PROBABILISTIC RISK ASSESSMENT OF AN ISLANDING OPERATION OF JORDAN RIVER GENERATION

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Executive Summary

Jordan River generation (JOR-G1) is located in the South Vancouver Island, and it is connected to the BC Hydro system via the 138 kV radial line designated as 1L146. There are three delivery points designated as Jordan River (JOR), Sooke (SOO), and Colwood (CLD) loads connected to the 1L146 corridor. The maximum output of JOR-G1 is 170 MVA. The JOR-G1 is limited by the water condition as the annual capacity factor of the plant is only 0.16 approximately. The JOR-G1 has a load following capability that could facilitate an islanding operation to serve the remaining when the 1L146 is out of service.

Probabilistic risk assessment for an islanding operation of JOR-G1 is conducted in this report to investigate the risk of load curtailment with and without an islanding operation capability. The following results are obtained:

- *Although there is a concern that the JOR-G1 may not be dependable subject to the water condition to provide an islanding operation capability, the historical reliability data however indicate that the 1L146 is highly reliable (very low unavailability). This implies that the probability of having an islanding system is very low.*
- *The expected energy not supplied (EENS) with and without an islanding operation capability of the JOR-G1 are 20.46 and 36.23 MWh/yr respectively (based on 2006 load forecast). The magnitude of these risks is not significant.*
- *The benefit of having an islanding operation capability is a 44% reduction of the EENS (risk of load curtailment is reduced).*
- *The severity index designated as Delivery Point Unavailability Index (DPUI) of the specified islanding system is considerably less than the historical DPUI of the entire BC Hydro system. The DPUI with and without an islanding operation capability are 8.04 and 14.24 system·minutes respectively, while the DPUI of the entire BC Hydro system is approximately 25 to 30 system·minutes. This indicates that the reliability of the designated islanding system is well above the system average.*

Table of Content

1. Background

Jordan River generation (JOR-G1) is located in the South Vancouver Island and is connected to the BC Hydro system via the 138 kV radial line designated as 1L146. There are three delivery points designated as Jordan River (JOR), Sooke (SOO), and Colwood (CLD) loads connected to the 1L146 corridor as shown in Figure 1. The maximum output of JOR-G1 is 170 MVA. The JOR-G1 is limited by the water condition. Although the heavy rains produce high peak flows in fall and winter seasons that could match with the peak load in the South Vancouver Island area, the JOR-G1 is still not quite dependable throughout the year as the annual capacity factor of the plant is only 0.16 approximately. The historical annual average plant generation of JOR-G1 is 242 GWh/yr [1].

Jordan River generation has a load following capability that could facilitate an islanding operation to serve the remaining when the 1L146 is out of service. Probabilistic risk assessment for an islanding operation of JOR-G1 is conducted in this report to investigate the risk of load curtailment with and without an islanding operation capability. The historical data for JOR-G1 generation pattern (5 years) and JOR, SOO and CLD load characteristics were obtained from Plant Information (PI) system and used in the study. The historical reliability data of 1L146 over 20 years (1986 – 2006) were obtained from the Reliability Database Management System (RDMS).

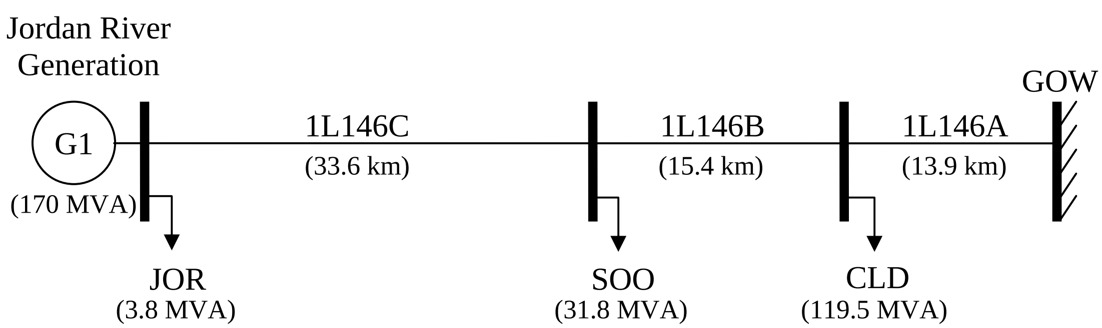

Figure 1: Single line diagram of a potential islanding system.

2. Jordan River Generation Pattern

The historical data for JOR-G1 indicates that heavy rains in the fall and winter produce high peak flows, and the historical annual average plant generation is 242 GWh/yr [1]. This refers to an average capacity factor of 0.16 annually. Historical power output data of Jordan River Generation (JOR-G1) were obtained from Plant Information (PI) system during April 2001 – March 2006 (5 years). Hourly average power output of JOR-G1 for the last five years is presented in Figure 2.

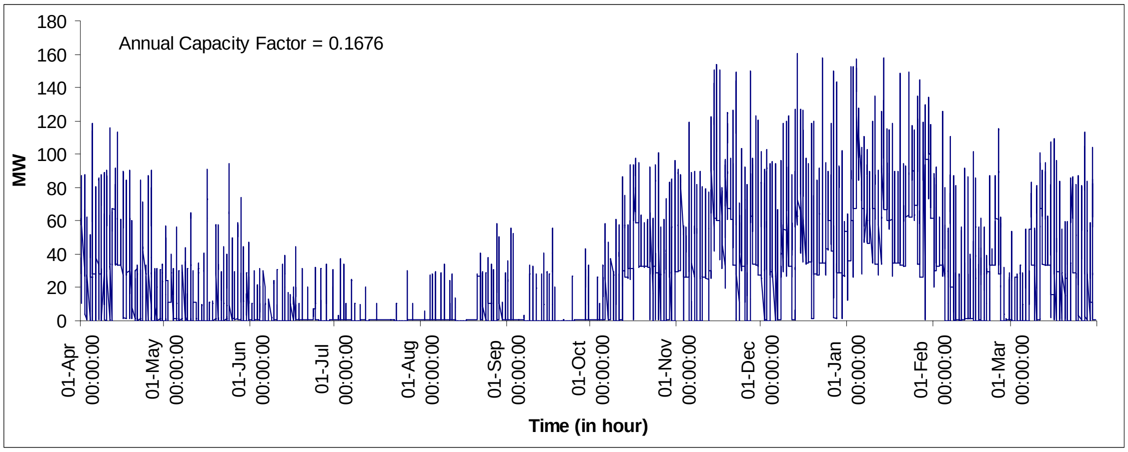

Figure 2: Hourly average power output of Jordan River generation using five years data.

Figure 2 indicates that the power output (MW) of JOR-G1 is totally dependent on the water conditions, which have a high power output in winter season and very little output during summer season. The average annual capacity factor (average output divided by peak output) during five years records is 0.1676. In reliability perspective, the unavailability of JOR-G1 due to a mechanical failure is very small compared to that due to the water deficiency. Based on the data shown in Figure 2, there are 3932 hours in a year (on average) that have the power output less than 4.0 MW (assuming that having less than 4.0 MW output will not be able to serve JOR load under an islanding operation). This fact can be translated to the unavailability of 0.4489 (3932 hours divided by 8760 hours). The unavailability of JOR-G1 due to a mechanical failure is 0.0124 [2]. This indicates that the unavailability of JOR-G1 due to a mechanical failure is negligible when comparing with the unavailability of JOR-G1 due to the water deficiency.

3. Unavailability of 1L146 (from GOW to JOR)

1L146 basically composes of three sections as shown in Figure 1. The total length of 1L146 is 62.9 km. The most critical line section is 1L146A (GOW to CLD) as the loss of this line section will result in the loss of total load at CLD, SOO and JOR (if an islanding operation mode of JOR-G1 is not allowed). 1L146A is, however, the shortest line section among the three sections. The historical reliability data of 1L146 was obtained from the Reliability Database Management System (RDMS) during April 1986 to March 2006 (20 years) and summarized in Table 1.

Table 1: Historical reliability data of 1L146 obtained from the RDMS (1986 – 2006).

Types of Forced Outages	Failure Frequency (failure/year)	Repair Time (hours)	Unavailability (/year)
Line Related	0.39506	3.88	0.000175
Terminal Related	0.14815	0.55	0.000009
Total (Line and Terminal Related)	0.54321	2.97	0.000184

Based on the historical reliability data presented in Table 1, the reliability data of the three individual line sections (1L146A, 1L146B and 1L146C) can be obtained as shown in Table 2.

Table 2: Reliability data of the 1L146A, 1L146B and 1L146C.

Line Section	Length (km)	Failure Frequency (failure/year)	Repair Time (hours)	Unavailability (/year)
1L146A	13.9	0.12004	2.97	0.000041
1L146B	15.4	0.13300	2.97	0.000045
1L146C	33.6	0.29017	2.97	0.000099

4. Generation Adequacy Analysis

The focus of this analysis is on how adequate the specified system would be in terms of generation and load balance if 1L146 is out of service. There are two basic scenarios conducted in this section. These two scenarios are based a capability of an islanding operation of the JOR-G1; 1.) islanding operation is not permitted, and 2.) islanding operation is permitted. The study conditions used in the analysis are as follows:

Study Conditions:

- A model of balancing resources (generation and load) is used the analysis.
- A 2006 load forecast is used in the study. The historical load curves are prorated to match with the 2006 peak load forecast.
- Unavailability of JOR-G1 due to a mechanical failure is very small compared to that due to the water condition, and therefore a forced outage of JOR-G1 is negligible for this study.
- If there is a fault on one of the 1L146 sections, it is assumed the fault section can be isolated within a minimal time period.
- An annual JOR-G1 maintenance is assumed to be taken place during summer (light load and deficiency of water to generate power).
- If the islanding operation is permitted, it is assumed that there is a crew readily standing by at the site in order to facilitate the islanding operation mode.

4.1 Islanding Operation of JOR-G1 Is Not Permitted

This section considers the traditional system operation when 1L146 is out of service resulting in a disconnection of Jordan River generation from the system. The following three outage conditions are considered:

a.) Loss of 1L146A (resulting in loss of JOR, SOO and CLD loads)

Under the outage of 1L146A, loads at JOR, SOO and CLD will be totally curtailed when the islanding operation of JOR-G1 is not permitted. The combined annual load curve of JOR, SOO and CLD loads was obtained from PI system and presented in Figure 3.

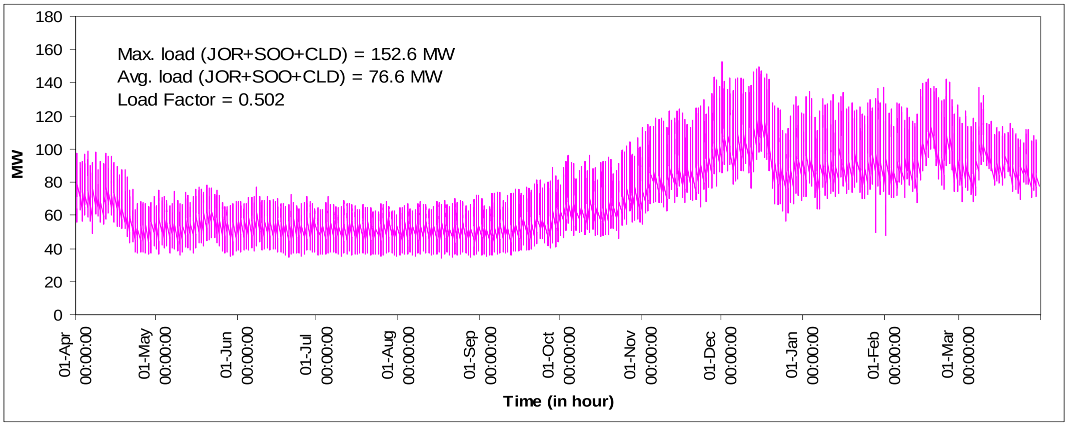

Figure 3: The combined annual load curve of JOR, SOO and CLD loads (prorated for 2006).

If the islanding operation of JOR-G1 is not permitted, the loss of 1L146A will result in the total load curtailment at JOR, SOO and CLD.

Unavailability of 1L146A = 0.000041
Average load (to be curtailed) = 76.6 MW
Expected Energy Not Supplied (EENS) = Average load×Unavailability×8760
= 76.6×0.000041×8760 = 27.51 MWh/yr

Therefore, the risk of load curtailment under 1L146A out of service without an islanding operation of JOR-G1 is 27.51 MWh/yr. (Note that this value is based on load demand in 2006. The risk in the future years can be calculated by prorating the average load using the growth rate).

b.) Loss of 1L146B (resulting in loss of JOR and SOO loads)

Under the outage of 1L146B, loads at JOR and SOO will be totally curtailed when the islanding operation of JOR-G1 is not permitted. CLD load is assumed to be supplied from GOW. The combined annual load curve of JOR and SOO loads was obtained from PI system and presented in Figure 4.

If the islanding operation of JOR-G1 is not permitted, the loss of 1L146B will result in the total load curtailment at JOR and SOO.

Unavailability of 1L146B = 0.000045
Average load (to be curtailed) = 18.6 MW
Expected Energy Not Supplied (EENS) = Average load×Unavailability×8760
= 18.6×0.000045×8760 = 7.33 MWh/yr

Therefore, the risk of load curtailment under 1L146B out of service without an islanding operation of JOR-G1 is 7.33 MWh/yr.

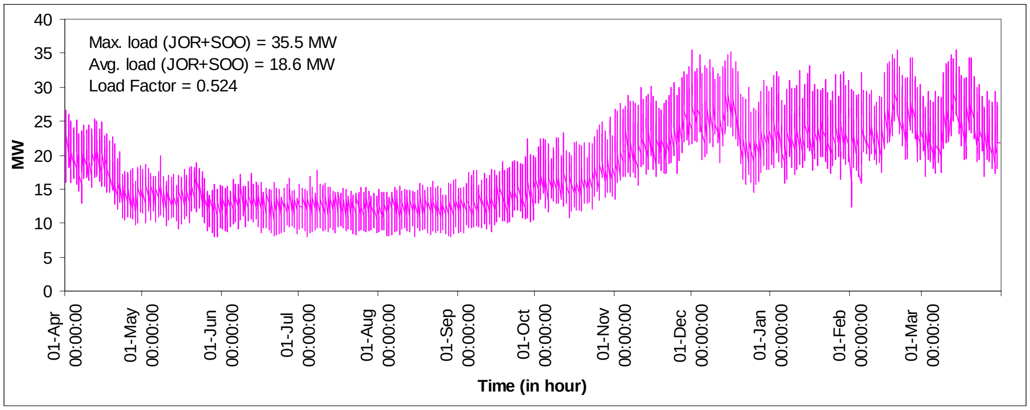

Figure 4: The combined annual load curve of JOR and SOO loads (prorated for 2006).

c.) Loss of 1L146C (resulting in loss of JOR load)

Under the outage of 1L146C, JOR load will be totally curtailed when the islanding operation of JOR-G1 is not permitted. SOO and CLD loads are assumed to be supplied from GOW. The annual load curve of JOR load was obtained from PI system and presented in Figure 5.

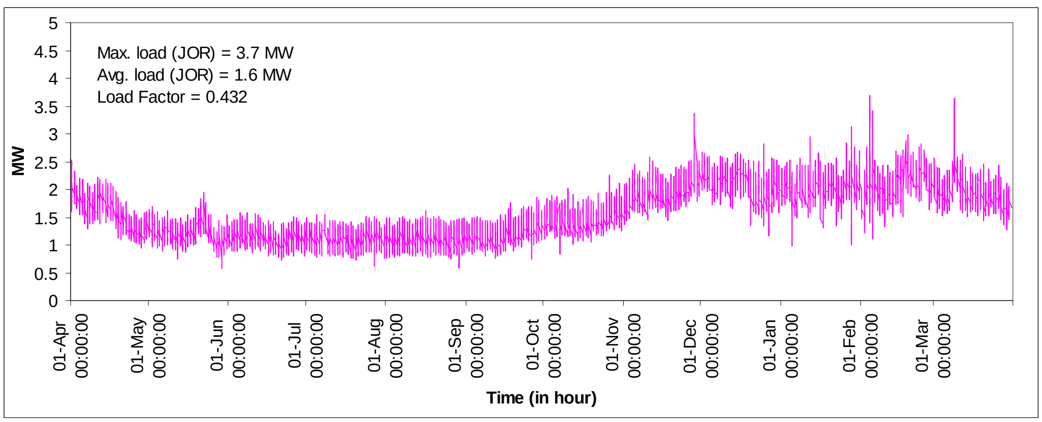

Figure 5: The annual load curve of JOR load (prorated for 2006).

If the islanding operation of JOR-G1 is not permitted, the loss of 1L146C will result in the total load curtailment at JOR.

Unavailability of 1L146C = 0.000099
Average load (to be curtailed) = 1.6 MW
Expected Energy Not Supplied (EENS) = Average load×Unavailability×8760
= 1.6×0.000099×8760 = 1.39 MWh/yr

Therefore, the risk of load curtailment under 1L146C out of service without an islanding operation of JOR-G1 is 1.39 MWh/yr.

In conclusion, the total risk of load curtailment due to one of three line sections out of service without an islanding operation permission can be obtained by summing all the EENS in Sections a.), b.) and c.) altogether.

The total EENS (islanding operation is not permitted) = 27.51+7.33+1.39 = 36.23 MWh/yr.

4.2 Islanding Operation of JOR-G1 Is Permitted

An islanding operation mode of Jordan River generation is considered in this section. The loss of one of 1L146 sections will create an islanding system, which is supplied by the JOR-G1 only. The following three outage conditions are considered:

a.) Loss of 1L146A (resulting in loss of JOR, SOO and CLD loads)

Under the outage of 1L146A, loads at JOR, SOO and CLD will totally depend on the availability of Jordan River generation, which is limited by the water condition. Therefore, a supply and demand balancing model can be used to represent an islanding system as shown in Figure 6.

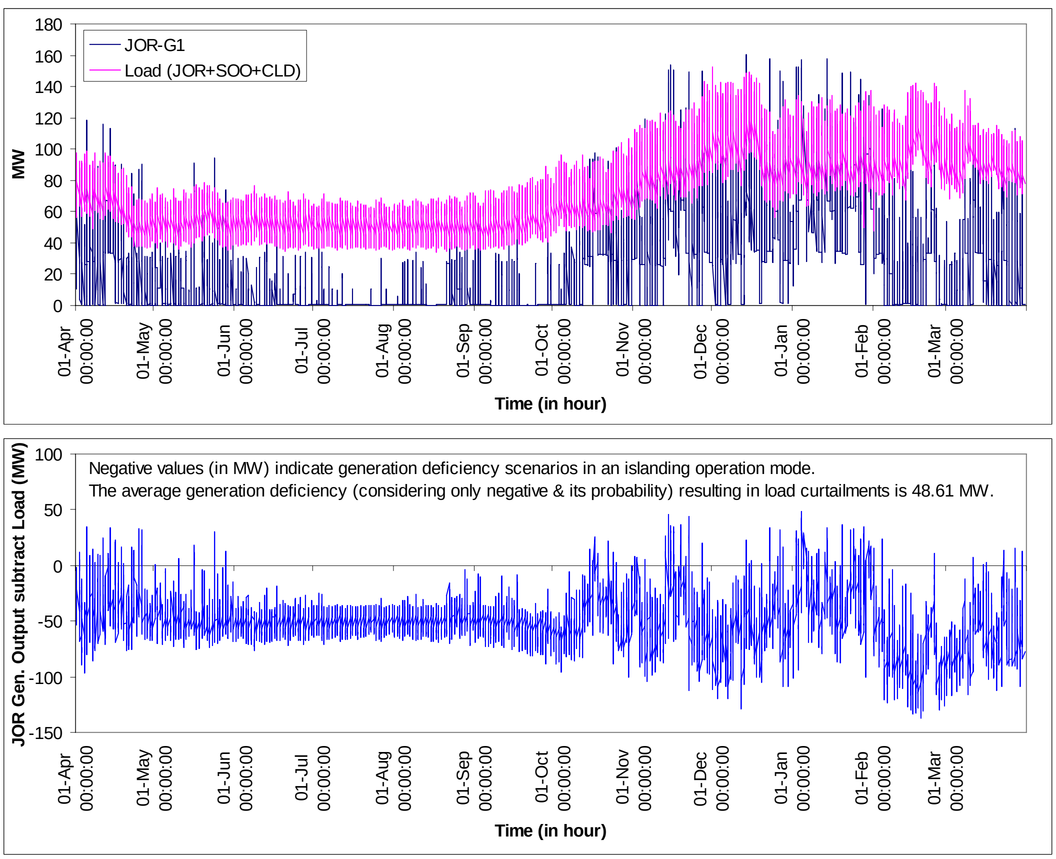

Figure 6: Supply and demand balancing model for the islanding system under 1L146A out of service.

As shown in Figure 6 (the bottom graph), the average load to be curtailed under 1L146A out of service is 48.61 MW instead of 76.60 MW presented in Figure 3. This implies that the firm capacity of Jordan River generation that can equivalently replace the loads is approximately (76.60–48.61) or 27.99 MW. This value is very close to the capacity factor of JOR-G1, which is around 0.16 to 0.17.

If the islanding operation of JOR-G1 is permitted, the loss of 1L146A will result in some of load curtailments at JOR, SOO and CLD (when JOR-G1 output is less than load).

Unavailability of 1L146A = 0.000041
Average load (to be curtailed) = 48.61 MW
Expected Energy Not Supplied (EENS) = Average load×Unavailability×8760
= 48.61×0.000041×8760 = 17.46 MWh/yr

Therefore, the risk of load curtailment under 1L146A out of service with an islanding operation of JOR-G1 is 17.46 MWh/yr.

b.) Loss of 1L146B (resulting in loss of JOR and SOO loads)

Under the outage of 1L146B, loads at JOR and SOO will totally depend on the availability of Jordan River generation, which is limited by the water condition. CLD load is assumed to be supplied from GOW. The supply and demand balancing model for the islanding system under the 1L146B out of service is shown in Figure 7.

As shown in Figure 7 (the bottom graph), the average load to be curtailed under 1L146B out of service is 6.64 MW instead of 18.60 MW presented in Figure 4. This implies that the firm capacity of Jordan River generation that can equivalently replace the loads is approximately (18.60–6.64) or 11.96 MW. This firm capacity is quite low compared to the maximum capacity of JOR-G1. The capacity factor in this case is therefore considerably lower than 0.16. This is due to the fact that the total load (JOR and SOO) in the islanding system is small. The amount of water (if available) will be spilled in order to facilitate the JOR-G1 to balance with the islanded load.

If the islanding operation of JOR-G1 is permitted, the loss of 1L146B will result in some of load curtailments at JOR and SOO (when JOR-G1 output is less than load).

Unavailability of 1L146B = 0.000045
Average load (to be curtailed) = 6.64 MW
Expected Energy Not Supplied (EENS) = Average load×Unavailability×8760
= 6.64×0.000045×8760 = 2.62 MWh/yr

Therefore, the risk of load curtailment under 1L146B out of service with an islanding operation of JOR-G1 is 2.62 MWh/yr.

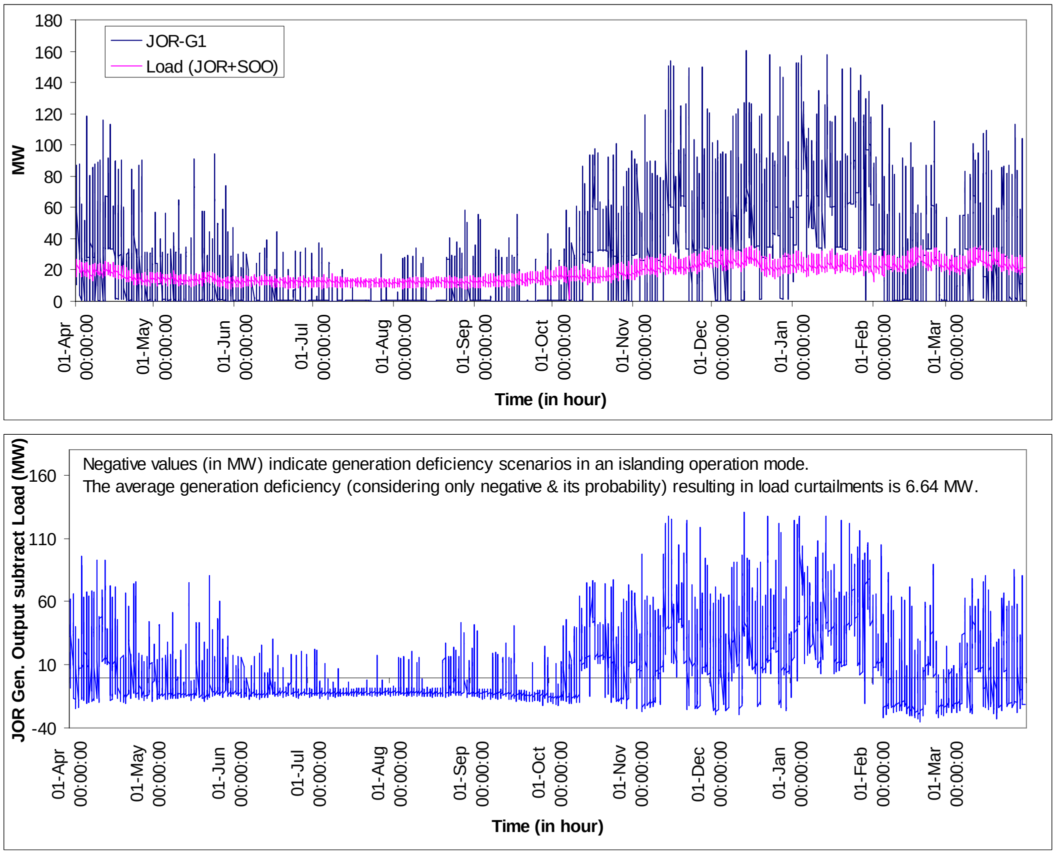

Figure 7: Supply and demand balancing model for the islanding system under 1L146B out of service.

c.) Loss of 1L146C (resulting in loss of JOR load)

Under the outage of 1L146C, load at JOR will totally depend on the availability of Jordan River generation, which is limited by the water condition. SOO and CLD loads are assumed to be supplied from GOW. The supply and demand balancing model for the islanding system under the 1L146C out of service is shown in Figure 8.

As shown in Figure 8 (the bottom graph), the average load to be curtailed under 1L146C out of service is 0.44 MW instead of 1.60 MW presented in Figure 5. This implies that the firm capacity of Jordan River generation that can equivalently replace the loads is approximately (1.60–0.44) or 1.16 MW. This firm capacity is very little compared to the maximum capacity of JOR-G1. The capacity factor in this case is therefore extremely smaller than 0.16. This is due to the fact that the total load (JOR) in the islanding system is very small. The significant amount of water (if available) will be spilled in order to facilitate the JOR-G1 to balance with the islanded load.

If the islanding operation of JOR-G1 is permitted, the loss of 1L146C will result in some of load curtailments at JOR (when JOR-G1 output is less than load).

Unavailability of 1L146B = 0.000099
Average load (to be curtailed) = 0.44 MW
Expected Energy Not Supplied (EENS) = Average load×Unavailability×8760
= 0.44×0.000099×8760 = 0.38 MWh/yr

Therefore, the risk of load curtailment under 1L146C out of service with an islanding operation of JOR-G1 is 0.38 MWh/yr.

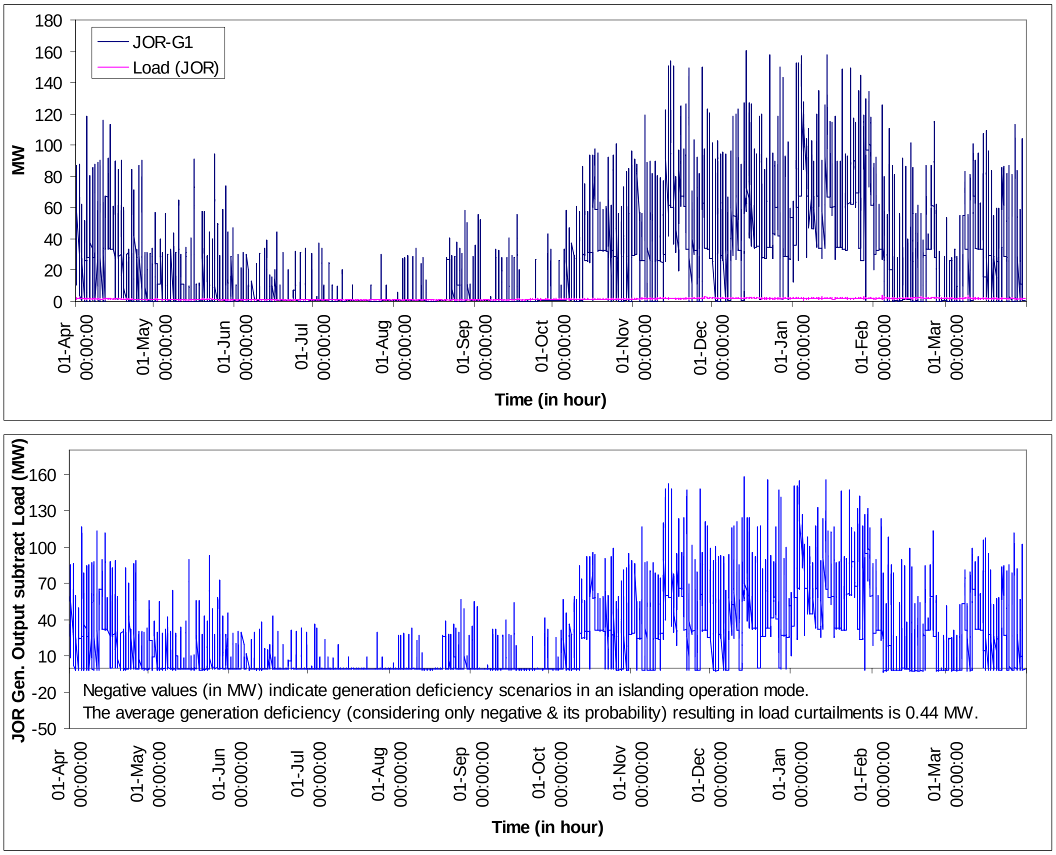

Figure 8: Supply and demand balancing model for the islanding system under 1L146C out of service.

In conclusion, the total risk of load curtailment due to one of three line sections out of service with an islanding operation permission can be obtained by summing all the EENS in Sections a.), b.) and c.) altogether.

The total EENS (islanding operation is not permitted) = 17.46+2.62+0.38 = 20.46 MWh/yr.

5. Conclusions

Probabilistic risk assessment for an islanding operation of Jordan River generation is conducted in this report. The expected energy not supplied (EENS) is used in this analysis to represent the risk of load curtailment at JOR, SOO and CLD. Although there is a concern that the JOR-G1 may not be dependable subject to the water condition to provide an islanding operation capability, the historical reliability data however indicate that the 1L146 is highly reliable (very low unavailability). This implies that the probability of having an islanding system is very low. Therefore, the risk of load curtailment at JOR, SOO and CLD is not significant as proven by the EENS results. The total EENS with and without the islanding operation permission are 20.46 and 36.23 MWh/yr respectively. This implies that with an islanding capability, the risk reduces by (36.23–20.46) or 15.77 MWh/yr. This is equivalent to a 44% reduction of the risk of load curtailment.

Given that the Jordan River generation has a load following capability that facilitates the islanding operation, the risk of 20.46 MWh/yr could be expected. In addition, the severity index designated as Delivery Point Unavailability Index (DPUI) used by BCTC indicates that the historical DPUI of the overall BC Hydro is approximately 25 to 30 system·minutes. The risk of 20.46 MWh/yr shown above can be translated to the DPUI by dividing with the total islanded load (JOR, SOO and CLD = 152.6 MW) and then multiplied by 60 minutes. The DPUI of the JOR, SOO and CLD in this case is approximately (20.46×60/152.6) or 8.04 system·minutes. Even if the JOR-G1 has no islanding capability, the DPUI for this case is (36.23×60/152.6) or 14.24 system·minutes. These two DPUI values prove that the reliability of the designated islanding system is well above the average DPUI of the BC Hydro system.

References

[1] BC Hydro, "*Making the connection: the B.C. Hydro electric system and how it is operated – 2nd revision*", BC Hydro, Vancouver, 2000.

[2] Wenyuan Li, "*Expected Energy Not Served (EENS) Study for Vancouver Island Transmission Reinforcement Project: Part 1 – Reliability Improvements due to VITR*", British Columbia Transmission Corporation (BCTC), Vancouver, Canada, December 8, 2005.