Q. **Reference Avalon Capacity Study:**

Please provide the predicted/assumed annual Bipole outage rate for the LIL for each of the following faults/events, and for each provide the minimum and maximum time to resume operation of at least one of the poles:

a. A broken neutral/earth return conductor with or without contact to a HVDC conductor

b. A broken HVDC conductor with contact to the other pole

c. Up to 3 fallen towers

d. More than 3 fallen towers

e. The failure of any equipment common to both poles that could result in a trip of both poles

f. The unavailability of the sea electrodes (also state the maximum power that can be delivered using metallic return)

g. Any control and protection failures that could cause both poles to trip

h. Any generic/latent fault in pole equipment which may result in accelerated ageing, the need for replacement of the control and protection system, or other additional maintenance, and/or any other needs to take one pole out of service for a prolonged period, during which the trip of the remaining pole would cause a Bipole outage

i. Catastrophic events such as a fire that affects both poles, extreme weather conditions that could damage the overhead lines, switchyard equipment or buildings, acts of terrorism

j. The outage of all 3 HVdc cables

A. The bipole Forced Outage Rate ("FOR") is the percentage of a year the bipole will be unavailable for service given the frequency of a particular forced event occurring and the duration of the resulting outage. Bipole FOR (%) is calculated as:

$$FOR\ (\%) = \frac{(f \times d)}{8760} \times 100 \text{ where,}$$

$f = The\ number\ of\ events\ in\ 1\ year.$

$d = duration\ of\ outage\ in\ hours$

For each scenario posed below, the FOR is calculated based on design information on expected failure rates. For many of the scenarios below, multiple events would have to happen in succession to result in the bipole outage described. As a result, the probability of the event occurring would become much less than the design information. For example, the failure of an HVdc conductor could be estimated as a 150-year event. However, for a bipole outage to occur, a conductor would have to break, make contact with the other pole conductor and ground. Nalcor does not have data to calculate the probability of this scenario occurring; however, it is clear that it is much less probable than a break of the conductor alone. As such, Newfoundland and Labrador Hydro utilized known design information for the bipole FOR calculations; the result is a more conservative FOR value.

a. A broken neutral/earth return conductor with or without contact to a HVdc conductor:

The design of the overhead line portion of the Labrador-Island Link ("LIL") was undertaken using the overhead line design standards in force, namely CAN/CSA C22.3 No. 1 and CAN/CSA C22.3 No. 60826. A significant amount of historical data, including historical and modern studies, on-site test tower data, as well as local experience when available, was utilized in the determination of the meteorological loading. The design of the LIL meets CSA 150-year ice and wind loading recommendations for glaze ice zones off the Avalon Peninsula and CSA 500-year ice and wind loading recommendations on the Avalon Peninsula. For rime ice zones, such as the Long Range Mountains, the line design exceeds 500-year designs for both rime ice and wind.

Failure of an electrode (neutral/earth return) conductor without contact with an HVdc conductor would not result in a bipole outage. A bipole outage would only occur upon failure of an electrode conductor when the conductor breaks and then makes contact with the HVdc pole conductor and ground. While the failure of an electrode could be estimated as a 150-year event, the scenario where the conductor remains in contact with an HVdc pole is highly improbable. In the event of this type of failure mode, a fault analysis would need to be performed by engineering and control technicians and line crews would be dispatched to the fault location and perform repairs (if required) to allow monopole operation.

While an extreme weather event can happen at any time of year, the LIL overhead transmission line is most at risk of being exposed to its worse conditions (Strong Winds, Glaze icing, or In-Cloud icing) from September to May. The site can be reached by access road sections, helicopters, snowmobile, or heavy equipment should road access be difficult due to extreme snow. The time to return to monopole operation would be dependent on weather conditions, location of fault and site access. This could result in a repair time of 8 to 24 hours resulting in a FOR of 0.00183%. As stated previously, while this FOR is for a broken electrode conductor, the additional condition of a conductor remaining in contact with an HVdc pole for a bipole outage decreases the probability.

b. A broken HVdc conductor with contact to the other pole:

Failure of an HVdc conductor without contact with another HVdc conductor would not result in a bipole outage. A bipole outage would only occur when the HVdc conductor on one of the two poles breaks and then makes contact with the other HVdc pole conductor and ground. As detailed in Part a, while the failure of an HVdc conductor could be estimated as a 150-year event, the scenario where the conductor would break and then swing to make contact with the other pole and ground at the same time is a highly improbable event. For this failure mode, a fault analysis would need to be performed by engineering and control technicians. Line crews would be dispatched to the fault location and perform repairs (if required) to allow monopole operation. The time to return to monopole operation would be dependent on weather conditions, location of fault and site access. This could result in a repair time of 8 to 24 hours resulting in a FOR of 0.00183%. As stated previously, while this FOR is for a broken conductor, the additional condition of a conductor remaining in contact with an HVdc pole for a bipole outage decreases the probability.

c. Up to 3 fallen towers:

This scenario would result in a bipole outage. For possible small scale failures such as a cross arm or steel section failure, the repair timeline to return to monopole operation could be one week considering favorable access and weather conditions. On the extreme side with up to three consecutive tower failures in a remote location, severe weather and difficult access due to snow depths, the repair timeline could be three weeks or greater to allow for a return to service in monopole operation. For this failure mode, a Nalcor engineered temporary bypass would most likely be the repair solution. Gaining site access via a snow cleared access road would be beneficial but not necessary as tracked vehicles could access the site. Helicopters would be utilized for fast transport of materials and crews to the work site. Downed tower debris would have to be removed and a temporary bypass solution installed. The failure of a tower could be estimated as a 150-year event[1] with a FOR of 0.0384%.

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[1] Other transmission lines are designed for a 50-year event, and distribution is typically designed to a 25-year event

d. More than 3 fallen towers:

This scenario would result in a bipole outage. A repair timeline of two weeks could be possible considering a favourable access location, weather and failure method. With a catastrophic failure of multiple towers in multiple/remote locations it would be greater than six weeks to return to monopole operation. The failure of more than three towers could be estimated as a 150-year event with a FOR of 0.0768% or greater.

e. The failure of any equipment common to both poles that could result in a trip of both poles:

A failure of a transmission tower would result in a bipole outage. Refer to Parts c and d for outage duration and FOR for this type of failure.

A busbar failure in the neutral (common) area of the HVdc terminal stations would likely result in a bipole outage. The ac and dc terminal stations were designed for a 50-year lifespan; however, extreme weather events similar to the loading on the LIL overhead line in that area were also taken into account in the design of the stations to reduce the probability of failure of the terminal station equipment for an extended period of time. When considering the multiple pieces of equipment in the HVdc station typical failure includes breakers, disconnects, Current Voltage Transformers, and Potential Transformers. Although a busbar failure is possible, considering the number of failures related to the equipment listed above, a busbar failure in a terminal station is an extremely low probability event. For this failure mode, a fault analysis would need to be performed by engineering and control technicians and maintenance crews would be dispatched to perform repairs to allow monopole or bipole operation. The time to return to service is dependent on weather, location of the fault and site access conditions. This could take 8 to 48 hours or more, resulting in a FOR of 0.0110%.

f. The unavailability of the sea electrodes (also state the maximum power that can be delivered using metallic return):

This scenario would not result in a bipole outage. The LIL can deliver a maximum of 408 MW of continuous power to the Soldiers Pond Terminal Station using metallic return in monopole mode.

g. Any control and protection failures that could cause both poles to trip:

As per the design there is no single point of failure of the control and protection system that would cause a bipole outage.

h. Any generic/latent fault in pole equipment which may result in accelerated aging, the need for replacement of the control and protection system, or other additional maintenance, and/or any other needs to take one pole out of service for a prolonged period, during which the trip of the remaining pole would cause a bipole outage:

Each pole of the LIL is designed for 2.0 per unit overload for 10 minutes and 1.5 per unit steady-state overload. Therefore, in its configuration for maximum bipole output, the LIL is operating well below the equipment's rated value and the resultant impact of long-term outages can be covered by the designed overload of the pole. Further, since the equipment is operating below its rated values, the stress and aging of components is reduced leading to a decreased likelihood of equipment failure.

This scenario is a double-contingency event. The bipole is designed within the stations to be fully redundant so that a single event (planned or forced) will not result in a complete bipole outage. To approximate the outage rate for a scenario when a monopole event occurs during another preexisting monopole event, the scheduled plus forced monopole outage rates can be multiplied by the monopole forced outage rate.

Using CIGRE[2] industry data, an expected monopole FOR of 1.11% can be considered along with a scheduled outage rate of 3.8% for both poles. Therefore, the outage rate in this situation would be:

$$FOR(\%) = (1.11\% + 3.8\%) \times 1.11\% = 0.055\%$$

This calculation uses data which includes all planned and forced outages. The situation where a latent fault causes an extended outage would be a subset of this data and as such the expected outage rate would be smaller than 0.055%.

i. Catastrophic events such as a fire that affects both poles, extreme weather conditions that could damage the overhead lines, switchyard equipment or buildings, acts of terrorism:

Please refer to Newfoundland and Labrador Hydro's response to PUB-NLH-054.

j. The outage of all 3 HVdc cables:

The scenario that could result in the loss of all three submarine cables resulting in a bipole outage is iceberg scour. This failure mode was considered in the design and the submarine cables across the Strait of Belle Isle are installed inside directionally drilled boreholes from land to the ocean floor, emerging at a depth of approximately 70 m. A natural sea berm restricts icebergs greater than 60 m from entering the Straight of Belle Isle. Once on the ocean floor, the cables were laid in the naturally occurring contours (valleys) on the seabed to provide further protection. In addition, the cables were then covered in a rock berm in all areas not protected by the directional drilled boreholes. While the failure of a single subsea cable due to iceberg scour could be estimated as a 12,000-year event, the subsea cable system was designed and installed

[2] The International Council on Large Electric Systems ("CIGRE").

to minimize the probability of this failure occurring. Based on this failure mode, the fault location would have to be determined, a special cable splicing vessel would have to be secured and depending on weather, time of year, and location of fault the repairs could take 6 to 18 months and have a FOR of up to 0.0125% or greater for a single cable failure. It should be noted that a single cable failure with the calculated FOR of 0.0125% would result in no loss of power transfer on the LIL. An outage of all three HVdc cables decreases the probability even further.