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Grid Resilience Strategy – Natural Hazards: High Level Pragmatic Approach

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SUMMARY

This paper outlines Hydro One's (Canadian electricity utility) grid resilience adaptation strategy with concerned related to extreme natural hazards, but excludes human caused hazards (e.g. cyber).

Electricity utilities in North America and elsewhere, experience disruptions caused by extreme weather events, with higher intensity and frequency, consistent with the other sectors per reports issued by the Insurance Bureau of Canada. Climate change causes longer term weather changes. The Ontario electricity sector "Climate Change Mitigation (CCM)" in the past undertook steps (coal-electric stations shut-down) to stabilize, or reduce GHG (greenhouse gases) and continues to support CCM with the purpose of lowing or stalling climate change; and outline the high level Climate Change Adaptation (CCA) that realizes climate change is inevitable, and steps are taken to reduce the impacts of extreme natural events on the electricity grid; with the latter being the focus of this paper.

For this initial high-level work for resilience adaptation strategy, Hydro One sought an understanding of grid "resilience"; examined historical data relevant to "extreme" electricity grid disruptions; examined existing grid planning, engineering and operational (including emergency) practices; sought advice from technical subject matter experts regarding grid resilience; examined lessons from other utilities through published materials; briefly examined the grid changes noting the large amount of renewable (solar, wind) generation in Ontario; and examined the consideration of Non-Wires Alternatives (NWAs), as well as potential use of macro/ micro-grids, and energy storage in the future. Hydro One applies lifecycle principles in grid management, and lifecycle phases are used to "cross check" CCA options. This portion of the work is qualitative rather than quantitative.

This initial high level, qualitative work outlines Hydro One Grid Resilience Adaptation Strategy for natural hazards. The lessons from the development of the high-level grid adaptation strategy, call for further quantitative work with the need to define a CCA framework with focus on the electricity sector.

KEYWORDS

Transmission & distribution grid resilience, extreme value, climate change, mitigation, adaptation.

[1.0] INTRODUCTION

The purposes of this paper are to: (a) increase awareness of the risk exposure and vulnerability of an electricity utility's, i.e. Hydro One's transmission and distribution infrastructure to "climate change" which has resulted in more extreme natural hazards (e.g. weather); (b) outline a strategy and mitigation measures to address grid impacts of climate change; and, (c) outline higher priority recommendations. This paper examines extreme natural hazards, and excludes human caused hazards (e.g. cyber).

Hydro One's Transmission (T) network, including about 30,000 circuit km of high voltage lines and more than 300 substations, delivers electricity safely and reliably from generation sources to large industrial customers and municipal utilities, and provides 98% of Ontario's transmission capacity. Hydro One's Distribution (D) network spans over 123,000 circuit km and more than 1000 stations, distributing electricity to about 1.4 million residential, business, commercial and industrial customers.

The transmission and distribution system span over 640,000 square kilometers, mostly in heavily forested and rugged terrain. With Ontario's large geographic area and complex climatic conditions, weather has significant impacts on the planning, design, asset management and operation of the transmission and distribution systems. With the large service territory, the system can be vulnerable to a variety of extreme weather conditions and other effects which can impact reliability performance. Changing meteorological conditions, including an increased in frequency of extreme weather events, may result in increased equipment failures and extended system recovery time. Other adverse impacts on the management and operations of assets include accelerated corrosion of steel components, more rapid wood decay, wildfire hazards, mud slides, flooding, reduced opportunity for live line maintenance, delays in restoration operations, and reduced transmission transfer capability.

The electricity industry is a sub-sector of Energy sector in general per US Dept. of Homeland Security's critical infrastructure list which covers 16 sub-sectors, including water system, healthcare, dams, information technology sectors and so forth. The overall coordination among these sub-sectors is essential to maintain societal resilience.

In order to address aging gird issues, Hydro One implements ongoing "system renewal" projects and other equipment "sustainment" programs. This includes equipment Asset Condition Assessments and major equipment overhauls, major repairs, equipment replacement, etc.

[2] RELIABILITY & RESILIENCE

Reliability and resiliency are two different concepts widely used by electricity utilities. In general, (a) Reliability involves a low impact, high probability situation; and, (b) Resiliency involves high impact, low probability (HI-LP) events and the ability of the system to recover to an acceptable steady state condition. For North American Electric Reliability Corporation (NERC), resilience is a critical aspect of reliability that provides an Adequate Level of Reliability (ALR).

While electricity utilities have a common purpose in addressing the impact of extreme events, utilities have not adopted common definition of resilience. The North American Transmission Forum (NATF), resilience (adapted from 2018 NATF Resiliency Summit) is defined as the ability of the system and its components (both the equipment and human components) to minimize damage and improve recovery from non-routine disruptions, including high impact, low frequency (HILF) events in a reasonable amount of time.

The US National Infrastructure Advisory Council (NIAC) (2009) defines critical infrastructure resilience as: "the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure… depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event." With further consideration of different perspectives of resilience, NERC Reliability Issues Steering Committee (RISC), breaks the definition into: **Robustness** – ability to absorb shocks and continue operating; **Resourcefulness** – ability to detect and manage a crisis as it unfolds; **Rapid recovery** – ability to get services back as quickly as possible in a coordinated and controlled manner and taking into consideration the extent of the damage; and **Adaptability** – ability to incorporate lessons from past events to improve resilience.

[3] CLIMATE CHANGE, EXTREME WEATHER & PROJECTIONS, & UNCERTAINTY

Climate Change: The concept of "climate change" (CC) and associated effects are increasingly acknowledged and recognized. In 1988, the United Nations (UN) and World Meteorological Organization (WMO) jointly established the Intergovernmental Panel on Climate Change (IPCC), to assess CC based on the latest science and technology. Increasingly, there is an enhanced understanding of how adaptation and mitigation strategies can manage the risks of CC (IPCC, 2014). The "scientific consensus" is that CC is a by-product of human activities, including GHG emissions from the combustion of fossil fuels. As the effects of climate change and extreme weather impact on the system and performance, it is critical to implement appropriate mitigation measures.

Historical Extreme Event Impacts in Canada & Ontario: The impact of extreme weather has increased over time. According to the Insurance Board of Canada (IBC), severe weather, such as ice storms, floods, windstorms and tornadoes caused $1.9 B in insured damages in 2018. Unlike single significant events such as the Quebec ice storm, Calgary floods and Fort McMurray wildfires in 1998, 2013 and 2016 respectively, no single event in 2018 led to a high pay out, rather it was a result of multiple smaller severe weather events. The rate of occurrence of extreme events has been increasing over the past 35 years, as measured by catastrophic insurance claims. Figure 3.0-1 provides the historic catastrophic insurance losses in Canada and Ontario for major natural hazards, while Figure 3.02 provides the frequency of occurrence of extreme events.

Figure 3.0-1: Catastrophic Losses in Canada & Ontario ($Billions, 1983-2018)

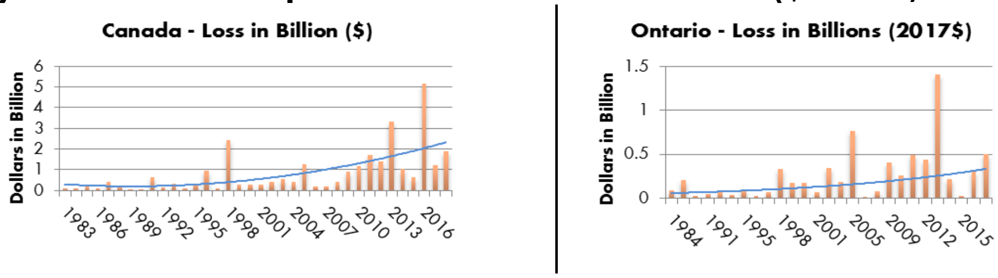
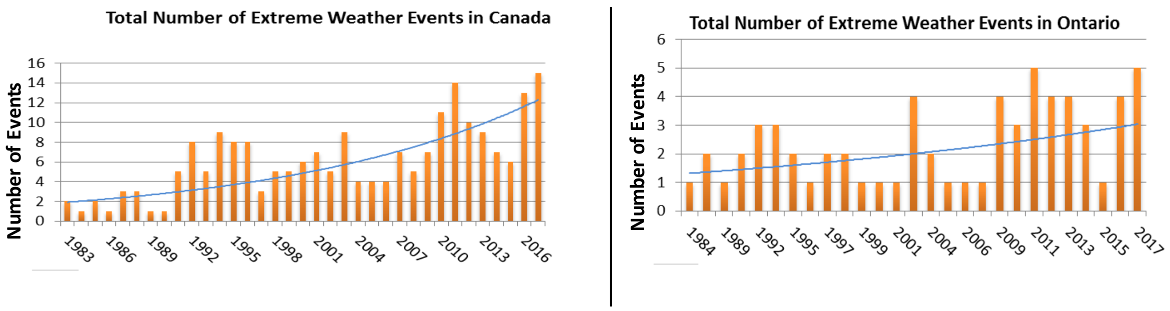


Figure 3.0-2: Frequency of Extreme Weather events in Canada & Ontario (1983-2017)



With more occurrences of extreme weather events, Hydro One has two main concerns: [i] impact on reliability performance; and [ii] impact on resilience of the transmission system.

Climate Change Projection in Ontario: The Canadian and Ontario governments have used the IPCC's GHG emissions projections, to estimate in weather patterns, including average and variability for extreme weather projections. The electricity industry needs to undertake work to develop "reference scenarios" including weather projection for practical applications within the industry.

Extreme Hazards & Grid: Develop a list of key natural hazards for Ontario includes flooding/ heavy rains (urban)/ precipitation; forest fires; extreme cold & freezing rain/ icing/ snow; extreme high temperatures/ heat waves; lightning storms; tornadoes (usually local); high winds (wide area); earthquakes/ seismic; and geomagnetic disturbances (GMD)/ solar storms.

Deep Uncertainty – Defiant Challenge & Extreme Value Analyses: Figures 3.03 and 3.04 (non-Ontario specific) illustrate the uncertainty and variability in the intensity of grid hazards as reflected in a) the range of restoration time versus the amount of warning time before a grid hazard event occurs, and b) the uncertainty to the causes and detectability using the limited knowledge and technology regarding natural hazards.

Figure 3.0-3: Range of Restoration Time Versus Warning Time before Hazard Occurrence

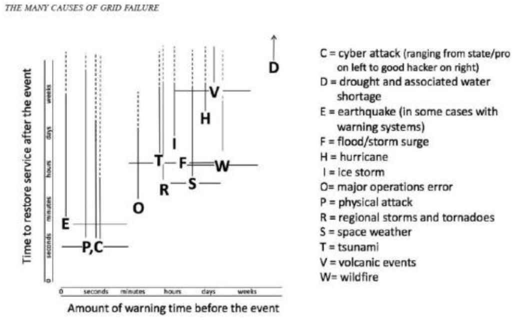
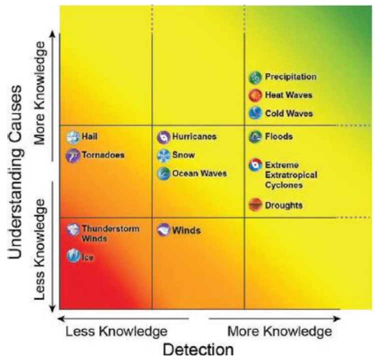


Figure 3.04: Knowledge of Causes Versus Detection for Grid Hazards



[Source: NASEM; Enhancing the Nation's Electrical System, pg. 51 and 55, 2017]

Experts in resilience analysis, state that with "deep uncertainty" there is insufficient information to apply conventional risk management analyses approaches which rely on Subjective Expected Utility (SEU) Theory. In particular, deep uncertainty is characterized by a) uncertainty about the model form or validity for predicting future conditions; b) ignorance about appropriate assumptions or subjective beliefs about uncertainty before observing relevant future events; c) disagreement among experts and decision makers about preferences and priorities for future action. The first 2 factors are prominent as shown in Figures 3.0-3 and 3.0-4. For Ontario, the knowledge and detection of lightning (thunderstorms) is better compared to the level noted in Figure 3.04, including lightning information collected since 1976, at the Toronto CN Tower at 553.3 m height. The third factor is an emerging consideration which the industry is still examining, and a consensus has not been reached on grid resilience metrics. This uncertainty calls to Extreme Value Analyses (EVA) for resilience, beyond usual risk management.

[4.0] GRID RESILIENCE IMPACTS INCLUDING NATURAL HAZARDS

[4.1] Grid Resilience Needs Practicality

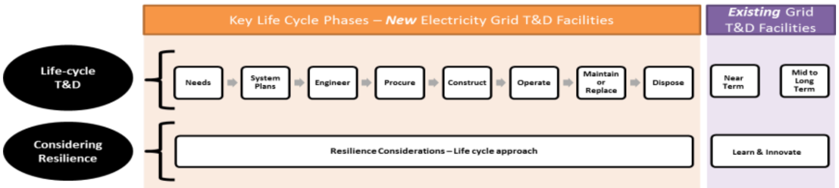
Grid resilience experts (Proc. Of the IEEE, vol. 105, No. 7. July 2017, pg. 1254) note that a comprehensive upgrade of the entire grid is too costly to be practical, and cannot guarantee full continuity of electricity supply. Utilities worldwide recognize that, based on experience with extreme natural hazards, they may not manage the immediate impacts of all natural events at all times via design enhancements. There are practical alternatives to maintain grid resiliency to address the impact of low-probability, high-consequence extreme hazards. Mitigation, such as selective load shedding may be a practical operating mode if in "degraded" states following an extreme hazard, and allow further actions to return the grid to a normal operating level.

[4.2] Grid Resilience Analyses Within Lifecycle Approach - Natural Hazards

Three-Step High Level Approach for Assessing Resilience Options:

a) For each natural hazard, qualitatively consider the consequence on the grid facilities, identify industry and technical engineering requirements relevant to the impacts, and identify potential mitigation actions;
b) Consider integrated grid facilities, and system operating impacts, including Ontario Power System Restoration Plan (OPSRP), emergency preparedness plans, storm response, and potential mitigations;
c) Identify advanced technology, concepts or methodologies to improve grid resiliency.
To ensure key factors are considered, a "cross-check" within a life cycle approach is considered as part of the analyses as illustrated in Figure 4.2-1.

Figure 4.2-1: Life Cycle Resilience Approach



In this document, mitigation action is grouped into four categories including a) Planning; b) Engineering and c) Operations & Maintenance (O&M) and d) Grid System Operating; and, this broadly aligns with a life cycle approach for facilities.

[4.3] Resilience "Threshold": Transmission 2β Method & Distribution >10,000 Customers method

<u>Transmission</u>: With no industry accepted resilience metrics, transmission reliability based event definitions based on historical events and reliability data are examined for scale of customer impact. In statistics, variability is measured by standard deviations. Exploratory work on variance is underway and one approach to account for uncontrollable events is the exclusion of major events criteria, referred to as the '2β Method', specifically, the exclusion of any event with 10,000 MW-minutes or more of unsupplied energy. This threshold is about 1.95 (log normal; and "rounded to 2") standard deviations above the average. This is application of EVA. As a cautionary reminder, when developing resilience statistics, the utility sector only has grid reliability information for less than 50 years; and, the sample size for "resilience" events can be small, given that HI-LP events usually have return period of 20, 50, 100 or more years. Data set for evaluating long-time period historical extreme grid event risks is challenging.

Table 4.3-1 provides the percent contribution of each weather/environment hazard to all the major events, which had over 10,000 MW-minutes unsupplied energy based on 2011 to 2020 data. The highest contributor to unsupplied energy is flooding, followed by tornado, forest fire, lightning, and wind. These five weather/natural hazards contribute to about 96.5% of all weather/ natural hazard related major interruptions. The reader is cautioned of potential "unconscious bias" of the relative importance of hazards; additional hazards are not unimportant, rather deep uncertainty of certain hazards calls for fuller analyses, and may be hazards in combination (ice accretion & wind, etc).

Table 4.3-1 – Delivery Point Interruptions by Natural Hazards

Hazard Types	% of # of interruptions	% of interruption duration	% of MW-Minutes Loss
Forest Fire	3.5	40.4	11.1
Flood	16.9	12.9	50.2
Freezing Rain	1.8	0.0	0.0
Ice	20.8	5.3	3.0
Lightning	21.6	5.3	6.0
Snow	6.1	0.7	0.5
Tornado	11.6	28.4	24.6
Wind	17.6	6.9	4.4
All	100	100	100

Distribution: For Hydro One's distribution system, the historical extreme or force majeure events, involving loss of 10% or more of customers during an event, with primary causes that included tree contacts, defective equipment, unknown/other and loss of supply.

[4.4] Adaptation/ Resilience Risk Reduction Actions & Recommendations

Climate Change Adaptation (CCA) recognizes that climate change is inevitable despite CCM efforts, and it exerts significant pressure on physical, socio-economic systems, and practices, processes, or standards, which aims to reduce current and future impacts of extreme natural events (including weather). Where such hazards are expected (albeit rarely), consequence mitigation measures may be needed when the hazard exceeds a "coping range" for consequence. Tables 4.4-1, provides for each natural hazard, an estimate of grid impact (in the past); with identification of grid issues and adaptation/ resilience /recommendations in three main lifecycle work areas – planning, engineering, grid operating/ operations & maintenance (O&M) (Collectively "operations"); and for some human caused hazards.

Table 4.4-1: Natural Hazards – Adaptation/ Resilience Actions

Hazard	Impact	Issue	Mitigation Actions Planning	 Engineering	 Operations
Natural/Environmental Threats for Hydro One					
Forest Fire	4.2% of T-SAIFI Weather 48.2% of T-SAIDI Weather 13.3% of MW-min loss Weather	115 kV transmission lines in north-east and north-west are vulnerable	1) Forecast "Dry" period and identify vulnerable geographic pockets 2) Spare transmission line components		1) Ensure compliance with conductor sag clearance requirements
Lightning	14.2% of T-SAIFI Weather 8.5% of T-SAIDI Weather 11.4% of MW-min loss Weather	Southern Ontario experience highest levels of lightning in Canada	1) Assess impact of backflash 2) Grounding integrity at tower footings of key transmission lines	1) Identify key transmission stations with poor reliability and check if field installation meets engineering specifications 2) Conduct technical review of stations with missing lightning protection	
Wind	16.3% of T-SAIFI Weather 12.9% of T-SAIDI Weather 9.9% of MW-min loss Weather	Southern Ontario experience high winds and the frequency and magnitude is on increase	1) Ensure vegetation clearance on ROWs are maintained to standard 2) Replace defective line insulators prone to fail under cantilever force exerted by wind 3) Considering grid security needs keep separate ROWs for new lines	1) New bulk supply transmission lines use return period of 50 years for design. 2) Design structure "arms", that can break-away to mitigate cascading tower collapse.	1) Ensure adequate maintenance and provide accurate asset condition assessment information.
Flood	8.2% of T-SAIFI Weather 13.3% of T-SAIDI Weather 49.3% of MW-min loss Weather	Historically an issue for GTA with one major event in 2013 causing outage in multiple cities	1) Identify all critical stations (NERC) that are within water flood plains and check adequacy for storm-water drainage, sump-pump systems, and consistency with municipal storm water systems.	1) Update engineering standards for factor in (100 year return period for rain water storm) 2) Consider temporary off-site storm water holding pool 3) Change grade profile to hold large quantity of water	1) Ensure technical "acceptance" of new equipment, systems for flooding or storm water draining as per engineering specifications. 2) Ensure draining systems are cleared of debris and equipment such as sump-pump is periodically tested
Freezing Rain/Icing/Snow	55.3% of T-SAIFI Weather 15.6% of T-SAIDI Weather 13.8% of MW-min loss Weather	Line insulators lose their dielectric strength in progressive ways as the leakage distance on insulator shrinks	1) The power system and customer electricity security requirements needs to be adequately considered and specified in planning specifications by system planning staff.	1) Hydro One engineering requirements exceed industry requirements (CSA and IEEE for transmission lines and station design).	1) The power system and customer electricity security requirements needs to be adequately considered and specified in planning specifications by system planning staff.
Tornado	0.8% of T-SAIFI Weather 1.63% of T-SAIDI Weather 2.36% of MW-min loss Weather	In Canada most of the tornadoes are observed in Ontario. Southwestern Ontario is one of the two tornado "alleys" in Canada.	1) Hydro One is undertaking research work with the University of Western Ontario to assess ways to mitigate the impacts of high intensity wind events, based on new theoretical work; followed by computerized analytical work; and, further validation in a scaled three dimensional purpose-built laboratory.		
Seismic Distrubance	No Statistics	Ontario is in low seismic activity zone, except a small geo-pocket in Ottawa and North Bay.	1) Hydro One has already revised technical specification for auto transformers and bushings based on expected seismic acceleration. 2) Ensure planning specifications identify seismic concerns when situating equipment	1) Hydro One has already revised technical specification for auto transformers and bushings based on expected seismic acceleration. 2) Ensure planning specifications identify seismic concerns when situating equipment	
Geo-magnetic	No Statistics	GICs can damage and distrupt power system as in Quebec in 1989.	1) Hydro One's existing work program on GMD/GIC augments earlier work on major power transformers and now includes GIC monitoring. (new and replacement planned in 2019-2020) at 13 trasnformer stations. 2) IESO studies to identify equipment with GIC concerns and accordingly Hydro One plans to implement mitigation plans.		
Heat Wave & Drought	No Statistics	When the maximum temperature is 32°C or more and persists for three or more consecutive days –it impacts thermal loading limits of critical assets.	1) Hydro One's planning specifications already incorporate rise in ambient temperatures for power transformers to maximum of 55 or 65°C above pre-specified loading. 2) Plan and provide load transfers if certain transmisison assets are expected to be overloaded where practical or provide electrical load shedding scheme.		1) Factor in "real-time" information on weather for grid operations to ensure full use of system equipment capabilities and continuity of electricity supply. 2) Operationally implement load transfer or load shedding schemes if necessary.

This table are applicable to both the transmission and distribution systems. For the distribution system, modernization work programs emphasize "reliability first", and concurrently provide for "resilience indirectly". Investments include (i) Distribution Automation (DA) – upgraded impedance-based protective relays for distribution, use of faulted current indicators (FCIs) at distribution lines to provide visual aids to enable faster restorations; more line sectionalizers/ reclosers to provide appropriate isolation when an electrical fault occurs; and, where practical design "fault location, isolation, service restoration" (FLISR) systems where multiple distribution sources may permit enhancing availability; (ii) upgraded telecommunications to permit enhanced protection & control (as above); and (iii) other priority recommendations related to design similar to transmission system concerns.

[4.5] Integrated Grid Operating & Resilience

For the bulk transmission system, the need to maintain real-time generation-load balance, satisfy regulatory requirements to handle system contingencies, and provide continue customer supply, has resulted in embedded resilience. This resilience is supported by following electricity sector industry standards (e.g. NERC, NPCC) to allow for grid undergoing "contingencies", with the design of a "meshed" bulk grid, station configuration for enhanced operating flexibility, dual feeds above certain load and embedded generation thresholds, , and a grid architecture which allows other electricity pathways after a contingency or maintenance outage(s); planned capability of certain components such as power transformers, lines and cables to be temporarily overloaded for times to permit system re-dispatch; and possible support from neighboring interconnections. Some resilience comes from provision for mobile equipment, and adequate strategic equipment spares to avoid lengthy replacement or repair delays.

For integrated grid system operating, Hydro One's system controllers in coordination with the IESO, operate and control the entire Hydro One transmission grid from the Ontario Grid Control Centre (OGCC). Backup Control Centre (BUCC) facilities are also provided at a different location. To monitor and control Hydro One's transmission assets and the system as a whole, OGCC has a centralized system with a suite of specific grid operating tools, together with access to a province-wide telecommunication and station control infrastructure. In addition to managing huge numbers of grid system maintenance outages and restore forced outages, OGCC staff must address the impact of hazards (weather, fire, etc), equipment failure and human-actions which could potentially result in major grid disruptions. The grid covers a large geographic area for all of Ontario and interconnected grid neighbors. Hydro One has significant distribution modernization and at the OGCC also has a distribution management system (DMS) with comparable operating capabilities to the transmission system.

Further, the OGCC has [i] qualified people (e.g. experienced system controllers certified as NERC Reliability Coordinators); [ii] technology/ tools, including Network Management System (NMS) includes real time monitoring and control (RTMC); grid state estimation, equipment limit calculator (ELC); real time contingency analysis (RTCA – power load flow analyses tool); training simulator; and operating flexibility tools including rotational load shedding (RLS); automatic voltage reduction tools; and other systems including real-time post contingency limits rating calculation, automatic and manually-armed special protection schemes, SCADA rehearsal mode/ drills/ training; space weather tool (SWT) for monitoring the GMD impact from solar storms; separately, with IESO draw on interconnections support via the neighbouring utilities; [iii] Processes and Co-ordination to respond to major grid disruptions, including: Hydro One's Storm Response (first developed mid-1990s & continually enhanced) to address major events ("storms"); other action plans including Emergency Management, Business Continuity, Cyber Security Emergency Preparedness; IESO's OPSRP; & other tools/processes.

Such embedded resilience is difficult to evaluate, when the grid technical planning base is focused on reliability. With the wide range of climate change projections, and a broader range of natural and other hazards, continual assessments of adequacy are needed.

[4.6] Lifecycle Phases & Resilience Planning

Table 4.6-1 provides linkages among the key lifecycle phases and key high-level actions for Reliability & Resilience planning, and Operational Response.

Table 4.6-1: Lifecycle & Reliability/ Resilience Planning & Operational Resilience Response

LIFE CYCLE ⬇	Reliability & Resilience Planning	Operational Resilience Response to Hazards
Grid System Planning	• Reliability Standards (Regulatory) • Grid Requirements (Electrical Security, ROW (right of way) needs) • Configuration System Assessments: DESN; flexible break & half station circuit breaker config; • System Analysis (Capability & Constraints) • Critical Load/ Electrical Bus • Resilience Metrics (e.g. N-k contingencies and load cuts) • Emergency Voice Communications (e.g. use of ionosphere); continue direct telecom connect for key devices to OGCC SCADA • Advanced Technical Plans, Innovation, Validation Projects (Macro/ Microgrid; Adv. Grid Re-Config, NWA/Non-Wires-Alt; Adv. Tech Concept; +)	✓ If required, use backup/ spare equipment ✓ Provide Support As Needed, Particularly If Significant Grid Disruption/ Damage Has Occurred
Engineering	• Equipment Standards • Standardization • Asset Configuration • Advance Technology Standards	✓ Equipment Substitution (e.g. Towers) ✓ "Virtual" Protection & Control (P&C) Team for P&C setting for adequate grid operations (for major grid disruption, with long duration repairs)
Procurement	• Multi-year Equipment/ Services Contracts (including equipment for "normal" annual storm response) • Backup/ Spares for Long Lead-time Equipment At Central/Regional Locations	✓ Emergency Purchases ✓ Preposition Mobile Transformers/ Equipment As Needed
Construction	• Ensure Built to Specifications and Functioning • Use of special construction materials (e.g. concrete, grout) under extreme temperatures (e.g. cold); and guides to defer construction (e.g. temperature is outside technically acceptable range).	✓ Prepare Active Construction Sites If Hazard Forecast(e.g. Equipment Tie-down, Materials Stored In Enclosures)
Operating	• Operating Procedures • Emergency Outage & Incident Command, Continual Management to Support Guides/Procedures	✓ Damage Assessment ✓ OMS (Outage Management) ✓ Set Priorities (Crews/Materials) ✓ Incident Management ✓ MUS (mobile unit stations)/transformers ✓ Load Reduction (System Voltage Reduction) ✓ Load Shedding ✓ Interruptible load/load shifting
Operating – Emergency & Major Incident	• Emergency Outage & Incident Command, Continual Management to Support Guides/Procedures • Mutual Assistance Agreements (MAAs) • Multi-hazard, ,multi--day, multi- party Major Grid Incident "Simulation"	✓ See items above (under Operating) ✓ Co-ordinate with Provincial Emergency Mgt. Entities ✓ Back-up Control Centres ✓ Provision for "paper" copies of Key System Diagrams, Maps, Procedures
O&M	• Consistent O&M; (ACA) Asset Condition Assessments • T&D Veg Mgt, OCP (Optimal Cycle Protocol) • Insulator Washing (e.g. road salt spray, dust accumulation)	✓ MAAs
System Renewal / Sustainment	• Major equipment overhauls, major repairs, replacement, with ACAs & factor future system needs	✓ Enable Focus On Equipment (Planned For System Renewal), If Related To Grid Facility Potentially Impacted By Oncoming Hazard
Evaluate, & Learn	• As Needed	✓ As Needed
<<Feedback Grid Planning	• < <Feedback Loop: Grid Planning	✓ << Feedback Loop: Grid Planning

[4.7] Advanced Resilience Adaptation Options For Transmission & Distribution Systems
Table 4.7-1 is a summary of the high level grid resilience adaptation strategy for natural hazards.

Table 4.7-1: Lifecycle & Advanced Adptation Options For Transmission & Distribution Systems

			Priority Recommendations	Transmission Focus	Distribution Focus
Planning /	Operating	1	Advance grid system resiliency analyses tools	N-k mesh analyses; multiple islands & restoration; extreme value analyses; resilience metrics examination	Practicality of existing DERs (after FIT, microFIT contracts close out), & potential energy storage, to create microgrids for Distribution restoration, with OGCC/IESO).
		2	Impact prediction for natural hazards with GIS & equipment withstand capabilities for pre-disruption & post disruption work plans	Meshed system ✔ [= applicable here]	Radial system ✔; Leverage recent installation - weather prediction tool
		3	Prepare high-level restoration plans	TSs (E.g. only 2 underground cable supplies to TS)	Selective "rental" generation use (e.g., "containerized" natural gas/ diesel/ fuel oil/ veg oil engine-generator or micro-turbine-generator; or portable PVs to the extent available; or energy storage equipment) under extreme weather conditions, particularly for vulnerable customers (e.g. old age homes)
Planning &	Engineering	4	Back-up inventory for major equipment, including mobile units	✔; considering mobile circuit breakers	✔
		5	Last resort - voice comm. (e.g. Ionosphere) & continue direct telecom device to SCADA	✔	✔
Operations &	Maintenance	6	Vegetation management for Right Of Ways (ROW)	✔; Continue OCP (optimum cycle protocol) For ROWs – Reliability1st/Resilience indirect	✔; Continue OCP (optimum cycle protocol) For ROWs – Reliability1st/Resilience indirect
		7	Insulation washing for salt/dry dust; effective grounding; and soil moisture for U/G cable	✔	Generally not applicable ✗
Operating	Planning /	8	Reliable and sufficient real-time data	e.g. PMUs/ Synchro-phasors	e.g. leverage DMS for restoration with appropriate telecom (& continue AMI/ advanced meter infrastructure analytics)
		9	P&C-T re-setting for entire TS outages (recall floods): Agile–virtual team; consider selective remote-reset of P&C-T for major disruption	✔	Generally not applicable ✗
		10	System Operating Training & Drills	✔	✔

[5.0] REMARKS – CHALLENGES FOR A RESILIENCE PLAN

Building on qualitative resilience strategy work, a resilience implementation plan needs quantitative analyses, with rationalized options for economic resilience investments. The latter poses a dilemma: for resilience /adaptation options, funds/ investments are "invested" now/ near-term, and the "benefits" (e.g. avoided costs of damage) may/may not be realized between now and long-time horizons (10s to 100s of years), with high uncertainty of HI-LP events. The economic evaluations is further challenged with the grid "architecture" facing significant change, due to more decentralized renewable energy sources (with more grid operational issues) and multi-area operations (e.g. different grid operational "rules" involving macro/ microgrids with availability of energy storage technology).