Yukon Next Generation Hydro and Transmission Viability Study:

Jurisdictional Transmission Line Technical Logistics Analysis

Submitted By: Midgard Consulting Incorporated

Date: July 6, 2015

Executive Summary

The Yukon Development Corporation (YDC) has commissioned Midgard Consulting Incorporated (Midgard) and its team of sub-consultants to complete the Yukon Next Generation Hydro and Transmission Viability Study. The study, delivered through a series of technical papers, is intended to help inform the decisions necessary to solve the territory's growing energy gap and to support Yukon's continued economic growth and development.

The goal of this report titled *Jurisdictional Transmission Line Technical Logistics Analysis* is to investigate whether or not extending the Yukon's transmission system to another jurisdiction would:

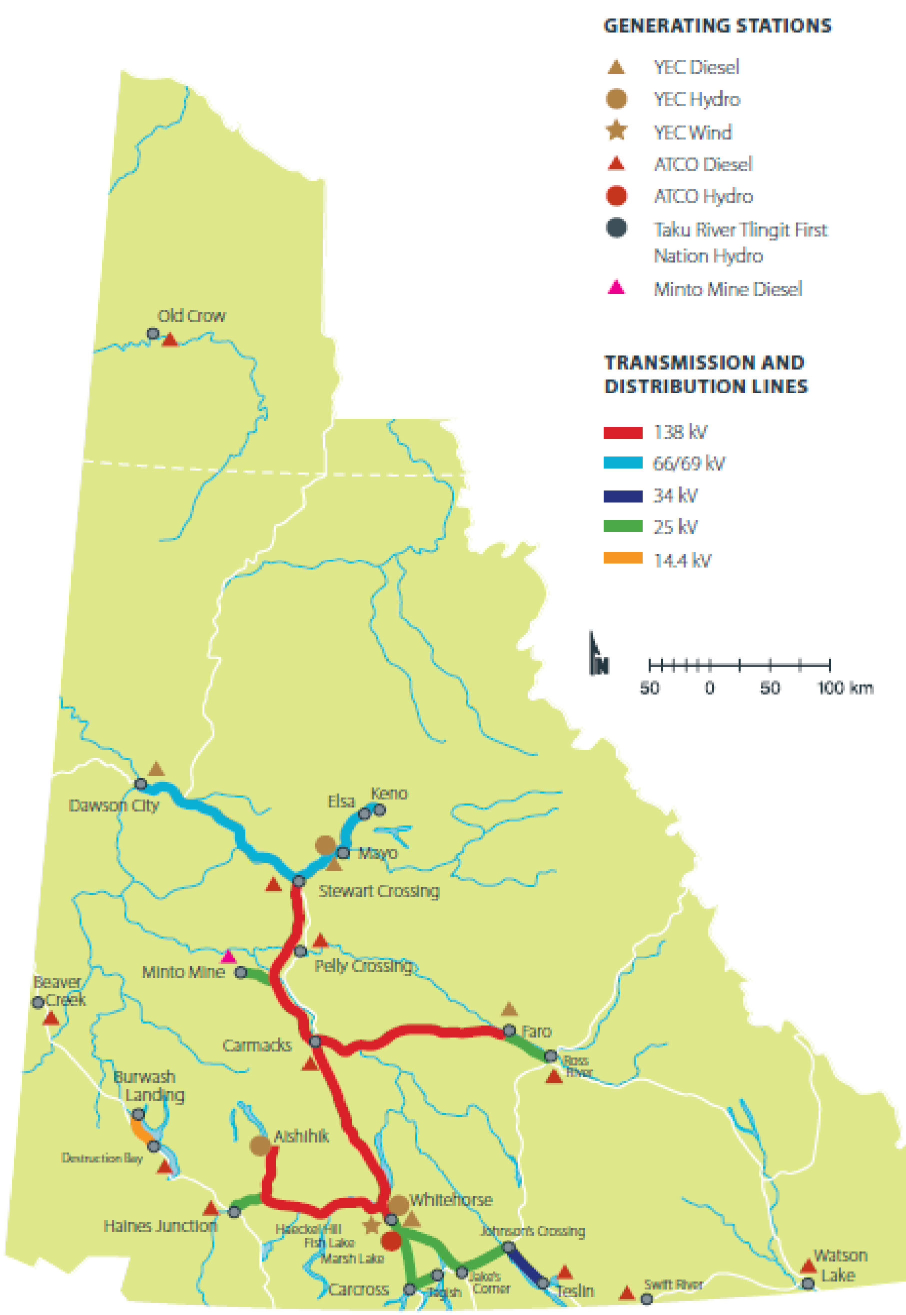
1. Influence the selection of the Next Generation Hydroelectric options
2. Improve the ability to scale out generation supply options
3. Improve the ability to mitigate industrial load interruption risks
4. Require prerequisite Yukon based load and supply to support an inter-jurisdictional connection.

The Yukon power system is isolated from all of its neighbouring jurisdictions, and is therefore considered to be an electrical "island". In effect, this means that the Yukon electrical system must be completely self-sufficient, able to instantaneously match electricity demand and generation (i.e. autonomously control frequency and voltage), and also able to self-restore following generation or transmission outages without assistance from neighbouring systems.

Upon review, the performance of the Yukon system compares favourably with the performance of other North American utilities. Although the possibility of interconnecting with a neighbouring system could support electricity trade and improve Yukon frequency stability while simultaneously enabling generation reserve sharing with neighbours, the economic benefits of generation reserve sharing may be negated because the Yukon will continue to maintain redundant diesel generation backup in remote communities, and interconnection would likely require the Yukon to meet additional regulatory requirements such as the Western Electricity Coordinating Council (WECC) Mandatory Reliability System standards.

An overview map showing the Yukon's current electrical system and transmission grid, including key generation sources and key industrial sites across the territory is shown in Figure 0.1, and a detailed drawing of the interconnected Yukon transmission system is shown in Figure 0.2.

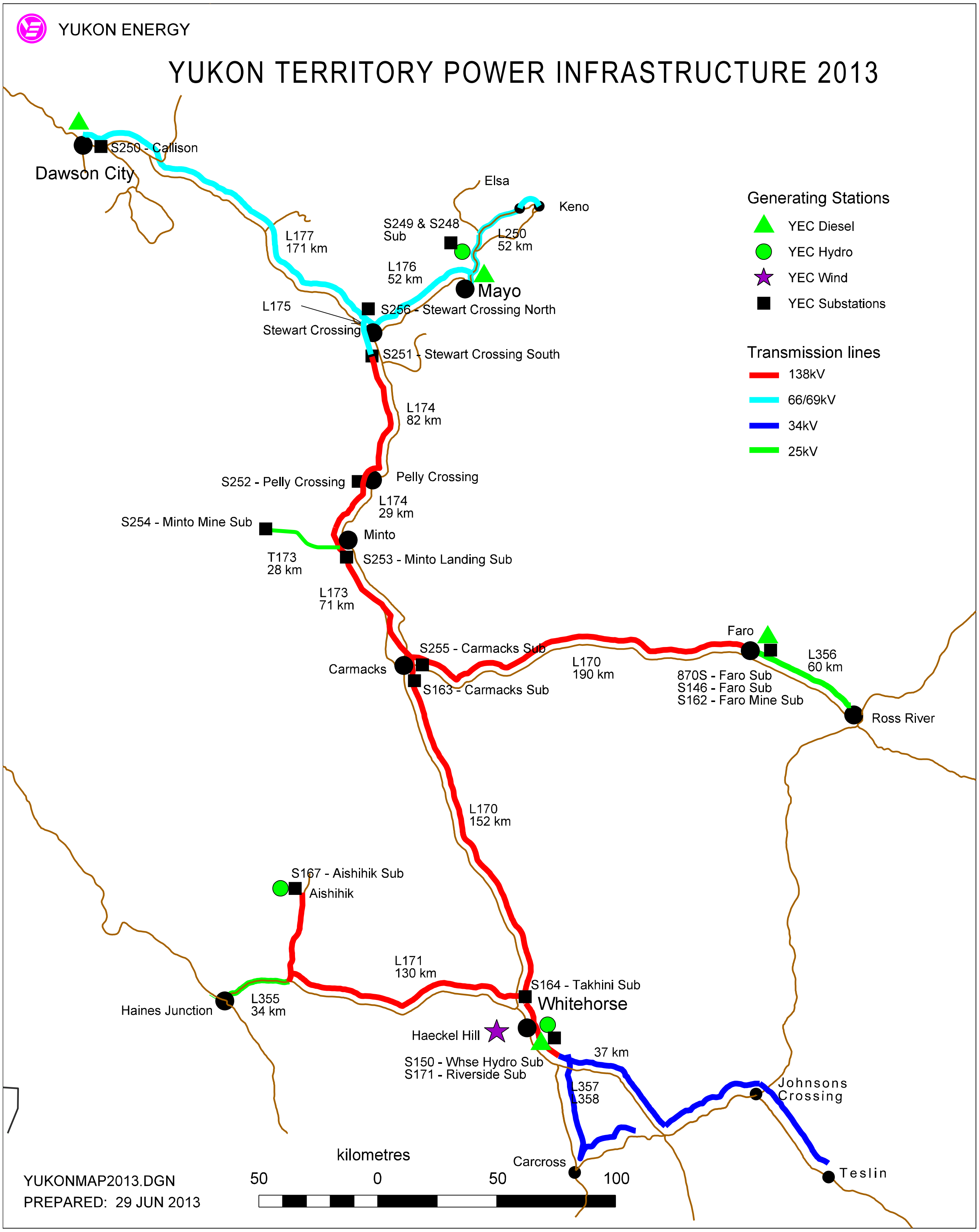
Figure 0.1: Map of Yukon and its Existing Electrical Infrastructure



YEC SYSTEM	(in MW)
Hydro Facilities	
Whitehorse	40.0
Aishihik	37.0
Mayo	15.1
Total	92.1
Wind Facilities	
Haeckel Hill	0.8
Diesel Facilities	
Whitehorse	23.0
Faro	8.5
Dawson	5.1
Mayo	2.5
Total	39.1
TOTAL YEC SYSTEM	132.0

ATCO SYSTEM	(in MW)
Hydro Facilities	
Fish Lake	1.3
Diesel Facilities	
Carmacks	1.5
Haines Junction	1.5
Teslin	1.5
Ross River	1.0
Watson Lake	5.0
Beaver Creek	0.9
Destruction Bay	0.9
Old Crow	0.7
Pelly Crossing	1.2
Stewart Crossing	0.1
Swift River	0.3
Total	14.6
TOTAL ATCO SYSTEM	15.9
Other Diesel	
Minto Mine	8.0
Total Yukon Capacity	**155.9**

Figure 0.2: Single Line Diagram of Yukon Territory Power Infrastructure

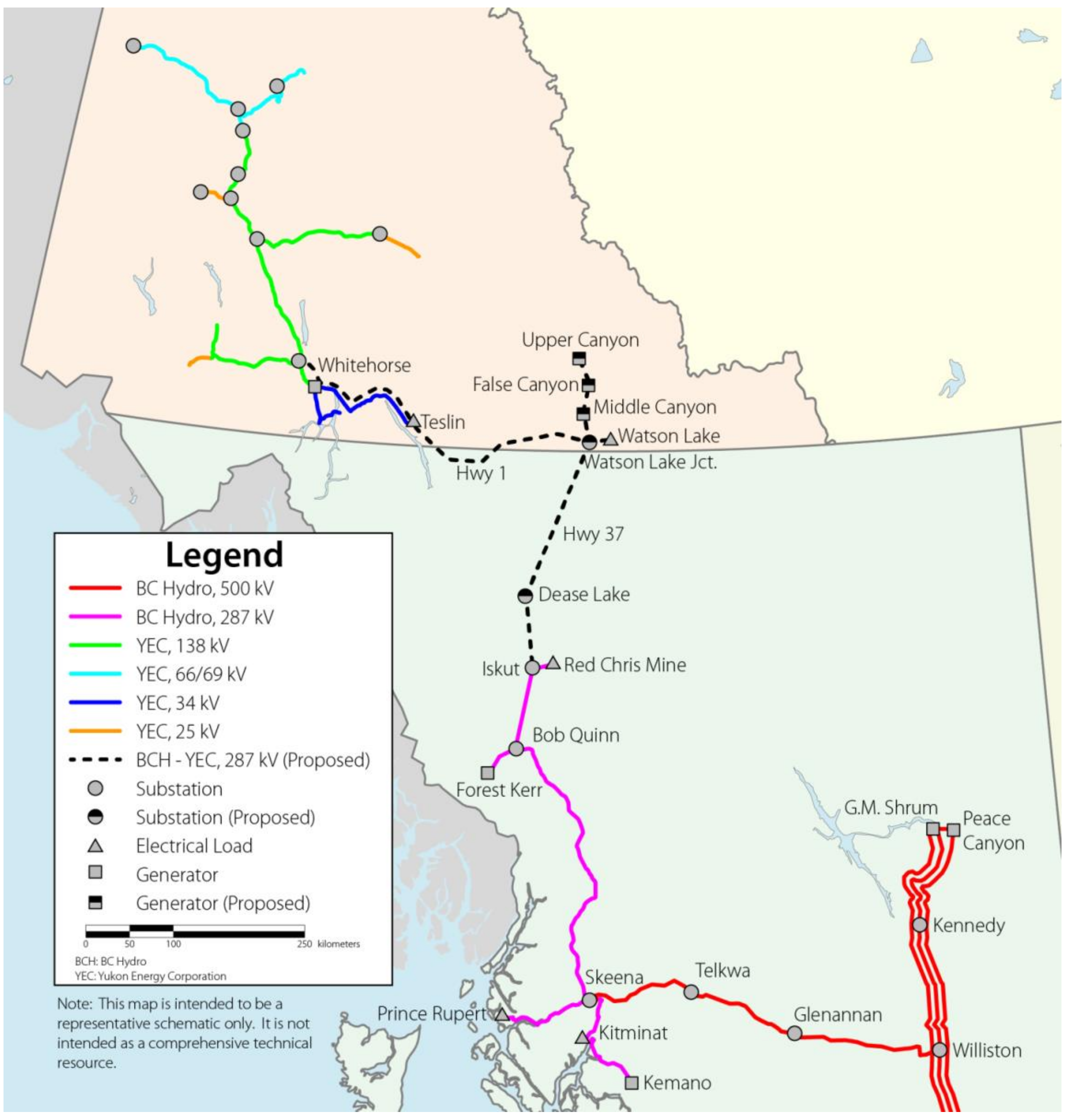


A preliminary review of Yukon's neighbours identified a number of potential interconnection sites, but given the considerable technical and economic hurdles that would be faced implementing an interconnection longer than 1,000 km, only the two options with interconnection path lengths shorter than 1000 km were chosen for further consideration: [1]

- Option 1: Whitehorse to Iskut, British Columbia – 745 km
    - Option 1A: Includes the addition of a connection to Upper Canyon, False Canyon and/or Middle Canyon
- Option 2: Aishihik to Fairbanks via Delta Junction, Alaska – 660 km

Figure 0.3 displays the proposed Whitehorse to Iskut interconnection layouts (Option 1 & 1A).

Figure 0.3: Proposed Whitehorse to Iskut Interconnection Layout



[1] The proposed Whitehorse to Skagway interconnection will not be considered in this report because it was assessed in the March 2015 Morrison Hershfield report, *Viability Analysis of Southeast Alaska and Yukon Economic Development Corridor*.

The proposed route from Aishihik to Fairbanks via Delta Junction (Option 2) is shown in Figure 0.4.

Figure 0.4: Proposed Aishihik to Delta Junction Interconnection

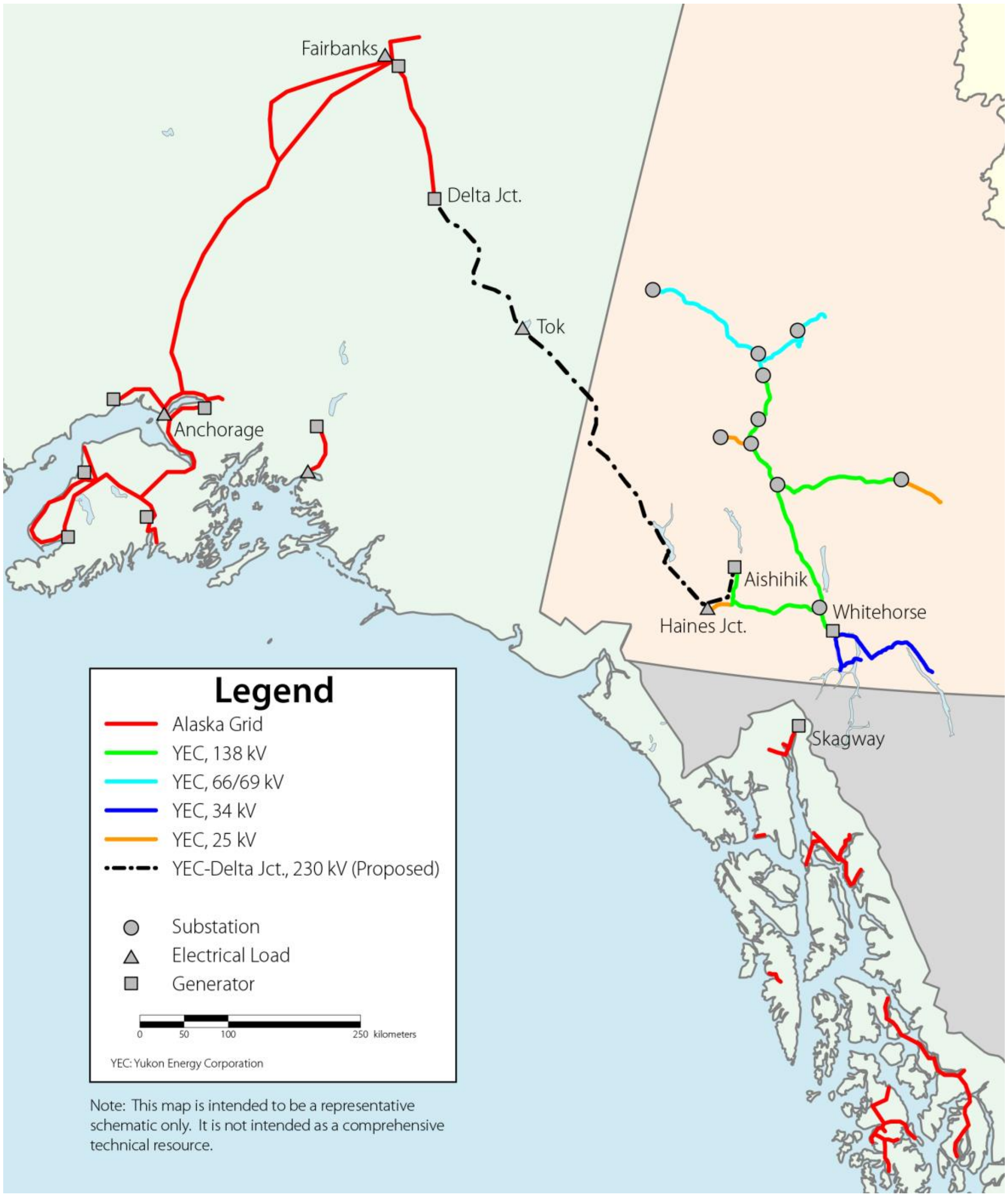


Table 0.1 compares the technical analysis and cost estimates prepared for the two Interconnection Options studied in this report (including variant #1A for the Yukon to BC Interconnection Option based upon specific Next Generation Hydro siting alternatives):

Table 0.1: Comparison of Interconnection Option Results

Interconnection Option	Description	Distance (km)	Capital Cost ($M)	Potential Net Yukon Export[2] Capacity (MW)
#1	287 kV from Whitehorse (Takhini) to Iskut, BC	763	$1,710	64 - 127[3]
#1A	Same as option 1 with Next Generation Hydro sites developed near Watson Lake	763	$1,710	94 - 139[4]
#2	230 kV from Aishihik to Delta Junction	662	$1,325	70 - 80[5]

These results confirm the findings of past studies[6], and demonstrate that the cost of implementing any Interconnection Option between the Yukon and its nearest neighbouring jurisdictions is high relative to the transfer capacity enabled by any of the interconnections. Table 0.2 lists the Capital Cost per MW of Net Export Capacity for each option studied.

Table 0.2: Comparison of Costs per MW of Net Export Capacity

Interconnection Option	Description	Capital Cost per MW of Potential Net Export Capacity ($M)
#1	Whitehorse to Iskut, BC	$13 - $27
#1A	Whitehorse to Iskut, BC (Next Generation Hydro near Watson Lake)	$12 - $18
#2	Aishihik to Delta Junction	$16 - $19

[2] This report studies the Export Capacity of the various interconnection options because that parameter has the greatest potential impact upon Next Generation Hydro site and size selection. Import capacities will be similar to the stated export capacity, although the impact of incremental generation at Forrest Kerr or Delta Junction would be the reverse, i.e.: the import capacity of interconnections to BC or Alaska would expand with increased generation output at Forrest Kerr or Delta Junction, respectively.

[3] Net Exports are dependent upon output of Forrest Kerr Hydro because Forest Kerr output creates transmission constraints

[4] Net Exports are dependent upon output of Forrest Kerr Hydro because Forest Kerr output creates transmission constraints

[5] Net Exports are dependent upon output of Delta Junction generation

[6] For example, the Yukon - BC Interconnection Costing study issued by BBA in April 2011.

Glossary and Abbreviations

Alternating Current (AC): Interconnected power systems operate with a sinusoidal voltage signal, unlike the Direct Current (DC) batteries used in vehicles and flashlights. The alternating current characteristic allows voltage to be easily increased at a generator using a step-up transformer, enabling economical long distance transmission of electricity. The voltage is reduced again at load centers using step-down transformers to provide service to customers at manageable voltages.

Ampere (A): The unit used to quantify the magnitude of electrical current flowing through a conductor (often colloquially referred to as an "amp").

BC Hydro: The British Columbia Hydro and Power Authority. The Crown Corporation responsible for providing electric service to most of the Province of British Columbia. An interconnection from the Yukon to BC would likely terminate at BC Hydro's Tatogga substation near Iskut.

Bus: An energized conductor to which transmission lines or other electrical apparatus are connected. Buses are typically located in substations, and are used as a voltage reference point for the purpose of power system studies.

Customer Average Interruption Duration Index (CAIDI): A system reliability parameter calculated by dividing total annual customer interruption hours by total customer interruptions.

Federal Energy Regulatory Commission (FERC): The US agency that establishes and regulates tariffs applicable to interstate electrical transmission services. A Canadian entity requires a FERC license to trade electricity with an American counterparty.

Golden Valley Electric Association (GVEA): The power utility that serves the Fairbanks, Alaska region. An interconnection from Yukon to the Alaska interconnected system would likely terminate at GVEA's Jarvis Creek substation near Delta Junction.

Hertz (Hz): Cycles per second. The parameter used to quantify AC system frequency.

Island: In power systems, an island is an electrically isolated system that is not interconnected with other systems. The Yukon grid is an electrical island.

Kilovolt (kV): One thousand volts. The unit normally used to quantify the voltage potential of high-tension power system lines, buses and equipment.

Mandatory Reliability System (MRS): The obligatory contractual commitment required from all western interconnected system members to abide by WECC reliability rules, including specified penalties for non-compliance.

Megawatt (MW): The unit of electrical power, derived by taking the product of voltage and current. One volt times one amp equals one watt. A megawatt is one million watts.

Nominal Voltage: The “target” voltage of a power system component, e.g.: 25 kV, 138 kV, or 230 kV. The actual measured voltage at a specific point in the power system at a particular time will typically fall within a specified range of the nominal voltage, but depending upon operating conditions the actual measured voltage is unlikely to actually equal the nominal voltage.

PowerEx: A BC Hydro subsidiary responsible for power trading activities.

System Average Interruption Frequency Index (SAIFI): A system reliability parameter calculated by dividing total number of annual customer interruptions by total customers.

System Average Interruption Duration Index (SAIDI): A system reliability parameter calculated by dividing total annual customer interruption hours by total customers

Swing Bus: A simulated generator bus that is used to balance power system loads and generators during system studies. The Swing Bus either absorbs surplus power or generates power to balance total power generation and consumption when solving system simulations.

System Frequency: The rate of oscillation of the system voltage. In North America system frequency is usually 60 Hz, although in Europe and other international jurisdictions 50 Hz is also used.

Voltage Angle: The real-time vector relationship between the sinusoidal voltage at two different points on the power system. This is an important parameter to consider when evaluating long interconnections since it is operationally difficult to maintain synchronism between two systems with steady state voltage angles much greater than 33°.

Western Electricity Coordinating Council (WECC): The WECC is the agency that oversees Bulk Electric System reliability in the Western Interconnection, which includes the Provinces of Alberta and British Columbia, the northern portion of Baja California, Mexico, and all or portions of the 14 Western United States. Implementing an interconnection with British Columbia would require Yukon to become a WECC member.

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1 Introduction

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The report is divided into five sections that describe the:

1) Existing Yukon System:
    a. Existing Yukon electricity system components
    b. Historic System Performance and the Potential Benefits of Interconnection
    c. Interconnection Market Opportunities
    d. Regulatory Issues Associated with Interconnection
2) Interconnection Options – Overview of Neighbouring Systems
3) Interconnection Options – Technical Analysis of Interconnection Paths
    a. Transfer Capacity
    b. Technical Constraints
4) Interconnection Options – Capital Cost Estimates
5) Summary of Results

1.1 Existing Yukon Electric System

The current Yukon electric grid has a peak load of 84MW[7] that is presently supplied by 156 MW[8] of installed generation at 21 separate plants.

The electrical grid is configured as a set of radial transmission lines emanating out from core transmission substations located near Whitehorse, Carmacks and Stewart Crossing. South of Stewart

[7] The 84 MW (83.69MW) peak load occurred on 5 January 2015.

[8] Excess generation above the 84MW peak load is required to provide redundant sources of generation as part of contingency planning should a generator or transmission line fail.

Crossing the backbone system is energized at 138 kV, and north of Stewart Crossing the system is energized at 69 kV[9]. Other lower voltage systems, energized at either 35 kV or 25 kV, connect to the 138kV transmission system and reach out to smaller communities around the Yukon (e.g. Haines Junction, Ross River, communities south of Whitehorse etc.).

The largest proportion of annual electric energy (typically 95% and up to 99% depending upon annual hydrology) is generated by hydroelectric facilities located at Whitehorse (40 MW), Mayo (15 MW) and Aishihik (37 MW). Diesel generation plants are located at Whitehorse, Faro, Mayo, Dawson City, Carmacks, Haines Junction, Teslin, Ross River, Stewart Crossing and Pelly Crossing to supply local backup energy in the event of a transmission outage, or to augment hydroelectric generation when necessary during peak demand times. For example, in the winter when electricity demand is the highest, the Whitehorse hydro plant can be de-rated to 25 MW during periods of low winter flows on the Yukon River and backup diesel may be required to meet peak demands. In addition to diesel and hydroelectric generation, there is a wind generating facility (0.8 MW) at Haeckel Hill near Whitehorse, and a natural gas generation facility will be completed in Whitehorse in 2015. Table 1.1 summarizes the on-grid generation resources in Yukon and their corresponding annual electrical energy production.

Table 1.1: Generation Asset with Annual Electrical Energy Production (Fish Lake Excluded): On-Grid

Generation resource	Type	Annual Electrical Energy Production (MWh)
Whitehorse	Hydro	250,200
Aishihik	Hydro	112,700
Mayo	Hydro	80,900
Whitehorse Diesels 1 - 7	Diesel	Backup & Peaking Generation
Faro Diesels 1, 3, 5 & 7	Diesel	Backup & Peaking Generation
Mayo	Diesel	Backup & Peaking Generation
Dawson Diesel 1 - 5	Diesel	Backup & Peaking Generation
Carmacks	Diesel	Backup & Peaking Generation
Haines Junction	Diesel	Backup & Peaking Generation
Teslin	Diesel	Backup & Peaking Generation
Ross River	Diesel	Backup & Peaking Generation
Stewart Crossing	Diesel	Backup & Peaking Generation
Pelly Crossing	Diesel	Backup & Peaking Generation
Haeckel Hill	Wind	440[10]
Whitehorse LNG #1	Natural Gas	Planned: Backup & Peaking Generation
Whitehorse LNG #2	Natural Gas	Planned: Backup & Peaking Generation

[9] Although some segments are nominally rated at 66 kV

[10] Haeckel Hill : "Next Generation Hydro Information Request 06.10.14 - Attachment 3", Tab : Request #1- Historical gen

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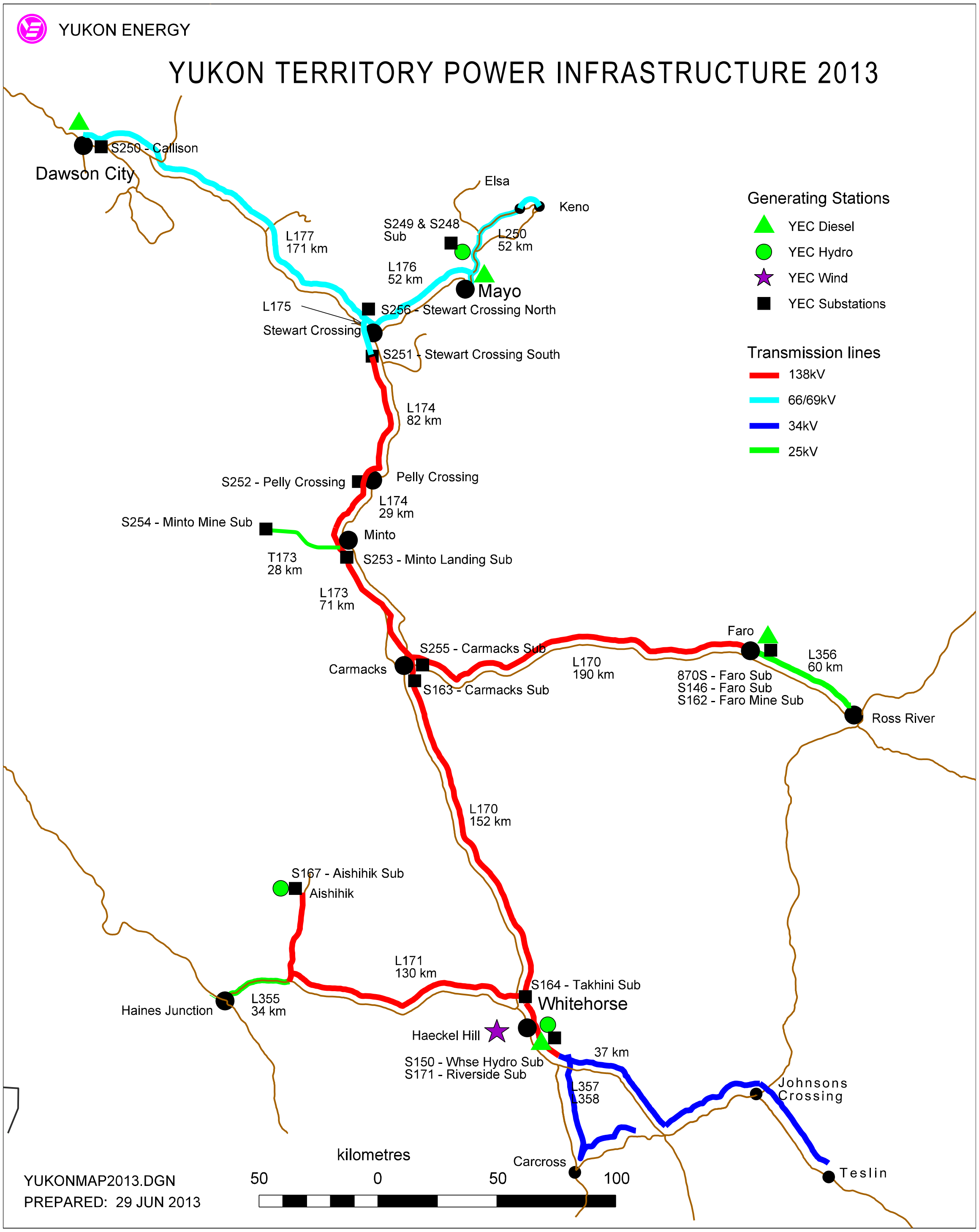
Figure 1.2: Single Line Diagram of Yukon Territory Power Infrastructure



1.2 Historic System Performance and Potential Benefits of Interconnection

The Yukon power system is isolated from all of its neighbouring jurisdictions, and is therefore considered to be an electrical "island". In effect, this means that the Yukon electrical system must be completely self-sufficient, able to instantaneously match electricity demand and generation (i.e. autonomously control frequency and voltage), and also able to self-restore following generation or transmission outages without assistance from neighbouring systems.

Because the Yukon peak system load is small (peak load of 84 MW in 2015) in comparison with the large interconnected North American systems (e.g.: Western System 150,000 MW, Eastern System 600,000 MW), the Yukon electrical system is more susceptible to operating frequency fluctuations due to instantaneous changes in load and generation. As a result, the Yukon system must be configured and operated to enable self-recovery from the worst-case loss of generation and/or transmission facilities, or else be prepared to endure relatively large deviations in system frequency and/or temporary loss of electricity to loads (i.e. blackouts) while generation and/or transmission failures are mitigated or repaired.

In comparison, large interconnected systems are able to share resources between neighbouring jurisdictions and thereby minimize sensitivity to instantaneous load and generation changes. Because of the ability to instantaneously draw upon support from neighbouring systems during system events such as equipment failures, each member of an interconnected system is able to carry less spinning and non-spinning generation reserves (i.e. unutilized generation capacity) than would be required under islanded operation (i.e. in the Yukon with 156 MW of installed generation required to reliably serve an 84 MW peak load). In addition, the operating frequency for each neighbour of an interconnected system is effectively clamped to the operating frequency of its adjacent neighbours as long as they remain interconnected. Deviations greater than 0.1 Hz[11] from the nominal 60 Hz[12] system frequency are very uncommon in the large North American interconnected systems, even following outages to very large individual generating plants[13].

Despite the fact that the electrically isolated Yukon system is faced with the operational challenges described above, the actual performance of the YEC Yukon system compares favourably with the Canadian Electric Association (CEA) average. Although the frequency of system interruptions in the Yukon is almost three times higher than the CEA average (largely owing to the isolated nature of the

[11] Hz is the abbreviation for hertz, which is the internationally recognized unit for cycles per second.

[12] Nominal system frequency in North America is 60 Hz (hertz or cycles per second). Large rotating loads such as industrial process drives and even some electronic systems are very sensitive to the system frequency, and even small frequency deviations can cause operational problems if they last for an extended period. In some cases even a few seconds would be considered an extended period, and for very large deviations a fraction of a second could cause problems.

[13] Note that in rare cases interconnection enables disturbances to propagate between neighbouring jurisdictions.

system, the challenging topography, the severe climate and the radial configuration of the Yukon transmission system), the average duration of individual Yukon customer outages is shorter than the CEA average (see Table 1.2)[14].

Table 1.2: YEC Annual Reliability Indices (5-Year Average to 2012)

Index	YEC Results	CEA Average	YEC Yukon Performance
System Average Interruption Frequency Index (SAIFI)[15]	7.62	2.68	Worse
System Average Interruption Duration Index (SAIDI)[16]	4.91	6.83	Better
Customer Average Interruption Duration Index (CAIDI)[17]	0.68	2.53	Better

As seen in the better than average SAIDI and CAIDI metrics, the ability of the Yukon to rapidly restore electricity to customer loads following interruptions can be at least partly attributed to the presence of redundant backup diesel plants at most load centers. Although distributed redundant diesel backup is not a typical configuration in the southern interconnected CEA jurisdictions, this configuration is reasonable for the Yukon’s electrically isolated system with sparse customer density and harsh winter climate. Redundant generation effectively means that the Yukon carries a relatively high proportion of non-spinning generation reserves since these community diesel plants are used primarily for backup purposes. Note that some diesel plants are also used to help serve peak winter loads, especially when a lack of water (i.e. fuel) constrains generation levels at the Yukon’s hydroelectric plants.

1.3 Interconnection Market Opportunities

In addition to operational benefits, interconnection with a neighbouring jurisdiction potentially enables the sale of electricity during times of surplus and the purchase of electricity during times of high demand or generation deficiency.

Besides the electric energy trading opportunities, there may also be an opportunity to provide ancillary services such as “resource firming[18]” to jurisdictions with a high ratio of variable energy

[14] 2012 Yukon Energy Annual Report of Key Performance Indicators

[15] System Average Interruption Frequency Index = Total customer interruptions/Total customers

[16] System Average Interruption Duration Index = Total customer interruption hours/Total customers

[17] Customer Average Interruption Duration Index = Total customer interruption hours/Total customer interruptions

[18] Resource Firming is an ancillary service whereby the service provider (typically a hydro or simple cycle gas plant) instantaneously complements the output of a variable energy resource such as a wind power plant by generating more when the wind plant output

resources such as wind and solar. For example, establishing a robust market for firming services has become an important objective for Western Electricity Coordinating Council (WECC) member utilities because the penetration of variable energy resources (primarily wind) continues to increase across the western interconnection (e.g. Western Canada and Western United States).

When considering the market benefits of interconnection, it is important to understand the market structure of the interconnecting jurisdiction. For example, the BC Hydro system is operated as a vertically integrated monopoly and therefore a transparent market for power trading does not exist in BC, and all trades are subject to competition from PowerEx (a wholly owned subsidiary of BC Hydro). Although point to point energy transport services ("wheeling" services[19]) are available within and across BC under BC Hydro's open access tariff[20], energy transport transactions can be interrupted on short notice due to BC Hydro "Network Economy" constraints which are not subject to independent 3rd party appeal or review.

The present report focuses upon the technical aspects of interconnection and does not provide a detailed discussion of the market opportunities for sales and purchase of electric energy or ancillary services that might arise from interconnection – the existence of these benefits is simply pointed out for completeness. A separate Report *Yukon: Market Benefits Assessment* will look at the market potential attributable to the most promising interconnection options.

1.4 Regulatory Issues Associated with Interconnection

Although interconnecting the Yukon to a neighbouring system could potentially deliver both technical and economic benefits and opportunities, depending upon the selected jurisdiction an interconnection would also require the adoption of new operating practices and standards.

A connection to the BC Hydro system would require the Yukon to join the WECC Mandatory Reliability System, which would likely require additional Yukon operator training, impose new operating codes and protocols, and might ultimately require additional capital investments in control and monitoring systems. For example, the Yukon would be required to adhere to the WECC's "Coordinated Off-Nominal Frequency Load Shedding and Restoration Plan" which mandates specific load shed percentages for low frequency system conditions. The net result of these WECC mandated upgrades could be significant additional costs to Yukon ratepayers.

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drops and generating less when the wind plant output increases, thereby effectively maintaining a constant output from the combined resources.

[19] "Wheeling" is the standard electricity market term for transporting power across an interconnected transmission system from a generation source (seller) to a load (buyer). The party offering wheeling services often is not either the seller or the buyer, but may simply be the operator of transmission facilities comprising all or part of the transaction path.

[20] BC Hydro holds a license issued by the US Federal Energy Regulatory Commission (FERC) under its Open Access Tariff 888 that enables BC Hydro to trade electricity with US-based counterparties.

A connection between Alaska and the Yukon would require the jurisdictions to establish interchange agreements and joint operating procedures. In addition to the normal state and territorial environmental permitting and facility siting processes, building a transmission interconnection across the Canada/US border would require National Energy Board of Canada (NEB) approval and a US Presidential Permit, and might also require approval by the US Federal Energy Regulatory Commission (FERC). Power and ancillary service exchanges with American entities located in either the contiguous United States or Alaska would likely require the Yukon to obtain a FERC power marketing permit. It is not clear at this time what the full extent of financial impacts to Yukon ratepayers would result from these approvals, permits and requirements, but Yukon ratepayers should anticipate additional costs associated with these activities.

In addition to regulatory and legislative requirements, interconnection would expose the Yukon electrical system to operational impacts from system events originating in neighbouring jurisdictions. Appropriately responding to extra-jurisdictional system events often requires very different actions than would be required when operating as an isolated system. For example, an interconnection would likely require the Yukon to implement new Special Protection Schemes[21] (SPS) to automatically separate the Yukon from its interconnected neighbour when specific events occur. In other words, the Yukon would need to be able to operate as both an interconnected system and an isolated system in response to certain interconnected system events.

1.5 Interconnection Introduction Summary

Yukon system performance compares favourably with the performance of other CEA utilities. Although the possibility of interconnecting with a neighbouring system could support electricity trade and improve Yukon frequency stability while simultaneously enabling reserve sharing with neighbours, the economic benefits of reserve sharing may be negated because the Yukon will continue to maintain redundant diesel generation backup in remote communities and will likely be required to meet additional regulatory requirements (e.g. WECC Mandatory Reliability System standards).

In summary, the extent of available market benefits from trade will be heavily influenced by market structure of the selected interconnecting jurisdiction. Interconnection would likely impose new operating procedures and protocols, and would possibly require additional capital investments in controls and monitoring facilities (beyond the cost of building the interconnection). Additionally, permitting for international interconnections will be more complex than for interconnections entirely within Canada.

[21] Special Protection Schemes are sometimes also called Remedial Action Schemes or RAS

2 Interconnection Options – Overview

A preliminary review of Yukon's neighbours identified the following set of potential interconnection sites. Distances are based upon paralleling the shortest highway route between the nearest point on the Yukon transmission system to the listed neighbouring terminus point:

- Iskut, British Columbia – 745 km
- Hudson's Hope, British Columbia – 1,300 km
- Fairbanks via Delta Junction, Alaska – 660 km
- Skagway, Alaska – 175 km
- Grande Prairie, Alberta – 1,500 km
- Hay River (Taltson Grid), NW Territories – 1,750 km
- Behchoko (Snare Grid), NW Territories – 1,860 km

Given the considerable technical and economic hurdles that would be faced implementing an interconnection longer than 1,000 km, the two options with interconnection path lengths shorter than 1000 km were chosen for further consideration are[22]:

- Iskut, British Columbia – 745 km
- Fairbanks via Delta Junction, Alaska – 660 km

2.1 Iskut, British Columbia

The recent completion by BC Hydro of the 287 kV Northern Transmission Line (NTL) running 340 km north from Skeena substation near Terrace to Bob Quinn Lake, and the further 93 km extension of the 287 kV transmission system north from Bob Quinn Lake to Tatogga Lake substation near Iskut[23], has effectively pushed the northern terminus of BC Hydro's 287 kV system to within 745 km of Whitehorse.

Although 287 kV is not a common utility transmission voltage[24], because the existing NTL is already energized at 287 kV, 287 kV would be the most economical and practical operating voltage to select for an interconnection between the BC Hydro and Yukon systems. An operating voltage of 138 kV would not be technically feasible for a path of this length, and although a higher operating voltage (e.g.: 500 kV) would be technically superior, it would be less economically feasible, especially when evaluated against the anticipated maximum transfer capacity requirements considered for the Yukon.

[22] The Whitehorse-Skagway interconnection has been separately studied in a March 2015 Morrison Hershfield report, *Viability Analysis of Southeast Alaska and Yukon Economic Development Corridor*, and is not evaluated in this report.

[23]The 93km extension was as part of the Red Chris Mine electrification project

[24] 230kV / 240kV is the nearest common transmission voltage

An interconnection with BC following a route parallel with Yukon Highway 1 and BC Highway 37 would pass near Watson Lake, YT. Several potential Next Generation Hydro sites are located just north of Watson Lake along the Robert Campbell Highway, namely Middle Canyon, False Canyon and Upper Canyon. Since developing any of these sites could materially improve the export capability of a BC interconnection, a separate sub-option was modeled to understand the impact of developing one or more of these hydroelectric projects[25].

The key features of the Whitehorse to Iskut transmission line interconnection path are:

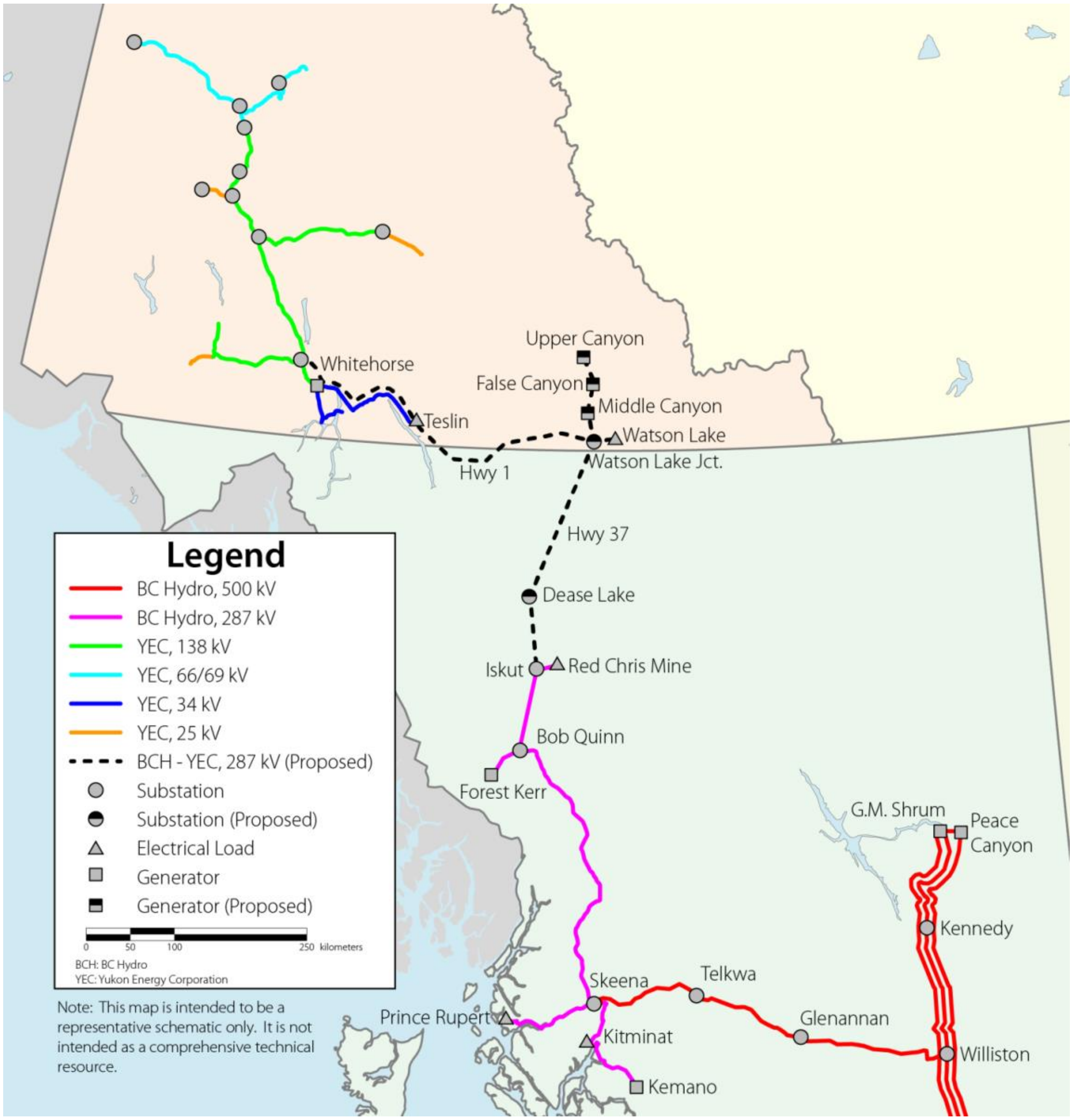
- Line Length: 745 km following Yukon Highway 1 (Alaska Highway) and BC Highway 37
- Voltage: 287 kV nominal voltage on recently completed line from Iskut to Skeena
- Load Centers:
    - British Columbia: Dease Lake, 50 MW load at Red Chris Mine near Iskut
    - Yukon: Teslin[26], Watson Lake
- Generation Centers: 200 MW Forrest Kerr hydro plant 40 km SW of Bob Quinn Lake
- Sub-Options: Yukon generation at Middle, False and/or Upper Canyons
- Interconnection Terminus: Substantial load and generation centers near Skeena substation (Prince Rupert, Terrace, Kitimat, Kemano)
- Terminus Grid Size: Creates an interconnection with the 150,000 MW WECC system

Figure 2.1 shows the proposed Whitehorse to Iskut interconnection layout.

[25] This configuration was studied solely to gauge the impact of mid-path generation upon transfer capacity of the BC interconnection, and does not presuppose that any of these projects would be economically viable Next Generation Hydro selections.

[26] Although Teslin is presently connected to the Yukon system via a 34 kV line from Whitehorse, it is also close to the optimal location for an intermediate voltage control bus on the proposed 287 kV transmission line between Whitehorse and Iskut. It is assumed that the Teslin load would be connected to this new substation, for the purpose of conducting system studies.

Figure 2.1: Proposed Whitehorse to Iskut Interconnection Layout



2.2 Fairbanks, Alaska via Delta Junction

The Golden Valley Electric Association (GVEA) provides electrical service to the city of Fairbanks and surrounding area. Total GVEA peak load is approximately 230 MW, and total generation is approximately 280 MW of generation.

The GVEA operates a 138 kV transmission line that extends southeast approximately 120 km along the Alaska Highway from Fairbanks to the Jarvis Creek substation near Delta Junction. The Jarvis Creek substation serves approximately 20 MW of local load and includes a solid-state voltage regulation device[27]. A 28 MW diesel generating plant is connected to the Jarvis Creek substation[28]. The Fairbanks area is connected to the Anchorage area via an existing 115/138 kV system[29] with a net transfer capacity of approximately 75 MW.

The key features of the Aishihik to Fairbanks interconnection path include the following:

- Line Length: 660 km from Aishihik to Delta Junction (Jarvis Creek substation location), 120 km from Delta Junction to Fairbanks
- Voltage: 230kV from Aishihik to Delta Junction. The existing 120 km long transmission line from Jarvis Creek substation to North Pole substation in Fairbanks is 138kV
- Terminus Grid Size: 230 MW Fairbanks regional load and 280 MW generation (largely coal and diesel) with existing 75 MW transfer capacity between Fairbanks and the Anchorage area

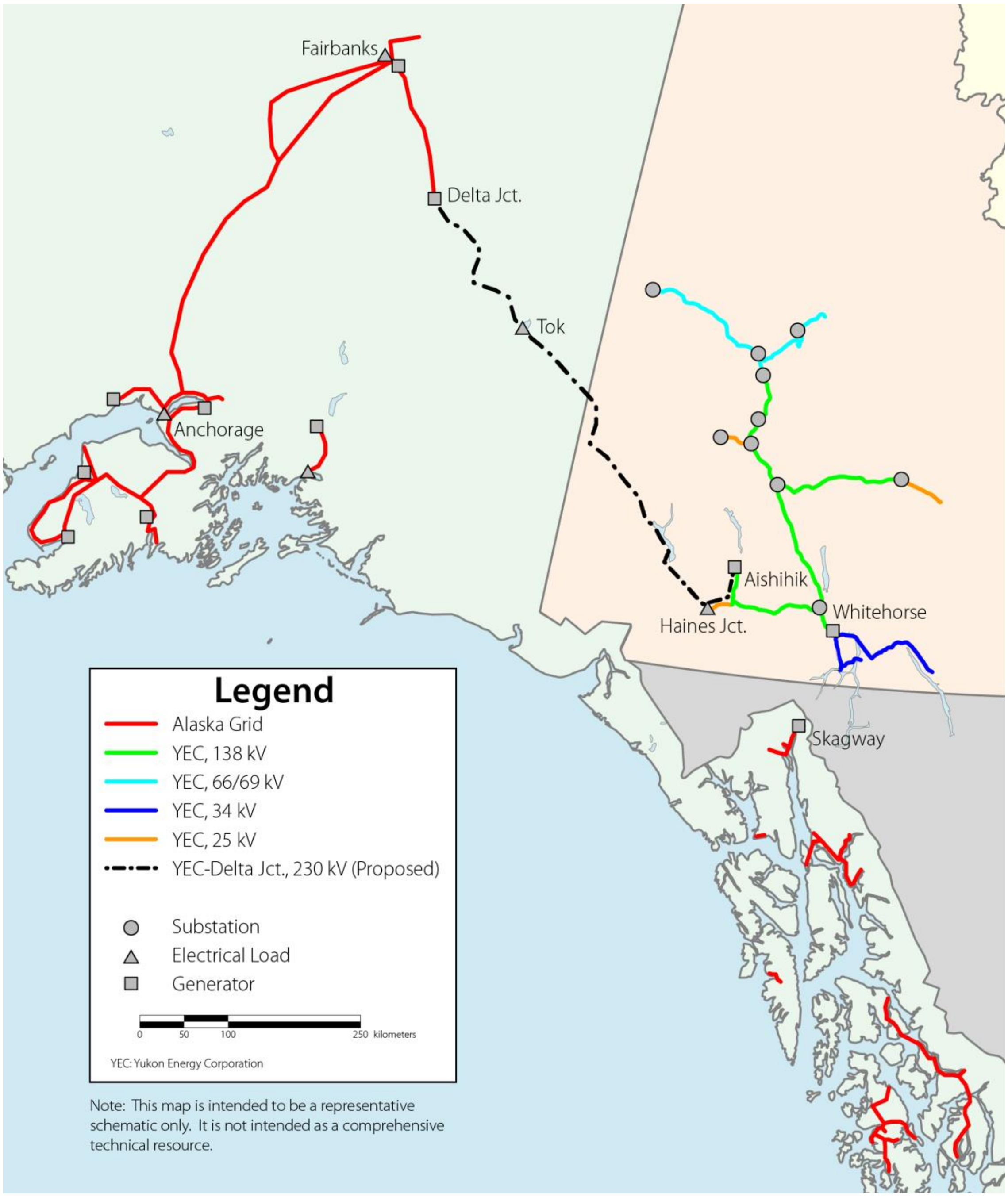
A map showing the route from Aishihik to Fairbanks via Delta Junction is shown in Figure 2.2.

[27] This substation features a - 8 to +36 MVAr Static VAr Compensator to dynamically control voltage on the 138 kV bus.

[28] The normal operating mode of this plant (baseload or backup) is unknown,

[29] Some parts of the interconnection between Fairbanks and Anchorage are constructed to 345 kV standards, although the lines are presently operated at 138 kV.

Figure 2.2: Proposed Aishihik to Delta Junction Interconnection



3 Interconnection Options – Technical Analysis

Midgard developed simplified models of the Whitehorse to Iskut and Aishihik to Fairbanks interconnection options based upon the assumptions listed in the above respective Interconnection Options - Overviews, and utilized publicly available information about the BC Hydro and Alaska power systems.

Midgard's power system analysis was carried out using the Siemens PSS®E[30] power system simulation software, and was restricted to evaluating voltage profiles and angles to enable estimation of total transfer capacity for the various configurations considered. Since public access is not available for the power system models used by the respective jurisdictional utilities, simplifying assumptions based on publicly available information were utilized to approximate the external systems.

A more comprehensive suite of system analyses, including transient and voltage stability studies covering a broad set of present and future system forecast load cases would be necessary before any of the studied interconnection options could be advanced to development. Both the Yukon and external system operators will need to participate in any subsequent detailed analysis of these interconnection options.

3.1 Option 1 – Whitehorse to Iskut, British Columbia Interconnection Analysis

The modeled path for the BC interconnection assumed a new 287 kV transmission line from Takhini substation near Whitehorse to BC Hydro's recently completed Tatogga substation near Iskut, BC.

The recently commissioned 200 MW Forrest Kerr hydroelectric plant is tied into the 287 kV interconnection path at the Bob Quinn Lake substation located 90 km south of Iskut, and it is assumed that this plant will have a higher priority for transfer capacity on the BC Hydro system between Bob Quinn Lake and Skeena substation than will Yukon exports. Because of Forrest Kerr, the Bob Quinn Lake substation represents a bottleneck on this southbound transmission path, which necessitated extending the system model further south to BC Hydro's 500 kV Skeena substation. This extension enabled analysis of Forest Kerr's impact on the transmission transfer capacity across the full range of Forrest Kerr output from 0 MW to 200 MW[31].

The following list of assumptions was used to create the simplified system model for the Whitehorse to Iskut BC interconnection option:

[30] PSS®E is a registered trademark of Siemens AG

[31] Note that McLymont Creek (66 MW) and Volcano Creek (16 MW) hydro plants are presently being constructed near the Forrest Kerr plant, and these facilities will likely further constrain the available transfer capacity of this interconnection path after they are commissioned. The impact of these future plants has not been modeled in the present analysis.

- Nominal Voltage: 287 kV
- Conductor Spacing: Flat phase configuration with 6.7 m spacing between adjacent phases
- Conductor Type: Double bundle 477 MCM[32] ACSR[33] Hawk phase conductors
- Voltage Support: 60 MVAr shunt reactors at the intermediate substations at Teslin, Watson Lake Junction and Dease Lake
- Generation Centers: Forrest Kerr hydro plant production between 0 MW and 200 MW
- Terminus Grid: Swing bus at BC Hydro's 500/287 kV Skeena substation

As expected, system analysis demonstrates that the generation level at Forrest Kerr is inversely related to the total available transfer capacity for Yukon exports. Table 3.1 shows the maximum Yukon export capacity for different Forrest Kerr production levels, assuming that the selected Next Generation Hydro site is connected into the existing Yukon grid at a point west or north of Whitehorse (Option 1).

Table 3.1: Interconnection Option 1 – Potential Export Capacity

Forrest Kerr Output (MW)	Power Leaving Yukon (MW)	Interconnection Losses[34] (MW)	Potential Net Yukon Export Capacity (MW)	Voltage Angle Whitehorse to Skeena
0	131.8	5.2	126.6	33.8°
50	116.8	5.0	111.8	33.6°
100	101.8	5.3	96.5	33.5°
150	86.8	6.1	80.7	33.5°
200	71.8	7.4	64.4	33.6°

Table 3.2 below shows the impact on available transfer capacity from the Yukon to BC if one or more of the Middle, False and Upper Canyon Next Generation Hydro sites are developed and connected to the new Yukon to BC interconnection at Watson Lake Junction (Option 1A).

[32] MCM is an abbreviation for "thousand circular mils", which is a common wire size parameter. One circular mil is equivalent to a single strand of wire with a diameter of one-thousandth of an inch.

[33] ACSR is an abbreviation for Aluminum Conductor, Steel Reinforced

[34] Note that Interconnection Losses are calculated from Whitehorse to BC Hydro's Skeena substation

Table 3.2: Interconnection Option 1A – Potential Export Capacity

Forrest Kerr Output (MW)	Power Leaving Yukon (MW)	Interconnection Losses[35] (MW)	Potential Net Yukon Export Capacity (MW)	Voltage Angle Whitehorse to Skeena
0	163.8	5.5	139	33.6°
50	148.8	5.7	143.1	33.5°
100	133.8	6.4	127.4	33.5°
150	118.8	7.6	111.2	33.5°
200	103.8	9.3	94.5	33.6°

These results demonstrate that the available capacity for export via an interconnection with BC Hydro would be improved by developing one or more of the Next Generation Hydro sites located near Watson Lake. Note that the primary purpose of these sites would be to serve internal Yukon load, the side benefit of siting a hydroelectric project in this location would be to improve system operational flexibility and market access opportunities relative to other Next Generation Hydro sites located further from the transfer path.

Additional details of the Option 1 & 1A power system analysis are shown in Appendix A.

3.2 Option 2 – Aishihik, YT to Fairbanks, Alaska Interconnection Analysis

The modeled path for the Fairbanks interconnection includes a new 230 kV transmission line from the Aishihik hydro plant near Haines Junction to the Jarvis Creek substation near Delta Junction, Alaska. To account for the negative impact on transfer capacity of the existing 120 km 138 kV line from Delta Junction to Fairbanks, the modeled path was further extended from the Delta Junction (Jarvis Creek substation) terminus westward to GVEA's North Pole substation in Fairbanks.

Although both the Yukon and the Fairbanks systems presently operate at a nominal voltage of 138 kV, this voltage was not considered for the interconnection line as it would be technically impractical given the 660 km distance between the two jurisdictions. Therefore, 230 kV was selected as the minimum practical voltage at which such an interconnection could be implemented.

The following list of assumptions was used to develop the system model for this interconnection:

- Voltage:
    - 230 kV nominal voltage for the 660 km line from Aishihik, YT to Delta Junction, Alaska
    - 138 kV nominal voltage for the 120 km line from Delta Junction to Fairbanks

[35] Note that Interconnection Losses are calculated from Whitehorse to BC Hydro's Skeena substation

- Conductor Spacing:
  - Flat phase configuration with 5.6 m spacing between adjacent phases for 230 kV
  - Flat phase configuration with 4.6 m spacing between adjacent phases for 138 kV
- Conductor:
  - Double bundle 477 MCM ACSR Hawk conductor on the 230 kV line segments
  - Single bundle 477 MCM ACSR Hawk conductor on the 138 kV line segment
- Voltage Support: 65 MVAr shunt reactor at the intermediate substation at Tok

The total available transfer capacity on the path for exports from the Yukon is shown in Table 3.3 for Delta Junction generation output of 0 MW and 20 MW.

Table 3.3: Interconnection Option 2 – Export Capacity

Delta Jct Output (MW)	Power Leaving Yukon (MW)	Interconnection Losses (MW)	Potential Net Yukon Export Capacity (MW)	Voltage Angle Aishihik to Fairbanks
20	75	5.4	69.6	32.5°
0	85	5.1[36]	79.9	33.6°

Additional details of the Option 2 power system analysis and results are provided in Appendix A.

[36] Note that path losses decrease as loading on 138 kV cct from Delta Jct to Fairbanks drops

4 Interconnection Options – Capital Cost Estimates

Based upon the required facilities identified in the technical analysis section above, Midgard has prepared conceptual-level cost estimates for implementing any of the proposed interconnections between the Yukon transmission system and neighbouring jurisdictions.

Cost estimates have been developed for the following Interconnection Options:

- Option 1: Whitehorse, Yukon – Iskut, British Columbia
- Option 2: Aishihik, Yukon – Delta Junction, Alaska

4.1 Interconnection Option 1: Whitehorse, Yukon to Iskut, British Columbia

Table 4.1 lists the 287 kV transmission segment lengths between intermediate substations required to interconnect Whitehorse with the existing Iskut substation.

Table 4.1: Whitehorse – Iskut Interconnection Route

From:	To:	Approximate Distance
Whitehorse (Takhini)	Teslin	194 km
Teslin	Watson Lake Junction (Highway 1 & 37)	240 km
Watson Lake Junction (Highway 1 & 37)	Dease Lake	235 km
Dease Lake	Iskut (Tatogga)	94 km

The interconnection from Whitehorse to Iskut would include the following major cost components:

- 763 km of single circuit, three phase 287 kV transmission line strung with double bundle 477 MCM Hawk ACSR phase conductors
- Three intermediate 287 kV substations with transformers to serve local loads, located at:
  - Teslin, YT
  - Junction of Highways 1 & 37 (west of Watson Lake, YT)
  - Dease Lake, BC
- 287 kV Termination Bays at each end of the interconnection:
  - Takhini Substation in Whitehorse
  - Tatogga Substation near Iskut, BC
- 287/138 kV transformer and new 287 kV bus at Takhini Substation
- Reactive power control equipment at the intermediate and terminus substations (shunt reactors, and likely a combination of switched shunt capacitors and either Static VAr Compensator (SVC) or synchronous condenser at each of the intermediate substations)

To ensure voltage regulation and reasonable dynamic performance, additional costs to account for reactive power compensation equipment (e.g.: switched shunt reactors and synchronous condensers) has been included at intermediate substations.

It would be possible to materially increase the maximum power transfer of this interconnection by including series compensation, but as these components would greatly increase the overall interconnection costs they have been excluded from this study. Adding series compensation at a later date is feasible if additional power transfer capacity is required between the Yukon and British Columbia in the future.

The cost estimates include both the direct and indirect costs derived from unit costs taken from recent transmission line and substation projects, and modified using professional judgement and supplier information. The substation costs include provisions for material, design and construction costs, along with project and construction management costs. Table 4.2 provides a high-level cost breakdown by major component for the Whitehorse – Iskut intertie option.

Table 4.2: Whitehorse – Iskut Interconnection Costs

Major Cost Item	Unit Cost ($M)	Quantity	Estimated Cost ($M)
287 kV Transmission Line	$2.0[37]	763 km	$1,525
287 kV Intermediate Substations	$50[38]	3	$150
287 kV Termination at Takhini Substation (Whitehorse)	$25	1	$25
287 kV Termination Bay at Tatogga Substation (Iskut)	$10	1	$10
		Total Cost	**$1,710**

The estimated cost of implementing a transmission interconnection from Whitehorse to Iskut is approximately $1,710 million, largely driven by the cost of constructing 763 km of new 287 kV transmission line through remote, rugged, forested terrain.

4.2 Interconnection Option 2: Aishihik, Yukon to Delta Junction, Alaska

Table 4.3 lists the transmission line voltage and distances required to connect the Yukon grid at the existing Aishihik substation to the existing Jarvis Creek substation at Delta Junction, Alaska.

Table 4.3: Aishihik – Delta Junction Interconnection Route

From:	To:	Transmission Line Voltage	Approximate Distance
Aishihik (Canyon)	White River	230 kV	262 km
White River	Tok	230 kV	228 km
TOK	Delta Junction	230 kV	172 km

[37] Per unit transmission line costs were derived from actual costs incurred implementing BC Hydro's recently completed 287 kV line from Skeena to Bob Quinn Lake

[38] Based upon recently incurred and estimated remote substation project costs, and augmented with reactive power compensation equipment costs taken from April 2011 Yukon - BC Interconnection Costing Report by BBA

The studied interconnection from Aishihik to Delta Junction includes the following major cost components:

- 662 km of single circuit, three phase 230 kV transmission line
- New 230/138 kV substation on Highway 1 near Aishihik
- Two intermediate 230 kV substations along the route at the White River, Yukon and Tok, Alaska
- New termination bays, 230/138 kV transformers and 230 kV buses at Jarvis Creek Substation at Delta Junction, Alaska

The route between the new Aishihik terminal and Delta Junction generally follows the Alaska Highway from Haines Junction westward. The per unit transmission construction costs are relatively high due to remoteness, rough terrain and discontinuous permafrost along the route.

Because both the Yukon and Alaska bulk transmission systems presently operate at a nominal voltage of 138 kV, new 230/138 kV transformers and 230 kV buswork will be required at the western terminus substation Delta Junction. A new 230/138 kV substation will be required at the eastern interconnection terminus near Aishihik (likely in proximity to the existing 138/25 kV source substation that serves Haines Junction).

To ensure voltage regulation and reasonable dynamic performance, reactive power compensation equipment has been included at the intermediate substations at the White River, Yukon and Tok, Alaska.

The cost estimates include both the direct and indirect costs for the transmission lines and substations, and were estimated based on recent project examples, professional judgement and supplier information. Similar to Interconnection Option 1, the substation costs include provisions for required material (i.e.: foundations, transformers, breakers, shunt reactors and protection & controls), design and construction costs (i.e.: engineering, planning and construction services) as well as project and construction management costs (i.e.: permitting and access, management, procurement and contingency costs). Table 4.4 provides a high-level cost breakdown by major component for the Aishihik – Delta Junction intertie option.

Table 4.4: Aishihik – Delta Junction Interconnection Costs

Item	Unit Cost ($M)	Quantity	Estimated Cost ($M)
230 kV Transmission Line	$1.7[39]	662 km	$1,125
230 kV Intermediate Substations	$50	2	$100
230/138 kV Terminus Substation near Aishihik (Canyon)	$50	1	$50
230 kV bay, buswork and transformer at the Delta Junction (Jarvis Creek) terminus	$25	1	$50
		Total Cost	**$1,325**

The estimated cost of implementing a transmission interconnection from Aishihik to Delta Junction is approximately $1,325 million, largely driven by the cost of constructing 662 km of new 230 kV transmission line through rugged, remote terrain with discontinuous permafrost.

[39] Based on costs of recent 230 kV projects, including a premium for construction in a remote area with discontinuous permafrost.

5 Summary of Results

Table 5.1 compares the technical analysis and cost estimates prepared for the two Interconnection Options studied (including variant #1A for the Yukon to BC Interconnection Option based upon a specific Next Generation Hydro siting alternative):

Table 5.1: Comparison of Interconnection Option Results

Interconnection Option	Description	Distance (km)	Capital Cost ($M)	Potential Net Yukon Export Capacity (MW)
#1	287 kV from Whitehorse (Takhini) to Iskut, BC	763	$1,710	64 - 127[40]
#1A	Same as option 1 with three (3) Next Generation Hydro sites developed near Watson Lake	763	$1,710	94 - 139[41]
#2	230 kV from Aishihik to Delta Junction	662	$1,325	70 - 80[42]

These results confirm the findings of earlier studies, demonstrating that the cost of implementing any Interconnection Option between the Yukon and the nearest neighbouring jurisdictions is high relative to the transfer capacity enabled by any of the interconnections. This outcome is a direct consequence of the considerable distances separating the Yukon from neighbouring systems, the sparse population and load density of the Yukon, and the relatively small transfer capacity needed to fully satisfy the Yukon requirements for the foreseeable future. Table 5.2 lists the Capital Cost per MW of Net Export Capacity for each option studied.

Table 5.2: Comparison of Costs per MW of Net Export Capacity

Interconnection Option	Description	Capital Cost per MW of Net Export Capacity ($M)
#1	Whitehorse to Iskut, BC	$13 - $27
#1A	Whitehorse to Iskut, BC (Next Generation Hydro near Watson Lake)	$12 - $18
#2	Aishihik to Delta Junction	$16 - $19

[40] Net Exports are dependent upon output of Forrest Kerr Hydro

[41] Net Exports are dependent upon output of Forrest Kerr Hydro

[42] Net Exports are dependent upon output of Delta Junction generation

Given the above results and the other findings discussed in this report, it is possible to respond to the questions posed in the goal statement set out at the beginning of Section 1 , namely, to investigate whether or not extending the Yukon's transmission system to another jurisdiction would:

- Influence the selection of the Next Generation Hydroelectric options?

  Development of an interconnection between Whitehorse and the BC Hydro grid at Iskut would provide market access for 64 – 127 MW of export capacity for Next Generation Hydro sites (not including the Middle and False Canyon sites), and 94 – 139MW of export capacity for the Middle and False Canyon sites. Development of an interconnection between Aishihik and Delta Junction would provide access to 70 – 80MW of export capacity for Next Generation Hydro sites.

  It should be noted that this report does not assess whether or not the export capacity could be absorbed by the connected market, nor does it assess the economics of such trade.

- Improve the ability to scale out generation supply options?

  Developing an interconnection to Iskut, BC would provide the technical potential to export 64 to 139 MW of power, enabling the Yukon to reduce the risk of stranding Next Generation Hydro assets during periods of low local demand.

  Similarly, developing an interconnection to Delta Junction, Alaska would provide the technical potential to export 70 to 80 MW of power to reduce the risk of stranding new assets.

- Improve the ability to mitigate industrial load interruption risks?

  The reliability performance indices for the Yukon presently compare favourably to those of southern interconnected Canadian jurisdictions. Interconnection with an external jurisdiction would likely improve Yukon system frequency stability, but it would not likely materially reduce the risk of industrial load interruptions.

- Require prerequisite Yukon based load & supply to support an inter-jurisdictional connection?

  The size of the existing Yukon load and supply, and the projected growth in these parameters over the planning horizon, is likely inadequate to justify the capital cost of developing interconnections with either Iskut, BC or Delta Junction, Alaska.

Appendix A: Power System Analysis

A.1 Whitehorse to Skeena with Next Generation Hydro connected within existing Yukon System (Interconnection Option 1)

A.1.1 Transmission Line Route and Distances

The following table gives the voltage class and the respective distances of the transmission line segments that comprise the path.

From:	*To:*	*Transmission Line Voltage (kV)*	*Distance (km)*
Whitehorse	Teslin	287	194
Teslin	Watson Lake	287	240
Watson Lake	Dease Lake	287	235
Dease Lake	Iskut	287	94
Iskut	Red Chris Mine	287	15
Iskut	Bob Quinn Lake	287	93
Bob Quinn Lake	Forrest Kerr	287	40
Bob Quinn Lake	Skeena	287	340

A.1.2 Generation and Load Profile

The following table lists the maximum generation capability and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Location	*Power Generation (MW)*	*Reactive Power Generation (MVArs)*	*Power Load (MW)*	*Reactive Load (MVArs)*
Whitehorse[43]	300	146	100	49
Watson Lake	-	-	3.2	1.5
Dease Lake	-	-	1	0.5
Iskut	-	-	1	0.5
Red Chris Mine	-	-	50	24
Bob Quinn Lake	-	-	-	-

[43] 300 MW of Whitehorse generation is assumed at Whitehorse solely for the purpose of analyzing interconnection capacity limits. 300MW is not intended to indicate that additional generation is being considered for Whitehorse.

Forrest Kerr	200	97	-	-
Skeena	Swing Bus	Swing Bus	-	-

A.1.3 Conductor Characteristics

The following table provides the conductor characteristics for the 287 kV interconnection option.

Voltage Class (kV)	*Conductor Type*	*GMR (ft)*	*External Diameter (In)*	*Bundle*	*Phase Spacing (m)*	*Conductor Spacing*
287	Hawk 477 MCM	0.0289	0.858	2	6.7	18”

A.1.4 Line Characteristics

Using a 100 MVA system base and 287 kV line voltage, the following line parameters were calculated based on the conductor characteristics and tower structure assumptions:

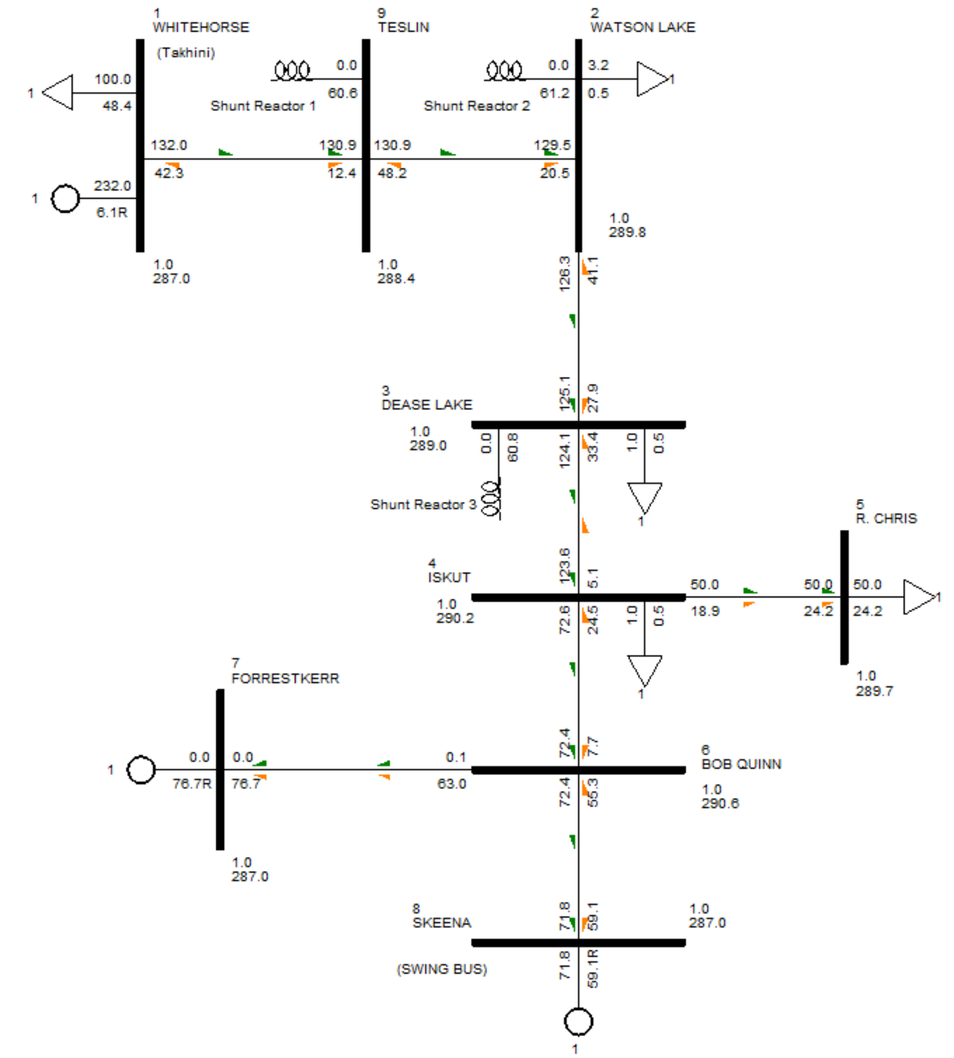
From:	*To:*	*Distance (km)*	*Line Voltage (kV)*	*Per Unit Resistance (pu)*	*Per Unit Reactance (pu)*	*Charging B (pu)*
Whitehorse	Teslin	176	287	0.0064	0.0877	0.6970
Teslin	Watson Lake	240	287	0.0080	0.1091	0.8599
Watson Lk	Dease Lk	235	287	0.0078	0.1062	0.8423
Dease Lk	Iskut	95	287	0.0031	0.0424	0.3426
Iskut	Red Chris	15	287	0.0005	0.0067	0.0542
Iskut	Bob Quinn	93	287	0.0031	0.0415	0.3354
Bob Quinn	Forrest Kerr	40	287	0.001	0.0178	0.1444
Bob Quinn	Skeena	340	287	0.0115	0.1562	1.2090

60 MVAr switched shunt reactors are assumed at Teslin, Watson Lake and Dease Lake in order to maintain the Voltage within nominal limits between 1.1 pu and 0.9 pu.

A.1.5 PSS®E Power Flow Simulation

Using the above estimated parameters and assumptions, a PSS®E model was built and simulations were carried out to estimate the maximum power flow possible from the Yukon system to BC Hydro maintaining acceptable system conditions. The voltage is maintained between a nominal range of 1.1 per unit to 0.9 per unit at all buses, and the maximum Sending End to Receiving End voltage angle is taken to be 33° to avoid angular instability for minor system perturbations.

Location	***Bus Type***	***Compensators***
Whitehorse	Generation Bus – Type 2	-
Teslin	Load Bus – Type 1	-60 MVArs
Watson Lake	Load Bus – Type 1	-60 MVArs
Dease Lake	Load Bus – Type 1	-60 MVArs
Iskut	Load Bus – Type 1	-
Red Chris Mine	Load Bus – Type 1	-
Bob Quinn Lake	Load Bus – Type 1	-
Forrest Kerr	Generation Bus – Type 2	-
Skeena	Swing Bus – Type 3	-



A.1.6 Results

Forrest Kerr Generation quantities are varied and Yukon generation is maximized while maintaining voltage and angle limits at all buses, with net transfers absorbed by the swing bus at Skeena to simulate exports into or out of the BC Hydro system.

FORREST KERR @ 0 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	232	1	**33.39**
Teslin	0	1.0048	26.75
Watson Lake	0	1.0097	18.63

Dease Lake	0	1.0068	11.06
Iskut	0	1.0112	8.07
Red Chris	0	1.0095	7.89
Bob Quinn Lake	0	1.0124	6.37
Forrest Kerr	0	1	6.42
Skeena	-71.79	1	0
Power Out of Yukon	**128.8 MW**		
Losses	**5.01 MW**		
Net Yukon Exports	**123.79 MW**		

FORREST KERR @ 50 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	218	1	**33.47**
Teslin	0	1.0096	27.53
Watson Lake	0	1.0164	20.35
Dease Lake	0	1.0113	13.67
Iskut	0	1.0137	11.02
Red Chris	0	1.012	10.84
Bob Quinn Lake	0	1.0125	9.64
Forrest Kerr	50	1	10.2
Skeena	-107.91	1	0
Power Out of Yukon	**114.8 MW**		
Losses	**4.89 MW**		
Net Yukon Exports	**109.9 MW**		

FORREST KERR @ 100 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	203	1	**33.32**
Teslin	0	1.0138	28.14
Watson Lake	0	1.0224	21.92
Dease Lake	0	1.0151	16.16
Iskut	0	1.0156	13.88
Red Chris	0	1.014	13.7

Bob Quinn Lake	0	1.0122	12.84
Forrest Kerr	100	1	13.9
Skeena	-142.6	1	0
Power Out of Yukon	**99.8 MW**		
Losses	**5.19 MW**		
Net Yukon Exports	**94.6 MW**		

FORREST KERR @ 150 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	188	1	**33.26**
Teslin	0	1.0173	28.83
Watson Lake	0	1.0271	23.54
Dease Lake	0	1.0178	18.69
Iskut	0	1.0167	16.76
Red Chris	0	1.015	16.58
Bob Quinn Lake	0	1.0114	16.06
Forrest Kerr	150	1	17.63
Skeena	-176.83	1	0
Power Out of Yukon	**84.8 MW**		
Losses	**5.97 MW**		
Net Yukon Exports	**78.8 MW**		

FORREST KERR @ 200 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	173	1	**33.29**
Teslin	0	1.02	29.6
Watson Lake	0	1.0306	25.22
Dease Lake	0	1.0194	21.26
Iskut	0	1.0169	19.67
Red Chris	0	1.0153	19.49
Bob Quinn Lake	0	1.01	19.32
Forrest Kerr	200	1	21.39
Skeena	-210.56	1	0
Power Out of Yukon	**84.8 MW**		
Losses	**5.97 MW**		
Net Yukon Exports	**78.8 MW**		

FORREST KERR @ 200 MW & No Export from Yukon			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	103.2	1	12.16
Teslin	0	1.0275	11.89
Watson Lake	0	1.0418	11.65
Dease Lake	0	1.0286	11.71
Iskut	0	1.0239	11.76
Red Chris	0	1.0223	11.58
Bob Quinn Lake	0	1.0145	13
Forrest Kerr	200	1.0005	15.07
Skeena	-144.7	1	0
Power Out of Yukon	**0 MW**		
Losses	**3.26 MW**		
Net Yukon Export	**0 MW**		

FORREST KERR @ 0 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	103.2	1	-5.49
Teslin	0	1.03	-5.77
Watson Lake	0	1.0473	-6.02
Dease Lake	0	1.037	-5.97
Iskut	0	1.0334	-5.93
Red Chris	0	1.0318	-6.11
Bob Quinn Lake	0	1.0248	-4.72
Forrest Kerr	0	1.009	-4.65
Skeena	52.67	1	0
Power Out of Yukon	**0 MW**		
Losses	**0.67 MW**		
Net Yukon Export	**0**		

A.2 Whitehorse to Skeena with Upper, Middle & False Canyon Hydro connected to Watson Lake Junction (Interconnection Option 1A)

A.2.1 Transmission Line Route and Segment Lengths

The following table provides the voltage class and the respective distances of the transmission line segments that comprise the path.

From:	***To:***	***Transmission Line Voltage (kV)***	***Distance (km)***
Whitehorse (Takhini)	Teslin	287	194
Teslin	Watson Lake	287	240
Watson Lake	Middle Canyon	287	50
Middle Canyon	False Canyon	287	36
False Canyon	Upper Canyon	287	27
Watson Lake	Dease Lake	287	235
Dease Lake	Iskut	287	94
Iskut (Tatogga)	Red Chris Mine	287	15
Iskut (Tatogga)	Bob Quinn Lake	287	93
Bob Quinn Lake	Forrest Kerr	287	40
Bob Quinn Lake	Skeena	287	340

A.2.2 Generation and Loads

The following table lists the maximum generation capability and load parameters for all buses considered in the power flow simulation.

Location	*Pgen (MW)*	*Qgen (MVArs)*	*Pload (MW)*	*Qload (MVArs)*
Whitehorse (Takhini)	300	146	100	49
Watson Lake	-	-	3.2	1.55
Middle Canyon	14	6.8	-	-
False Canyon	58	28.1	-	-
Upper Canyon	25	12.1	-	-
Dease Lake	-	-	1	0.5
Iskut (Tatogga)	-	-	1	0.5
Red Chris Mine	-	-	50	24.21
Bob Quinn Lake	-	-	-	-
Forrest Kerr	200	97	-	-
Skeena	Infinite	Infinite	-	-

A.2.3 Line Characteristics

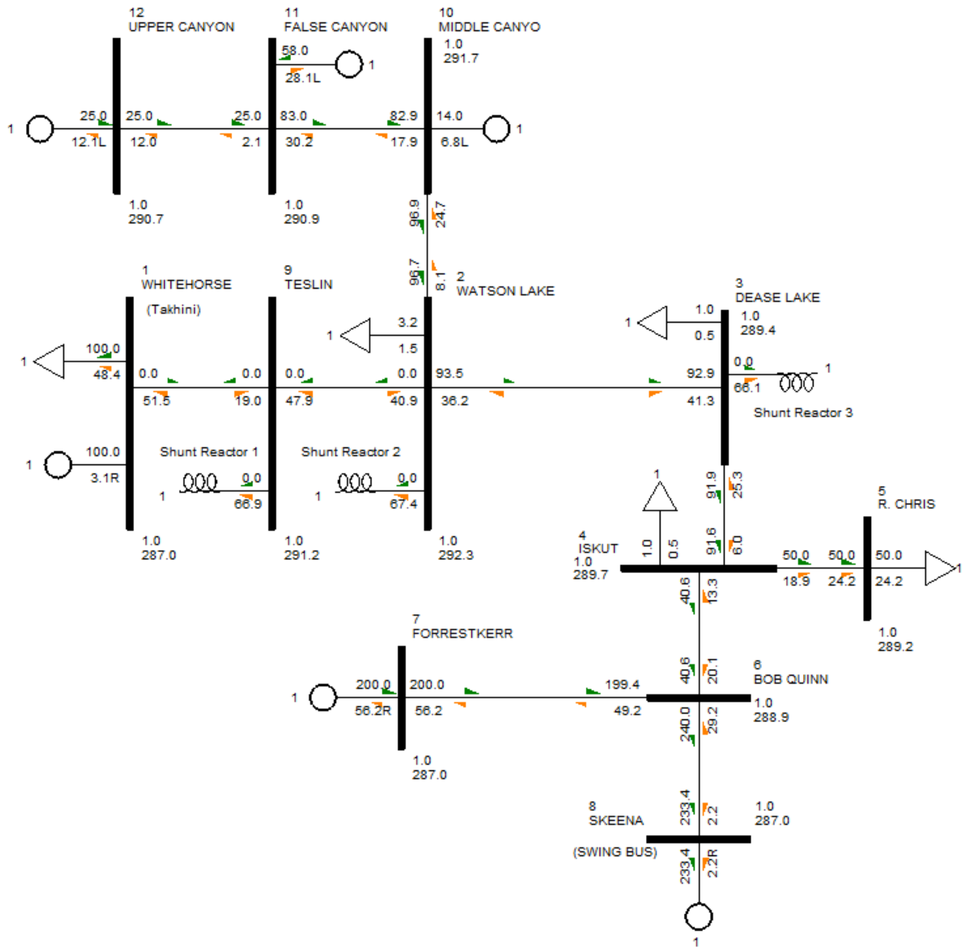
The following table lists the line parameters that were calculated based on the conductor characteristics and tower structure assumptions:

From:	*To:*	*Distance (km)*	*Line Voltage (kV)*	*Per Unit Resistance (pu)*	*Per Unit Reactance (pu)*	*Charging B (pu)*
Whitehorse	Teslin	194	287	0.0058	0.0794	0.6329
Teslin	Watson Lk.	240	287	0.0080	0.1091	0.8599
Watson Lake	Middle Canyon	50	287	0.0016	0.0224	0.1805
Middle Canyon	False Canyon	36	287	0.0012	0.0161	0.1300
False Canyon	Upper Canyon	27	287	0.0009	0.0121	0.0975
Watson Lk.	Dease Lake	235	287	0.0078	0.1062	0.8423
Dease Lake	Iskut	94	287	0.0031	0.0424	0.3426
Iskut	Red Chris	15	287	0.0005	0.0067	0.0542
Iskut	Bob Quinn	93	287	0.0031	0.0415	0.3354
Bob Quinn	Forrest Kerr	40	287	0.001	0.0178	0.1444
Bob Quinn	Skeena	340	287	0.0115	0.1562	1.2090

A.2.4 PSS®E Simulation

The configuration is the same as Case 1, except that one or more of the Next Gen Upper, Middle and the False Canyon hydroelectric projects are connected to Watson Lake Junction substation, and -65 MVAr shunt reactors are assumed at the three intermediate substations.

Location	***Bus Type***	***Compensators***
Whitehorse (Takhini)	Generation Bus – Type 2	-
Teslin	Load Bus – Type 1	-65 MVArs
Middle Canyon	Generation Bus – Type 2	-
False Canyon	Generation Bus – Type 2	-
Upper Canyon	Generation Bus – Type 2	-
Watson Lake Jct	Load Bus – Type 1	-65 MVArs
Dease Lake	Load Bus – Type 1	-65 MVArs
Iskut (Tatogga)	Load Bus – Type 1	-
Red Chris Mine	Load Bus – Type 1	-
Bob Quinn Lake	Load Bus – Type 1	-
Forrest Kerr	Generation Bus – Type 2	-
Skeena	Swing Bus – Type 3	-



A.2.5 Results

In this case it is assumed that one or more of the Middle Canyon, False Canyon and Upper Canyon plants are operated at full capacity at all times, and only Whitehorse and Forrest Kerr generation quantities are varied. The model may change, but the results would be similar as long as one or more of the three plants are constructed. Losses and export out of the Yukon are calculated for the different Forrest Kerr production levels.

FORREST KERR @ 0 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	170	1	**33.9**
Teslin	0	1.0053	30.36
Middle Canyon	14	1.002	27.29
False Canyon	58	1	28.06
Upper Canyon	25	1	28.24
Watson Lake	0	1.003	26.04
Dease Lake	0	0.995	16.05
Iskut	0	1.0029	12.11
Red Chris Mine	0	1.0012	11.92
Bob Quinn Lake	0	1.0093	9.53
Forrest Kerr	0	1	9.57
Skeena	-106.2	1	0
Power Out of Yukon	**163.8 MW**		
Losses	**5.5**		
Net Yukon Exports	**158.3 MW**		

FORREST KERR @ 50 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	155	1	**33.76**
Teslin	0	1.0071	30.98
Middle Canyon	14	1.0031	28.83
False Canyon	58	1.0004	29.61
Upper Canyon	25	1	29.79
Watson Lake	0	1.005	27.59
Dease Lake	0	0.9977	18.54
Iskut	0	1.0044	14.98
Red Chris Mine	0	1.0027	14.79
Bob Quinn Lake	0	1.009	12.75
Forrest Kerr	50	1	13.29
Skeena	-141.04	1	0
Power Out of Yukon	**148.8 MW**		
Losses	**5.75 MW**		
Net Yukon Exports	**143.05 MW**		

FORREST KERR @ 100 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	140	1	**33.64**
Teslin	0	1.0092	31.6
Middle Canyon	14	1.006	30.38
False Canyon	58	1.003	31.16
Upper Canyon	25	1.0024	31.33
Watson Lake	0	1.0083	29.14
Dease Lake	0	1.0007	21.06
Iskut	0	1.0058	17.86
Red Chris Mine	0	1.0042	17.68
Bob Quinn Lake	0	1.0083	15.98
Forrest Kerr	100	1	17.04
Skeena	-175.37	1	0
Power Out of Yukon	**133.8 MW**		
Losses	**6.4 MW**		
Net Yukon Exports	**127.4 MW**		

FORREST KERR @ 150 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	125	1	**33.55**
Teslin	0	1.0117	32.26
Middle Canyon	14	1.0105	31.95
False Canyon	58	1.0076	32.72
Upper Canyon	25	1.0069	32.9
Watson Lake	0	1.0127	30.72
Dease Lake	0	1.0037	23.61
Iskut	0	1.0071	20.78
Red Chris Mine	0	1.0054	20.6
Bob Quinn Lake	0	1.0073	19.25
Forrest Kerr	150	1	20.81
Skeena	-209.2	1	0
Power Out of Yukon	**118.8 MW**		
Losses	**7.6 MW**		
Net Yukon Exports	**111.2 MW**		

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FORREST KERR @ 200 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	110	1	**33.57**
Teslin	0	1.0133	33.02
Middle Canyon	14	1.0136	33.62
False Canyon	58	1.0107	34.38
Upper Canyon	25	1.0101	34.55
Watson Lake	0	1.0157	32.4
Dease Lake	0	1.0055	26.22
Iskut	0	1.0074	23.76
Red Chris Mine	0	1.0057	23.58
Bob Quinn Lake	0	1.0057	22.58
Forrest Kerr	200	1	24.64
Skeena	-242.5	1	0
Power Out of Yukon	**103.8 MW**		
Losses	**9.3 MW**		
Net Yukon Exports	**94.5 MW**		

FORREST KERR @ 0 MW, WHITEHORSE = 100 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	100	1	12.23
Teslin	0	1.0165	12.16
Middle Canyon	14	1.0208	13.34
False Canyon	58	1.018	14.1
Upper Canyon	25	1.0174	14.27
Watson Lake	0	1.0229	12.14
Dease Lake	0	1.0144	6.64
Iskut	0	1.0164	4.46
Red Chris Mine	0	1.0147	4.28
Bob Quinn Lake	0	1.0143	3.52
Forrest Kerr	0	1	3.58
Skeena	-40.3	1	0
Power Out of Yukon	**93.8 MW**		
Losses	**1.5 MW**		
Net Yukon Exports	**92.3 MW**		

FORREST KERR @ 200 MW & WHITEHORSE = 100 MW			
Location	***Generation (MW)***	***Bus Voltage (p.u.)***	***Voltage Angle (degrees)***
Whitehorse	100	1	30.41
Teslin	0	1.0146	30.35
Middle Canyon	14	1.0164	31.55
False Canyon	58	1.0136	32.31
Upper Canyon	25	1.013	32.48
Watson Lake	0	1.0185	30.34
Dease Lake	0	1.0082	24.79
Iskut	0	1.0094	22.58
Red Chris Mine	0	1.0077	22.4
Bob Quinn Lake	0	1.0068	21.64
Forrest Kerr	200	1	23.7
Skeena	-233.4	1	0
Power Out of Yukon	**93.8 MW**		
Losses	**8.4 MW**		
Net Yukon Exports	**85.4 MW**		

A.3 Aishihik, Yukon to Fairbanks, Alaska (Interconnection Option 2)

A.3.1 Transmission Line Route and Distances

The following table provides the voltage class and the respective distances of the transmission line segments that comprise the path.

From:	***To:***	***Transmission Line Voltage (kV)***	***Distance (km)***
Aishihik	White River	230	262
White River	Tok	230	227
Tok	Delta Junction	230	172
Delta Junction	Fairbanks	138	120

A.3.2 Generation and Load Profile

The following table lists the maximum generation capability and load parameters for all buses considered in the power flow simulation.

Location	***Pgen (MW)***	***Qgen (MVArs)***	***Pload (MW)***	***Qload (MVArs)***
Aishihik	300	145.29	100	48
White River	-	-	-	-
Tok	-	-	2	1
Delta Junction	28	13.56	20	10
Fairbanks	Swing Bus	Swing Bus	230	111

A.3.3 Assumed Conductor Characteristics

The following table provides the conductor characteristics for the interconnection option.

Voltage Class (kV)	***Conductor Type***	***GMR (ft)***	***External Diameter (In)***	***Bundle***	***Phase Spacing (m)***	***Conductor Spacing***
230	Hawk 477 MCM	0.0289	0.858	2	6.7	18”
138	Hawk 477 MCM	0.0289	0.858	1	4.6	N/A

A.3.4 Line Characteristics

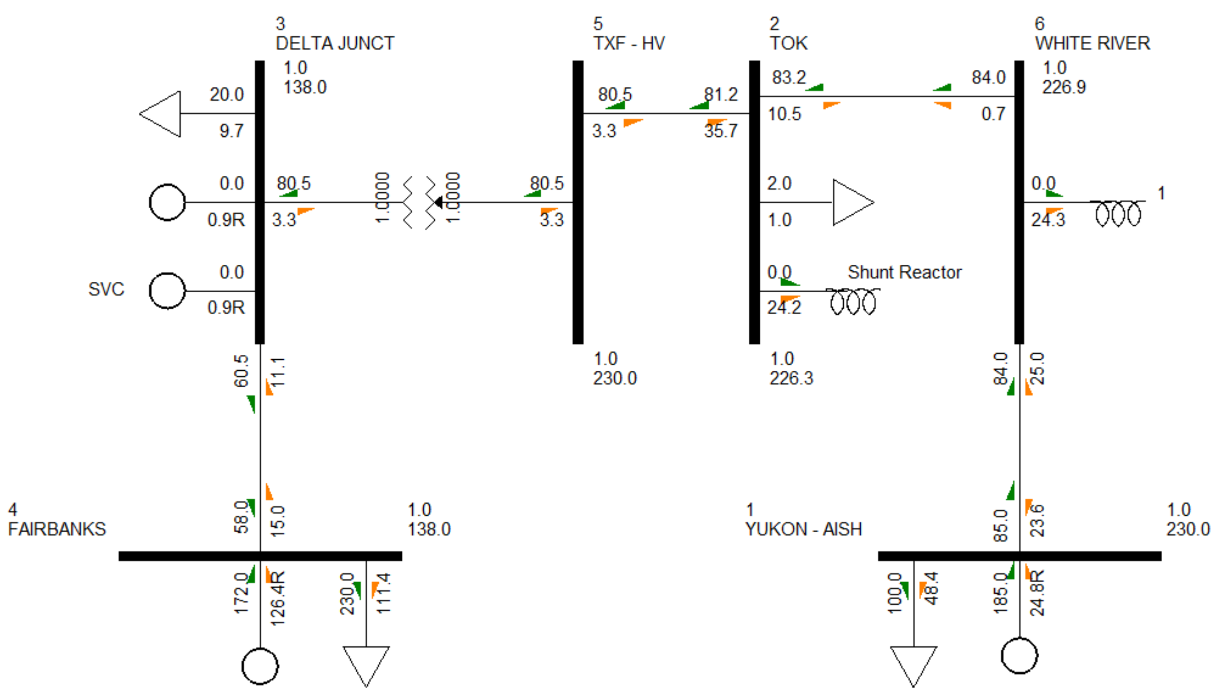
The following table lists the line parameters that were calculated based on the conductor characteristics and tower structure assumptions:

From:	***To:***	***Distance (km)***	***Line Voltage (kV)***	***Per Unit Resistance (pu)***	***Per Unit Reactance (pu)***	***Charging B (pu)***
Aishihik	White River	262	230	0.01365	0.1792	0.6255
White River	Tok	227	230	0.01177	0.1546	0.5432
Tok	Delta Jct	172	230	0.0089	0.1164	0.4128
Delta Jct	Fairbanks	120	138	0.0685	0.3113	0.0762

A.3.5 PSS®E Power Flow Simulation

Yukon Load is assumed to be 100 MW. The Static VAr Compensator at Delta Junction is rated at Qmax = 36 MVArs and Qmin = -8 MVArs. Imports and exports are controlled by varying Yukon generation, with the Swing Bus at Fairbanks adjusting local loads appropriately.

Location	***Bus Type***	***Compensators***
Yukon System	Generation Bus – Type 2	-
White River	Load Bus – Type 1	-25 MVArs
Tok	Load Bus – Type 1	-25 MVArs
Delta Junction	Generation Bus – Type 2	-8/+36 MVAr SVC
Fairbanks	Swing Bus – Type 3	-



A.3.6 Results

Yukon @ 175 MW & Delta Jct. Gen @ 20 MW			
Location	**Generation (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Aishihik	175	1	**32.5**
White River	-	0.9904	24.73
Tok	-	0.9873	17.99
Delta Junction	20	1.0000	13.08
Fairbanks	162.4	1	0
Power Out of Yukon	**75 MW**		
Losses	**5.4 MW**		
Net Yukon Exports	**69.6 MW**		

Yukon @ 185 MW & Delta @ 0 MW			
Location	**Generation (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Aishihik	185	1	**33.3**
White River	-	0.9863	24.43
Tok	-	0.9840	16.75
Delta Junction	0	1	11.15
Fairbanks	172.02	1	0
Power Out of Yukon	**85 MW**		
Losses	**5.02 MW**		
Net Yukon Exports	**79.9 MW**		