CANA HIGH VOLTAGE

AESO Engineering Studies

Basis of AESO Weather Loading Maps

Final Report

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1 Background

The Alberta Electric System Operator (AESO) requested CANA High Voltage Ltd. (CHV) to review the basis for weather loading specified in the 502.2 Technical Requirements and to summarize findings in a report to the Transmission Rules Working Group (TRWG).

This study was to capture the development history and sources of the meteorological loads in a single document such that the basis for this information could be captured for future reference.

2 History of Transmission Line Design Loads in Alberta

To assist with understanding the development of meteorological loads for transmission lines in Alberta, a brief discussion of the historical series of studies and developments is included. This establishes the context in which the ISO 502.2 Technical Requirements were developed.

2.1 Historical Development of Meteorological Loads Prior to AESO

Prior to construction of the first 500kV transmission lines in Alberta in the early 1980s, the primary source for transmission line meteorological loadings was the Electrical Protection Act of Alberta[1] which mirrored loading areas specified in the CSA C22.3 standard.

Although neither document specified pure wind loads on bare conductor for transmission line design, both acknowledged that in locations where high winds were known to occur, or if "large conductors" were used, that a check should be made for wind loading on bare conductor. Particularly in Southern Alberta, wind on bare conductor was generally known to exceed the provisions of the EPA (based on operating experience) and some transmission facility owners (TFOs) chose to develop internal standards of design for these conditions. These were applied to the design of transmission lines in their operating areas.

With the impending development of their first 500kV lines, Calgary Power Ltd. recognized the need for a more comprehensive approach to establishing meteorological loads; particularly in view of the investment required for these very expensive facilities. They retained a California based company, Meteorological Research Inc. (MRI) to perform a study for portions of the province likely to see 500kV construction[2]. Their report established new wind and ice loading criteria for central Alberta, extending South to Pincher Creek and the Phillips Pass area. MRI used their icing model to predict ice and wet snow accretion with a statistical extreme value analysis to predict return period loadings for various events. This was the first time wet snow

[1] "Regulations Governing the Generation, Tranformation, Transmission, and Distribution of Electrical Power and Joint Use Systems in the Province of Alberta Under the Electrical Protection Act", Alberta Labour, July, 1976.
[2] "Meteorological Study of the Wabamun Lake-Edmonton-Calgary and Phillips Pass-Pincher Creek-Calgary Transmission Line Routes", MRI 77 FR-1520, October, 1977.

accretion was quantified in Alberta for design consideration in transmission lines. However, the MRI investigators observed that their ice accretion model was better suited to glaze ice than wet snow.

The next significant development in weather loading for transmission lines occurred in May, 1986, when a severe wet snow storm damaged large portions of the transmission and distribution systems in Southern Alberta. In fact, the damage was so widespread that the system came uncomfortably close to dropping Southern Alberta, including Calgary, from the transmission grid. While this event was certainly not the first (or last) time that the system suffered transmission line failures due to wet snow, the impact was so broad that the utility industry was forced to recognize that wet snow events could be more widespread than previously considered.

Shortly after the May snowstorm, TransAlta Utilities began development work for a proposed North-South 500kV project from the Edmonton area to Calgary area. Various studies of this corridor were undertaken to establish a design basis for meteorological loading.

- A Montreal-based company, Weather Engineering Corporation of Canada Ltd., was retained to conduct a study of wind loading throughout Southern Alberta. Their study[3] incorporated wind gust data to determine return period loading for the design of transmission structures. Approximately ten years had passed since the original MRI report and, with the passage of time, new data was available.
- TransAlta became aware of a post-doctoral study being conducted by Dr. Karen Finstad at the University of Alberta on wet snow accretion. At the time, the study was being conducted for a Norwegian utility. TransAlta arranged co-funding of the study to obtain access to its results and to the computer software being developed for wet snow accretion modeling.

In 1999, ESBI (the independent system operator at the time) issued their technical requirements[4] for interconnection to the Alberta transmission system. For the first time, use of reliability based design using return-period loading became mandatory in the Province of Alberta. ESBI specified a minimum return period of 50 years for both wind and combined (ice and wind) loadings. TransAlta Utilities provided ESBI with their wind study and other information which allowed ESBI to expand the study across Northern Alberta. With this information, and data from Environment Canada, ESBI generated a wind speed map for the entire province to accompany their technical requirements. ESBI did not provide maps for ice or wet snow accretion.

Anticipating expansion of the 500kV system in the early 2000's, AltaLink decided to revisit the wet snow modeling conducted previously. Dr. Alan Peabody, Dr. Karen Finstad and Dr.

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[3] "Wind Study for TransAlta System Area", Weather Engineering Corporation of Canada Ltd., January, 1989.
[4] "Technical Requirements for Connecting to the Alberta Interconnected Electric System (IES) Transmission System", Part 3: Technical Requirements for Connecting Transmission Facilities, December, 1999.

Kathleen Jones were retained by AltaLink to review previous work and update it with wet snow and wind design values, using Environment Canada hourly data and the current version of Dr. Finstad's wet snow model. This culminated in a report[5] with updated values of combined wet snow and wind, for different return periods, for Southern Alberta and several important improvements to the wet snow model.

AltaLink also asked Ron Hopkinson to provide updated wind loading maps for Southern Alberta, using available Environment Canada hourly and gust wind data.

2.2 AESO Directed Development

With the re-structuring of the electric utility industry in Alberta in the early 2000's, the AESO was formed and took over most responsibilities previously administered by ESBI. They adopted the ESBI wind loading map and re-issued a similar map with their corporate designation.

By 2008 the Alberta transmission system was facing prospects of a multi-billion dollar expansion. The AESO recognized the need for a comprehensive review of weather loads considering the investment in new transmission facilities that was planned. New studies were initiated:

- The AESO initiated the Transmission Rules/Tower Review Work Group (the WG) with the objective of establishing a set of minimum requirements for transmission facility design in the Province of Alberta. They also undertook to coordinate the design of new tower families which were to meet the new minimum requirements. This group was composed of representatives and subject experts from the provincial transmission facility owners and the AESO.
- Ron Hopkinson, of Custom Climate Services, was retained to review and update the previous wind studies. Since completion of the previous wind studies for AltaLink, a number of new monitoring stations had been installed across the province and additional years of data was available for some of the "newer" automated recording stations, giving a better cross section of data than what had been available for previous studies.
- Dr. Karen Finstad, Ron Hopkinson, and Dr. Kathleen Jones were retained as an expert team to update the previous wet snow studies undertaken for AltaLink, expand their scope to incorporate the whole province, and to make use of the more recent years' data.

By this time, the Finstad model had begun to achieve broad recognition as an effective tool for the modeling of wet snow accretion in combination with wind loading. It had been used by several utilities around the world. Analyses were conducted using weather data collected from major weather stations in Alberta and the model's projections were calibrated against historical

[5] Peabody, A, Finstad, K, and Jones, K; "Snow Accretion Modeling in Southern Alberta", 2005.

wet snow events in Southern Alberta where sufficient data had been recorded to permit comparison.

3 The Meteorological Loading Investigations

As noted previously, the AESO initiated major meteorological study was to establish the loadings to be used for design of transmission lines in the province of Alberta. Carl Orde was retained by the AESO to manage this project due to his extensive experience in this field and his contacts with international experts who were experienced with this type of work.

3.1 Wind Loading

Wind loading studies were conducted by Ron Hopkinson, of Custom Climate Services. Mr. Hopkinson had done similar work for a number of clients in North America. He had been employed previously with Environment Canada and was one of their wind loading experts prior to his establishment of Custom Climate Services.

In Alberta, wind gusts have been measured at most weather stations over many years. This extensive wind gust data was collected from Environment Canada for analysis. Also available was significant data from a more recent proliferation of automatic weather stations. Unfortunately, most of the automatic stations had less than 15 years of data so their information was of limited use.

Gust data was separated into annual extremes, and analyzed using a Fisher Tippet type 1 (Gumbel) extreme value analysis using the method of moments for parameter estimation. This provided the return period representations of wind speeds which were used to develop wind speed contour (isotach) maps for various return periods. The results of this work were summarized in Ron Hopkinson's report to the AESO[6].

Generally, this study slightly reduced wind loads in comparison with the ESBI "Appendix B" criteria used to that time. This is fairly common in extreme value analysis - as more years of data are added the highest extremes have a lesser influence over the whole.

The Working Group then compiled the results of this report into a series of wind isotach maps for 50, 75, and 100 year return periods which were issued by AESO for mandatory use in transmission line design for the Province of Alberta. The maps are part of the ISO 502.2 Technical Requirements.

[6] "Design Wind Study for Alberta", Ron Hopkinson, Custom Climate Services Inc., December, 2008.

3.2 Wet Snow Modeling and Combined Loads

Methods for the development of design loadings for combined ice and wind were less established than for pure wind loading. TransAlta Utilities and, later, AltaLink had been working at the leading edge of research in ice and wet snow accretion on conductors for some years.

AltaLink provided the AESO with the work and data they had completed in 2005 to establish wet snow loading parameters for Southern Alberta. They had undertaken this work based upon their planned North-South 500kV project (which was later cancelled). The AESO proposed to include this work, incorporating more recent data, and expanding the analysis to include the entire province of Alberta.

Carl Orde gathered a team of experts in this field comprised of:

- Dr. Karen Finstad, author of the Finstad wet snow computer model;
- Ron Hopkinson, formerly of Environment Canada, with expert knowledge of available meteorological data and techniques for extracting pertinent data;
- Dr. Kathleen Jones, of CRREL, an expert in the statistical analysis of extreme meteorological data.

This was a team of renowned experts recognized throughout North America and, perhaps globally, for their work in the development of meteorological loading standards.

Massive quantities of meteorological data were compiled for analysis from those weather stations across the province of Alberta having detailed hourly records. The wet snow accretion model was "tuned" against a handful of known events where thickness of the accreted snow "sleeves" was either measured or estimated and reported. In addition, an extensive search of archived periodicals, newspapers, and other references were searched for information on wet snow to validate model-predicted events.

In order to establish a return-period basis for the loadings, two extreme value statistical models were evaluated against the model-generated data:

- Epochal Maxima with Generalized Extreme Value (GEV) Distribution
- Peaks-Over-Threshold and Generalized Pareto Distribution

Ultimately, the GPD (Generalized Pareto Distribution) analysis was chosen for the final report[7] for this study.

The combined wet snow and wind loading for various return periods were then further developed by the Working Group and converted into a map dividing the province into four zones labeled A through D. Each zone was designated with different combinations of combined ice and wind to be used for transmission line design.

[7] Finstad, K., Hopkinson, R, Jones, K, "Wet Snow Modeling for Alberta – 2009", Report for AESO, November, 2009.

4 Comparison with Other Load Specifications

It is instructive to compare the findings of the AESO meteorological studies with the practice prior to these studies, and with current practices at utilities elsewhere in Canada.

4.1 Comparison to Previous Design Criteria

Table 4.1 contrasts the design data used for development of some towers for the BC Tie Line (1201L) constructed in the 1980's based upon 50 year return data derived from the MRI report. If such a line were to be constructed today, it would be constructed with the values shown in table 4.1 for a theoretical new single circuit 500kV line in the same area. This presumes that pertinent provisions of the ISO 502.2 Rules would apply, including the requirement for a 100 year return period loading, as well. It should be noted that 50 year return loadings were used for the design of 1201L because, at the time, the line was expected to be used only for energy interchange between the two provinces and its current critical nature in the Alberta power grid was not foreseen.

Table 4.1: Comparison of AESO Loads with 1201L Design Criteria

LOAD CASE	WEATHER LOAD DESCRIPTION	RETURN PERIOD	ICE ACCRETION (mm)	ICE DENSITY (Kg/m$^{3)}$	WIND PRESSURE ON CONDUCTOR (Pa)	TEMP. (deg. C)
1201 L TransAlta ~1980	EPA Heavy	-	12.7	900	383	-18
	High Wind	50 yr.	0	N/A	1460	5
	Wet Snow	50 yr.	46	500	307	-18
	Rime Ice	50 yr.	64	400	134	-18
New Zone A 500kV Line*	CSA Heavy	-	12.5	900	400	-20
	High Wind**	100 yr.	0	N/A	1590	-5
	Wet Snow	100 yr.	70	350	320	-5
	Rime Ice	-	70	350	0	-30

Notes:
** Theoretical line uses same route, tower configuration as 1201L (TSA Tower)*
*** Wind pressure computed using Modified ASCE 74 Methodology; 0.80 Gust Factor*

A similar analysis is conducted for the 500kV KEG (Keephills-Ellerslie-Genesee) and illustrated in Table 4.2.

Table 4.2: Comparison of AESO Loads with KEG Line Design Criteria						
LOAD CASE	WEATHER LOAD DESCRIPTION	RETURN PERIOD	ICE ACCRETION (mm)	ICE DENSITY (Kg/m^3)	WIND PRESSURE ON CONDUCTOR (Pa)	TEMP. (deg. C)
KEG Lines TransAlta ~1978	EPA Heavy	-	12.7	900	383	-18
	High Wind	75 yr.	0	N/A	810	5
	Wet Snow	75 yr.	47	500	270	-18
	Rime Ice	-	-	-	-	-
New Zone C 500kV Line*	CSA Heavy	-	12.5	900	400	-20
	High Wind**	100 yr.	0	N/A	844	-5
	Wet Snow	100 yr.	50	350	230	-5
	Rime Ice	-	50	350	0	-30

Notes:
** Theoretical line uses same route, tower configuration as KEG Lines (KA Tower)*
*** Wind pressure computed using ASCE 74 Methodology; 0.80 Gust Factor*

At the time of the KEG lines and the BC Tie Line, 240kV construction was not designed for return period loading. It was considered to be a lower security facility, not requiring the higher reliability assigned to the 500kV lines. The governing design conditions tended to be EPA-specified deterministic loads.

4.2 Comparison to Other Utilities and Practices

In general, utility companies are hesitant to share their design criteria outside of facility owner groups and associations. Much of the following has been collected from conversation and from documents which have not been offered for public circulation. The following should not be considered definitive, but is generally representative of the current practice. Most Canadian utilities have adopted a reliability-based (return period loadings) design practice as detailed in CSA C22.3 No. 60286 for their new transmission line facilities.

4.2.1 BC Hydro

BC Hydro has adopted a reliability-based approach to design for its new transmission line facilities. Design for a recent 230kV transmission line included the following requirements:

- Weather loads to be 100 year return;
- Weather loadings include glaze ice, high wind, and combined ice/wind loadings.

For their 500kV system, BC Hydro also uses a reliability based design approach. During a presentation by Barry Anderson, of BC Hydro, at a 2005 workshop on atmospheric icing, he indicated that 500kV and other critical lines were designed for a 200 year return period loading.

4.2.2 SaskPower

From conversation with persons who have worked within SaskPower design areas, this organization has recently begun to adopt reliability based design approaches and have undertaken studies to establish return-period loading criteria.

4.2.3 Manitoba Hydro

Manitoba Hydro has adopted a reliability-based design approach based on the CSA reliability based design standard. This standard provides three return periods of 50, 150, and 500 years.

For their +/- 500 kV HVDC Bipole III line, they have reportedly adopted a 150 year return period for weather loads. Lines will be designed for ice alone, wind alone, and ice-wind combined loads.

4.2.4 Hydro 1 (Formerly Ontario Hydro)

Ontario Hydro began to adopt reliability-based design in the early to mid-1970's. These facilities constructed primarily in the Niagara Peninsula, have performed well even under extreme load conditions such as those experienced in the Quebec/Ontario ice storm of 1998.

Weather loadings for 230 and 500kV include the following:

- High wind loading of 160 km/hr, reportedly equivalent to a 100 year return event;
- Combined ice and wind loading based on operating experience, but generally thought to correspond with a 75 to 100 year event;
- A 50mm radial glaze ice with no wind, thought to correspond with a 75 to 100 year event.

4.2.5 Hydro Quebec

Hydro Quebec had begun to adopt reliability-based design by the early 1970's, with full adoption by the 1990's. Their service area was initially divided into two zones, each with two reliability levels. Their normal level ranged from 50 to 150 year return period; their high ranged from 150 to 500 years.

Their primary design concerns focus on glaze ice conditions with design accretions ranging from 35 to 65mm, depending on the area and target reliability levels. Their transmission standards are based on the IEC 60286 with revisions to reflect local conditions.

More recently, their service area has been expanded up to 8 ice zones. Their current practices are to design for three reliability levels with return periods of 50, 150, and 500 years consistent with the CSA C22.3 No. 60286.

5 Conclusions

Conclusions are as follows:

1. Use of return-period loads within Alberta pre-dates the AESO initiatives by many years. They were used in the design of the TransAlta 500kV lines constructed in the early 1980's.
2. The team brought together by the AESO to analyze Alberta meteorological data, to develop standardized return-period loads for use across the province were highly recognized experts with extensive experience in this type of work.
3. All major transmission facility owners in Alberta provided representatives to the Transmission Rules/Tower Review Work Group where they were provided with opportunities to review and comment on findings, and to provide input into the development of the meteorological loads.
4. The meteorological loads prepared for the ISO 502.2 Rules compare reasonably with the loadings developed previously, with much more limited data, for the 500kV work done by TransAlta almost 35 years ago. In fact, if the KEG transmission facilities were designed today, the loadings used for design may well have been slightly reduced.
5. Virtually all major Canadian utilities have either implemented reliability based design, or are in the process of doing so. Many of these utilities specify higher levels of reliability (ie: 150 year return) than those required by the AESO (100 year return) for high-security lines.