



7th International Workshop on Atmospheric Icing of Structures
7^e Congrès international sur le givrage atmosphérique des structures

3-7 June, 1996 — Université du Québec à Chicoutimi

Validation of Ice Accretion Models for Freezing Precipitation Using Field Data

A. Haldar*, C. Pon†, P. McComber‡, M.A. Marshall§, M. Ishac¶, A. Goell|| & M. Kastelein**

Abstract

This paper presents an overview of the Canadian Electricity Association (CEA) sponsored *Wind and Ice Load* project that is presently being pursued by two electrical utilities (Newfoundland and Labrador Hydro (NLH) and Ontario Hydro (OH)) and one University (*École de Technologie, Supérieure*) in collaboration with Hydro-Québec, Canada. The objective of this project is to validate three ice accretion models for freezing precipitation verified by long term field data obtained from three full-scale, test sites. These sites have been developed at three different regions in Canada, which are exposed to freezing precipitation. One site is located near St. John's, Newfoundland, a second at Ottawa, Ontario, and the third at Québec City, Québec. (The site near Québec City has been developed by Hydro-Québec (HQ).) Preliminary results obtained from the three ice accretion models—using specific storm data from the test sites—show that two models underpredict ice accretion, while the third one overpredicts.

Keywords

Model validation, freezing precipitation, ice accretion, test sites, transmission line, wind and ice loads.

1 Introduction

Each year, forced power outages are experienced across Canada, because of transmission line icing. Electrical utilities often encounter severe damages, which cost several million dollars. These damages are mainly attributed to combine wind and ice loads

caused by freezing precipitation. To understand the ice accretion problem better, CEA sponsored a project that incorporates monitoring three full-scale, test sites to collect wind and ice-load data on transmission lines.

These sites are designed to serve as instrumented monitoring stations to record continuously: wind speed, direction, ambient temperature, precipitation, icing with an ice detector, load along the insulator string, swing angles in both directions (transverse and longitudinal), and ice information from passive ice meters. Furthermore, NLH's test site is instrumented with load cells to measure tensile loads in the guy wires and conductors. This site also has a remote ice growth detector that monitors ice accretion on a 100 cm long by 2.54 cm diameter cantilever beam [4].

Figure 1 shows the locations of these test sites in Canada. The data collected will be used to validate three ice accretion models: 1) **Châiné** and **Skeates** [1], 2) **MRI** [2] and 3) **Makkonen** [3].

1.1 Site Descriptions

1.1.1 NLH's Test Site

At NLH's test site, there are three structures: a central guyed steel V-tower (the main structure), and two wooden end structures. A single conductor is strung from one wooden end structure through the middle phase connection of the central tower to the other wooden end structure. These three structures form a straight line in the east-west direction, with each end structure located approximately 213.4 m from the central tower. (Refer to Figure 2.)

Many sensors are installed on the central tower. The central tower is supported by four guy wires. A load cell is connected in series with each guy to measure the tension. Further, there are two swing transducers and an axial load cell installed between the insulator string and the centre of the tower bridge. Bracing members on the bridge provide an ideal location for most of the meteorological sensors—e.g., a heated anemometer (speed and direction). Strain gauges have been installed on selected members at the

*Sr. Engineer, Newfoundland & Labrador Hydro

†Sr. Research Engineer, Ontario Hydro's Technologies

‡Professor, *École de Technologie, Supérieure*

§Development Engineer, Newfoundland & Labrador Hydro

¶Design Engineer Specialist, Ontario Hydro

||Supervising Design Engineer, Ontario Hydro

**Technologist, Ontario Hydro

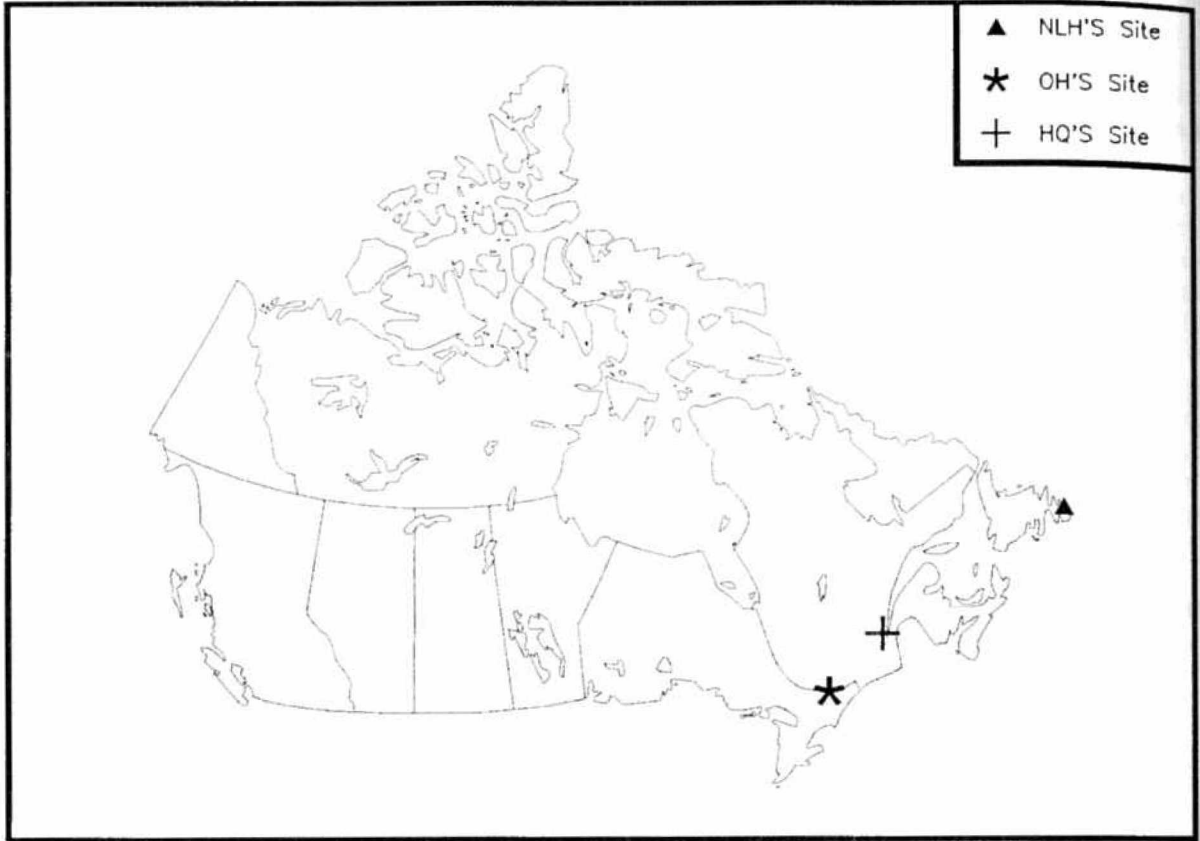


Figure 1: Locations of Test Sites.

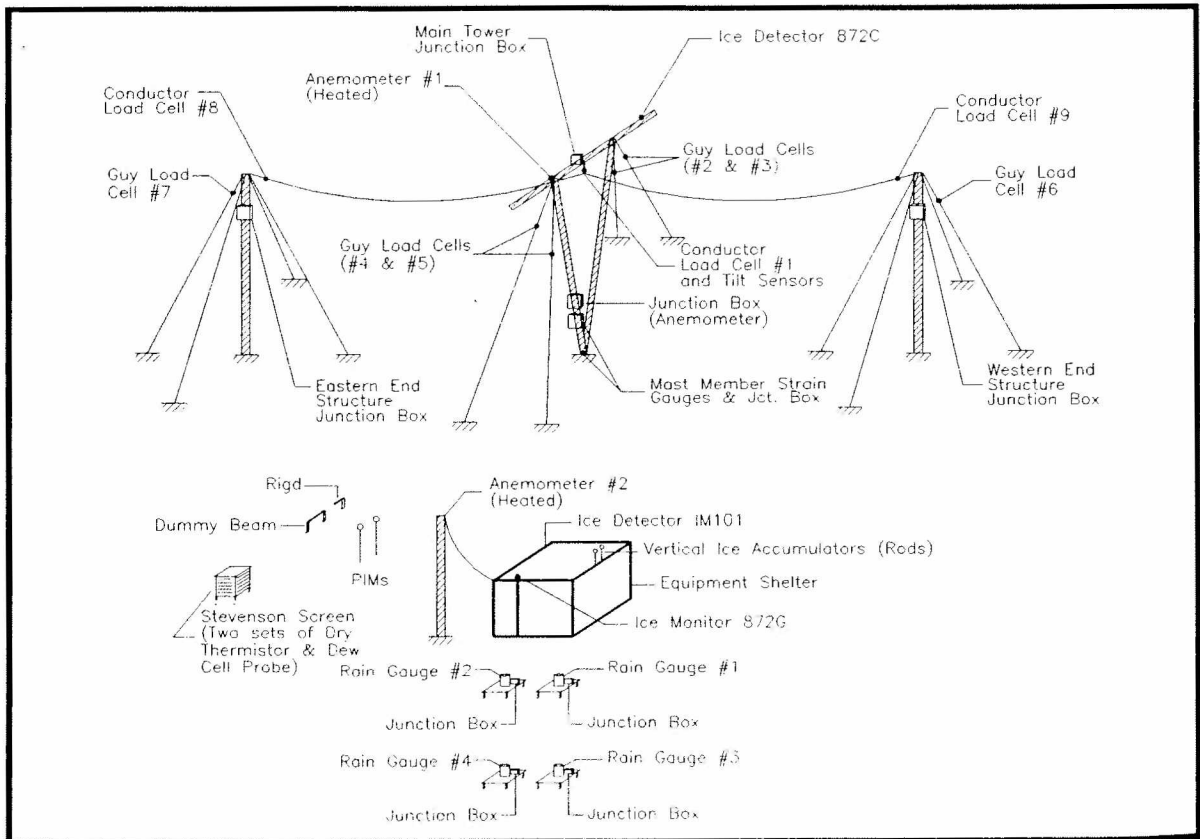


Figure 2: NLH's Test Site.

base of the tower to measure the loads transferred to the foundation by the tower.

At two locations near the equipment shelter, there are six meteorological sensors: two temperature gauges (dry thermistors), a dew cell and relative humidity sensor, housed in a Stevenson's screen (i.e., solar radiation shield), and four precipitation gauges. Additionally, there are two passive ice meters (PIMs), a remote ice growth detector (RIGD¹) and a *dummy-beam* to check the accumulated ice mass reported by the RIGD manually.

1.1.2 OH's Test Site

Ontario Hydro (OH) has been maintaining its test site for measuring wind and ice loads on a 500-kV transmission tower, near the Ottawa airport, since 1989. Some additional sensors were added to the test site to record the parameters required to run the three ice accretion models. Figure 3 delineates the layout of the test site. The test site is now complete with the following sensors:

- a load cell package (TLNS²-10), measures wind and ice load on the conductor,
- conventional anemometer (i.e., non-heated), at 2 m above the top of the tower,
- ice-free anemometer, at 10 m above ground on the tower.
- temperature sensor, in a solar radiation shield,
- relative humidity sensor (dew-point is calculated from temperature and humidity),
- ice detector, modified Rosemount ice-detector,
- passive ice meter, being monitored at Ottawa airport, 3 km from the tower, and
- precipitation gauge, with a heater to measure freezing precipitation.

1.1.3 HQ's Test Site

At 25 km northwest of Québec City and 9 km north of the Québec-City airport, the test site at Mt. Bélair is noticeable with its altitude of 490 m in a corridor formed by the Laurentian Valley and surrounded by the Laurentian Mountain ridge.

The main winds, which generally travel northeast (along the axis of the St. Lawrence river), experience an uplift when they pass over Mt. Bélair. This test site provides measurements of several meteorological parameters, and records mainly wind and ice loads on a 315-kV transmission line. Further, HQ

¹RIGD was developed by NLH's Technical Support Group.

²TLNS-10: TRANSLOAD system developed by Ontario Hydro.

also installed a load measuring system on a 735-kV line, which is situated adjacently to the 315-kV line. (N.B.: The 735-kV line is at the same elevation as the 315 kV. Therefore, it is assumed that the exposure to atmospheric phenomenon is the same for both lines.) Both lines run over Mt. Bélair. Notwithstanding, for the CEA study, the 315-kV line was chosen for the icing load measurements.

As depicted in Figure 4, a TLNS-10 is installed on the tower, which supports the 315-kV line. The site is also equipped with two heated anemometers located on the 315-kV line at 12 m and 10 m above the ground, respectively. Moreover, a heated precipitation gauge and a passive ice meter are located on the ground about 15 m away from the 315-kV line tower.

2 Concerns and Problems

2.1 NLH's Test Site

Starting at 11:00 p.m., March 11, 1994, a three-hour icing event was recorded at NLH's test facility. At approximately 11:30 p.m., the wind direction sensor for anemometer #2 (Figure 2) stopped working. Fortunately, the main tower anemometer was functional and it recorded the wind direction varying between 15°northeast and 25°northeast. Based on the data from two rain gauges, over 70% of the freezing precipitation fell during the first hour of the storm, with significantly less rain for the remaining two hours.

2.2 OH's Test Site

During the 1993-1994 winter, OH's test site experienced only one icing storm attributable to freezing precipitation. Anemometers at the site malfunctioned during the storm. Therefore, wind data from the Ottawa airport were used to complete the data set for the icing event. Further, the modified Rosemount ice detector malfunctioned with the data acquisition system, during the icing event.

2.3 HQ's Test Site

Data have been continuously recorded starting on November 25, 1994. However, initially, some meteorological parameters were not available. For instance, the precipitation gauge did not work before February 7. Besides, the load measurement system on the 315-kV line (i.e., TLNS-10) never worked correctly. Accordingly, estimated ice loads on the conductor were obtained from the load measuring system installed on the 735-kV line—the one next to the 315-kV line. Regarding the wind direction and speed, the anemometers were out of order part of the time during some icing events. These anemometer problems were probably ascribed to icing from freezing precipitation.

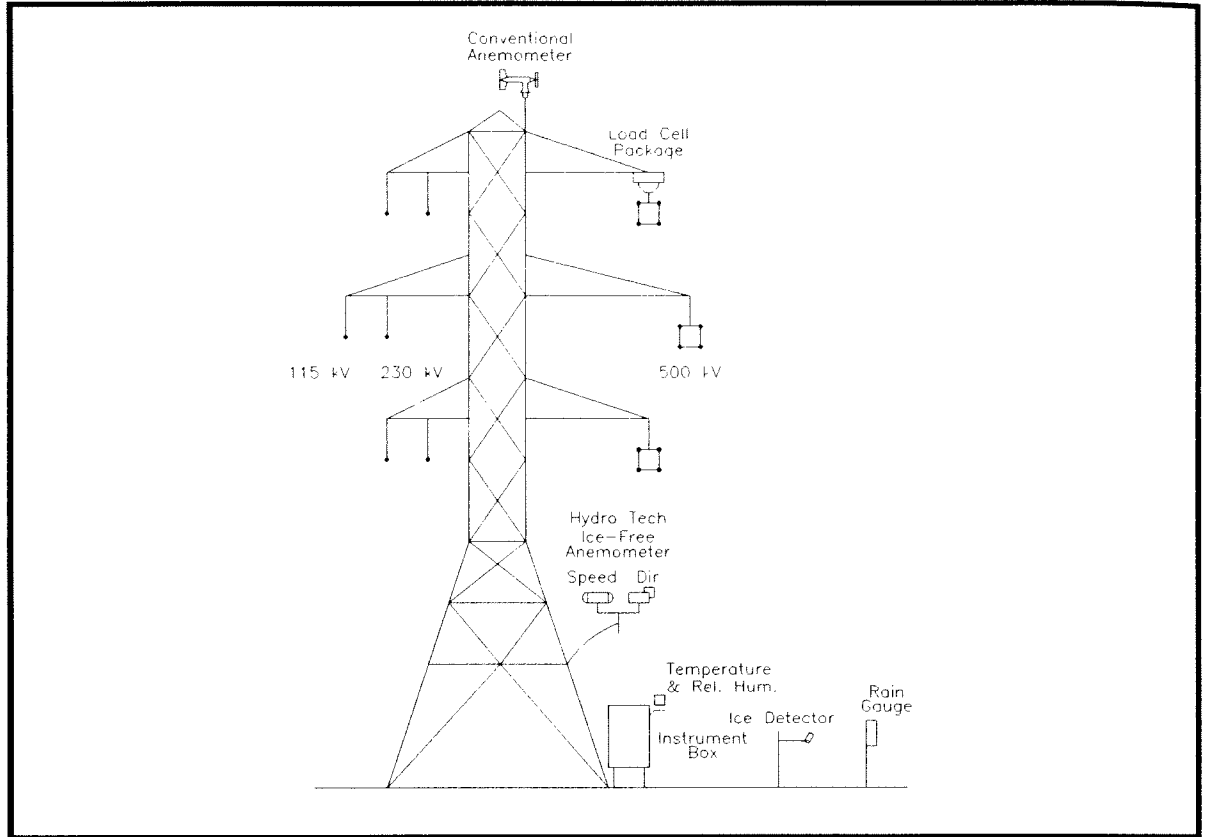


Figure 3: OH's Test Site.

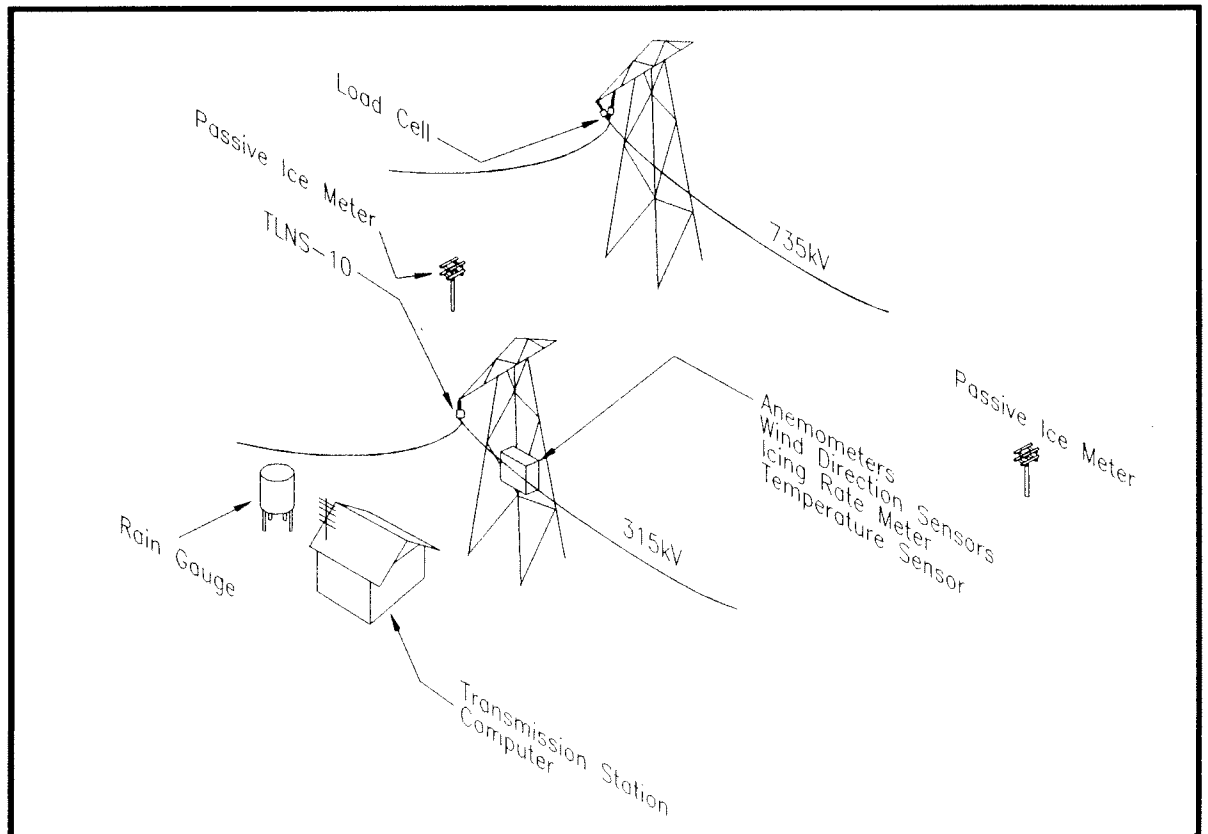


Figure 4: HQ's Test Site.

3 Results

From each test site, a specific icing event was selected for this model validation study. For each icing model, the required input parameters were: the wind speed component normal to the transmission line (i.e., conductor), precipitation intensity, temperature and relative humidity. Each model outputs load per unit length on the conductor, and the equivalent radial ice thickness. These results were then compared with those obtained from field measurements at each test site.

3.1 NLH's Site Results

Input parameters for the icing event were obtained from the following: Averaged wind speeds ranged from 24.79 kmph to 31.67 kmph, wind direction changed from 0° north to 22.9° northeast, precipitation intensity was 15 mm, and the ambient temperature varied between -1.12°C and -2.28°C. Table 1 epitomizes the results obtained.

Table 1: NLH's Model Comparisons.

Model	Estimated Loads, Nm ⁻¹
MRI	3.9
Makkonen	4.0
Chainé & Skeates	27.37
Measured (RIGD)	5.0
Measured (Load Cell)	4.1

3.2 OH's Site Results

Parameters for the icing models were extrapolated from the hourly averaged wind data at the Ottawa airport and icing data from the test site. Table 2 shows the results obtained.

Table 2: OH's Model Comparisons.

Model	Estimated Loads, Nm ⁻¹
MRI	2.72
Makkonen	1.89
Chainé & Skeates	8.21
Measured (Load Cell)	3.18

3.3 HQ's Site Results

Hydro-Québec's site experienced 12 icing events caused by freezing rain or in-cloud icing between November 28, 1994, to April 18, 1995. Ice loads at HQ's test facility were significant. That is, they exceeded the minimum ice accretion (100 gm⁻¹) necessary, and are suitable for icing model verifications.

Data comparisons for an icing event, which occurred on March 7-8, are presented in Table 3.

Table 3: HQ's Model Comparisons.

Model	Estimated Loads, Nm ⁻¹
MRI	0.93
Makkonen	1.12
Chainé & Skeates	2.54
Measured (Load Cell)	1.55

4 Discussion of Results

4.1 NLH's Site Results

Both the **MRI** and **Makkonen** models were acceptably accurate in estimating the ice loads. The **MRI** model computed the ice load to be 3.9 Nm⁻¹, while the **Makkonen** model resulted in 4.0 Nm⁻¹. These values correspond to the remote ice growth detector (RIGD) and the conductor-load-cell values of 5.0 Nm⁻¹ and 4.1 Nm⁻¹, respectively. When compared with the loads reported by the load cell, the **MRI** and **Makkonen** had error margins of 4.87% and 2.44%, in the order given. Results from **Chainé** and **Skeates's** model—when compared with the actual measurements (RIGD and load cell)—show error margins of 569.4% and 446.3%, respectively.

4.2 OH's Site Results

Data gleaned from OH's test facility also confirmed that the **MRI** and **Makkonen** models predict values that are closer to the actual (i.e., load cell) field measurements. That is, when compared with the results obtained using the **Chainé** and **Skeates's** model. This is seen from the data tabulated in Table 2; the **Chainé** and **Skeates's** model highly overpredicts the load.

4.3 HQ's Site Results

As shown in Table 3, the results obtained from HQ's test facility exemplifies the findings reported by the other two utilities (i.e., Ontario Hydro and Newfoundland and Labrador Hydro). Again, the **Chainé** and **Skeates's** model overestimated the data obtained from actual field measurements by 64%. Both the **MRI** and **Makkonen** models underestimated the field-measured load by 40% and 28%, respectively.

5 Concluding Remarks

It is still early, at this stage in the CEA project, to make any definitive conclusions regarding the three

ice accretion models. Nevertheless, based upon the data from the three icing events presented in this paper, it is concluded that the **Chainé** and **Skeates's** model overestimates the accreted ice, for freezing precipitation. On the other hand, the results also suggest that the **MRI** and **Makkonen** models underpredict the load. Whether these trends are influenced by such parameters as wind speed, *etc.*, can only be verified when more field data are obtained and analyzed. Presently, the three electrical utilities are acquiring and processing other storm data to validate the three ice accretion models further.

Acknowledgments

The authors express gratitude to the various people listed below, for their continued interest, support and contribution to the project:

Tsoi Yip	AES
Roger Van Cauwenberghe	AES (R.I.P.)
David Reeves	V.P., TRO, NLH
Fred Martin	Director, TRO, NLH
Jim Nugent	TeleControl, NLH
Brian Hemeon	EMS, NLH
Terry Gardiner	TRO, NLH
Robert Taylor	TeleControl, NLH
Jean Laffamme	HQ
Yvon Coté	HQ
Robert Chapman	Manitoba Hydro.

Finally, financial support from CEA under contract number 331T992 is also gratefully acknowledged.

References

- [1] **P.M. Chainé & P. Skeates**, "Ice Accretion Handbook (Freezing Precipitation)," *Industrial Meteorology—Study VI*, Environment Canada, Toronto, Canada, 1974.
- [2] **Meteorological Research Inc.**, *Ontario Hydro Wind and Ice Loading Model*, MRI77 FR-1496, 1977.
- [3] **L. Makkonen**, "Modelling of Ice Accretion on Wires," *Journal of Applied Meteorology*, Vol. 23, pp. 929-939, 1984.
- [4] **M.A. Marshall, A.K. Haldar, T.J. Gardiner & C.J. Young**, "Hydro's Remote Ice Growth Detector (RIGD)," *NECEC'94, Sponsored by: IEEE*, St. John's, Newfoundland, April 29, 1994.

Addresses of Authors

A. Haldar & Mervin A. Marshall, Newfoundland & Labrador Hydro, P.O. Box 12400, St. John's, Newfoundland A1B 4K7.

C. Pon & M. Kaskelein, Ontario Hydro Technologies, 800 Kipling Avenue, Toronto, Ontario M8Z 5S4.

P. McComber, *École de Technologie, Supérieure*, 4570 Avenue Henn-Julien, Montréal, Québec, H2T 2C8.

M. Ishac & A. Goel, Ontario Hydro, 700 University Avenue, Toronto, Ontario, M5G 2L6.