Twenty Years of Ice Monitoring Experience On Overhead Lines In Newfoundland and Labrador

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Abstract-**The paper presents the author's twenty years experience in developing an ice monitoring program in Newfoundland and Labrador Hydro's transmission system. In general, the program included the measurements of wind and ice loads at remote locations and the development and long term monitoring of a fully instrumented test line for collecting wind and ice load data. The knowledge gained from the operation of this test line led to the further development of a remote ice growth detector (RIGD) to measure ice load. A numerical analysis of a rime icing event using the average liquid water content (LWC) indicates that the model predicts the measured RIGD load reasonably but underestimates the load on the conductor significantly. It is suggested that the model prediction can be improved by including the torsional rigidity of the cable and the time history of the LWC.**

Key Words– Overhead line ice loads, ice monitoring, freezing precipitation, rime icing model, ice detector, liquid water content, droplet radius, transmission line failure, line upgrading.

I. INTRODUCTION

Newfoundland and Labrador Hydro (NLH) manages approximately 5300 km of transmission line operating at 69 kV, 138 kV, 230 kV and 735 kV voltage levels. The transmission network system consists of wood pole as well as steel and aluminum tower lines. Given the vast region covered by NLH's transmission system, it is exposed to a severe harsh, cold environment. Most low pressure storm systems moving across North America, particularly on the eastern seaboard, pass over Newfoundland (Figure 1) and result in heavy precipitation (freezing rain or snow) with strong wind conditions. These maritime storms stall for a day or two and quite often deposit heavy freezing precipitation or snowfall during the winter months, which creates significant operational challenges in maintaining the overhead line system in Newfoundland and Labrador.

Since the commissioning of its transmission lines in the 60's, many parts of NLH's system have experienced multiple ice storms and severe ice loadings. The original design wind and ice loads for these lines were based on CSA (Canadian Standards Association) heavy load, which was 12.5 mm glaze ice combined with 117-km/hr wind with appropriate overload factors. Upon review of the pertinent information available at the time, two basic load conditions evolved**:** Normal Zone with 25.4 mm radial glaze ice and Ice Zone with 38 mm radial glaze ice. The Ice Zone was used for a small section of the transmission line system. The overload factor for all metal tower design was 1.33 while for wood pole structure, this factor was 2.0.

Several large ice accumulations have been observed. Since 1965, there have been at least four (4) major line failures on the Avalon Peninsula (eastern part of Newfoundland, Figure 1). Similar line failures have also been observed in other parts of Newfoundland (Haldar, 1990) including the Buchan's Plain, located in the western part of Newfoundland (elevation 600 m above MSL, Figure 1).

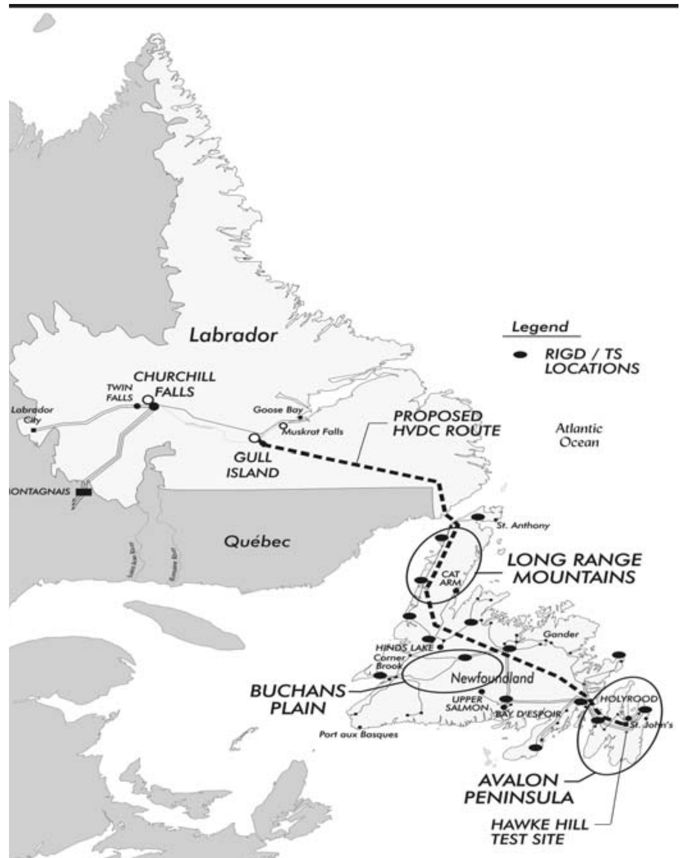

Fig. 1 Newfoundland and Labrador Map showing the proposed HVDC route, Avalon Peninsula, Buchans Plain and RIGD stations

The line failures on the Avalon Peninsula occurred in 1970, 1984, 1988 and 1994 (Haldar, 1995). Figure 2 depicts the observed glaze ice sample on conductor during the 1984 failure. The ice sample weighed approximately 7.8 kg/meter. Figure 3 depicts the bridge failure of a 230 kV suspension tower (guyed-V) under vertical ice load in 1988. In 1994, one 230 kV wood pole line on the Avalon Peninsula failed causing a forced outage in the system. In all cases, the lines experienced conductor/hardware failures due to ice overload. In many cases, this led to moderate to severe cascades indicating an inherent weakness in the design with regard to coordination of strength (Haldar, 2006). The ice load was also significantly underestimated in certain sections of these lines on the Avalon Peninsula and on the Buchans Plain (Figure 1).

Fig. 2 Glaze ice sample from conductor (1984 storm)

The 1994 line failure caused a cascading event in which seven (7) H-frame wood pole structures (230 kV) were lost due to the failure of a forged eye bolt on a dead end structure (Figure 4). The replacement cost of the failed section of this line alone was approximately $500,000 dollars. In 1970 and in 1984, NLH incurred several million dollars in repair costs and a long forced outage time before the system was brought back into operation.

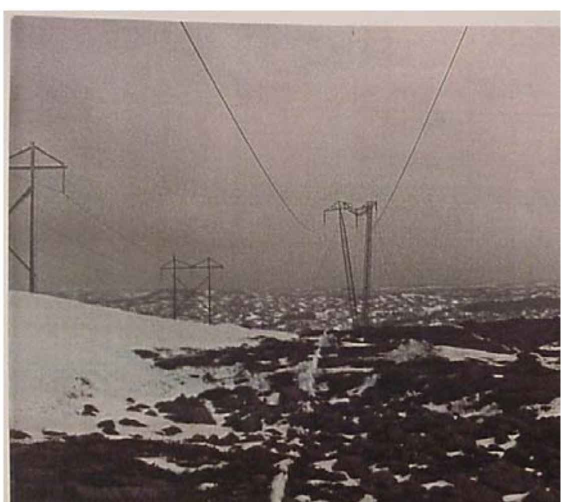

Fig. 3 Bridge failure of a Guyed-V suspension tower in 1988

In 1995, a detailed failure investigation study (Haldar, 1995) concluded that the observed failure rate of the system based on the many events over a 30-year operational life could be modeled with an annual rate of 0.1 (10-year return period) for the entire Avalon region. In reviewing the observed ice load on conductors (Figures 2 and 5), it is noted that 38 mm to 50 mm of equivalent radial glaze ice was found to be on the conductors and /or on guy wires in many instances. This information was used later to revise the original design ice load (Normal Zone) to 63 mm radial glaze ice thickness for the upgrading of the existing transmission line system (Haldar,1995, 2006).

Fig. 4 Failure of a forged eye bolt in 1994

II. SCOPE

The primary objective of this paper is to summarize the author's experience in developing various ice monitoring programs in NLH's system during the past 20 years. The paper will also present the analysis of a specific icing event that occurred in 1997 near St. John's. The ice accretion model developed by Meteorological Research Incorporated (MRI, 1977) will be used to analyze this icing event and a comparison of the measured ice load with that obtained from the MRI model will be presented.

Fig. 5 Glaze ice observed during 1994 line failure

III. PUPRPOSE OF ICE MONITORING PROGRAM

The purpose of a long term ice monitoring program is twofold. First, the program is to predict the design wind and ice loads on overhead lines with an adequate confidence level. Second, the program is to update the loading information on existing lines to ensure that the management of these lines is done in a manner such that the forced outages due to combined wind and ice overloading can be minimized.

The remote monitoring will also provide long term “trend line” data which can be used by NLH to make decisions on future upgrading and/or up-rating of lines in a more “pro active” manner. It may also help NLH to avoid a major system failure in the future. The real time monitoring data can be brought directly to the NLH’s Energy Control Center (ECC) via networking and can also provide an “alarm” to the system operator based on specific design threshold levels set into the system for various regions.

IV. MODEL STUDY

After the major line failures of 1984 on the Avalon Peninsula, the author initiated a desktop study to assess the probabilistic climatic loading on two existing parallel 230kV steel transmission lines near St. John’s. The climatological data from seven weather stations were used with a specific ice accretion model (Makkonen, 1984) to assess the loading on these lines. Figure 6 presents the flow diagram for the Makkonen model.

The obvious advantage of using the Makkonen (1984) model is that it accommodates: i) time dependencies, ii) changes from wet to dry growth conditions (or vice versa) during the ice accretion process, iii) variations in the ice density and iv) the relative angle between the direction of the wind and the conductor. The methodology to assess the probabilistic climatic loads on these two 230 kV lines was reported at the IWAIS meeting in Paris (Haldar, Mitten and Makkonen, 1988).

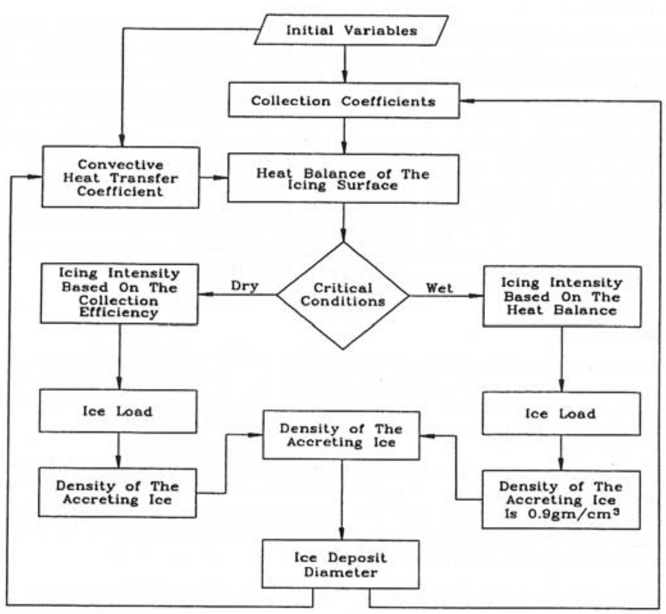

Fig. 6 Flow diagram

At the end of this study, a number of issues were raised with particular reference to model validation using field data. It was realized at the time, that the only limited information available was from a laboratory environment. No information was noted under full scale field condition. In view of this, uncertainty in model prediction (model error) could not be quantified.

V. FIELD PROGRAMS in 80’s and 90’s

During the 60’s, NLH was also developing the Upper Churchill hydroelectric project in Labrador (Figure 1). At present, most of the plant output is exported to Quebec with a small percentage being used in Labrador. Later, NLH undertook the feasibility of transporting Labrador power to the island with a proposed 1200 km long ± 400 kV HVDC line with an undersea DC cable link to the island (Figure 1). The proposed line route would traverse the Long Range Mountains which is also known for severe in cloud glaze and rime icing conditions (Figure 1).

To study the icing phenomenon along the proposed DC transmission line route, NLH installed a number of ice monitoring test stations (test spans and guyed towers at specific locations along the route) and operated these stations from 1979-87. Initially, the ice load on the proposed line was estimated using an ice accretion model with a limited data set obtained from the nearby airport and/or weather stations along the proposed line route. The model predicted ice loads were later revised based on the observed ice data from the various test sites located along the route. Figure 7 depicts a typical icing event that was observed on a test tower located on the top of the Long Range Mountains (Figure 1).

Fig. 7 Observed rime icing event on the Long Range Mountain

In the early 90’s, NLH developed the Hawke Hill test site (Figure 1) to monitor long term wind and ice loads on a nonenergized single phase line built to 230 kV standard. The test site is 35 km west of the St. John’s International Airport and is located 275 m above MSL. The main objective was to study the occurrence of the glaze icing phenomenon and to validate various ice accretion models under freezing precipitation condition using long term field data. The site consists of one suspension steel lattice tower (guyed-V) to support the phase conductor and two single guyed wood pole dead end structures to terminate the conductor. The two spans are approximately 214 m in length and the central tower supports a single phase conductor with a 28 mm diameter (Haldar, 1993).

The Hawke Hill test site (Figure 8) was specifically designed to serve as an instrumented monitoring station to continuously record: wind speed, wind direction, temperature, precipitation, ice accretion rate using ice detector, horizontal and vertical loads at the insulator attachment point, swing angles in both directions, end tension in the cable, strains in selected tower members at the foundation level and the loads in the guy wires.

The site is also equipped with a Remote Ice Growth Detector (RIGD) which is situated 1.5 m above the ground level and is made of a 25.4 mm diameter aluminum hollow pipe, one meter long and uses three strain gages to monitor the ice load (Figure 9).

accretion with known thickness. As soon as this frequency is reached, the heater is activated to de-ice the sensor. A new cycle begins and the probe starts accumulating ice. A frequency time history during the March 31, 2007 storm event is shown in Figure 12. A problem is noted in Figure 12 in recording the data beyond the 14th hour because of the malfunction of the ice detector. The frequency time history can be used to estimate the cumulative mass on the probe. This icing mass can also be used to calibrate against the conductor load based on a long term data.

The site is also equipped with a passive ice meter (Figure 13), which consists of a vertical stand with four faces; each face consists of several rods interconnected to represent various conductor sizes. The ice thicknesses on these rods are measured manually.

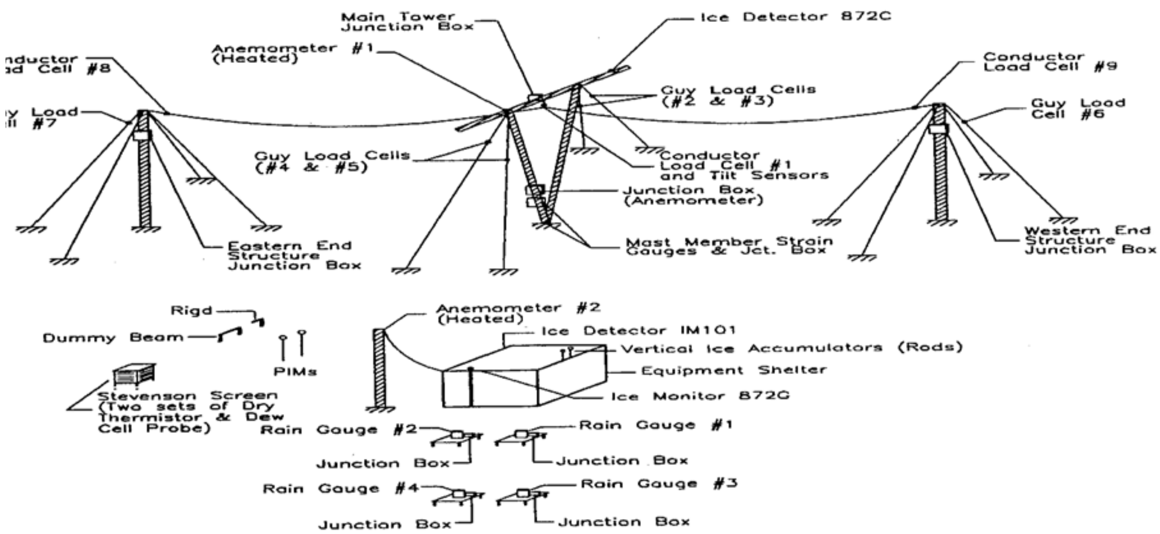

Fig. 8 Hawke Hill test site showing the various instrumentation arrangement

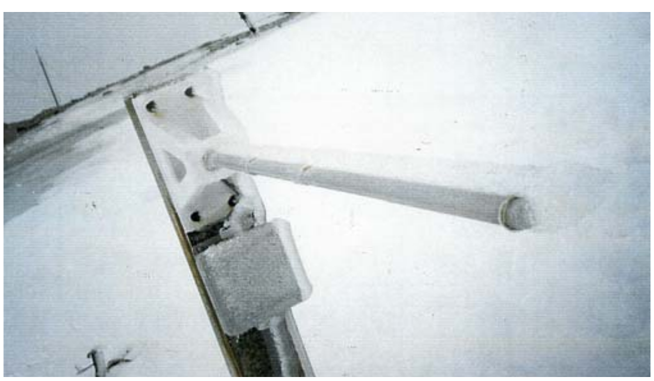

Fig. 9 RIGD beam with accreted ice

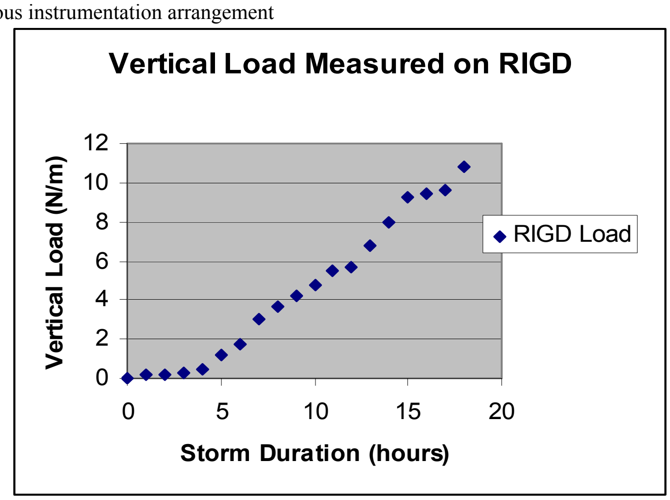

Fig. 10 Measured time history of load during March 31, 1997 event

Figure 9 depicts the ice accretion captured on RIGD beam due to an icing event in 1997. Figure 10 presents the time history of measured load during the icing event.

The test site also has an ice detector (Figure 11) which provides the accumulated ice mass based on frequency shift. The initial rest frequency is set as 40 kHz and a 500 Hz shift in frequency is used to estimate a predetermined amount of ice

Canadian Electricity Association (CEA) in 1994 initiated a project to validate three ice accretion models using the field data. The first part of this project was to “beta test” the models with historical airport data and the second part was to validate these models with field data. The validation process was restricted to freezing precipitation only. Three Canadian utilities including NLH participated in this project and a total number of 22 storms were monitored in 1994-98 and the data analyzed. Details of the test sites and other associated information can be found in the CEA report (Haldar, Pon and McComber, 1998). Figure 14 presents the comparison for storm events that produced a load above 5.0 N/m. Results show that two models overestimated while one model underestimated the measured loads.

Fig. 11 Ice Detector

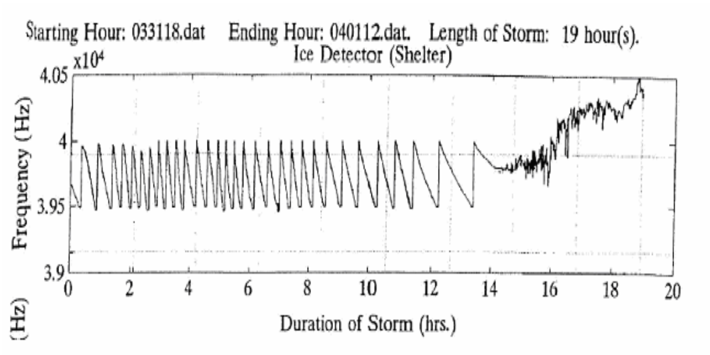

Fig. 12 Frequency response time history during March 31, 1997 storm

Fig. 13 Passive ice meter (PIM)

In 2006, NLH upgraded the Hawke Hill test site with regard to the following items: i) loading sensors and signal conditioners, ii) software, hardware and data communication protocol and iii) grounding. NLH also installed a commercially available compact weather station for field testing which consists of multiple sensors to measure: i) wind speed and direction, ii) pressure, iii) temperature, iv) humidity and v) precipitation.

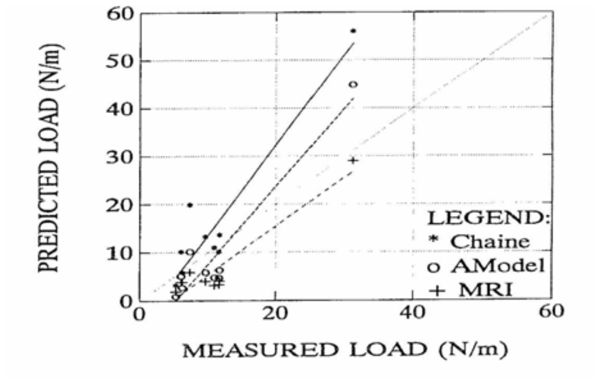

Fig. 14 Comparison of measured versus predicted loads (CEA 331T 992 report, Haldar, Pon and McComber, 1998)

As part of the proposed power development in Labrador, NLH installed one ice monitoring test site at Gull Island) in 1999 (Figure 1). The site operated for three years. It was a remote test site where the instrumentation was done on a test tower. Figure 15 presents the instrumented tower. The instrumentation set up included: (1) a heated anemometer to measure wind speed and direction, (2) temperature and humidity probe, (3) a RIGD ice beam and (4) a precipitation gauge. The power was supplied by battery bank with a solar panel. The data was collected via a data logger and transmitted to an office computer via satellite communication.

Fig. 15 Typical test tower installed at the Gull Island site (Labrador, Figure 1)

A. CAT1 Device (http:// www.cat-1.com/)

In 2000, NLH installed a CAT1 system on a 230 kV H-Frame wood pole dead end structure, located a few kilometers west of the Hawke Hill test site. This site is at a lower elevation than the Hawke Hill test site. The CAT1 system presented in Figure 16 is primarily used to measure ampacity of a line based on change in line tension due to increase/decrease in temperature but can also be used in the winter months to detect an icing event and to estimate ice load. The change in the line tension can be used to estimate the ice load and Figure 17 presents an icing event where the data from the RIGD at the Hawke Hill test site is compared with that measured by the CAT1 system.

Fig. 16 CAT1 system installed on a 230 kV dead end structure

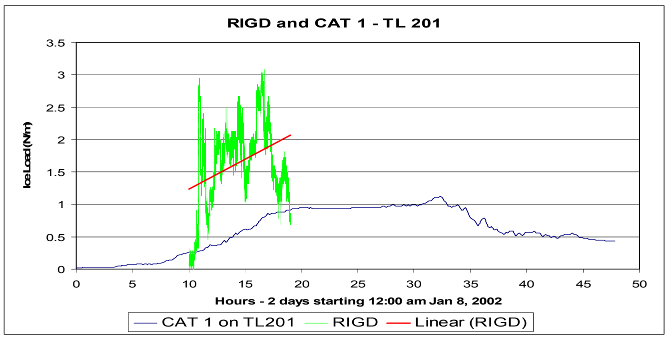

Fig. 17 Comparison of measured ice load on RIGD and from CAT1 system

B. AIC Device (http://www.protura.no/)

In 2004, NLH in cooperation with the CEATI Wind and Ice Storm Mitigation Interest Group, a consortium of 19 electric utilities from around the world (see http://www.ceati.com) installed an automatic ice control (AIC) device on a 230 kV wood pole line located next to the test line. The ice control device operates as a shaker to remove any ice from an energized line and is effective for one or two spans on either side of the span where the device is installed. The device operates using the line current as the main power source and uses advanced communication protocol not only to transmit data but also provide a picture of accreted ice on the span and removal of this ice by the shaker. Data is transmitted directly to the NLH control center.

Fig. 18 Automatic ice control device installed on a 230kV line near St. John's

During its operation in NLH's system, the device only worked for a limited period during the non-icing season and experienced major problems ranging from sensor malfunction to communication failure for unknown reasons. It is the author's opinion that the device would require improvements before it can be used reliably and routinely to remove ice from highway crossing spans, river crossing spans, etc.

VI. CURRENT MOMITORING PROGRAM (2006-08)

In 2005, the author initiated the implementation of a remote ice monitoring program by networking a number of RIGD ice monitoring sensors (Figure 9) installed at 15 selected terminal stations (TS) across the island (Figure 1). Under a three year capital program, each terminal station will have one RIGD beam and the ice data will be transferred to the Energy Control Center (ECC) via RTU (remote terminal unit). The specific locations are depicted in Figure 1. Figure 19 depicts a typical installation at a terminal station on the Northern Peninsula. Figure 20 presents a typical time history of ice load measured during an ice storm in the same area in 2007.

Fig. 19 RIGD beam installed at a terminal station

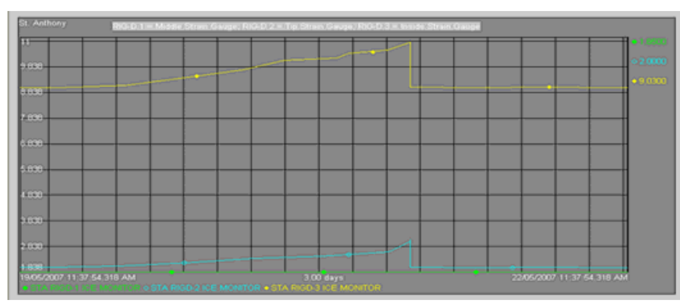

Fig. 20 Typical load time history plot from RIGD

The analysis of the loading time history indicated that the actual ice load was 10 N/m, which translates to an equivalent ice thickness of 10 mm radial glaze ice on a 25.4 mm diameter rod. Figure 21 presents a photograph of ice accretion on distribution cables during the event.

VII. ANALYSIS OF AN ICING EVENT (1997)

On the evening of March 31, 1997 (18:00 hours), there was an icing event which was captured at the Hawke Hill test site. The duration of the event was approximately 18 hours. The following morning, a site visit revealed that the icing event was primarily in-cloud icing. The nearby weather station at the St. John's International Airport recorded drizzle in the early evening followed by only a trace amount of precipitation throughout the night into the morning hours. The cloud ceiling was low and there was a persistent fog condition throughout the night with very low visibility. The RIGD beam shown in Figure 9 measured a significant amount of icing and the accreted ice shape formed from one side of the beam indicating the prevailing wind direction. Figure 22 presents the wind data perpendicular to the test line while Figure 23 presents the temperature profile.

Fig. 21 Photograph showing the icing on distribution cable

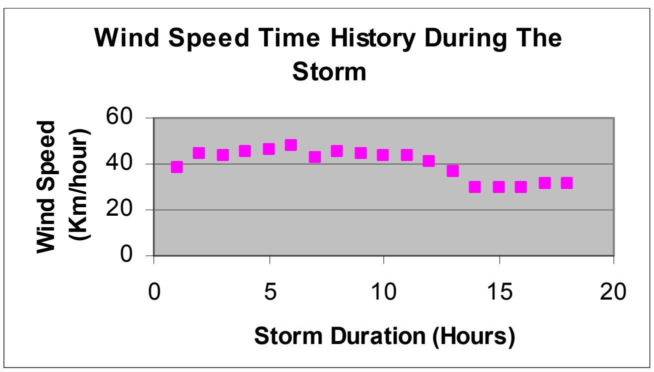

Fig. 22 Wind speed perpendicular to the test line (km/hour)

Figure 24 presents the correlation of vertical ice loads measured on RIGD beam and on the conductor. The ratio is almost 1:3.3. The two possible explanations are: (1) the height effect and (2) the torsional rigidity of the conductor. It is well known that the rate of ice accretion increases as the cable rotates due to eccentric ice weight thus increasing the effective cross section of the iced conductor.

The liquid water content (LWC) during the icing event is estimated from Figure 12 based on the average accreted ice mass per hour, wind speed and the exposed surface area of the probe (ice-detector) facing the wind. A calibration factor is used to convert the average cumulative frequency (Hz) to accreted mass (gm) following Laforte and Allaire (1993).

The MRI model (1977) was used to predict the ice accretion amount for this storm event. The input parameters required are conductor diameter, wind speed perpendicular to the test line, temperature, liquid water content (LWC), barometric pressure, and the cloud droplet radius.

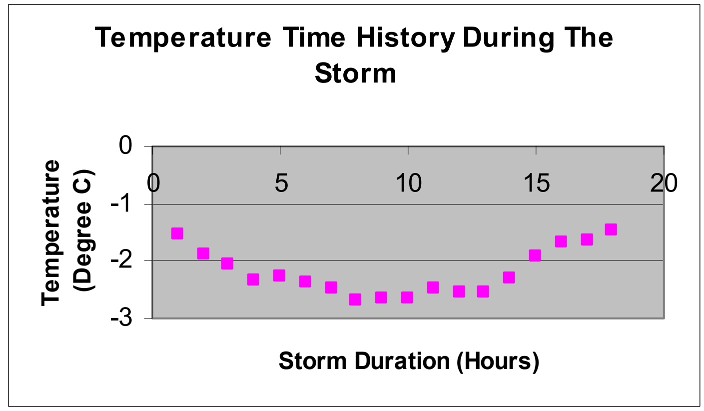

Fig. 23 Temperature profile during the icing event

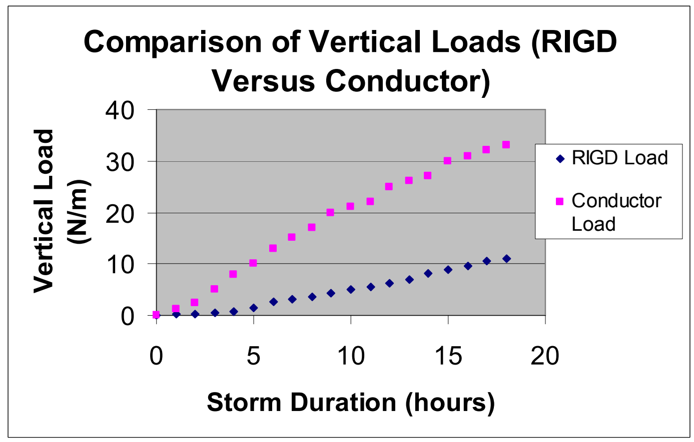

Fig. 24 Correlation of RIGD Load versus Vertical Conductor Load on Main Tower

The last two parameters, the pressure and the droplet radius were not measured at the test site but the input data on pressure was taken from the nearby weather station located at the St. John's International Airport. The droplet radius is rarely available and is normally not measured. The model is sensitive to this parameter. Initially, a cloud droplet radius of 20 micron was assumed in the analysis with two other values (10 micron and 40 micron) used to study the sensitivity of this parameter. Figure 25 compares the measured vertical loads (N/m) on the RIGD beam and on the conductor with those obtained from the model for various droplet radii.

The duration of the analysis is restricted to fourteen hours because of the malfunction of the ice detector after this period (Figure 11). The results of the comparison show clearly that the measured load on the RIGD beam can be captured reasonably assuming a droplet radius of 20 micron. However, the same conclusion can not be drawn for the conductor load. In this case, the model is under predicting the load considerably. The model prediction can be improved by including i) the torsional rigidity of the cable in the formulation and ii) the time history of the LWC during the

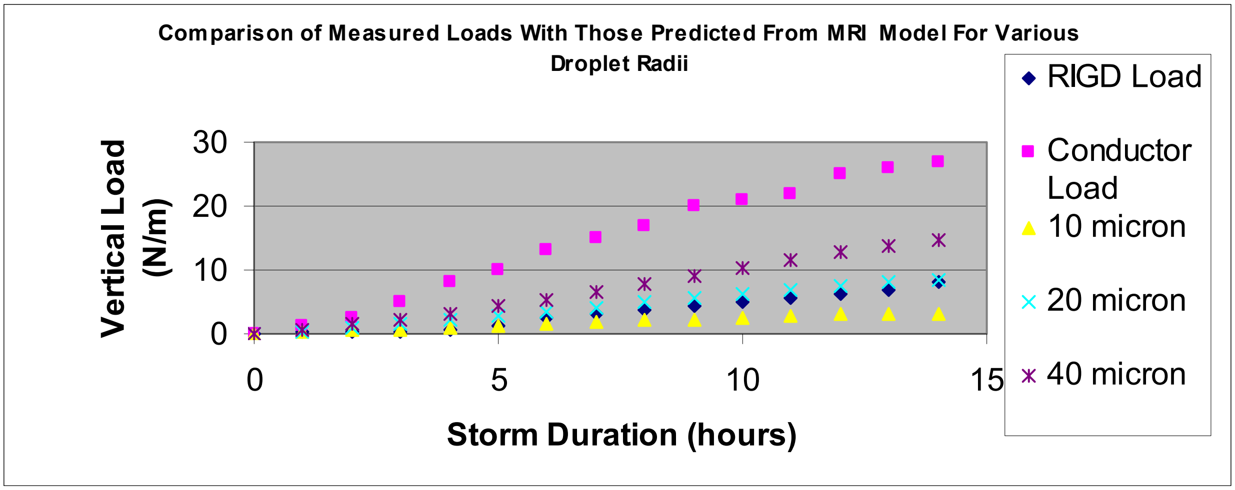

Fig. 25 Predicted load from MRI model (on RIGD & on Conductor)

storm rather than taking the average value of LWC for the entire storm duration. This will also require the modification of the current software.

VIII. SUMMARY AND CONCLUSIONS

This paper presents the author's twenty years experience in developing a number of remote ice monitoring programs in Newfoundland and Labrador. The knowledge gained from the various monitoring programs led to the development of a remote ice growth detector (RIGD) which NLH is currently using as a measurement tool for the purpose of collecting long term ice load data. A number of terminal stations (TS) on the island (Figure 1) are being networked via RTU to transmit this RIGD ice load data to the ECC.

It is hoped that this information can be used in the future not only to predict the long term design ice loads on new HV lines in different regions of the island but also to provide "trend line" data for validating design ice loads on existing overhead lines. The data analysis of a specific rime icing event showed that the MRI ice accretion model predicted the load on RIGD beam reasonably but underestimated the load on the conductor significantly. It is suggested that the model prediction can be improved considering the torsional rigidity of the cable and the time history of the LWC during the storm. The knowledge gained from atmospheric icing on overhead lines can also be used at NLH's wind energy sites to monitor the performance of wind turbine under icing.

IX. ACKNOWLEDGEMENTS

The author would like to thank his colleagues in Newfoundland and Labrador Hydro who provided their technical and field support over the years in developing and maintaining the test sites, particularly the monitoring of Hawke Hill test site. The author would also like to thank his colleagues nationally and internationally with whom he has had many discussions on the ice monitoring issues particularly the model validation process using measured field data. Finally, the author sincerely appreciates the long term support provided by the NLH Senior Leadership Team in developing the knowledge and technology in remote ice monitoring on overhead lines.

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