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YUKON ENERGY CORPORATION

PROPOSED CARMACKS-STEWART CROSSING TRANSMISSION/INTERCONNECTION PROJECT

OUTLINE PLANNING SUMMARY FOR PROJECT ESTIMATING PURPOSES ONLY

Report 8259-005, -006

January 2003

1.0 AUTHORIZATION

This study and report have been authorized through phone call from Alex Love, P. Eng, Yukon Energy Corporation, in December, 2002, subsequent to his request (through fax) for estimate to handle the assignment.

2.0 INTRODUCTION AND SCOPE

Yukon Energy Corporation (YEC) are considering interconnection between the existing southern Whitehorse-Aishihik-Faro (WAF) transmission/generation system and the corresponding northern Mayo-Dawson system (the latter being commissioned at this time, January, 2003).

The interconnection would be between existing transmission at Carmacks and the Mayo-Dawson transmission at Stewart Crossing.

The supporting arguments for that interconnection are not part of this report.

YEC have asked for a preliminary transmission planning study to

a) see if such interconnection is technically and operationally sensibly attainable,

b) to outline the prospective capital cost items for such interconnection,

c) to determine the operating (capacity) losses on the interconnection and on the now existing (or soon to be commissioned) systems.

The scope does not include estimate of energy losses because those losses will be contingent on the system load factor and loading profile, and would in any event represent a relatively sophisticated study in itself.

To preclude misunderstanding, the scope does not include estimate of the monetary value of the capital costs or operating costs themselves - only, as in Item b and c, preceding, what the items are, or may, be.

Finally, the scope - and the content of this report - do not include fault or stability studies.

These would obviously be required prior to commitment to the project.

3.0 SUMMARY

Please refer to Section 14.0 and subsections for equipment requirements, outline specification, and broad application.

Section 3.1 includes a number of remarks that apply to all of the options, and those comments will not be repeated under each heading.

In summary:

3.1 Option 1
Option 1a
69 kV, Carmacks-Stewart Crossing, 397 MCM Conductor, With or Without Cable, No Upgrade Intended

1) 69 kV transmission with 397 MCM conductor will accommodate a total 35 MW north from Carmacks with only a very small comfort level as to prospective performance.

2) The system is very real and reactive power sensitive; small changes will alter the voltages across the whole system (true for all of the options).

3) Operating essentially flat voltage profile will give best operation.

It will require incremental reactive power dispatch.

It will increase the transmission losses, because of the fairly low X/R ratio of the transmission, and the transfer of reactive power.

4) The increased compensation will increase the transformer ratings (because of reactive dispatch).

Actual rating will depend on the contingencies to be covered (YEC decision).

5) OLTC on the Stewart Crossing transformation with 138 kV options is mandatory for a number of reasons.

6) Same is true for Carmacks transformation with 69 kV options.

7) The individual blocks of shunt compensation (capacitors or reactors) will have to be limited in rating to preclude

i) excessive voltage change when switching and prior to OLTC operation,

or

ii) synchronous condensers will have to be applied that will span the prospective switching magnitudes (and so correct for the switched block).

Judgment suggests that individual reactors and capacitors would have to be restricted to about 2 MVAR - possibly 3 MVAR - rating on any one breaker.

8) Cables or not will have little impact on the planning and operation other than that those cables (if 138 kV operation) would have to be fitted with shunt reactors, and the reactors should be switched because the cable charging could be a real asset at high loadings.

8) Transmission losses north from Takhini at the postulated 37 MW loading (after altering reactive to get the voltages to sensible levels, and including Carmacks and Faro towns) will total 17.43 MW, 45.8% of the load.

Transformation and synchronous condenser losses are estimated as about 1 MW.

Capacitor and reactor losses will probably be about 0.25% of rating.

9) Doing <u>very</u> rough extrapolation suggests that if losses were ignored, there might be marginal incremental capacity available, but not more than a couple of MW <u>at most</u>; the very high losses are a pretty good indication that the system is approaching - not yet quite at - voltage instability.

<u>3.2</u> <u>Option 2</u>
<u>Option 2a</u>
<u>138 kV, Carmacks-Stewart Crossing, 266 MCM Conductor, With or Without Cable</u>

1) 138 kV transmission between Carmacks and Stewart Crossing, with or without cable, will accommodate a 35 MW power transfer north from Takhini (mines included) in a reasonable but not completely (operationally) comfortable manner.

2) The increased compensation will increase the transformer ratings (because of reactive dispatch).

Actual rating will depend on the contingencies to be covered (YEC decision).

3) Cables or not will have little impact on the planning and operation other than those cables would have to be fitted with shunt reactors, and the reactors should be switched because the cable charging would be a real asset at high loadings.

4) Transmission losses north from Takhini at the postulated 37 MW loading (including Carmacks and Faro towns) will total 9.2 MW, 24.8% of the load.

Transformation and synchronous condenser losses are estimated as about 1 MW.

Capacitor and reactor losses will probably be about 0.25% of rating.

10) Doing very rough extrapolation suggests that if losses were ignored, and the cable reactors were switched, with the cable charging then available to the system, that cable charging and other incremental compensation could probably (not certain) accommodate up to a 45 MW distributed load.

The losses would increase to about 15 MW (estimated).

Additional synchronous condensers would almost certainly be required.

3.3 Option 2b
69 kV, Carmacks-Stewart Crossing, 266 MCM Conductor, With or Without Cable, Upgrade to be Accommodated

1) The comments in Section 3.1 apply here as well, but there are obviously still greater constraints.

2) The system will accommodate 21 MW to Stewart Crossing, 5 MW to the postulated mine loads, 2 MW to Carmacks and Faro with essentially no margin.

3) Transformation and synchronous condenser losses are estimated as about 1 MW.

Capacitor and reactor losses will probably be about 0.25% of rating.

27mw?

4) Transmission losses north from Takhini at the postulated 37 MW loading (again, after trimming up the voltages through reactive dispatch) will total 16.62 MW, 62% of the load.

(The transmission losses for all cases look to be very high; I checked them a number of ways, though, and the results are consistent.)

5) There is no marginal capacity available; the system is very soft, and the increment to voltage collapse is negligible.

3.4 Synchronous Condenser Application

1) 138 kV transmission will include one synchronous condenser at each of Carmacks and Stewart Crossing.

It may be possible to operate with the contingency of one of those two condensers out of service.

2) For 69 kV transmission, the system likely would not be operable at all (other than at much reduced load), and so two condensers would likely be required at each of Carmacks and Stewart Crossing.

3.5 Series Compensation

Series compensation was examined as to application and performance.

The X/R ratios of the transmission - all options - are too low for that technology to offer any significant benefit - and it could incur risks.

3.6 Cables

1) If the interconnection is at nominal 138 kV, the postulated cable will require switched shunt reactors at each terminal.

2) Different ratings at the two terminals would be much desired, 5 MVAR at the south terminal, 10 MVAR at the north, on 138 kV base.

3) Those reactors would be applicable for operation of the cable at 69 kV as well; both cable charging and reactor absorption would go down as the square of the voltage.

4) If nominal 69 kV interconnection (and for the sensibly attainable loadings), reactors would probably not be required at all at the cable terminals.

3.7 Stewart Crossing Transformation with 69 kV Operation

1)) For 69 kV operation of the line, transformation will still be required in some context at Stewart Crossing to accommodate connection of shunt compensation (condensers in particular).

3.8 Faro Reactor

1) The Faro 8 MVAR reactor and allied breaker would be relocated to Carmacks; that reactor has no ongoing useful role at Faro.

3.9 Stewart Crossing-North

1) Complementary transformation and additional shunt compensation will be required at Callison, the latter almost certainly including one or more synchronous condensers.

2) Shunt compensation in the form of capacitors will probably be required in the Mayo-north area, the latter for the maximum load delivery to the mining areas.

Neither of the foregoing were examined in any detail.

3.10 Mining Loads Compensation

1) Any mining loads should be requested to compensate to 1.0 power factor at transmission voltage, that power factor to be fairly constant for different mine loads.

4.0 APPLICATION OF THE REPORT

It is understood that the report will be used for estimating capital and operating costs, that estimating not constituting part of this report since

a) such input was not requested, and

b) I do not have the project management experience to be able to undertake such work anyway.

It is also understood that YEC will use the loss estimates for determining

c) the value of energy losses based on their planned interconnection loading profile,

d) the value of capacity losses - that is, the amount of system capacity that is gobbled up by interconnection losses - and

e) the intercept of capacity loss with system loading.

5.0 METHOD OF HANDLING

YEC asked for input suited to estimating the costs of alternatives with the intent of deciding whether the project would be economically viable or not, and, as an additional but not secondary consideration, whether the resulting system would be sensibly operable, or whether it would end up as a performance and technical nightmare.

Accordingly, and as agreed verbally, the report is based on

a) analyses that are more than "back of the envelope", but are not really comprehensive;

b) representative (but pretty accurate) numbers for different gear such as line charging, transformer impedances, and so on;

c) a fair bit of judgment based on experience.

Appendices are included that demonstrate transmission characteristics along with rough methods of approximating practical loading limits.

Those guides (which I have found to be pretty reliable over the years) were used to identify sensible loading limits without a lot of calculation that was going to lead nowhere anyway.

The appendices also include other items as identified in the index.

Detailed calculations were worked out for some few cases once the limits were identified.

The items are split up as much as possible under different sections so that the reader can identify those items that he/she may want to examine in some detail or simply gloss over.

Finally, and this was discussed with Alex Love, who asked how I would do the analyses.

First, I can claim a lot of experience in power system planning (almost 55 years in the utility business since graduation), but do not have any competence at all in computer usage, other than as a typewriter.

Accordingly, the analyses were done using a calculator.

But, apart from my lack of competence on computers, I wanted to obtain a "feel" for the system, getting a sense of sensitivity to reactive dispatch, voltage profiles, and so on.

In my opinion and experience (having worked with many others who do know computers), doing the work manually would better develop that "feel" for the system through a "ramp" approach, rather than the "step" approach that might result from using computer analysis.

I think Mr. Love was sympathetic to that opinion.

And, obviously, if the project does go ahead, the final analyses will have to be more accurate and more comprehensive, then justifying the use of computer analysis.

6.0 DESIRED TRANSFER CAPABILITIES

Ultimate power transfer capability north from Carmacks was defined by YEC as

a) 10 MW to anticipated mining loads between Carmacks and Stewart Crossing, and

b) 25 MW to the Mayo-Dawson system at Stewart Crossing.

It is assumed that if the required transfers were ever to exceed those amounts, that any or both of

a) additional transmission, or

b) new generation north of Stewart Crossing

would be considered.

The detail of such possibilities are outside the scope of this report.

It was implicit in the definition of scope by YEC, and checked with Alex Love during later phone conversation, that if the project was indeed staged, starting with nominal 69 kV transmission voltage, that they (YEC) wanted at least a judgmental definition of what amounts other than the predefined could be handled; they (YEC) did not just want a conclusion that the above amounts could be accommodated.

7.0 ACCURACY OF THE RECOMMENDATIONS AND IDEAS

Extrapolating from preceding sections, there is the possibility that there will be error or omission in this report.

Having some knowledge of the system, though, and in particular having done the basic planning for the Mayo-Dawson interconnection, it is likely, in my opinion, that even worst case error or omission will not lead to more than perhaps a 10% error in identification (and cost) of the total capital cost items (lines + stations).

The preceding paragraph is based on the belief or opinion that if there is indeed such error or omission, that it will relate more to station equipment than transmission; the station costs being substantially more than transmission, any percentage error on the station requirements will come out to a significantly smaller percentage of the overall project costs.

At the same time, areas where there may be doubts or unease about the likely needs will be referred to in the report, to lessen the prospect of nasty surprises.

8.0 DESIGN ASSUMPTIONS IDENTIFIED BY YEC

Design assumptions or exclusions as identified by YEC were defines as

a) direct current interconnection will not be considered;

b) line shielding will not be applied;

c) synchronous condensers and/or other shunt compensation will be considered;

d) breaker application is to accommodate high speed clearing of all transmission (and presumably allied transformation) faults.

YEC have also requested input on line geometry.

Notes relating to Item d, preceding include:

a) The proposed breaker application indicated in the sketches will not result in 100% selectivity for all station faults; the switchgear costs would end up being too high if each transformer in a station, for example, had a full complement of breakers at all voltages.

b) Transformers having a low probability of failure (about one in 17 years for utility power - not distribution - transformers), the single line diagrams are developed showing no breakers on the 138 kV at Stewart Crossing or for corresponding configurations at other stations, but with recognition of the need for separate breakers on the secondaries so that any parallels between transformation can be broken (without total interruption to the respective station).

c) Similar argument will apply for transmission faults.

At Carmacks, for example, loss of the Takhini line requires total interruption to the transmission at that location because the system will not be operable with backfeed from Stewart Crossing or Faro.

Accordingly, no breaker is shown on the Takhini line at Carmacks.

9.0 DESIGN OPTIONS IDENTIFIED BY YEC

The design options identified by YEC include:

a) Option 1: a 66 kV, 112 mile, overhead line, 397 MCM conductor, Carmacks-Stewart Crossing, no cable, (actually, 69 kV will be considered in this report, because that is the nominal rating of the Mayo-Dawson line);

This option assumes no intent to upgrade, otherwise a 397 conductor probably - not dead certain - would not be applied.

b) Option 1a: item a, 397 MCM conductor, but with a 6 mile (10 kM) 69 kV cable section part way along the circuit (I think roughly half way), and displacing a corresponding section of overhead line;

c) Option 2: item a repeated, but 138 kV design, 266 MCM conductor, no cable;

d) Option 2a: item b repeated, but 138 kV design, 266 MCM conductor, with cable;

e) Option 2b: item a repeated, 266 MCM conductor, with cable, initial operation at 69 kV, but the line and cable applied suited for later conversion to 138 kV operation.

Transformation would be applied consistent with the required interfaces between existing and new transmission voltages and with required supply to distribution loads.

10.0 LOAD CHARACTERISTICS AND SWITCHED MAGNITUDES

The loads in the Callison area and the villages between Carmacks and Callison are assumed to be primarily residential and commercial, with small industrials.

There will - or could - also be mining loads along the Carmacks-Stewart Crossing line section, those loads to presumably include mine and mill motors, some of which - skip hoists for example - could be significant, and variable in magnitude at fairly frequent intervals.

Assumed maximum individual motor sizes - or other comparable items such as, for example, welders - at the postulated mines or industrial loads is 250 hp.

(Even that rating could be a nuisance in the context of voltage drop if across the line start was applied; this item admittedly was not checked in any detail.)

Average system power factor is assumed as 0.9 at peak load, probably not too much different at light load.

Maximum switched load on any one distribution feeder or mining complex - not transmission voltage - at any station is assumed as about 3 MW.

11.0 INTERFACING DATA FROM YEC, EXTRAPOLATION TO POSSIBLE FUTURE SYSTEM ADDITIONS (EXCLUSIVE OF THIS PROJECT)

The various existing interfacing input data from YEC relating directly to the Carmacks-Stewart Crossing project follows.

There may be, in addition, some reference to what could be pertinent in interfacing possible future projects, such as additional generation, just for the record.

Not sure of the immediately preceding paragraph at this time.

12.0 INPUT DATA

The input data from YEC or assumed by myself that is pertinent to this first planning evaluation follows, with request that YEC check that it has been correctly interpreted.

12.1 Existing Generation Types

The existing generation on the system includes both hydro and diesel sets.

It is assumed that following interconnection, the diesel plants at the different stations along the route will not normally be operated, but will serve as backup supply during equipment outage - line fault, for example.

It is assumed, too, that since the diesels will generally be pretty small compared to transmission characteristics (for example, line capacitive current), the diesels will be applied for immediate area loads only, with minimum (if any) requirement to interconnect or transmit over anything higher than possibly 25 kV or a few miles to other locations.

The one exception might be the Dawson diesel plant, which has capacity, along with compensation at Callison, that might accommodate handling power transfer across some amount of 69 kV transmission, possibly even 138 kV for shorter distances.

12.2 Existing Generator Ratings and Characteristics

The Whitehorse generation totals about 45 MVA, rated 0.85 power factor.

The X_ds range from 0.85 to 1.075.

The other characteristics are on record if needed.

I do not have the Aishihik machine characteristics at this time; probably not essential, since Aishihik is electrically far enough away from the Carmacks interconnection that it will not be a ruling consideration.

The Mayo machines will influence things indirectly, and they are on record as part of the planning report from this office for the Mayo-Dawson interconnection (but not listed herein).

This matter of generator characteristics, voltage regulators, and excitation are items that will require consideration by YEC prior to final commitment to the project.

12.3 Existing Hydro Plant, Hydraulic Characteristics

The existing hydro electric generators on the system are either fairly short penstock (Whitehorse units) or are fitted with surge tanks (Mayo and Aishihik).

(There are a couple of very small hydro plants in the immediate Whitehorse area, but they will not be relevant to this report.)

Accordingly, the prospective system overspeeds on full load rejection are probably in the order of 25% or so.

Whatever the overspeed (and the less the better), it will influence the capability of the system to withstand load rejection without dropping transmission (which, if dropped, could make the overspeeds worse), since line charging (vars) will increase in proportion to frequency, while the disposal capability will be less than the inverse of frequency.

A bit of elaboration on this is included in Appendix 11.

12.4 Callison Synchronous Condenser

Again, the numbers for the different machine characteristics at Callison are on record in the planning report for the Mayo-Dawson project.

12.5 Shunt Reactors

Existing shunt reactor application includes:

12.5.1 Mayo

1.1 MVAR fixed,
1.1 MVAR switched,

both on the 6.9 kV system.

12.5.2 Callison

1.1 MVAR fixed,
1.1 MVAR switched.

12.5.3 Faro

1 x 8 MVAR, on the 138 kV, switched.
This 8 MVAR reactor and allied breaker to be relocated to Carmacks.

2 x 2 MVAR on a transformer tertiary, independently switched.

12.5.4 Carmacks

None (at this time).
The 8 MVAR reactor at Faro to be relocated to Carmacks.

12.5.5 Takhini

8 MVAR on the 138 kV, switched.

12.6 Transmission

12.6.1 Line Voltages, Lengths, Conductor Sizes, Existing Transmission

Line distances are recorded in North American, not European, units, because all of the technical data that I have relating to line characteristics are in those (North American) units, and I do not want to introduce inadvertent error in repeat translation from one to the other.

It is pretty obvious, I suppose, but recorded nonetheless, that to translate the numbers that are included in subsequent sections, following, from miles to kilometers:

a) multiply resistance values by 0.625;

b) multiply reactance values by 0.625;

c) multiply line charging values by 0.625;

d) multiply phase shift by 0.625.

Existing line voltages, lengths, and conductor sizes follow:

Aishihik-Takhini:	138 kV, 80 miles, 300 MCM ACSR
Takhini-Carmacks:	138 kV, 95 miles, 266 MCM ACSR
Carmacks-Faro:	138 kV, 106 miles, 266 MCM ACSR
Mayo-Stewart Crossing:	69 kV, 32 miles, 266 MCM ACSR
Stewart Crossing-Callison:	69 kV, 108 miles, 397 MCM ACSR

Postulated new transmission alternatives:

Carmacks-Stewart Crossing	112 miles, no cable or 106 miles + 6 miles of cable

both of the above at either 69 or 138 kV, or possibly initially 69 kV with later conversion to 138 kV.

Conductor options as stated by YEC include 266 and 397 MCM.

Those sizes are to more or less match the Carmacks-Stewart Crossing transmission capacity with

a) the incoming supply from Takhini, and

b) the ongoing to Stewart Crossing,

the latter at 69 or 138 kV, whichever applies.

12.6.2 Line Geometry

YEC had asked for comment on line geometry.

I do not know what to say except that the existing Takhini-Faro line design or any other conventional 138 kV configuration would work; I would see no problem with electric or magnetic fields in any technical context.

As to whether there could be effect on health for anyone living near the line, I simply do not know, and I think the utility industry is still not certain on this item.

I do not have the existing lines' geometry, but will assume typical values or configurations for the analyses.

It is accurate to say that any errors that may result in line charging or whatever will be irrelevant to this initial and outline report.

13.0 TRIAL LOAD FLOWS

A number of trial runs were done to using the guides of power angle, short circuit levels, voltage profiles, required reactive, and so on (and as outlined in the appendices) to get an idea of the limits of practical operation.

The runs - and all ongoing runs - were done with a pretty flat voltage profile, not more than about 3 to 5% droop or rise between any of the stations.

That was to try to reduce losses (which doesn't always work) and, in particular, to avoid any possibility of triggering voltage instability (see Appendix 15).

Those trial runs are not included in the report ; they were simply an assist to myself in getting some idea of required equipment ratings, particularly shunt compensation.

14.0 SINGLE LINE DIAGRAMS, AND STATION EQUIPMENT IDENTIFICATION AND RATINGS

The practical transmission limits and required compensation were used to develop (I think) self-explanatory single line diagrams, Sketches 1, 2, 3, 4, 5, and equipment ratings and application based on no contingencies of equipment outage.

The need or not to cover contingencies will be decided by YEC.

If they do, through duplicate transformation or whatever, that will make the situation better in the context of load flows (less reactive losses).

The various station equipment is identified, following, and the numbering (other than for line voltages and conductor size) used to relate it to the different single line diagrams.

14.1 Option 1 Carmacks Transformation
Option 1a
Option 2b

138/69/13.8 kV auto-transformer

Total capacity in one or more units:
18/24/30/33 MVA on the primary and secondary
6/ 8/10/11 MVA on the tertiary

± 10% probably in the series winding; not in the neutral, nor as 69 kV taps.
Reason is to have the tertiary follow the 69 kV regardless of tap position.

(The tertiary voltage may be optimized to other than 13.8 kV.)

Expected (not specified) order of magnitude impedances:

High - low:	7% on base 18 MVA
High - tertiary:	20% on base
Low - tertiary:	-1% on base

(No error in the -ve sign.)

14.2 Option 1 Stewart Crossing Transformation
Option 1a
Option 2b

There being no 138 kV transmission and 138/69 kV transformation, Stewart Crossing will require a separate unit as connection to the shunt compensation - capacitors, reactors, condensers.

It may be possible to specify a transformer that would be reapplicable - perhaps at Callison - after 138 kV is applied between Carmacks and Stewart Crossing.

That prospective reapplication might require some ability to reconnect internally, etc., such facility likely costing very little (compared to a new transformer for Callison, for example).

The item is noted.

The detail can wait.

In the meantime:

69/13.8 kV transformer.
Star grounded/delta.
6/8/10/11 MVA on the primary and secondary.

No off-load taps.
No OLTC.

The neutrals of the three phases to be brought out on separate 15 kV bushings, however, for possible insertion of a neutral end regulator in the future.

14.3 Cable and Allied Compensation Option 1a

If 69 kV design between Carmacks and Stewart Crossing without intent to upgrade, then:

a) 350 MCM, 69 kV class, oil filled copper cable or Al equivalent would be required if the postulated 35 MW loaded was ever to be realized.

b) Facts are, however, that that loading is only marginally attainable because of system performance, including significant voltage profiles beyond the range of common sense, high reactive transfers to maintain voltage as far as possible, and the high losses.

c) Accordingly, likely no larger than about 4/0 copper would be justified;; I could be wrong on that, though, if 69 kV design with 397 MCM line was to be loaded to the operational limit, losses not being regarded as a constraint.

d) That 4/0 rating could also constitute a bottleneck if the system was ever upgraded through additional transmission - not increasing the voltage.

e) In any event, the cable charging in an amount of 4 MVAR would almost certainly not require compensation - application of shunt reactors - at the cable terminals.

The high probability is that it would be practical to dispatch that reactive to Carmacks and/or Stewart Crossing, even at light system load.

f) Accordingly, cable reactors were not considered for the test runs at 69 kV.

Option 2a

If 138 kV between Carmacks and Stewart Crossing, then:

a) 4/0 or 250 MCM 138 kV class, oil filled copper cable or Al equivalent would be required if the postulated 35 MW loaded was ever to be realized;

b) Cable charging would total about 16 MVAR.

c) That amount probably exceeding practical dispatch in total to Carmacks and Stewart Crossing, shunt reactors would almost certainly be required at both cable terminals, with allied breakers.

Pretty certain, but not absolutely certain, of the preceding paragraph.

d) The north terminal reactor would be rated 10 MVAR, and

the south terminal reactor rated 5 MVAR.

e) The different combinations of connection and disconnection would result in any of

15 MVAR
10 MVAR
5 MVAR, and
0 MVAR being connected, with corresponding net reactive to system being

1 MVAR
6 MVAR
11 MVAR
16 MVAR,

all at nominal 138 kV.

f) Apart from the convenience of var dispatch - item e, preceding - the shunt reactance should be split anyway to avoid loading the cable to excess with reactive transfer.

Considerations are losses and thermals - including possible long term soil dryout;

That dispatch capability was not included in the load flows for 138 kV transmission, because I did not know if YEC would consider the cost of the breakers (to get access to that reactive) to be justified.

If breakers are indeed applied, it will only make things better.

<u>Option 2b</u>

If Option 2b was to be modified to include initial operation at 69 kV, then cable reactors could be included or not, but again, almost certainly not needed at that 69 kV (see Option 1a, this section).

<u>All options</u>

Cable arresters will be required, both terminals.

The specification to include the obvious protection of the cable, but including the need as well to withstand cable discharge current on conduction.

<u>14.4</u> <u>Option 2</u> <u>Stewart Crossing Transformation</u>
<u>Option 2a</u>

138/69/13.8 kV auto-transformer

Total capacity in one or more units:
13.5/18/22.5/25 MVA on the primary and secondary.
6/8/10/11 MVA on the tertiary.

or possibly

15/20/25/28 MVA on the primary and secondary.
6/8/10/11 MVA on the tertiary.

± 10% in the series winding; not in the neutral, nor as 69 kV taps.
Reason is to have the tertiary follow the 69 kV regardless of tap position.
But that requirement is not confirmed; the OLTC might end up in another location on the winding.

(The tertiary voltage may be optimized to other than 13.8 kV.)

Expected (not specified) order of magnitude impedances:
High - low:' 7% on base 13.5 MVA.
High - tertiary: 20% on base.
Low - tertiary: -1% on base (regardless of tertiary voltage).

(No error in the -ve sign.)

14.5 138 kV Breakers - All Options

138 kV breaker.
No less than 600 amperes.
No less than 1,000 MVA interrupting capacity.

Rated to accommodate line switching with up to 20 MVAR reactive (line charging) current.

Application on an effectively grounded system.

14.6 Carmacks/Faro Line Breaker at Takhini

No switching surge studies could be, or were, done.

Applying judgment though, and recognizing the possibility that the Carmacks/Faro line breaker at Takhini could be confronted with unscheduled tripping (cause undefined), that breaker could be required to interrupt up to about 30 to 35 MVAR of line charging at rated or even higher voltage.

I have no idea if the existing breaker could withstand that duty.

If not, the solution could be replacement by a breaker with suitable characteristics, or addition of switching resistors on the existing breaker.

(I think the existing breaker is actually an S & C circuit switcher, though, so adding resistors may not be an option; don't know that for sure.)

The item is flagged.

14.7 69 kV Breakers - All Options

69 kV breaker.
No less than 600 amperes.
No less than 1,000 MVA interrupting capacity.

Rated to accommodate line switching with up to 20 MVAR reactive (line charging) current.

Application on an effectively grounded system.

14.8 138 kV Switchgear Disconnects - All Options

All rated 600 amperes.

14.9 138 kV Transformer Disconnects - All Options

All rated 600 amperes.

At Stewart Crossing (if transformers applied), the transformer disconnects to be power operated.

At Stewart Crossing (if transformers applied), the disconnects to be fitted with side mounted power operated (close only) two phase ground switches on the transformer side.

600 amperes, 5 seconds.
Closing capability against maximum 2,000 ampere fully offset wave.
Desired closing time no greater than 2 to 3 seconds (to prestrike, not necessarily full closed).

14.10 138 kV Buswork - All Options

No less than 300 ampere rating.

14.11 69 kV Buswork - All Options

No less than 600 ampere rating.

14.12 Tertiary Breakers - All Options

Voltage class consistent with transformer tertiary voltage selection.

Current ratings consistent with tertiary voltage
15 MVA equivalent at any voltage.

Interrupting rating 350 MVA.

14.13 Tertiary Capacitors - All Options

The ratings have not been optimized.

Tentatively rated 2 to 5 MVAR, contingent on YEC operational withstand during switching thereof and resulting step voltage change.

14.14 Tertiary Reactors - All Options

The ratings have not been optimized.

Tentatively rated 2 to 5 MVAR, contingent on YEC operational withstand during switching thereof and resulting step voltage change.

14.15 Synchronous Condensers - All Options

The ratings have not been optimized.

Tentatively rated +5, -3 MVAR.
Probably 4.16 or 6.9 kV preferred (lowest cost).

The preferred X_d, direct axis reactance, is no less than about 0.8 per unit, to accommodate reactive dispatch during worst case system overspeed (guessed/estimated as 10% for upsets from which the system will recover).

X_d/X_q to be submitted by the manufacturer.

14.16 Tertiary Grounding/ Station Service Supply - All Options

Tertiary resistive grounding is desired.

The items are not shown on the single line diagrams.

Application would typically be
13.8 kV grounding transformer + allied neutral resistor
Star/delta or zigzag at the manufacturer's option.

Ground current:	25 amperes, 10 seconds
Fault recurrence:	In not less than 60 seconds

The rating of that transformation would almost certainly allow it to be used as station service supply as well.

The primary would likely be zigzag.

If no Lg connected station service loads, the secondary could be any configuration.

If Lg connected secondary loads,

a) star secondary could be applied, but with prior check on the phantom delta impedance of the transformer, or

b) zig-zag secondary could be applied (but this is an unlikely application).

14.17 Potential Transformers

Options 1, 1a, 2b

At Carmacks:
one three phase set of 138 kV potential transformers, on the Takhini line.

(probably) one three phase set of 69 kV potenial transformers (depends on relaying application.

At Stewart Crossing:
One three phase set of potential transformers.

Options 2, 2a

At Carmacks:
one three phase set of 138 kV potential transformers, on the Takhini line.

At Stewart Crossing:
one single phase 138 kV potential transformer.

(probably) two three phase sets of 69 kV potenial transformers (depends on station configuration.

14.18 Metering, Relaying, Control - All Options

Conventional application.

Probably about 10% of the respective station (and not including transmission) costs.

14.19 Communications - All Options

Interstation communications will or may be required for any or all of

voice
telemetering
supervisory control
transfer trip or other role in relaying

possibly other roles, none yet defined.

15.0 TEST CASES

The system performance is very much affected by the transmission characteristics.

Obvious, I suppose, but noted nonetheless because of the fairly low X/R ratios of the transmission itself and the distances (which are pretty long for either 69 or 138 kV).

A lot of cases were tested.

I wish I could record all of them, but it would be pretty time consuming and, I think, not accomplish very much.

Introductory comment and constraints on the specific load flows and others that might be done (and on the applications engineering that will ensue if the project goes ahead) follow:

1) Shunt compensation is obviously required for reactive dispatch.

Capacitors and reactors will fill that role in part.

2) The capacitor/reactor blocks will be magnitudes such that voltage correction will be required when they are switched.

To assign that role to transformer OLTC would result in too slow correction, and would literally wear the tap changers out in pretty short order; this could be an operating and maintenance nightmare.

3) Synchronous condensers will therefore be required, range to span the amounts of capacitors/reactors to be switched in any one block, plus a sensible amount of margin.

(Which is the reason that +5 -3 MVAR condensers are suggested, spanning the suggested 2 to 5 MVAR capacitor and reactor ratings.)

Static vars compensators were not considered as an alternative to condensers because there is a desire to get the fault levels up to assist in relaying performance, distribution transformer fuse blowing, and the like.

Condensers will provide such assist.

Static var compensators will not.

4) The options were tested with as flat voltage profile as was sensibly attainable,

a) to reduce or at least compromise on losses, and

b) to forestall as far as possibly any drift toward voltage instability.

5) All of the options resulted in pretty "soft" performance, with real sensitivity to both real and reactive loading.

The 69 kV cases, and particularly 69 kV with 266 MCM conductor, were obviously worse in that context.

6) Series compensation of the transmission was tested to see what improvement might be obtained.

No gain of any relevance.

The X/R ratios of the lines are too low to make this an effective option.

And such compensation cannot be applied to excess, because a zero reactance system is not stable - sounds odd, but true.

Further, too much series compensation would lessen the effectiveness of shunt compensation in voltage correction, and so would allocate a greater role to the OLTCs.

Could wear them out.

Finally, I would have a bit of unease about the possibility of subsynchronous hunting; it might happen if the numbers were right (I could rough out numbers, but you would really need an expert on series compensation, which I am not), and if the system was prone to such hunting, the resolution could be pretty costly.

7) Satisfactory (although not ideal) steady state performance can be obtained at Carmacks, Faro, Stewart Crossing, Callison, and Mayo-Elsa for defined loadings.

The dynamic situations are the problem.

The lines are so long - and I refer particularly to Carmacks-Stewart Crossing, with the prospective mining loads - that the tapped loads, such as the mines, McQuesten, and so on, will be subject to relevant voltage changes as the "through" power changes, even though the stations - Carmacks, Stewart Crossing, Mayo, and Callison are all maintained at satisfactory levels.

(Again, though, those prospective voltage changes at approximately mid-point between Carmacks and Stewart Crossing will be reduced if cable is applied with cable reactors, and the reactors are switched.)

In summary, altering the Callison loads, for example, and even with flat voltage at that station, will swing the intermediate loads on the transmission.

8) Without reflection on anyone's competence, but as an assist in the concept if one is not familiar with this:

a) set two vectors, equal magnitude, in the same orientation at the two ends of a straight line in space;

the vectors parallel each other;

b) join the tips with a piece of string drawn taut;

c) for zero angle along the line - that is, zero load on the circuit - the vectors will be in phase, and the distance from the string to the base line will be the same all the way along the circuit;

d) now alter the angle (that is, alter the power transfer) between the vectors to say 30 degrees by rotating one of the vectors, but not tilting it toward the other (have to let the string stretch a wee bit);

the distance to the base line at the terminals remains unchanged;

the distance say at mid point is substantially less than that at the terminals (lower voltage).

The foregoing analogy is not dead-on as to magnitudes, of course, but it conveys the idea in principle very accurately.

And the foregoing illustrates pretty clearly, I think, why the terminal voltages on a circuit could be in pretty good shape while those along the line would vary with line loading (and corresponding power angles).

9) Continuing from Item 7, the tests showed that regulators or reactive switching at the tap points - the mines and so on - could correct those voltages.

But so doing will swing the terminal voltages.

The voltage control and reactive dispatch gear at the different stations could - and I am just about dead certain would - start to argue with each other, particularly at higher loadings, ending up in voltage oscillation.

10) As a <u>very</u> rough guide, the prospective swings (not the absolute voltages) at any station will vary as the square of the transmission loading.

That has to be qualified by identifying the real and reactive load components.

But it is a guide.

11) I tried, as best I could, to monitor for impending voltage instability.

That was through altering the reactive support at a station.

For the 69 kV options between Carmacks and Stewart Crossing (with the operationally attainable, not the defined 35 MW, loading), even as little as a 3 MVAR change has a dramatic effect on the voltages across the system; that applies for 69 kV with 266 MCM conductor in particular.

The 138 kV options are less sensitive, but still "soft" - in fact, just about equally so for the postulated peak loadings of 35 MW at that voltage.

(The foregoing paragraph is based on a comparison of 138 kV transmission with 266 MCM conductor to 69 kV with 397 MCM.)

12) Although again, I cannot possibly tabulate all of the test runs, I did want to be as sure as possible that there was not something wrong in the analyses.

Accordingly, I did a rough comparison against the planning for the Mayo-Callison transmission, now being commissioned.

In the work that I had done thereon, and I think confirmed by independent check by others, it appeared that that 69 kV system would be able to handle about 10, possibly 15 MW between Stewart Crossing and Callison if supply was available at Stewart Crossing, of course, and with a pretty healthy system behind it.

That was with a 397 MCM conductor, as is actually applied.

13) Again, there were at least two independent checks on that preliminary work, and, as far as I know, no different conclusion.

So,

a) assuming the healthy bus to be at Carmacks,

b) recognizing the facts of either a 266 MCM or possibly 336 MCM conductor at 69 kV between Carmacks and Stewart Crossing, and

c) pretty close to the same distances for the two line sections,

loading up to 15, possibly 20 MW between Carmacks and Stewart Crossing appeared to represent what might be attainable.
I then used a MW-miles approach.

Same result.

I then used the line power angle approach (Reference, Appendix 6).

Same result.

14) The same was done for 138 kV transmission options.

One would expect that the transmission capacity would go up roughly as the voltage squared, and if 10 to 15, possibly 15 to 20 MW was attainable at 69 kV, then presumably 40, possibly 60 MW would be attainable at 138 kV.

Not the case, because there is a "source impedance" at Carmacks that has to be taken into account, and that impedance is more relevant to 138 kV transmission capacity than to 69 kV.

14) In summary of all of the foregoing, I am pretty confident that the defined capacities at the two voltages are close to reality; there may be error, but not in amounts that would seriously mislead YEC.

15.1 Test Runs, Results and/or Conclusions Thereof

Three basic applications were tested without cable, because the cable has little or no effect on system performance - only on the requirement for switching or not, and with possible spin off effect on shunt compensation needs.

The three, in brief repetition, are

69 kV, 266 MCM conductor;

69 kV, 397 MCM conductor

138 kV, 266 MCM conductor.

Again, without discounting the need to do a reasonably comprehensive report, there was no apparent gain in examining the cases with cable options in detail; cable ratings, requirement or desire for switching or not, and allied items are covered in other sections.

15.1.1 Results, Options 1 and 1a, 69 kV, 397 MCM Conductor, With or Without Cable

Case 1

Load Flow 1

26 MW to Stewart Crossing
10 MW to the mines
2 MW to Carmacks village + Faro

Total 38 MW + losses north from Takhini.
Losses: 15.57 MW, 42% of load.

Cable or not does not much matter.

The system was first tested with 15 MVAR shunt compensation support exiting Stewart Crossing to the south.

Working north to south, the voltages and reactive flows are reasonable as far as Stewart Crossing.

It is obvious that cable charging - if cable was included - would be an assist, displacing part of the reactive delivery from Stewart Crossing.

At nominal 4 MVAR, it would have noticeable, but not likely great or ruling impact.

In any event, the results in that Load Flow 1 shows a 75.6 kV voltage at the Carmacks station.

That would not be a problem for the line itself, nor for the Carmacks transformation if the OLTC thereon was suitably located; that would likely require neutral end OLTC rather than in the series winding.

But the 76 kV to 69.7 kV voltage profile along the line raises alarm regarding voltage stability; it is not proof that there would be a problem, but certainly indicates - in my opinion - justification for some real unease.

And, of course, if load rejection were to occur, the voltages could then be a little on the wild side.

No way to plan or operate a system.

Case 2 Results, Options 1 and 1a, 69 kV, 397 MCM Conductor, With or Without Cable

Case 2

Load Flow 2

Case 1 was repeated to try to get the Carmacks voltage to a reasonably sensible level.

26 MW to Stewart Crossing
10 MW to the mines
2 MW at Carmacks village + Faro

Total 38 MW + losses north from Takhini.
Losses: 17.43 MW, 45.8% of load.

The system was then tested with 20 MVAR (instead of 15 MVAR) support at Stewart Crossing - Reference, Load Flow 2.

That corrected the Carmacks voltage to 70 kV.

It is not the intent to repeat this type of comparison for a multitude of cases, but this one shows the dramatic effect of a correction of var dispatch.

Note the effect, too, of straightening out the voltage profile through reactive dispatch on a fairly low X/R ratio transmission system; the losses go up.

(Doesn't always apply, of course; it depends on the loading.)

One again has to recognize the consequences of major load loss - say tripping the Callison line.

The required correction would be well beyond the capacity of synchronous condensers, unless really big ones, in the 10 to 12 MVAR range.

Switching reactive off at Stewart Crossing would be an option, of course, but with the breakers confronted with higher than rated voltage and higher than rated or intended reactive switching duty.

15.1.2 Results, Options 2 and 2a, 138 kV, 266 MCM Conductor, With or Without Cable

Case 3

Load Flow 3

25 MW to Stewart Crossing
10 MW to the mines
2 MW at Carmacks + Faro
Total 37 MW + losses north from Takhini.
Losses: 9.2 MW, 24.8% of load.

The load flow is considered self-explanatory, no elaboration needed.

Voltages and reactive flows are all pretty reasonable.

As with all of the other load flows, the intermediate loads (at the mines) will be subject to noticeable voltage variations as their loads change - even if the Stewart Crossing and Carmacks voltages are held pretty constant.

15.1.3 Results, Option 2b, 69 kV, 266 MCM Conductor, With or Without Cable

Case 4

Load Flow 4

20 MW to Stewart Crossing
5 MW to the mines
2 MW at Carmacks + Faro

Total 27 MW + losses north from Takhini.
Losses: 9.24 MW, 34% of load.

Again, the load flows are self-explanatory.

The voltage at Carmacks is 75.6 kV.

Again, that is too high.

Case 5

Load Flow 5

Case 4 was repeated to try to get the Carmacks voltage to a reasonably sensible level by reallocation of var dispatch.

20 MW to Stewart Crossing
5 MW to the mines
2 MW at Carmacks + Faro

Total 25 MW + losses north from Takhini.
Losses: 16.7 MW, 62% of load.

Compared to Case 4, and recognizing the fact of same loads (as distinct from losses), the losses appear to be ridiculously high; one would have a fair suspicion of error in the analysis.

I certainly did.

I cannot find such error.

The cause (as far as I can make out) is the extra reactive dispatch from Stewart Crossing, that affects the losses all the way to Takhini.

15.1.4 Comment on Losses

The losses in all cases appear to be very high.

Again, I checked in a number of ways, and cannot find any error.

But I do note that this item should be monitored; in spite of best effort, I may have made some stupid mistake and repeated it.

16.0 CONCLUSIONS

I am not too happy with this report.

It is obviously based very much on judgment and experience, and, I think, is close to reality, but is not nearly as comprehensively documented as I would like.

Much of the time was spent in testing other possibilities in principle - series compensation for example - to see if they could be made to help in any context.

I did not think YEC wanted much input on exclusions - what would not work.

They wanted what would work.

But I had to determine what could be sensibly included for consideration, even though eventually rejected.

YEC did not specifically ask for recommendations.

Never being one to mind my own business, implicit recommendation, or at least suggestion or opinion, is included anyway.

In my opinion, the defined options were sensible ones - they could not be judged as to performance, etc., until they were examined.

The intended compensation for all options would accommodate system energization without distress.

Turning to the load flows, voltage performance, and the like, I do not think that any of the 69 kV options are worth considering, unless

a) the prospective transfer will never exceed about 10, 12, maybe 15 MW, or,

b) if it does, additional transmission would be built (probably for security of supply, as well as capacity).

I think, too, although not part of the scope nor actually done (it would be far too soon, since there is not even commitment to the project), that stability and fault levels with 69 kV operation would be real problems.

As for 138 kV transmission, there is likely no sense in mismatching the line capacities themselves by applying say a 397 MCM conductor to Stewart Crossing when there is only 266 MCM on the Takhini-Carmacks circuit.

Applying 266 MCM conductor, with or without cable, and with 138 kV operation, will accommodate the defined 35 MW transfer in the steady state.

I do not know with certainty whether performance at 138 kV and that 35 MW transfer north from Carmacks would correspond to operating requirements for quality of supply.

I am more than a little uneasy that it would not.

As for correcting that performance, if I am right, I think the only realistic answer would be a greater amount of synchronous condensers; not cheap, I know, but I cannot see any other solution.

17.0 CLOSING COMMENTS

I want to be sure that YEC feel they have received value for money.

The length of the report would perhaps not support that.

I hope the content would.

A lot of time - by far the most - was in considering possible alternatives for voltage correction and so on.

Would OLTC fill roles that might otherwise be assigned to compensation - and the converse?

What would be the optimum location for compensation?

Dynamic vs fixed?

The result, in my opinion, was to pretty much eliminate the alternatives that entailed much risk of poor performance, and that is why optimization was concentrated on the defined options with necessary enhancement.

I hope the end result - this report - corresponds to YEC intent and need.

A. B. Sturton

January/2003

APPENDICES

APPENDIX 1 LOAD AND SHORT CIRCUIT LEVELS

Assuming flat voltage at one end of a line or system, the following are pretty good guides for initial approximation of the operability of a system:

a) if the ratio of three phase fault to load at the load terminal is greater than 10 (and assuming nothing very dramatic in the way of large motors or the like), the system will likely be sensibly operable with no undue sophistication;

b) for ratios between 10 and 5, there will be increasing nuisance, and capital costs for voltage correction and the like;

c) for ratios between 5 and about 2 or so, satisfactory operation will become more difficult, and there may be a need for significant sophistication, with allied costs;

d) for ratios less than 2, very real difficulties appear, approaching the level of unmanageability.

APPENDIX 2 LINE RESISTANCE

Line resistance is obviously determined by conductor size.

Some smaller conductors, not much used anymore, have the characteristic of sudden and quite dramatic increase in effective resistance at currents below thermal withstand.

That is because of the "lay" of the Al strands over the Fe.

It is assumed that such conductor (such as a 266 MCM 6/7) would not be applied on any new circuits, and that the conventional or expected performance would apply.

APPENDIX 3 LINE REACTANCE

For circuits including and between about 12 kV and 138 kV, the reactance will typically be about 0.7 ohms/mile.

At less than 12 kV the number will usually be a bit less - less spacing.

At above 138 kV, the converse applies - unless bundled conductor configuration is used (not likely for this project).

That 0.7 number was used in the first approximations in this report to get a sense of performance.

Once the conductor size was determined (266 MCM ACSR, 26/7), accurate numbers were used.

Only the more accurate analysis is included in the report.

APPENDIX 4 LINE CHARGING

Typical line charging (capacitive) currents at different voltages are listed, following:

Voltage	MVAR/MILE
12 kV	0.001
25	0.004
34.5	0.075
69	0.030
138	0.10

The corresponding ohmic values can be readily worked out.

The numbers are the phase-neutral, positive and negative sequence numbers.

The zero sequence numbers are different to the positive and negative sequence, but are seldom required for planning studies.

APPENDIX 5 LINE SURGE IMPEDANCE AND SURGE IMPEDANCE LOADING

The following has acknowledged errors in it because it is very condensed; all I want to do is demonstrate the principles.

Power flow through a reactance causes a fall-back in power angle.

It also results in a reactive power (I^2X) loss.

A transmission line or cable has reactance and capacitance.

It will use up vars for through power flow, but will also generate vars V^2/X_C) from line capacitance.

The reactive losses are proportional to the sum of the real and reactive components of "through" current.

The generated reactive (line charging) is more or less constant as long as the line does not have too significant a voltage change along it.

For a zero resistance line, and for real power throughput only, the loading at which line (I^2X) reactive losses equal line V^2/X_C) reactive generation is called the Surge Impedance Loading (SIL).

The ohmic impedance corresponding to SIL is defined as Surge Impedance (SI).

$$SI = \sqrt{L/C}$$

$$= \sqrt{X_L \times X_C}$$

Typical SILs and SIs for distribution and lower to medium voltage overhead transmission follow:

Voltage	SI	SIL
4.16 kV	375 ohms	0.046 MW
12.47	400	0.388
25	400	1.560
34.5	400	3.0
69	400	12.0
138	400	48.0

The surge impedance for cable will typically be about 50 ohms or so (one can work out the numbers from the cable data), and the SILs at different voltages will be about 8 times the above numbers.

APPENDIX 6 LINE POWER ANGLES

The theoretical line power angle - the phase shift across the line, with fall-back in the direction of power flow - will be 0.12 degrees/mile at SIL (surge impedance loading), and proportional to loading (as a multiple of SIL) for up to about 2 x SIL; after that, errors start to appear in the short cut approach.

Any reactive component of through power flow in association with line resistance will cause phase shift as well; var flow and the line resistance will cause advance - not fall-back - of power angle.

An integrated analysis is obviously required to get accurate results, but again, the foregoing allows for "getting a handle" on probable performance before going into too much detail.

No point in going to sophistication if the "back of the envelope" approach shows beyond any doubt that the plan or idea, whatever it may be, is not going to work anyway.

Assuming that resistive drop is not an unmanageable problem (in the context of required voltage correction or losses), the following are not too bad guides for identifying likely performance of transmission:

a) if the power angle is less than 10 degrees at peak load, likely no problem;

b) if the angle is between 10 and 15 degrees, some voltage correction will likely be required (probably would be anyway);

c) between 15 and 20 degrees, the line will likely be operable, but noticeable voltage control and var dispatch will be required;

d) between 20 and 30 degrees, things get progressively tougher, and significant sophistication and costs may start to appear;

e) beyond 30 degrees will typically require a healthy level of sobriety to develop a sensibly operably system, and the capital costs will start to increase fairly dramatically (as, likely, will losses).

The forgoing is a pretty informal way of presenting the case, but I think it is close to reality - although there are acknowledged omissions.

The foregoing guides were used as assists in the first approximations for analysis of the Carmacks - Stewart Crossing interconnection.

APPENDIX 7 LINE TERMINAL VOLTAGE ON AN UNLOADED, UNCOMPENSATED CIRCUIT (CABLE OR OVERHEAD LINE)

To determine the per unit terminal voltage on an unloaded circuit that is open at the far terminal

a) take the line length in miles;

b) multiply it by the phase shift in degrees at SIL (0.12 degrees/mile);

c) take the cosine of item b;

d) get the inverse of item c;

e) the resulting number will be the per unit voltage at the remote (and open) terminal, as a multiple of the actual local station voltage;

Contingent on circumstances, the local station voltage may be normal, high, or low.

Thus, item e will depend on local station conditions.

APPENDIX 8 LINE CORONA

I am no expert on corona, but have some experience with it.

Typically, the item would belong under a presentation on applications engineering - which this file is not - but it could affect conductor or even voltage selection, which are planning functions.

Without further ado, the comments (relating to transmission only, not distribution) follow:

a) Corona may be influenced by any or all of

- line voltage
- line geometry and conductor spacing
- line conductor diameter
- line altitude above sea level
- atmospheric conditions

b) Existing designs on the YEC system - with presumably satisfactory operation - include down to 266 MCM at 138 kV.

c) My judgment is - taking into account the altitude - that less than about 266 MCM might trigger incipient corona.

d) At the same time, losses, voltage regulation, reactive dispatch, and other considerations would likely preclude any smaller conductor anyway.

Thus, (from Item d) I do not think that consideration of corona will impose any constraint on line conductor selection, but at the same time (and for 138 kV in particular) I would not go much smaller without checking with someone who is a corona expert.

As for 69 kV, the corona constraints would be less, of course, but again, I think other items would rule in conductor selection.

No conclusion in the foregoing; just a note or two of caution.

APPENDIX 9 LINE ELECTRIC AND MAGNETIC FIELDS

I am aware of, but am no expert on, the existent of electric and magnetic field around transmission.

Accordingly, I am extremely hesitant to offer numbers that might well be in significant error.

From actually working (as an employee, for 17 years) for one of the largest utilities in Canada, though, with much field work, and having worked for all of the generating utilities in Canada (except British Columbia Hydro) when with a major engineering company and as an independent, I am extremely doubtful that the intensity of either type of field would be relevant.

It will be assumed for this report that such fields are not a constraint; if factual data is required, someone with competence and experience that I do not have would be required to get the numbers.

Further, it would require someone in the medical profession, not and engineer, to judge the relevance of the numbers if effect on humans was the concern.

APPENDIX 10 LINE TRANSPOSITIONS

It is probably accurate to say that, in the very great majority of cases, the prospective differences in individual phase reactances and resulting negative sequence voltage from circuit loading are what compel the inclusion of transpositions to eliminate such negative sequence.

In this case of the Carmacks-Stewart Crossing circuit, and because the total transmission is so considerable compared to system short circuit levels and so on, the ruling consideration may instead be the differences in phase charging currents on an untransposed line.

It is possible, too, in the absence of transpositions, that steady state (capacitive) neutral currents might be a problem.

It is neither justified nor sensible to calculate to see if the transpositions could be eliminated; they might, for now.

But the situation could change as loads increase.

The only sensible action is to include full transpositions.

And, to preclude oversight, the transpositions on the Takhini-Faro circuit - which it is assumed were applied at the time - must be examined to be certain that they will correspond to need with the line sectionalized at Carmacks.

APPENDIX 11 EFFECT OF LOAD LOSS AND SYSTEM OVERSPEED ON REACTIVE GENERATION AND COMPENSATION

Load loss - or possibly some other circumstances - will result in system overspeed, magnitude dependent on the amount of load loss, the integrated inertias of the various rotating plant, and on generator governor action.

Print outs of frequency regulation for scheduled operation on the WAF system show very good control.

As said earlier in the report, the various generation is equipped with pretty short penstocks or surge tanks.

Accordingly, and without having an actual number, the gating times are likely pretty short (5 seconds or so?).

Machine inertias are assumed as fairly typical for hydro plant of this type, with H = perhaps 3.0 or so.

Now a full load rejection is pretty unlikely, but it would represent worst case.

To demonstrate the point that I want to make, suppose a full load rejection did occur.

The initial rate of frequency rise would be

$$\frac{df}{dt} = \frac{60}{2H} \times dP$$

where dP is the per unit load change (in this case, 100% or 1 per unit).

With H = assumed 3.0 and dP = 1, the initial rate of frequency rise, prior to governor action, will be

$$\frac{df}{dt} = \frac{60 \times 1}{2 \times 3} = 6 \text{ Hz/second}$$

Now there are three things that will act in conjunction to worsen any prospective reactive disposal:

a) the line charging for any given voltage will increase in proportion to frequency;

bear in mind that that assumes the same voltage profile along the line, which will not be the case (see ongoing items);

b) the reactive disposal capability of shunt reactors will be in inverse proportion to frequency, assuming constant voltage;

EFFECT OF LOAD LOSS AND SYSTEM OVERSPEED ON REACTIVE GENERATION AND COMPENSATION

c) the X_d of a synchronous machine will increase at significantly higher than inverse proportion to frequency because the generator (or synchronous condenser) slides toward the unsaturated mode of operation, and so the var absorbing capability will drop, typically quite dramatically;

d) referring back to Appendix 7, the voltage rise at higher frequency will be greater.

Everything works against holding the voltage down during overspeed.

In my opinion, this is a very important item for consideration in selecting a transmission voltage; there is no point in prejudging its effect, but it will be significant.

Just to put one item to rest (because I have heard this argument): tripping generation to get the voltage down is not an option; such action would just make matters worse - maybe a lot worse.

If the voltage is up very much - possibly more than 110% nominal, although I cannot offer an exact number - transformer core heating will occur at a very rapid rate.

Even if On Load Tap Changers (OLTC) were applied and happened to be at the right location in the transformer to accommodate more turns on the (problem) high voltage side, it could turn out that the switching of currents with high harmonic current (which would certainly apply for severe overvoltage) would introduce internal switching surges and possibly transformer fault.

Not a likely occurrence, but don't rule it out.

As an aside, a very similar situation was flagged on the Mayo-Dawson transmission project, where overspeeds and the allied reactive generation and disposal could have been real problems; in that case - as YEC obviously knows - the possibility (and consequences thereof) were taken seriously enough that braking resistors are applied at Mayo to control the overspeeds.

Braking resistors in the amounts probably needed for worst case on the WAF-Mayo-Dawson integrated system would be a very expensive proposition, in an amount such that other alternatives would be much desired.

APPENDIX 12 PROBABLE OPERATING CONSTRAINTS IN SHUNT COMPENSATION AND DISPATCH THEREOF

This section is very much a judgmental presentation, because I cannot "prove" that what I say is right.

But I think the approach is reasonably close to reality.

1) Shunt reactors will obviously be required for any of the postulated transmission configurations.

2) Shunt capacitors might be needed, too, as loads increase.

3) Both would have to be at least partly switched - the capacitors, if they are ever needed, probably all switchable.

4) Both applications would represent "step" control of the voltages.

5) There could - almost certainly would - be complementary control in the form of OLTC to straighten out the var flows on transmission and so preclude what might otherwise be pretty steep voltage profiles along the lines with corresponding loss increase.

6) Now looking at the almost certain mode of operation, the system or parts thereof was first analyzed with shunt reactor application to preclude overvoltages.

7) As loads were applied, some reactors were switched off.

8) Item 7 resulted in "step" voltage changes roughly equal to reactor rating/three phase short circuit level at the point of switching.

9) I do not know what YEC would regard as tolerable voltage changes for such switching; my suspicion is probably no more than ± 5%, otherwise the customers might start to express some annoyance.

10) Although OLTC will almost certainly be required for all of the postulated configurations, that gear cannot possibly be fast enough to effect correction of reactor or capacitor switching within the (operationally) tolerable time limits.

11) From all of the foregoing, it was obvious, I think, that "ramp" var control in some amount would be required to offer rapid "ramp" var dispatch and allied rapid voltage correction.

12) The preliminary analyses - again, not tabulated - suggested that such control would be required at Carmacks and at Stewart Crossing for either 138 kV or 69 kV interconnection between those two stations.

APPENDIX 12 continued

PROBABLE OPERATING CONSTRAINTS IN SHUNT COMPENSATION AND DISPATCH THEREOF

13) The "swing" capability on the ramp control (and there are two possibilities for such control) would have to correspond to the maximum block of switched reactive - reactors or capacitors - or close to it.

14) The higher to interconnecting voltage, the more compensation.

15) The more compensation, the greater the need to either

a) restrict the size of switched blocks, or

b) increase the rating of the ramp control gear.

Either a or b represented significant additional cost, and compromise was obtained through using the amounts shown in the station layouts.

APPENDIX 13 SYNCHRONOUS CONDENSERS VS STATIC VAR COMPENSATORS

1) Referring to Appendix 12, either static var compensators or synchronous condensers could be considered as ramp control gear.

2) There will, I think, be a relevant argument in support of the condenser.

That argument is (as applies on the Dawson system with supply from Mayo) that the fault levels will be quite low, and while those low levels will not be too much of a pest for station or line protection, they could be real problems in having distribution transformer fuses blow properly - if at all - for transformer fault.

The preceding paragraph was not the ruling, but was a significant supporting, argument for the synchronous condenser at Callison.

3) In my opinion, the application should be condenser, not the static var compensator, even if capital cost and losses are higher.

APPENDIX 14 PROBABLE CONSTRAINTS IN BREAKER APPLICATION AT ABOVE RATED VOLTAGE OR REACTIVE SWITCHING CAPABILITY

1) Existing or new transmission breakers will have suitable voltage and reactive (line dropping) capability for scheduled switching - including faults.

2) The typical constraints are prospective longitudinal recovery voltages.

3) There has to be recognition, though, that as the system is extended north, that contingency situations could result in dropping substantially more transmission than was planned for, and at above rated system and breaker voltage.

As one example, major upset, load loss, and overvoltages might require or result in need to drop the entire transmission north of Takhini through opening the breaker at that station.

That could be a lot of reactive power, even with compensation applied.

4) I guess that all that can be said for the moment is that breaker considerations suggest caution in getting too much series transmission toward the north connected at Takhini.

4) This consideration will result, I think, in a technical and operational bias against 138 kV as the interconnecting voltage between Carmacks and Stewart Crossing.

5) There will be corresponding bias against cable application in the Carmacks-Stewart Crossing line section, unless it is significantly compensated.

6) It has to be assumed, though, that there will be some transmission planned between Carmacks and Stewart Crossing, otherwise this report has no purpose.

Accordingly, there will be some prospective incremental reactive dispatch or switching (or whatever) duty looking from Takhini north.

I do not want to leave the impression that the Takhini breaker itself would be the only stumbling block; if it was, change the breaker and apply one with tripping, and possibly preinsertion resistors (which will reduce switching surges, among other things).

It is simply that the Takhini-Carmacks-Stewart Crossing transmission, even without cable, is going to have a lot of prospective reactive on it, and that could be a risk for most or all of the breakers on the system, and the transformers.

7) I don't think a report of this nature should be used for telling stories, but there is one example that illustrates the foregoing concerns (I did not see the event, but was told about it later by the utility).

APPENDIX 14 continued
PROBABLE CONSTRAINTS IN BREAKER APPLICATION AT ABOVE RATED VOLTAGE OR REACTIVE SWITCHING CAPABILITY

A 138 kV minimum oil breaker was applied in temporary configuration to switch an approximate 180 mile uncompensated line.

The breaker closed without distress to pick up the line.

The breaker flashed over longitudinally on all three phases, external to the interrupters.

End of breaker!!

Pretty good glow in the sky, too, while the breaker was proceeding to disintegrate!

APPENDIX 15 VOLTAGE INSTABILITY

Voltage instability is not the same as angular.

Voltage instability was first identified (as far as I know) about 45 years ago; the utility I worked for at the time encountered it in 1957 or so, when the Monday morning load was applied with some OLTCs on transformation in other than optimum position.

It has been encountered by a number of utilities since then.

The concept is presented, following:

a) a system can be loaded to some amount at transformer secondary voltage with suitable OLTC settings and shunt compensation;

b) if the transmission voltage drops, the OLTC can be altered to correct the secondary;

c) but that "boost" reduces the transmission voltage further;

d) a runaway condition can occur until a new and stable operating configuration is obtained, with possibly satisfactory secondary voltages, but much below normal transmission voltage;

There can in theory - and in fact, in some cases - two operating points for the transformer OLTC to give satisfactory voltage

Please refer to Sketch 7.

That sketch shows transmission operating voltage vs load.

APPENDIX 15 continued
VOLTAGE INSTABILITY

The OLTC can correct the voltage to give satisfactory load (secondary) voltages.

But there are two intercept points, one above the other on the sketch.

If the system is loaded with normal voltages, then any incremental loading can be accommodated through OLTC action.

If the system is loaded with the lower intercept point, then any incremental loading cannot be accommodated through OLTC action, and the system will collapse - or may.

Shunt compensation (capacitors) may "mask" the situation, but collapse at some loading will occur.

The only solution is to drop load, slide around the "nose" of the loading profile curve, get the voltage up, and reload.

It is an odd thing to see on an operating utility.

As the load is dropped, the transmission voltage starts to rise, of course.

The tap changer starts to correct.

The transmission voltage rises some more.

There is a slow motion, gradual correction, again as one slides the load/voltage combination around the "nose" to operation at the higher and desired point, which will result in voltage stability for load increase within system capability.

The item is not academic by any means, and will impose constraints on a long transmission system such as Takhini-Callison.

The item has been recognized in this report.

APPENDIX 16 SYNCHRONOUS CONDENSERS

Synchronous condensers will have various applicable reactances.

All of them, except for the direct axis synchronous reactance, X_d, will vary in proportion to frequency.

The X_d will increase at a significantly greater rate than proportional because, for constant terminal voltage, the machine will be sliding from (intended) saturated operation toward unsaturatted.

That slide may have a very dramatic effect on the var absorbing capability during overspeed.

The desired reactive dispatch capability (from any synchronous condensers that may be applied) would likely require the X_d thereof to be in the order of 0.9 or so (at rated frequency).

In this prospective application (the Carmacks-Stewart Crossing interconnect), the desire to preclude tripping of those condensers during overspeed will likely suggest that the X_d be dropped to 0.8 or so of what might otherwise apply.

The foregoing is not recommendation at this time; the item is simply flagged to insure check in the final planning studies, and because the lower value may entail additional cost for the machine(s).

APPENDIX 17 BREAKER SWITCHING RESISTORS, TAKHINI

This item is partial repetition of Appendix 14, but refers to effect of switching surges on other than breakers.

The comments likely will not apply for operation of the Carmacks-Stewart Crossing line at 69 kV - with or without cable.

They might, for 138 kV operation.

Switching surges will appear in some amount for line energization and dropping.

The intent would be to do staged energization, from
- Takhini - Carmacks
- Carmacks - Stewart Crossing
- Carmacks - Faro
- Stewart Crossing - Callison

Switching surges would not likely be a problem for such sequence.

If there was unscheduled tripping of the Takhini breaker, however, that breaker could be switching about 300 miles of line, and possibly only partly compensated cable (it would depend on pre-trip operating circumstances).

That amount of reactive switching, 30 MVAR or so even without the cable, might exceed breaker withstand of longitudinal recovery voltages; that has already been referred to in Appendix 14.

It might introduce switching surges in excess of transformer impulse withstand.

I would be a bit uneasy about relying on arresters to protect transformers against surge surges; unlike lightning, they can be repetitive for any switching.

Accordingly, check will be required that the existing Takhini breaker and the system transformation will be able to withstand prospective switching surge duty, or constrain the switching surges, whichever applies.

I cannot offer an unqualified opinion.

If tripping (the more likely requirement) or preinsertion resistors were required, the probability - not certainty - is that about 400 ohm rating would be required, about 8 to 16 milliseconds insertion time.

And, be sure to check with the supplier as to repeat withstand within short time frames of a minute or two.

Again, there is no certainty of such need.

There might be.

Failure to include them if required might lead to transformer failure on line switching.

Has been known to happen.

A. B. Sturton

APPENDIX 18 FREQUENCY CONTROL AND NATURAL OSCILLATION

There is no certainty that the following apply.

They might.

Correction after the fact if there was/were indeed problem(s) could be very expensive.

The items and possibilities are simply flagged for attention and/or analysis.

A Governor Droops and Gating Times

The electrical distance between Mayo (and any future northern generation) and the WAF system will require significant angular change before the machines load or unload.

A 10 MW loading, for example (an arbitrary number) will correspond to about 0.10 degrees/mile at 69 kV, 0.025 degrees at 138 kV.

There are acknowledged errors in that; the reactive loading on these fairly low X/R ratio circuits will affect power angle as well.

The time between governor and gate action (as a result of off normal frequency or even manual control) to alter load may possibly - I stress possibly - be such that low frequency oscillation could occur.

The solution might be to alter gating times if there was a potential problem, and if the hydraulics could withstand it.

B Natural Oscillatory Frequency

This is not the same postulated situation as Item A, preceding.

The Mayo and WAF systems will have a natural oscillatory frequency between them, independent of hydraulics or governor action.

I have no idea what it would be.

If self damping, all to the good.

If not self damping, the consequences could be less that desired or possibly even intolerable in the contexts of any of

a) voltage changes concurrent with angular change and transmission loading;

b) possible detrimental effect on the station hydraulic systems (oscillatory pressure changes in the penstocks);

c) generator pole face heating because of angular change - both electrical and magnetic.

I stress that I do not know that the foregoing would be problems, the magnitude thereof if they did exist, and the means and cost of correction.

I simply suggest that the items be included for consideration in any ongoing analyticals relating to project (technical) planning.

A. B. Sturton

APPENDIX 19 REACTIVE DISPOSAL DURING SYSTEM ENERGIZATION, TAKHINI -NORTH

Energization of the transmission system north of Whitehorse will be from Takhini for the foreseeable future; there is no way that it could be accommodated from any other location.

The prospective transmission reactive power - line charging current - will have to be accommodated without assigning an excess to the Whitehorse system.

Energization may be without transformation (at Carmacks and/or Stewart Crossing) connected, because of prospective switching surges; that item has been flagged in the report, but not examined.

Accordingly, transformer tertiary reactors may not be available (at the time of energization).

The worst prospective line charging case will be for 138 kV transmission between Carmacks and Stewart Crossing.

Energization, line reactive generation, and allied reactive disposal will almost certainly have to be in sequence, including:

a) Takhini-Carmacks, about 9.5 MVAR, easily handled by the 8 MVAR line reactor at Takhini, complemented by the 8 MVAR reactor at Carmacks, relocated from Faro.

b) Carmacks-Stewart Crossing, about 11 MVAR (any cable would be compensated through cable reactors), handled by the Carmacks 8 MVAR reactor, with an approximate 3 MVAR dispatched to Takhini and the Whitehorse system.

c) Connection of Stewart Crossing transformation and allied tertiary reactors, accommodating energization at 69 kV through to Callison.

d) Energization of the Carmacks-Faro line, 10 MVAR, and the secondary reactors at Faro.

The foregoing numbers are subject to refinement.

The 69 kV ongoing from Stewart Crossing to Callison can be realistically assumed as fully compensated by Stewart Crossing tertiary reactors with a lot of spare.

The sum of	
Takhini-Carmacks	9.5 MVAR
Carmacks-Stewart Crossing	11 MVAR
Carmacks-Faro	11 MVAR
comes to	31.5 MVAR

The Takhini 138 kV reactor is	8 MVAR
The (relocated) Carmacks reactor will be	8 MVAR
The Faro secondary reactors are	4 MVAR
The Stewart Crossing tertiary reactors will be about	5 MVAR
tallying to	25 MVAR

Given the pretty low direct axis reactances of the Whitehorse generation, it is sensible to assume that 5 MVAR or more could be assigned to them without distress, to give a total 30 MVAR reactive disposal capability, just about matching need.

The foregoing assumes an unloaded system.

The disposal needs would drop as load was applied.

The foregoing brief analysis demonstrates that the reactive disposal, as outlined in this report, would probably accommodate staged energization (which would be required anyway) without distress.

If there is error in the foregoing (and there may be), and it turns out that additional compensation was required, that compensation would likely be connected on the 138 kV at Carmacks, switched, and in an amount of about 8 MVAR.

The item is flagged as a possibility, so that there are no nasty surprises.

A. B. Sturton.

YUKON ENERGY

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FAX

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From:	Alex Love Ph (867) 393-5313 Fx (867) 393-5322 alex.love@yec.yk.ca	**Date:**	February 14, 2003
		Subject:	Stewart – Carmacks Feasibility Report
		File #:	J001017
To:	A.B. Sturton Consultants Inc. 142 Martin Street Mont St. Hilaire, PQ J3H 3J5 Ph (450) 464-5852 Fx (450) 464-5852		
Cc.:		**Total Pages:**	2

Thank you for your report on the Stewart – Carmacks Transmission line Engineering and Operational Feasibility. I think it is pretty good and address most if not all of our feasibility concerns as well as several we had not identified. We may have more questions come as more people get a chance to read your report but for now I have the following comments and questions.

1) You had inquired about the possibility of a neutral end regulator on the Callison transformer. The transformer installed at Callison has only a single bushing at the neutral end.

2) In your cover letter you state that the 138 kV option will work probably tolerably up to 35 MW out of Carmacks. Does this suggest that it will work even more tolerably at lower power levels?

3) 9.0 Mayo – Dawson has actually been built for 66 kV. I am assuming that the difference between 66 and 69 kV will result in no change to the conclusions of this report.

4) 12.5.3 Moving the 8 MVAR from Faro to Carmacks, I assume that with the 8 MVAR at Carmacks, and 2 x 2 MVAR at Faro that the receiving end voltage at Faro will be acceptable even at light load?

5) Appendix 14 – Does the breaker flashover occur upon an attempt to open the breaker?

6) Appendix 16 – Would there be benefit to running the synch condenser as a peak shaver? – i.e. with rotating inertia as a method of limiting over frequency excursions on the loss of load?

7) Load Flow 1 & 2 – Assuming that there is a typo in the top center 138 kV should be 69 kV.

8) For the shunt compensation (Reactors, Capacitors, Synch Condensors) I assume it would not matter if this is applied at 13.8kV, 6.9 kV or whatever voltage is most convenient.

9) Sec 15.5 Metering, Relaying, Control, Inter station communications, Station Auxiliary power Supplies appears to be missing – What I am really interested in is the inter station communications – I need to get a handle on whether we need / should run fibre optic cable or not.

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COPY

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February 15, 2003
File: 8259-008

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Yukon Energy Corporation

Report on Proposed Carmacks-Stewart-Crossing Transmission Interconnection Project

Files 8259-005, 006
December/2002-January/2003

ADDENDUM 1

Response to Items and Questions by Yukon Energy Corporation

Alex,

Response to your fax is through an addendum, rather than another appendix, and so eliminating any need for redoing the reference file index and so on.

I have included numbered reference to the questions and items since that might be useful in any ongoing discussion.

As with the previous files, the originals of this issue will be mailed.

This tidy up is not billable.

Regards,

A. B. Sturton

Attachment: Addendum 1 to the reference report.

Yukon Energy Corporation

Report on Proposed Carmacks-Stewart-Crossing Transmission Interconnection Project

Files 8259-005, 006
December/2002-January/2003

ADDENDUM 1, FILE 8259-009

Response to Items and Questions by Yukon Energy Corporation

Items cross referenced to fax dated February 14, 2003, Alex Love to Sturton, and using the same numbers.

Q, Question by Yukon Energy Corporation
C, Comment by Yukon Energy Corporation

C1: The fact of only one neutral bushing rather than three separate ones on the existing Callison transformer - even though three had been specifically suggested - is not a disaster, but it will preclude addition of a neutral end regulator if or when required.

Q2: From the analyticals, the system (with 138 kV transmission between Carmacks and Stewart Crossing) will apparently work in a tolerable manner - again, not ideally - at loadings up to about 35 MW.

2) The performance would certainly be better at lower loadings, and the impact of any percentage day to day or hour to hour load change will be less.

3) The desired compensation for lower loadings may be somewhat different to that indicated in the report, but the cost differential, if any, will almost certainly be a negative amount - that is, lower - although by a pretty negligible amount.

4) The reason (for the comment in Item 3) is that much of the compensation is for reactive disposal (reactors, of course), or for synchronous condenser capacity to span the reactive switching of reactors or capacitors, as well as not assigning all of the reactive dispatch to those rectors/capacitors and so wearing out their allied breakers.

Q3: Operation of the Carmacks-Stewart Crossing transmission at 66 kV rather than 69 kV will reduce the practical transfer capability.

2) If that line section was the ruling consideration - the most relevant impedance between say Takhini and Callison - one could say with reasonable accuracy that the transfer capability would be roughly proportional to voltage^2, or almost 9%.

3) Both Takhini-Carmacks and Stewart Crossing- Callison are relevant impedances as well, however, and applying a judgment (detailed analysis would take a fair bit of time), I would think that 66 kV operation of the Carmacks-Stewart Crossing transmission rather than 69 kV would reduce the transfer capability by about 5%.

4) The overall losses would go up, again by guessed/estimated 5%.

5) Required compensation would change, with additional capacitors probably required, but almost certainly not reactors.

6) The system would be "softer", more sensitive to load changes and so requiring more frequent voltage correction, however attained.

7) As an aside, I am dead certain that the Stewart Crossing-Callison line section itself could be operated at 69 kV as long as the terminal equipment, notably transformation can accommodate it (which is why three neutral bushings on the Callison transformers were suggested in the Mayo-Callison planning).

Q4: The intent and assumption in reference Report 8259-005, -006 is that Carmacks will be operated at fairly flat voltage, about 138 kV.

2) The Carmacks-Faro line is 106 miles.

Phase shift at surge impedance load is 0.12 degrees/mile (see the main report and appendices for this type of analysis).

Miles x phase shift = 106 x 0.12 = 12.72 degrees.

Terminal voltage at Faro for an unloaded line will be the inverse of $\cos^{-1}$ 12.72 = 102.52% of Carmacks.

3) This item was not examined in detail as part of the report, but judgment suggests that that voltage would be entirely tolerable.

Taking into account the facts of

a) secondary reactors at Faro in an amount of 4 MVAR (which, if connected, would bring the voltage down, of course),

b) probable off load taps on the Faro transformation (but this to be checked), and

c) voltage regulator(s) on the Faro transformation secondaries,

the extreme probability, I think, is that Faro would be operable in an entirely satisfactory manner without the 8 MVAR, 138 kV reactor at that station.

4) This item would require check in ongoing detailed planning studies - which, as said often, the reference files are not.

If incremental reactive loading was to be required at Faro, it is very probable that the operationally preferred and very much lower cost option would be additional reactors on the transformer low voltage at Faro.

5) My guess/judgment at this time is that you will not need them, <u>UNLESS</u> there are no off load taps on that transformation.

And even without off load taps, you still might not need them.

Again as an aside, and without off load taps, the primary concern would be, I think, possible transformer overfluxing.

<u>Q5</u> Yes, the postulated problem (with the breaker) would be on breaker tripping.

2) Switching surges can occur on closing, but the possible detrimental effect thereof is typically on transformation, or in causing line flashover, and not on breakers.

3) When tripping, and for dropping an unloaded line (or a capacitor), there can be very high rates of rise of recovery voltage (RRRV) or longitudinal voltage <u>ACROSS</u> the contacts; not phase to ground or phase to phase on either or both sides, but longitudinal.

4) A representative withstand of that RRRV for 138 kV breakers would be about 1.7 kV/microsecond, but the number is obviously breaker specific, and the application and duty would have to be spelled out in breaker purchase.

5) If the RRRV is too high, then

a) the breaker will fail to interrupt (not necessarily flash over externally) with obvious consequences, or, more likely,

b) reignition or restrike will occur as the breaker opens, resulting in arcing on other that the intended or design interrupting contacts, and with deterioration of the interrupting gas, oil, or whatever insulating medium applies, then leading to inability to interrupt those reignitions or restrikes.

The end result is nearly always breaker failure, sometimes rather catastrophic.

6) Arresters, even on both sides of the breaker, are pretty much useless in correcting the foregoing situation, again because the problem is not ABSOLUTE rise (which arresters would attend to) but RATE OF RISE, which arresters will not look after.

Q6: The rotational energy or H constant in hydroelectric machines in the 10 to 25 MW or so will usually be about 2.5 MW-sec/MVA.

2) Adding the turbine usually results in an H constant of between 3 and 3.5.

It can vary, but the number, preceding, will allow us to "get a handle" on the question.

3) Small condensers, up to about 10 MVA or so, usually have an H constant of about 1.

4) Accordingly, and comparing say 25 MW of hydro generation against a 5 MVA condenser, with total energy equal to

hydro generation = 3.5 x 25 = 87.5 MW-sec

condenser = 1 x 5 = 5 MW-sec.

the effect of the condenser inertia in stabilizing frequency would be negligible.

Which is not to denigrate the question.

5) Inertia is sometimes intentionally built into machines for stability, to assist in frequency control, or whatever.

In this case, the size of the condenser(s), the costs of increasing the rotating mass and applying corresponding bearings, and the incremental losses (both windage and friction) would almost certainly rule out the idea as an attractive proposition.

C7: Yes, there is error on the load flows.

Four out of five show 138 kV where the drawing should read 69 kV.

2) You will appreciate that the errors occurred in copying and then editing drawings.

I could blame Mrs. S., who did an excellent job on those drawings, but the fact is, I was the one who should have caught those oversights.

An appropriate level of humiliation is acknowledged, along with profuse apology being offered.

C8: The comment is absolutely correct.

The most economic voltage for the various shunt compensation can be selected; it will have no technical or operational impact, or, if any, so small as to be undetectable.

C9: I am not dead certain about the interstation communications requirements; it will depend on the applications engineering - not yet done, of course.

But I think sensible judgment can be applied regarding need.

1) Common sense suggests that there will be need for voice communication - however accomplished.

2) There will be a very strong argument in support of station status monitoring, to assist in evaluating system configuration, particularly after upset.

That monitoring would include transmittal of annunciation/alarm functions where something happens without any change in switchgear status.

3) There will be very strong argument for telemetering of various operational information such as loadings, voltages, etc.

4) There will be corresponding argument in support of supervisory control for both

a) anticipated situations such as connecting/disconnecting shunt reactive (capacitors, reactors, etc.), and

b) contingency situations such as line outage requiring connection of reactors prior to energization and the like.

Items 2 and 3 lead logically into Item 4.

It could be argued that that role could be handle automatically.

It probably could - as long as all contingencies could be identified with absolute certainty of no omission, which is a patently ridiculous assumption.

I would under no circumstance assign all actions, scheduled or otherwise, to automatic control.

5) Transmittal of data logging, such as oscillograph records, would be a real assist in evaluation of contingency situations by other than change in station status - and I think you already have some of that transmittal on the system.

6) Transfer trip or transfer block circuits associated with line protection will probably be much desired, not because of system stability, but because selective and high speed clearing will almost certainly be needed - if not actually mandatory - to constraint the nuisance of extended voltage drop on the whole system for line fault.

I would classify this as an operational, not a technical consideration.

7) Station faults such as transformer failure can be effectively cleared by automatic ground switches.

There are some relevant qualifiers, though:

a) The fact of pretty low fault levels will constraint the prospective damage for such station equipment failure.

Accordingly, high speed clearing is not required as long as the fault is cleared.

b) If reliance is placed on automatic ground switches to effect transfer trip, there has to be recognition that those switches could fail for circumstances such as icing, jamming of the mechanisms in the extreme temperatures that may apply (Yukon Energy Corporation doesn't need me to tell them that), and so on.

It could be argued that the associated isolator - a power operated disconnect on a transformer - could then be opened to clear the fault, recognizing that the disconnect would almost certainly flash over with operation of the remote station line protection.

A valid argument - as long as the disconnect is not iced up too.

c) It could then be argued that even without a ground switch closing or a disconnect opening (and probably flashing over, which is exactly what would be desired), that transformer fault, for example, could be cleared by remote line protection.

Not necessarily so; faults - particularly constrained faults such as turn to turn within a transformer or a condenser - almost certainly would not be seen by line protection or transformer overcurrent protection, and so the ongoing fault, although not very big in magnitude, could result in enormous damage because of the time factor.

I digress here, but in my experience, the prospective damage for an enclosed fault - in a transformer, breaker, condenser, whatever - will increase in proportion to about the cube of the clearing time for any given fault magnitude in amperes.

d) The foregoing Items a, b, and c suggest very strongly, in my opinion, that high speed clearing for station faults is much desired, and that total reliance on automatic ground switches or the like is not sufficient; separate transfer trip circuits are justified for security of operation as well as speed of fault clearing.

8) Yukon Energy Corporation will know far better than I do what the best interstation communications medium is.

I do not have a strong communications background (my competence, whatever it may be, covers 25 to 60 Hz and about 40% overspeed, but none of the kilo- and mega- cycle type of thing).

Based on all of the foregoing, this Item C9, though, there will be pretty strong argument in support of the different voice, telemetering, relaying, and other channels, and, from the little that I know technically about the options and their comparative cost and reliability, it would seem to me that fiber optics application would be justified and is the best bet.

I do have reasonable confidence that all of the foregoing is realistic in the context that the items may affect project estimating.

As said in report 8259-005. -006, though, the various input is not sufficiently comprehensive to allow for immediate commitment to the project without refining and checking the analyses and doing the required applications engineering; I do not want to mislead Yukon Energy Corporation on that.

The foregoing may be a bit longer than was expected as response, but I did want to be as sure as possible that the supporting considerations, as well as the replies or comments themselves, were covered.

A. B. Sturton