Study Committee B3

Substations and electrical installations

Paper 10258_2022

Short-Circuit Current Management at Hydro-Québec
Uprating Versus Limiting Solutions

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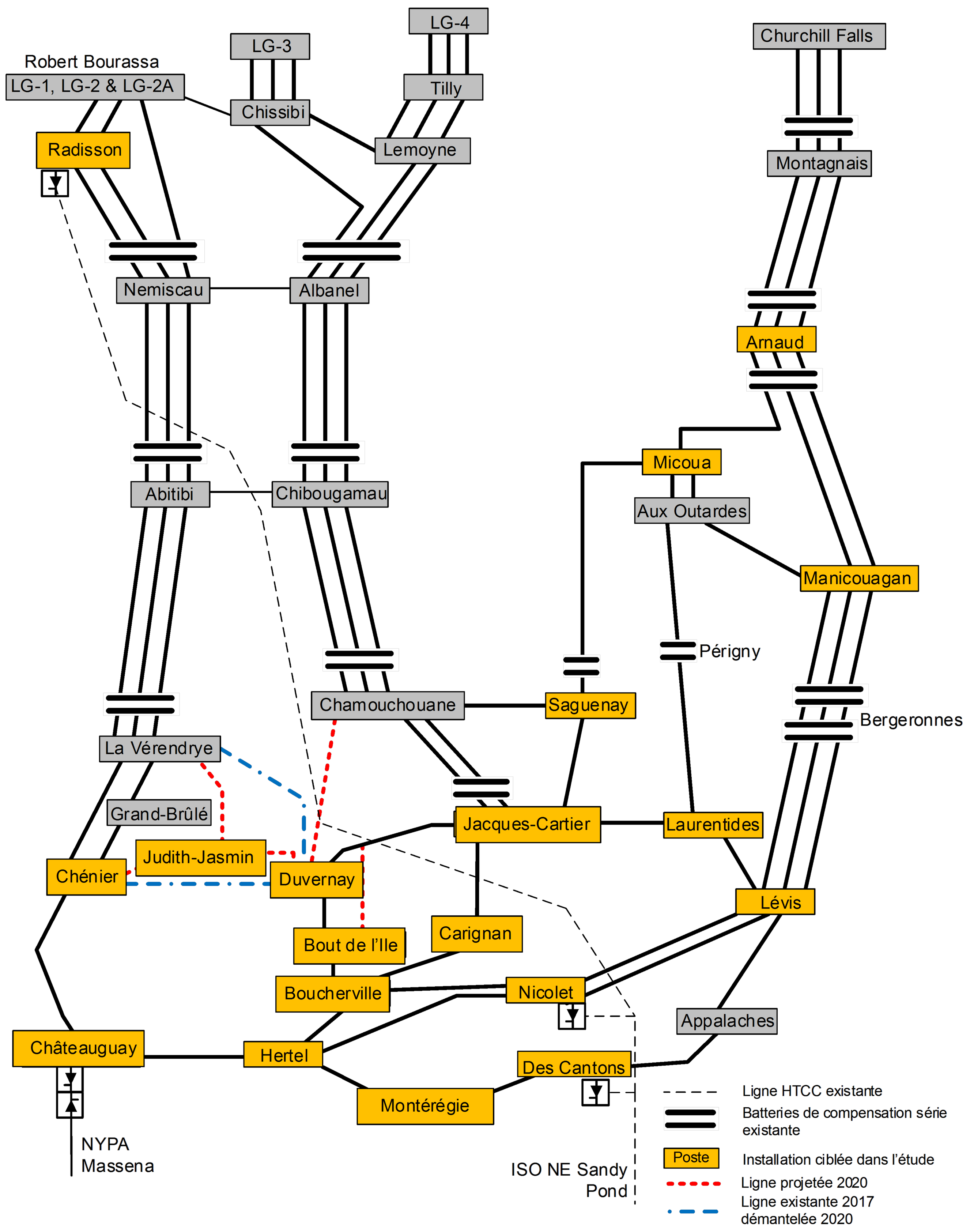
Motivation

- The majority of Hydro-Québec's (HQ) AIS 735-kV substations have high short-circuit levels on the LV side (120 to 315 kV).
- Network planners need to know far in advance what technical aspects must be addressed if the short-circuit rating threshold is exceeded with their project.
- The normal timeframe of a project limits the study of many possible options, hence justifies the need for a global and integrated vision and strategy for the BULK system.



Method/Approach

- Literature review on short-circuit current management
- Survey of electric utilities' practices
- Identify and quantify the impact and risks related to a short-circuit increase
- Evaluate the feasibility/costs of the most promising short-circuit limitation solutions (EMTP simulations, manufacturers' input, HQ's research center - IREQ).
- Preventive and proactive global approach to guide network planners with regards to Isc management

Objects of investigation

735 kV (HV side)	**Stable → maximum of 40 kA**
Uprate studied on:	N/A, actual rating is sufficient !
120 kV to 315 kV (LV side)	**Actual maximum rating of 50 kA expected to be exceeded.**
Uprate studied on the following technical topics:	- Substation electrical apparatus - AC transmission lines / cables - Grounding grids - Portable grounds - Control and protection - Auxiliary services - Telecommunications

Challenges

- SF_6 HV circuit breakers already derated due to cold climate (-50°C) and asymmetric factor of 2,7 (high X/R ratio).
- Unknown extent and amplitude of expected short-circuit rise in the short and long-term:
  - How many substations will rise above 50 kA ?
  - What will the next required short-circuit rating be? 56 kA, 63 kA, or even more ?
- Electrical apparatus is often adapted for Hydro-Québec's needs which means that "off-the-shelf products" can seldom be used, and product qualification is necessary.

Conclusion

- Uprating for Isc > 50 kA will be costly and time-consuming :
  - Feasibility issues for certain critical technical aspects (circuit breakers and portable grounds) depending on the new required short-circuit rating;
  - Should be prepared well in advance to clearly define the needs and study the impacts.
- There are many existing short-circuit limiting solutions
  - They differ in complexity, cost and efficiency;
  - Some do not apply to high-voltage systems;
  - A few of them have not yet being applied on Hydro-Québec's BULK system
- A global approach is better than a project by project « tunnel-vision » strategy since the schedule and budget limit the possible options, including uprating.

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Impacts on substation equipment qualification and purchasing

- 5 years is needed to qualify all types of substation apparatus for a short-circuit rating higher than 50 kA.
- Qualification costs should be about the same as actual cost for 50 kA rating (→ not all tests have to be repeated).
- ≥ 2 suppliers secures procurement while limited quantities may hinder manufacturers' development interest.
- Unit purchase cost vs. 50 kA model will depend on :
  - Short-circuit rating: 63 kA?, 80 kA?
  - Required quantities (10?, 100 ?)
  - Usage of existing vs new design

HV equipment	Expected unit price vs 50 kA (p.u.)
Circuit breakers	2 to 3
Surge arresters, switches, series reactors, power cables, instrument transformers	1 to 2
Others	1

Detailed analysis of critical topics

- **Temporary grounding** (substations and power lines): Already problematic above 35 kA → ergonomic issues arise when handling 500 MCM caliber grounds.

  Possible solutions for Isc > 50 kA (can be combined):
  - Limit Isc during maintenance by opening two disconnect switches in series, removing a busbar section or changing the system topology;
  - Use multiple portable ground assemblies in parallel (still not fully protected during installation);
  - Add grounding switches : hard to implement in existing substations. To use these as temporary grounds, maintenance shall be up-to-date.
- **Circuit breakers:** derated 63-kA pure SF_6 circuit breakers used in -30°C market are adapted for gas mixtures (adding CF_4 or N_2) for our needs, i.e. 50 kA, -50°C and X/R = 30. Possible solutions include:
  - Use of dead tank breakers with heating blankets (currently not considered reliable enough);
  - Use of GIS instead of AIS : not a viable economic option for uprating an existing AIS substation.
- **Grounding grid:** Increased fault current combined with high soil resistivity (> 10 kΩ.m is common in Quebec) may lead to touch voltage issues (depends on location).
- **Telecommunications equipment:** ground potential rise is also substation-dependent but may be studied in advance. When necessary, fiber optic liaisons may be used but are costly.

Summary of impact analysis for every technical aspects of an HV system

	Invalidated characteristics due to short-circuit uprate					Potential impact	
	Breaking current	Short-circuit withstand		Failure mode	Other	Delay	Cost
		Thermal	Mech.				
Temporary grounding		X	X			2	2
Circuit breakers	X	X	X	X		2	2
Permanent grounding		X	X		V_{touch}	1	2
Telecommu-nications					GPR	1	2
Surge arresters			X	X		1	1
Current transformers		X	X	X		1	1
Voltage transformers			X	X		1	1
Series reactor for capacitor banks		X	X			1	1
Switches (earthing and disconnect)		X	X			1	1
Auxiliary services		X		X		0	1
Rigid busbars		X	X			0	1
Flexible busbars		X	X			0	1
Transmission lines		X	X			0	0
Protection and relays					T_{pr}	0	0
Power transformers and shunt reactors		X	X			0	0
Bushings (wall and transformer)		X	X			0	0
Shunt capacitor banks			X			0	0
Insulated power cables		X		X		0	0

Presented in descending order of potential impacts on costs and delay

Classification of impact of a short-circuit uprate on project delays and costs

0 : Low impact = Project price range and schedule within the normal range. Does not mean that there is nothing to do !

1 : Moderate impact = allow for additional time and costs related to new equipment qualification, replacements, etc.

2 : Major impact = long delays/costs to be expected (product development, detailed studies, working methods review and acceptance by workers).

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I_{sc} management approaches

- Modify system operations (ex.: busbar splitting)
- Change equipment rating (transformer impedance, short-circuit withstand or breaking capacity)
- Add fault-current limiters (FCL) on neutral or HV bus (proven and well-established vs. R & D)
- Combining different methods may become the best approach (i.e. uprate to 63 kA and use FCL to limit below this rating).

Mitigation methods and solutions

Mitigation methods and solutions	Relative cost	Technical complexity	Delays (years)	Extent of use	
				HQ	Elsewhere
Busbar splitting	$	0	< 1	Bulk	Common
Hot-standby transformer	$	0	< 2	Non-Bulk	Unknown
Transformer neutral reactor	$	0	< 2	Bulk	Common
Current-limiting reactor	$$	0	2-3	≤ 25 kV	Common
Saturable core reactor	$$$-$$$$	1	3-4	No	Very limited
Uprating > 50 kA → Existing section	$$$–$$$$	2	5	No	Common
Uprating > 50 kA → New AIS section	$$$$	2	5	No	Common
Superconductor FCL	$$$$	2	5	No	Very limited

Presented in ascending order of combined relative cost and complexity
Delays include: planning studies, tech. specs, product qualification, project realization

Rejected solutions

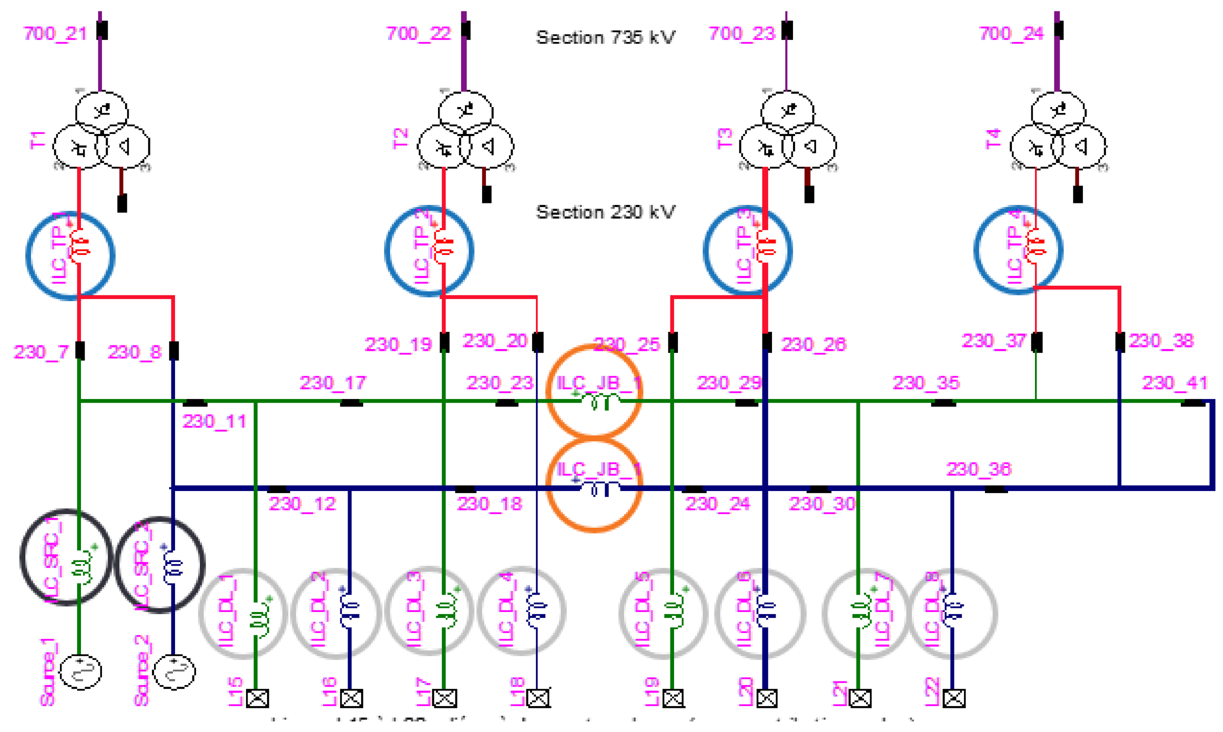
- **Sequential breaker tripping:** may undermine stability and still requires uprate/replacement of other equipment types.
- **Increasing system voltage level:** better applies to a new grid.
- **↑ transformer impedance (Z):** Already at 20%, higher Z affects voltage regulation and post-fault dynamic behavior.

Survey results from 15 utilities

System characteristic	%	Remarks
-50 °C minimum T	20%	2 utilities also having Isc > 50 kA
Isc > 50 kA	73%	63 kA and 80 kA ratings
Mitigation methods used by 11 utilities where I_{sc} > 50 kA		
Non-conventional solutions	0%	Confirmed by 3 leading suppliers
Sequential breaker tripping	9%	Up to 500 kV
Transformer neutral reactor	45%	Up to 550 kV
Current limiting reactor (HV bus)	55%	Up to 550 kV
Busbar splitting	73%	Up to 800 kV

FCL possible substation positions

- Bus-tie (orange circles) is the most efficient location for HV systems, especially with an even number of transformers.



Comparison of 3 bus-tie FCL

Characteristics analyzed	Air-core reactor	Saturable core reactor	Super-conductor FCL
Steady-state △V and losses			
Breaker TRV			
Post-fault recuperation time			
Footprint			
Maintenance			
Complexity			
Extent of use			
Supplier diversity and solidity			
Price			

Conclusions

- System specific requirements (-50 °C and X/R = 30) make uprating above 50 kA very costly and complex.
- Product development and major revision of working methods are necessary which means feasibility can be jeopardized.
- Huge cost and complexity gap exists between “standard” current-limiting solutions and non-conventional FCLs.

Recommendations

- A global portrait of Isc increase is a key factor in determining the best approach.
- Consider alternative fault-current limiting options not yet implemented in 735-kV substation as well as GIS.
- Study well in advance the critical aspects outlined in the study (temporary grounding, circuit breakers, etc.)
- Combining different methods may end up being the best global strategy.