with transmission lines, while 2.71 ha (or 40%) are compatible (short term effects).
			Score	1	1	2	1	5	5	3	1
Terrestrial and Wildlife Habitat	Effects to terrestrial wildlife and habitat including footprint effects, potential removal, disturbance and/or destruction of habitat, potential disturbance to wildlife movement/habitat fragmentation	20	Reasoned Argument	Affects 2.52 ha of terrestrial and wildlife habitat, including SWH for bat materinty roosts, special concern and rare wildlfie species, and turtle wintering areas. Located along the periphery, and slightly within the Important Bird Area; not anticipated to impact movement of avian species.	Affects 2.52 ha of terrestrial and wildlife habitat, including SWH for bat materinty roosts, special concern and rare wildlife species, and turtle wintering areas. Located along the periphery, and slightly within the Important Bird Area; not anticipated to impact movement of avian species.	Affects 2.19 ha of terrestrial and wildlife habitat, including SWH for bat materinty roosts, special concern and rare wildlfie species, and turtle wintering areas. Located along the periphery, and slightly within the Important Bird Area; not anticipated to impact movement of avian species.	Affects 2.19 ha of terrestrial and wildlife habitat, including SWH for bat materinty roosts, special concern and rare wildlife species, and turtle wintering areas. Located along the periphery, and slightly within the Important Bird Area; not anticipated to impact movement of avian species.	Affects 3.0 ha of terrestrial and wildlife habitat, including SWH for bat materinty roosts, special concern and rare wildlife species, and turtle wintering areas. Located within the Important Bird Area with the potential of impacting movement of avian species.	Affects 3.55 ha of terrestrial and wildlife habitat, including SWH for bat materinty roosts, special conern and rare wildlife species, and turtle wintering areas. Located within the Important Bird Area with the potential of impacting movement of avian species.	Affects 2.66 ha of terrestrial and wildlife habitat, including SWH for bat materinty roosts, special concern and rare wildlife species, and turtle wintering areas. Located within the Important Bird Area with the potential of impacting movement of avian species.	Affects 1.04 ha of terrestrial and wildlife habitat, including SWH for bat materinty roosts and special concern and rare wildlife species. Located outside of Important Bird Area; not anticipated to impact movement of avian species.
			Score	3	3	3	3	2	1	2	5
Species at Risk & Species of Conservation Concern	Effects to Species at Risk and Species of Conservation Concern, and their habitats	20	Reasoned Argument	Affects 6.60 ha of confirmed and/or potential Species at Risk habitat (Butternut, Eastern Foxsnake, SAR Bats) and species of conservation concern (Climbing Prairie Rose, Honey Locust and Mapleleaf).	Affects 6.66 ha of confirmed and/or potential Species at Risk habitat (Butternut, Eastern Foxsnake, SAR Bats) and species of conservation concern (Climbing Prairie Rose and Mapleleaf).	Affects 5.59 ha of potential Species at Risk habitat (Eastern Foxsnake, SAR Bats) and species of conservation concern (Climbing Prairie Rose, Honey Locust and Mapleleaf).	Affects 5.65 ha of potential Species at Risk habitat (Eastern Foxsnake, SAR Bats) and species of conservation concern (Climbing Prairie Rose and Mapleleaf).	Affects 4.94ha of potential Species at Risk habitat (Eastern Foxsnake, Lake chubsuker, Lilliput and SAR bats) and species of conservation concern (Eastern Wood-pewee, Mapleleaf and Spotted Sucker).	Affects 4.58 ha of potential Species at Risk habitat (Eastern Foxsnake, Lake chubsuker, Lilliput and SAR bats) and species of conservation concern (Eastern Wood-pewee, Mapleleaf and Spotted Sucker).	Affects 5.47 ha of potential Species at Risk habitat (Eastern Foxsnake, Lillput and SAR bats) and species of conservation concern (Eastern Wood-pewee, Mapleleaf and Spotted Sucker).	Affects 5.12 ha of potential Species at Risk habitat (Eastern Foxsnake and SAR bats) and species of conservation concern (Eastern Wood-pewee , Honey Locust and Mapleleaf).
			Score	1	1	3	3	5	5	3	4
Natural Hazards, Wetlands and Floodplain Areas	Distance of the route that occurs within/in close proximity to floodplain areas, wetlands, areas of erosion concern	15	Reasoned Argument	Traverses 1.78 ha of regulated lands, including potential impacts to 0.65 ha of wetland.	Traverses 1.78 ha of regulated lands, including potential impacts to 0.65 ha of wetland.	Traverses 1.78 ha of regulated lands, including potential impacts to 0.65 ha of wetland.	Traverses 1.78 ha of regulated lands, inlcuding potential impacts to 0.65 ha of wetland.	Traverses 3.74 ha of regulated lands, including potential impacts to 0.49 ha of wetland.	Traverses 3.74 ha of regulated lands, including potential impacts to 0.49 ha of wetland.	Traverses 3.74 ha of regulated lands, including potential impacts to 0.49 ha of wetland.	Traverses 0.33 ha of regulated lands, none of which are wetlands.
			Score	3	3	3	3	1	1	1	5
Designated Natural Areas	Alignment with existing land use designations as defined by the PPS, local Municipal Official Plans and the Important Bird Area (IBA)	15	Reasoned Argument	Traverses 1.47 ha of designated Significant Woodland, 2.85 ha of designated Important Bird Area lands and 0.37 ha of the Big "O" Conservation Area.	Traverses 1.47 ha of designated Significant Woodland, 2.85 ha of designated Important Bird Area lands and 0.37 ha of the Big "O" Conservation Area.	Traverses 1.13 ha of designated Significant Woodland, 2.85 ha of designated Important Bird Area lands and 0.37 ha of the Big "O" Conservation Area.	Traverses 1.13 ha of designated Significant Woodland, 2.85 ha of designated Important Bird Area lands and 0.37 ha of the Big "O" Conservation Area.	Traverses 1.53 ha of designated Significant Woodland and 43.09 ha of designated Important Bird Area lands.	Traverses 1.30 ha of designated Significant Woodland and 59.73 ha of designated Important Bird Area lands.	Traverses 1.30 ha of designated Significant Woodland and 58.41 ha of designated Important Bird Area lands.	Traverses 0.96 ha of designated Significant Woodland and 0.24 ha of the C.M. Wilson Conservation Area. Does not impact designated Important Bird Area lands.
			Score	5	5	5	5	2	1	1	5
Natural Environment Factor Total Weighted Score				245	245	315	285	335	300	235	360

Criteria	Metric of Measurement/Scoring	Criteria Weight	Alternative Routes								
			Scoring Scale: 1 = Most Effect 3 = Neutral 5 = Least Effect	Alternative 1A	Alternative 1B	Alternative 1C	Alternative 1D	Alternative 2A	Alternative 2B	Alternative 2C	Alternative 3
Socio-Economic Environment			Socio-Economic Environment Factor								
Existing land use designations	Alignment with existing land use designations as defined by the Provincial Policy Statement and local Municipal Official Plans (does not include Designated Natural Areas or Natural Environment designations under the PPS)	10	Reasoned Argument	Local Official Plans (OPs) permit transmission facilities on any land use designation provided development satisfies applicable legislation. Alternative 1A generally follows existing transmission ROWs (as encouraged by local OPs) but approaches Tilbury's fringe area where the line deviates south around the community. This deviation aligns with the OP but is not as pronounced as Alternative 1B and 1D. Alternative 1A co-locates with 41.67km of existing infrastructure.	Local Official Plans (OPs) permit utility/transmission facilities on any land use designation provided development satisfies applicable legislation. Alternative 1B generally follows existing transmission ROWs (as encouraged by local OPs) but approaches Tilbury's fringe area where the line deviates south around the community. This deviation aligns with the official plan and is further from the fringe area compared to Alternative 1A and 1C. Alternative 1B co-locates with 36.4km of existing infrastructure.	Local Official Plans (OPs) permit utility/transmission facilities on any land use designation provided development satisfies applicable legislation. Alternative 1C generally follows existing transmission ROWs (as encouraged by local OPs) but approaches Tilbury's fringe area where the line deviates south around the community. This deviation aligns with the official plan but is not as pronounced as Alternative 1B and 1D. Alternative 1C co-locates with 34.75km of existing infrastructure.	Local Official Plans (OPs) permit utility/transmission facilities on any land use designation provided development satisfies applicable legislation. Alternative 1D generally follows existing transmission ROWs (as encouraged by local OPs) but approaches Tilbury's fringe area where the line deviates south around the community. This deviation aligns with the official plan and is further from the fringe area compared to Alternative 1A and 1C. Alternative 1D co-locates with 29.5km of existing infrastructure.	Local Official Plans (OPs) permit utility/transmission facilities on any land use designation provided development satisfies applicable legislation. All variations of Alternative 2 cross through a built-up area/Urban Area designation at the northern area of Comber which is not preferred by the municipality. Alternative 2A is separated from Tilbury's Urban Fringe Area. Alternative 2A co-locates with 26.04km of existing infrastructure of which 15.66 km involves repurposing an existing idle transmission line.	Local Official Plans (OPs) permit utility/transmission facilities on any land use designation provided development satisfies applicable legislation. All variations of Alternative 2 cross through a built-up area/Urban Area designation at the northern area of Comber which is not preferred by the municipality. Alternative 2B is separated from Tilbury's Urban Fringe Area. Alternative 2B co-locates with 24.29km of existing infrastructure of which 3.65 km involves repurposing an existing idle transmission line.	Local Official Plans (OPs) permit utility/transmission facilities on any land use designation provided development satisfies applicable legislation.All variations of Alternative 2 cross through a built-up area/Urban Area designation at the northern area of Comber which is not preferred by the municipality. Alternative 2C is separated from Tilbury's Urban Fringe Area. Alternative 2C co-locates with 19.81km of existing infrastructure..	Local Official Plans (OPs) permit utility and transmission facilities on any land use designation provided development satisfies applicable legislation. Unlike other alternatives, Alternative 3 does not parallel existing transmission lines which is discouraged in local OP policies. It does avoid built-up areas and Urban Fringe Areas as identified in the Municipality of Lakeshore OP. Alternative 3 co-locates with 1.5km of existing infrastructure.
			Score	5	5	5	5	4	4	3	1
Future land use designations	Alignment with future land use designations including potential future settlement area expansion plans, growth areas and development boundaries, as defined by the Provincial Policy Statement and local Municipal Official Plans (does not include Designated Natural Areas or Natural Environment designations under the PPS)	7.5	Reasoned Argument	Does not traverse land identified for future development potential.	Does not traverse land identified for future development potential.	Right of way traverses 10.78 ha of lands identified for future development potential by local municipality.	Right of way traverses 10.78 ha of lands identified for future development potential by local municipality.	Right of way traverses 14.65 ha of lands identified for future development potential by local municipality.	Right of way traverses 14.65 ha of lands identified for future development potential by local municipality.	Right of way traverses 9.85 ha of lands identified for future development potential by local municipality.	Does not traverse land identified for future development potential.
			Score	5	5	2	2	1	1	2	5
Agricultural Operations	Effects to agricultural operations including farming of land, movement of farm machinery and access to processing facilities	20	Reasoned Argument	Traverses 164.06 ha of prime agricultural land, of which 41.67 km is co-located with existing infrastructure.	Traverses 173.65 ha of prime agricultural land, of which 36.40 km is co-located with existing infrastructure.	Traverses 177.74 ha of prime agricultural land, of which 34.75 km is co-located with existing infrastructure.	Traverses 187.31 ha of prime agricultural land, of which 29.50 km is co-located with existing infrastructure.	Traverses 165.74 ha of prime agricultural land, of which 10.38 km is co-located with existing infrastructure and an additional 15.66 km includes reusing an existing idle transmission corridor (inluding replacing existing Tx towers) which provide easier ROW access and maximizes the use of existing ROW corridors without widening or creating new corridors.	Traverses 183.6 ha of prime agricultural land, of which 20.64 km is co-located with existing infrastructure and an additional 3.65 km includes reusing an existing idle transmission corridor (inluding replacing existing Tx towers) which provide easier ROW access and maximizes the use of existing ROW corridors without widening or creating new corridors.	Traverses 195.74 ha of prime agricultural land, of which 19.81 km is co-located with existing infrastructure.	Traverses 211.91 ha of prime agricultural land, of which 1.50 km is co-located with existing infrastructure.
			Score	5	4	4	3	5	3	2	1
Petroleum Operations	Effects to petroleum operations including access to petroleum wells or resources and distribution networks/ pipelines	2.5	Reasoned Argument	Alternative 1A has 2 abandoned petroleum wells within the ROW and crosses 24.96 ha of petroleum pool resources.	Alternative 1B has 2 abandoned petroleum wells within the ROW and crosses 24.96 ha of petroleum pool resources.	Alternative 1C has 2 abandoned petroleum wells within the ROW and crosses 26.18 ha of petroleum pool resources.	Alternative 1D has 2 abandoned petroleum wells within the ROW and crosses 26.18 ha of petroleum pool resources.	Alternative 2A has 2 abandoned petroleum wells within the ROW and crosses 5.48 ha of petroleum pool resources.	Alternative 2B has 2 abandoned petroleum wells within the ROW and crosses 5.48 ha of petroleum pool resources.	Alternative 2C has 2 abandoned petroleum wells within the ROW and crosses 13.46 ha of petroleum pool resources.	Alternative 3A has 2 abandoned petroleum wells within the ROW and crosses 32.99 ha of petroleum pool resources.
			Score	2	2	2	2	5	5	4	1
Effects to residential buildings, properties or site plans	Effects to existing residential properties including proximity to existing homes, site plan alteration or building effects	15	Reasoned Argument	92 residential homes and/or residential parcels are located within the project study area for Alternative 1A	79 residential homes and/or residential parcels are located within the project study area for Alternative 1B	76 residential homes and/or residential parcels are located within project study area for Alternative 1C	63 residential homes and/or residential parcels are located withinthe project study area for Alternative 1D	107 residentia homes and/or residential parcels are located withinthe project study area for Alternative 2A	80 residential home and/or residential parcels are located within the project study area for Alternative 2B	103 residential homes and/or residential parcels are located within the project study area for Alternative 2C	58 residential homes and/or residential parcels are located within the project study area for Alternative 3
			Score	2	3	4	5	1	3	1	5
Effects to commercial/industrial buildings, properties, site plans or business operations/ supply chains	Effects to existing commercial or industrial properties including proximity to commercial/industrial operations, building effects or supply chain effects	10	Reasoned Argument	5 commercial properties are located within the right of way for Alternative 1A .	5 commercial properties are located within the right of way for Alternative 1B.	4 commercial properties are located within the right of way for Alternative 1C.	4 commercial properties are located within the right of way for Alternative 1D.	3 commercial properties are located within the right of way for Alternative 2A.	3 commercial properties are located within the right of way for Alternative 2B.	3 commercial properties are located the right of way for Alternative 2C.	No commercial properties are located within the right of way for Alternative 3.
			Score	1	1	2	2	3	3	3	5
Source water Protection	Effects to source water resources including policy areas and drinking water sources for private landowners	10	Reasoned Argument	Crosses 91.21 ha of Source Water Protection designated areas.	Crosses 94.56 ha of Source Water Protection designated areas.	Crosses 129.56 ha of Source Water Protection designated areas.	Crosses 132.86 ha of Source Water Protection designated areas.	Crosses 125.8 ha of Source Water Protection designated areas.	Crosses 129.14 ha of Source Water Protection designated areas.	Crosses 104.81 ha of Source Water Protection designated areas.	Crosses 117.97 ha of Source Water Protection designated areas.
			Score	5	5	1	1	1	1	4	2
Cultural Resources	Effects to properties or landscapes with cultural heritage resource potential	10	Reasoned Argument	Potentially affects 24 properties with cultural heritage value or interest as well as four properties within the nationally significant Buxton NHSC and one property listed on the Lakeshore Municipal Heritage Register.	Potentially affects 24 properties with cultural heritage value or interest as well as four properties within the nationally significant Buxton NHSC and one property listed on the Lakeshore Municipal Heritage Register.	Potential to affect 27 properties with cultural heritage value and interest including sites at the Buxton NHSC and a property listed on the Lakeshore Municipal Heritage Register.	Potential to affect 26 properties with cultural heritage value and interest including sites at the Buxton NHSC and a property listed on the Lakeshore Municipal Heritage Register.	Potential to affect 28 properties with cultural heritage value or interest but does not impact the Buxton NHSC.	Potential to affect 25 properties with cultural heritage value or interest but does not impact the Buxton NHSC.	Potential to affect 18 properties with cultural heritage value or interest but does not impact the Buxton NHSC.	Potential to affect 17 properties with cultural heritage value or interest while also affecting the Buxton NHSC.
			Score	1	1	2	2	3	3	4	3

			Alternative Routes								
Criteria	Metric of Measurement/Scoring	Criteria Weight	Scoring Scale: 1 = Most Effect 3 = Neutral 5 = Least Effect	Alternative 1A	Alternative 1B	Alternative 1C	Alternative 1D	Alternative 2A	Alternative 2B	Alternative 2C	Alternative 3
Archaeological Resources	Effects to lands with archaeological potential, proximity to known archaeological sites	15	Reasoned Argument	Traverses 79 features with archaeological potential.	Traverses 69 features with archaeological potential.	Traverses 73 features with archaeological potential.	Traverses 65 features with archaeological potential.	Traverses 52 features with archaeological potential.	Traverses 46 features with archaeological potential.	Traverses 54 features with archaeological potential.	Traverses 69 features with archaeological potential.
			Score	1	2	2	3	5	5	4	2
Aggregate Resources Extraction Areas/Operations (Pits/Quarries)	Effects to aggregate extraction site operations including expansion plans, and site operations	0	Reasoned Argument	No aggregate resources or operations were identified within the PSA	No aggregate resources or operations were identified within the PSA	No aggregate resources or operations were identified within the PSA	No aggregate resources or operations were identified within the PSA	No aggregate resources or operations were identified within the PSA	No aggregate resources or operations were identified within the PSA	No aggregate resources or operations were identified within the PSA	No aggregate resources or operations were identified within the PSA
			Score	5	5	5	5	5	5	5	5
Socio-Economic Factor Total Weighted Score				307.5	317.5	290	300	320	310	280	275
Technical and Cost			Technical and Cost Factor								
Line Length	Total length of each route or variation	20	Reasoned Argument	Total line length is 48.04 km.	Total line length is 48.68 km.	Total line length is 48.48 km.	Total line length is 49.11 km.	Total line length is 48.26 km.	Total line length is 48.32 km.	Total line length is 47.74 km.	Total line length is 49.35 km.
			Score	5	3	3	1	4	4	5	1
Line Angles	Number of turns in each route/variation, as well as the angle of the turn (sharper or wider than 30^0)	20	Reasoned Argument	Alternative 1A requires 5 turns greater than 30^0.	Alternative 1B requires 6 turns greater than 30^0.	Alternative 1C requires 7 turns greater than 30^0.	Alternative 1D requires 8 turns greater than 30^0.	Alternative 2A requires 7 turns greater than 30^0.	Alternative 2B requires 7 turns greater than 30^0.	Alternative 2C requires 8 turns greater than 30^0.	Alternative 3 requires 3 turns greater than 30^0.
			Score	4	3	2	1	2	2	1	5
Crossings	Total number of crossings of: watercourses, railways, Highways, Existing 230 kV transmission lines, etc.	12.5	Reasoned Argument	Crosses 0.04 km of railway, 1.81 km of roadway, 0.81 km of utilities, 2.11 km of watercourse, 2.47 km of constructed drains, and 0.13 km of wind farm transmission line for a total of 7.38 km of infrastructure crossings within the ROW.	Crosses 0.04 km of railway, 1.94 km of roadway, 0.69 km of utilities, 2.21 km of watercourse, 2.47 km of constructed drains and 0.13 km of wind farm transmission line for a total of 7.48 km of infrastructure crossings within the ROW.	Crosses 0.04 km of railway, 2.19 km of roadway, 0.80 km of utilities, 1.89 km of watercourse, 2.22 km of constructed drains and 0.13 km of wind farm transmission line for a total of 7.27 km of infrastructure crossings within the ROW.	Crosses 0.04 km of railway, 1.59 km of roadway, 0.68 km of utilities, 1.99 km of watercourse, 2.21 km of constructed drains and 0.13 km of wind farm transmission line for a total of 6.64 km of infrastructure crossings within the ROW.	Crosses 0.29 km of railway, 1.93 km of roadway, 1.24 km ofutilities, 1.57 km of watercourse, 2.65 km of constructed drains and 0.04 km of wind farm transmission line for a total of 7.72 km of infrastructure crossings within the ROW.	Crosses 0.31 km of railway, 1.71 km of roadway, 1.27 km of utilities, 1.63 km of watercourse, 2.46 km of constructed drains and 0.04 km of wind farm transmission line for a total of 7.41 km of infrastructure crossings within the ROW.	Crosses 0.29 km of railway, 1.85 km of roadway, 0.56 km of utilities, 1.94 km of watercourse, 2.89 km of constructed drains and 0.04 km of wind farm transmission line for a total of 7.56 km of infrastructure crossings within the ROW.	Crosses 0.05 km of railway, 2.06 km of roadway, 0.35 km of utilities, 2.59 km of watercourse, 3.38 km of constructed drains and 0.15 km of wind farm transmission line for a total of 8.58 km of infrastructure crossings within the ROW.
			Score	4	3	4	5	3	4	3	1
Parallel & Adjacent to Existing Infrastructure	Total distance of each route/variation that parallels an existing transmission line corridor (preference to routes/variations with longer parallel distance) Total distance of each route/variation that parallels a non-TX linear infrastructure/corridor (E.g., Highway 401; preference to routes/variations with longer parallel distance) Total distance parallel/adjacent to underground facilities (pipelines, sewers, communication/power line, etc.) preference to routes/variations with less parallel distance	5	Reasoned Argument	Parallels 41.67 km of existing infrastructure but does not reuse the existing idle line corridor.	Parallels 36.40 km of existing infrastructure but does not reuse the existing idle line corridor.	Parallels 34.75 km of existing infrastructure but does not reuse the existing idle line corridor.	Parallels 29.50 km of existing infrastructure but does not reuse the existing idle line corridor.	Parallels 26.04 km of existing infrastructure of which reuses 15.66 km of existing idle line ROW which parallels an existing active rail line.	Parallels 24.29 km of existing infrastructure of which reuses 3.65 km of existing idle line ROW which parallels an existing active rail line.	Parallels 19.81 km of existing infrastructure but does not reuse the existing idle line corridor.	Parallels 1.5 km of existing infrastructure but does not reuse the existing idle line corridor.
			Score	5	5	5	4	4	3	3	1
Proximity to Wind Turbines	Proximity to wind turbines	5	Reasoned Argument	Similar to Alternatives 1B, 1C and 1D, Alternative 1A does not directly impact any existing wind turbines. There are however, 2 turbines within a 150-200m radius and one turbine within 100-150m radius of the ROW. This is similar to other Alternative 1 options but worse than Alternative 2 and 3 options.	Similar to Alternatives 1A, 1C and 1D, Alternative 1B does not directly impact any existing wind turbines. There are however, 2 turbines within a 150-200m radius and one turbine within 100-150m radius of the ROW. This is similar to other Alternative 1 options but worse than Alternative 2 and 3 options.	Similar to Alternatives 1A, 1B and 1D, Alternative 1C does not directly impact any existing wind turbines. There are however, 2 turbines within a 150-200m radius and one turbine within 100-150m radius of the ROW. This is similar to other Alternative 1 options but worse than Alternative 2 and 3 options.	Similar to Alternatives 1A, 1B and 1C, Alternative 1D does not directly impact any existing wind turbines. There are however, 2 turbines within a 150-200m radius and one turbine within 100-150m radius of the ROW. This is similar to other Alternative 1 options but worse than Alternative 2 and 3 options.	Similar to Alternatives 2B and 2C, Alternative 2A does not directly impact any existing wind turbines. There is however one turbine within 150-200m of the ROW and two turbines within 200-250m of the ROW. This is similar to Alternatives 2B, 2C, 3 but better than Alternative 1A, 1B, 1C and 1D.	Similar to Alternatives 2A and 2C, Alternative 2B does not directly impact any existing wind turbines. There is however one turbine within 150-200m of the ROW and two turbines within 200-250m of the ROW. which is similar to Alternatives 2A, 2B and 2C but better than Alternative 1A, 1B, 1C and 1D.	Similar to Alternatives 2A and 2B, Alternative 2C does not directly impact any existing wind turbines. There is however one turbine within 150-200m of the ROW and two turbines within 200-250m of the ROW.	Alternative 3 does not directly impact any existing wind turbines. There is however one turbine within 150-200m of the ROW and one turbine within 200-250m of the ROW which is similar to Alternatives 2A, 2B and 2C but better than Alternative 1A, 1B, 1C and 1D.
			Score	3	3	3	3	4	4	4	4

Criteria	Metric of Measurement/Scoring	Criteria Weight	Scoring Scale: 1 = Most Effect 3 = Neutral 5 = Least Effect	Alternative Routes							
				Alternative 1A	Alternative 1B	Alternative 1C	Alternative 1D	Alternative 2A	Alternative 2B	Alternative 2C	Alternative 3
Impacted Property Parcels and Property Acquisition	Real Estate and land acquisition considerations, including the total number of property parcels traversed and the anticipated number of property buyouts	25	Reasoned Argument	Property rights required on 164 property parcels and requires a buy-out of 6 identified properties.	Property rights required on 166 property parcels and requires a buy-out of 3 identified properties.	Property rights required on 174 property parcels and requires a buy-out of 4 identified properties.	Property rights required on 177 property parcels and requires a buy-out of 1 identified property.	Property rights required on123 property parcels and requires a buy-out of 4 identified properties.	Property rights required on 132 property parcels and requires a buy-out of 1 identified property.	Property rights required on 163 property parcels and requires a buy-out of 1 identified property.	Property rights required on 165 property parcels.
			Score	2	2	2	3	4	5	3	3
Overall Constructability	Other considerations affecting the complexity of construction, such as information on soils, construction obstacles and potential construction conflicts	12.5	Reasoned Argument	Alternative 1 line options are located in soil type composed of course-grained glaciolacustrine deposits (Sand and gravel with minor silt) and till (Clayey to silty in composition and stiff to very stiff). These options are less favorable than option 3A but better than option 2A, 2B and 2C based on the publicly available geotechnical data. Routes 1C and 1D are less desirable due to conflicts with MTO.	Alternative 1 line options are located in soil type composed of course-grained glaciolacustrine deposits (Sand and gravel with minor silt) and till (Clayey to silty in composition and stiff to very stiff). These options are less favorable than option 3A but better than option 2A, 2B and 2C based on the publicly available geotechnical data. Routes 1C and 1D are less desirable due to conflicts with MTO.	Alternative 1 line options are located in soil type composed of course-grained glaciolacustrine deposits (Sand and gravel with minor silt) and till (Clayey to silty in composition and stiff to very stiff). These options are less favorable than option 3A but better than option 2A, 2B and 2C based on the publicly available geotechnical data. Routes 1C and 1D are less desirable due to conflicts with MTO.	Alternative 1 line options are located in soil type composed of course-grained glaciolacustrine deposits (Sand and gravel with minor silt) and till (Clayey to silty in composition and stiff to very stiff). These options are less favorable than option 3A but better than option 2A, 2B and 2C based on the publicly available geotechnical data. Routes 1C and 1D are less desirable due to conflicts with MTO.	Alternative 2 options are located in soil type composed of course-grained glaciolacustrine deposits (Sand and gravel with minor silt) and till (Clayey to silty in composition and stiff to very stiff). For these reasons, these options are the least favorable based on the publicly available geotechnical data and will be the most expensive area to design and build the tower foundations. In addition, variation 2A and 2B will required to dismantle the 115 kV circuit K6Z (~16km along Route 2A and ~3.6 km along Route 2B). Route 2C does not require removal of idle TX towers, and less distance in undesirable soil types, but is not preferred by MTO and will likely have much more involved permitting/review process and potential for conflicts with MTO construction/maintenance work).	Alternative 2 options are located in soil type composed of course-grained glaciolacustrine deposits (Sand and gravel with minor silt) and till (Clayey to silty in composition and stiff to very stiff). For these reasons, these options are the least favorable based on the publicly available geotechnical data and will be the most expensive area to design and build the tower foundations. In addition, variation 2A and 2B will required to dismantle the 115 kV circuit K6Z (~16km along Route 2A and ~3.6 km along Route 2B). Route 2C does not require removal of idle TX towers, and less distance in undesirable soil types, but is not preferred by MTO and will likely have much more involved permitting/review process and potential for conflicts with MTO construction/maintenance work).	Alternative 2 options are located in soil type composed of course-grained glaciolacustrine deposits (Sand and gravel with minor silt) and till (Clayey to silty in composition and stiff to very stiff). For these reasons, these options are the least favorable based on the publicly available geotechnical data and will be the most expensive area to design and build the tower foundations. In addition, variation 2A and 2B will required to dismantle the 115 kV circuit K6Z (~16km along Route 2A and ~3.6 km along Route 2B). Route 2C does not require removal of idle TX towers, and less distance in undesirable soil types, but is not preferred by MTO and will likely have much more involved permitting/review process and potential for conflicts with MTO construction/maintenance work).	This line route option is located primarily in a most appropriate and favorable soil type composed of till (Clayey to silty in composition and stiff to very). This route will be the most cost effective to design and build the tower foundation.
			Score	3	3	2	2	1	1	1	5
Technical and Cost Factor Total Weighted score				357.5	285	265	237.5	310	342.5	280	295
Anishnawbek and Haudenosaunee Culture, Values and Land Use				Anishnawbek and Haudenosaunee Culture, Values and Land Use Factor							
Proximity to Areas of Historical Significance	Relative proximity to Anishnawbek and Haudenosuanee identified areas of historical significance associated with the Thames River	14.3	Reasoned Argument	Not in close proximity to identified areas of historic significance.	Not in close proximity to identified areas of historic significance.	Not in close proximity to identified areas of historic significance.	Not in close proximity to identified areas of historic significance.	Alternative 2A is closer (than other alternatives) in proximity to identified area of historic significance, but not as close as Alternative 2B.	Alternative 2B is in closest proximity to identified area of historic significance.	Not in close proximity to identified areas of historic significance.	Not in close proximity to identified areas of historic significance.
			Score	5	5	5	5	3	1	5	5
Effects to First Nations revenue generating projects	Potential for effects to identified project sites (eg. Belle River and North Kent Wind Farms)	14.3	Reasoned Argument	Effects to revenue generating projects are not anticipated.	Effects to revenue generating projects are not anticipated.	Effects to revenue generating projects are not anticipated.	Effects to revenue generating projects are not anticipated.	Effects to revenue generating projects are not anticipated.	Effects to revenue generating projects are not anticipated.	Effects to revenue generating projects are not anticipated.	Effects to revenue generating projects are not anticipated.
			Score	5	5	5	5	5	5	5	5
Areas that support hunting/trapping/ harvesting grounds	Effects on lands with habitat or vegetation types that support or have potential to support hunting/trapping/harvesting activities and medicinal plants	14.3	Reasoned Argument	Affects 6.92 ha of lands identified that have potential to support hunting, trapping, and harvesting activities.	Affects 6.99 ha of lands identified that have potential to support hunting, trapping, and harvesting activities.	Affects 6.29 ha of lands identified that have potential to support hunting, trapping, and harvesting activities.	Affects 6.37 ha of lands identified that have potential to support hunting, trapping, and harvesting activities.	Affects 6.18 ha of lands identified that have potential to support hunting, trapping, and harvesting activities.	Affects 5.51 ha of lands identified that have potential to support hunting, trapping, and harvesting activities.	Affects 6.92 ha of lands identified that have potential to support hunting, trapping, and harvesting activities.	Affects 6.73 ha of lands identified that have potential to support hunting, trapping, and harvesting activities.
			Score	1	1	3	3	3	5	1	1

Criteria	Metric of Measurement/Scoring	Criteria Weight	Scoring Scale: 1 = Most Effect 3 = Neutral 5 = Least Effect	Alternative Routes							
				Alternative 1A	Alternative 1B	Alternative 1C	Alternative 1D	Alternative 2A	Alternative 2B	Alternative 2C	Alternative 3
Areas that support fish bearing waters with identified or inferred habitat of game fish species	Effects to identified aquatic habitat and/or known watercourses with fishery management programs	14.3	Reasoned Argument	Traverses 2.11 km of watercourse, crossing 43 watercourses in total with potential to effect fish habitat. Does not cross any watercourses with publicly known fish stocking programs.	Traverses 2.21 km of watercourse, crossing 46 watercourses in totalwith potential to effect fish habitat. Does not cross any watercourses with publicly known fish stocking programs.	Traverses 1.89 km of watercourse, crossing 42 watercourses in total with potential to effect fish habitat. Does not cross any watercourses with publicly known fish stocking programs.	Traverses 1.99 km of watercourse, crossing 43 watercourses in total with potential to effect fish habitat. Does not cross any watercourses with publicly known fish stocking programs.	Traverses 1.57 km of watercourse, crossing 26 watercourses in total with potential to effect fish habitat. Does not cross any watercourses with publicly known fish stocking programs.	Traverses 1.63 km of watercourse, crossing 28 watercourses in total with potential to effect fish habitat. Does not cross any watercourses with publicly known fish stocking programs.	Traverses 1.94 km of watercourse, crossing 32 watercourses in total with potential to effect fish habitat. Does not cross any watercourses with publicly known fish stocking programs.	Traverses 2.59 km of watercourse, crossing 46 watercourses in total with potential to effect fish habitat. Does not cross any watercourses with publicly known fish stocking programs.
			Score	2	2	3	2	5	5	4	1
Effects to rare/undisturbed native habitats/ecosystems	Effects to rare habitats in Southwestern Ontario including tall grass prairies, savannah, native woodlands, natural wetlands, etc. and measured level of disturbance of native habitat and ecosystems based on calculated average coefficient of conservatism	14.3	Reasoned Argument	Affects 1.85 ha of native habitat . The measured level of disturbance to native habitats (within Alternative 1 routes) is calculated at 3.83 average coefficient of conservatism (highly disturbed).	Affects 1.85 ha of native habitat. The measured level of disturbance to native habitats (within Alternative 1 routes) is calculated at 3.83 average coefficient of conservatism (highly disturbed).	Affects 1.51 ha of native habitat. The measured level of disturbance to native habitats (within Alternative 1 routes) is calculated at 3.83 average coefficient of conservatism (highly disturbed).	Affects 1.51 ha of native habitat. The measured level of disturbance to native habitats (within Alternative 1 routes) is calculated at 3.83 average coefficient of conservatism (highly disturbed).	Affects 1.90 ha of native habitat. The measured level of disturbance to native habitats (within Alternative 2 routes) is calculated at 3.21 average coefficient of conservatism (highly disturbed).	Affects 1.67 ha of native habitat. The measured level of disturbance to native habitats (within Alternative 2 routes) is calculated at 3.21 average coefficient of conservatism (highly disturbed).	Affects 1.67 ha of native habitat. The measured level of disturbance to native habitats (within Alternative 2 routes) is calculated at 3.21 average coefficient of conservatism (highly disturbed).	Affects 1.03 ha of native habitat. The measured level of disturbance to native habitats (within Alternative 2 routes) is calculated at 3.72 average coefficient of conservatism (highly disturbed).
			Score	1	1	2	2	3	4	4	3
Rare/Sensitive species regeneration potential	Long-term effects to SAR and their regeneration potential	14.3	Reasoned Argument	Affects 6.58 ha of potential SAR habitat (Butternut, Eastern Foxsnake and SAR bats) and subsequent regeneration potential,	Affects 6.64 ha of potential SAR habitat (Butternut, Eastern Foxsnake and SAR bats) and subsequent regeneration potential,	Affects 5.57 ha of potential SAR habitat (Eastern Foxsnake and SAR bats), including subsequent species regeneration potential.	Affects 5.63 ha of potential SAR habitat (Eastern Foxsnake and SAR bats), including subsequent species regeneration potential.	Affects 4.79 ha of potential SAR habitat (Eastern Foxsnake, Lake Chubsucker, Lilliput and SAR bats), including subsequent species regeneration potential.	Affects 4.42 ha of potential SAR habitat (Eastern Foxsnake, Lake Chubsucker, Lilliuput and SAR bats), including subsequent species regeneration potential.	Affects 5.27 ha of potential SAR habitat (Eastern Foxsnake, Lillliput and SAR bats), including subsequent species regeneration potential.	Affects 5.12 ha of potential SAR habitat (Eastern Foxsnake and SAR bats), including subsequent species regeneration potential.
			Score	1	1	3	3	5	5	4	4
Co-Location of existing infrastructure	Length of line that is cited within or beside existing linear infrastructure	14.3	Reasoned Argument	Parallels 41.67 km of existing infrastructure.	Parallels 36.40 km of existing infrastructure.	Parallels 34.75 km of existing infrastructure.	Parallels 29.50 km of existing infrastructure.	Parallels 26.04 km of existing infrastructure.	Parallels 24.29 km of existing infrastructure.	Parallels 19.81 km of existing infrastructure.	Parallels 1.5 km of existing infrastructure.
			Score	5	5	5	4	4	3	3	1
Anishnawbek and Haudenosaunee Culture, Values and Land Use Factor Total Weighted Score				285.7	285.7	371.4	342.9	400.0	400.0	371.4	285.7

Final Accumulated Total Overall Weighted Score	1195.7	1133.2	1241.4	1165.4	1365.0	1352.5	1166.4	1215.7

ENVIRONMENTAL DEFENCE INTERROGATORY - 10

Reference:
No reference provided.

Interrogatory:
a) With respect to Hydro One's selection of the proposed tower and conductor technologies, please file the IESO's latest draft of its transmission losses guideline.

b) Please calculate the cost-effectiveness of using a larger conductor that would account for the value of both the energy savings and the capacity savings.

Response:
a) Hydro One has no updates to its response as provided in Exhibit I, Tab 2, Schedule 7.

b) Please see part a).

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HAUDENOSAUNEE DEVELOPMENT INSTITUTE INTERROGATORY - 05

Reference:
Project Costs

Preamble:
In Procedural Order No. 2, dated August 23, 2022, the Ontario Energy Board ("OEB") made

> provision for supplemental interrogatories to allow parties to explore the quantum of Environmental Assessment costs or costs related to Indigenous consultation, that are included in the application." The OEB also indicated that it "would be assisted by a better understanding of what these costs are forecast to be, to the extent that they are reflected in the Project budget and are intended to ultimately be recovered through rates.

Interrogatory:

1) What is the quantum of Hydro One's costs in relation to the Environmental Assessment (alternatively, an Environmental Study Report)?
    a. Please provide materials detailing Hydro One's costs relating to the Environmental Assessment and/or Study Report.

    b. Do these costs include the completion and delivery of the final Environmental Study Report?

    c. If not, what are the expected costs to complete and deliver the final Environmental Study Report?

    d. When does Hydro One expect to deliver a final Environmental Study Report?

2) What is the quantum of Hydro One's costs in relation to Indigenous consultation?
    a. Please provide materials detailing Hydro One's costs relating to Indigenous consultation.

3) What is the quantum of Hydro One's costs in relation to engagement and/or consultation with the Haudenosaunee Confederacy, whether through the Haudenosaunee Confederacy Chiefs Council (the "HCCC") or the Haudenosaunee Development Institute ("HDI")?
    a. Please provide materials detailing Hydro One's costs relating to engagement and/or consultation with the Haudenosaunee Confederacy, whether through the HCCC or HDI.

4) What is the quantum of capacity funding provided by Hydro One to Indigenous groups or Nations in relation to the proposed project?
   a. Please provide materials detailing Hydro One's provision of capacity funding to Indigenous groups or Nations in relation to the proposed project.

5) What is the quantum of capacity funding provided by Hydro One to the Haudenosaunee Confederacy in relation to the proposed project, whether through the HCCC or HDI?
   a. Please provide materials detailing Hydro One's provision of capacity funding to the Haudenosaunee Confederacy in relation to the proposed project, whether through the HCCC or HDI.

   b. If capacity funding has not been provided to the Haudenosaunee Confederacy, please explain why.

6) What is the quantum (actual or estimated) of Hydro One's costs in relation to the following:
   a. Obtaining the consent of the Haudenosaunee, through the HCCC, to proceed with the proposed project on land subject to established Haudenosaunee treaty rights and interests?

   b. Justifying the infringement of established Haudenosaunee treaty rights and interests resulting from Hydro One's proposed project?

   c. Responding to protest relating to construction of Hydro One's proposed project on treaty lands?

   d. Hydro One's exposure to discrimination-based legal claims where Hydro One has entered into equity agreements with particular Indigenous groups to the exclusion of others?

7) Will the costs enumerated in Question 6 form part of Hydro One's future rate-based applications in respect of the proposed project?
   a. How are the costs enumerated in Question 6 accounted for in terms of assessing material risks associated with Hydro One's proposed project?

Response:

1)

a. The costs specific to the preparation of the Class Environmental Assessment Report for the Chatham to Lakeshore Project are currently estimated to be approximately $3,500,000.

b. Yes.

c. Please refer to response to part b).

d. Upon successful conclusion of the Section 16 Order Request process the Environmental Study Report will be finalized and submitted to the MECP, thus concluding the Class EA process.

2) Estimated costs directly related to Indigenous consultation initiatives are approximately $7 million. These costs take into account both project specific factors (e.g., number and extent of communities affected, nature of impacts, etc.) and more general factors (e.g., prior project experiences, planned engagements and external resourcing requirements).

In this case, the Government of Ontario's decision to delegate administrative responsibilities of Crown consultation to Hydro One listed the Indigenous governments to be consulted.[1] Hydro One's overall project cost estimates are in alignment with these requirements.

A portion of this cost estimate includes the possible provision for Capacity Funding Agreements ("CFA"s). Capacity funding is intended to provide affected Indigenous governments with internal and external resources in order to conduct consultative tasks if required. This may include activities such as reviewing environmental and archeological studies, conducting and participating in community meetings and taking part in field activities. Capacity funding has been offered to all Indigenous governments included in the Crown Delegation list for the Project.

The amount of funding contemplated under an individual CFA is commercially sensitive and subject to negotiations which take into account the uniqueness of each group and the specific circumstances. Hydro One's business practice is to not disclose this information while understanding that this information may be disseminated to members of a particular Indigenous government including leadership members.

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[1] November 29, 2019 Ministry of Energy, Northern Development and Mines letter to Hydro One listing the Indigenous governments to be consulted is provided as Attachment 1 of this response.

3) Please see Response 2 above.

HCCC and HDI will have knowledge of the funding offered by Hydro One to support consultation and assist in facilitating the HCCC/HDI participation, monitoring and outstanding field work that was carried out during the spring of 2022. These amounts do not result in a material impact to the rate impacts associated with the overall estimated project costs. Nor do these costs result in any material change to the overall project cost estimates as outlined in the Application.

In view of these circumstances, Hydro One does not consider disclosure of further detail as providing additional assistance to the Board in its consideration of the relief sought in this application.

4) Please see Response 2 above.

5) Please see Response 3 above

6) Capacity funding was provided to Haudenosaunee Confederacy to monitor and participate in spring 2022 project fieldwork activities and, in line with Hydro One's approach with Indigenous governments on the Project, has been offered additional Capacity Funding to support other engagements required on the Project.

7) Hydro One's budgeting process does not specifically evaluate the items described in Question 6 (a)-(d) above. Instead, and as noted in Response 2 above, the approach considers project specific attributes, such as Indigenous government input, proximity of the Project to an affected Indigenous community, consultations carried out with communities, evaluation of the concerns raised through consultations, experience with other projects and the costs to mitigate such impacts.

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Ministry of Energy,
Northern Development
and Mines

77 Grenville Street, 6th Floor
Toronto ON M7A 2C1

Ministère de l'Énergie,
du Développement du Nord
et des Mines

77, rue Grenville, 6e étage
Toronto ON M7A 2C1

Ontario

November 29, 2019

VIA EMAIL

Elise Croll
Director, Environmental Services
Hydro One Networks Inc.
483 Bay Street
South Tower, 12th Floor
Toronto, Ontario M5G 2P5

Re: Chatham to Lakeshore Transmission Line Project

Dear Ms. Croll:

Thank you for your letter dated July 5th, 2019 requesting clarification from the Ministry of Energy, Northern Development and Mines (ENDM) on the duty to consult requirements for the proposed Chatham to Lakeshore Transmission Line Project (the Project).

As your letter states, the preliminary scope of the Project consists of a new, 230 kilovolt double-circuit line between the existing Chatham Switching Station in the Municipality of Chatham-Kent to the proposed Lakeshore Transformer Station, in the Town of Lakeshore. The Project will help ensure the transmission system remains adequate to meet electricity demand, which is expected to increase significantly over the next decade due to strong agricultural growth in the Windsor-Essex area.

On behalf of Ontario (the Crown), ENDM has reviewed the information provided by Hydro One with respect to the Project and assessed it against the Crown's current understanding of the interests and rights of communities in the area. In doing so, ENDM has determined that the Project may have the potential to affect First Nation and/or Métis communities who hold or claim Aboriginal or treaty rights protected under section 35 of Canada's *Constitution Act* 1982.

The Crown has a constitutional duty to consult and, where appropriate, accommodate Aboriginal communities when the Crown contemplates conduct that might adversely impact established or asserted Aboriginal or Treaty rights. While the legal responsibility to meet the duty to consult lies with the Crown, the Crown may delegate the day-to-day, procedural aspects of consultation to project proponents.

The Crown must satisfy itself that both the substantive and procedural aspects of consultation are completed before issuing certain regulatory approvals. The Crown may use existing regulatory processes as a vehicle for fulfilling its constitutional duty, including the

"Class Environmental Assessment for Minor Transmission Facilities" (Class EA) under Ontario's *Environmental Assessment Act*. These consultation obligations are in addition to the public and Aboriginal consultation requirements outlined in the Class EA.

I am writing to advise you that on behalf of the Crown – including all provincial ministries – that ENDM is delegating the procedural aspects of consultation to Hydro One through this letter. ENDM expects that Hydro One will undertake the procedural aspects of consultation with respect to any regulated requirements for the proposed Project. The Crown will fulfill the substantive aspects of consultation and retain oversight over all aspects of the process for fulfilling the Crown duty. Please see below for details about the responsibilities of Hydro One in fulfilling the procedural aspects of consultation.

Based on the Crown's assessment of First Nation and Métis community rights and potential project impacts, the following Aboriginal communities should be consulted on the basis that they have or may have constitutionally protected Aboriginal and/or Treaty rights that may be adversely affected by the Project.

Community	Mailing Address
Aamjiwnaang First Nation	978 Tashmoo Ave. Sarnia, ON N7T 7H5
Bkejwanong (Walpole Island) First Nation	RR 3 Wallaceburg, ON N8A 4K9
Caldwell First Nation	14 Orange St. Leamington, ON N8H 1P5
Chippewas of Kettle and Stony Point First Nation	6247 Indian Lane Kettle and Stoney Point First Nation, ON N0N 1J1
Chippewas of the Thames First Nation	RR1 Muncey, ON N0L 1Y0
Oneida Nation of the Thames	RR2 Southwold, ON N0L 2G0
Six Nations of the Grand River First Nation Six Nations of the Grand River Elected Council	1695 Chiefswood Rd. Oshweken, ON N0A 1M0

Haudenosaunee Confederacy Chiefs Council/Haudenosaunee Development Institute	16 Sunrise Court, Suite 600 Oshweken, ON N0A 1M0

This rights-based consultation list is based on information that is subject to change. Aboriginal communities may make new rights assertions at any time, and other developments can occur that may require additional Aboriginal communities to be notified and/or consulted. If you become aware of potential rights impacts on communities that are not listed above at any stage of the consultation and approval process, kindly bring this to the attention of ENDM immediately, along with any information supporting the claim. ENDM will then assess whether it is necessary to include the community on the rights-based consultation list above.

The Crown relies on consultation conducted by proponents when it assesses the Crown's obligations and directs proponents during the regulatory process. It is ENDM's expectation that Hydro One will communicate directly with the communities listed above and that Hydro One will:

- Notify the communities that Hydro One has been delegated the procedural aspects of consultation by the Crown;
- Notify the communities that they may contact the Crown directly should they have any questions or concerns;
- If you have any questions or concerns relating to a specific ministry's mandate, you may contact any of the following ministry representatives. Indigenous communities may also be offered the following contact information should they wish to communicate directly with the Crown:

Ministry/Contact	Phone/Email
Chloe Lazakis – Senior Advisor, Indigenous Energy Policy Unit, **Ministry of Energy, Northern Development and Mines**	416 648 0294 Chloe.lazakis@ontario.ca
Craig Newton – Environmental Planner, **Ministry of the Environment, Conservation and Parks**	519 873 5014 Craig.newton@ontario.ca
Joe Vecchiolla – Policy Lead, Realty Policy Branch, **Ministry of Government and Consumer Services**	647 267 3247 Joseph.vecchiolla@ontario.ca

- Provide First Nation and Métis communities with timely notice of the project for the purposes of considering possible impacts on their Aboriginal and/or treaty rights;
- Provide First Nation and Métis communities with information about the project including anticipated impacts, and information on project timelines;
- Follow up with First Nation and Métis communities to ensure they have received project information and that they are aware of the opportunity to express comments and concerns about the project;
- Explain the regulatory and approval processes that apply to the project;

- Gather information about how the project may adversely impact the relevant Aboriginal and/or treaty rights (for example, hunting, fishing);
- Consider the comments and concerns raised by First Nation and Métis communities and providing responses;
- Where appropriate, discuss accommodation, including mitigation or other measures to address potential adverse impacts on Aboriginal and/or treaty rights;
- Where appropriate, develop and discuss with the Crown appropriate accommodation measures;
- Take reasonable steps to foster positive relationships with the First Nation and Métis communities;
- Bear the reasonable costs associated with these procedural aspects of consultation;
- Facilitate Aboriginal communities' capacity to participate in consultation on the project, which may include providing capacity funding;
- Maintain records of activities in relation to carrying out the delegated procedural aspects of consultation and providing information to ENDM.

As part of its obligations to the Aboriginal communities owed the duty to consult, the Crown will provide notification letters to the affected communities of delegation to Hydro One and copy Hydro One on the out-going correspondence.

I trust that this information provides clarity and direction regarding the respective roles of the Crown and Hydro One. If you have any questions about this letter or require any additional information, please contact Chloë Lazakis (above).

Sincerely,

Samir Adkar
Director
Energy Networks and Indigenous Policy
Ministry of Energy, Northern Development and Mines

c: Craig Newton
Ministry of the Environment, Conservation and Parks

Joe Vecchiolla
Ministry of Government and Consumer Services

HAUDENOSAUNEE DEVELOPMENT INSTITUTE
INTERROGATORY - 06

Reference:
Exhibit B-1-1

Preamble:

> Hydro One is committed to working with Indigenous Peoples in a spirit of cooperation and shared responsibility. We acknowledge that Indigenous Peoples have unique historic and cultural relationships with their land and a unique knowledge of the natural environment. Forging meaningful relationships with Indigenous Peoples based upon trust, confidence, and accountability is vital to achieving our corporate objectives. Hydro One has been engaging with communities since early in the development process and will continue that engagement throughout the life cycle of the Project. Additionally, Hydro One has, and will continue to throughout the life cycle of the Project, engaged in extensive economic participation negotiations with impacted Indigenous communities including employment, training, contracting and equity participation in the Project.

Interrogatory:

1) Describe Hydro One's "extensive economic participation negotiations with impacted Indigenous communities".
   a. What employment agreements have these negotiations resulted in? Please describe each agreement, including the parties to the agreement and general financial terms.

   b. What training agreements have these negotiations resulted in? Please describe each agreement, including the parties to the agreement and general financial terms.

   c. What contracting agreements have these negotiations resulted in? Please describe each agreement, including the parties to the agreement and general financial terms.

   d. What other agreements have these negotiations resulted in? Please describe each agreement, including the parties to the agreement and general financial terms.

2) Describe any "equity participation" of Indigenous groups or Nations in the proposed project.
   a. Please provide materials detailing such equity participation in the proposed project.

3) Describe any “equity participation” of the Haudenosaunee in the proposed project.
   a. Please provide materials detailing such equity participation in the proposed project.

   b. Is Hydro One willing to discuss and/or negotiate with the Haudenosaunee, through HDI, any “equity participation” of the Haudenosaunee in Hydro One’s proposed project?

   c. Will Hydro One commit to discussing and/or negotiating with the Haudenosaunee, through HDI, any “equity participation” of the Haudenosaunee in Hydro One’s proposed project?

4) Does any Indigenous group or Nation have an equity interest in Hydro One’s proposed project?
   a. If so, please provide details regarding any Indigenous group or Nation’s equity interest.

<u>Response:</u>

1) All of the requested information pertains to areas of negotiation related to potential accommodations and economic reconciliation-based initiatives. These types of agreements are commonly used as a means to formalize mitigation of potential infringements to Indigenous rights, and to collaborate with Indigenous governments to advance meaningful action towards reconciliation through economic participation.

   To date, Hydro One has not entered into any definitive accommodation agreements with any of the Indigenous governments in which it has consulted with.

2) Reference to “equity participation” in the Preamble to this question is intended to describe Hydro One’s expectation that the project may eventually be restructured (post in-servicing) in order to allow impacted Indigenous communities the option to acquire an equity interest in the restructured entity. The approach envisioned would be similar to the structure used for Hydro One’s Bruce to Milton Transmission Project. As noted in Exhibit B, Tab 10, Schedule 1, Affiliate Transmission Partnership Regulatory Accounts (“ATP”) deferral accounts have been approved for the purpose of tracking costs associated with a future restructured entity (i.e., limited partnership). Currently, discussions with impacted Indigenous governments are ongoing. No definitive agreements pertaining to equity participation have been reached.

   If ongoing discussions lead to definitive agreements, Hydro One would anticipate the timing of this type of transaction to occur following Project completion and once project costs are finalized. This type of transaction would reflect Hydro One’s commitment to advancing meaningful action on reconciliation and not specifically tied to potential impacts on Aboriginal and Treaty Rights.

3) As indicated in Response 2 above, no definitive agreements regarding equity participation have been reached with any Indigenous government. Hydro One declines to provide any further responses to the questions posed on the basis that the requested information is not relevant to the issues arising in this proceeding as set out in the Board's Procedural Orders.

4) Please see Response 2 above.

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HAUDENOSAUNEE DEVELOPMENT INSTITUTE
INTERROGATORY - 07

Reference:

Conditions of Approval

Preamble:

In Procedural Order No. 2, dated August 23, 2022, the OEB noted that:

> standard conditions for an electricity leave to construct approval already include a requirement that a proponent "obtain all necessary approvals, permits, licences, certificates, agreements and rights required to construct, operate and maintain the project." Approvals that Hydro One requires with respect to the Environmental Assessment are covered by this provision.

Interrogatory:

1) Has Hydro One finalized or received a final Environmental Assessment (or, alternatively, a final Environmental Study Report)?

   a. If so, please provide the final Environmental Assessment/Study Report.

   b. If not, will Hydro One move forward with its application for leave to construct (or, in other words, continue to seek leave to construct through its application) absent a final Environmental Assessment/Study Report?

   c. Will Hydro One move forward with its application for leave to construct (or, in other words, continue to seek leave to construct through its application) with a final Environmental Assessment/Study Report that:

      i. Does not find that the Crown's duty to engage and/or consult with the Haudenosaunee, whether through the HCCC or HDI, was sufficiently or adequately discharged?

      ii. Does not address the sufficiency or adequacy of the Crown's duty to engage and/or consult with the Haudenosaunee, whether through the HCCC or HDI?

Response:

1)

a. The Environmental Study Report has not yet been finalized and submitted to the MECP.

b. Hydro One would not expect the Board's authorization for leave to construct would permit project construction to proceed before it has submitted a final Environmental Study Report with MECP. Please refer to Exhibit I, Tab 1, Schedule 10.

c. Hydro One declines to respond to part (c) of this question as it seeks Hydro One to speculate on what actions may or may not be taken as a result of judicial or governmental decisions that may or may not be taken. Hydro One expects conditions to any approval issued by the Board in this proceeding would need to be fulfilled prior to commencing construction of the project. Hydro One continues to submit that the standard conditions of approval are appropriate for this Project.

THREE FIRES GROUP INTERROGATORY - 08

Reference:

Exhibit B-1-1
Hydro One Indigenous Relations Policy

Preamble:

HONI notes that it has been engaging with communities since early in the development process and that it will continue to engage impacted Indigenous communities throughout the life cycle of the Project.

HONI's Indigenous Relations Policy provides that HONI has the goal of achieving "the agreement and support, articulated in UNDRIP as "Free Prior and Informed Consent", of Indigenous peoples" and recognizes the "obligations industry has in Reconciliation with Indigenous people, to address meaningful and measurable change in cultural understanding and economic outcomes."

In Procedural Order No. 2 ("**PO2**"), dated August 23, 2022, the Board indicated that reasonableness of Hydro One's estimates of the cost of the Project is an issue in this proceeding and the OEB accepts that costs related to Indigenous engagement may have an impact on the total Project costs.

Interrogatory:

a) Please outline the extent to which HONI has analyzed Indigenous rights and territorial claims to support its approach to the Project and manage costs associated with Indigenous consultation.

b) Please outline the extent to which HONI would benefit from a one-window Indigenous consultation coordinating entity for the Project on all relevant issues.

c) Please quantify the impact on Project costs that HONI would anticipate from a one-window Indigenous consultation coordinating entity for the Project on all relevant issues.

Response:

a) Please refer to Exhibit I, Tab 3, Schedule 5.

b) Hydro One recognizes the unique and distinct nature of each Indigenous government engaged on a project. Therefore, Hydro One does not utilize this approach. Consistent with Hydro One's best practices, engagement is initially conducted individually with

Indigenous groups as potential rights-holders. In cases where Indigenous groups delegate their representation to third party organizations or groups, HONI will then respect and welcome this approach and engage with the delegate acting on behalf of the rights-holders.

c) Please refer to part b above.

THREE FIRES GROUP INTERROGATORY - 09

Reference:
Exhibit B-6-1
Exhibit C-1-1

Preamble:
HONI states that "the NPV energy price sensitivity analysis confirms that the 1443 kcmil conductor is the most prudent method to meet the needs of the Project".

HONI also notes that it will make use of 159 self supported lattice towers with nominal spans of 350m and 10 H-frame structures used to cross other transmission lines.

In PO2, the Board indicated that questions regarding the tower and conductor technologies selected by HONI are in scope as the selection may impact price or reliability.

Interrogatory:
a) Please discuss reliability impacts and/or improvements related to the choice of tower for:
   i. HONI customers generally; and
   ii. Indigenous customers.

b) Please discuss reliability impacts and/or improvements related to the choice of conductor technologies for:
   i. HONI customers generally; and
   ii. Indigenous customers.

Response:
a) Transmission system reliability data is collected in aggregate form and does not capture specific customer demographics.

   Reliability impacts and/or improvements related to the design of transmission facilities (e.g., towers and conductors) are general topics monitored by Hydro One, among others in the electricity transmission sector. Selection of tower designs and conductor facilities consider factors such as geographic location and weather conditions. The tower design and conductors for the Chatham to Lakeshore Project are unremarkable. The design and conductors are consistent with other Hydro One transmission towers and conductors used across its system and have a proven track record of providing reliable transmission service. No unique circumstances exist that would cause Hydro One to deviate and incur incremental costs to study new or unique tower designs or conductor facilities. The reliable transmission of high voltage electricity across transmission towers and conductors is not dependent upon end-use Indigenous versus non-Indigenous customer characterizations.

b) Please refer to part a) above.

THREE FIRES GROUP INTERROGATORY - 10

Reference:
Exhibit B-6-1

Preamble:
HONI notes that the Project will also improve the reliability and quality of energy supply by providing an additional transmission path for system generation to be delivered to the area west of Chatham as well as preserve the Ontario-Michigan intertie capability.

In PO2, the Board indicated a review of the cost and potential ratepayer (including Indigenous ratepayers) and reliability implications of HONI's proposed route is in scope of this proceeding.

Interrogatory:
a) Please discuss HONI's assessment of the reliability impacts and/or improvements of the proposed line. In your discussion, please quantify the anticipated impacts on SAIDI, SAIFI, and DPUI following the completion of the Project by completing the below (or similar) tables for both (i) HONI customers generally and (ii) Indigenous customers:

i. Frequency of Momentary Interruptions

	2021	**2022 (estimate)**	**Y1****
# of momentary interruptions for HONI customers			
# of momentary interruptions for Indigenous customers			
# of DPs in Project area			
T-SAIFI-m*			

**T-SAIFI-m = Total number of momentary interruptions / total number of DP monitored*
***Y1 = First full in service year following completion of the Project*

ii. Frequency of Sustained Interruptions

Year	2021	2022 (estimate)	Y1
# of sustained interruptions for HONI customers			
# of sustained interruptions for Indigenous customers			
# of DPs in Project area			
T-SAIFI-s*			

**T-SAIFI-s = Total number of sustained interruptions / total number of DP monitored*

iii. Overall Frequency of Interruptions

Year	2021	2022 (estimate)	Y1
# of overall interruptions for HONI customers			
# of overall interruptions for Indigenous customers			
# of DPs in Project Area			
T-SAIFI-all*			

**T-SAIFI-all = Total number of momentary and sustained interruptions / total number of DP monitored*

iv. Duration of Sustained Interruptions

Year	2021	2022 (estimate)	Y1
Duration of sustained interruptions (minutes) for HONI customer			
Duration of sustained interruptions (minutes) for Indigenous customer			
# of DPs in Project Area			
T-SAIDI*			

**T-SAIDI = Total duration of sustained interruptions / total number of DP monitored*

v. Delivery Point Unreliability Index

Year	2021	2022 (estimate)	Y1
Total Unsupplied Energy (MW x minutes) for HONI customers			
Total Unsupplied Energy (MW x minutes) for Indigenous customers			
System Peak Load (MW)			
DPUI*			

**DPUI = Total unsupplied energy / system peak load*

Response:

The information requested in this response (anticipated changes in SAIDI SAIFI and DPUI) are metrics that do not relate to the statements cited in the Preamble to this question. The reliability and quality of energy supply expected from the Project (i.e., additional transmission path for system generation to be delivered in the area west of Chatham as well as preserve intertie capabilities) are matters that relate to the overall need for the project as determined by the IESO. These are matters which fall outside the scope of the Board's Procedural Orders in this proceeding. Hydro One has no information to comment on whether, if at all, the IESO took into account expected changes in metrics such as SAIDI, SAIFI and DPUI. Hydro One does note the transmission system is built such that adequate and secure supply is assured over a wide range of conditions so that loss of one or more system elements (i.e., line or transformer) will not result in any violation of thermal and stability limits. As a result of this, the system is built with redundancy so that failure of a network element will generally not result in a Delivery Point (DP) interruption. DP performance is only affected by loss of network transmission system elements if multiple contingencies or overlapping single contingencies occur and more than one element suffers an outage. Thus, typical DP interruption frequency and duration statistics do not provide complete information on the reliability performance of the network transmission system.

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POLLUTION PROBE INTERROGATORY - 09

Reference:

Exhibit I-6-1b

> *"Hydro One does not have a reporting metric that will demonstrate the Project's specific contribution to reliability."*

Interrogatory:

a) Please detail what specific evidence is available to validate Hydro One's claim that the proposed project will improve reliability (i.e beyond general claims that it will)?

b) Please describe the quantitative metric(s) Hydro One has used to identify the reliability issue that the proposes project will resolve.

c) What metric(s) will the OEB be able to use to validate that the project in fact delivered improved reliability as stated by Hydro One in its evidence?

d) Would Hydro One be able to validate the enhanced reliability in the post-construction report to the OEB? If not, why not.

Response:

a) The reliability and quality of energy supply expected from the project (i.e., additional transmission path for system generation to be delivered in the area west of Chatham as well as preserve intertie capabilities) are matters that relate to the overall need for the project as determined by the IESO. Please refer to Exhibit B, Tab 3, Schedule 1, Attachment 2 of the pre-filed evidence, for the report on the need for bulk transmission reinforcement in the Windsor – Essex region. As noted in the report, the new proposed 230kV double circuit line will increase the transfer capability West of Chatham to 1500MW from the current capability of 1100MW with Lakeshore TS in-service, thereby increasing the ability to adequately serve load in the region.

   As a result of the increase in transfer capability, the new line will improve the reliability of supply in the Windsor – Essex region by materially reducing the need to identify and select customers for potential rejection for system contingencies. Please refer to Exhibit F, Tab 1, Schedule 1, Attachment 1 of the pre-filed evidence, for the System Impact Assessment which provides details of the rejection requirements following the incorporation of the new line and before its incorporation. Additionally, the IESO System Impact Assessment also explicitly concludes that that the Project is expected to have no material adverse impact on the reliability of the integrated power system and recommends that a Notification of Conditional Approval for Connection be issued.

b) Hydro One has not used any quantitative metric(s) to identify the reliability issues the new line will resolve. Please refer to part a).

c) There will be no metrics available. Please refer to part a).

d) Any post-construction report, if required, would not provide information on enhanced reliability.

POLLUTION PROBE INTERROGATORY - 10

Reference:

Exhibit I-6-2

> *"Natural gas is typically used for heat and carbon dioxide to feed the crops, whereas electricity is typically used for lighting and ventilation. So, while both projects may supply the same customers, the needs and purposes of each project are unique and not duplicative."*

EB-2022-0088 - Exhibit A-2-1, Page 2

> *"The Project as proposed is designed to reliably serve increased demands for firm service in the Panhandle Market, including, in particular, incremental demands from the greenhouse, automotive, and power generation sectors."*

Interrogatory:

a) If the OEB approves the request for an incremental natural gas transmission pipeline to serve increased electricity generation in the area (including the Brighton Beach Generating Station), why can that not be used to provide the incremental reliable electricity instead if increased electricity transmission infrastructure?

b) Given the plans for increased electricity generation in the area from natural gas, what opportunity will that provide for exports of electricity to the broader system (grid) and will that enhance broader system reliability. Please explain in detail.

c) Please provide a copy of all documentation (e.g. reports, presentations, etc.) that relate to leveraging natural gas power generation to increase electricity demand and maintain reliability.

Response:

a-c) Information Requests concerning need and alternatives to the Project are beyond the scope of issues established for this proceeding as described by the Board in its Procedural Orders. Hydro One therefore declines to respond to these questions.

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POLLUTION PROBE INTERROGATORY - 11

Reference:
Exhibit I-6-3

Interrogatory:
Hydro One's response to Exhibit I, Tab 6, Schedule 3 did not answer the question asked. More specifically,

a) Would Hydro One be able to expropriate lands if it had requested an exemption rather than filing for Leave to Construct approval?

b) What other reason does Hydro One have for not requesting a Leave to Construct exemption from the OEB.

c) Please detail the costs (by major activity and amount) that would have been saved if Hydro One received an exemption from the OEB rather than pursuing a full Leave to Construct proceeding.

Response:
a) Subsection 99(1) of the Act addresses the persons who may apply to the Board for authority to expropriate land for a work. Hydro One interprets this section to require as a precondition to seeking authority to expropriate as either (i) persons who have leave under this Part (i.e. leave granted pursuant to section 92) or (ii) persons who have been exempted from the requirement to obtain leave by the Board under section 95.

b) Hydro One's rationale for not seeking exemptions to seek Leave to Construct are based on the express language found in The Executive Council of Ontario's Order In Council 1499/2020 (Exhibit B-3-1 Attachment 1), its interpretation of section 96.1 and the discretion afforded to the Board described in section 95.

   The Order In Council provides express directions on how Hydro One and the Board are expected to proceed with the timely development and implementation of the Chatham to Lakeshore Transmission Project. For example, the preamble to the Order in Council (at page 3 of 6) states:

   > AND WHEREAS the Government has determined that the preferred manner of proceeding is to require Hydro One Networks Inc. to undertake the development of the transmission line project including any and all steps

> that are deemed to be necessary and desirable in order to seek required approvals.

The Ministerial Direction to the Board incorporated into the Order In Council (page 5 of 6, paragraph 1) provides direction on the amendment of Hydro One's electricity transmission licence to include a "…requirement that Hydro One proceed to develop and seek approvals for a new 230 kilovolt (kV) double-circuit transmission line from the existing Chatham Switching Station to the new Lakeshore Transformer Station to be located at Leamington Junction (Chatham to Lakeshore Line), including associated station facilities to connect the Chatham to Lakeshore Line at the terminal stations." (emphasis added)

Further, the Order in Council is the underlying basis upon which the Chatham to Lakeshore Transmission Line project is a "priority project" as that term is used in section 96.1 of the Ontario Energy Board Act. This section states:

> **Lieutenant Governor in Council, order re electricity transmission line**
> **96.1** (1) The Lieutenant Governor in Council may make an order declaring that the construction, expansion or reinforcement of an electricity transmission line specified in the order is needed as a priority project. 2015, c. 29, s. 16.
>
> **Effect of order**
> (2) *When it considers an application under section 92* in respect of the construction, expansion or reinforcement of an electricity transmission line specified in an order under subsection (1), the Board shall accept that the construction, expansion or reinforcement is needed when forming its opinion under section 96. 2015, c. 29, s. 16. (emphasis added)
>
> **Obligations must be followed**
> (3) *Nothing in this section relieves a person from the obligation to obtain leave of the Board for the construction, expansion or reinforcement of an electricity transmission line specified in an order under subsection (1)*. 2015, c. 29, s. 16. (emphasis added)

Without more, subsections 96.1(2) and (3) expressly contemplate that priority project applicants seek relief in accordance with section 92 of the Act. It is for this reason that Hydro One has made application in this manner.

Regarding the exemption described in section 95 of the Act, this provision reads as follows:

> **Exemption, s. 90 or 92**
> **95** The Board *may*, *if in its opinion special circumstances of a particular case so require*, exempt any person from the requirements of section 90 or 92 without a hearing. 1998, c. 15, Sched. B, s. 95 (emphasis added)

Section 95 grants the Board the discretion to exempt a person from the requirements of section 92 without a hearing if in its opinion a special circumstance exists. Hydro One submits it is the Board's decision whether or not to exercise this discretion.

In the present circumstances, Hydro One chose not to request the Board to exercise discretion because doing so would be inconsistent with the express language found in the Order in Council, namely to seek required approvals (as opposed to seek exemptions from these approvals). Had the Government of Ontario intended the Board to exercise its discretion under section 95, Hydro One would have expected the Order In Council to include express directions to this effect. The Order in Council does not include such language nor does Hydro One interpret the Order in Council to be a special circumstance that would exempt it from the requirement of obtaining leave of the OEB.

The Board is the master of its own procedure and through the Notice of Hearing and Procedural Directions has made it abundantly clear that the Board intends to proceed and hear Hydro One's application in an expedited manner and determine whether relief sought in accordance with section 92 should be granted.

c) The information requested is based upon a hypothetical that the Board exercised discretion in a manner inconsistent with the express language found in the Order In Council. Hydro One has had no reason to conduct such analysis and in any event submits this type of information would have little, if any relevance, to the question of whether the relief sought in the application before the Board should be granted or not.

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POLLUTION PROBE INTERROGATORY - 12

Reference:

Exhibit I-6-6

> *"Chapter 7 of the draft Environmental Study Report ("ESR) for the Project describes the potential environmental effects (both natural and socio-economic environment) of the project as well as associated measures that Hydro One has committed to avoid, mitigate or restore these effects."*

Interrogatory:

Chapter 7 of the ESR identifies significant features and required mitigation measure, but does not provide any information of guidance related to the costs estimates to avoid or mitigate impacts.

Please describe how Hydro One translated the detailed feature impacts and mitigation requirements in the ESR to arrive at the cost estimate in the application.

Response:

Chapter 7 of the draft ESR, particularly the commitments to environmental avoidance, mitigation and restoration measures as summarized in Table 7-1 of the draft ESR, were provided as part of the tender package to firms bidding on the Engineering, Procurement and Construction (EPC) contract for the Chatham to Lakeshore Project.

The EPC bidders were pre-qualified and are highly experienced specialists in Transmission Line construction and complying to ESR commitments and mitigations. The requirements of the ESR are part of the Owners Requirements and form part of the EPC contract to which the EPC contractor must comply.

Most of the mitigation measures for this Project are standard and considered good practice in the construction industry as well as in transmission line construction. This includes the following conditions:

- "Construction haul routes and schedule will be shared with local Municipalities in advance of construction, as necessary"; or
- "General clean site policies will be implemented requiring pick-up and disposal of refuse and construction waste on a regular basis"; and
- "Concrete wash water will not be discharged onto the ground at the Project site. All water from concrete chute washing activities will be contained in leak proof containers or in an approved settling pond".

All specific costs to meet the Owners Requirements which included the ESR, are included at the activity level of item constructed by the EPC contractors which Hydro One uses to assess against industry and historic benchmarks and are not broken out as per the ESR.

POLLUTION PROBE INTERROGATORY - 13

Reference:
Exhibit I-6-6

> *"Table 7-1 of the draft ESR provides a summary of the information included in Chapter 7."*

Interrogatory:
Pollution Probe was unable to find Table 7-1. Please provide a copy of the table in your response to this interrogatory.

Response:
As described in the draft ESR, Table 7-1 provides a summary of potential effects, the associated mitigation, and the net effects identified for the proposed Project, during the construction and operation and maintenance phase.

Table 7-1 is found at page 7-41 of the draft ESR or page 270 of the electronic file found at the hyperlink provided for the draft ESR: https://www.hydroone.com/abouthydroone/CorporateInformation/majorprojects/Chatham-to-Lakeshore/Documents/Chatham-to-Lakeshore-Line_Draft_ESR.pdf

A copy of the table is being provided as Attachment 1 of this response for ease of reference.

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Table 7-1: Summary of Potential Effects, Mitigation Measures and Net Effects

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
AGRICULTURAL RESOURCES			
Crop Loss	<u>Construction & Maintenance</u> Temporary removal of crops and soils supporting crop production, as well as permanent removal of land available for agricultural production as a result of project infrastructure (e.g. tower footings).	The following mitigation is recommended to address these potential effects: • Contact will be maintained with landowners and stakeholders regarding work schedules and other items of interest (e.g. access routes, minimizing disturbances to existing and planned farm operations, etc.); • Where practical, construction and maintenance activities will be scheduled to avoid the growing season or sensitive times of year (e.g., extreme wet periods). To the extent practical, activities will be scheduled to occur during non-growing seasons or during frozen conditions; • Access roads, staging areas, tower construction and stringing activities will be constructed to a minimum length and width required to accommodate the safe movement of construction equipment; • Existing farm lanes and other existing access routes will be used whenever practical. In the event farm lanes are absent, access will be focused along field edges, to the extent possible; • Work will be limited to the planned access roads, staging and work areas. If a later expansion to these areas is required, it will be discussed with the landowner in advance; • Where practical, towers will be located along property lines to minimize impediment on agricultural operations, to the extent possible; and • Lands will be restored following construction and maintenance activities (e.g., removal of temporary access roads, removal of erosion and sediment controls (ESC), disking of lands, aeration, and cultivation of soils to alleviate soils compaction where required), where feasible.	Net effects include permanent removal of land available for agricultural production as a result of project infrastructure (e.g. tower footings); not considered significant. Crop loss and lands out of production as a result of the proposed Project will be compensated.
Soil Compaction	<u>Construction & Maintenance</u> Compaction of soil caused by movement of construction equipment or maintenance vehicles over agricultural lands.	In addition to the mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Equipment with low bearing capacity will be used, where practical; and • Where practical, temporary access roads and work pads will be built in agricultural fields using measures such as mats or, geotextile and crushed rock, or equivalent means, which can be easily removed when construction is complete to allow for re-cultivation of the area.	No significant net effects are predicted.
Soil Mixing	<u>Construction</u> Potential for excavation activities to cause mixing of soil horizons, thus lowering the quality of soil.	In addition to the mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Augered tower footings or screw-pile foundations will be utilized to the extent feasible to minimize soil excavations; • Stripping or excavated soils will be minimized to the extent practical; • Where soil stripping is required, topsoil and subsoils will be removed and stockpiled separately; • Depths of soil being removed will be carefully monitored and minimized during stripping activities; • Volume of topsoil and subsoil salvaged will be maximized, where practical;	No significant net effects are predicted.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• Soils will be stripped under generally dry conditions (not saturated), such that rutting, soil mixng, or other undesired ground disturbance is minimized to the extent practical; • Vegetation, stone piles, fencing and deleterious materials will be removed prior to stripping; • For backfilling operations, topsoil and subsoil will be replaced in reverse order of excavation to minimize the potential for admixing and maximizing future growing potential; and • Soil cover on exposed areas within agricultural areas will be discussed with the landowner, and if hydroseed application is used, it will be limited to annual rye or similar, and will not contain any weed species.	
Disturbance to Farm Operations	<u>Construction</u> Potential to disturb farm operations including planting and harvesting schedules, spraying, tiling activities, etc. <u>Operation</u> Impediments to the maneuverability of agricultural equipment.	The mitigation outlined above addresses these potential effects.	Some agricultural fields will have new transmission structures. No significant net effects are predicted.
Vegetation Removal	<u>Operation</u> Partial removal or fragmentation of existing hedgerows and windbreaks between agricultural land parcels.	The following mitigation is recommended to address these potential effects: • Vegetation that will not affect construction or line clearances will be retained, where possible; • Hedgerows and windbreak areas impacted by construction will be replaced with compatible vegetation post-construction, in consultation with the landowner; and • Hydro One will undertake a Biodiversity Initiative to offset vegetation loss or transition (e.g., from woodlot to a compatible vegetation community) that cannot otherwise be avoided or mitigated. This initiative will be conducted subsequent to completion of the Class EA and OEB Leave-to-Construct processes.	Net effects include permanent removal of incompatible vegetation (hedgerows/windbreaks) to ensure the safe operation of the transmission line; not considered significant. Incompatible vegetation removal will not represent a loss of vegetation on the landscape, but rather a transition from vegetation that is incompatible with

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
			transmission line corridors, to vegetation that is compatible.
Contamination of Organic or Identity Preserved (IP) Crops	Construction & Maintenance Potential for activities, including use of herbicides to control noxious weeds or vegetation, to contaminate organic or IP crops or agricultural fields transitioning to organic/IP crop types. Potential for inadvertent movement of trace soils between agricultural fields which contain organic or IP crops.	In addition to the mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Contact will be made with landowners to determine if organic or IP operations are present which may require additional considerations during construction planning; • Field crews will be informed if working in organic or IP croplands; • Equipment and vehicle inspections and cleaning will be established during construction, to minimize the potential for inadvertent transport of trace soils between contaminated and non-contaminated agricultural fields; • Cleaning will be conducted using a risk-based approach, whereby vehicles and equipment that have come in contact with soils will be inspected and cleaned of dirt/debris/seeds; and • Cleaning will occur in a manner that ensures that runoff is contained and waste materials can be collected. • Work areas will be assessed during pre-construction activities to identify the presence of weed species, degree of infestation, and the distribution of weeds within the Project footprint and the immediately adjacent areas; • Work areas will be monitored for weeds throughout the Project and until the Project has been completed; • A project-specific Weed Control Plan will be developed in consultation with landowners prior to construction, as necessary; • The Weed Control Plan will be managed by an Ontario Professional Agrologist to meet the requirements of the municipal and land use authority; • The transmission ROW will be monitored for establishment of weeds until the Project is completed; • Corrective measures for managing weeds may include herbicide application, mowing, and hand pulling; and • Weed control during construction will be conducted by the construction contractor.	No significant net effects are predicted.
Damage to Field Tiles	Construction & Maintenance Potential for equipment to damage or crush existing agricultural tile drains.	In addition to the mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Landowners will be consulted to determine existing field tile locations in support of avoidance/protection measures; • Tile drains will be avoided and/or protected (e.g., through tower locations, temporary construction access), to the extent practical; and	No significant net effects are predicted. If tile damage to tile drains occurs as a result of construction activities and/or maintenance activities, the tile

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• Where practical, temporary access roads and work pads will be built in agricultural fields using measures such as mats or, geotextile and crushed rock, or equivalent means.	will be repaired by a licensed tile drainage contractor in consultation with affected landowner.
Livestock Stress, Loss or Injury	<u>Construction & Maintenance</u> Potential for activities to be required within livestock managed areas (grazing fields, pastures, etc.) resulting in potential for livestock stress, injury or loss. In addition, potential use of implosive splicing may scare or startle agricultural livestock.	In addition to the mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Landowners will be informed in advance of upcoming work activities which may disturb or pose a risk to livestock, and consulted with respect to potential mitigation measures, such as moving or containing livestock, as necessary; • Field crews will be informed about livestock in the vicinity of work areas to confirm they are aware of the need to secure gates, are cognizant of noise sensitivity controls, and to ensure clean–up of construction materials and debris at the end of each day to minimize potential livestock ingestion; • If excavations cannot be closed immediately, exclusion fencing will be erected to protect livestock from entering; • Vehicles / Equipment will be inspected and cleaned as necessary prior to entering onto designated lands to prevent the potential introduction of diseases; • Existing gates and fences will be used as required. All fences and gates will be left in "as-found" condition following construction; • Livestock access control gates and fencing will be installed during construction at roads and between fenced fields as necessary to prevent escape of livestock or movement of livestock into work areas; • Prior to any use of implosive splicing, a Blasting Communication and Management Plan will be developed outlining proper storage, security, detonation, and notification requirements; • Area residents, municipal authorities, police department, and other crews within 1.6 km will be notified about the use of implosive splicing, one week prior to the work commencing; • Signs shall be posted on all roadways leading to a blasting area in accordance with government rules and regulations; and • Maintain safe distances of the blasting site from other employees, vehicles, equipment, structures, and fire hazard sources. Perform blasts during pre-determined times.	No significant net effects are predicted. Compensation will be made for loss or injury to livestock directly resulting from activities associated with the proposed Project.
Electric and Magnetic Interference	<u>Operation</u> Some farmers have raised concerns regarding potential for overhead transmission lines to interfere with automated or GPS-	Hydro One acknowledges the concerns raised, as well as insistence by some farmers currently working fields below transmission lines, that localized issues have been observed beneath the transmission lines. While we do not anticipate effects to communication systems in farm equipment, Hydro One will work with concerned farmers to collect information on the systems of concern, and contact manufacturers of these systems to gain further insight into potential concerns and possible solutions, if applicable.	No significant net effects are predicted. While obstructions such as buildings or trees are known to

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	guided farm equipment, when said equipment is directly below the conductors.		block reception of GPS signals, published studies assessing these concerns indicate that overhead power line conductors are too thin to cause appreciable screening. Likewise, corona or sparking on a power line generates insufficient noise at frequencies used for GPS to interfere with its operation.
ARCHAEOLOGICAL RESOURCES			
Archaeological Resources	<u>Construction</u> Disturbance to lands with potential to support archaeological resources.	Prior to construction, a Stage 2 Archaeological Assessment will be completed within the identified areas of archaeological potential along the new transmission line corridor in accordance with Ministry of Heritage, Sport, Tourism and Culture Industries (MHSTCI) requirements. In the event the Stage 2 Archaeological Assessment identifies the need for further assessment, a Stage 3/4 Archaeological Assessment will occur as required and as outlined in the "Standards and Guidelines for Consultant Archaeologists", Ministry of Tourism, Culture and Sport (2011). Should archaeological artifacts be encountered during construction, work in the vicinity will cease and a licensed archaeologist will be engaged immediately to ensure compliance with the provincial *Heritage Act*. Likewise, should any human remains be encountered during construction, work in the vicinity will cease and the police and coroner notified immediately as well as the Registrar of Cemeteries to ensure compliance with the *Funeral, Burial and Cremation Services Act.*	No significant net effects are predicted. Additional archaeological investigations will be completed prior to construction, as required.
CULTURAL HERITAGE RESOURCES			
Cultural Heritage Resources	<u>Construction:</u> Based on the baseline findings of the Cultural Heritage Existing Conditions Report, there is the potential for project-related works to adversely affect known and potential built heritage resources within the study area. No cultural	Additional studies are required to confirm potential built heritage resources along the transmission line ROW for the proposed Project. To the extent practical, work will be planned in a manner that avoids adverse effects to identified built heritage resources. In the event a built heritage resources cannot be feasibly avoided and will be directly impacted through destruction, alternation, or disruption, a property specific Cultural Heritage Evaluation Report (CHER) and/or Heritage Impact Assessments (HIAs) will be completed to confirm the cultural heritage value or interest, and heritage attributes of the impacted built heritage resource and identify all adverse effects. All evaluation and	No significant net effects are predicted. Additional cultural heritage evaluations and/or heritage impact assessments will be completed prior to construction

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
	heritage landscapes were identified in the study area associated with the preferred route for the new transmission line.	assessments will be in compliance with the Hydro One *Cultural Heritage Identification and Evaluation Process* and MHSCTI Standards and Guidelines. Appropriate mitigation or conservation measures that reduce or avoid potential adverse effects will be recommended based on the understanding of the cultural heritage value or interest, and heritage attributes of potential affected built heritage resources.	where impacts to potential built heritage resources may occur.
LAND USE AND COMMUNITIES			
Business Operations	<u>Construction</u> Potential for activities to disrupt commercial or industrial operations.	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Contact will be maintained with business owners regarding work schedule and other items of interest; • Access to businesses will be maintained at all times during construction to the extent feasible. If existing access cannot be maintained, arrangements will be made for alternate access, including public signage as required; and • Construction activities and equipment will be managed to avoid damage and disturbance to adjacent properties, structures and operations.	No significant net effects are predicted.
Existing and Future Land Use Designations and Potential Future Development	<u>Operation:</u> While transmission lines can be largely compatible with development, its location within areas zoned to allow future commercial/industrial development, or otherwise targeted/identified for future development potential, will introduce certain restrictions to future uses within the lands occupied by the transmission line ROW.	The following mitigation is recommended to address these potential effects: • Throughout the province, development (both residential and commercial/industrial) occurs around existing transmission line corridors and stations. Uses deemed to be compatible with overhead transmission lines are often approved within transmission line ROWs. Hydro One has existing departments and processes to review proposals for developments that are planned adjacent to or within transmission line ROWs, and facilitate compatible uses of these corridors; • Typically there are no restrictions placed on development or new construction outside of the transmission line ROW itself; • Where and when future development projects or initiatives are proposed to occur along or within the ROW for the new transmission line, Hydro One will apply its existing processes to review and facilitate these future developments, including potential compatible uses within the transmission line ROW; and • Hydro One will work with Municipalities to consider potential means of accommodating potential future development during design of the transmission line, within the property fabric traversed by the line.	No significant net effects are predicted. While there will be restrictions to future development within 2 m of the transmission line ROW, the Project will not impede development of adjacent lands, and there will be opportunities for compatible uses to be developed within the ROW. Hydro One will commit to working with local Municipalities to identify community benefit opportunities

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ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
			to enhance the broader landscape.
Local Roads and Traffic	Construction Potential for increased traffic, including heavy equipment, on local and regional roads. In addition, stringing of conductors across hjghways and roadways may require temporary road closures and detours.	The following mitigation is recommended to address these potential effects: • A pre and post-construction road survey will be completed to document impacts to local roads caused by heavy equipment and increased construction traffic during construction activities, and will be shared with Municipal staff in advance of construction work commencing; • Adherence to seasonal load restrictions; • Damage to local and regional roads as a direct result of construction activities associated with the proposed Project will be repaired; • Where required, a Traffic Control Plan will be developed and shared with local municipalities, as necessary; • Construction haul routes and schedule will be shared with local Municipalities in advance of construction, as necessary; • Construction traffic will access the construction area from the existing road network at specified construction access/egress locations; • Common parking areas will be established for construction crews; • Conductor stringing will utilize rider poles, boom-tipped riders or other protective measures in an effort to avoid road closures and other disruptions during stringing, to the extent practical; • If temporary road or highway closures (e.g., rolling closures) are required during stringing or other construction activities, the construction contractor will coordinate closely with the appropriate road authority to ensure that proper notice is provided and that required signage and traffic controls are utilized. The duration of any temporary closures will be minimized to the extent practical; • Local advertisements (e.g. radio, newspaper, etc.) will be issued and road signage will be erected to provide notification / pre-construction information to area residents on timelines and construction routes, and potential detours, if required; and • Traffic control officers or flag persons will be assigned to assist with construction entry/exit, as necessary.	No significant net effects are predicted.
Mud and Construction Debris	Construction & Maintenance Potential for tracking of mud and migration of construction debris to areas outside of the construction zone.	The following mitigation is recommended to address these potential effects: • Roads will be cleaned/scraped to remove mud on an as needed basis; • Mud mats will be installed (on an as need basis) as a mechanism to reduce the transport of mud; • Vehicles / equipment will be inspected and cleaned , as necessary, Construction sites will be kept tidy at all times and waste bins will be available wherever solid wastes are generated; • Waste materials will be collected and transported to a licensed or approved waste management facility on a regular basis; and	No significant net effects are predicted.

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		• General clean site policies will be implemented requiring pick-up and disposal of refuse and construction waste on a regular basis.	
Electric and Magnetic Fields (EMF)	<u>Operation</u> Potential exposure to increased EMF once the transmission line is energized.	The following mitigation is recommended to address these potential effects: • EMF levels associated with the proposed Project are anticipated to remain significantly lower than the general public exposure limits; and • The proposed Project will be designed and operated in accordance with appropriate regulatory requirements.	No significant net effects are predicted Health Canada does not consider that any precautionary measures are needed regarding daily exposures to EMFs at extremely low frequencies. There is no conclusive evidence of any harm caused by exposures at levels found in Canadian homes and schools, including those located just outside the boundaries of power line corridors. .
Noise & Vibration	<u>Construction & Maintenance</u> Potential disturbance as a result of noise, including potential use of implosive splicing and their associated increased vibrations levels.	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Construction will be completed in accordance with local noise control by-laws (Municipality of Lakeshore Noise By-Law 106-2007 and Municipality of Chatham-Kent Noise By-Law 178-2017), or applicable exemptions.	No significant net effects are predicted.
NATURAL ENVIRONMENT RESOURCES			
Physical Environment			
Spills	<u>Construction & Maintenance</u> Potential inadvertent release of deleterious substances including oil, gasoline or other liquids.	The following mitigation is recommended to address these potential effects: • Refueling of vehicles and equipment will be completed in a designated location located away from sensitive receptors, such as designated source water protection areas, watercourses, surface drainage features, wetlands, etc.; • Fuelling of vehicles/equipment will occur utilizing an emergency spill tray to capture any accidental release of fluids;	No significant net effects are predicted.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• Fuelling operations will require the operator to visually observe the fuelling process 100% of the time; • If refuelling must occur outside of designated areas, additional containment or other mitigation and spill prevention measures will be utilized; • An Emergency Response Plan and spill cleanup equipment will be maintained and be readily accessible at all times during construction and maintenance activities; • Spills will be addressed and remediated as soon as possible after a spill; • Areas impacted by a spill will be secured, and unauthorized personnel will be kept out of the affected area until further assessment and/or clean-up is conducted; • Clean-up and the disposal of contaminated materials will be managed in accordance with provincial regulations and guidelines; • Fuels, chemicals, lubricants or other deleterious substances will be stored on level ground in properly contained storage areas; • Only approved aboveground petroleum storage tanks will be used during the construction phase of the Project, and will be stored in designated fuelling areas and with additional temporary containment measures; • Work conducted near Provincially/locally designated Vulnerable Areas (namely Wellhead Protection Areas [WHPAs]; Intake Protection Zones [IPZs]; and Highly Vulnerable Aquifers [HVAs]) will be avoided or limited, where practical; • ERCA, the LTVCA and/or the Municipality of Lakeshore/County of Essex and Municipality of Chatham-Kent will be consulted in order to undertake the proper action for managing the potential threats to source water protection areas; and • The MECP Spills Action Centre (SAC) will be notified of all reportable spills.	
Waste Generation	<u>Construction & Maintenance</u> Solid and/or liquid waste will be generated.	The following mitigation is recommended to address these potential effects: • Waste and recyclables will be sorted, segregated and removed to a licensed or approved waste management facilities site and/or recycling facility; • Excess construction materials (i.e. waste, granular fill, clay) will be removed from construction sites and areas on an ongoing basis; • Concrete wash water will not be discharged onto the ground at the Project site. All water from concrete chute washing activities will be contained in leak proof containers or in an approved settling pond; • Liquid and solid sewage wastes held in portable tanks will be removed by a licensed contractor and taken to licensed or approved disposal areas; • Waste materials will be contained and not allowed into sensitive receptors such as waterbodies, riparian areas, wetlands or agricultural fields;	No significant net effects are predicted.

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		• Waste materials will be collected and transported to a licensed or approved waste management facility; and • All testing, handling, storage, transport and disposal of waste will be completed in accordance with all applicable legislation.	
Excess Materials Management	<u>Construction & Maintenance</u> Excess materials including topsoil and subsoil, may be produced during site excavations.	The following mitigation is recommended to address these potential effects: • All excess materials will be tested, if necessary, and managed in accordance with O. Reg. 406/19. All efforts will be made to manage soils onsite; • Soil testing to meet the requirements of O. Reg. 406/19, will be completed, if necessary, during geotechnical investigations and prior to or during construction; • If excess soil is deemed to be suitable, Hydro One will work with landowners to explore opportunities for re-use within the property; and • Any excess soil required to leave the site will be taken to an approved facility licensed to accept the soil based on its characterization.	No significant net effects are predicted.
Atmospheric Environment			
Climate Change	<u>Construction & Maintenance</u> Emissions will be generated from vehicles and equipment.	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Equipment will be properly serviced and maintained; • Idling of construction vehicles and equipment will be kept to a minimum and GPS or other navigation tools will be used in vehicles to optimize routing; and • The transmission line will be designed to adequately withstand the effects of climate change.	No significant net effects are predicted.

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Air Quality	Construction & Maintenance Potential for fugitive dust and impacts to air quality from vehicle emissions.	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Vehicles will not exceed posted speed limits; • Minimize and stabilize vehicular traffic and exposed soils in high traffic areas with suitable cover material; • Avoid excavation and other construction activities that have the potential to release airborne particulates during excessively windy and prolonged dry periods, to the extent practical; • If excavation or other construction activities with a potential to release airborne particulates must occur during windy conditions, dust controls will be utilized; • Cover or otherwise contain loose construction materials with the potential to release airborne particulates during transport, installation or removal; • Disturbed areas will be restored as soon as practical to minimize duration of soil exposure; and • Effective dust suppression techniques, such as on-site watering, will be implemented as necessary.	No significant net effects are predicted.
Noise and Vibration	Construction & Maintenance Potential disturbance as a result of noise, including potential use of implosive splicing and their associated increased vibrations levels.	Refer to the mitigation recommended for Noise and Vibration under Land Use and Communities above.	No significant net effects are predicted.
Surface Water Resources			
Soil Rutting & Vegetation Removals	Construction & Maintenance Potential for vehicles and equipment to create rutting in soils, creating ponding or channelization leading to additional erosion of soils. Vegetation removals have the potential for increases in both overland flow and water temperature, as well as	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Where practical, activities with potential to cause rutting, ponding/channelization or erosion will be planned during stable and dry ground conditions; • Existing watercourse crossings and constructed access routes will be utilized to the extent practical; • Where required, temporary crossing structures will be installed for construction access at watercourses and other low lying areas and will be removed upon completion of construction; • Existing, natural drainage patterns and flows will be identified and maintained to the extent possible; • Equalization culverts or similar methods may be used in construction of access roads; • Compatible vegetation will be retained and buffered to protect sensitive receptors, where practical.	No significant net effects are predicted.

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	mobilization and transport of organic debris and sediment to nearby watercourses and municipal drains.	• Machine clearing and grubbing will be restricted near sensitive environmental areas, hand clearing will be required within watercourse banks/riparian areas or in wetlands. • Vegetation removals will be minimized to the extent possible, and replanted/seeded with compatible vegetation as required; • Where erosion is of a concern, exposed soils in previously vegetated areas will be re-vegetated as practical, or have other ESC measures applied as necessary; • Construction access and laydown areas will be restored following completion of construction; • Cleared vegetation will be relocated to designated areas away from aquatic features; • Equipment operation adjacent to water features will be minimized, where practical; • Works adjacent or around watercourse banks will be conducted during appropriate conditions and times of the year (e.g., dry or frozen conditions), to the extent practical; • ERCA and LTVCA will be consulted (specifically for ESC measures) during detail design.	
Dewatering	Construction Potential increase in surface water flows resulting from dewatering activities.	The following mitigation is recommended to address these potential effects: • Construction water will be discharged in compliance with permits and/or approvals from MECP and the Municipality of Lakeshore/County of Essex and Municipality of Chatham-Kent, as required; • A construction water management plan will be developed prior to construction and implemented appropriately (e.g., passing discharge water through a filter bag or drum before discharge to the environment to capture sediment and slow down the water velocity, etc.), as required; and • Where practical, opportunities to maximize retention times and reduce surface flow velocities will be executed.	No significant net effects are predicted.
Erosion and Sedimentation	Construction Potential for erosion, sedimentation and soil loss during site preparation and construction	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • An ESC plan will be developed prior to construction and ESC measures will be identified and implemented as required; • Areas with high erosion potential will be identified and avoided, to the extent practical; • Construction activities near sensitive features or areas may be suspended during extreme wet weather events, and crews will review and consider weather forecasts in their planning of such work; • ESC installations will only be removed after disturbed areas are restored, accumulated sediment has been disposed, and construction activities in the vicinity are completed; • In an effort to reduce potential erosion, mechanical or vegetation erosion control measures will be employed, such as buffer strips, erosion control blankets and sedimentation fences, as required; • Equipment operation on slopes adjacent to streams will be minimized to the extent practical;	No significant net effects are predicted.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• Disturbed areas near water features or sensitive environmental areas will be restored as soon as practical; and • ESC measures will be regularly inspected (including after each significant rainfall event; >10 mm) and repaired where necessary to maintain functionality.	
Construction work within areas regulated by Conservation Authorities	Construction Potential for infrastructure (towers, watercourse crossings) to be located within Conservation Authority regulated lands.	The following mitigation is recommended to address these potential effects: • ERCA and LTVCA will be consulted during detailed design and construction planning; • Design of the transmission line will avoid or minimize the extent to which transmission towers are located within regulated areas, to the extent practical; • If necessary, a Permit For Development, Interference with Wetlands and Alternation to Shorelines and Watercourses will be obtained through the applicable Conservation Authority (ERCA and LTVCA) prior to construction; and • Construction work (e.g., tower construction, temporary construction access) within regulated areas will be conducted during stable (frozen/dry) ground conditions, to the extent practical or isolated with appropriate ESC measures and other environmental mitigation measures.	No significant net effects are predicted. Permit for Development, Interference with Wetlands and Alterations to Shorelines and Watercourses will be obtained in advance of construction, where necessary.
Source Water Protection			
Source Water Protection (SWP)	Construction and Maintenance Potential for contamination of surface water through spills or leaks.	Refer to the mitigation recommended for Spills under Physical Environment.	No significant net effects are predicted.
	Construction and Maintenance Potential for impacts to designated surface water Intake and Wellhead Protection Area(s) and Significant Groundwater Recharge Areas.	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • The Project will comply with relevant legislation and policies such as: Clean Water Act, Provincial Policy Statement, Official Plans, and Source Water Protection Plans	No significant net effects are predicted.
	Construction Potential for impacts to private drinking water wells.	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Municipal wells and local private water wells within the area are not anticipated to be affected in any measurable way by potential construction dewatering of tower foundation holes or excavations from tower construction; and • The majority of wells exploit aquifer(s) that are at much greater depth than the proposed tower excavations. In the event dewatering activities create a minor radius of influence, shallow well aquifers,	No significant net effects are predicted.

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		groundwater levels and flows are expected to return to pre-construction conditions during the construction period.	
Groundwater Resources			
Groundwater Quality	<u>Construction</u> Disturbance of contaminated soil has the potential to contribute to groundwater contamination.	Refer to the mitigation recommended for Spills and Excess Materials Management under Physical Environment.	No significant net effects are predicted.
Groundwater Quantity	<u>Construction</u> Disturbance and compaction to soil has the potential to inhibit infiltration.	Refer to mitigation recommended for Soil Compaction under Agricultural Resources.	No significant net effects are predicted.
	<u>Construction</u> Dewatering activities / removal of groundwater have the potential to result in temporary lowering of aquifers.	Refer to mitigation recommended for Dewatering under Surface Water Resources. Additional mitigation recommended includes: • If deemed necessary, a hydrogeological assessment will be conducted to inform construction planning, permitting and management; • A construction water management plan will be developed prior to construction; and • Groundwater resources within the area are not anticipated to be adversely affected by dewatering of tower foundation holes or excavations from tower construction. Such effects will cease upon the completion of construction dewatering.	No significant net effects are predicted.
Designated or Special Natural Areas			
Important Bird Area (IBA)	<u>Construction and Operation</u> Potential for bird collisions within the Eastern Lake St. Clair IBA.	The following mitigation is recommended to address these potential effects: • The majority of the area of the IBA that is traversed by the proposed Project will involve replacement of an existing idle 115 kV transmission line; • Visual mitigation measures (e.g., bird diverters and/or similar measures) will be incorporated during detailed design as a mechanism to improve bird visibility of the transmission line within the IBA; • In support of detailed design, a review of potential wildlife habitat associated with the transmission line ROW will be used to identify locations for potential visual mitigation measures; • Towers and access roads will be located to avoid sensitive habitats, where practical. • Conduct vegetation removal outside of the migratory bird breeding season (i.e., April 5 to August 31; zone C1 as provided by ECCC 2018), where practical; and • In the event vegetation clearing is required during the breeding bird season, nest searches conducted by a qualified person will be completed in accordance with applicable provincial and federal requirements.	No significant net effects are predicted.

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Significant Woodlands	<u>Construction</u> Removal of portions of woodlands (transition to compatible vegetation) within the ROW. <u>Maintenance</u> Vegetation management within the ROW to ensure that incompatible vegetation does not threaten the safe and reliable operation of the transmission line.	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • The extent of clearing and vegetation removal required for the transmission line ROW within woodlands will be minimized to the extent practical; • Woodlands will be taken into account when planning access, and the footprint of work areas/access within woodlands will be minimized to the extent practical; • Incompatible vegetation will be salvaged or felled as appropriate; • Conduct tree removals associated with woodlands outside of the migratory bird breeding season (i.e., April 5 through August 31, zone C1 as provided by ECCC 2018) and the bat active season (i.e. April 1 through September 30), where practical; • In the event vegetation clearing is required during the breeding bird season, nest searches will be conducted by a qualified person in accordance with applicable provincial and federal requirements; • In the event woodlands with the potential to support bats require tree removals, bat acoustic surveys will be completed during the month of June in accordance with agency approved protocols to determine Species at Risk (SAR) bat habitat use (or lack thereof). Where acoustic surveys confirm SAR bat habitat use, the MECP will be consulted regarding permitting/approvals next steps under the Endangered Species Act, 2007 (ESA); and • Snags (dead standing trees) and cavity trees that do not pose a risk to the operation of the transmission line will be identified and retained.	Net effects include permanent removal of incompatible vegetation (portions of woodland) to ensure the safe operation of the transmission line; not considered significant. Incompatible vegetation removal will not represent a loss of vegetation on the landscape, but rather a transition from vegetation that is incompatible with transmission line corridors, to vegetation that is compatible. Hydro One will undertake a Biodiversity Initiative to offset habitat loss or transition (e.g., from woodlot to a compatible vegetation community) that cannot otherwise be avoided or mitigated. This initiative will be conducted subsequent to completion of the Class EA and OEB Leave-to-Construct processes.
Natural Heritage Features			
Vegetation	<u>Construction & Maintenance</u> Removal of vegetation within proposed activity work areas.	Refer to mitigation recommended for Hedgerows and Windbreak under Agricultural Resources and IBA and Significant Woodlands under Designated or Special Natural Areas. Additional recommended mitigation includes: • Tree protection zones will be used to delineate and protect trees that do not require removal for construction activities or operation of the transmission line, as necessary;	Net effects include permanent removal of incompatible vegetation to ensure the safe operation of the transmission line; not considered significant.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• Non-salvageable limbs will be disposed of by chipping or removal to designated areas; • Tree removals adjacent to watercourses will be cut such that their root systems remain intact to maintain soil stability, and compatible bank/riparian vegetation will be retained to the extent practical; • Isolated trees (i.e. not associated with woodlands) identified as having the potential to support bats will be removed outside of the bat active season (i.e. April 1 through September 30); and • In the event isolated trees with the potential to support bats require removal during the bat active season, exit surveys will be completed following agency approved protocols. Where surveys confirm no habitat use, the isolated tree(s) can be removed. In the event habitat use is confirmed, removals will be completed between October 1 and March 31.	Incompatible vegetation removal will not represent a loss of vegetation on the landscape, but rather a transition from vegetation that is incompatible with transmission line corridors, to vegetation that is compatible. Hydro One will undertake a Biodiversity Initiative as outlined above.
	Construction Accumulation of cleared vegetation.	In addition to the applicable mitigation outlined above, the following additional mitigation is recommended to address these potential effects: • Essex County and the Municipality of Chatham-Kent are designated areas by the Canadian Food Inspection Agency (CFIA) prohibiting the movement of Ash firewood and wood Ash products. As such, wood waste will be managed in accordance with federal requirements and best practices.	No significant net effects are predicted.
Fish and Fish Habitat	Construction & Maintenance Potential disturbance to fish habitat as a result of vegetation loss, soil erosion, sedimentation, etc.	Refer to mitigation recommended for Spills under Physical Environment. Additional mitigation includes: • The creation of new water crossings during construction will be avoided to the extent feasible by using existing access and crossings (e.g. bridges, culverts) and by accessing work areas from either side of watercourses/drains, where practical; • Construction access, laydown and work areas will be planned to avoid waterbodies and potential fish habitat to the extent practical (e.g., maintaining distance from watercourse banks except where crossings exist or are required); • Any disturbance to waterbodies, shorelines, riparian areas, etc. will be stabilized to prevent erosion immediately; • An ESC plan will be developed to include mitigation measures such as constructing watercrossings during low flow conditions, retaining compatible stream bank vegetation, use of ESC during construction and restoration, and storing materials away from sensitive receptors (e.g. watercourses, drains, wetlands); • Project wastes will be stored and/or removed from all riparian areas immediately; • Disturbed areas will be restored to a pre-disturbed state or better, upon completion of construction;	No significant net effects are predicted. Hydro One will undertake a Biodiversity Initiative as outlined above where there is opportunity to create and/or enhance aquatic habitat.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• If permanent or temporary works are required below the high water mark of a watercourse with potential fish habitat, a Request for Review will be prepared and submitted to the DFO in support of a Letter of Advance and / or approvals under the *Fisheries Act*; • Transmission line structures will be set back from watercourse banks and located outside of regulatory floodplains, to the extent practical; and • Work will be conducted in accordance with a permit from the applicable Conservation Authority when working within their regulated area.	
Woodlands	<u>Construction</u> Removal of woodlot (transition to compatible vegetation) within the transmission ROW. <u>Maintenance</u> Vegetation management within the transmission ROW to ensure that incompatible vegetation does not threaten the safe and reliable operation of the transmission line.	Refer to mitigation recommended for Significant Woodlands under Designated or Special Natural Areas.	Net effects include permanent removal of incompatible vegetation to ensure the safe operation of the transmission line; not considered significant. Incompatible vegetation removal will not represent a loss of vegetation on the landscape, but rather a transition from vegetation that is incompatible with transmission line corridors, to vegetation that is compatible. Hydro One will undertake a Biodiversity Initiative as outlined above.
Wetlands	<u>Construction</u> Potential impacts to wetlands as a result of vegetation loss, soil erosion, sedimentation, etc.	Refer to mitigation recommended for Spills under Physical Environment, Soil Rutting & Vegetation Removal under Surface Water Resources and Significant Woodland under Designated or Special Natural Areas.	Net effects include permanent removal of incompatible vegetation to ensure the safe operation of the transmission line; not considered significant. Incompatible vegetation removal will not represent a

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
			loss of vegetation on the landscape, but rather a transition from vegetation that is incompatible with transmission line corridors, to vegetation that is compatible. Hydro One will undertake a Biodiversity Initiative as outlined above.
Species at Risk (SAR)	<u>Construction & Maintenance</u> Potential disturbance or loss of SAR and / or SAR habitat.	Refer to mitigation recommended for Soil Rutting & Vegetation Removal under Surface Water Resources, Significant Woodland under Designated or Special Natural Areas and Vegetation under Natural Heritage Features. Additional mitigation includes: • Impacts to potential SAR habitat will be avoided, where possible. In the event impacts cannot be avoided, MECP will be consulted regarding permitting / approval requirements under the ESA during detailed design. • Boundaries of SAR habitats will be identified and flagged off and protected; • To the extent possible, incompatible vegetation / trees with the potential to provide SAR habitat will be removed / trimmed to the extent that they no longer pose a risk to overhead transmission lines while still maintaining their potential SAR habitat characteristics. Alternatively, incompatible vegetation will be replaced with compatible vegetation to maintain SAR habitat; • Snags (dead standing trees) and cavity trees with the potential to provide SAR habitat that do not pose a risk to the operation of the transmission line will be identified and retained to the extent practical; • Construction personnel will be aware of the potential presence of, and able to identify, SAR with the potential to occur within the general work areas; • Should SAR be encountered during construction activities, activities will be stopped until it has been determined that harm will not occur. The required activities will be assessed to determine whether the work / schedule can be modified, or mitigation measures employed, to avoid potential effects on SAR and their habitat; • In the event the proposed Project has the potential to impact Barn Swallow nesting habitat, the activity qualifies for registration under Section 23 of Ontario Regulation 242 / 08;	Net effects include permanent removal of incompatible vegetation to ensure the safe operation of the transmission line; not considered significant. Incompatible vegetation removal will not represent a loss of vegetation on the landscape, but rather a transition from vegetation that is incompatible with transmission line corridors, to vegetation that is compatible. Permitting under the ESA, SARA and / or the Fisheries Act will be obtained in advance of construction, where necessary.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• If avoidance of SAR and / or SAR habitat is not possible, MECP and / or DFO will be consulted to mitigate the impact of the activities and / or assess the need for permitting / approvals under the ESA, SARA or the *Fisheries Act*; • If as SAR is harmed or killed as a result of work activities, the MECP will be notified and the relevant work activities will cease within the immediate area until the species has been removed by personnel authorized to handle SAR; and • SAR observed during construction activities will be reported to the MECP.	
Wildlife Habitat	<u>Construction & Operation</u> Potential disturbance or loss of wildlife habitat, including habitat fragmentation.	Refer to mitigation recommended for Significant Woodland under Designated or Special Natural Areas and Vegetation under Natural Heritage Features. Additional mitigation includes: • Boundaries of important wildlife habitats will be identified and flagged prior to clearing; • Trees containing stick nests and areas where active animal dens or burrows are encountered will be left undisturbed until unoccupied, as determined by a qualified person; • Promotion of wildlife habitat through vegetation control and brush piles; • Birds of prey may construct stick nests on transmission structures. Osprey nests are most common on transmission structures, but Bald Eagle nests are occasionally encountered. If there are eggs or young in the nest, it is Hydro One protocol to leave the nest until the young have fledged unless there is an immediate safety concern to be addressed. If there are no eggs or young observed, the nest will be removed and replaced; and • Construction personnel will be aware of the potential for wildlife which may be encountered with the within the general work areas.	Net effects include permanent removal of incompatible vegetation to ensure the safe operation of the transmission line; not considered significant. Incompatible vegetation removal will not represent a loss of vegetation on the landscape, but rather a transition from vegetation that is incompatible with transmission line corridors, to vegetation that is compatible. Hydro One will undertake a Biodiversity Initiative as outlined above.
Invasive Species	<u>Construction</u> Potential for inadvertent spread of invasive species propagules through the movement of soil, debris and / or plant material via construction vehicles and equipment.	Refer to mitigation recommended for Agricultural Resource effects. Additional mitigation includes: • Construction crews will be educated on the importance of avoiding inadvertent spread of invasive species, and to identify the invasive species that are known to occur or are likely to occur within work areas; • Areas identified as having invasive species present will be considered during access and construction planning. Stands of invasive plant species will be avoided to the extent practical during construction; • Equipment and vehicle inspections and cleaning will be established during construction, to minimize the potential for inadvertent transport of invasive species propagules;	No significant net effects are predicted.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• Crews will be educated and informed of invasive species known or with potential to occur in work areas; and • Special treatment areas (e.g. invasive species) will be designated and tracked for future maintenance works.	
ANISHNAWBEK AND HAUDENOSAUNEE LANDS AND TRADITIONAL TERRITORY			
Anishnawbek and Haudenosaunee Lands and Territory	<u>All Phases</u> Potential to affect First Nations and Haudenosaunee interests.	• Some communities expressed interest in being involved with future archaeological and natural environment field work. Hydro One and its consulting archaeologist will work with interested communities to include representatives from interested communities in archaeological and environmental fieldwork; • Anishnawbek and Haudenosaunee communities will be provided opportunities to review the findings of archaeological field surveys and archaeological assessment reports; • If archaeological artefacts are encountered during construction, work in the vicinity will cease and a licensed archaeologist will be engaged immediately to ensure compliance with the provincial Heritage Act; • Hydro One understands that Bald Eagles are considered sacred. Bald Eagles occasionally build nests on transmission line structures; if there are eggs or young in the nest, it is Hydro One protocol to leave the nest until the young have fledged unless there is an immediate safety concern to be addressed. If there are no eggs or young, the nest will be removed and replaced. • Should Hydro One become aware of a deceased Bald Eagle along the transmission line corridor, we will note their location and inform interested communities, in the event that they would like to provide a ceremony; • Several communities have expressed a desire to protect and mitigate adverse effects to natural environment features such as SAR, wildlife and aquatic habitat, and natural or naturalized areas with their traditional territory that could be used for hunting, gathering, harvesting or other traditional uses. Mitigation measures to address effects to these features are described above under Natural Heritage Features; • A community expressed concerns regarding potential effects to nearby projects which generate revenue for the community. Hydro One does not believe that these projects will be interrupted by the proposed Project, as the eventual in-servicing of the future Lakeshore TS will serve to avoid or mitigate any potential temporary outages required to the transmission circuits connecting these facilities as a result of construction of the proposed Project; • Some communities are currently conducting Traditional Ecological Knowledge (TEK) studies. Should these communities wish to share some or all of the findings of these studies with Hydro One and the construction contractor, this information will be taken into consideration during the construction planning of the proposed Project to the extent practical. This may include working with private landowners to provide	No significant net effects are predicted.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		potential opportunities to harvest traditional use plant species ahead of construction, or to provide input into post-construction restoration plans for natural or naturalized areas; and • Some communities have expressed an interest in participating in the Biodiversity Initiative that Hydro One is committing to for the proposed Project, which will seek opportunities to create or enhance habitats to offset any adverse effects to habitats as a result of the Project. Hydro One will involve interested communities in the Biodiversity Initiative, including potential incorporation of TEK where that information is willingly provided.	
RECREATIONAL RESOURCES			
Recreational Resources	<u>Construction & Maintenance</u> Potential for temporary disturbance to tourism and enjoyment of recreational resources (e.g., trails, etc.).	The following mitigation is recommended to address these potential effects: • Disturbance to existing recreational resources will be avoided, to the extent practical; and • Safety precautions will be utilized throughout the Project area to protect the public such as anti-climbing devices and appropriate signage, where necessary.	No significant net effects are predicted. Hydro One will commit to working with local Municipalities to identify community benefit opportunities to enhance the broader landscape.
VISUAL AND AESTHETIC RESOURCES			
Visibility of the Project by Sensitive Receptors	<u>All Phases</u> Potential visual impacts to sensitive receptors with views of the Project.	Location of transmission structures is one of the largest factors influencing the visual effects to specific receptors. Design of the transmission line (e.g., placement of structure locations) will consider visibility to nearby sensitive receptors.	Construction of the new transmission structures will result in a visual change to the landscape. Hydro One will commit to working with local Municipalities to identify community benefit opportunities to enhance the broader landscape.
TECHNICAL CONSIDERATIONS			
Wind Turbines	<u>Construction & Operation</u> The transmission line will be constructed and operated within	The following mitigation is recommended to address these potential effects: • Direct impacts to existing wind energy facilities or their transmission lines are not anticipated as part of the Project; and	No significant net effects are predicted.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
	proximity to adjacent established wind energy facilities, including turbines and overhead or buried collector lines.	• Contact will be maintained with wind facility operators regarding work schedule and other items of interest.	
Infrastructure Crossings	All Phases Permanent overhead crossing of Highway 401, Highway 77 and Highway 40 (Communication Road), as well as construction of a new transmission line parallel to Highway 401 and other highways, including municipal roads.	Refer to mitigation recommended for Local Roads & Traffic under Land Use Communities. Additional mitigation includes: • Permanent impacts to Highway 401 or any other municipal road crossings are not anticipated as part of this project; • Temporary or rolling closure of Highway 401 may be required to facilitate stringing, and duration of any temporary closures will be minimized to the extent practical; • Where the new transmission line parallels the Highway 401, setback distances provided by the MTO will be respected; • Work within the MTO Highway 401 ROW will require an Encroachment Permit and consultation and input from Ministry staff during design; and • Works within 400m of a 400-series highway will require a Land Use permit from the MTO. Site specific traffic control plans will be developed to accommodate crossings.	No significant net effects are predicted.
	Construction Underground utility crossing.	The following mitigation is recommended to address these potential effects: • Equipment with low bearing capacity will be used, where feasible; • Temporary access roads and work pads will be built using mats or geotextile and crushed rock, and/or other protective measures will be implemented as deemed necessary; and • Contact will be maintained with applicable utility operators regarding work schedule and other items of interest.	No significant net effects are predicted.
	Construction and Operation Permanent overhead crossing of the existing railway line ROWs.	The following mitigation is recommended to address these potential effects: • Temporary flagging operations of railway lines may be required to facilitate construction of the aerial crossing; and • Hydro One will work with applicable rail authorities during design.	No significant net effects are predicted.
	All Phases Crossings of constructed drains.	Refer to applicable mitigation recommended for Fish and Fish Habitat under Natural Heritage Features and Spills under Physical Environment. Additional mitigation includes: • Municipal drainage superintendents will be consulted during design and construction planning, to discuss any potential effects to municipal drains; • Placement of transmission structures will avoid Municipal drains to the extent practical;	No significant net effects are predicted.

ENVIRONMENTAL CONCERN	PROJECT PHASE & POTENTIAL EFFECTS	MITIGATION MEASURES	NET EFFECTS
		• The creation of new crossings during construction will be avoided to the extent practical by using existing access and crossings (e.g. bridges, culverts) and by accessing work areas from either side of drains, where feasible; and • Disturbed areas will be restored to a pre-disturbed state or better, where feasible.	

POLLUTION PROBE INTERROGATORY - 14

Reference:

Exhibit I-6-6c

> *"The environmental and socio-economic mitigation and restoration costs included in the line cost estimate is $ 3.8M."*

Interrogatory:

a) Please provide a detailed breakdown by specific activity for the cost estimate of $3.8M related to environmental and socio-economic mitigation and restoration costs.

b) Please provide all backup material used to develop the develop the environmental and socio-economic mitigation and restoration cost estimate.

c) Did Hydro One leverage contractor estimations specific to this project to determine its environmental and socio-economic mitigation and restoration cost estimate? If yes, please provide a copy of those materials. If no, what other means did Hydro One use to validate that the cost estimate is reasonable.

Response:

a) The environmental mitigation and restoration costs referenced in the Preamble to this Question are based upon responses received from the engineering, procurement and construction ("EPC") bid process. Each EPC bid received was required to address environmental mitigation and restoration requirements as identified in the Environmental Study Report ("ESR"). Hydro One has not required its EPC Contractor to prepare a detailed breakdown of the environmental and restoration costs in the form requested. Hydro One does not consider the effort to do so nor the detailed breakdown information as materially assisting the Board in its deliberations into the relief sought in this application. The EPC Contractor's estimate for these types of costs is less than 1.5% of the overall cost estimate for the Project. Given the nature of the Project and magnitude of this estimate, Hydro One has not considered environmental mitigation and restoration costs to be a material risk associated with the Project.

b) Please see response to part a).

c) Please see response to part a).

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POLLUTION PROBE INTERROGATORY - 15

Reference:

No Reference Provided

Interrogatory:

a) Please provide the total cost estimate related to potential expropriation activities for the proposed project. Please break the estimate down into components of costs to the extent possible.

b) Please provide an estimate of the costs related to an OEB proceeding for expropriation should that be required.

c) Have the costs related to expropriation (including potential proceeding) been including in the costs estimate for this proceeding or will they be incremental to the project costs estimated in this proceeding? If they are included, please provide all evidence references.

Response:

a) Hydro One designed its Chatham to Lakeshore Project ("Project") Land Acquisition Compensation Principles to encourage voluntary settlements with property owners from whom Hydro One requires property rights to support the Project. As such, the Project budget reflects obtaining all rights voluntarily. Estimates for direct expropriation costs, incremental to the real estate budget (which is based upon voluntary settlements) is contained in Hydro One's contingency budget as shown in Exhibit B, Tab 7, Schedule 1. Hydro One is not prepared to disclose the specific amount of the contingency budget that comprises expropriation costs as this information would provide commercially sensitive information that would reasonably be expected to be used in negotiations with landowners regarding the quantum of individual or group voluntary settlements.

b) Hydro One cannot opine on the costs related to an OEB proceeding for expropriation should that be required, specifically any intervenor cost awards and/or regulator administration/hearing costs, as those would be specific to the interests expressed by intervenors and the format in which the OEB determines to review any potential expropriation application, i.e., a written hearing or oral hearing. Irrespective of this limitation, Hydro One anticipates that expropriation proceedings costs would not be material to the overall cost of the Project and have been included in the contingency estimate.

c) See response a) for expropriation costs.

THE ROSS PROFESSIONAL CORPORATION FIRM INTERROGATORY - 02

Reference:

EB-2022-0140 - Hydro One Networks Inc. Leave to Construct Application - Chatham by Lakeshore - Update to Exhibit B-3-1, June 8, 2022 ("**Application**")

Exhibit B-7-1, Table 1

Draft Environmental Study Report, June 11, 2021 ("**ESR**"), Page 2-2 (or Page 37/305)

Interrogatory:

The Application's referenced table provides the estimated capital cost of the Chatham x Lakeshore Line for the preferred route (namely, route 2A). The table includes a breakdown of the preferred route's line costs with respect to (a) materials; (b) labour; (c) equipment rental & contractor costs; (d) sundry; (e) contingencies; (f) overhead; (g) allowance for fuds used during construction; (h) real estate; and (i) the total cost of the line work.
Similarly, in its ESR, HONI indicated that it considered 8 route alternatives which it had undertaken to study before arriving to its preferred route (namely, route 2A).

a) For each of the 7 alternative routes considered by HONI (namely, 1A, 1B, 1C, 1D, 2B, 2C, and 3A), we ask HONI to provide a breakdown of the capital costs in the same manner and detail as that provided for the preferred route (namely, route 2A).

Response:

a) While detailed cost estimates were not completed on all route alternatives (i.e., only conducted for the preferred route, once it had been selected), relative costs of each route alternative were considered in the route evaluation through the equal application of seven different technical and cost evaluation criteria.

   To evaluate each of the routes, a weighted Multi-Criteria Decision-Making analysis method (typical decision-making tool), was used, which included the following key steps:

   - Collecting feedback from Anishnawbek and Haudenosaunee communities, community members and stakeholders, as well as collecting available information across four categories: Natural Environment, Soc-*io-Economic Environment, Technical and Cost and First Nations and Haudenosaunee Culture, Values and Land Use.

- Using the feedback and information collected to build an evaluation framework by: i) Identifying a wide variety of evaluation criteria under each category, ii) Assigning weighting (importance) to each evaluation criterion (e.g., we heard very loud and clear from the community the importance of considering effects to agricultural operations, and this was therefore included as a criterion we evaluated and weighed to be of most importance within the socio-economic category), and iii) Assessing each route alternative based on the framework to select the preferred route.

As per the Class Environmental Assessment for Minor Transmission Facilities (2016), the evaluation of route alternatives considered technical and cost criteria in addition to the other environmental criteria, to ensure that the selection of the preferred route would adhere to the Class EA process by weighing technical and cost factors relative to other natural and socio-economic environmental factors. In fact, the definition of “Environment” within the Environmental Assessment Act *includes the natural, social, cultural, built and economic environments.* The Class EA process compels the proponent to assess and evaluate viable alternatives through the consideration of the robust definition of “Environment” (including cost) to select a preferred alternative.

Technical and cost criteria were developed by the Hydro One project team to capture aspects which generally related to costs of constructing and operating the transmission line (e.g., total line length, sharp angle towers, requirements for new property rights, etc.). The technical and cost criteria were also assigned relative weightings by the Hydro One project team, such that criteria deemed to have a greater effect on overall cost of the project (e.g., angle towers and requirements for new property rights) were given a higher weight than those criteria deemed to have less direct impact to overall project cost (e.g., proximity to existing wind turbines). A detailed description of how the technical and cost criteria were applied to each of the three route alternatives and their associated variations is presented in Table 5-6 of the draft ESR and is provided as Attachment 1 of Exhibit I, Tab 1, Schedule 18 for ease of reference.

Through this process, the entirety of each route was objectively evaluated. A key component of the Class EA process was ensuring that the evaluation of each route was conducted through a balanced framework, incorporating feedback received and weighing that feedback over the entire length of the proposed route.

A detailed description of how the technical and cost criteria were applied to each of the 8 route alternatives considered during the Chatham x Lakeshore Class EA is presented in Table 5-6 of the draft ESR provided as Attachment 1 of Exhibit I, Tab 1, Schedule 18 for ease of reference.

Hydro One also provides that there is a cost and schedule impact to ratepayers for a detailed cost estimate for each individual alternative that would be imprudently incurred if undertaken for all route variations that the EA would otherwise reject based on all the other criteria defined above. The development of detailed cost estimates and updating those cost estimates can have a cost impact of millions of dollars/route studied, including obtaining data that can impact the quality of the estimate. For example, investigative labour-intensive analysis such as LiDAR surveys, engineering design work to determine number and type of structures, determining location of temporary access roads, geotechnical investigation and foundation design are only conducted on the preferred alternative to underpin the estimate provided in Exhibit B, Tab 7, Schedule 1. This information would be required for all routes if the requested information sought in this interrogatory were to be provided. For further context, to conduct the type of investigative analysis that would be required to underpin a detailed estimate, early access to property is required. The undertaking would therefore include negotiating early access agreements with property owners, and compensating them accordingly, to obtain access to individual properties to conduct the aforementioned analysis. This all has a cost and a corresponding impact to project schedule.

From a schedule perspective, Hydro One provides that the schedule impact of providing detailed cost estimates for each considered route in the EA could be quite material and anticipates that the delay would be reflected in years of delays on the in-service date. This is predicated on the fact that even simply completing the aforementioned deliverables (e.g., geotechnical studies and negotiating early access agreements) are either seasonally constrained or require adequate time to reach conclusion. Delays to the schedule have further impacts to the overall cost of any project, including escalating AFUDC costs and inflationary pressures. Moreover, for this specific project, further delays to the schedule would impact the defined in-service date identified by the IESO to the detriment of the reliability and quality of service benefits that the increase in transfer capability delivered by this line provides; namely materially reducing the need to identify and select customers for potential rejection for system contingencies.

Hydro One's position is that developing the detailed high-quality estimates (either cost or schedule) sought by this interrogatory for each independent route such that it can be reasonably compared with the cost estimate provided in Exhibit B, Tab 7, Schedule 1 is not practical and imprudently burdens transmission ratepayers with costs. This approach would also unnecessarily burden property owners that would otherwise not be impacted by a route that had been assessed to not be the preferred route based on the consultation activities defined by the Class EA process.

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THE ROSS PROFESSIONAL CORPORATION FIRM
INTERROGATORY - 03

Reference:

EB-2022-0140 - Hydro One Networks Inc. Leave to Construct Application - Chatham by Lakeshore - Update to Exhibit B-3-1, June 8, 2022 (“Application”)

Exhibit B-4-1 (or page 64/225)

Interrogatory:

In its Application, HONI indicated that the Chatham x Lakeshore Project is categorized as a “Development Project” that provides for additional system capacity and maintains reliability and quality of electricity supply.

a) We ask HONI to provide detailed particulars as to how the preferred (namely, route 2A) compares, with respect to reliability and quality, to each of the 7 alternative routes that were studied by HONI (namely, 1A, 1B, 1C, 1D, 2B, 2C, and 3A).

Response:

Please refer to Exhibit I-Tab 1-Schedule 18.

Additionally, Hydro One provides that to determine the viable routes for the new transmission line, Hydro One mapped out known technical and environmental features such as waterbodies, dense residential areas, environmentally significant areas, areas in close proximity to/conflicting with existing infrastructure, amongst others, and sought opportunities to parallel linear infrastructure and utilize existing easements. Based on that information, Hydro One’s design team developed three viable route alternatives and associated variations that respected the above-noted constraints and opportunities, while also minimizing potential project effects and costs by considering total line length, line angles required, and avoidance of transmission line crossings where feasible.

This process resulted in the identification of routes determined by the Project team to inherently be both technically and economically feasible and reasonable. As such, route alternatives which would not have met the need for the project (e.g., for a safe and reliable new 230 kV supply to the Lakeshore TS), or would have introduced technical challenges, such as unacceptable or unreasonable risks to reliability and quality of service of the new transmission line, were not carried forward for further consideration through the Class EA process. Therefore, the route evaluation conducted in the Class EA for the Chatham x Lakeshore project considered only those route alternatives which the Hydro One project team had deemed to be reasonable and acceptable in terms of their ability to safely and reliably provide a supply of 230 kV electricity to the Lakeshore TS.

In short, the Class EA process *only* assessed and evaluated alternatives deemed to provide a safe and reliable supply of electricity. An inherently reliable transmission line was the base-case requirement of the undertaking.

THE ROSS PROFESSIONAL CORPORATION FIRM
INTERROGATORY - 04

Reference:

EB-2022-0140 - Hydro One Networks Inc. Leave to Construct Application - Chatham by Lakeshore - Update to Exhibit B-3-1, June 8, 2022 ("Application")
Exhibit B-4, 5, 6, 7, 7.1
Exhibit C-1-1

Interrogatory:

With many countries experiencing difficulty in expanding transmission right-of-way, alternatives to the lattice tower construction proposed by HONI should be considered and evaluated to determine if monopole transmission structures, which require smaller right-of-way space can eliminate the need for expanded right-of-way and additional costs to ratepayers. HONI did not provide cost/benefit analysis demonstrating that they had considered the reliability/cost to ratepayers/landowners with alternatives to HONI's proposal for ACSR conductors and lattice towers (versus alternative such as, ACCC conductors and monopole towers.).

a) We ask HONI to provide evidence is support of the lattice tower construction as opposed to the monopole construction with respect to price, reliability and quality of service.

b) We ask HONI to provide evidence is support of the use of ACSR conductors as preferred over other conductor technologies with respect to price, reliability and quality of service.

c) When providing the evidence referenced in b above, please also provide any projections as to future load demand in the project service area and the ability of the present proposed conductor technology to meet the future needs.

Response:

a) Monopole construction is widely understood to be higher in cost per km than lattice towers. Monopoles are generally used in physically constrained areas such as urban environments or narrow corridors between existing infrastructure where these physical constraint impact offset the higher cost of the use of Monopoles.

b) Monopole structures are generally more costly than lattice towers due to following reasons:

i. Foundation cost is considerably higher due to the fact that the load for monopoles are concentrated in a single point
ii. Lower average spans for monopoles resulting in increased number of structures and further encumbrances on traversed property
iii. Increased transportation cost for monopoles as lattice towers could be bundled and shipped in fewer deliveries
iv. Higher cost of plates
v. Monopoles require specialized plate bending machine with high capital cost
vi. Lattice towers using steel angles are very easy to fabricate and galvanize
vii. The thickness of monopole plate increases rapidly with tower height and loads
viii. Galvanization of monopole sections are much more difficult than steel angles.

Both types of towers are in wide use by Hydro One where their selection aligns with the construction constraints and would meet the reliability requirements.

c) One of the primary determinants in selecting a conductor for the Project is cost. In 2008, the Electric Power Research Institute completed a report entitled the *Demonstration of Advanced Conductors for Overhead Transmission Lines* for the California Energy Commission ("the Report"). The Report is provided as Attachment 1 of this response. At Table 5-1, the Report outlines that ACCC conductors are considerably more expensive than ACSR/TW (about 3 times the cost of ACSR/TW). An extract of Table 5-1 of the Report is provided below for ease of reference with the two identified conductors highlighted. Recent cost estimates received by Hydro One on projects confirm that the cost disparity between conductor options remains relatively unchanged, today.

Table 5-1
Price Comparison for HTLS Conductors with Respect to Current–Carrying Capacity (as of March 2008)

Conductor	Current Capacity	Price	Conductor Length (miles)
Conventional ACSR	1	1	> 500,000 in US (230 kV and above)
ACSS (Round and Trap Wire, all strengths)	1.8 to 2.0	1.2 (HS steel core) 1.5 (HS285 UHS core)	34,000 in US 800 with HS285
GTACSR (Gap)	1.6-2.0	2	6,400
ACIR (Invar core)	1.5-2.0	3 – 5	12,000 (4,000 ZTACIR)
ACCR (Aluminum composite core)	2-3	5 – 6.5	500
ACCC (Carbon Fiber composite core)	2	2.5 – 3.0	1,200

ACCC conductors are commonly used for refurbishment projects for incremental transfer capacity increase and where the additional costs are offset by deferring the construction of new transmission lines or to resolve thermal rating restrictions due to low sag clearances at high temperatures. The IESO has identified that a new transmission line is required to address the need of the Project. Additionally, due to the lack of data, there are also some concerns about the behavior of this conductor under heavy winter loading conditions and galloping, which are still being assessed by the wider industry, as the use of this conductor is relatively recent (2005). As ACCC conductors are not standard to the Hydro One system, the use of this type of conductor will require the development of non-standard hardware to meet Hydro One's requirements. The current project schedule will not allow for the design, fabrication and testing of these parts. Finally, the use of Hydro One's standard ACSR/TW conductor will allow the use of standard hardware components which are well proven to meet reliability requirement. The use of Hydro One standard parts simplifies the maintenance process for emergency spare parts, which is considered a major operational advantage.

d) The demand forecast for the Windsor-Essex region is provided in Exhibit B, Tab 3, Schedule 1, Attachment 2 in the IESO published report, “Need for Bulk Transmission Reinforcement in the Windsor-Essex Region”.

Hydro One notes that the conductor technology selected for this project does not individually affect the ability to meet future demand, as the IESO applies planning criteria in accordance with North American Electric Reliability Corporation (NERC) standards and the Northeast Power Coordinating Council (NPCC) reliability directories to assesses transfer capability limits of the *entire* West of Chatham interface which presently consists of four 230kV circuits and will be expanded to six 230kV circuits following the completion of this project. Thus, the capability of this interface would be defined by the most limiting circuit(s), and since the new conductors would have higher ratings than some of the existing ones, further increasing the conductor size of this project would not increase the interface capability.

Energy Research and Development Division
FINAL PROJECT REPORT

Demonstration of Advanced Conductors for Overhead Transmission Lines

1017448

Prepared for: California Energy Commission
Prepared by: Electric Power Research Institute

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ELECTRIC POWER
RESEARCH INSTITUTE

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Demonstration of Advanced Conductors for Overhead Transmission Lines is the final report for the Demonstration of Advanced Conductors for Overhead Transmission Lines project contract number E21-WA-002 & 119 conducted by Electric Power Research Institute. The information from this project contributes to Energy Research and Development Division's Energy Technology Systems Integration Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

This is a reprint of the publically available final report from EPRI. This report describes a jointly funded collaborative research project to evaluate the operational performance of advanced High-Temperature, Low-Sag (HTLS) conductors. Twenty utilities funded this project. Among them, 15 utilities are from the United States, two from Canada, and one each from United Kingdom, Spain, and France. They are listed below.

American Electric Power (AEP)
American Transmission Company (ATC)
Arizona Public Service (APS)
California Energy Commission (CEC)
San Diego Gas & Electric (SG&E)
Southern California Edison (SCE)
Pacific Gas & Electric (PG&E)
CenterPoint Energy
Duke Energy
Exelon
Hawaii Electric
Long Island Power Authority (LIPA)
Southern Company
Tennessee Valley Authority (TVA)
Xcel Energy
British Columbia Transmission Company (BCTC), Canada
Électricité de France (EDF), France
Hydro One Networks, Canada
National Grid, UK
RED Electrica de Espana (REE), Spain

Demonstration of Advanced Conductors for Overhead Transmission Lines

1017448

Final Report, July 2008

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This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Demonstration of Advanced Conductors for Overhead Transmission Lines. EPRI, Palo Alto, CA: 2008. 1017448.

PRODUCT DESCRIPTION

This report describes a collaborative research project to evaluate the operational performance of advanced High-Temperature, Low-Sag (HTLS) conductors through approximately three years of field experience. The results of the project provide general information on installing, sagging, and clipping HTLS conductors and about their long-term behavior at different electrical current levels and in various geographical locales. Key information is provided on design, installation, operation, and maintenance of selected HTLS conductors and their hardware accessories.

Results and Findings

This report summarizes information on the mechanical and electrical characteristics of five types of HTLS conductors, including: Aluminum Conductor Steel Supported/Trapezoidal Wire (ACSS and ACSS/TW), Gap-type Aluminum Conductor Steel Reinforced [G(Z)TACSR], Aluminum Conductor Invar steel Reinforced [(Z)TACIR], Aluminum Conductor Composite Reinforced (ACCR), and Aluminum Conductor Composite Core (ACCC).

The report focuses on field trials at four utility test sites: CenterPoint Energy, HydroOne, Arizona Public Service, and San Diego Gas & Electric. It includes descriptions of data monitoring systems and instrumentation for each site. The report specifically includes information on the accessories used with HTLS conductors (splices, dead-ends, and terminations) and discusses the complex process of estimating service life of HTLS conductors based on the manufacturers' technical and laboratory test data as well as the field data obtained in this study.

Challenges and Objectives

Several manufacturers in United States and abroad have developed advanced new HTLS conductors for use in high-voltage transmission lines. These conductors are designed to overcome the traditional limiting factors in conductor performance in terms of strength loss and sag increase by being capable of continuous operation at temperatures above 100^{o}C while exhibiting low thermal elongation with temperature. The goal of this project was to provide EPRI member utilities with practical experience in handling, installing, and terminating these new types of conductor and to verify in practice the claims of manufacturers regarding their performance in an operating transmission line.

This project is intended to document specific aspects of stringing, sagging, and clipping of various commercially available HTLS conductor systems and to verify that the actual physical behavior of HTLS conductor in an operating transmission line is consistent with various manufacturer-supplied design parameters in use by utilities. The ultimate goal of this work is to help utility participants choose when to use such conductors, how to choose between various types, and how to avoid problems during installation and over the life of the line.

Applications, Values, and Use

The project offered a unique opportunity for participating utilities to gain real-world experience that will aid them in designing, specifying, handling, installing, inspecting, and maintaining advanced HTLS conductors. The field trials, laboratory tests in this project and additional future tests will make it possible to evaluate the long term-performance of the new conductors and their associated splices and dead-ends and will eventually result in guidelines in the form of a combination of written reports, videos, and classroom and field training.

The demonstration aims to raise confidence in using HTLS conductors and thus accelerate the application of the technology to increase power flow in the existing transmission circuits. The results of this project will position utilities as informed buyers and users of this technology.

EPRI Perspective

This general report is one of two final reports on EPRI's HTLS project. A second, more detailed, technically oriented report is scheduled for publication in the first half of 2009. The primary target audience for this general report includes utility executives, managers, system planners, and line design engineers who are looking for reliable information on HTLS conductors and their likely application to uprating existing lines.

Approach

HTLS conductors were installed at four utility test sites, and the project team documented installation procedures. Once the lines had been energized, the team monitored a variety of conductor parameters. They continuously recorded sag, tension, weather, and line current data and manually collected other parameters—splice resistance, conductor and hardware temperature, corona, electric and magnetic field profiles, and visual data—at regularly scheduled intervals over the test period.

Keywords

ACSR
ACSS
ACSS/TW
(Z)TACIR
G(Z)TACSR
ACCC
ACCR
HTLS (High-Temperature, Low-Sag)
Line uprating
Zirconium aluminum
Overhead transmission
Ultra-high strength steel
Sag
Structure tension loads
Annealed aluminum

EXECUTIVE SUMMARY

More than 80% of existing transmission lines use Aluminum Conductor Steel-Reinforced (ACSR) conductors, which can be operated continuously at temperatures up to 100°C. Beyond this temperature, the aluminum strand layers in these conductors begin to lose mechanical strength and the original design safety factors on tensile loading may be compromised. In addition, at conductor temperatures above the maximum selected in the original design, the electrical clearances to ground and other conductors may not be adequate due to excessive sag.

Given the difficulty in building new transmission lines, the normal increase in electrical load served with population, and the sometimes rapid shift in power flows resulting from open access rules for new generation, the power flow on certain existing lines may reach the line's thermal limit that is determined primarily by the phase conductor's maximum operating temperature.

In response to these challenges, manufacturers in United States and abroad have developed new conductors capable of continuous operation at temperatures above 100^{o}C without any reduction in tensile strength while exhibiting reduced rates of increase in sag with these high temperatures. Such conductors are referred to, in this report, as High-Temperature, Low-Sag (HTLS) conductors.

HTLS conductors are capable of continuous operation at temperatures between 150^{o}C and 250^{o}C, depending on the particular design, without losing tensile strength and with lower rates of sag change with temperature than for normal ACSR conductors. HTLS conductors can often replace conventional ACSR in an existing transmission line with little or no modification to supporting structures, thus saving both time and money and simplifying the regulatory processes.

While these conductors have passed industry standards tests for performance, utilities are wary of installing these yet unproven technologies without having first gained an insight into their performance in a real-world setting. Consequently, in 2003, the Electric Power Research Institute (EPRI) started a collaborative research project to evaluate the performance of a few of these advanced conductors. This project aims to provide participating utilities with information on the operational performance of these new conductors through approximately three years of field experience.

This general report is one of two final reports on EPRI's HTLS project. A second, more detailed, technically oriented report is scheduled for publication in the first half of 2009. The primary target audience for this general report—based on a consensus at the February 28, 2006 project meeting and subsequent telephone and email discussions—includes system planners who are looking for general information on HTLS conductors and inexperienced line engineers seeking insight into the process of reconductoring existing lines with HTLS conductors.

This project is intended to document unique aspects of stringing, sagging, and clipping of various commercially available HTLS conductor systems and to verify that the actual physical behavior of HTLS conductor in an operating transmission line is consistent with various manufacturer-supplied design parameters in use by utilities. The ultimate goal of this work is to help utility participants choose when to use such conductors, how to choose between various types, and how to avoid problems during installation and over the life of the line.

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1
INTRODUCTION

This report describes the objectives, methodology, and results of EPRI's High-Temperature, Low-Sag (HTLS) Project. The project is intended to document unique aspects of stringing, sagging, and clipping of various commercially available HTLS conductor systems and to verify that the actual physical behavior of HTLS conductor in an operating transmission line is consistent with various manufacturer-supplied design parameters in use by utilities.

This report describes general information related to the project and is designed for utility executives, managers, system planners and engineers who are seeking insight into the process of reconductoring existing transmission lines with HTLS conductors. A second, more detailed, technically oriented report is scheduled for publication in the first half of 2009.

Included in this report are ten sections, with background information on the drivers behind HTLS conductors and this project, a review of the state-of-the-art of HTLS conductors with discussions of terminations and splices, a description of opportunities for upgrade applications with HTLS conductors, a description of the four field test sites, a description of tests for predicting the service life of HTLS conductors, and a review of knowledge gained in the project.

To set the stage for the report, Section 1 leads off with a brief introduction to the HTLS project, with information on the background of the project, objectives, scope, tasks, schedule, and funders and participants.

Background

The demand for electric power is increasing at a rate of about 25% per decade, while new transmission facilities are being constructed at a rate of only 4% per decade. Deregulation of the power industry has allowed power to be dispatched from new low cost generation sources. This has altered the power flow patterns of the high-voltage transmission network. As a result, many transmission lines are overloaded, and transmission bottlenecks have been created, restricting power transfer from one location to another. Additional transmission capacities are therefore required. The most common way to raise transmission capacity is to construct new lines. However, today the regulatory process to acquire rights-of-way takes substantially longer than in the past in order to address environmental and public concerns. The new process thus further compounds the problem of imbalance between the demand and supply of transmission capacities.

One approach to addressing this dilemma involves optimizing the use of existing network assets to increase transmission capacity. If the power flow limitation is determined by a transmission line thermal rating, the rating can be increased by:

- Operating the existing conductors at a higher temperature.
- Replacing the existing conductors with a larger (lower resistance) conductor.
- Replacing the existing line conductors with an HTLS conductor of the same diameter as the original but capable of high temperature operation.

Each of these uprating alternatives presents challenges. Operation of older, existing conductors at higher temperatures requires a careful inspection to be certain that the conductor and its connectors are in good physical condition. Operation above $100^{o}C$ may cause unacceptable loss of ultimate tensile strength and increased sags at higher operating temperatures may not be possible due to minimum clearance requirements. Replacement with a larger conductor will impose higher mechanical loads on existing structures and may necessitate extensive upgrades or replacement of existing structures.

In response to the challenge of finding a reliable high temperature conductor for line uprating, manufacturers in the United States and abroad have developed HTLS conductors which can be installed and operated safely in existing lines. In many cases, HTLS conductors can be used to replace existing conventional aluminum or copper conductors with little or no modification to supporting structures.

EPRI HTLS Project

Power utilities are interested in installing these new conductors on their systems. However, there have been very few experiences with these conductors in North America. Their reliability is a major concern. Consequently, in 2003, the Electric Power Research Institute (EPRI) started a collaborative research project to evaluate the performance of a few of these advanced conductors that are capable of significantly increasing the current-carrying capacity of thermally constrained transmission lines. The two drivers behind the HTLS conductor project are:

1. **Meeting Capacity Needs.** Today networks are being forced to support power flows for which they were never designed. Upgrading the transfer capacity of existing lines through the application of HTLS conductors yields a large increase in thermal rating at modest cost that can be implemented quickly.

2. **Real-world Performance Testing.** In recent years, conductor manufacturers have brought to market a range of new, nontraditional conductor types. Although some of these conductors may have passed most or all accepted industry standards tests for performance, utilities are wary of installing these new technologies without having first gained an insight into their performance in a real-world setting.

2
SYSTEM IMPACT OF RECONDUCTORING WITH HTLS CONDUCTORS

Overhead lines are unique. They involve public safety directly both in terms of electrical clearances and structural adequacy. One of the fundamental limitations on power flow through overhead lines is limiting the conductor temperature to a level which neither causes a reduction in the conductor strength nor causes an increase in sag sufficient to infringe upon minimum electrical clearances to ground, buildings and other conductors. Conductor temperature can only be indirectly controlled by the power system operator by limiting line current. The link between line current and conductor temperature is influenced by weather conditions along the line.

Thermal, Voltage, and Phase Shift Limits for Overhead Lines

Determining the degree to which maximum power flow constraints can be eased by reconductoring an existing overhead transmission line with HTLS conductor, can be complex. The increase in permissible power flow over the reconductored line may be limited by other series equipment such as air disconnects, line traps, substation bus, or transformer bank capacity. Also, the power flow through critical interfaces (multiple “parallel” power circuits connecting power system regions) may not be greatly increased by reconductoring a single line since other circuits may still limit the total power flow.

For an overhead line, any increase in maximum allowable power flow resulting from reconductoring with HTLS conductor is dependent on its length as well as on the original design assumptions, the condition of its existing structures, and the type of conductors originally selected. As shown in Figure 2-1, increasing the thermal capacity of a 345 kV line which is more than 75 miles long will not allow higher power flows since the limit is due to voltage drop rather than high temperature of the conductor.

In general, it may be stated that maximum power flow on the transmission system is a function of the overall system topology (transmission lines, transformers, generation, series and shunt compensation, and load), and that many non-thermal system considerations can also limit the maximum power flow on a specific transmission circuit. Therefore, transmission circuit ratings are often developed on a system basis, rather than on an individual line basis. The overall limit may be between operating areas irrespective of ownership or individual lines, and may change during a day based on system conditions. Reconductoring an existing line to greatly increase its thermal limitation on power flow may or may not be economic and useful in terms of the system.

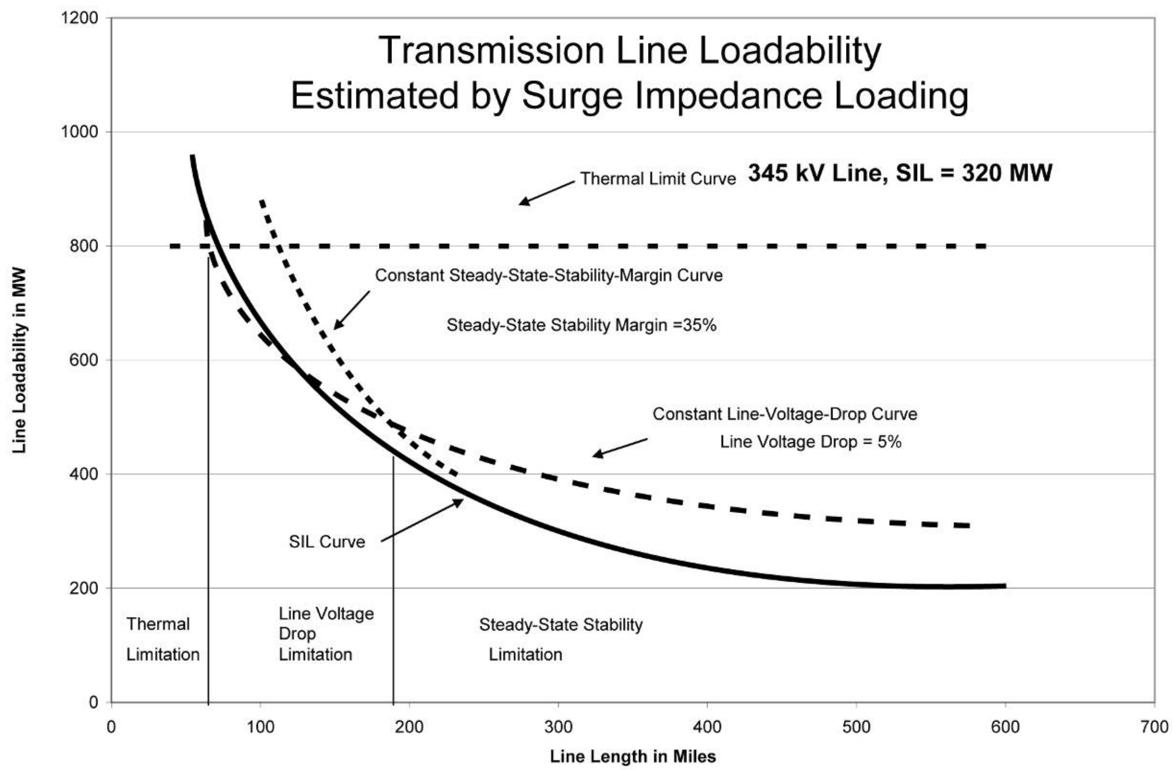


Figure 2-1
Transmission line power flow limits based on length.

Thermal Limits due to Sag

Figure 2-2 is a basic sag-clearance diagram, which illustrates how minimum ground clearance must be maintained under both heavy loading and high temperature events over the life of both new and re-rated transmission lines. The figure shows ground clearance and line sags under normal conditions, high ice/wind load, and high temperature conditions for a ruling (or "equivalent") span. Note that the sum of the minimum ground clearance, the buffer, and the sag at maximum temperature is the minimum attachment height, which determines structure height and spacing. In a detailed line design that has many different spans, this sort of sag-clearance calculation must be developed for all spans (Ehrenburg 1935, Winkleman 1959).

As can be seen from Figure 2-2, any transmission conductor must meet the minimum electrical clearance requirement, throughout the life of the line, under all environmental conditions including high wind and/or ice loading and high temperature. Therefore, sag calculations must take into account plastic elongation resulting both from high tension events - STC ("Short-Term Creep") - and long term exposure to everyday tension – LTC ("Long-Term Creep") as well as any elastic or thermal elongation that occurs. The increase in sag due to thermal elongation at high conductor temperature is based on the final sag not the initial. The elastic increase in sag due to ice or wind load is also based on final sag.

When reconductoring an existing line with HTLS conductor, sag clearance calculations must consider the initial sag of the replacement conductor, its plastic elongation over time, and it elastic and thermal elongation relative to its final sag position. HTLS conductors must do more than simply elongate less in response to high temperature, they must also be strong enough (elastic modulus) to limit elastic sag increase under ice and wind load and they must not exhibit high plastic elongation in response to high tension or long term application of more modest tension.

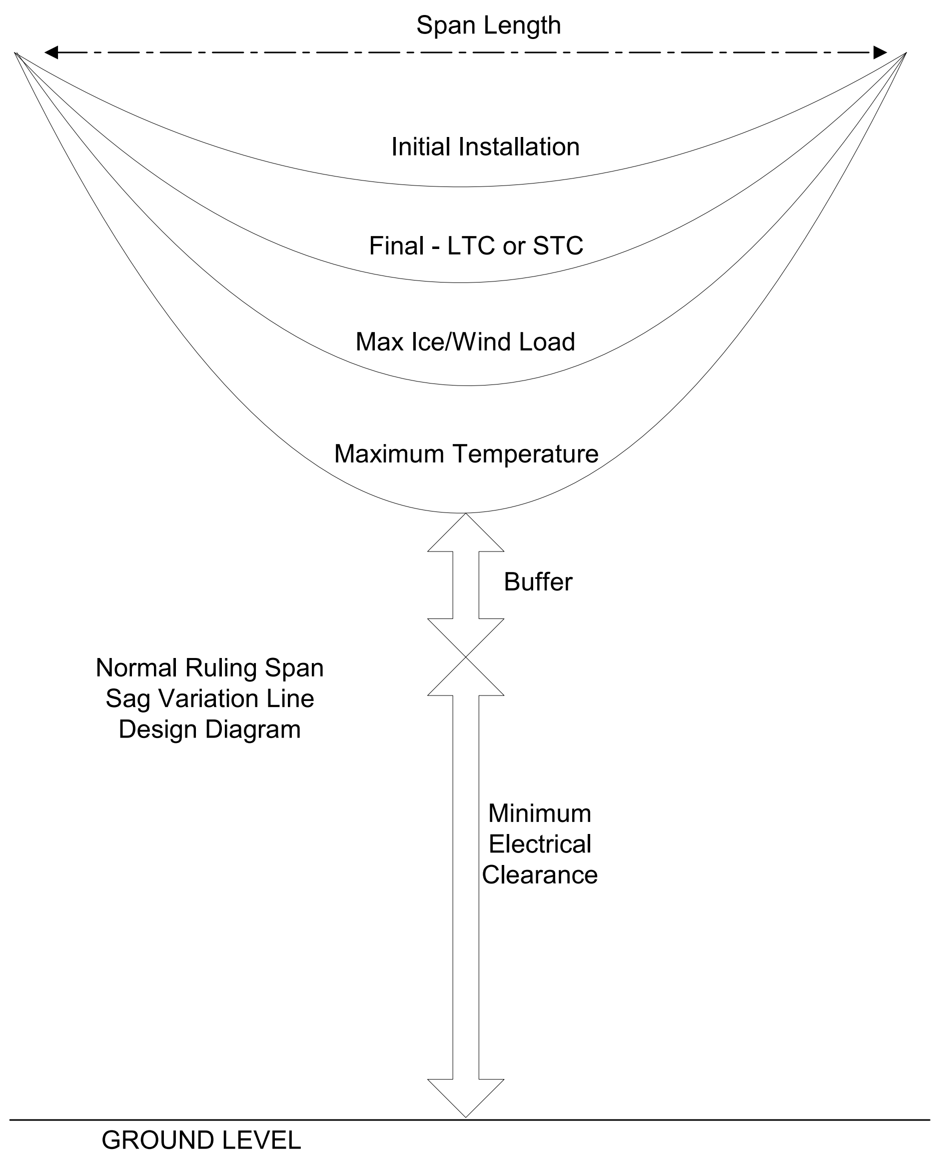


Figure 2-2
Sag-clearance diagram

Thermal Limits due to Loss of Strength

Construction codes require that maximum conductor tension not exceed a certain percentage of the energized conductor's breaking strength. A significant reduction in the breaking strength can weaken the energized conductor and lead to a tensile failure during subsequent high ice and wind loading events. To avoid this, the conductor must not operate at a high enough temperature for a long enough period of time so as to reduce its breaking strength more than 10%, and it must not be installed at such a high everyday "unloaded" tension that its strands fatigue due to wind vibration.

The American Society for Testing and Materials (ASTM) or the International Engineering Consortium (IEC - International Electrotechnical Commission) standards specify the minimum tensile strength of aluminum and copper wires, which is the stress at which the wire breaks. At temperatures above 75°C, the tensile strength decreases with time. Temperatures below 300°C do not affect the tensile strength of galvanized, aluminum-clad, or copper-clad steel wires. Thus, extended exposure of conductors made up largely of aluminum or copper wires to temperatures above 75°C can eventually reduce the line's design tension safety factor during high ice and/or wind loading events.

Figure 2-3 shows the reduction in tensile strength with time and temperature for a sample of 0.081 in. (0.2 cm) diameter hard drawn copper wire, as described in (Hickernell et al. 1949). There are 8760 hours in a year, so the diagram clearly shows that:

- sustained operation below 85ºC yields no measurable reduction of tensile strength
- sustained operation at 100ºC yields a 10% reduction in 600 hours (25 days)
- only 40 hours at 125°C reduces the wire tensile strength by 10%.

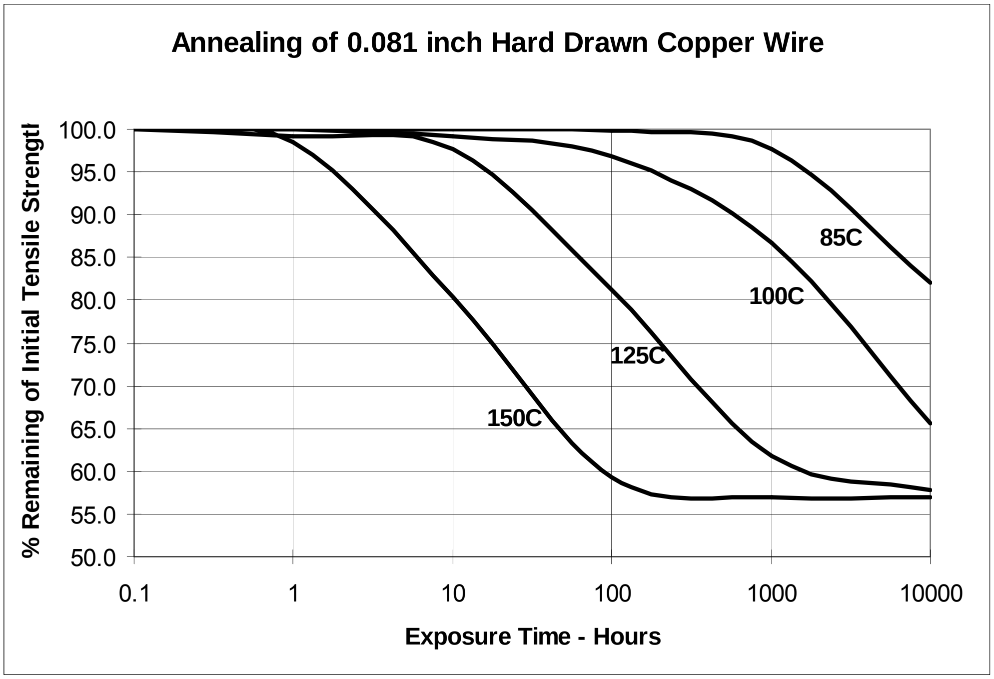


Figure 2-3
Annealing of 0.081 inch OD hard drawn copper wire at high temperature.

Figure 2-4 shows similar tensile strength reduction data for 1350-H19 "EC" hard drawn aluminum wire. (It is taken from Aluminum Association 1989). In general, tensile strength reduction of aluminum wires at temperatures of less than 90ºC is considered negligible. At 100ºC, the tensile strength of the wire is reduced by 10% after 5000 hours. At 125ºC, the tensile strength is reduced by 10% after only 250 hours.

When compared to copper, aluminum appears to anneal somewhat more slowly, though the difference is probably not important in transmission line applications. The source of the copper wire data also noted a significant amount of variation in the annealing rates for wire obtained from different manufacturers.

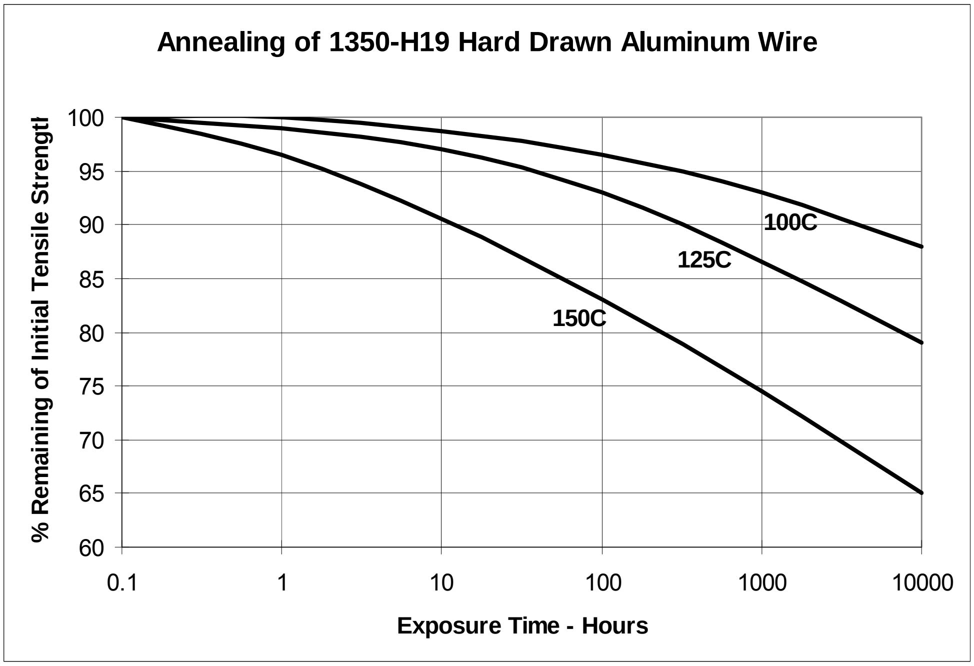


Figure 2-4
Annealing of 1350-H19 Aluminum wire at high temperature

HTLS Conductors - How They Work

As noted previously, the acronym, HTLS, stands for "High-Temperature, Low-Sag" conductors. The name summarizes the key properties of the conductors: They can be operated at high temperature (i.e. above 100ºC) for extended time periods without losing tensile strength or otherwise deteriorating mechanically, electrically, or chemically and they elongate less with temperature than normal all aluminum or steel-cored aluminum conductors.

In addition to these properties which are related to the maximum conductor temperature, HTLS conductors must also display the desirable properties associated with conventional transmission conductors:

- Mechanical properties – low weight per unit length, high elastic modulus, and low plastic elongation under high mechanical loading to so that existing lines can be reconductored with a minimum of structure modification yet remain mechanically reliable.
- Robust handling characteristics – HTLS conductors must be easily installed and terminated using methods familiar to existing experienced contractors.
- Chemical properties – Resistant to corrosion over lifetimes of 40 years or more. Insensitive to ultraviolet aging in the presence of sunlight and ozone.
- Low electrical resistance – Exhibit composite resistance less than or equal to the original conductors with the same diameter.

3 PROJECT DESCRIPTION

This research project aims to provide participating utilities with information on the operational performance of a number of new HTLS conductors through approximately three years of field experience. The project provides a unique opportunity to showcase these emerging technologies and to gain the real-world experience necessary to produce engineering guidelines that will aid utilities in designing, specifying, handling, installing, inspecting, and maintaining these conductors. In this case, the guidelines take the form of a combination of written reports, videos, and classroom and field training. Through this project, the long-term performance of such conductors, as well as associated splices and dead-ends, will be evaluated, based on field-trial and laboratory tests.

Finally, this project is envisioned as a co-operative effort between the funding utilities and manufacturers. The project does not aim to produce any intellectual property that will need to be protected by a patent. Instead the project aims to demonstrate and raise the confidence for using HTLS conductors and thus accelerate the application of the technology to increase power flow in the existing transmission circuits.

The results of this project will position utilities as “informed buyers and users” of this technology. The project also avoids duplication of research and test work completed by others in the industry. Instead, it brings these parties and their results into this project.

Scope

This project answers the following key questions:

Conductor Performance

- **Field Trials.** What characteristics of operating experience with the conductors can be gained from the field trials?
- **Laboratory Tests.** What conclusions are drawn from the experimental tests and analysis?
- **Manufacturer Claims.** How do published manufacturer claims compare to field and laboratory performance?

Design and Engineering

- **Design Parameters.** What are the design parameters (as required by line designers) for these conductors?
- **Engineering Changes.** What engineering changes (compared to standard ACSR) are necessary when designing, specifying, ordering, shipping, handling, installing, inspecting, and maintaining these conductors?
- **Existing Tower Design.** What is the impact of these new conductor types on the existing tower design? Do towers need to be redesigned to accommodate these conductors? What tower features inhibit the use of these conductors?
- **Handling**. What special handling precautions apply when shipping conductors to a site or while on site?
- **Installation.** What special tools and precautions are needed when installing these new conductors? What factors need to be considered when installing these conductors (e.g., slack-stringing versus tension-stringing)?

Conductor Aging

- **Aging Factors.** How do these conductors age, and what factors influenced aging? Further, how does aging affect performance? How does the long-term, mechanical performance of these conductors compare to the traditional conductor ACSR? If they do not compare, what are the areas of concern?
- **Long-Term Performance.** What is the long-term performance of line hardware, specifically splices and dead-ends? Performance covers repeatability of installing reliable splices and dead-ends—equipment needed to install a splice.
- **High-Temperature.** What is the effect of sustained high-temperature operation on the conductor, splice, and dead-end?
- **Connection.** How should these high-temperature conductors be connected to existing line conductors?

Conductor Fittings

- **Long-Term Performance.** How do these devices perform under high temperature over long periods of time?
- **Laboratory Performance.** Under accelerated environmental conditions, how do these products perform, and are there any concerns about the long-term integrity of these products?
- **Specifications.** What factors should be considered when specifying a conductor fitting for a particular operating environment?

Economics

- **Refurbishment Costs.** What are the comparative costs to upgrade an existing line section using different HTLS conductors?
- **New Line Costs.** What are the comparative "costs of operation" and "lifetime costs" when installing and operating networks using these new conductors as compared with the conventional ACSR?

Inspection and Condition Assessment

- **Inspection.** What techniques should be used to inspect and assess the condition of the conductors?

Engineering Guidelines and Training

- **Guidelines.** What engineering guidelines and training materials are required? What form should these materials take, and how should they be delivered?

Issues Not Addressed

This project does not address the following issues:

- **Grid.** This project does not explore the impact of these new conductors on the grid system. Upgrading the transfer capacity of a particular line within a grid system will alter power flow patterns. Changes in these patterns may potentially lead to network instability. This project focuses purely on line upgrades and performance.
- **Properties:** HTLS conductors generally operate with stable mechanical properties at higher temperatures and increase in sag with temperature at a lower rate than the original conductor. However, this issue will not be a scope of research in this project.
- **Speculative Designs.** Conductors at the research and development stage are not covered. This project evaluates only commercially or near commercially available conductors. The products considered are limited to manufacturers that are capable of manufacturing readily in amounts required in typical refurbishment projects.
- **Acceptance Tests.** This project does not aim to repeat standard conductor acceptance tests. Therefore, the project only considers conductors that have already passed most or all accepted industry standard tests.
- **New Conductors.** This project does not result in the development of new conductors.

Conductor Types

To address the issues within the project scope, conductors proposed initially for investigation were:

- ACSS or ACSS/TW (Aluminum Conductor Steel Supported)
- G(Z)TACSR (Gap–Type, Thermal Resistant Al-alloy)
- ACCR (Aluminum Conductor Composite Reinforced)
- ACCC (Aluminum Conductor, Composite Core)
- CRAC (Composite Reinforced Aluminum Conductor)

CRAC was a conductor proposed by Goldsworthy, a U.S. manufacturer, however, the manufacturer never manufactured or offered for sale. Instead, the Invar conductor was selected. In an Invar conductor, an Invar core (an alloy of nickel and steel) is used to replace the steel core of the conventional ACSR. The HTLS conductors for the project were supplied by:

- Southwire of Georgia, USA for the Aluminum Conductor, Steel Supported Trapezoidal Wire (ACSS/TW)
- 3M of Minneapolis, USA for the Aluminum Conductor, Composite Reinforced (ACCR)
- CTC of California, USA for the Aluminum Conductor Composite Core (ACCC)
- J-Power System, Japan for the Gap-Type Aluminum Conductor Steel Reinforced (GTACSR)
- LS Cable, Korea (formerly LG Cable) for the Zirconium-Type Aluminum Conductor Invar steel Reinforced (ZTACIR),

Tasks

The scope of work includes mainly six tasks. Each task is briefly described below.

Task 1 – Test Site Selection

Candidate test lines and associated test spans were evaluated. Suitable sites for the high-temperature, low-sag conductors were then selected. Four sites were chosen for the five conductors, as shown in Table 3-1.

Table 3-1
Conductor Test Sites

Host Utility	Field Trial Location	Data Collected since	Conductor Tested
CenterPoint Energy	Houston, Texas	May 26, 2003	ACSS/TW (Southwire)
Hydro One	Ottawa, Canada	October 24, 2004	Gap & Invar (J Power and LS Cable)
Arizona Public Service	Phoenix, Arizona	June 17, 2005	ACCC (CTC)
San Diego Gas & Electric	Oceanside, California	July 21, 2005	ACCR (3M)

Line designs were conducted for the conductors. This exercise generated the engineering tasks for reconductoring.

Task 2 – Reconductoring

This task includes the purchase of the conductor, temporary removal of the existing conductor, the possible modification of the towers, installation of the new conductors and associated line hardwares, and commissioning and energization of the line.

Task 3 – Field Monitoring, Laboratory Testing, and Interim Reporting

This task covers the selection and installation of field monitoring equipment, such as video sagometer, load cells, vibration recorder, and weather stations to monitor the long-term performance of the conductors and associated hardware. Conductor sag and tension were monitored continuously through sagometer and load-cells. Measurement of electric and magnetic field profiles under the transmission lines, measurements of hot spots on surfaces of conductors and hardwares (such as splices, dead-ends, and towers), measurement of splice resistance, and measurements of vibrations were taken during each site visit. These field measurements provide utilities with necessary information on the operational performance of new HTLS conductors through approximately three years of field trial experience.

Task 4 – Development of Supporting Engineering Guidelines

Under this task, EPRI develops and delivers Engineering Guidelines covering the design, specification and installation of these HTLS conductors. These guidelines will be in the form of a demonstration on installation, videos of the field installation, a workshop, and a technical report. These guidelines are directed at line designers, line inspectors, and field and maintenance crews.

Task 5 – Final Reporting

Compilation and analysis of the field data in a final project report, including recommendations and application guides. This report also contains an analysis of the cost options.

Task 6 – Test Site Decommissioning

This task assumes that the host utility wishes to remove the conductor from the test spans and restore the line to its original conductor. Restoration of original conductors is under this task. Removal of HTLS conductors is under host utility's discretion.

Schedule

Field trials of these HTLS conductors were started in the summer of 2003. Originally, it was planned that each type of conductors would be subjected to 3 years of high operating temperatures. Due to difficulties in procuring HTLS conductors and in acquiring field trial sites, the project was extended to enable the project to collect three summers of high operating temperature data. The updated schedule is as follows:

- Data Collection: Continued to May 2008
- Development of Methodology for Conductor Life Prediction: Continued to December 2008
- Evaluation of Conductor Performance by Laboratory Tests: Continued to December 2008
- Completion of Field Trial and Analysis: December 2008
- Publication of General Report entitled "Demonstration of Advanced Conductors for Overhead Transmission Lines": July 2008
- Publication of Technical Report: June 2009

Funding Members

Twenty utilities are funding this project. Among them, 15 utilities are from the United States, two from Canada, and one each from United Kingdom, Spain, and France. They are listed below.

1. American Electric Power (AEP)
2. American Transmission Company (ATC)
3. Arizona Public Service (APS)
4. California Energy Commission (CEC)
5. San Diego Gas & Electric (SG&E)
6. Southern California Edison (SCE)

7. Pacific Gas & Electric (PG&E)

8. CenterPoint Energy

9. Duke Energy

10. Exelon

11. Hawaii Electric

12. Long Island Power Authority (LIPA)

13. Southern Company

14. Tennessee Valley Authority (TVA)

15. Xcel Energy

16. British Columbia Transmission Company (BCTC), Canada

17. Électricité de France (EDF), France

18. Hydro One Networks, Canada

19. National Grid, UK

20. RED Electrica de Espana (REE), Spain

Participants

The project was managed by EPRI. Field trial sites were offered by four utilities—CenterPoint Energy, Hydro One, Arizona Public Service, and San Diego Gas & Electric—who also provided labor and material for the installation. Manufacturers were on site during conductor stringing. Monitoring equipment was installed by EPRI staff with assistance from the utilities. Regular site inspections were conducted by EPRI staff. In addition, two research organizations were involved in this project. Oak Ridge National Laboratory (ORNL) performed metallurgical and mechanical tests on ACSR and connections in an attempt to develop a methodology for predicting the service life of HTLS conductors. Due to the complexity of the subject, the focus was on the behavior of the connection. The Research and Development Division of the Électricité de France (EDF) was responsible for the assessment of service life of an epoxy-based carbon composite core.

4
HTLS CONDUCTOR MATERIALS

The vast majority (approximately 80%) of bare stranded overhead conductors used in transmission lines consist of a combination of 1350-H19 (nearly pure aluminum – 1350 - drawn to the highest temper possible – H19) wires, stranded in one or more helical layers around a core consisting of one or more galvanized steel strands. By varying the size of the steel core, the composite tensile strength and elastic modulus of an ACSR conductor of given resistance can be varied over a range of 3 to 1.

The mechanical and electrical properties of ACSR (and all aluminum conductors such as AAC, AAAC, and ACAR) are quite stable with time so long as the temperature of the aluminum strands remains less than 100^oC. Above 100^oC, the work-hardened aluminum strands lose tensile strength at an increasing rate with temperature though the steel core strands are unaffected by operation at temperatures up to at least 300^oC (though the galvanizing may be damaged by prolonged exposure to temperatures above 200^oC) .

The sag-temperature behavior of ACSR is also dependent on the size of the steel core. At moderate to low conductor temperatures, the thermal elongation rate of ACSR is between that of steel (11.5 microstrain per ^oC) and that of aluminum (23 microstrain per ^oC). For example, with Drake ACSR, the thermal elongation is 18.9 microstrain per ^oC, at a conductor temperature below the kneepoint temperature (about 70^oC under final conditions) Above the kneepoint temperature, the thermal elongation of any ACSR conductor is approximately that of steel alone (11.5 microstrain per ^oC).

HTLS conductors are able to operate continuously at temperatures above 100^oC (the HT part) and exhibit thermal elongation rates which are less than ACSR (the LS part). No HTLS conductor can be stranded out of conventional 1350-H19 aluminum wires and ordinary galvanized steel wires.

As shown in the following tables, the wire materials used for HTLS conductors are capable of continuous operation at temperatures in excess of 100^oC with stable electrical and mechanical properties. For example, annealed aluminum strands can be run continuously at 300^oC without any deterioration in conductivity. As will be discussed in later chapter, all of the HTLS conductors considered in this study consist of a high strength core surrounded by one or more layers of aluminum wires which carry most of the electrical current. For those HTLS conductors with annealed aluminum strands, the conductor stiffness and breaking strength is largely determined by the core. For those HTLS conductors with Zirconium aluminum strands, the composite conductor strength and stiffness depends on both the reinforcing core and the aluminum strand layers.

With the exception of the CTC carbon fiber composite core, the various aluminum alloys and the reinforcing materials are normally in wire form with a wire diameter of the order of 0.1 to 0.2 inches. In certain designs, the aluminum wires are provided with a trapezoidal cross-section in order to maximize the aluminum area for a given conductor diameter. The reinforcing core wires are typically round. The properties of the wires vary with wire diameter. Generally the smaller the wire, the more work hardening done in drawing it and the higher its tensile strength, though such variations with wire diameter are typically modest.

As can be seen in Table 4-1 and Table 4-2, the properties of the conducting aluminum wires and the reinforcing core wires are dramatically different. These differences can be used to advantage in various designs.

Table 4-1
Characteristics of aluminum and aluminum alloy wires

Type of Aluminium		Minimum Conductivity [%IACS]	Typical Tensile Strength [Mpa] [kpsi]	Allowable Operating Temperature(ºC)	
				Continuous	Emergency*
Hard Drawn 1350 aluminum	1350-H19 (HAL)	61.2	159 – 200 23 - 29	90*	125*
Thermal Resistant Zirconium aluminum	TAL	60	159 – 176 23 - 26	150	180
Extra Thermal Resistant Zirconium aluminum	ZTAL	60	159 – 176 23 - 26	210	240
Fully Annealed 1350 aluminum	1350-0	61.8**	59 – 97 8.5 – 14	350	350

* - Manufacturers often suggest performing rating calculations at 75^{o}C/100^{o}C
** - Typical conductivity for annealed aluminum is 63.0%.

Table 4-2
Characteristics of reinforcing core materials.

Core material	Min. Tensile Strength @tensile failure [kpsi]	Modulus of Elasticity [Gpa] [Mpsi]	Min. elongation at tensile failure %	Coef. Of Linear Expansion ($x10^{-6}$) per ^{o}C	Allowable Operating Temperature(ºC)	
					Continuous	Emergency
A Galv. Steel Zn-5Al-MMSteel(B802)	200-210	206 29	3.0-4.0	11.5	180 250	200 350
A Galv. HS (B606) Zn-5Al-MM HS (B803)	220-235	206 29	3.0-3.5	11.5	180 250	200 350
A Galv. UHS Zn-5Al-MM UHS	265-285	206 29	3-3.5	11.5	180 250	200 350
CTC Carbon Fiber composite core	310-360	114 17	2.0	1.6	180	200
3M Ceramic Fiber reinforced aluminum	200	220 32	0.64	6.0	250	300
Alum. Clad (AW) 20.3% IACS	150-195	162 24	3.0	13.0	150	200
Alum. Clad Invar Steel 14% IACS	175-185	152 22	3.0	3.7	210	240

As discussed in the next section of this report, the temperature limits and typical mechanical and electrical characteristics of any composite HTLS composite conductor is a complex combination of these material properties and the connectors, terminations, and hardware provided by the manufacturer.

Comments on HTLS conductor materials

Notice some of the unique properties of the HTLS conducting component materials as described in Table 4-1. In contrast to ordinary 1350-H19 aluminum, TAL and ZTAL aluminum can be operated at 150^{o}C and 210^{o}C, without any loss of tensile strength, and annealed aluminum (1350-0) can be operated continuously at 350^{o}C without any change in mechanical or electrical properties. These aluminum wires have approximately the same electrical conductivity as 1350-H19.

5
DESCRIPTION OF HTLS CONDUCTOR SYSTEMS

Introduction

The most common conductor used in the utility transmission line applications is ACSR, consisting of one or more layers of aluminum strands wrapped helically around a core consisting of one or more galvanized steel strands. Although this very common conductor consists only of aluminum, steel and zinc, it’s mechanical and electrical behavior is surprisingly complex as the electrical current through it and the conductor weight varies widely over the 40+ year life of a modern transmission line.

Terminations, splices, hardware, and installation procedures for standard ACSR overhead conductors are well understood, and problems are relatively rare when manufacturer’s installation instructions are followed. The majority of line hardware associated with the suspension and support of the ACSR conductors has been designed to operate at a maximum temperature of 100°C or less. The introduction of new types of conductor may require conductor accessories to withstand temperatures as high as 250°C. The electrical connection of 250°C conductor poses not only special concerns for the tensile properties of the dead-end fittings, but also the additional problems associated with the high-temperature electrical interface. Moreover, there is a need for new equipment designs and procedures to handle the accessories. It seems likely that problems and uncertainties involving tension stringing, termination, splices, and support of new types of HTLS replacement conductors will be a primary focus in subsequent field tests.

The long-term reliability of ACSR conductor systems depends not only on the conductor itself but also on the connectors, terminations, and hardware supports that are specifically designed to work with the conductor. Many times, it has been found that the ability of the conductor system to withstand severe ice loads, high winds, or very high temperatures, is limited by the connectors and hardware rather than by the conductor itself. HTLS conductor systems are no different. There is no point in providing HTLS conductors for overhead lines unless they are supplied with connectors and hardware that is reliable and easy to install.

In the same sense as ACSR, HTLS conductors may consist of relatively simple wire materials, yet behave in ways that can be quite complex. In the last section of this report, the properties of the wire materials used in HTLS conductors are described in Table 4-1 and Table 4-2, yet the various combinations of these materials into HTLS conductors is not always easy to understand. Also, as with ACSR, the long-term reliability of the various HTLS conductor systems depends heavily on the connectors and support hardware.

This section of the report describes the electrical and mechanical properties of the various composite HTLS conductor systems made up of the materials described in Section 4.

Conventional ACSR versus HTLS Conductors

ACSR conductor (see Figure 5-1) has a steel core, consisting of one or more steel wires, surrounded by one or more layers of 1350-H19 aluminum wires. 98% to 99% of the electrical current in ACSR flows in the aluminum strands. Depending on the relative size of the steel core and the aluminum wire cross-section, as little as 15% and as much as 65% of the composite ACSR strength is due to the steel core.

1350-H19 aluminum wires, which are nearly pure aluminum, begin to anneal slowly at around 93°C. At 100°C, 125°C, and 150°C, these aluminum wires lose 10% of their ultimate tensile strength in a year, two weeks, and 12 hours, respectively. Beyond 150°C, aluminum strands rapidly anneal but the steel core wires are not affected by these temperature levels.

With regard to sag at high temperature, the steel core elongates at approximately half the rate of the aluminum layers so that conductor tension is transferred from the aluminum layers to the steel core as the conductor temperature rises. At a sufficiently high temperature, all of the conductor tension is in the steel core and the elongation rate beyond this "kneepoint" temperature is essentially that of steel alone. The proportion of total tension carried by the aluminum layers and the steel core varies with the relative areas of steel and aluminum, the temperature of the conductor and the tension history (creep elongation).

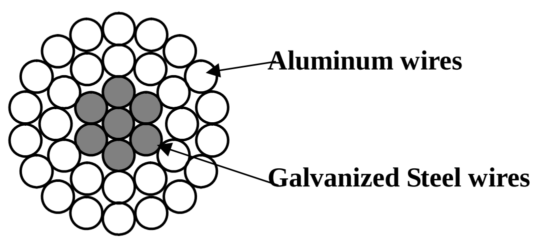


Figure 5-1
Cross-section of 30/7 ACSR conductor

General Description of HTLS Conductors

As noted previously, the acronym, HTLS, stands for "High-Temperature, Low-Sag" conductors. The name summarizes the key properties of the conductors: They can be operated at high temperature (i.e. above 100°C) for extended time periods without losing tensile strength or otherwise deteriorating mechanically, electrically, or chemically and they elongate less with temperature than normal all aluminum or steel-cored aluminum conductors.

All HTLS conductors consist of a high-strength, low-elongation core surrounded by high-conductivity, aluminum strands. Each conductor has certain advantages and disadvantages, which are briefly discussed in this chapter. With the exception of ACSS, utility field experience with HTLS conductors operating at such high temperatures is very limited.

In addition to the HTLS conductor properties which are related to the maximum conductor temperature, these conductors must also display the desirable properties associated with conventional transmission conductors:

- Mechanical properties – low weight per unit length, high elastic modulus, and low plastic elongation under high mechanical loading so that existing lines can be reconductored with a minimum of structure modification yet remain mechanically reliable.
- Robust handling characteristics – HTLS conductors must be easily installed and terminated using methods familiar to existing experienced contractors.
- Chemical properties – Resistant to corrosion over lifetimes of 40 years or more. Insensitive to ultraviolet aging in the presence of sunlight and ozone.
- Low electrical resistance – Exhibit composite resistance less than or equal to the original conductors with the same diameter.

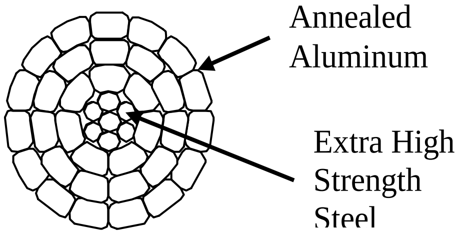
HTLS conductors considered in this study are:

- **ACSS and ACSS/TW** – Aluminum Conductor Steel Supported/Trapezoidal Wire – Annealed aluminum strands over a conventional steel stranded core. Operation to 250ºC.
- **G(Z)TACSR** – Gap-type TAl (heat resistant) Aluminum Conductor Steel Reinforced. Operation to 150ºC.
- **(Z)TACIR** – ZTAl (Extra heat resistant) Aluminum Conductor Invar steel Reinforced. Operation to 150ºC (TAl Aluminum Alloy) and 210ºC (ZTAl Aluminum Alloy).
- **ACCR** – Aluminum Conductor Composite Reinforced – High-temperature alloy aluminum (ZTAl) over a composite core made from alumina fibers embedded in a matrix of pure aluminum. Operation to 210ºC continuous and 240ºC emergency.
- **ACCC** – Aluminum Conductor Composite Core – High-temperature alloy aluminum helically wired around a hybrid polymer matrix composite core with both carbon and glass fibers. Continuous operation to 180ºC.

The operating temperature limit of a HTLS conductor is a complex combination of the properties of the outer layers of aluminum strands and the reinforcing core. Operating temperature limits for ACSR and for HTLS with high temperature zirconium alloy aluminum are normally determined by loss of tensile strength in the aluminum. HTLS conductors with annealed aluminum wires can be determined by damage to the reinforcing core. In all cases, the temperature limitation may also be determined by possible deterioration of the connectors and hardware. Therefore, operating temperature limits for HTLS conductors are normally less than or equal to the operating temperature limits of the individual component materials shown in Tables 4-1 and 4-2.

ACSS and ACSS/TW

ACSS conductor is a thoroughly tested conductor that is commercially available from multiple vendors in the United States. ACSS was first invented in the 1960s and has been sold widely in North America for over 30 years. It consists of fully annealed aluminum wires (1350-O) stranded over a core of high-strength, extra-high-strength (EHS), ultra high strength (UHS) steel, with other characteristics being similar to ACSR conductor. ACSS demands a cost premium over regular ACSR which is modest when compared to other HTLS technologies. ACSS is typically available in three different designs: standard round strand ACSS (similar to standard ACSR conductor), trapezoidal wire of equal area, and trapezoidal wire of equal diameter. In addition, it is possible to obtain all three ACSS conductor designs with any of the standard types of steel core wire having an anti-corrosion coating of hot-dipped zinc, aluminum cladding, or zinc-5% aluminum-mischmetal alloy (Zn-5Al-MM).



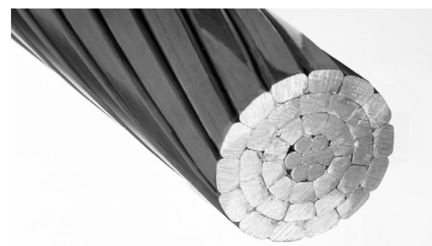


Figure 5-2
Cross-section of ACSS/TW conductor

ACSS (or ACSS/TW) has comparatively lower thermal elongation over a wide range of conductor temperatures, and the operating temperature can go as high as 300°C with Zn-5Al-MM Galfan coating on the steel core wires. The temperatures are limited to 180^{o}C when the conductor core uses ordinary hot-dipped zinc coatings. Trapezoidal shaped aluminum strands (see Figure 5-2), which minimize interstices, provide higher aluminum area compared to the equivalent diameter round-wire ACSR construction. These aluminum strands are annealed to withstand higher temperature operation; however, they are softer, resulting in more susceptibility to damage from improper handling and/or installation.

If the ACSS or ACSS/TW conductor is pre-stressed, the tension in the annealed aluminum strands is quite low and its self-damping is quite high. This allows its installation at smaller everyday sags than ACSR and helps to reduce or prevent vibration fatigue damage in challenging installations such as river crossings.

Depending upon original design conditions and conductor design, in most cases, reconductoring with ACSS/TW allows an increase of at least 30% in thermal rating of an existing line. The choice depends upon the particular uprating application. Since the conductor consists of conventional steel and aluminum, the cost premium, relative to conventional ACSR, is less than 50% in most cases. ACSS is available in the United States from three different manufacturers.

Although ACSS and/or ACSS/TW can be pulled in and sagged using the same procedures used for ACSR, particular attention needs to be given while stringing ACSS conductors. As the outer layer of the conductor is made of soft annealed aluminum strands, ACSS should not be dragged across the bare ground, over rocks, or fences etc. Parallel jaw grips should be closely sized to the conductor diameter and the clamp surface needs to be clean to minimize strand distortion.

The splicing, installation, and termination of ACSS or ACSS/TW is no more complicated than for ACSR conductors, however, the annealed strands, being very soft, should be handled with care. Also because of the annealed aluminum strands, the two-stage ACSS compression splice is somewhat longer than those designed for an ACSR conductor. ACSS conductors require two-stage sleeve splices that are a bit longer than normal ACSR splices but are otherwise conventional in application. Similarly, ACSS requires no special suspension clamp design, and tension-stringing installation is straightforward. High temperature tolerant suspension clamps must be used with ACSS or ACSS/TW in order to allow the maximum operating temperature that these HTLS conductors are capable of reaching.

G(Z)TACSR (Gap Conductor)

G(Z)TACSR, Gap-type Thermal-resistant aluminum alloy ACSR conductor, developed by J Power, Japan, is commercially available in the United States. GTACSR has a unique construction. There is a small gap between the steel core and the innermost trapezoidal-shaped aluminum layer such that the core can move independently from the aluminum layer, allowing the conductor to be tensioned on the steel core only (see Figure 5-3). The original gap-type design had only the inner aluminium layer trapezoidal, with round-wire strands used outside. The new design has all outer layers made of trapezoidal shape to maintain compact stranding and to minimize electrical resistance and increase the effective cross-sectional area on aluminum strands. The steel core is especially strengthened to increase the safety factor, because the core is responsible for withstanding the entire tensile load at high temperature. However, at low temperature the full hard aluminum strands carry load and help to limit sag under ice and wind loads. This effectively fixes the conductor's knee-point to the erection temperature, allowing the low-sag properties of the steel core to be exploited over a greater temperature range.

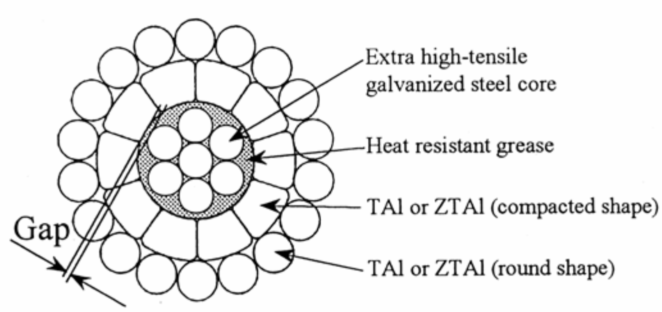


Figure 5-3
Cross-section of G(Z)TACSR Conductor

The gap is filled with heat-resistant grease (filler) to reduce friction between the steel core and the aluminum layer and to prevent water penetration. The aluminum layers being made up of either TAl (150°C) or ZTAl (210°C) heat-resistant zirconium alloy aluminum strands. Either type of zirconium aluminum alloy has a conductivity which is only slightly less than 1350-H19 (60% versus 61.2% IACS).

G(Z)TACSR is a Gap-type super (Z) Thermal-resistant aluminum alloy ACSR conductor built with a higher heat-resistant aluminum zirconium (Al-Zr) aluminum alloy and extra-high-strength galvanized steel core. With a small quantity of Zr added during smeltering of aluminum, there is a significant improvement in current carrying and annealing characteristics. GZTACSR can be operated continuously at 210°C without loss of tensile strength.

A special procedure is followed during the installation of G(Z)TACSR conductor. The aluminum layers of conductor must be de-stranded, exposing the steel core, which can then be gripped by a come-along clamp. The conductor is then sagged on the steel core, and after compression of a steel clamp, the aluminum layers are re-stranded and trimmed, and the aluminum body of the dead-end clamp is compressed. Although this special erection technique is different from that employed with conductors of standard construction (i.e., ACSR), the compression splices and bolted suspension clamps are similar. In addition, to ensure proper performance of this conductor, a special type of suspension clamp hardware must be installed at every three suspension spans.

National Grid, UK has successfully installed about 300 km (185 miles) length of GTACSR in its 400-kV line. More than 1500 km (930 miles) have already been installed in Libya. The Electricity Generating Authority of Thailand (EGAT) has also installed about 500 km (310 miles) of gap conductor, and it plans to add more in its 220-kV system. In addition, there are other installations (more than 300 km or 185 miles) in Saudi Arabia, Qatar, and other Asian countries. Extensive laboratory test data and detailed installation instructions are also available from the manufacturer. The installation of this conductor is more complex and labor intensive than ACSR. Its termination requires the unwinding of aluminum wires at each termination and splice. The high-temperature thermal elongation has been verified by test. Special semi-strain-type suspension fittings are required for the long lines.

The special construction of gap-type conductors and their increased capacity require that accessories and the possible combinations that involve the accessories be specially designed. Some examples of accessories that are peculiar to certain HTLS (e.g., gap type) conductors include the following photograph (Figure 5-4), which shows the termination procedure for GTACSR conductor before being installed. Here the aluminum strands are shown as the crew is separating them in order to grip the steel core. Since the conductor core is responsible for carrying 100% of the tensile load of the conductor, compression-type dead-end clamps used in gap-type conductor require a relatively larger size than those used for ACSR with the equivalent diameter to allow for the increased current capacity.

Figure 5-4
Removal of gap conductor strands at the termination at the EPRI Lenox Lab

Gap conductors have grease in the gap between the core and the aluminum strands. This grease needs to be replaced with high-temperature grease before the steel-end is crimped to grip the core at 50% overlap (see Figure 5-5).

Unlike ACSR conductors, gap-type conductors require that the conductors must be installed such that the aluminum layers are compressed while only the steel core is under tension in order to gain maximum benefit from the small-sag properties. Similarly, as the wire stranding construction of gap-type conductor is different from that of ACSR, and the current capacity is large, unique designs for termination hardware are also required for gap-type conductor.

Figure 5-5
Application of high-temperature grease on core-grip portion

ZTACIR (INVAR)

ZTACIR is a Zirconium alloy Aluminum Conductor Invar steel Reinforced conductor. The conductor is similar to ACSR conductor (see Figure 5-6); the major difference being that the core is made of high strength invar alloy wire, instead of conventional steel wire. Invar is an alloy of steel (64%) and nickel (36%). Nickel possesses a very small linear coefficient of thermal expansion which is practically invariable with heat. This property provides excellent sag control performance at high temperature beyond the knee point. Hence it is recommended to operate beyond the knee point. This conductor has relatively low sag at higher temperature. ZTACIR has a maximum continuous operating temperature of 210°C and can carry twice the current capacity of ACSR conductor. The coefficient of linear expansion of invar wire (2.8 to 3.6 x 10^{-6}) is on the order of one-third of that of galvanized steel wire. However, tensile strength of invar wire (1080 MPa) is lower than galvanized steel wire. Tensile strength of the conductor is about 8% lower than normal ACSR conductor. As the conductor has the same structure and size as of ACSR, the stringing method is also identical to that of ACSR.

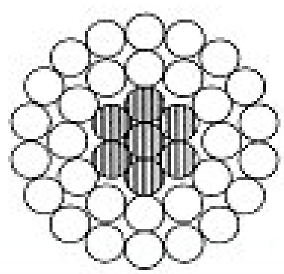


Figure 5-6
Cross-section of ZTACIR Conductor

ACCR and ACCR/TW

ACCR is built with outer layers of heat-resistant aluminum-zirconium (Al-Zr) wires (round or trapezoidal) and a proprietary fiber-reinforced aluminum matrix composite core. Both the composite core and the outer Al-Zr strands contribute to the overall conductor strength and conductivity. The outer alloy aluminum wires are round and of the same construction type as ACSR conductors. The Al-Zr layers and the core wires are helically stranded as in ACSR conductors. The composite core has a lower thermal elongation property and equal or greater strength than galvanized steel. The core wire looks physically similar to steel core, but it is eight times stronger than aluminum and about the same stiffness as the steel core. Each core wire contains thousands of small-diameter, ultra-high-strength, and aluminum oxide fibers. The ceramic fibers are continuously oriented in the direction of the wire, and fully embedded within high-purity aluminum. Currently, 3M is the only manufacturer of this type of conductor, and the production unit is based in Wisconsin, USA.

Figure 5-7
Cross-section of ACCR Conductor

The strength of this core is comparable to steel, but it possesses additional properties. For example, the alumina fibers have a lower thermal expansion than aluminum or steel; the core has a greater resistance to corrosion; it exhibits lesser creep; it has no undesirable magnetic properties. It can operate continuously at 210ºC. The outer wires surrounding the composite core are made up of high temperature-resistant ZTAL strands. ZTAL aluminum limits the maximum operating temperature of the ACCR conductor.

Xcel Energy successfully completed a field test of ACCR conductor in its 115 KV system in Minneapolis with a single 800-ft span to replace equivalent ACSR conductor in Minneapolis in 2001. More than ten utilities have now successfully installed ACCR conductor in their systems including Hawaiian Electric, Arizona Public Service (APS), Bonneville Power Administration (BPA), Western Area Power Administration (WAPA), and Pacific Gas and Electric (PG&E). Field test results appear to be positive with no unusual problems during installation or afterward. The installation of this conductor appears to be reasonably straightforward but may require special large blocks and careful handling. 3M has conducted various mechanical and electrical tests that meet the criteria for the conductors' mechanical and electrical integrity with its hardware.

Under a Department of Energy (DOE) project, a two-span ACCR line was tested in Oak Ridge National Laboratory (ORNL) at high temperature for an extended time period. ORNL published multiple field trial reports on "477, 795 kcmil, 675 TW, and 1272 kcmil ACCR conductor". 3M has invested considerable engineering effort in studying the details of the conductor's and the accessories' behavior under the realistic high-temperature conditions of this study. 3M has also developed technical information on ACCR conductor and its accessories including installation guidelines and laboratory test results. 3M also provides technical support to the potential users of ACCR conductors. ACCR conductor has been field-tested for more than five years.

The compression-type hardware for the dead-end assembly of ACCR conductors uses a modified two-part approach, as in the ACSR or ACSS conductor. One part grips the core, and then an outer sleeve grips the aluminum strands, as shown in Figure 5-8. This approach prevents notching of the core wires. The gripping method ensures that the core remains straight to evenly load the wires, and also ensures that the outer aluminum strands suffer no lag in loading relative to the core.

Figure 5-8
Termination of ACCR HTLS conductors

ACCC and ACCC/TW Conductor

Aluminum Conductor Composite Core (ACCC) cable was developed to improve several key performance metrics over conventional ACSR conductors. A lightweight circular-shaped advanced composite core – designed as a single piece rod – acts as a mechanical support and high–performance, trapezoidal-shaped, fully annealed 1350-0 aluminum strands fit well around the circular surface of the core in a helical shape with minimum interstices compared to the conventional ACSR conductor (see Figure 5-9). This leads to increase the effective cross-sectional area for aluminum strands, increasing the current carrying capacity. The cross-sectional area of the aluminum Suwannee (ACCC/TW) conductor is 30% higher than the equivalent diameter ACSR (Drake).

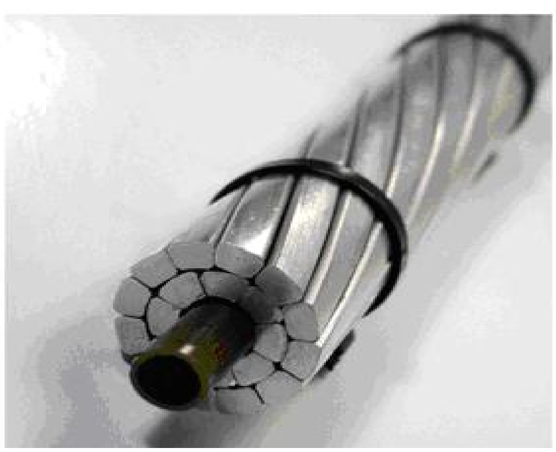


Figure 5-9
Cross-section of an ACCC Conductor

To increase the strength of the conductor, a carbon/glass fiber, polymer matrix composite core is used to replace the stranded steel core used in ACSR conductor. Carbon fibers are situated in the core, and are surrounded by a "shell" of E-glass fibers, as shown in Figure 5-10. The composite core in the ACCC is a low-density material with much lower coefficient of thermal expansion (CTE) and a high strength-to-weight ratio. The density of the composite is 1.935 mg/m^3, while the density of steel is 7.78 mg/m^3. The annealed aluminum strands allow operating continuously at elevated temperatures of up to 200°C with dramatically less sag.

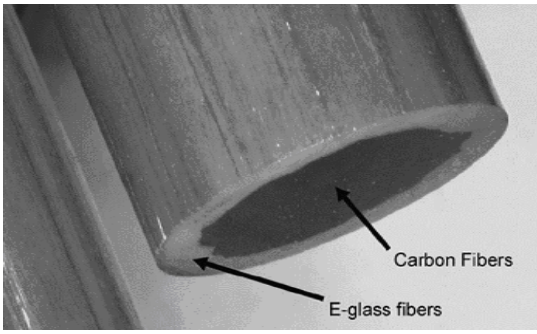


Figure 5-10
ACCC core showing the glass and carbon fiber

The composite core used in the ACCC conductor is a solid, single-piece rod with no interstices, unlike cores in ACSR and ACSS conductors. As the core has a smooth surface and it bears the overall tensile strength of the conductor, the dead-end assembly (Figure 5-11) has been designed to create a stronger crimp compared to that of ACSR conductor that forms a very solid aluminum press that fits around the composite core, as shown in Figure 5-11.

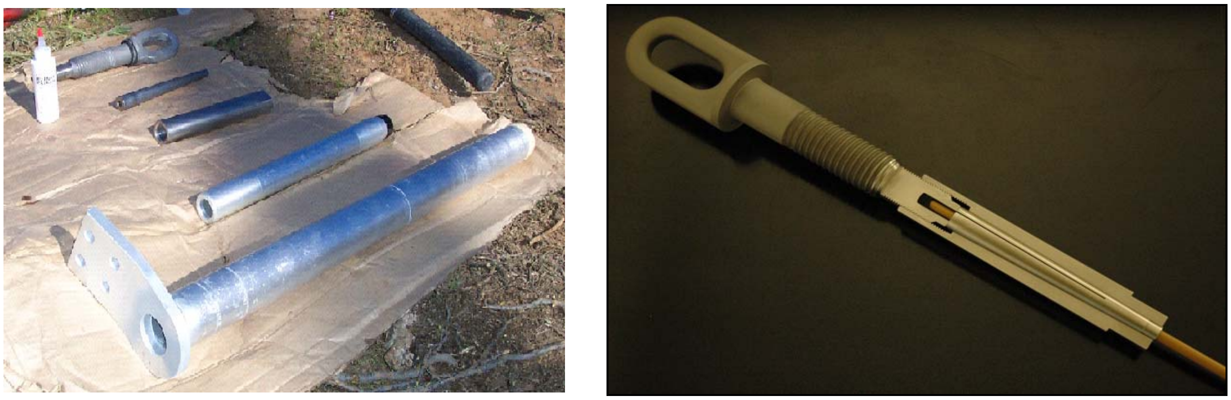


Figure 5-11
Dead-end fittings hardware used for ACCC conductor

Technology Maturity and Cost Comparison of HTLS Conductors

Field testing of HTLS conductors should include verification that recommended methods of termination, support, and tension stringing work reasonably well with ordinary utility crews. No such field tests are possible until the HTLS conductor manufacturers provide installation recommendations and confirmation that connectors, support clamps, and terminations work well at the extreme temperatures that are likely to be encountered in HTLS conductor applications.

In addition to the hardware accessories, special attention needs to be given in selecting an appropriate inhibitor for HTLS compression joints. The maximum temperature limit of 250°C for which some manufacturers are rating their HTLS conductor will cause connectors to experience internal temperatures in excess of what traditional mineral-oil-based inhibitor compounds will tolerate. The base mineral oil of such inhibitors begins to break down at 162°C. A synthetic base inhibitor has been developed that will perform in the temperature range for HTLS conductors.

HTLS conductors are more expensive than conventional conductors from the initial investment perspective. But HTLS conductors can carry significantly higher current compared to the conventional conductors (see Table 5-1). In this case, the cost associated with conventional conductors can be comparable or sometimes higher when we take into account the upgrade cost for transmission towers and accessories including land and environment for the equivalent current that HTLS conductors can carry. Table 5-1 shows the cost of various HTLS conductors with similar cross-sectional area. The cost includes the cost of the conductor only. Other technical characteristics of the conductor, such as the sag and tension behavior that determine whether structure modifications are required, must be considered to determine the overall cost of replacement. The conductor length for the US system covers ACSR conductor above 230 kV.

Table 5-1
Price Comparison for HTLS Conductors with Respect to Current–Carrying Capacity (as of March 2008)

Conductor	Current Capacity	Price	Conductor Length (miles)
Conventional ACSR	1	1	> 500,000 in US (230 kV and above)
ACSS (Round and Trap Wire, all strengths)	1.8 to 2.0	1.2 (HS steel core) 1.5 (HS285 UHS core)	34,000 in US 800 with HS285
GTACSR (Gap)	1.6-2.0	2	6,400
ACIR (Invar core)	1.5-2.0	3 – 5	12,000 (4,000 ZTACIR)
ACCR (Aluminum composite core)	2-3	5 – 6.5	500
ACCC (Carbon Fiber composite core)	2	2.5 – 3.0	1,200

The price figures are obtained from the respective manufacturers. This economic comparison does not take into account the economic benefits associated with greater revenue generated as a result of increased current throughput capacity from HTLS conductors.

Some of the HTLS conductors considered for this field test have been in the electricity market for just a few years. ACSS has been commercially available in North America since 1970. Among the newer HTLS conductors, none has seen extensive use in North America. There are a total of 20 to 40 field installations of the newer HTLS conductors throughout the United States. Many of them are only a few spans long.

The market penetration for gap and invar conductors throughout the North America is especially low. In Japan, the use of TACSR (ACSR with TAl aluminum) is used widely whereas the other Japanese HTLS conductors have seen very limited application.

Table 5-2 presents the technology status, availability of proof-of-concept tests, detailed fittings and test data, and manufacturing specifications for associated hardware and accessories.

Table 5-2
Summary of HTLS Development Status

HTLS Conductor	Proof-of-Concept Tests	Detailed Test and Fitting Data	Field Tests	Manufacturing Specification
ACSS	Yes	Yes	Yes	ASTM
ACSS/TW	Yes	Yes	Yes	ASTM
GTACSR	Yes	Yes	[3]	[2]
TACIR	Yes	Yes	[1]	[2]
ACCR (3M)	Yes	Yes	Yes	Yes*
ACCC (CTC)	Yes	Yes	Yes	Yes

[1] – No field test in the United States.

[2] – Japanese manufacturing standards exist.

[3] – Field test at National Grid.

* – Partial ASTM standards and manufacturer specifications

6
UPRATING APPLICATIONS FOR HTLS CONDUCTORS

The power transmission system, in any region, is a complex combination of lines (including underground cable) and substations. With the exception of relatively short "radial" lines connecting generating stations to the system, power flow reaching any load point in the system flows over multiple "parallel" paths (circuits). In any path (circuit), the power flow moves through multiple series elements.

Power circuits consist of series and parallel combinations of electrical equipment (each subjected to mechanical, electrical, and thermal stresses) whose collective purpose is to transmit power safely and reliably under widely varying operational situations. Each element of such circuits is typically specified to have certain power flow limits that allow their safe, reliable operation for an extended period of time (e.g., 40 years).

Increased power flow inevitably means increased electrical current flow or increased circuit voltage, since power is the product of these quantities. In general, for substation equipment and underground cables, increasing the operating voltage is difficult or impossible, whereas increasing the maximum electrical current is both possible and economic. Overhead lines are often capable of sustaining either higher voltage or higher current levels if certain modifications are undertaken.

Power transmission circuits are typically bimodal in terms of power flow. Under normal operation, it is not unusual for power transformers and lines to operate at much less than half of their power flow capacity, only approaching their operational limits under relatively rare emergency events.

There are basically three methods of increasing power flow: load control; improved modeling and monitoring; and physical modification of existing equipment. Load control devices are not considered in this report. Improved models may allow operation of equipment with reduced safety factors but without any practical reduction in safety or reliability (e.g., an improved model for the high-temperature sag of ACSR conductor). Improved monitoring of environmental factors (air temperature, wind speed, humidity, etc.) may allow the use of less conservative assumptions, again without reducing safety and reliability.

With monitors communicating data in real-time, it may be possible to run equipment at higher power levels most of the time by avoiding the use of "worst case" assumptions. This approach is called dynamic thermal ratings. It is unlikely that such real-time monitoring would allow any increase in non-thermal operating limits.

Many opportunities exist for the physical modification of overhead lines. Lines are the primary means of power transfer over long distances. They have thermal ratings just as power transformers, substation terminal equipment, and underground cables, but, for long lines, power flow limits may also be necessary to avoid excessive voltage drop or system stability problems. In addition, since the public has access to the area under lines, there may also be limits on voltage and current related to environmental effects and public safety.

Sometimes a power transmission line possesses a definite power flow limit based on its design parameters. In other situations, the power flow on a line may need to be limited because of concerns regarding voltage drop, possibility of voltage collapse, and system stability, both steady state and transient, which have little to do with the line design.

Series reactance, shunt admittance, and their combination, surge impedance, are relevant to system transfer limits. System planners have long recognized this relationship, particularly where there are prospects of changing the line surge impedance, either by adding equipment (e.g., series capacitors) or by modifying the line itself (e.g., reconductoring, voltage uprating, etc.).

Reconductoring lines with HTLS conductors can be a very cost-effective way to increase the thermal rating of an overhead transmission line, but there are a number of things that it can't do. Reconductoring an overhead line with HTLS conductors has no impact on voltage drop or on electrical phase shift along the line. Therefore, if power flow on an overhead line circuit is limited in order to keep the receiving end voltage above 95% of the sending end voltage, then reconductoring the line with a HTLS conductor will not help.

Also, if the flow of power through a particular overhead line circuit is limited in order to avoid overheating a power transformer or an underground cable in series with the overhead line, reconductoring with HTLS conductor will do nothing to change the limitation.

Similarly, HTLS conductors will do nothing to change the electric and magnetic fields produced by the line. These fields are dependent upon the physical spacing of the conductors, the diameter of the conductors, and their geometric arrangement (e.g., delta, horizontal, etc.). Replacing existing power conductors while preserving the original structures, typically leaves electric and magnetic fields unchanged.

Finally, HTLS conductor can only be used to uprate lines whose structures are in good or excellent condition. If the existing structures are in poor condition, then uprating the line with any replacement conductor, including HTLS, is simply not sensible.

Electrical Losses for HTLS Conductors

The cumulative cost of electrical losses in an overhead transmission line is a function of the phase conductor resistance, the square of the line current, and the duration of high current loading. HTLS conductors have roughly the same electrical resistance as conventional conductors having the same cross-sectional area of aluminum. They can, of course, be applied safely in lines with much higher losses (higher current) than conventional conductors.

Therefore, the cost of electrical losses is one of the issues to be evaluated in uprating existing lines.

If the line operates routinely at line currents that approach its thermal limit, then the cost of the resulting electrical losses is likely to be significant. For short lines, which experience occasional high electrical loads, HTLS conductors are often an excellent method of uprating. For longer lines, which routinely experience high loads, the addition of another line or the rebuilding of the existing line to support a larger ACSR conductor may be justified by the cost of electrical losses.

For reconductoring short lines (e.g., less than 20 miles long), electrical losses are unlikely to be significant, and the use of HTLS conductors is usually a reasonable and economic option. For longer lines, reconductoring with HTLS conductor may also be economic, if the frequency and duration of high current loads is low.

Impact of HTLS on Electric and Magnetic Fields

In the normal application of HTLS conductors, they are used to replace the original conductors of existing lines while re-using the original structures ("reconductoring"). Reconductoring normally leaves the original ground level electric field, electric induction, corona discharge levels, and audible noise levels unchanged. However, the ground level magnetic field and magnetic induction levels will increase if the line current increases as a result of the higher line thermal rating.

The levels of magnetic field associated with any transmission line are primarily a function of the conductor spacing, the geometric arrangement of the three phase conductors, and the power flow on the line. The presence or absence of a steel core within the transmission line conductors does not alter the magnetic fields outside of the conductor.

Identifying Appropriate HTLS Line Uprating Applications

The methods used to increase the thermal rating of an existing overhead line vary widely. Reconductoring an existing line with HTLS conductor is just one of many alternatives. Since HTLS conductors may be more expensive than conventional aluminum stranded conductors, they are not suitable in every uprating situation. In very general terms, the most promising applications for reconductoring with HTLS conductor involve the following scenarios:

- If the existing line's conductors are in poor condition, but the structures and foundations are in relatively good shape, then HTLS conductors are likely to be competitive with conventional conductors.
- If the structures and foundations are in good condition, the existing line's conductors are all aluminum (i.e., no steel core), and present line rating must be increased by more than 30%, then HTLS conductors are likely to be a good choice.
- If the existing line structures and foundations are in good condition, and the electrical clearances along the line are at or near to the minimums prescribed by the NESC, then reconductoring with HTLS conductor may be warranted.

- If the existing line is in good physical condition, is presently rated at a conductor temperature between 75°C and 125°C, and the minimum increase in thermal rating is in excess of 20%, then reconductoring the line with HTLS conductor is likely to prove economic.

Again, in very general terms, the least promising scenarios wherein reconductoring with HTLS conductor will prove economic or practical are the following:

- If the structures or foundations of the existing line are in poor condition, then there is little or no reason to reconductor with HTLS or conventional conductor.
- If the existing line is in good physical condition, and the rating is to be increased by less than 20%, it is likely that an alternative method of uprating will be more attractive than reconductoring with HTLS.
- If the line is more than 10 miles long, and the daily normal load peak reaches a power flow level near to the line's thermal rating, then the cost of electrical losses may indicate the need for reduced resistance rather than increased operating temperature.
- If the line is 500 kV or above, reconductoring with HTLS conductors is not typically required, because the existing thermal rating is already much higher than the limits on power flow related to voltage drop and phase shift.

As an example, consider the plot of ampacity versus maximum allowable conductor temperature, shown in Figure 6-1. Of course the relationship between ampacity and temperature limit applies to any line with this size conductor. It works equally well for the existing line or for the reconductored line with a 795 kcmil conductor.

Three temperature ranges are indicated in Figure 6-1. Range **A** goes from 49°C to 75°C. Range **B** goes from 75°C to 125°C, and Range **C** goes from 125°C to 180°C:

- The conductor temperatures in Range A are typical of unmodified existing lines built prior to 1970 according to the older NESC code, which required electrical clearances be met at 120°F rather than the "maximum conductor temperature for which the line is designed to operate" (NESC Rule 232A, 2003).
- The conductor temperatures in Range B are typical of either more recently built lines or lines that have previously undergone a thermal uprating without replacing the original conductors.
- Lines having maximum conductor temperatures in Range C are less common. Here the asset owner has typically made a special provision to handle these high temperatures safely. Special connectors, frequent inspections, and severely limited emergency durations may be required to operate ACSR in this range.

If the structures and foundations of an existing line are in good condition, and if the required increase in thermal rating is greater than 30%, then existing lines with temperature limits in Range B are prime candidates for reconductoring with HTLS conductor.

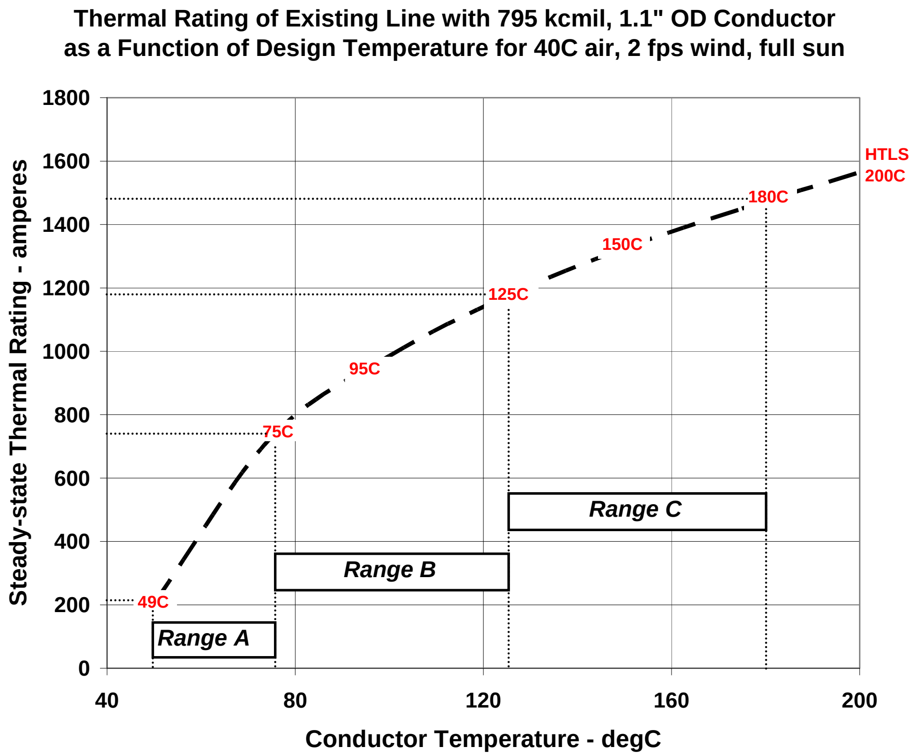


Figure 6-1
Plot of Ampacity versus Maximum Allowable Conductor Temperature

If the maximum allowable temperature of the existing line is in Range A, and the line (including conductors) is in good physical condition, then the line can typically be uprated sufficiently without needing to resort to reconductoring with HTLS conductor.

Finally, if the existing line's conductors are limited to temperatures in the temperature Range C, it is unlikely that reconductoring with HTLS will yield a large enough increase in rating to justify the cost.

In any of these temperature ranges, reconductoring with HTLS conductor may turn out to be both effective and economic, nonetheless, the most likely application of HTLS is in reconductoring existing lines with maximum conductor temperatures in temperature Range B.

Choosing the Best HTLS Conductor System in a Given Application

The field test incorporates tests and analyses of a wide range of HTLS conductors as described in the following section. In those line uprating situations, where HTLS conductor seems to be a sensible solution, there is still the matter of deciding which HTLS conductor is the best choice.

One of the primary determinants is cost. While this is a changing factor, with the exception of ACSS, the other types of HTLS conductor cost from 2 to 6.5 times as much as conventional conductor of the same size. ACSS typically costs less than 50% more than conventional conductor. This is one of the major reasons that ACSS is so widely used in North America.

Maximum operating temperature is similar for most of the HTLS conductors studied. The range of manufacturer's recommended maximum operating temperature for ZTAl or annealed aluminum is from 200°C to 250°C. In almost any practical application, the difference in rating between a conductor at 200°C and one at 250°C is a secondary consideration.

Rate of sag increase with temperature varies over a fair range between the HTLS designs. In an application where electrical clearances are very close to NESC Code minimums, conductors like ACCR and ACCC, which use special composite cores having minimal thermal elongation, are most likely to be attractive.

Rate of sag increase with ice load is determined by the modulus of the composite conductor. In reconductoring lines that experience heavy ice loading, HTLS conductors like ACCR (3M) and GTZACSR (J Power), which use full hard aluminum and steel cores, are likely to be attractive choices. The recent introduction of ACSS/TW with an ultra high strength core makes the use of ACSS more likely in high ice load areas.

Installation simplicity may be a very important factor in choosing the "right" HTLS conductor, especially for a small contractor or small utility with limited experience and small construction or maintenance staff. ACSS and ACSS/TW have been in use for over 30 years. There are very minor issues in installation. The installation of ACCR and GZTACSR has been carefully documented.

Confidence in manufacturer claims is a fundamental issue in selecting HTLS conductor. All the manufacturers of HTLS conductor have been quite careful to prove their claims of long-term physical behavior.

7
FIELD TRIAL MONITORING OF HTLS CONDUCTORS AND THEIR ACCESSORIES

Introduction

This project was intended to provide participating utilities with the necessary information on design, installation, operation, and maintenance issues. Although three years of field trial experience is relatively short compared to the life-span of the conductors, this project provides general information on how HTLS conductors operate at different current ratings and geographical locales and provides key information on design, installation and operation of selected HTLS conductors and their hardware accessories. Moreover, given that electric utilities have very limited operational experience with HTLS conductors, especially with recently commercialized conductors, this field measurement program identifies any aging and degradation problems on conductors and accessories operated at elevated temperature for a considerable period of time. Although manufacturers provide laboratory tests and installation guides for their HTLS conductors and accessories, these field tests will help utilities to validate the performance in a real system.

The basic motivation for reconductoring an existing line with HTLS conductor is to increase the thermal rating of the existing line without completely rebuilding/modifying the existing infrastructure. In each of the field-test lines, the original conductor was replaced with an equivalent HTLS conductor, and the energized line was monitored under the same operational conditions. Although HTLS conductors are expected to operate at higher current rating with increased temperature, some of the reconductored HTLS conductors at the field test sites were not necessarily operated at high temperatures because of the real-life situation at the site.

This section describes the data monitoring and instrumentation used in the field trials and the procedures for field data observations and analysis. The section also describes the four field test sites at CenterPoint Energy, Hydro One, Arizona Public Service, and San Diego Gas & Electric. A summary of the field test sites is shown in Table 7-1.

Table 7-1
Summary of HTLS Field Tests

Location	Conductor Type	Conductor Diameter (in.)	Voltage (kV)	Number of Spans	Total Length (ft)	Number of Splices
CenterPoint Energy	ACSS/TW	1.108	138	4	2280	2
Hydro One	GAP	1.108	230	4	1800	2
	Invar	1.108	230	5	1900	2
Arizona Public Service	Carbon Fiber Composite	1.108	69	4	956	2
San Diego Gas & Electric	Aluminum Composite	1.108	69	3	902	2

Data Monitoring and Instrumentation

The objective of the line monitoring program is to determine whether anomalies in these field trial sites were observed in terms of physical, electric, and mechanical properties of the HTLS conductors and their accessories while being operated at different current ratings and ambient conditions. The determination of load capacity in a high-voltage transmission network must take into account, on the one hand, the ambient conditions, such as temperature, wind speed, wind direction, and solar radiation and, on the other hand, the electric conditions of operation. This is to respect the minimum safety distances and to maintain the voltage and the network stability within suitable limits. To evaluate the thermal conditions of HTLS conductors in the test sites, physical and electrical properties of the live conductors were monitored continuously, including ambient conditions with appropriate instruments. Some of the line parameters (e.g., current, temperature, ground clearance) were monitored continuously, whereas other parameters (splice resistance, corona activities, and electromagnetic field) were monitored at regular intervals during each site visit. The description of the measurement process for each parameter is described as follows:

Current

As current is primarily responsible for increasing the temperature of the conductor, the chronological current data for HTLS conductors in each field trial site is obtained from the respective host utility. It is a common practice for utilities to monitor and record the current flowing through each transmission and distribution line in substations for a continuous period of time.

Sag and Tension

As utilities increase the electric load in their transmission lines, the conductors heat up, anneal, and sag. The ground clearance – a basis for line's rating calculation – becomes a real limiting factor as the utility has to maintain a safe clearance between energized conductors and the ground mandated by National Electric Safety Code (NESC). In this context, ground clearance needs to be closely monitored by a conductor sag monitoring device called sagometer. As the temperature of the conductor increases, the remaining ultimate mechanical strength of the conductor decreases. To avoid the failure of the conductor, the tensile load on the conductor needs to be closely watched such that the applied tensile load never exceeds the given ultimate strength of the conductor. Hence the mechanical tension and vertical clearance (i.e., sag) are continuously monitored from load cell and sagometer (see Figure 7-1). The monitoring system is equipped with a data acquisition and processing unit.

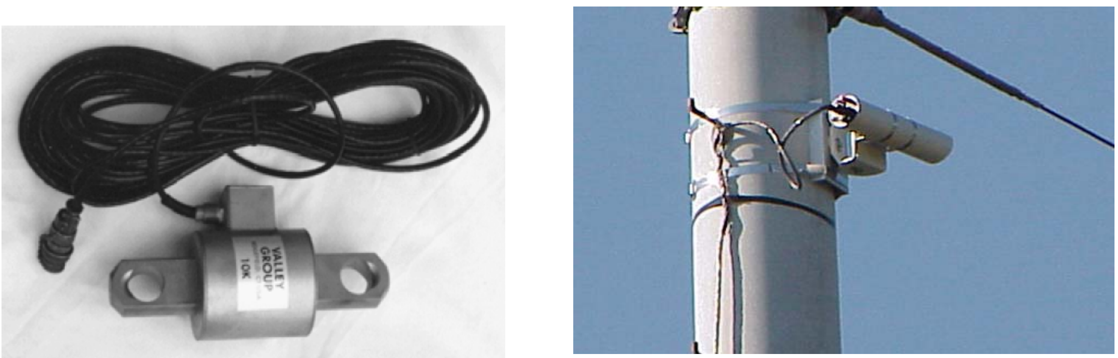


Figure 7-1
Load cell (left) (Valley Group Inc.) & video sagometer (right), at one of the field trial sites

The data acquisition is done at 1-minute intervals for all channels. The vertical clearance data is obtained from a data acquisition and analysis system, a communications system and an antenna, and the target on the line. All the measuring equipments are mounted on transmission line structures. At the time of installation, the location of the conductor or target is calibrated to the measured ground clearance. At any later time, line sag is computed by determining the new location of the conductor using image-processing techniques and the calibration constants. The resulting ground clearance information can be made available in real time using telemetry, or it can be logged for historical study. With the known relationship between sag, temperature, and the conductor, the relative sag position of the conductor at any given time from its initial position could be used to determine the temperature at which the conductor is operating at that given time.

Ambient Conditions

A conductor is supposed to operate without degrading its physical properties. The physical properties of the conductor are dependent on the level of current that it is carrying and weather conditions, especially temperature, solar radiation, wind speed, and wind direction. The lowest thermal capabilities occur when the wind speed is low and the ambient temperature and solar radiation are high. This is the reason that utilities usually design transmission and distribution lines based on a target operating temperature at a prescribed set of ambient conditions. Taking these factors into consideration, the ambient condition is measured in the field. The measurement of weather parameters is helpful to assess the conductor behavior at different ambient conditions. The ambient measurement system consists of an anemometer to measure wind speed and direction, rain gauge to measure precipitation, and a net radiation sensor and ambient temperature sensor to measure solar radiation and ambient temperature, respectively. The chronological wind speed (both two dimensional and three dimensional) are recorded from 2-D and 3-D anemometers, respectively. By monitoring transmission lines that limit transmission capability, it may be possible to increase the transfer capacity and allow increased transmission usage.

Figure 7-2
Ambient condition measurements from a set of instruments: anemometer, rain gauge etc. powered though a solar panel

Splice Resistance

The splice, which connects the two pieces of the conductor, is the weakest link of the transmission line. When two conductor pieces are joined with splices or dead-ends, the compression on splices and dead-ends over the conductor surface forms the conductance interface between the conductor surface and the inner surface of the splice fitting through the hydraulic crimping process. Because of the extra mass of the compression fitting compared to the mass of the conductor that it connects, all compression fittings should operate cooler than the conductor. This is because the added mass and diameter allow for greater heat transfer and radiation to keep them cooler. However, during the repeated process of heating and cooling, alternately at the peak and off-peak hours, the compression fitting loses its mechanical integrity, increasing the contact resistance. This may cause the interface temperature to go excessively higher than the conductor surface temperature. The temperature beyond 93ºC is very critical for ACSR conductors because outer aluminum strands start to anneal beyond this temperature.

The resistance across the splices is measured with a live line micro ohmmeter, called an "Ohmstik." The joint resistance can be measured while the line is energized. The Ohmstik measures the micro-ohm resistance of conductors, connectors, splices, and switching devices positioned directly on an energized, high-voltage line (see Figure 7-3). The Ohmstik calculates resistance by measuring the AC amperage in the line and the voltage drop due to the resistance of the line segment under test. Using the AC current in the line ensures that realistic current distributions through the connection are being measured. The instrument is pressed against the splice or connector in such a manner that the connection under the test is between the two electrodes. The conductor, for which the resistance is to be measured, is reached from the bucket truck, and the resistance is measured by placing electrodes at the mouth of the splice, and at the center of the splice. In a few seconds, the instrument is removed from the line, and the line amperage and resistance are displayed on the front panel of the display unit. This measurement helps to identify any problems associated with the integrity of splices on the conductor and helps to rectify any future problems.

Figure 7-3
Splice resistance measurement with a Sensor Link OhmStik at the site

Corona

Corona is a luminous partial discharge from current carrying conductors and insulators due to ionization of the air, where the electrical field exceeds a critical value. When conductors and insulators are exposed to high electric field, which occurs at high-voltage and ultra-high-voltage levels, the ionization takes place causing air to discharge. Corona, if not always a problem by itself, is often an indicator of a fault. Corona is an indication of contamination, like salt, on insulators. In some cases it can indicate imminent tripping. Corona is accompanied by excitation of nitrogen molecules, leading to emission of UV radiation when the electric field exceeds a critical value. The corona discharge emits radiation in the 280-405 nanometer (nm) spectral range, mostly in the ultraviolet (UV) range, and therefore is invisible to the human eye. However, relatively weak emission at about 400 nm might be observed at night under conditions of absolute darkness. The DayCor® corona camera is a bi-spectral Solar Blind UV-Visible imager, designed to detect these very faint UV emissions in the solar blind UV band, with high signal-to-background ratio.

After the initial energization of the transmission line, the test span conductor and associated hardware were viewed with a daytime DayCor® camera at different time interval during each site visit. The images were updated following each site visit during the entire field trial period. Similar procedures as presented in the EPRI "Guide to Corona and Arcing Inspection of Overhead Transmission Lines" were followed during the inspection process. Figure 7-4 shows corona images of one of the sections of newly installed HTLS conductors observed during the inspection process.

Figure 7-4
Corona observations on HTLS conductor surfaces installed in one of the field trial sites

Electric and Magnetic Field (EMF)

In recent years there has been a concern over possible adverse health effects due to electric and magnetic fields. Electric fields are created by electric charges whose strength depends on the voltage on the conductor. This means that a high-voltage power line produces a stronger electric field than a low-voltage power line. Electric fields represent the forces that electric charges exert on one another. In this context, lateral profiles of electric and magnetic field are observed at a height of 1 meter above the ground as per ANSI/IEEE standard under the transmission line. The measurements were done at mid-spans of every span of the test line along the ground surface perpendicular to the conductor line from an electromagnetic field (EMF) meter called STAR 1000™. The lateral profiles were taken along a 100-ft line perpendicular to the conductors at the mid-spans of the test line such that the 50-ft point is directly under the conductor (see Figure 7-5).

In general, the material that ACSR conductor is made up of makes no direct difference on EMF exposure level on the ground. However, there are some claims in the electric industry that some conductors will alter the electric and magnetic fields at the ground level. Therefore, EMF observation is made in order to verify this fact.

Figure 7-5
EMF measurement process under a transmission line

Infrared (IR) Measurements

In an electrical system, elevated temperature whether on insulators, conductor, splices or other accessories caused by electrical failure can lead to mechanical failure. Thus, there is a need to observe the temperature on various components of an overhead line in order to identify potential failures. Among the various line components, the fitting connecting two conductors is a critical component in terms of electrical and mechanical integrity. As temperature rises, the resistivity of the materials at the interface between the conductor strands and the aluminum sleeve increases. As the resistivity increases, the temperature of the fitting increases. This can lead to thermal runaway, which may lead to failure that could be catastrophic.

Knowing this relation, field inspections of fittings with infrared technology could be used to locate pending failures and prioritize maintenance efforts to remove or remediate at-risk fittings. Conventional maintenance rules-of-thumb indicate that a fitting that has been identified as hotter than the conductor needs replacement. To identify possible thermal runaway problems on transmission line components, especially on compression fittings, a long-wave infrared camera, fitted with a 7 degree telephoto lens set atop a tripod, is used. In these field trials, spots were painted on infrared target locations during installation of the conductor with a white-colored paint of known high emissivity to improve the accuracy of the temperature measurements while minimizing the effects from solar heating. In addition, visual photographs were taken at each target location to assist in interpretation of the corresponding infrared images. Figure 7-6 shows an IR image and the visual image of the same dead-end assembly, which assists in the interpretation of the infrared image.

Figure 7-6
Visual and IR images of a dead-end assembly on a HTLS transmission system

Visual Inspection

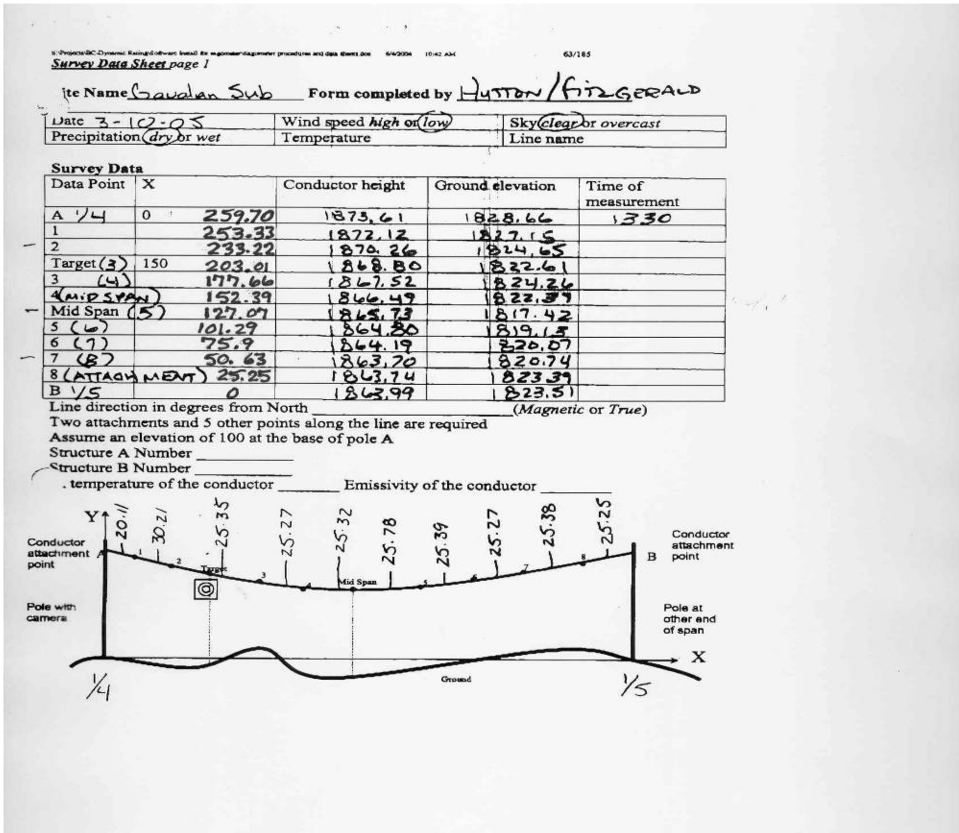
Visual inspection continues to be an important part of transmission line operation and maintenance practice, especially in high-voltage systems. In a high-voltage transmission network, problems associated with insulation failure due to various reasons, including short-circuit currents, can cause severe burn-outs. A burnout could be easily identified through visual inspection. Visual inspections of the test line are considered to be an important part of the HTLS conductor assessment. Regular visual inspections will help the project in identifying any major problems on the conductors, splices, and associated hardware.

Every site visit includes visual inspections using binoculars, camera, zoom lens and other complementary accessories as needed. Figure 7-7 shows pictures of several main components of the test segment taken during one of the site visits from a high-resolution camera.

Figure 7-7
Visual inspection along the line components of a transmission system involving HTLS conductors in one of the field trial sites

Field Survey

At least once (usually more) during each site visit, a survey is done along the ground surface underneath the HTLS conductors. A survey sheet (see Figure 7-8) is filled out by the surveyors. The data recorded include the distance at different points along a span between two pole structures, and conductor height and ground elevation at these points. The survey helps to assess the geographical profiles of a field trial site and provide important information on conductor clearance along the test line routes.



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Survey Data Sheet page 1

ite Name Gavalan Sub Form completed by HUTTON/FITZGERALD

Date 3-10-05	Wind speed *high* or *low*	Sky *clear* or *overcast*
Precipitation *dry* or *wet*	Temperature	Line name

Survey Data

Data Point	X	Conductor height	Ground elevation	Time of measurement
A 1/4	0 259.70	1873.61	1828.66	1330
1	253.33	1872.12	1827.15	
2	233.22	1870.26	1824.65	
Target (3)	150 203.01	1868.80	1822.61	
3 (4)	177.66	1867.52	1824.26	
4 (MID SPAN)	152.39	1866.49	1822.39	
Mid Span (5)	127.07	1865.73	1817.42	
5 (6)	101.29	1864.80	1819.15	
6 (7)	75.9	1864.19	1820.07	
7 (8)	50.63	1863.70	1820.74	
8 (ATTACHMENT)	25.25	1863.74	1823.39	
B 1/5	0	1863.99	1823.51	

Line direction in degrees from North ______ (*Magnetic* or *True*)
Two attachments and 5 other points along the line are required
Assume an elevation of 100 at the base of pole A
Structure A Number ______
Structure B Number ______
. temperature of the conductor ______ Emissivity of the conductor ______

Figure 7-8
Sample of survey data taken on a particular day between two structures

CenterPoint Energy Field Test

The test line is located on the CenterPoint Energy (CNP) transmission system designated as "138 kV Ckt 06G-3 – Jefferson Sub – Pasadena Sub (North Circuit)" in Houston, Texas (see Figure 7-9). The existing north-side circuit consisting of three phases of 2-subconductor bundle of 795 kcmil ACSR was replaced with three phases of single-conductor of 959.6 kcmil (Suwannee) ACSS/TW. The conductor was supplied by Southwire of Carrollton, GA. Installation of conductor and monitoring instruments was completed at the CNP site on May 26, 2003. The test line includes five structures with four spans in a vertical three-phase arrangement. The total length of the test segment is approximately 2,880 ft and runs east to west.

Figure 7-9
Towers and instruments installed at the CNP Energy site

Field Data Observations and Analysis at CenterPoint Energy Field Test Site

The sag and tension monitoring system is mounted on one of the transmission towers in the test line. The system monitors transmission line tension and ambient conditions that affect transmission line operating temperatures. The sag of any conductor is dependent on the coefficient of thermal expansion (CTE) of the conductor, the length of the conductor span, the height of the transmission line towers, and the tension along the conductor. The thermal expansion of any conductor depends on the conductor surface temperature. The sag is higher when the conductor temperature is higher, which takes place when the current flowing through the conductor is higher. The tension on the conductor is monitored from the load cell installed at the dead-end assembly.

Conductor core temperature with respect to ground clearance at the target was calculated based on a Power Line Systems - Computer Aided Design and Drafting (PLS-CADD) and SAG10 model, and the temperatures data curve was validated with the actual infrared measurements taken during the site inspections. These measurements show that the conductor was not operated at or beyond the critical temperature limit.

Comparing the temperature from the weather-based model (EPRI model) and the sag/tension-based model (SAG10) estimates shows a reasonably good agreement. However, it was recommended that direct measurement of conductor temperature be made to resolve subtle points of thermal model accuracy.

In addition to the continuously monitored data, frequent visits were made to the field sites to measure splice resistance across the splices just to make sure that splices were installed and hence working properly. This will identify any flaws during the installation and operation. This trend clearly indicated no abnormalities during the installation and operation process.

The electric and magnetic field profiles were measured along a 100-ft line perpendicular to the conductors at the mid-spans of the test line directly under the conductor. A visual inspection of the test line was performed. Digital pictures were taken along the test line to document the condition of the conductor, splices, and associated hardware. Infrared (IR) imaging was performed to detect any hot spots along various components of the line, including the conductor. To detect corona activity, the test span conductor and hardware accessories were also viewed thoroughly with a DayCor camera. No noticeable corona activity was observed from the DayCor camera.

Hydro One Field Test

The test line was located on a Hydro One 230-kV transmission circuit, east of Ottawa, Canada. The two outermost phase overhead conductors (1843 kcmil, 1.6-in. diameter, 72/7 ACSR) of L24A circuit was bypassed by two temporary wooden pole lines for an approximate distance of 1,600 ft (see Figure 7-10). One wooden pole line carried a single "GZTACSR" Gap type with 795 kcmil (1.108 in. diameter) Drake conductor (single phase), as shown in Figure 7-11. This Gap test segment consisted of four spans, approximately 1800 ft. in length, and included five structures (two dead-ends and three suspension poles). The other wooden pole lines carried a single Invar type with 1.108 in. diameter conductor along the five spans. The Gap GZTACSR conductor was supplied by J-Power, Japan, and the Invar conductor was supplied by LS Cable, Korea. Two splices were used for each Gap and Invar conductor in their sections. Conductors and accessories, including monitoring instruments, were installed on October 24, 2004. Existing outer-phase conductors were placed in the original condition with the intention of restoring the circuit quickly to its original physical condition to avoid any possible customer interruption.

Figure 7-10
Towers before (left) and after (right) the bypass

Figure 7-11
Zoom view of wooden poles carrying the Gap conductor

The Gap-type conductor used in the Hydro One field site is classified as “GZTACSR,” with an outside diameter of 1.108 in. and 469.5 mm^2 of total cross-section area. The conductor is concentric-lay-stranded, made from round and trapezoid super-thermal-resistant aluminum alloy wire (ZTAL) and zinc-coated extra–high-strength steel (see Figure 7-12).

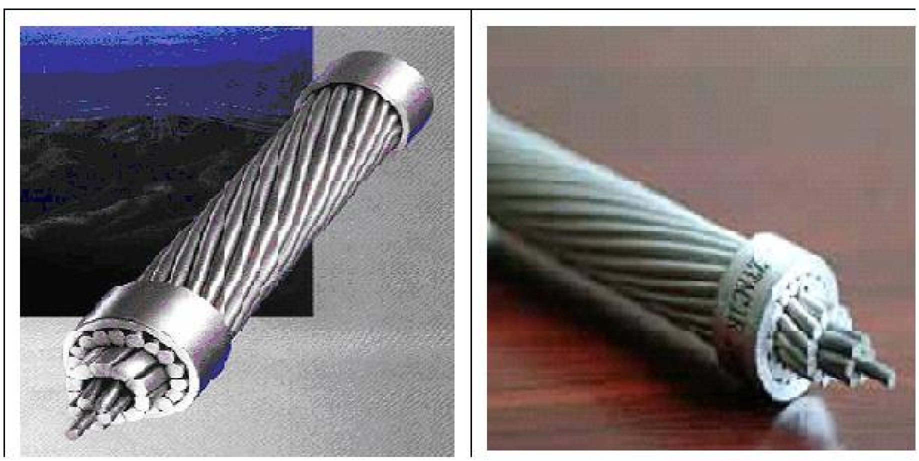

Figure 7-12
Gap (left) and Invar (right) conductors installed at Hydro One

The inner alloy layer is made from trapezoidal wires to form a tube. The installation of Gap-type conductor at the Hydro One site was the first of such installation in North America.

Invar conductor was initially developed in Japan by J-Power using a core made of invar, which is an alloy of iron and nickel (see Figure 7-12, right). Invar steel alloy wires have a reduced rate of thermal elongation and a slightly lower tensile strength than high strength steel wires. The current-carrying capacity of the invar conductor is increased by using a super-thermal-resistant aluminum alloy wire (ZTAL) on the conductor.

Field Data Observations and Analysis at the Hydro One Field Test Site (Gap)

Continuous data on sag, tension, and the weather were monitored and analyzed for the Gap and Invar conductors installed at the Hydro One site. An important and distinct observation on pole tilt was noticed at this site because of the wet ground. The higher tensile force along the conductor tends to pull the newly installed poles together; as a result, the tilt (the vertical displacement) is observed at the pole. However, this has nothing to do with this particular type of the conductor. The tilt was measured by a set of inclinometers mounted inside the sagometer's camera unit. This observation was unique for the Hydro One site because it involved the installation of new wooden poles, which were displaced from their original position because of wet ground. The temporary dead-end pole installed for the Gap conductor at Hydro One was, unfortunately, placed in a relatively wet soil and was not guyed adequately.

The line design software program – Alcoa Sag10 – predicts the sag-tension-temperature behavior. SAG10 software is well recognized as the industry standard for calculating sag and tension for most conductors. The sag-temperature curve, as obtained from SAG10 model, was validated with at least one calibration point, which was obtained at the time when the conductor was carrying close to zero load, and the solar heating was nearly absent, such as at night. At this situation, the conductor temperature is very close to the ambient temperature, and the sagometer reading gives a data set for the calibration point. As expected, the conductor temperature increases as the current through the conductor increases.

The real-time weather (wind speed, wind direction, ambient temperature, and solar intensity), along with the real-time current, can be used to calculate the real-time conductor temperature using EPRI's Dynamic Thermal Circuit Rating (DTCR) program. Real-time simulations using DTCR were performed on the Gap data on a month-by-month basis.

In addition to the continuously monitored data, regular site visits were made to the field sites to measure splice resistance across the splices. In addition to the continuously monitored data, measurements of resistance across the splices showed no definite trend.

After the initial energization, the test span conductor and hardware were viewed with a DayCor camera. Because the cable was dragged on the ground before it was hung, there was a significant amount of mud and grass imbedded on the conductor. These contaminations became corona sources when the line was first energized. Over time, it is expected that corona will cease by itself. Some discharge activities were also observed in some dead-end structures, vibration recorders, and suspension insulators.

A number of IR images were taken, and the IR observation was compared with the corresponding digital pictures. However, no abnormal temperature was observed in any parts of the line, splices, and dead-ends.

The electric and magnetic field profiles were taken along a 100-ft line perpendicular to the conductors at the mid-spans of the test line at a height 1 m above the ground. The EMF meter was oriented for the maximum reading for determining the maximum induction effect.

Field Data Observations and Analysis at Hydro One Field Test Site (Invar)

Measurement activities on tension, sag, and weather parameters (wind speed, wind direction, ambient temperature, and solar intensity) on the Invar conductor started at the Hydro One field site from October 4, 2004. The conductor current data were provided by Hydro One on a regular basis. The sag data were obtained from sagometer measurements. The average conductor core temperature was deduced from the sag data using the SAG10 model.

The data on measured ground clearances from the sagometer and the measured tensions are very complete with little data lost. This is further substantiated by the fact that the measured tensions compare closely with the tensions computed from the sag measurements. This is quite different from the data for the Gap conductor where the dead-end poles were moving. Fortunately, this does not seem to be the case for the Invar.

Electric and magnetic field measurements were made in lateral directions along a 50 foot line on both sides of the transmission line using an EMF meter (STAR 1000^{TM}) such that the reference measurement was made just below the transmission line at the mid-span.

An infrared (IR) visual inspection of the conductor and its components showed no abnormal temperature behavior. After initial energization, the test span conductor and associated hardware were viewed with a DayCor daytime corona camera. A similar level of corona observation was noticed in the Invar conductor as was observed in the GAP type. The reason could be the same as for the Gap conductor—high-voltage operation and presence of contaminations with mud and debris on the conductor surface.

Arizona Public Service Field Test

The test line was located on the Arizona Public Service (APS) 69-kV transmission system at the Gavilan Peak Substation at the extreme northern part of Phoenix, Arizona (see Figure 7-13). The existing single vertical circuit of 795 kcmil ACSR was replaced with single conductor phases of 1020 kcmil (Drake overall diameter equivalent) ACCC conductor in four spans (956 ft) of single-pole structure along the Gavilan Peak Substation to Dove Valley Substation section. The conductor was supplied by Composite Technology Corporation (CTC) of Irvine, California. ACCC conductor was installed at Arizona Public Service site in March 2005. The line was energized on June 17, 2005. Two splices were installed on the bottom phase of the test line conductor, “splice one” on the west side and “splice two” on the east side. They are located approximately at mid-span between structures 69A60 and 70-H3. Installation of monitoring instrumentation was completed on May 12, 2005.

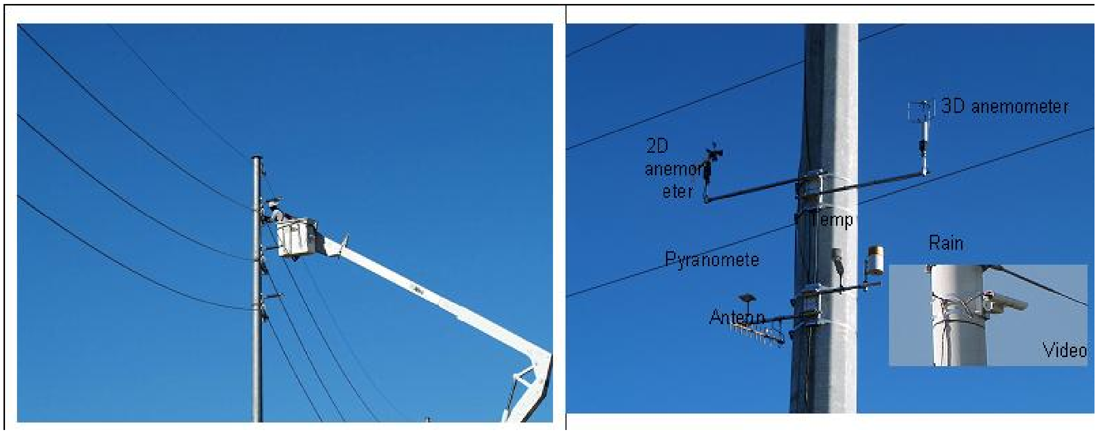

Figure 7-13
Towers and instruments installed at the APS site

The conductor used in the APS field site is classified as “Trapezoidal Shaped Concentric-Lay-Stranded Conductor” ACCC/TW with an outside diameter 1.108 in. and an aluminum cross-sectional area equivalent to 1020 kcmil (see Figure 7-14).

Figure 7-14
ACCC conductor (Suwannee) installed at APS site

Field Data Observations and Analysis at Arizona Public Service Field Test Site

The sagometer and load cells mounted on one of the transmission structures at the APS field trial site continuously monitor the sag and tensions on the conductors. Given the data on sag and clearance, SAG10 model is used to calculate the average temperature of the conductor. The tension on the conductor is monitored from the load cell installed at the dead-end assembly, whereas the sag or clearance is monitored from the sagometer. Tensions calculated from sag as measured from sagometer and measured tensions from load cells show remarkable agreement. This indicates that both measurements are good, and sag and tension can each be calculated from each other.

Faults in an electrical installation often appear as hot-spots, which can be detected by an IR camera. Hot spots are often the result of increased resistance in a circuit, which may be due to overloading in the circuit or insulation failure, which may be due to loose, oxidized, or corroded connectors. An infrared (IR) visual inspection was made of all components (i.e., dead-ends and splices), including the conductor at the site, during every site visit to detect possible temperature rise.

During each site visit, resistance measurements were taken across splices to make sure that they were installed properly, and that there was no increase in contact resistance, which can create hot spots.

Electric and magnetic field measurements were taken under the transmission line using an EMF meter (STAR 1000™) to record EMF levels. The strength of an electric field at a measurement point is dependent on the operating voltage of the line, and its value diminishes inversely to the square of the distance from the power line. No single instantaneous magnetic field measurement at a particular spot may be repeatable due to the changing current on the transmission line. Moreover, magnetic fields are altered by objects such as trees, buildings and vehicles, and by climatic conditions such as rain, making the measurements quite variable. It is to be noted that magnetic fields near most electrical appliances are usually stronger than fields directly beneath a transmission line.

Possible corona formation on the conductor and other components of the test line was monitored using a DayCor camera during the site visits in July 2005 and March 2006.

San Diego Gas and Electric Field Test

The test site was located on the San Diego Gas and Electric (SDG&E) 69-kV transmission circuit in Oceanside, North of San Diego, California. ACSR conductors of size 636 kcmil were replaced with 795 kcmil (T16, 1.108 dia.) ACCR conductor supplied by 3M of Minneapolis, MN along the three spans of the transmission line for a total length 902 ft. The towers are single-pole type, with horizontal insulators and suspension clamps (see Figure 7-15). Two splices are used in one of the three sections. Conductors, including monitoring instruments, were installed on July 21, 2005, and data were continuously collected thereafter.

Figure 7-15
SDG&E test site

The 3M conductor used in the SDG&E site is classified as “ACCR” with size 795 kcmil (1.108 in. diameter). The outer strands are composed of a temperature-resistant Al-Zr alloy, which can withstand temperature up to 210ºC continuously and 240ºC in emergency condition. The core of the conductor contains alumina fibers in an aluminum matrix (see Figure 7-16).

Figure 7-16
ACCR (3M) conductor and its cross-sectional area

Field Data Observations and Analysis at the San Diego Gas & Electric Field Test Site

Measurement activities on tension, sag, and weather parameters (wind speed, wind direction, ambient temperature, and solar intensity) on ACCR conductor at the SDG&E field site commenced on July 21, 2005 till February 2008. The conductor current data are continuously provided by SDG&E on a regular basis. The average conductor core temperature data, as deduced from the SAG10 model, are validated with actual measurements of temperature and sag, and are also compared with EPRI’s thermal model. The curve obtained from the SAG10 model can also be approximated with a fourth-order polynomial curve. Sag data were obtained from the sagometer installed on the poles.

In addition to the continuous data on various parameters (current, sag, wind velocity, solar radiation, and rain), measurements of EMF, corona discharge, and temperature were also carried out on the overhead conductor and other components at different intervals during the field inspection. Overall, the IR measurements have not shown that any piece of hardware was running hotter than expected.

After energizing the transmission line, the test span conductor and hardware were viewed with a DayCor camera. Low level corona activities were observed on some of the Preformed splices and dead-end. This may be due to contaminations of dirt and debris on the Preformed splice surface.

Resistance measurements were made across two splices (Preformed and compression type) to verify their electrical and mechanical integrity. These measurements, taken during site visits from 2005 to 2008, showed random variations, but no clear trend was detected with time.

During each visit, a thorough inspection was made of the test line and its components using binoculars, camera, and zoom lens. The general observation showed that the ACCR conductor, including all the components, appeared to be normal at every inspection.

Summary and Final Remarks

Overall, continuous data monitoring and line inspection during regular site visit show that HTLS conductors in all field trial sites are behaving according to expectations. Physical observations are normal, except at the SDG&E and Hydro One field trial sites, where corona is observed. Corona can be due to contamination on the surface of conductors and other accessories under high system operating voltage. It was found that when the conductors were dragged along the ground during installation, there were significant amounts of mud and debris embedded on the surface of the conductors and other accessories. These became a corona source after the line was energized. But corona activities ceased with time as the debris on the conductor was burned off from the heat of partial discharges. The high level of corona activities observed in the case of Hydro One system may be due to high system voltage (230 kV) compared to other field trial sites. The corona level is not that high in the case of SG&E site, where few Preformed splices create corona activities due to contaminations.

A distinct observation (i.e., pole tilt) was noticed on the wooden poles of the Hydro One field trial site due to the wet ground. This observation was unique because it involved the installation of new wooden poles in wet soil to divert the current from the original conductor to the Gap conductor. These dead-end poles shifted inward from the original vertical position due to the tensile force on the wires. As a result, the observed sag, as recorded from the sagometer, was higher than the actual sag. This resulted in overestimation of average conductor temperature using the SAG10 model. The HTLS conductors at the CenterPoint Energy and Hydro One sites are running near the optimal current ratings of the conductors, whereas the conductors at the SDG&E and APS sites are running at relatively low levels compared to their ratings.

Table 7-2
Overview of the data monitoring and field observations

Parameters / Field Trial Sites	Conductor Loading	Sag and Tension	Splice Resistance	Corona Observation	EMF	IR
CenterPoint Energy	High	Normal	Normal	Absent	Normal	Normal
Hydro One (Gap)	High	Normal*	Normal	Present	Normal	Normal
Hydro One (Invar)	High	Normal	Normal	Present	Normal	Normal
Arizona Public Service	Low	Normal	Normal	Absent	Normal	Normal
San Diego Gas & Electric	Low	Normal	Normal	Present	Normal	Normal

Note: *Sag measurements as recorded by the video sagometer were higher than estimated values due to shifting of the wooden pole structure.

8
PREDICTION OF SERVICE LIFE FOR HTLS CONDUCTORS

Introduction

One of the most perplexing questions regarding the use of HTLS conductors in existing overhead lines, concerns their service life. That is, how long will they continue to perform satisfactorily? To say the least, this is a complex question whose answer is not easy.

Overhead transmission lines are expected to function reliably for very long periods of time while fully exposed to high winds, ice storms, wind-induced conductor motions, high electrical current events, lightning strokes, and high voltage spikes produced by switching operations.

The tools available to help in predicting service life consist of laboratory and field tests prior to initial introduction of new conductors and historical maintenance/failure records which, unfortunately, can only be populated over extended periods of time.

Background & History

Power utilities have a long history regarding the probable service life of conventional conductors such as those stranded of aluminum (AAC), of copper (CU), and of aluminum reinforced with a steel core (ACSR). Utilities in North America and Europe have utilized ACSR in overhead lines for over 100 years (The design of overhead lines and application of various conventional conductors was widely discussed in the technical literature by 1920). Some such venerable lines are still in service. Based on experience, these conductors can be expected to perform satisfactorily for at least 40 years given typical designs and a wide range of weather conditions.

Other conductors made entirely of aluminum or of aluminum reinforced by steel have been introduced in the last century. ACAR and AAAC conductors were introduced in the 1960's. SDC conductor came into widespread use in Canada in the 1980's. T2 conductor was introduced in the 1970's and ACSS began to be used in 1970. Historical experience with these conductors has generally been good though certain problems appeared over time. For example, in a number of installations, ACAR conductors experienced vibration fatigue problems and SDC conductors were found to be difficult to install, repair, and seemed to have a higher than normal incidence of corrosion problems.

HTLS Conductor System Tests

Testing of transmission conductors falls into several categories – routine manufacturing tests, small scale laboratory testing of conductor systems, full scale laboratory testing, field testing in normal transmission lines, and long-term maintenance/failure data collection.

The routine manufacturing tests specified by industry standards such as ASTM and IEC establish a consistent assurance that the materials used in stranding the conductor and fabricating the hardware has the expected mechanical, electrical, and chemical characteristics. Industry standards are normally not available for new conductors but are developed as the conductor comes into widespread use.

Small scale laboratory tests are used to prove the conductor component and the composite conductor characteristics. Typically these tests include simple tensile strength, minimum elongation, conductivity, annealing, and various mechanical strand tests. Combining the component materials in a 20 to 100 ft length of stranded conductor, the tests are expanded to include stress-strain, creep elongation, vibration fatigue, self-damping, termination in clamps and splices, etc.

Full scale laboratory tests require the fabrication of stranded conductor lengths in excess of 1,000 feet. The conductor is pulled over sheaves under tension, spliced if necessary, sagged, clipped, and terminated. Measurement instruments are installed in order to record the sag-tension behavior of the conductor in response to weather and changing electrical load. The primary tests to be run in the full scale laboratory tests may vary with the claims made by the manufacturer. For example, with high temperature, low sag conductors, the tests may involve large electrical currents and the placement of multiple thermocouples along the span. For anti-vibration conductor, the tests may focus on vibration levels with the location of the test span in an area known to produce severe wind vibration.

Field tests of new conductors should only be attempted after a full series of laboratory testing has been successfully completed. The installation of the new conductor system is to be done by normal utility or contractor personnel although the manufacturer should be involved in order to assure compliance with special methods of handling and termination the conductor. The field test should involve a multiple span line section. Monitoring is useful to prove that the conductor behaves as claimed over an extended period of time. Monitoring of wind vibration, tension, sag, weather, and conductor temperature is useful though the test should be maintained for at least a year. Special handling and preparation of the novel conductor system should be documented for inclusion in the utility installation and acceptance testing practices.

All of the HTLS conductors have been tested to determine their mechanical self-damping. In general, the self-damping of ACCR and ACIR conductors are comparable to standard ACSR. G(Z)TACSR has higher self-damping than ACSR of the same Type number because of impact damping between the steel core and the inner layer of (Z)TAC trapezoidal strands. ACSS and ACCC, may have higher self-damping than ACSR if the tension in the aluminum strand layers has been reduced either by pre-stressing or by heavy ice or ice and wind loads but do not show elevated damping unless the tension level in the annealed aluminum layers has been reduced.

There is no clear evidence that the use of TW wires of any type has a significant impact on self-damping.

Higher self-damping of HTLS conductors translates into higher everyday installed tensions and lower high temperature sag. Increased initial stringing tension of HTLS conductors may be advantageous in reconductoring as long as the structure design tensions are not exceeded.

Manufacturers of HTLS conductors maintain technical data on their conductors and the results of their own laboratory tests. Section 8 compiles technical and laboratory test data for the following conductors:

- ACSS/TW (Southwire)
- G(Z)TACSR (J-Power)
- (Z)TACIR (LS Cable)
- ACCR (3M)
- ACCC (CTC)

The following laboratory tests are typical of the tests that were performed by the various manufacturers of HTLS conductors in order to prove that their product is suitable for use in power transmission lines. To help in describing each of the test procedures, specific manufacturers may be mentioned but each of the manufacturers performed all of these tests in essentially similar manners. Details of test results can be found at the manufacturer's websites.

Mechanical Laboratory Tests

The basic necessity is that new conductor systems demonstrate mechanical strength which meets or exceeds the manufacturer's claims. These tests are not unique to HTLS conductor systems but they are essential.

Tensile Elongation Test

The purpose of the tensile strength tests is to determine the ultimate strength of HTLS composite conductors or their core. The ultimate strength at ambient and high temperatures must be known so that safe operating parameters can be established. Tension tests on samples of conductor core and composite ACSS conductor confirm that the composite conductor and core can withstand over 100% of rated tensile strength.

For example, the breaking strength of GTACSR conductor was measured using 400 mm^2 GTACSR strung across a 300-m span length, with a maximum operating tensile load of 8,800 lbf. Pre-stress was applied to the steel core. When the test was carried out at several temperature levels, the test results satisfied the requirements for rated tensile strength, which take 90% of the load tensile load of the component strands.

To measure the sag-tension characteristics on the conductor, the conductor was supplied with a dc current source up to 3,000 A. It was observed that the conductor sag increased by 13% when the conductor was allowed 80% of the permissible current. The strain characteristics of ZTACIR/AW increased with temperature, as expected, at two different rates (slopes). This is due to two different expansion rates of outer aluminum wires and Invar/AW wires. It was observed that the transition temperature of ZTACIR/AW conductor was estimated to be approximately 94°C.

Also, tensile tests were performed by 3M to characterize the mechanical behavior of ACCR composite conductor. Tests were performed at the National Electrical Energy Testing, Research, and Applications Center (NEETRAC) using a 19-ft gauge length. The breaking load was determined by pulling the conductor to a 1,000-lb load, and then further loading to failure at 10,000 lbs/min. The results showed that the breaking loads for all three sets closely reached the rated breaking strength (RBS) (i.e. 31,134 lbs). Breaking loads for three laboratory sets were 102%, 100%, and 99% of RBS.

CTC did tensile testing to determine the ultimate strength of standard composite rods that are to be used in the core of ACCC/TW conductor. The ultimate strength at ambient and high temperatures must be known so that safe operating parameters can be established. A known tensile strength at several expected operating temperatures is necessary in the overall dynamic line rating, ensuring the tensile strength of the composite is never exceeded. Over 14 tests, the Drake (1020 kcmil) size standard composite rod exhibited a failure force of 39,084 ± 785 lb.

Compression Dead-End Tensile Strength

Two-piece steel and aluminum compression fittings developed by Alcoa Conductor Accessories were successfully installed and tensile-tested on ACCR. Tests showed the conductor attained the full rated breaking strength (RBS).

Other manufacturers demonstrated similar test data.

Full Tension Splice Tensile Strength

A variety of splice designs were recommended by the manufacturers. ACCR can utilize either a specially designed compression splice or a novel preformed grip. As an example of laboratory tests of full tension splices, two-piece compression joints were fitted to 477- kcmil 3M Brand Composite Conductor and then pulled to failure in a tension test. Measured joint strengths met the strength requirements of ANSI C119.4 (1998) – section 4.4.3 for full-tension connectors. The objective of the test was to verify the room temperature maximum load-carrying capability of the Alcoa-Fujikura Ltd. (AFL) Class 1, full-tension splices for 1272 kcmil ACCR conductor. The tension in the sample was increased at a rate of 5000 lbf/min until the failure occurred. The temperature of each sample was approximately 22°C during the test. ANSI C119.4 specifies that connectors should support greater than 95% RBS in a tension test. The AFL Class 1, full-tension splices for 1272 kcmil ACCR conductor meet this criterion.

Repair Sleeve Residual Tensile Strength

Alcoa Conductor Accessories compression repair sleeves were designed, manufactured, and fitted to 477-kcmil 3M Composite Conductor and then pulled to failure in a tension test. The joints held more than 98% RBS. This exceeds the requirement set forth by ANSI C119.4 (1998) – section 4.4.3 for full-tension connectors, that states the connector should hold at least 95% of the conductor's RBS.

Compression Dead-End Sustained Load Tests

3M has performed sustained load tests for dead-end connectors in accordance with ANSI C119.4. The Alcoa Fujikura Limited (AFL) dead-end sample showed no signs of problems during the load test, and exceeded RBS in a room-temperature tensile test following the 168-hour, 77% RBS sustained load period.

Single-pad dead-end was evaluated for sustained load for making mechanical connections onto 1020 kcmil ACCC Drake conductor used on overhead distribution and transmission lines for electric utilities as per ANSI C119.4. After three pulls, six samples of dead-ends met ANSI C119.4 sustained load and Class 1 full-tension requirements on 1020 kcmil ACCC Drake. The holding strength for these samples were recorded, resulting in 96.8, 111.8, and 112.5% of the conductor rated breaking strength.

Connector Sustained Load

3M contracted with NEETRAC for a connector sustained load test in accordance with ANSI C119.4. Alcoa Fujikura Limited (AFL) installed their compound compression splice designed for the 477 ACCR conductor. ANSI C119.4 requires that a splice hold 77% of the conductor RBS for 168 hours (7 days), and still hold 95% of the conductor RBS following the sustained load period. Following 170 hours at 77% RBS, the conductor failed mid-span at a load of 20,353 lbs (104.5% RBS). Therefore, the connector passes the ANSI requirement for sustained load. This test provides information on conductor stress-strain and creep characteristics. Splice elongation was measured before, during, and after the test. This "bonus" material is not required by ANSI C119.4, but is provided for information on the system performance.

Suspension Unbalanced Load

Unbalanced load tests simulate situations where neighboring spans have very different loads, which can happen due to non-uniform ice accumulation along the surface of the conductor. To mitigate this, the 3M assembly is designed to allow the conductor to slip, which then changes the sags of the adjacent spans and permits more equal tensions on the spans. In the test, a 795-kcmil suspension assembly was anchored, and a length of new, un-weathered conductor was pulled in an attempt to pull it through the assembly. Two tests exhibited no slip up to 15% RBS tension and then continuous slip at 20% RBS. Subsequent disassembly of the suspension and the conductor layers revealed no evidence of damage to the conductor or suspension components. Thus the suspension assembly provides satisfactory behavior.

Ductility Test

ACSS uses a mischmetal coating on the steel core wires to resist flaking at high temperatures. Southwire performed ductility tests on the special steel wires. Charpy Impact Test values on steel core shows that ACSS core does have as good or better performance than conventional steel.

Torsion Test

The objective of the test is to observe the mechanical performance of the conductor and core when subjected to twisting that could occur during installation.

CTC performed a test on ACCC/TW for informational purposes. The conductor was tensioned to about 4,100 lbf i.e. 10% of the conductor rated tensile strength. This tension is in the approximate range that the conductor would be pulled during installation. The conductor was twisted by hand using the lever rod. The test shows that the core can withstand 16 revolutions of twisting around its longitudinal axis without catastrophic failure maintaining substantial mechanical strength. After 16 complete revolutions of twist, a longitudinal crack appears along the length of the core. Similarly, a torsion test was performed on the whole conductor. The conductor was twisted in the opposite direction of the lay of the outer aluminum strands until some form of deformation or bird-caging occurred. A significant level of bird-caging occurred on aluminum strands of the conductor after two complete revolutions of twist on the conductor.

J-Power also studied torsional resistance of G(Z)TACSR. In two cases where 610 mm^2 GTACSR conductors were strung across a 30-m span and then subjected to tensile forces of 6,600 and 11,000 lbf respectively, tests measured the twisting torque in the central section of each of the test lines (twist angle: 10º to 80º). The results confirmed a torsional rigidity of 30-40 kgf-m^2/rad, which is equivalent to the value of ACSR.

Impact and Crush Tests

The objective of crush testing is to observe the damage inflicted on the whole conductor or the composite core when subjected to controlled crush loading. Both CTC and 3M performed such tests.

The ACCC/TW conductor was mounted between two plates of a crushing machine so that the lateral movement is prevented. The load is gradually increased from 0 lbf to 110,000 lbf. The Crush Test indicates that there is a significant deformation on aluminum strands after applying 51,000 lbf of crush loading. However, deformation on composite core is negligible compared to the aluminum strands.

For the impact tests, both samples exceeded their rated strength. Torsion testing demonstrated that outer aluminum layer strand failures occur well before any core strand failures. The crush test samples suffered no damage detectable by visual inspection. Evaluation of the crush test samples at 3M showed no significant damage to the metal matrix composite (MMC) core or other internal components.

Stress-strain and Creep Laboratory Tests

Stress-strain tests were performed for all HTLS conductors and stress-strain equations were developed so that sag-tension and line design calculations can be performed with software such as the SAG10 and PLS-CADD programs.

Stress-Strain Test

For example, the stress-strain behavior of 795-kcmil 3M composite conductor was determined in accordance with the 1999 Aluminum Association Standard entitled, "A Method of Stress-Strain Testing of Aluminum Conductor and ACSR." On the conductor, the test was started at 1,000 lbs, and the strain measurement set to zero. Load was then increased incrementally to 30%, 50%, 70%, and 75% of RBS, with the load relaxed to 1000 lbs between each increase. Finally the conductor was pulled to destruction. A repeat test was performed on the core, loading to the same strains as measured in the conductor test. The polynomial equation was derived from the testing data. The stress-strain curve for a 795-kcmil conductor and its core is publicly available in 3M's Aluminum Conductor Composite Reinforced Technical Notebook (Conductor and Accessory Testing).

Room Temperature Creep

Creep tests are time consuming and expensive yet it is crucial that the creep rate of the various HTLS conductors be known in order to predict the sag clearance of the line.

3M has successfully performed a series of tests designed to characterize the mechanical behavior of metal matrix composite (MMC) core of aluminum conductor composite reinforced (ACCR). This test is intended to provide the test data summary and conductor property coefficients for room temperature creep tests performed in accordance with Aluminum Association guidelines. Details on field test procedures and results can be found on 3M's homepage.

CTC performed creep tests on samples of Aluminum Conductor, Composite Core –Trapezoidal Wires (ACCC/TW), Drake size conductor. Epoxy resin dead-ends were used to terminate and tension the conductor. A servo-controlled control system ensured near-constant tension for the duration of the test. The long-term tensile creep of a conductor under constant tension is taken to be the permanent strain occurring between 1 and 1,000 hours.

Core Only – High-Temperature Creep

The composite cores used in the ACCC and ACCR HTLS conductors required separate creep tests at normal and high temperature. The conventional steel stranded cores used in ACSS and GTACSR have been tested extensively in ACSR conductors.

Typical high-temperature creep tests were performed at the NEETRAC laboratory on the metal matrix composite (MMC) core strand of 3M's 477 kcmil ACCR conductor. The Aluminum Association's 1999 guide on creep testing was used as a reference, with the exception that samples were tested at 150°C and 250°C. The test results demonstrate extremely low creep at both temperatures.

Wind-Induced Motion Laboratory Tests

Transmission conductors are subject to various types of wind-induced motions. A major concern is avoiding conductor failure due to vibration fatigue. To prevent fatigue failures, everyday conductor tension is limited to modest levels and vibration dampers can be installed near the support points. Another concern is large scale ice galloping motions that can cause flashovers and mechanical damage. The following laboratory tests were performed to evaluate the probable performance of the new HTLS conductors over the life of the line.

Galloping Test

Galloping, a high-amplitude vibration that occurs in transmission lines under certain resonant conditions, was tested at Preformed Line Products' (PLP's) facilities following IEEE 1138 test procedures. In these tests, the goal was to measure the endurance limit and to characterize any damage to suspension hardware or conductor. A length of 795-kcmil 3M composite conductor was terminated at each end using helical-rod dead-end assemblies with a helical-rod suspension assembly at a 5° turning angle in the center. This arrangement produced two spans, each of 82 ft (25m). The conductor was held under a constant tension of 25% RBS. An actuator created low-frequency (1.8 Hz) vibrations and produced a maximum vibration amplitude of 39 in. (1 m). In the test, 100,000 cycles were successfully completed with no damage to either the conductor or suspension hardware. The conductor was disassembled for visual inspection, which further indicated no damage.

Aeolian Vibration & Fatigue Testing

The purpose of this testing is to demonstrate that the conductor is normally resistant to fatigue failure and to determine the level of supplemental damping required to protect the conductor system when subjected to dynamic, wind-induced bending stresses.

Laboratory aeolian vibration testing at higher levels of activity than found in the field is commonly used to demonstrate the effectiveness of accessories under controlled and accelerated conditions. The only published industry test specification for aeolian vibration testing is for vibration testing of Optical Ground Wire (OPGW). This specification is IEEE 1138 and was adopted for the testing of both ACCC and ACCR.

In tests performed by 3M, using a vibration shaker, a 20-m sub-span of 795 kcmil ACCR was tensioned to 25% RBS using a beam/weight basket, and maintained at a vibration frequency of 29 Hz, and an antinode amplitude of 0.37 in. peak-to-peak (one-third of conductor diameter), for a period of 100 million cycles. Visual observations were made twice daily of the conductor and the suspension assembly (5° turning angle) during the test period. At the completion of the test period, the suspension assembly was removed and carefully inspected for wear or other damage. The section of the conductor at the support assembly was cut out of the span and dissected to determine if any wear or damage had occurred to the Al-Zr outer strand, the aluminum tape, or the composite core. After 100 million cycles of severe aeolian vibration activity, there was no wear or damage observed on the components of the suspension assembly or on any of the conductor constituents.

In tests performed by J-Power, 410 mm^2 GTACSR conductors (without any corrosion-resistant grease in their gap) were forcibly subjected to 2 $x10^7$ vibrations at 20.3 Hz, with maximum amplitude of 23 mm. The results showed no abnormalities other than the generation of very small amounts of black powder due to the friction of the aluminum with the steel core.

In assessing the fatigue performance of ACCC/TW conductor, the procedure described in IEEE 1138 (intended for aeolian vibration testing of overhead fiber optic ground wire) was implemented. After completion of 100 million vibration (peak to peak amplitude 0.449 in.) cycles on the conductor by a shaker, there was no sign of physical damage on aluminum strands or the core material. Unfortunately, the active dead-end sample for the conductor failed prematurely when tension tested to determine the remaining pullout strength.

Fatigue endurance of TAL and ZTAL, full-hard, zirconium alloy aluminum strands, is similar to that of ordinary 1350-H19 aluminum wires. Annealed aluminum strands (used in ACSS and ACCC) are slightly more prone to fatigue breaks than full-hard H19 aluminum strands of the same diameter but are typically at very low tension levels when the composite HTLS conductor is pre-stressed.

Self Damping Test

ACSS (and ACCC) may have higher self-damping than ACSR if the tension in the aluminum strand layers has been reduced either by pre-stressing or by heavy ice or ice and wind loads. If not pre-stressed, however, high initial tension levels may lead to premature failure from vibration fatigue unless dampers are installed.

There is no clear evidence that the use of TW wires of any type has a significant impact on self-damping.

The damping performance of ACSR and ACSS conductors varied considerably after stretching the conductor and allowing settling down to its original condition. The damping performance of ACSS and ACSS/TW conductors were superior compared to the ACSR and ACSR/TW conductors. However, there was no noticeable difference on damping performance between ACSS and ACSS/TW conductors. The damping of ACSS and ACSS/TW conductor was so great at 25 Hz that it became difficult to measure the vibration. The damping performance of all ACSR, ACSR/TW, ACSS, and ACSS/TW conductors were similar up to 20 Hz in the initial state.

Elevated Temperature Laboratory Tests

HTLS conductors are intended for use at temperatures in excess of 200°C. These tests are intended to show their ability to perform appropriately at high temperature without deterioration.

Temperature Rise Test on Suspension Clamp

The purpose of the laboratory test is to check if the temperature of the insulator's cement rises to values higher than its critical temperature, of above 100ºC. It is readily observed that, in the worst case, the replacement of the conductor introduces a temperature increase of 25ºC, approximately in the critical region of the insulator by comparison with the ACSR conductor. The critical region has been assessed as an insulating portion between socket eye and ball eye. The temperature recorded at the critical zone has been identified to be 60ºC. Thus, the highest temperatures attained anywhere in the insulator do not preclude it from working correctly.

Temperature rise Test on Compression Dead-end Clamp

The test consists in connecting 26' (8m) of Gap conductor, held up by means of a clamp system, to the terminals of a current source. The current source feeds a current to increase the conductor temperature until it reaches the maximum continuous working temperature. Simultaneously, by means of thermocouples, the temperature in different points of the dead-end clamp system is measured. It can be observed that the conductor temperature decreases in various points of the dead-end clamp. This effect is a consequence of Joule effect, which is due to the heat produced due to the flow of current and is lower than in the conductor. On the other hand, the surface available for heat dissipation is higher than in the conductor (increases natural convection). The test result shows that that the temperature on the limit of the ball socket is about 70ºC, which is lower than its critical temperature (i.e., 100ºC). Thus, it can be ensured that this temperature does not affect the correct functionality of the dead-end system.

The objective of the test was to determine if the tensile strength of the conductor/dead-end clamp system was adversely affected after being subjected to sustained elevated temperature at a constant tensile load. The conductor was tensioned to 4,670 lbf, or 15% of the cable RBS (31,134 lbf) and heated to 240ºC. This condition was maintained for 168 hours (7 days). At the end of the 168 hours, the cable was unloaded, allowed to cool naturally to room temperature and then tensioned to failure. The dead-end failed at 103% RBS, indicating that the dead-end sustained full load after being subjected to the high temperature.

Suspension Assembly Elevated Temperature Test

As with terminations and joints, it is necessary to understand the temperature difference between the conductor and the suspension assembly to ensure the assembly retains its strength. In this test, the conductor was heated to 240°C under a tension of 15% RBS for 168 hours. Using embedded thermocouples, the temperature profile was continuously monitored at the elastomer insert for a 795-kcmil 3M composite conductor. The suspension assembly was at 54°C when the conductor was at 240°C. Based on this temperature information and the rating of the elastomer material to 110°C, it is believed that these materials have sufficient durability at the maximum temperatures at which the suspension assembly operates.

Dead-End High-Temperature Sustained Load

The objective of the test was to determine if the tensile strength of the conductor/dead-end clamp system was adversely affected after being subjected to sustained elevated temperature at a constant tensile load. A 3M conductor was tensioned to 4,670 lbf, or 15% of the cable RBS (31,134 lbf) and heated to 240ºC. This condition was maintained for 168 hours (7 days). At the end of the 168 hours, the cable was unloaded, allowed to cool naturally to room temperature and then tensioned to failure. The dead-end failed at 103% RBS, indicating that the dead-end sustained full load after being subjected to the high temperature.

Compression Hardware – Current Cycle Tests

NEETRAC performed qualification tests on connectors for 795 kcmil 3M Brand Composite Conductor in its laboratory. A total of 21 compression connectors supplied by Alcoa Conductor Accessories (ACA) were connected in a series loop with 795 kcmil 3M Composite Conductor. The ANSI C119.4 methods and acceptance criteria were modified to reflect the operating temperature limits for the 3M Composite Conductor. All connectors performed well after 500 cycles from room temperature to 240°C. After meeting the ANSI 500-cycle criteria, the connectors were subjected to an additional 100 cycles at 300°C. All connectors successfully survived without any physical deterioration. One splice was installed using an experimental ACA high-temperature inhibitor compound. That sample ran marginally cooler than the identical connectors with standard filler compound.

Electrical Laboratory Tests

HTLS conductors must function in the presence of very high electrical stress levels. These tests are intended to demonstrate that the HTLS conductor will carry current with predictable electrical resistance and that it will withstand the electrical impact of arcing and corona.

Resistance

Conductor resistance is a major factor in overhead line ampacity. Nominal resistance is calculated in accordance with ASTM or other conductor specifications, using requirements for the size of the conductor components, resistivity of conductor materials, and stranding lay lengths. Direct measurement confirms the 3M Composite Conductor resistance is in accordance with nominal specifications. The 477 kcmil Composite Conductor measures 1.0 and 1.7% lower than the 3M specifications, depending on the measurement method.

Lightning Arc Test

The objective of the Lightning Arc Test performed by 3M is to compare the physical performance of ACCR conductors to ACSR conductors of equivalent aluminum alloy areas (i.e., kcmil) when subjected to increasing levels of lightning energy. Possible damages to conductors due to lightning arcs, including breakage and/or melting of the aluminum strands, are monitored. Splattering of melted metal may also cause damage to neighboring strands that are not directly affected by the arc. Ultimately, loss of tensile strength of the conductor is evaluated. Arcs are similar to lightning in that the current flows through a channel of ionized air. Each arc strike was conducted, the conductor sample being progressively tested along the length under various conditions of charge transference (current x duration). Charge transference ranged from nominally 50 coulombs to 200 coulombs. Typically currents are 100 – 400 amps and typically durations are 200-500 msec. When comparing the damage to both sizes of ACCR and ACSR conductors for all test levels, the visual assessment does not show that one performs better or worse than the other for the same size conductor.

The damage for all tests on both the 477 and 795 kcmil conductors was limited to the outer aluminum layer. There were no observations of damage to the inner aluminum layer or to the core. The 477 kcmil ACCR and ACSR conductors sustained more damage than the 795 kcmil ACCR and ACSR conductors for comparable energy levels. The 795 kcmil aluminum strand diameter (0.1749 in.) is larger than the 477 aluminum strand diameter (0.1355 in.). The smaller diameter wires are more vulnerable to damage.

High-Voltage Corona (RIV)

Testing was conducted by 3M to determine radio-influenced voltage (RIV) noise on a dead-end and on a mid-span splice joint. The ends of the helical rod had a standard “ball-end” finish. No noise (corona onset) was detected up to 306 kV (phase to phase) for the splice/joint in a single conductor configuration. The dead-end had a corona onset at 307 kV (phase to phase) for a single conductor configuration.

Short-Circuit Performance Test

The objective of the Short-Circuit Test is to observe the thermal and mechanical performance of HTLS conductors when subjected to increasing levels of short-circuit energy. Possible damages to conductors due to short-circuit currents are annealing and bird-caging of the aluminum strands. The conductors are subjected to increasing levels of short-circuit energy, as expressed by kA^2-sec, until physical damage, such as bird-caging or melting of the aluminum strands or clamps, is observed. The maximum temperatures in each conductor were recorded after each shot.

Weathering Laboratory Tests

Transmission conductors are intended to survive the effects of weather for at least 40 years without excessive deterioration. These tests are particularly important with regard to new materials such as the composite cores in ACCC and ACCR.

Corrosion Test

Stressed metals in a corrosive environment can exhibit stress corrosion characteristics. A sample of ACSS conductor was bent in a 4 in. diameter and subjected to a circulating sodium chloride solution for five weeks duration. No evidence of stress corrosion was observed.

The Salt Spray Corrosion Test was performed by CTC using an environmental chamber that complied with ASTM B117-03, standard practice for operating Salt Spray Apparatus. The objective of the Salt Spray Corrosion Test was to observe the effects on the whole conductor and the composite core of the ACCC conductor when exposed to a salt spray atmosphere for 1,000 hours. The salt-spray test shows that there is no major sign of discoloration or deterioration at the surface of the inner aluminum layer and core. However, there is an indication of dull color and discolored patches over the surface of the conductor.

Ultraviolet Light Exposure Test

The Ultraviolet Light Expose Test is to assess the mechanical performance of the ACCC/TW conductor core when exposed to ultraviolet (UV) radiation for an extended period of time. When bird-caging occurs on the surface of the conductor, the core is exposed to the sunlight. UV exposure on the core surface for an extended period of time can deteriorate the chemical properties of the core, ultimately deteriorating the mechanical strength of the conductor core.
To assess the potential damage to the composite core from UV, composite samples were exposed to sunlight for approximately 324 hours, and the tensile strength was measured after exposure to determine the retained strength. The tensile test on exposed core did not show any degradation in its mechanical strength, though the surface shows some less reflective surfaces after exposure to the sunlight.

Installation Tests in the Laboratory

ACSS, ACSS/TW and ACIR can be tension strung, spliced, and terminated using compression fittings which are quite similar but longer than those used with ordinary ACSR. Of course, single stage splices and terminations are not suitable for HTLS conductors as the steel core must be gripped separately and the aluminum tubing used in ACSS and ACSS/TW splices and terminations is both annealed and somewhat longer than those used for ACSR.

There are a few problems associated with the installation, operation, and maintenance of ACSS conductors and their accessories. A CIGRE study indicates that there have been occurrences of minor wire damage and bird-caging on some ACSS conductor installations (CIGRE, 2003). In addition, there have been some performance issues at splice locations with ACSS conductors.

Because aluminum strands on ACSS conductors are annealed, they require rubber-lined stringing blocks to avoid damage to the aluminum wires. The conductor may also need to be pre-tensioned.

Overall, ACSS/TW conductors can be installed using conventional equipment and installation procedures, as recommended in IEEE Standard 524 “IEEE Guide to the Installation of Overhead Transmission Line Conductors.” A bull wheel tensioner with a bottom grove diameter approximately 35 times the conductor diameter is recommended. A Stringing Sheave bottom grove diameter of 20 times the conductor diameter is recommended, however, the minimum stringing sheave diameters recommended in IEEE Std. 524 are acceptable (Thrash 2001).

The installation, splicing and termination of G(Z)TACSR is notably more complex than ACSR. The outer layers of aluminum wires must be unstranded at the termination to allow gripping the steel core and untensioning the aluminum wire layers. Also, in order to assure the free movement of the steel core relative to the aluminum layers after installation, a special type of suspension clamp must be installed at every 3 tangent structures.

Splice Sheave Criteria Test

The objective of the tests is to determine, in an indoor laboratory, the threshold combination(s) of sheave size(s), conductor angle(s) over sheave, and conductor tension(s) that cause breakage of the core wires on 590TW kcmil 3M Composite Conductor (ACCR/TW) during a single-pass test. The test conductor was strung over the sheave wheel and tensioned using pulling grips. Both ends were attached to a motor-driven, chain link loop system. The test was carried out in a temperature-controlled laboratory at 21ºC ± 2ºC. All four sheaves tested reached 25% of the conductor RTS at a specified break-over angle with no damage to the conductor. The 25% RBS tension was sustained by using a 24-in. diameter sheave for a 45° break-over angle, a 18-in. diameter sheave for a 33° breakover angle, a 16.75-in. diameter sheave for a 20° break-over angle, and an 8-in. diameter sheave for a 12° break-over angle. This test provides useful angle-per-sheave information for the design and further testing of sheave and multi-sheave configurations for 590TW ACCR.

CTC conducted the Splice Sheave Criteria Test on its 1020 kcmil ACCC/TW conductor. The test conductor was strung over the sheave wheel and tensioned using pulling grips. After 10 passes, there is a severe separation and deformation at the outer aluminum layer. A very moderate separation is observed at the inner aluminum layers.

Radial Impact Test

The objective of this test is to observe damage inflicted on the conductor surface due to impact load. The mass was raised to a certain height and released to impact directly at the surface of the conductor. A number of impact tests were performed on the CTC conductors in a combination of heights, masses, energies, and impacts used for impacting on the whole conductor and the core only. A similar test is repeated for 795 kcmil conductor as well. The damage to the aluminum strands of the ACCC conductor was more severe than the damage to the ACSR conductor. This is not surprising because the aluminum wires of ACCC conductor are fully annealed compared to the hard-drawn wires of ACSR conductors.

9
COMPARISON OF HTLS CONDUCTOR SOLUTIONS FOR IEEE LINE UPRATING TEST CASE

In 2005, the IEEE Towers, Poles, and Conductors Subcommittee 15.11, arranged a panel session during which the various manufacturers of HTLS conductors presented their solutions to a common uprating design problem. Though the design problem is not terribly similar to any of the field installations in this study, the solutions offered by the HTLS conductor manufacturers yield some useful insight into effective methods of increasing line thermal ratings by reconductoring with a HTLS conductor.

The Line Uprating Problem

The existing double circuit, 115 kV line has 26/7, 795 kcmil (403 mm^2) phase conductors. The structures are double circuit, steel lattice with concrete foundations as shown in the photograph. It was built in 1955 so it is about 50 years old. The structures and foundations are in excellent condition.

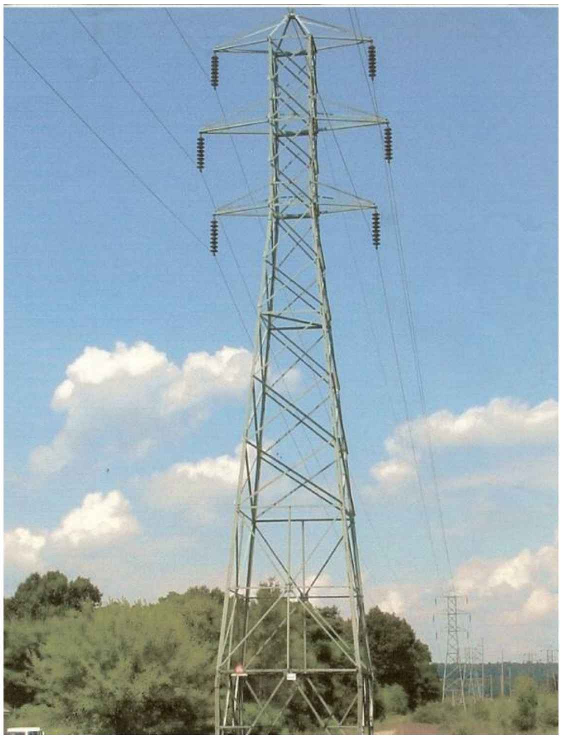

Figure 9-1
Photograph of Line Chosen as Uprating Design Case

The line sections to be reconductored have a ruling span of 1,000 feet (305 m) with individual spans ranging between 800 and 1,100 ft (244 and 335 m). The terrain through which the line passes is reasonably level. The line is relatively straight with a dead-end structure placed about every 10 spans.

Based on survey measurements, the Drake ACSR is calculated to be at a tension equal to 18% of its Rated Breaking Strength (RBS) at 60^{o}F (16^{o}C).

The original and present design loading conditions include a maximum ice loading of 1 inch (25 mm) radial ice at 32^{o}F (0^{o}C). The line clearance was originally determined by the conductor sag at 120^{o}F (49^{o}C) with a 4.5 ft (1.5 m) buffer. Present minimum electrical clearance requirements are the same as at the time the line was built.

In 1982, an asset manager discovered the generous clearance buffer of 4.5 ft (1.5 m) and the maximum conductor temperature was increased from 120^{o}F (49^{o}C) to 167^{o}F (75^{o}C). This increased the allowable high temperature ruling span sag from 25.4 ft to 28.3 ft using up most of the buffer. At 167^{o}F (75^{o}C), the summer rating is 880 amps with an assumed perpendicular wind speed of 3 ft/sec (0.91 m/sec), full sun, and an air temperature of 95^{o}F (35^{o}C).

Additional information about the line and its environmental conditions are:

- Altitude of the sun (Hc) = 71 degrees, corresponding to 42nd parallel at 12 noon on July 1st
- Azimuth of the sun (Zc) = 180 degrees, corresponding to a 12:00 noon condition where the sun is
- Total solar and sky radiated heat (Qs) = 95 W/ft^2 (1023 W/m^2)
- Azimuth of the line (Zl) = 270 degrees, corresponding to a line running East / West direction.
- Atmosphere: Clear
- Altitude of line: 0 ft above sea level
- Power Frequency: 60 Hz
- Wind Speed: 3 ft/sec (0.9 m/sec)
- Wind Direction: 90 degrees to line
- Solar Absorptivity Coefficient = 0.5
- Emissivity Coefficient = 0.5

The original line had vibration dampers installed, one per span. Over the 50 year life of the line, a few broken strands were discovered under suspension clamps.

The conductor sag with 1.0 inch (25.4 mm) of ice at 32^{o}F (0°C) and no wind is 29.1 ft (8.84 m). The complete original line design sag-tension calculations are included in the following table.

ALUMINUM COMPANY OF AMERICA SAG AND TENSION DATA
Uprating Case Study - Original Conductor Sag-Tension Data
IEEE TP&C Subcommittee
Conductor: DRAKE, 795.0 kcmil, 26/7 Stranding, ACSR
Area = 0.7264 Sq. in, Outside Diameter = 1.108 in, Weight = 1.094 lb/ft, RTS = 31,500 lb
Data from Chart No. 1-537 Aluminum Compression was calculated
Span = 1000.0 feet NESC Heavy Load Zone
Creep is NOT a Factor Rolled Rod

Design	Points				Final			Initial
Temp (°F)	Ice (in)	Wind (psf)	K (lb/ft)	Weight (lb/ft)	Sag (ft)	Tension (lb)	Sag (ft)	Tension (lb)
0.	.50	4.00	.30	2.509	23.91	13142.	23.02	13650.
						7263.A		7937.A
						5879.S		5713.S
32.	1.00	.00	.00	3.715	29.08	16026.	29.08	16026.
						8741.A		8741.A
						7284.S		7284.S
32.	.50	.00	.00	2.094	24.12	10877.	22.21	11807.
						5479.A		6879.A
						5398.S		4927.S
-20.	.00	.00	.00	1.094	16.04	8532.	13.52	10120.
						4560.A		6519.A
						3972.S		3601.S
0.	.00	.00	.00	1.094	17.39	7875.*	14.40	9506.
						3925.A		6077.A
						3950.S		3429.S
30.	.00	.00	.00	1.094	19.43	7047.	15.83	8646.
						3074.A		5428.A
						3973.S		3219.S
60.	.00	.00	.00	1.094	21.48	6379.	17.39	7874.
						2323.A		4805.A
						4056.S		3069.S
90.	.00	.00	.00	1.094	23.48	5837.	19.03	7195.
						1653.A		4215.A
						4184.S		2980.S
120.	.00	.00	.00	1.094	25.43	5392.	20.73	6607.
						1044.A		3661.A
						4348.S		2946.S
167.	.00	.00	.00	1.094	28.34	4841.	23.43	5850.
						183.A		2860.A
						4659.S		2990.S
212.	.00	.00	.00	1.094	30.04	4569.	25.97	5279.
						-24.A		2159.A
						4593.S		3120.S
257.	.00	.00	.00	1.094	31.42	4370.	28.45	4822.
						-55.A		1510.A
						4425.S		3313.S
302.	.00	.00	.00	1.094	32.78	4190.	30.83	4452.
						-85.A		899.A
						4275.S		3553.S

* Design Condition

Power System Requirements

The utility's System Planning Department has recently concluded that the thermal rating of the line must be increased from 880 amps to at least 1350 amps continuous. While this increase in line rating is presently adequate, the planners would be willing to invest additional capital if the line rating could be made 1,500 amperes or more to avoid the need for future upratings or line replacement.

Rebuilding the line or increasing the tower height is not considered an option since this would extend outage times and require an extensive series of public hearings. The best option appears to be re-conductoring the existing line with a new High Temperature, Low Sag conductor since the original conductor is 50 years old and has experienced some vibration fatigue damage even with vibration dampers in every span. Whatever the uprating method selected, the following design constraints must be met.

Reconductoring and Uprating Design Constraints

To meet minimum electrical clearance requirements, the maximum conductor sag cannot exceed 30 feet (9.14 m) under either high temperature or ice load conditions (i.e. 1.0 inch or 25.4 mm of ice, 32ºF or 0°C, no wind). This is equal to the final sag of the original Drake ACSR conductor at 100^{o}C.

The <u>maximum tension</u> of the HTLS replacement conductor cannot exceed the original maximum tension - 16,000 lbf (72,435 N) - by more than 5% nor can its <u>outside diameter</u> exceed the original conductor diameter of 1.108 in (28.1 mm) by more than 5%.

The <u>vertical weight</u> of an iced replacement conductor cannot exceed the original Drake iced conductor by more than 5% and the replacement conductor must avoid worsening the vibration fatigue problems.

In responding to this request for HTLS reconductoring proposals, the HTLS conductor suppliers are asked to provide the following information:

- A table listing the key properties of the proposed HTLS conductor
- Graphs showing the Final Sag and Final Tension vs. Conductor Temperature comparing the original
- 795 kcmil Drake ACSR with the proposed HTLS conductor
- An estimate of the line's thermal rating (i.e. maximum electrical current) at the maximum allowable temperature of the replacement conductor for this study
- A description of the hardware and installation method that would be used to install the conductor.
- Any other relevant information specific to the proposed HTLS conductor Physical Constraints (Save the structures)

Discussion of the ACSS Conductor Solution – General Cable

Design proposals were presented by each of the HTLS conductor manufacturers. Their comments, suggestions, and analysis of the design problem were similar but, of course, the HTLS conductor suggested depended on the manufacturer. The following detailed discussion on the use of ACSS (as originally presented by Mr. Gordon Baker of General Cable) was typical but more detailed than most. Of course it emphasizes the advantages of ACSS and ACSS/TW which are manufactured by General Cable.

Two candidate ACSS conductor designs have been proposed as possible solutions for the reconductoring problem. Figures 1, 2, 3 and 4 provide an indication of the physical and electrical properties of these conductors. 795 kcmil MALLARD ACSS TW (22/19) is the first choice. It will meet all of the defined design conditions including the 1,500 A enhanced ampacity rating. 795 kcmil DRAKE ACSS ULMS TW (26/7) conductor, is also a possible candidate. This design however, utilizes an ultra high strength steel core material.

There are a number of reasons why the MALLARD ACSS TW conductor was selected. a) ACSS can operate at high temperature without problems. b) The 795 kcmil size was retained in order to facilitate the ampacity rating and enable lower line losses. c) The TW (trapezoidal) configuration was chosen to reduce effect of the wind and ice loading. d) The "30/19" Type 23 (ratio of the aluminum to steel cross-sectional area) conductor chosen to provide high strength and maximize the sag and tension performance. The conductor utilizes regular strength steel to help reduce the overall conductor cost.

Using the same ampacity calculation weather assumptions and conductor surface parameters as with the original DRAKE ACSR, the calculated MALLARD ACSS/TW conductor temperature for 1350 amperes is 129°C (264°F). The calculated conductor temperature for 1,500 amperes is 154°C (309°F). Using the same sag and tension calculation parameters established for the DRAKE ACSR and the limits set by the utility, the MALLARD ACSS/TW conductor would achieve a final sag of 28.49ft @ 0°C (32°F)/1"ice; 26.75 ft sag @ 129°C (264°F); and 28.20 ft sag @ 154°C (309°F).

The DRAKE ACSS ULMS TW conductor design has been included to demonstrate a potential enhancement feature for ACSS. Because the steel component represents the bulk of the strength component in an ACSS conductor, in order to bump up the Conductor Rated Strength, a stronger grade of steel is required. It has been proposed that Extra High Strength, or Ultra High strength steel be utilized in ACSS conductors.

DRAKE ACSS TW built with Regular Strength (GA or MA) or High strength (HS or MS) steel will not meet the 30ft maximum sag limit for the 1" ice loading condition. If however, you were to build the conductor with the Ultra High strength steel, the ensuing conductor sag and tension calculations resulted in meeting all of the sag requirements.

Using the same ampacity calculation parameters established for the DRAKE ACSR, the calculated DRAKE ACSS/TW conductor temperature for 1,350 amperes is 133°C (271°F). The calculated conductor temperature for 1,500 amperes is 158°C (316°F). Using the same sag and tension calculation parameters established for the DRAKE ACSR and the limits set by the utility, the DRAKE ACSS/ ULMS/ TW conductor would achieve a final sag of 29.87ft @ 0°C (32°F)/1”ice; 26.36 ft sag @ 133°C (271°F); and 27.71 ft sag @ 158°C (316°F).

Figure 1 - Comparison of Physical Properties

Conductor	Area (kcmil)	Nominal OD (in)	Nominal Mass (lb/kft)	Vertical Mass @ 1" ice (lb/ft)	Maximum* Line Tension (lb)	Cndr Type	RTS (lb)
DRAKE ACSR with regular strength steel	795	1.108	1.093	3.715	16026	16	31500
MALLARD ACSS / GA / TW	795	1.046	1.234	3.778	16632	23	34300
DRAKE ACSS / ULMS** / TW	795	1.010	1.091	3.591	15081	16	30300
Maximum Limit	-	1.163	-	3.90	16800	-	-

* based on the previously defined sag and tension criteria, NESC Heavy, 1" ice loading, etc
** ULMS is an Ultra High Strength Steel, Zinc-5%Aluminum Mischmetal coated steel core wire. This grade of steel is under review by Bekaert Steel for commercial introduction. Initial introduction may be in Europe.

Figure 2 - Power Loss and Sag Comparisons

	conductor * temperature	ac conductor resistance (ohm/kft)	I²R Power losses/phase (kW/mile)	Sag‡ (ft)
795 DRAKE ACSR with Regular Strength steel	@ 880A 75C	0.02594	106	28.3
	@ 1350A (127C)	0.03087	297	-
	@ 1500A (153C)	0.03303	392	-
	@ 1" ice @ 0C	-	-	29.1
795 MALLARD / ACSS / TW with Regular Strength steel	@ 880A 75C	0.02557	103	23.6
	@ 1350A 129C	0.03019	291	26.8
	@ 1500A 154C	0.03233	384	28.2
	@ 1" ice @ 0C	-	-	28.5
795 DRAKE / ACSS / TW with Ultra High Strength Steel	@ 880A 76C	0.02578	105	23.2
	@ 1350A 133C	0.03062	294	26.3
	@ 1500A 158C	0.03277	389	27.7
	@ 1" ice @ 0C	-	-	29.9

maximum sag = 30ft

* based on the previously defined environmental conditions, 35C ambient, with sun and wind, etc
‡ based on the previously defined sag and tension criteria, NESC heavy, 1" ice loading, etc

Figure 3 - Maximum Amp Rating @ 30ft Sag

	conductor * temperature	conductor ampacity rating
795 kcmil DRAKE ACSR with Regular Strength steel	?	?
795 kcmil MALLARD / ACSS / TW with Regular Strength steel	185C (365F)	1655 A
795 kcmil DRAKE / ACSS / TW with Ultra High Strength Steel	200C (392F)	1700 A

* based on the previously defined environmental conditions, 35C ambient, with sun and wind, etc
30 ft sag (final condition) is based on the previously defined sag and tension criteria, NESC heavy, 1" ice loading, etc

Figure 4

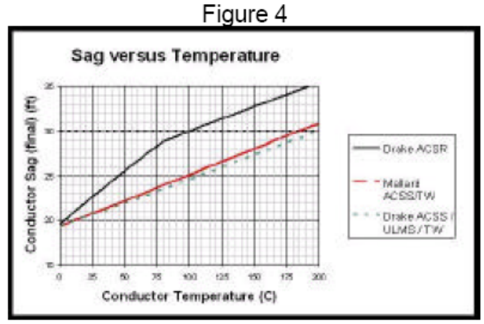

Figure 9-2
Summary of ACSS Line Uprating Analysis (Courtesy Gordon Baker, General Cable)

ACSS conductors are not a new conductor design. Since 1974, there are now thousands of miles of this conductor in operation. There is a very successful track record established. ACSS is included in the IEEE publication #524 - IEEE Guide to the Installation of Overhead Transmission Line Conductors. Deadends, Splices, Suspension Clamps, etc… and other associated high temperature hardware devices are available from multiple North American manufacturers.

ACSS and ACSS/TW conductors provide efficiency for today’s new line designs. ACSS and ACSS/TW conductors enable viable line reconductoring alternatives. ACSS and ACSS/TW provide growth capacity for future needs. The utility’s choice in using the 795 Mallard ACSS/TW conductor would be a wise investment in meeting their future needs.

Summary of HTLS Alternative Solutions

Each manufacturer presented their own solution to the uprating problem utilizing their type of HTLS conductor. All the HTLS suppliers were able to meet the reconductoring design limitations on sag, conductor OD, maximum structure tension load, and vertical weight while allowing continuous operation at 1,350 amps. The following table and graphs summarize the conductors presented during the panel session.

In the case of all ACSR and HTLS conductors, we are concerned with the composite behavior at high temperature. All of the HTLS conductors and the original ACSR conductor behave in a similar fashion at high temperature. In all the designs, the core has a lower thermal elongation rate than the outer layers of aluminum. As the temperature of the conductor increases, the sag also increases as described in the following:

1. At temperatures modestly above everyday levels, the conductors elongate at a rate which is due to the combined thermal elongation of the core and the outer layers of aluminum.
2. At a conductor temperature called the "kneepoint" temperature, the tension in the aluminum layers goes to zero and all the tension is in the core.
3. At temperatures above the kneepoint, the conductor elongates at a rate primarily determined by the core.

The goal of HTLS conductors is to minimize the thermal elongation rates both above and below the kneepoint temperature and to move the kneepoint to as low a temperature as is possible. A plot of Final Sag vs. Temperature for the various HTLS conductors considered in the IEEE Uprating case is shown in Figure 9-3. As shown in the graph, all of the conductors presented in the case study have less sag than the traditional ACSR conductor at elevated temperatures but this result is achieved in different ways.

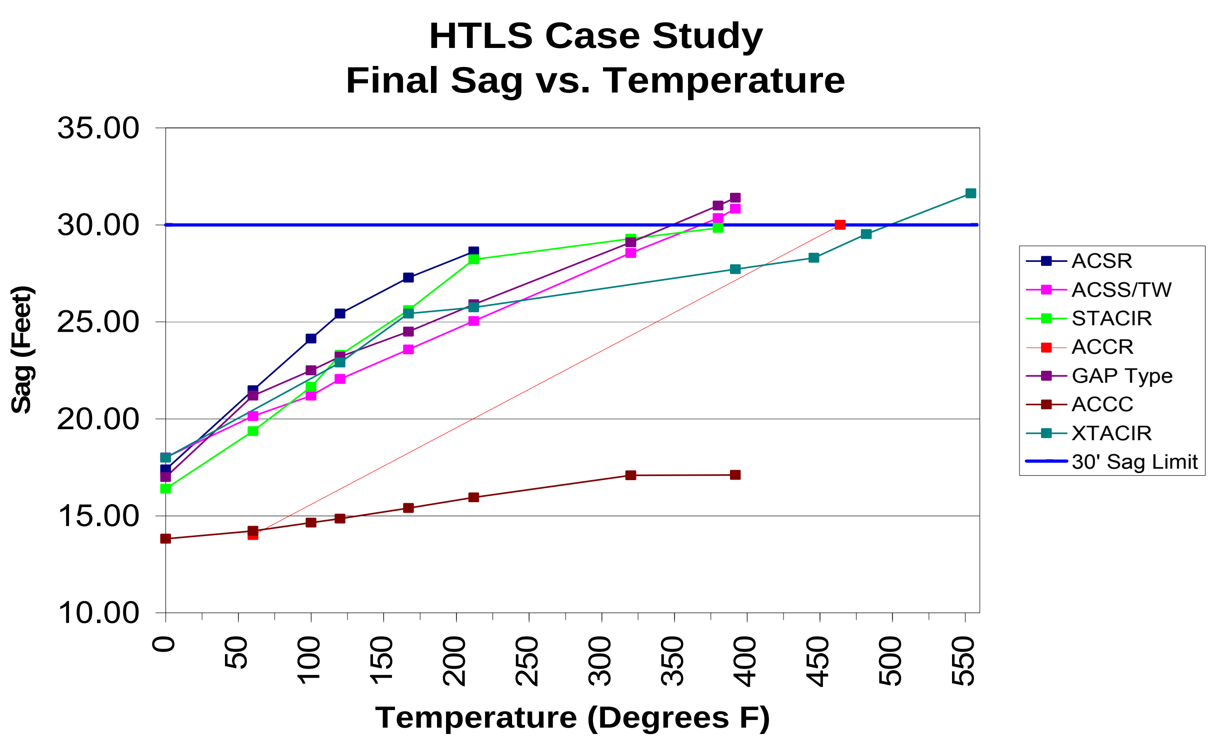

Figure 9-3
Comparison of Sag as a function of Conductor Temperature for IEEE Test Case

In particular, one can see that the kneepoint for the various HTLS conductors occurs at a lower conductor temperature than for ordinary ACSR (normally between 140°F or 60°C and 248°F or 120°C for high and low steel content ACSR, respectively). The annealed aluminum HTLS conductors (ACCC and ACSS) have a kneepoint temperature which is on the order of 60°F or 15°C since the annealed aluminum strands are assumed to have little or no tension under final conditions. The highest HTLS conductor kneepoint temperature occurs for those having an Invar steel core.

One can also see that the thermal elongation over the whole range of interest is much lower for ACCC than for any of the other conductors. Finally, note that both the ACCR and ACCC HTLS conductors are installed with less final everyday sag because of their lower weight per unit length.

Conductor ampacities were plotted below to show the gains in current flow after the HTLS conductors are installed. All of the proposed HTLS conductors exceeded the 1,350 and 1,500A goals while limiting the sag to acceptable levels.

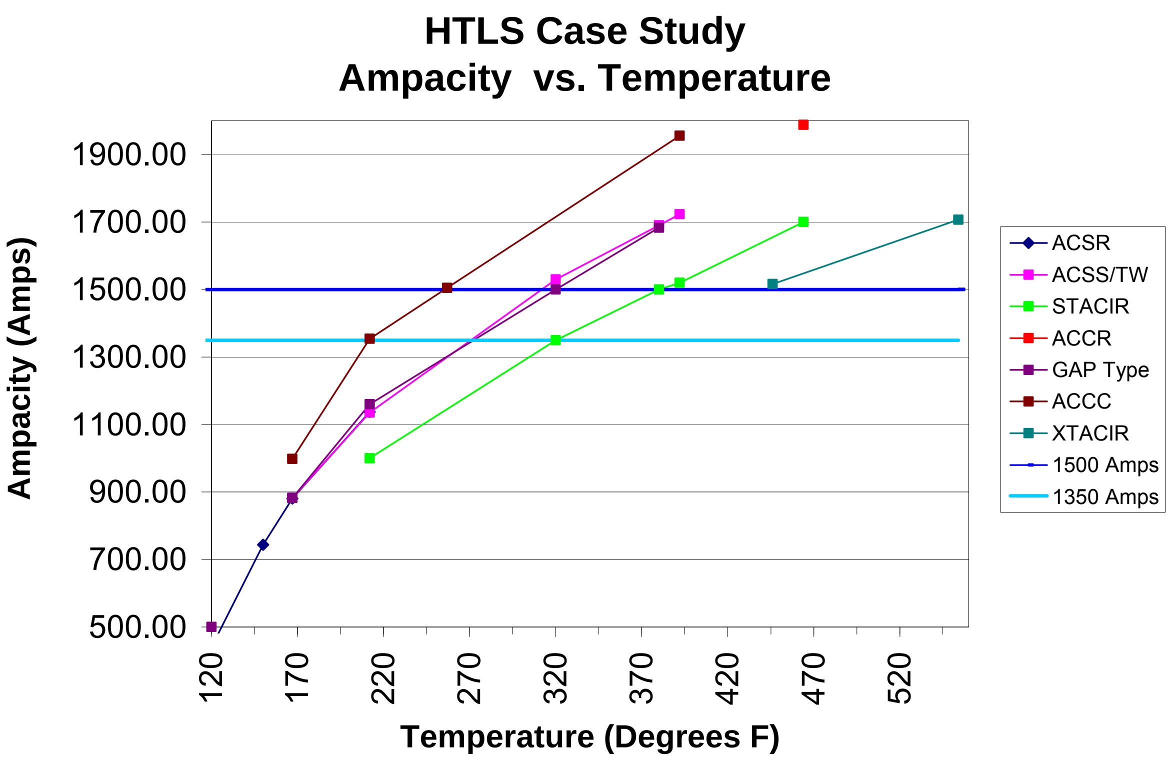

Figure 9-4
Comparison of HTLS Ampacities for IEEE Uprating Test Case

In addition to meeting the limitations on sag at high temperature, the various HTLS reconductoring solutions had to meet the limitation on sag under 1 inch ice loading at 32°F and to avoid pulling the conductor so tight that it developed wind vibration fatigue problems. The ACCC conductor and ACSS with its normal high strength steel core had the most difficulty in meeting these limitations. Both conductors use annealed aluminum strands, which if they are pre-stressed, yield low tension in the aluminum layers and high self-damping.

The ACCC conductor had the largest change in sag due to ice load since the composite core has a modulus which is only about 2/3 that of steel. In areas having severe ice load requirements, reconductoring with the ACCC and ACSS HTLS conductors may be challenging.

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CONCLUSIONS & RECOMMENDATIONS

The advantage of reconductoring existing lines with HTLS conductors is that the thermal rating of the line can be increased substantially with minimal modification to existing transmission line structures. To limit the need for structural modification, these high temperature replacement conductors must operate at much higher temperatures than ordinary bare overhead conductor without exceeding the original maximum sags and without causing a large increase in the original maximum tension and ice or wind structure loads. Increased sag would require raising the existing structures. Increased structure loads would require replacement or reinforcement of dead-end and angle structures and perhaps even tangent structures.

- One of the primary limitations on high temperature operation of ordinary bare stranded aluminum conductors is loss of aluminum tensile strength. Even when the aluminum strands have a substantial steel stranded reinforcing core, continuous operation is typically limited to 100^oC or less. HTLS conductors can operate continuously at temperatures between 150^oC and 250^oC depending on the particular design and wire materials.
- Those HTLS conductors which employ annealed aluminum are observed to have a lower elastic modulus than conventional ACSR. In geographical areas which experience severe ice loadings, this type of HTLS conductor may yield sags under heavy loading conditions which are comparable or even larger than the sag at high temperature.
- If HTLS conductors with annealed aluminum strands are pre-stressed, one may expect their self-damping properties to be very favorable and initial stringing sags may be quite small without causing vibration fatigue.
- Those HTLS conductors which employ high temperature resistant alloys of aluminum (e.g. TAL and ZTAL), have an elastic modulus which is comparable to conventional ACSR of the same stranding. While the sag under heavy loading conditions observed with these HTLS conductors is likely to be less than their high temperature sag, their high elastic modulus is likely to result in relatively high structure loads.
- HTLS conductors with TAL or ZTAL aluminum, are likely to yield self-damping properties which are similar to conventional ACSR.
- Limited corona testing of the various HTLS conductors indicates that these conductors are likely to yield corona noise levels similar to conventional ACSR of the same diameter.
- Each of the HTLS conductors studied appears to have suitable connectors and hardware available. There is no reason to suspect that these conductor systems are unreliable in the short run (up to 5 years).
- The installation of the various HTLS conductors does not appear to be a problem. The most complex conductor system to install is the Gapped HTLS (G(Z)TACSR). The simplest

conductor system is probably the ZTACIR conductor since the aluminum is not subject to damage during stringing and the core is not particularly sensitive to shear forces.

- There does not appear to be a compelling reason to choose one of the HTLS conductors over the others except possibly for cost. All of the HTLS conductors studied have the following characteristics:
  - Has a low thermal elongation rate.
  - Can operate continuously at temperatures well above 100°C without any deterioration of mechanical or electrical properties.
  - Has the same or lower resistance as the original conductor of the same outer diameter.

It is less clear which of the HTLS conductors studied in this project will work best in a particular uprating situation. However, stress-strain models for each of the HTLS conductors are available and utility engineers can evaluate each of the choices in a given uprating problem.

The best conductor choice ultimately depends on the existing clearance buffer, original design margins, environmental loading conditions, and the magnitude of the desired rating increase. The case study shows how HTLS conductors can be successfully used to obtain thermal rating increases of at least 50% and minimizing the need for expensive structure modifications.

11
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