Lightning Protection and Surge Arrester Application on NB Power Transmission Lines

John Williamson, NB Power Transmission Corporation, Canada
2008 IEEE PES Transmission and Distribution Conference and Exposition, Chicago

Abstract

This paper describes NB Power Transmission's experience in lightning protection and the use and application of surge arresters on 69 and 138 kV transmission lines over a seven-year period. During this time, about 2000 gapless surge arresters were installed with about 1500 of those installed on steel double circuit towers in one urban area.
Originally presented at the 2007 World Congress & Exhibition on Insulators, Arresters & Bushings in Brazil, this paper has been updated and revised for presentation at the 2008 IEEE PES Transmission and Distribution Conference and Exposition.

1. General Information

NB Power Transmission Corporation is one of four operating companies in the NB Power Group. NB Power is a provincial public utility on the eastern seaboard of Canada covering the province of New Brunswick.

Figure 1 – map showing location of New Brunswick

The NB Power transmission system includes 6800 km of transmission lines in voltage classes of 69, 138, 230 and 345 kV.

Lightning protection of these lines when applied would typically use shield wires. Shield wires have been applied to all transmission lines at 230 and 345 kV. Lightning protection using shield wires has been selectively applied to lines at 69 and 138 kV.

Figure 2 illustrates lightning flash density in Canada[6] as the number of flashes per square kilometre per year for cloud-to-ground lightning and cloud-to-cloud lightning combined, average data from 1998 to 2002. New Brunswick has a low-flash density in the order of 0.5 flashes per 100 km per year.

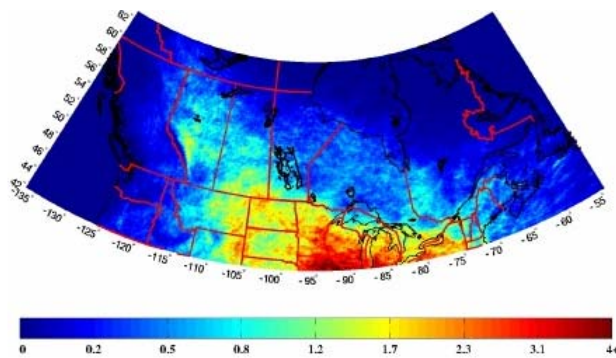

Figure 2 – lightning flash density in Canada

Still lightning outages can be a significant problem for NB Power in areas with high electrical resistivity soil. Much of this soil is rocky and it can be difficult to obtain good lightning performance due to the high resistance of structure grounding systems.

2. Experience with Shield Wires at 345 kV

In 2000, NB Power experienced a 345 kV fault under lightning conditions which caused an outage at NB Power's Point Lepreau Nuclear Generating Station. Subsequent field investigation found all three strings of 18 insulators flashed over at structure 331. A lightning fault had been recorded at this same structure in 1998.

Flashover of insulator strings on multiple phases after a lightning strike is evidence of poor grounding at the tower. An engineering study was carried out to investigate grounding problems along the line and provide mitigation techniques to eliminate the problem. Technical assistance was obtained from Kinectrics Inc. (formerly Ontario Hydro Research Institute).

The investigation included:

- gathering soil electrical resistivity data
- design and construction of different grounding electrodes
- computer modeling of soil and electrodes
- field measurement to verify designs using a new impulse injection technique
- selection of a preferred grounding electrode design

A helicopter survey using electromagnetic scanning was used to gather soil electrical resistivity data to create a two-layer soil model. The data gathered covered a distance of 29 km along the twin 345 kV transmission line right of way.

Test installations of six different electrode designs were constructed and field measurements were carried out to measure electrode ground resistance. Kinectrics Inc. proposed a new impulse injection technique to measure ground resistance on a multi-grounded system. Measurements were carried out to verify the electrode design and the computer model.

Reviewing the soil resistivity data with the electrode design, it was determined that 25% of the tower electrodes did not require additional grounding to achieve the target 22 ohms ground resistance. Field installation of grounding electrodes was carried out in selected areas of lightning activity and high soil resistivity. This work has resulted in improved performance of these 345 kV transmission lines.

3. Saint John Area Transmission Lines

Lightning performance improvements on NB Power 69 and 138 kV transmission lines were first considered in 1999 supplying the area around the city of Saint John. Many of these lines are supported on double circuit steel lattice towers installed over very rocky terrain (Figure 3). These towers were built in the 1950s with shield wires included as part of the design for lightning protection.

Figure 3 – typical 138 kV double circuit structure

Over the years, salt and industrial contamination has resulted in failures of the shield wires due to rust and corrosion. Difficulty in removing lines from service prevented replacement of the shield wires and shield wires began to disappear on these lines in many areas. With no shield wires and towers sitting on rock (poor grounding), the number of outages due to lightning had become problematic with industrial loads and processes being impacted.

Initially, to improve lightning performance it was thought that shield wires would have to be reinstalled along with improved grounding systems. The required line outages to replace shield wires on towers were difficult to obtain.

Acceptable lightning protection with shield wires is dependent on obtaining a low value for tower grounding resistance. With towers sitting on rock, obtaining low ground resistances was a huge challenge as well as an environmental issue in this urban location.

Although successful at 345 kV, it would be difficult to achieve improved lightning performance on the Saint John area transmission lines using shield wires with improved grounding systems. Other alternatives needed to be considered.

4. Line Arrester Applications in Saint John

Line arrester application was considered as an alternative to traditional shield wires for lightning protection.

Partial application of arresters at a tower requires a low grounding resistance to prevent backflash on the unprotected insulator string. The cost of upgrading the tower grounding system over rocky soil plus the disruption to property owners in this urban environment was a concern to NB Power. It was decided to apply arresters to all insulator strings on the selected towers.

Historical information from fault locating relays of lightning events was used to identify locations prone to lightning strikes. Arresters were then applied on all phases of the double-circuit towers in areas where lightning outages had been experienced in the past.

Figure 4 illustrates a typical double circuit 138 kV tower with arresters installed on all phases. No improvements were made to the existing tower grounding systems.

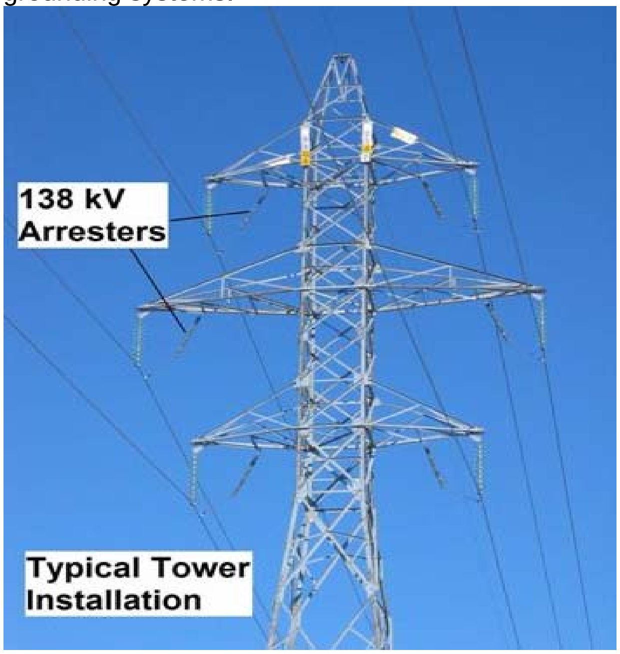

Figure 4 – typical double circuit tower with arresters

Arrestor components were supplied as a kit (Figure 5) which included leads, chain, disconnector and a hot line clamp. Installation required drilling a single hole in the steel crossarm to hang the assembly and then clamping the arrester lead on to the conductor. This work was done under de-energized conditions.

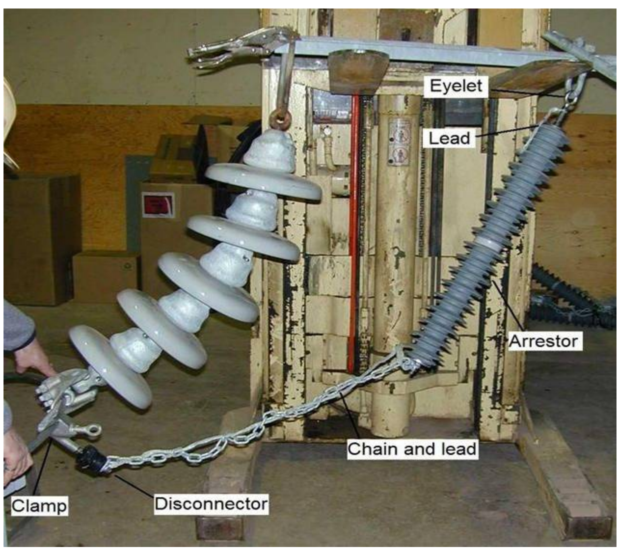

Figure 5 – components of arrestor kit

The purpose of the disconnector is to automatically disconnect the arrester from the transmission system under conditions where the arrester has failed internally and thereby isolate the faulty arrester from the system (Figure 6). Under normal lightning strikes, within the arrester rating, the disconnector does not operate.

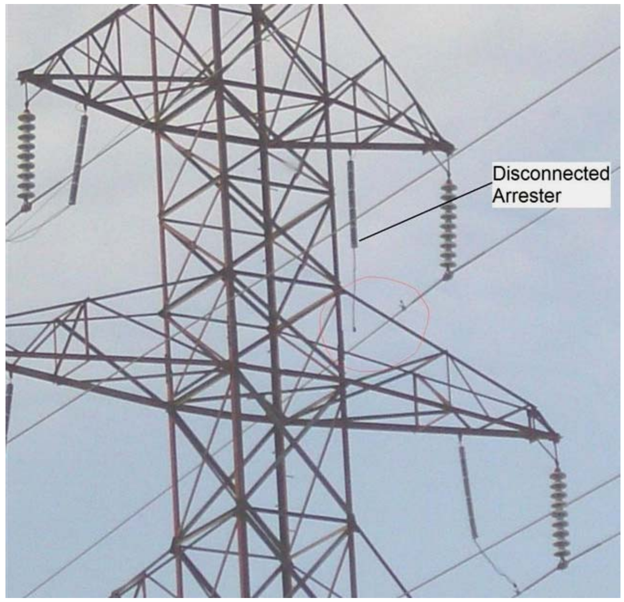

Figure 6 – line arrester which has disconnected

Table 1 provides a summary of lightning outages on transmission lines in the Saint John area. The summary specifically looks at lightning outages at structure locations where arresters were installed. However, the installation of these 1500 arresters was not complete until 2004.

From 1996 to 2002, 28 lightning outages occurred at the identified structure locations prior to arrester installation. From 2000 to 2007, two outages were experienced under lightning conditions. Both outages resulted from lightning arrester failures which were attributed to a lightning strike which exceeded the arrester's energy carrying capability. In that same period, there were three outages caused by failed arresters which were attributed to a manufacturing defect.

	Structures Before Arresters		Structures With Arresters	
Year	69 kV Faults	138 kV Faults	69 kV Faults	138 kV Faults
1996	0	0		
1997	1	7		
1998	4	2		
1999	2	1		
2000	1	4	0	0
2001	4	0	0	0
2002	0	2	0	0
2003			0	0
2004			1	0
2005			0	0
2006			1	2
2007			0	1

Table 1 – summary of lightning outages in Saint John, New Brunswick area

Historically, NB Power would experience at least two outages each year where the conductor would fall on the ground after an insulator flashover under lightning conditions. No events such as this have occurred since arresters were installed. Also, the lightning performance of these lines has improved to the point that industrial customers have recognized the improvement and have acknowledged this to NB Power.

5. Line Arrester Problems

NB Power's history with transmission line arresters spans a period of about seven years from October 2001 to March 2008. Within that period numerous manufacturing defects as well as installation problems have been experienced. It has also been observed that some hardware components supplied with the arrester are showing premature signs of wear. The following pictures illustrate examples of arrester problems experienced.

Manufacturing Defect

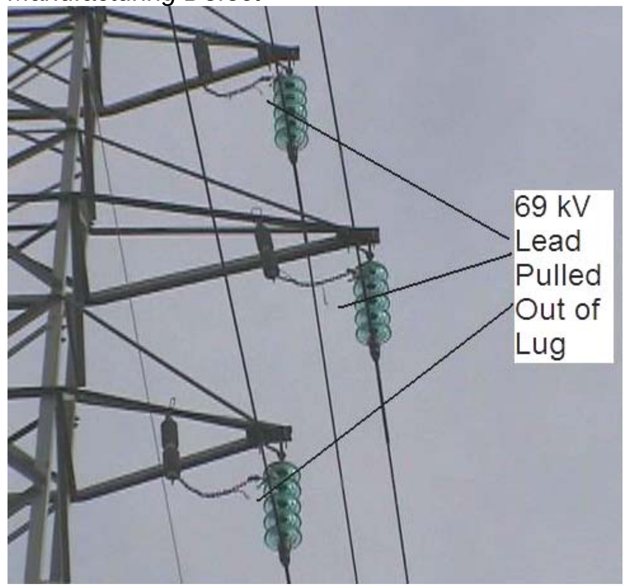

Figure 7 – 69 kV arresters with poor crimp on lug allowing strands to pull out

Improper Installation

Figure 8 – 69 kV disconnector broke because lead was too tight

Manufacturing Defect

Figure 9 – 138 kV improper moisture seal on weathershed end cap. Two units failed causing line outages

Manufacturing Defect

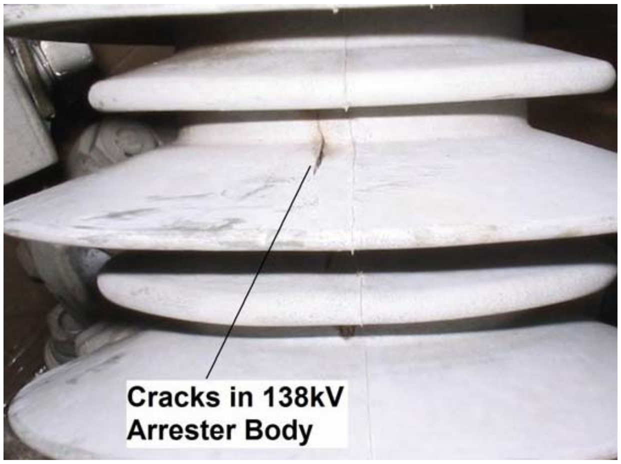

Figure 10 – 138 kV split in weathershed from internal tracking due to moisture ingress through end cap. Thermovision inspection recommended.

Manufacturing Defect

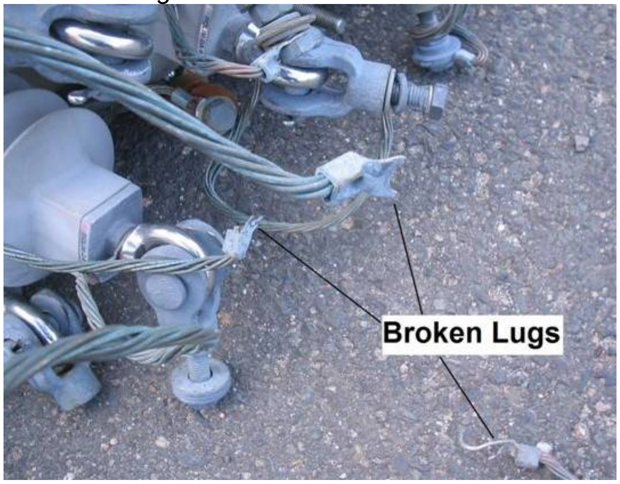

Figure 11 – 69 kV inferior lugs broke while in service

Design Defect

Figure 12A – 138 kV lead and chain worn out after six years of service.

Figure 12B – 138 kV close-up of chain link

Manufacturing Defect

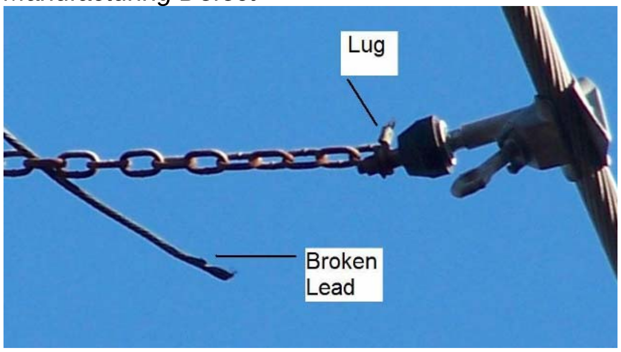

Figure 13 – 138 kV lead broken away from lug

NB Power purchased line arresters from three different manufacturers and experienced hardware problems with each of them (Table 2). In addition to the problems noted above there have also been other hardware problems such as suspension eyelets breaking and a failed pipe clamp on a deadend insulator\arrester assembly.

Supplier	69 kV Installed/Defective	138 kV Installed/Defective
A	627/120	794/220
B		516/3
C	30/30	

Table 2 – summary of defective arrester quantities

There have been five line outages due to failed arresters. Two outages resulted when a 69 kV arrester failed under lightning conditions. These failures were attributed to a high magnitude lightning strike beyond the arrester's energy carrying capability.

The other three outages due to failed arresters were at 138 kV and were attributed to a manufacturing defect. Investigation into these three failures concluded that the arresters had been supplied with an improper moisture seal on the weathershed end cap. This allowed moisture ingress, which resulted in an internal fault.

None of the other problems described herein have caused transmission line outages. Those problems have either been found by inspection or they have been self-isolating without causing an outage.

However, the hardware problems have been very problematic, time consuming and bring into question concerns for the longevity of the installed design. The condition of installed line arresters is monitored through field inspection and thermovision scanning of arresters while in service.

6. Other Arrester Installations on the NB Power Transmission System

Other installations of transmission line arresters on the NB Power transmission system include:

1. 138 kV single steel pole design with post insulator and arrestor assembly (three arresters at every second pole)
2. 138 kV steel H-Frame (suspended arresters at every insulator string)
3. 69 kV wood pole H-Frame (arresters installed on poles below the conductors)
4. 69 and 138 kV arresters installed at terminal stations across transmission line deadend insulator strings

<u>138 kV Single Steel Pole</u>

Figure 14 – 138 kV single steel pole side post design

The 138 kV single pole installation shown in Figure 14 was constructed with arresters installed at every second pole. Poles were at 80 meter spacing and every second pole was chosen in an effort to minimize cost. Each pole includes a grounding conductor around the pole one meter out from the pole. It has since been learned that a single arrester on the top phase of every pole would be a more efficient design, assuming grounding resistance is low. [8] The insulator/arrester assembly, which is appropriate for this application is shown in Figure 15.

Figure 15 – 138 kV arrester and insulator post assembly

<u>138 kV Steel H-Frame</u>

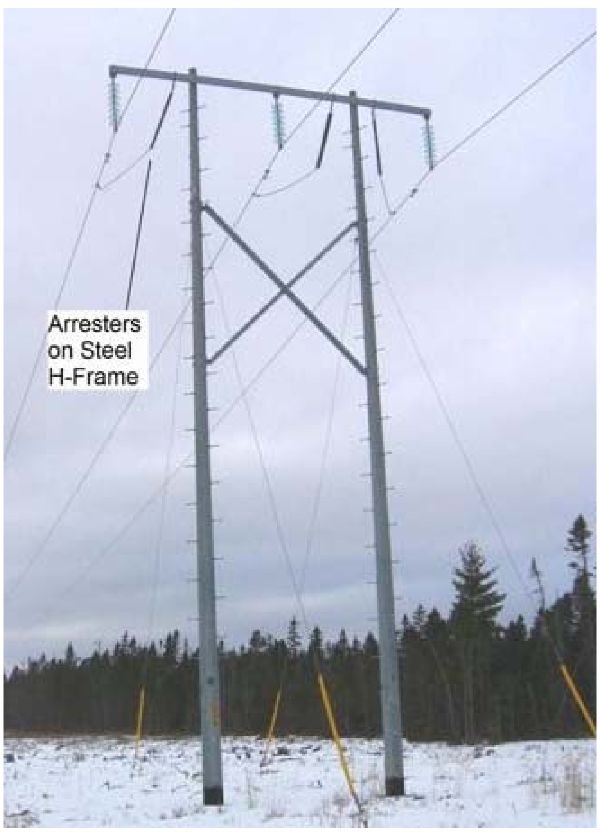

Figure 16 – 138 kV arrester installation on new steel H-Frame structures

In 2003, NB Power constructed a 25 kilometre 138 kV transmission line using a steel H-Frame design shown in Figure 16. Arresters were installed on all phases at every structure. No lightning outages have been experienced to date on this section of line.

<u>69 kV Wood Pole H-Frame</u>

Figure 17 – 69 kV arrester installation on wood pole H-Frame structures

In 2002, NB Power installed arresters on an existing 69 kV wood pole H-Frame transmission line (Figure 17). The arresters along with grounding conductors where installed while the line was energized. The installation was followed by a single transmission line outage to clamp the arrester lead to each phase conductor.

<u>Arresters Installed at Terminal Stations</u>

In 2002, NB Power experienced the failure of a 138 kV SF6 deadtank circuit breaker during lightning conditions. Following this event, a study was undertaken by Kinectrics Inc. on behalf of NB Power to investigate the application of line arresters on transmission line towers near the station. The study concluded that arresters installed at the transmission line deadend tower at terminal stations can provide a margin of lightning protection to a station SF6 breaker which is located within 100 meters of the deadend tower.

NB Power has since undertaken to install line arresters at transmission line deadend towers for stations with SF6 deadtank circuit breakers (Figure 18).

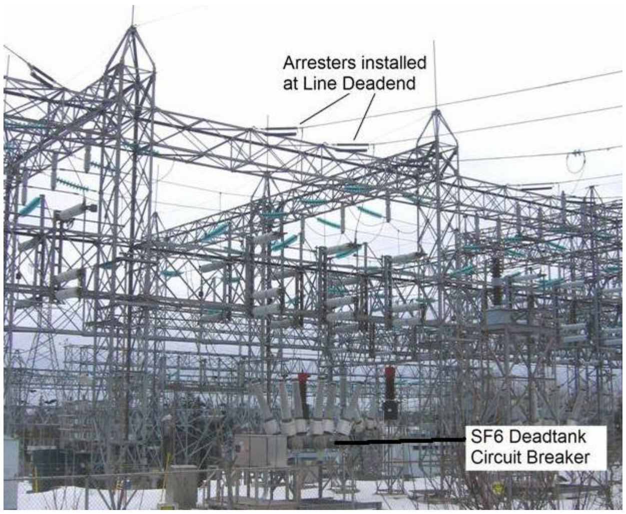

Figure 18 – terminal station showing arrester and insulator assembly at line deadends

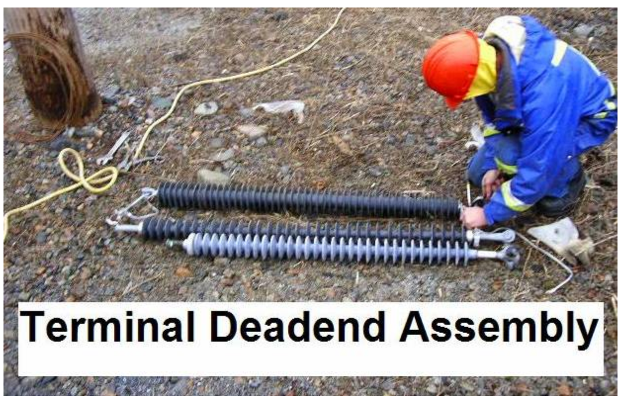

Figure 19 – 138 kV assembly being installed is longer then insulator being removed

Figure 19 shows a typical 138 kV insulator/arrester assembly used to deadend the transmission line. The picture illustrates that the insulator being removed was shorter then the insulator/arrester being installed. This can influence conductor sag and resulting clearances.

7. Lightning Detection System

NB Power has investigated the use of the Vaisala lightning detection system[5] as a tool to use along with present fault locating relays and other historical information.
An example of a lightning event in August 2006 was studied using the Vaisala information and is illustrated (Figure 20). Fault locating relays identified the 138 kV lightning fault location as being near structure 30. Information gathered from the lightning detection system identified six different lightning strikes within 1.5 seconds of the recorded fault time.

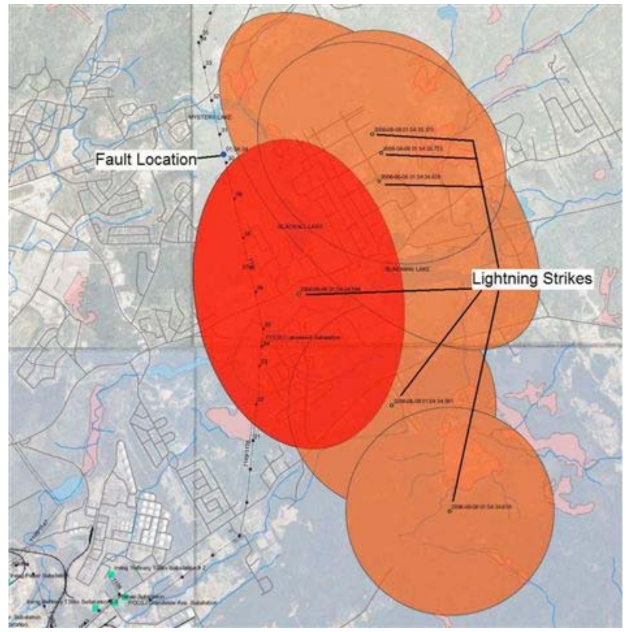

Figure 20 – example lightning detection system results for a transmission line fault

The ability of the lightning detection system data to confirm that a transmission line outage was caused by lightning was investigated. It was hoped that this would permit faster restoration by an operator. NB Power was not able to conclude that the technique was suitable to be used in this manner.
However, the lightning detection system will be used to generate a historical lightning map of the province. The map will be used to identify areas which are prone to lightning related outages and may be a suitable location for improvements to transmission line lightning performance.

8. Lightning Performance Software

NB Power has purchased the Sigma SLP[9] transmission line lightning performance software. This user friendly software allows easy modeling of the transmission line structure geometry. Computation variables include the addition of shield wires, ground resistance, insulation level, tower surge impedance and the addition of line arresters. Single or multiple lightning strokes of varying intensities can be applied. Line arrester currents and energies are calculated along with prediction of energy sharing between arresters. The software includes a graphical representation of traveling waves as well as the ability to profile electric and magnetic fields.

9. Industrial Customer Lightning Performance Mitigation

In 2007 an industrial customer requested NB Power's assistance to improve the lightning performance of their transmission supply. They stated that a single outage could cost them in the order of $650,000. Records indicated that they had 7 lightning outages in a 5 year period.

Investigation has revealed that at some structure locations, line arresters, shield wire or grounding improvements cannot be done because of the physical design of the structures.

However, improvements to the existing lightning protection is possible at most of the structures. Subsequently work is planned in 2008 as follows:

- 1.2 miles of 69 kV on 12 steel lattice towers

Where clearances permit, arresters will be added to all phases. Mounting will be below the energized conductors.

- 1.5 miles of 138 kV unshielded wood pole H-frame 14 structures

Arresters will be added to all phases. Mounting will be below the energized conductors. Grounding will be installed at each structure.

- 4.8 miles of 138 kV shielded wood pole H-frame 38 structures

Existing structure ground resistance will be measured using the impulse injection test technique suitable for a mutigrounded electrode. Sigma SLP software will be used to model the lightning performance using the measured structure ground resistance values. Improvements to the grounding system or the addition of arresters will be completed to achieve appropriate lightning performance.

The above mitigation steps will improve lightning performance along 7.0 miles of the 8.5 miles of transmission line supplying this customer including the 7 identified lightning outage locations. This work is estimated to cost in the order of $250,000.

10. Summary

When lightning protection is required for a particular transmission line, the pros and cons of shield wire versus transmission line surge arresters must be considered. The length of the insulator string, the resistance of the structure grounding electrode and the cost of the arresters or shield wire are all part of this decision.

In general, good lightning performance can be achieved using shield wires particularly on HV and EHV lines[7]. Conversely, shield wires are not usually appropriate at distribution voltages[7] which have shorter insulators and higher values of ground resistance because the grounding electrode is smaller.

To achieve lightning protection of transmission lines, line arresters are appropriate to apply at voltages such as 69 and 138 kV and are seeing increased use at even higher voltages.

One significant difference in considering shield wires versus line arresters is the need for low ground resistance at the tower. For lightning strikes within the arrester energy rating, line arresters can provide **zero** lightning outages when installed across all insulator strings at every tower. If the towers are steel, no additional grounding is required to achieve good lightning performance. Conversely with low ground resistance, shield wires can provide **good** lightning performance which "approaches" zero outages.

There is a fundamental difference between these two approaches for lightning protection of transmission lines.

> With shield wires, the goal is to get the lightning surge to pass into the ground before an insulator backflash occurs. If a backflash occurs, system power-follow current will flow through the ionized air. Protective relays will detect this current and signal the breaker to trip resulting in a transmission line outage.
>
> In the case of line arresters, the goal is to prevent the lightning strike from passing through the air by giving it another path. There is no opportunity for power-follow current to flow because the arrester switches off after the lightning strike has passed through. With no power-follow

current, the protective relays and breaker at the end of the line do not operate and there is no outage to the transmission line. Effectively, lightning which hits the transmission line will pass through to the tower steel and ground with no outage to the transmission line.

The ability of more than one arrester to share in conducting the lightning strike to ground can be an important consideration when considering the arrester energy carrying capability.
In 2008, a project to field test and verify the lightning energy sharing ability of line arresters as modeled in software will be considered by the WISMIG group of CEA Technologies Inc[10]

11. Conclusions

Line arresters installed on the NB Power transmission system have demonstrated their ability to eliminate lightning outages.
In July 2002, a three-day-long lightning storm struck the Saint John area and caused numerous transmission line outages. However, there were no line outages due to lightning on towers which had line arresters installed even though these towers were located in the middle of the lightning storm area. All line outages were at structures without arresters installed.

It is the opinion of the writer that 90% of the mechanical problems experienced with arresters and described in this paper can be eliminated by using arrester/insulator assemblies similar to that shown in Figures 15 and 19 above.

Lightning performance software such as Sigma SLP is an extremely powerful and valuable tool to assist the utility engineer to determine recommended improvements in transmission line lightning performance.

12. References

[1] CEA Technologies Report No. T023700-3102: HV Line Arresters: Selection Based on Grounding Impedance of Towers and Position; Prepared by EDF R & D; Principal Investigators: A. Xemard, J Michaud; Oct 2002

[2] CEA Technologies Report No. T063700-3334: Technology Watch on Lightning Phenomena; Prepared by Kinectrics Inc.; Principal Investigator: W. Chisholm; Sept 2006

[3] CEA Technologies Report No. T023700-3312B: Cost Benefit Analysis by Comparing Two Design Alternatives (Overhead Ground Wires Versus Surge Arresters); Prepared by Kinectrics Inc.; Principal Investigator: W. Chisholm; July 2006

[4] CEA Technologies Report No. T033700-3312A: Guidelines for the installation of surge arresters on sub-transmission lines using different structure designs at voltages from 69 kV to 345 kV; Prepared by Kinectrics Inc.; Principal Investigator: W. Chisholm; March 2005

[5] Vaisala Measurement Systems - Thunderstorm; https://thunderstorm.vaisala.com/

[6] Environment Canada; Meterological Service of Canada; Map of Lightning Hot Spots in Canada; url is http://www.msc.ec.gc.ca/education/lightning/hot_e.html

[7] Personal communication; Kinectrics Inc.;W Chisholm

[8] CEATI Workshop Sept 26-27 2006 Montreal; Overhead Transmission Line Protection Against Lightning; Dr Salih Sadovic; Presentation on TLSA Application on Unshielded Compact Lines

[9] Sigma SLP Lightning Performance Software Website http://www.sadovic.com/

[10] CEA Technologies Inc. Wind and Ice Storm Mitigation Interest Group (WISMIG) Website http://www.ceatech.ca/WISMIG.php