Q. Reference PUB-NLH-265: Does Hydro believe that a wide range of the rate of frequency change would complicate the design of the protection, or make the design of the protection easier? Please explain your answer in detail.

A. The application of rate of change of frequency (df/dt) relaying as part of an Under Frequency Load Shedding (UFLS) scheme has both advantages and disadvantages. Perhaps one of the bigger advantages is that for sudden loss of a relatively large amount of generation resulting in a significant df/dt, application of an appropriate df/dt relay setting can be used to quickly trip load to arrest the system frequency decay prior to governor action which, in turn, permits governor action to recover system frequency in a timely manner, and thereby reduce the overall magnitude of load that would otherwise be shed for the event.

Comparatively, systems with significant amounts of thermal generation may respond to frequency changes quicker than systems with significant amount of hydro-electric generation given the inherent delays introduced by the water start times associated with hydro-electric turbines. As a result, a df/dt relay based UFLS scheme can be of benefit for hydro-electric based systems. For example, a review of the Northeast Power Coordinating Council (NPCC) Directory 12 *Under Frequency Load Shedding Program Requirements* dated July 9, 2013, indicates that each Balancing Authority in the NPCC portion of the Eastern Interconnection with 100 MW or more of end user load will have five threshold stages of under frequency load shedding blocks. Four of these blocks must trip within 300 ms and one block is an anti-stall block that must trip in 10 s. There is no df/dt relaying. However, the directory also indicates that the Balancing Authority in the Québec Interconnection UFLS program consists of five threshold stages and four df/dt stages of load shedding blocks. Four of the Québec Interconnection threshold blocks must trip in 300 ms and one anti-stall block must trip in 20 s. Table 1 provides a comparison of the UFLS programs for NPCC portion of the Eastern Interconnection, the Québec Interconnection and the existing Island Interconnected System.

Table 1
Comparison of Existing Under Frequency Load Shedding Programs

	NPCC Portion of Eastern Interconnection ~ 118,000 MW Installed 1250 MW contingency (NE) with no load loss Minimum frequency 58.0 Hz			**Québec Interconnection** ~ 45,000 MW Installed 1000 MW loss 1st contingency with no load loss Minimum frequency 56.0 Hz				**Existing Island Interconnection** ~ 1900 MW Installed 170 MW loss 1st contingency with load loss Target Min Frequency 58.0 Hz			
Stage	System Freq. (Hz)	Load (%)	Time	df/dt (Hz/s)	System Freq. (Hz)	Load MW & MVAR	Time	df/dt (Hz/s)	System Freq. (Hz)	Load (MW)	Time
1	59.5	6.5-7.5	300 ms	-	58.5	1000	300 ms	-	58.8	40	100 ms
2	59.3	6.5-7.5	300 ms	-	58.0	800	300 ms	-	58.6	43	100 ms
3	59.1	6.5-7.5	300 ms	-	57.5	800	300 ms	-	58.4	50	100 ms
4	58.9	6.5-7.5	300 ms	-	57.0	800	300 ms	-	58.2	60	100 ms
5	59.5	2-3	10 s	-	59.0	500	20 s		58.1	90	100 ms
6	-	-	-	-	-	-	-	-	58.0	159	100 ms
7	-	-	-	-	-	-	-	-	59.0	40	15 s
1	-	-	-	-0.3	58.5	400	300 ms	-0.5	59.5	10	100 ms
2	-	-	-	-0.4	59.8	400	300 ms	-0.6	59.5	20	100 ms
3	-	-	-	-0.6	59.8	400	300 ms	-0.7	59.5	30	100 ms
4	-	-	-	-0.9	59.8	800	300 ms	-	-	-	-

Notes
Eastern Interconnection including Québec has installed capacity of approximately 610,000 MW

NE – New England

6.5 – 7.5% of NPCC load equates to approx. 4800 – 5500 MW for entire NPCC Portion of Eastern Interconnection 2015-16 peak load forecast of approx. 73,490 MW (non coincident). Quebec Interconnection forecast 2015-2016 peak load approx.. 38,200 MW. Data from **Northeast Power Coordinating Council Reliability Assessment For Winter 2015-16 FINAL REPORT Approved by the RCC December 1, 2015 (www.npcc.org)**

Existing Island Interconnected System ULFS relays are set to trip instantaneously except the 59.0 Hz block with a 15 second time delay. Instantaneous relay operation is considered to be 100 msec or 6 cycles, one cycle for relay and 5 cycles for the circuit breaker.

The review of the NPCC Directory 12 also provides insight into the acceptability of frequency excursion. The NPCC portion of the Eastern Interconnection (substantial thermal generation) requires that frequency decline is arrested at no less than 58.0 Hz, that the frequency does not remain below 58.5 Hz for more than 10 seconds and that the frequency does not remain below 59.5 Hz for more than 30 seconds. By comparison, the Québec Interconnection (predominantly hydro-electric) requires that the frequency decline is arrested at no less than 56.0 Hz, that the frequency does not remain below 58.5 Hz for more than 10 seconds and that the frequency does not remain below 59.5 Hz for more than 30 seconds. It is Hydro's belief that the additional frequency deviation permitted in the Québec Interconnection before arresting is due in part to the relative sizes of the Eastern Interconnection and the Québec Interconnection, the "slower" response times of hydro-electric versus thermal, and the ability of hydro-electric generators to withstand larger frequency deviations than higher speed thermal units. Hydro's existing UFLS stage at 59.0 Hz with a 15 second time delay is meant to trip load to push the frequency above 59 Hz to prevent damage to Holyrood thermal units due to off nominal speed operation.

Perhaps one of the bigger disadvantages of the application of df/dt relaying can be found in relatively small grids. In smaller grids with limited inertia, a high impedance transmission line fault can appear as a substantial increase in system load that may last longer than a typical line fault. Having too low a df/dt setting (i.e. 0.2 Hz/s as opposed to 0.9 Hz/s) can result in a false trip of the load shedding block as the load increase and sudden frequency decay may cause the df/dt relay to pick up and trip the circuit breaker. Consequently careful coordination between the df/dt relay settings (i.e. frequency set point and rate of change), the available system inertia to maintain frequency for the generation loss and the governor reaction time is required. To this end, a large number of df/dt stages over a large range of rate of change settings may be difficult to coordinate to ensure proper response to a multitude of generation loss scenarios over a wide range of system operating conditions.

A practicable application of df/dt relaying for the Island Interconnected System post LIL, given the system size and HVdc connections, may be to limit use to the very severe generation losses such as permanent bipole outage or complete loss of Bay d'Espoir plant at 600 MW, where the rate of change of frequency will be quite dramatic. This would leave the traditional threshold stages at set frequencies to respond for the less severe generation losses (i.e. loss of four units at Bay d'Espoir for a fault on a 230 kV bus followed by stuck breaker – up to 300 MW loss).

The impact of df/dt application is dependent, in part, on the governor response due to the water start times of the hydro-electric generators providing frequency control versus thermal units in combination with the amount of system inertia and the relative sizes of generation loss to inertia impact.