Q. At page 7 of Hydro's Report in support of its Application, Hydro relates that the "impedance mismatch" outlined therein results in a "loss" of transformer capacity in the magnitude of 31.8 MVA.

(i) Please explain how such capacity is "lost" and whether there are alternatives available to recapture such "lost" capacity in the loop short of installing a new transformer?; and

(ii) If there are alternates available to recapture such "lost" capacity, please provide the manner in which this could be done and a detailed cost estimate to do so?

A. (i) The following table provides the impedance value of each 230/66 kV power transformer in the Hardwoods – Oxen Pond Loop.

Table 1: Impedance Value

Hardwoods – Oxen Pond Loop Transformer Impedance Values		
Unit	**Rating MVA**	**Impedance %**
HWD T1	40/53.3/66.6	8.30
HWD T2	40/53.3/66.6	9.12
HWD T3	40/53.3/66.6	8.45
HWD T4	75/100/125	8.80
OPD T1	40/53.3/66.6	8.85
OPD T2	75/100/125	9.02
OPD T3	75/100/125	8.73

Electric current will flow along the path of least impedance. In situations with two or more transformers having the same impedance operate in parallel, the current will be equal in all transformers, and consequently all transformers will reach nameplate rating at the same time as load increases. In situations where there are multiple transformers in parallel with different impedances, such as the transformers in the Hardwoods – Oxen Pond Loop, more current will flow in the transformer with the lowest impedance than in the other units. In essence, the transformer with the lower impedance will carry more than its proportionate share of the total current. As a result, the transformer with the lowest impedance will reach its nameplate rating before the remaining transformers as load increases in the station.

If one considers the transformers in the Hardwoods Terminal Station and ignores the effects of the connected 66 kV transmission system and the Oxen Pond transformers, Hardwoods T1 is expected to reach 100% of its nameplate rating before T2 through T4. A simple load flow case with the 66 kV transmission disconnected and all the load being carried on the Hardwoods 66 kV bus, provides an example of the effects of impedance mismatch on station loading. Figure 1 provides a load flow plot of the Hardwoods Terminal Station with 304 MW of load on the 66 kV bus. One will note that transformer T1 is loaded to 100% of its nameplate rating, while T2, T3 and T4 are loaded to 91%, 98% and 94% of their nameplate ratings respectively. This mismatch in impedances results in approximately 16.8 MVA of transformer capacity being unavailable. Increasing the load on the Hardwoods 66 kV bus will result in the loading on T1 exceeding 100% of its nameplate rating before the remaining transformers reach 100% of rating.

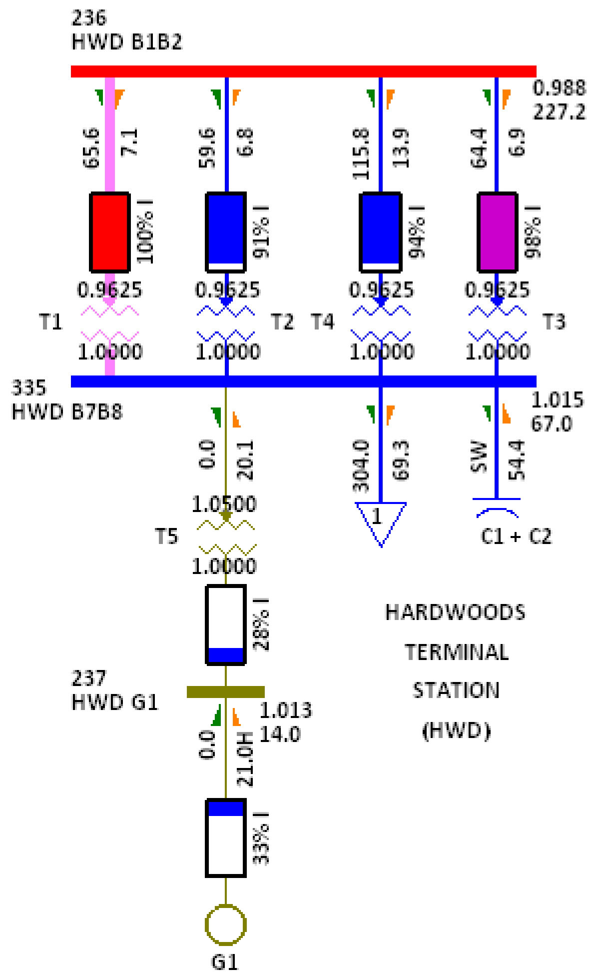

Figure 1: Hardwoods Maximum Transformer Loading

A similar analysis can be completed for Oxen Pond Terminal Station. Figure 2 provides a simple load flow plot of the Oxen Pond Terminal Station with a 66 kV bus load of 300 MW. One will note that transformer T3 is loaded to 100% of nameplate rating, while T1 and T2 are loaded to 96% and 98% of their nameplate ratings respectively. This mismatch in impedances results in approximately 8.2 MVA of transformer capacity being unavailable. Increasing the load on the Oxen Pond 66 kV bus will result in the loading on T3 exceeding 100% of its nameplate rating before the remaining transformers reach 100% of rating.

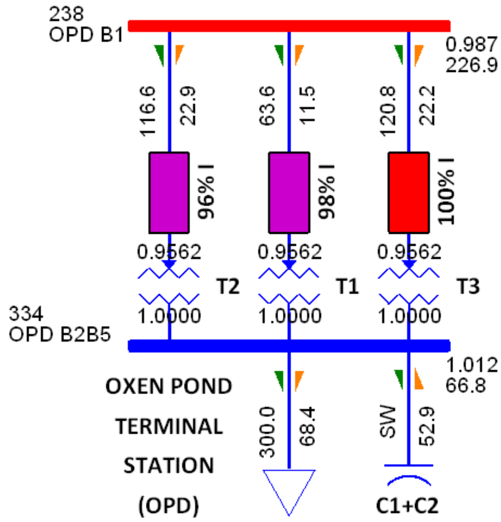

Figure 2: Oxen Pond Maximum Transformer Loading

From these examples it can be seen that variations in impedance of transformers within the same station result in unequal loading on the units and consequently transformer capacity that is unavailable to accept load once the lowest impedance transformer reaches its nameplate rating before the higher impedance units. These examples show the maximum loading on the transformers in a station is also dependent upon which, if any, of the transformers are out of service. Extending this further, if the loads are moved away from the Hardwoods and Oxen Pond 66 kV buses, and distributed unevenly around the St. John's Region by multiple 66 kV transmission lines with different lengths, paths and impedances, while the mismatch becomes more complex to calculate, unequal loading of the Hardwoods and Oxen Pond 230/66 kV transformers remains.

From a longer term transmission planning perspective, each of the three 125 MVA transformers in the Hardwoods – Oxen Pond Loop is considered to have equal opportunity of failure. However, the shift in station loadings and available transformer capacity to supply the load due to the impedance mismatch is very dependent upon which transformer fails. For the spreadsheet calculations found in the capital budget submission which summarize the Hardwoods – Oxen Pond Loop transformer loading situation and fulfillment of transformer back up criteria, Hydro has calculated a mismatch value of 31.8 MVA to be representative of what can be expected. The 31.8 MVA value is based upon the transformer mismatch with the lowest impedance 125 MVA unit out of service, load redistribution to provide maximum load at each terminal station, and consideration for current rating of the transformers and 230 kV bus voltages at the time of the event.

Two possible alternatives may be considered to address the loss in available transformer capacity due to impedance mismatch. The first would be to add generation to the 66 kV system to offset the loss. One will note from the capital budget submission that the existing Hardwoods combustion turbine is used to offset a portion of the unavailable/lost transformer capacity associated with the loss of a 125 MVA unit. However, the addition of new combustion turbine and fuel storage facilities may be considered cost prohibitive in comparison to additional transformer capacity if sufficient space is available within existing terminal stations to add such capacity.

The second alternative considers additional transformer capacity. With respect to adding transformer capacity to offset unavailable capacity due to impedance mismatch, it is worth noting that transformers purchased by Hydro are required to be designed and built according to CAN/CSA-C88-M90 “Power Transformers and Reactors”. Section 14 of this standard covers design tolerances. Table 9 of the standard indicates that the tolerance on impedance for a two winding power transformer, like the Hardwoods and

Oxen Pond units, is ±7.5% of the guaranteed value. The average value of impedance for transformers in the Hardwoods – Oxen Pond Loop equals 8.75%. Specifying a new 230/66 kV transformer with this impedance in attempt to "balance" the transformer impedances to ensure minimum mismatch and maximum transformer capacity availability is not without issue. Despite specifying a new 230/66 kV transformer for the Hardwoods – Oxen Pond Loop with an impedance of 8.75%, the manufacturer can design and build the unit with an impedance ranging between 8.09% and 9.40% and still meet the requirements of the CSA standard with no penalty on the project. If one compares the design tolerance range of 8.09% to 9.40% with the impedances provided in Table 1, one notes the existing transformer impedances more closely match than the tolerance permitted by the standard. While the manufacturer will attempt to design and build a transformer to the exact impedance specified, it is impossible to guarantee that two consecutive transformers of the same design will have the exact same impedance when completed.

The existence of impedance mismatch on multiple transformer stations is unavoidable, particularly when transformers are purchased at different times and built by different manufacturers. Design and manufacturing techniques today permit the impedances of new units to be within a very tight tolerance.

(ii) Hydro finds no economically viable alternative to eliminate impedance mismatch within the Hardwoods – Oxen Pond Loop short of installation of additional transformer capacity when warranted.