Design Considerations of a Real-World Interprovincial Energy Corridor Transmission Line

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***Abstract*—As an engineer sworn to provide benefits to society, the author presents herein an analysis of some of the probable benefits attributable to an idea, popular in some segments of society, for the establishment of a cross-Canada energy corridor containing both pipelines and power transmission line(s).**

Keywords—power transmission; direct current; line losses

I. Introduction

For more than a decade various proponents, for various reasons, have proposed that a defined energy corridor should be designated from eastern Canada to western Canada. Eastern proponents see this as an opportunity to replace coal fired electricity generation with their apparently abundant hydro and renewable based power. Western proponents see it as an opportunity to construct pipelines allowing oil and gas to be delivered to Eastern Canada.

While there are existing oil and gas pipelines delivering products at least as far east as Ontario, new pipelines farther east have been stymied by political objections for more than a decade now.

On the other hand, there are no, zero, power transmission lines connecting even Ontario to Saskatchewan or Alberta. Thus, no opportunities exist to use electricity sourced from renewables and non-fossil fueled sources in Quebec or Ontario to replace fossil fueled sources in Saskatchewan or Alberta.

This paper examines what such a power transmission line could look like, how it might be built, and some of the electrical characteristics that bear on its eventual utility. Also, important in the real-world sense, construction costs, construction duration, and operating and maintenance costs are estimated. Finally, some assessments of the net benefits of such a line are made.

II. Conceptual Design

A. Summary

The design concepts presented below are not intended to be exhaustive in scope sufficient to allow construction, but merely functional so that realistic estimates of performance, cost, and schedule, may be made to inform later discussion.

B. Starting Point

The area around Sudbury, Ontario has much experience with heavy industrial activities and consequently has a number of various capacity transmission lines already present, so without more specificity, this area is chosen as the starting "point" for the first energy corridor power transmission line.

C. Termination Point

A number of existing and former coal-fired power stations exist in south-central Alberta. For the purposes of this design, and ease of access, the area around Brooks, Alberta is chosen as the termination "point" for this first line.

D. Length of Line

The two named locations are served by the trans-Canada highway and are located 2,840 kilometers apart. For the purposes of this analysis, it is expected that a more direct power line route exists and that proper line right-of-way selection will result in a transmission line length of around 2,500 kilometers. This shortened length will yield better (lower) costs and (higher) efficiencies in later considerations.

E. Line Capacity

Earlier concepts proposed by others for this transmission line may be summarized as a transmission voltage of 765 kilovolts (kV), three phase alternating current with conductors sized to deliver 300 megawatts (MW). Such a size is too small in that it is unable to replace a single coal fired generator in the Alberta power system.

For the purposes of this conceptual design, the transmission line capacity has been selected as 1,000 MW, large enough to replace at least two (2) coal-fired generators in any plant in Alberta. No taps will be allowed.

F. Power Line Specifications

To improve the efficiencies of transmission, the line voltage has been selected to be 1,000 kV direct current.

Line conductor size selection is somewhat unorthodox. A single standard conductor, code word "Canary", rated 962 amps continuous, is large enough to deliver about 1,000 MW at 1,000 kV, but line losses would be extreme over the conceptual line length. Therefore, a bundle of four (4) Canary conductors in parallel is proposed for both conductors in the circuit.

This conductor selection is within the normal realm of transmission line design and may be built from essentially standard components. The transmission towers to carry this line will be typical single foundation towers, guyed in all directions, generally sixty meters (60m) high except where terrain or other considerations demand more clearance, arranged with the normal lightning protection and communication capacity. Ruling span lengths will be two hundred meters (200m) more or less as terrain requires.

The conductor weight and guying requirements are expected to push the tower structural steel weights up to where final tower assembly will have to be done at location rather than delivered complete.

The typical counter-poise buried conductor under the overheads will be required for control and is included in the following considerations.

G. Other Requirements

It is expected that power will be delivered to the transmission line from conventional three phase alternating current power lines. Similarly, power delivered by the concept line will be necessarily inverted to three phase alternating current for delivery to consumers at the destination. This rectification to direct current and the subsequent inversion are within the capabilities of available semiconductors. However, protection and control of such a high power and lengthy line, while possible, may be challenging given the voltage level the and direct current ampacity intended. Fault currents will no doubt be limited by the conversion equipment but even routine measurement and isolation equipment will be extensions of proven designs. In addition, certain line parameters will be inherently energetic and require other ameliorating strategies.

The degree of specialization needed will be a primary driver of the input and delivery substation cost which will otherwise be unremarkable.

III. Line Electrical Characteristics

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Without an exact detailed design and a set of representative line cross section which would allow detailed and exacting calculations it is still possible to estimate certain line characteristics accurately enough to provide useful insights.

A. Capacitance

As the conceptual power line is direct current, the geometry of the line conductors, using a typical equipotential surface radius, represents a relatively small capacitance, about 6×10^{-9} farads per kilometer and over the whole line length remains quite small. However, given the line voltage planned, at 1,000 kV, the energy stored in even this small capacitance will amount to almost 8 megajoules. This has several immediate consequences, none of which are unknown in the more typical power transmission line designs. They are:

i) Switching transients must be carefully managed.

ii) Voltage surge protection must be spaced over the whole line length so that no one unit disperses more than its rated energy capacity.

iii) Within the terminating stations spacing of the management devices will increase the station size.

B. Inductance

Like the line design impact of the capacitance of the conductors, the fact of direct current transmission minimizes the effect of conductor self and mutual induction since at even quasi-steady state the rate of change of the current flow is negligible so the only concerns will be during switching operations and analogous management strategies will be required in the terminating stations.

C. Line Protection

Since the terminating stations will be a converter (rectifier) or an inverter they will be constructed of large assemblies of various semiconductors. Currently available industrial semiconductors for this application are rated in thousands of amperes and thousands of volts and industrial practices are well developed to use, for example, optical control of the devices.

Measurement of operating parameters will be more difficult to do than in a similar alternating current situation but can be accomplished reliably.

Protection of the power line will not be as simple as opening a breaker because of the significant amount of energy stored in the conversion/inversion devices and in the fields around the conductors. Separation from the supply and load alternating current lines at each end may be accomplished by standard breaker applications but it will be desirable to ramp voltage and current up and down in the actual power line and this will require additional equipment in the terminating stations. It should be noted as well that other than the stored energy, there is no support for typical alternating current fault currents as the usual semiconductor control operate reliably in microseconds and therefore do not typically supply current to a detected fault.

IV. Construction

As described the concept power transmission line could be constructed in the course of, at most, two winters (the preferred time of year for power line construction in Canada) or three winters if the work is restricted to existing Canadian contractors. To accomplish this the line will be built in segments and finally connected into continuity which allows for appropriate material and equipment staging.

Right-of-way clearing will take an additional winter, prior to construction start and continue thereafter.

Engineering and procurement will require about one and a half years, some of which may reasonably overlap the clearing start.

Overall, the engineer-procure-construct period could be accomplished to energization in five years.

V. Project Cost

Physically similar power transmission lines constructed in similar locations in recent years have been constructed for prices of between $1M[1] and $2M per kilometer. Based on this recent experience and given the mix of anticipated terrains an average cost of $2M /km is reasonable and for the 2,500 km considered, this results in a completion cost of $5,000,000,000.

The terminating stations, for the various technical reasons given earlier, will be more expensive than typical substations. Their cost is estimated at $250M each, bringing the overall cost for this major segment of the work to $5,500,000,000, or five-and-a-half billion dollars.

A. Ownership Costs

The power line as conceived would be a long-lived asset. Therefore, a depreciation rate of two percent per year should be allowed, or $110,000,000 per year. Due to the anticipated robust construction, annual maintenance cost will be small and is therefore estimated at only $5,000,000 per year. Assuming the line would be privately funded, a return on this substantial investment of 5% annually would be reasonable. This return amounts to $275,000,000 per year. The total ownership cost per year is then $390,000,000.

B. Operating Costs

The least operating cost will be delivered if the line is 100% loaded 100% of the time. To achieve this delivery rate, of course, there will be associated power line losses and terminating station losses that must be included. Being direct current, the line losses are mainly resistive in nature and the quad-bundle wire is quite low resistance so over the 2,500 km length this will come to about 78 MW, or 8% of the line capacity. The terminating stations, which will include large supply and load transformers will therefore be about 50 MW losses, or 5% each, for a total loss budget, at full capacity of some 18%.

Another way to look at this number is to say that to deliver 1,000 MW to loads in the West, a total of 1,180 MW electricity must be supplied in the East.

The total operating costs will be lowest based on complete utilization of the power line for the whole year. Using that criteria, 1,000 MW delivered for 8,760 hours per year, including only the depreciation and maintenance costs, in the calculation, and allowing for power purchase in the East at $100/MWH ($0.10/KWH) makes the delivered cost of power at the West end to be $130/MWH or $0.13/KWH.

Adding in the real-world cost of capital as described above, will make the cost of delivered power $170/MWH or $0.17/KWH.

[1]All currency references are to Canadian dollars

VI. Other Considerations

A. Line Capacity

As large as the concept line is in terms of electrical transmission capacity, at least five, (5), such lines would be required to replace the remaining coal fired generating stations in Alberta alone. The individual lines would need to be separated by substantial distances to avoid material coupling either magnetically or electrically. Whether there are, in reality, 5,000 MW of continuously available surplus electricity in Eastern Canada would at minimum be debatable.

B. Right-of Way Location

The power line to supply the towns and villages close to the Ring-of-Fire area in Northwestern Ontario, some initial seventeen, 17, First Nations communities of the more than twenty that exist there, has been a government priority since 2013. The first communities will be energized in 2021.

The negotiation of the right-of-way location has occupied some years of effort by Watay Power, a First Nations owned power company and has not been universally accepted by all the local residents.

In the case of the concept power line, it is estimated that at least fifty (50) First Nations will be required to agree to the eventual line route. Whether or not such an agreement would even be possible is unclear at this time.

C. Project Schedule

As projected above, the concept power line might be engineered, procured, and constructed in as little as five years, which of course assumes that the routing is complete and the right-of-way fully understood and available.

The step of finally identifying the right-of-way, as described, and based on recent experiences in Ontario and Manitoba may take as long as five (5) years, but equally could take ten (10) years given the fact that the line route will cross four provinces and a multitude of First Nations areas.

Therefore, the minimum realistic schedule for the completion of the first transmission line would be at least eight years, assuming the risk of multiple segmented starts is acceptable. The most likely schedule duration would be at least ten years.

D. Power Pricing

Consumer power prices in Ontario [1], the likely source of the 1,000 MW transmitted on the concept line, appears to average about $100/MW based on IESO reports, with a heavy reliance on nuclear power in Ontario and on hydro power in Quebec for support. Thus, the estimate of an input power price of $100/MW.

This of course leads to an imported power price, fully loaded, of $170/MW when delivered into Alberta.

Unfortunately, the Albertan consumers are used to an average price, based on AESO [2] reports, of only $30/MW. Asking them to pay an almost 500% premium over that to justify constructing and connecting the concept line would appear to be fraught with difficulties.

VII. Conclusions

Design and construction of the concept power line is certainly practicable and the capital cost and ongoing expenses of such a power line are certainly within reason.

However, the limited capacity of the presented concept for a single transmission line, even though much better than the previously proposed lines, the probable lengthy schedule, and the very high cost of power delivered, all make even the very idea unacceptable since the purported benefits to society do not outweigh the very significant costs.

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References

[1] See Global Adjustment Rates and Average Hourly Ontario Energy Price as published by the Independent Electricity System Operator for the Province of Ontario.

[2] See the Pool Pricing table as published by the Alberta Electric System Operator.