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January 14, 2011

Ms. Erica M. Hamilton
Commission Secretary
British Columbia Utilities Commission
Sixth Floor – 900 Howe Street
Vancouver, BC V6Z 2N3

Dear Ms. Hamilton:

**RE: British Columbia Utilities Commission (BCUC)
British Columbia Hydro and Power Authority (BC Hydro)
Reporting of Forced Outage (January 2009)
Power Surge in Mission/Stave Falls Area
BCUC Order No. G-54-09 - Surge Arrester Report**

BC Hydro is writing in response to the directives contained in BCUC Letter No. L-60-10 dated August 17, 2010, to provide its business case with respect to overvoltage mitigation for events caused by contact between transmission and distribution conductors.

Background

Letter No. L-60-10 directed BC Hydro “to submit within 90 days of the date of this letter a mitigation plan that deals with the risk to customers from future incidents involving transmission lines having distribution underbuild.” The BCUC requested that the mitigation plan include an examination of alternatives, their costs and provide a recommended course of action to reduce or eliminate the current level of damage from contacts between transmission and distribution lines in underbuild situations.

On November 16, 2010 BC Hydro responded to the directive in Letter No. L-60-10. BC Hydro informed the BCUC that its business case had heretofore focused on the installation of Station Class surge arrestors but that in light of the integration of the British Columbia Transmission Corporation and BC Hydro, its business case needed to be updated to include transmission alternatives in the evaluation. BC Hydro committed to submitting its final business case with the BCUC by January 15, 2011 along with an implementation plan of the preferred solution.

Recommendation and Implementation

Based on the evaluation of the alternatives, the business case recommends that Station Class surge arresters be installed on distribution circuits that are underbuilt on

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transmission lines in coordination with planned transmission line refurbishment and maintenance over the next five years (Alternative 4). This coordination of the installation of Station Class surge arresters with planned transmission refurbishment is expected to result in a 20 per cent reduction in program costs when compared to the installation of Station Class arresters in isolation.

The implementation of the project envisages that those lines where no transmission maintenance or upgrade work is planned within the next five years will have Station Class surge arresters installed over the next two years. The component of the work that can be coordinated with other planned transmission work will be prioritized so that all lines that have experienced recent incidents or are otherwise considered to be at higher risk will also be addressed over the next two years. The remainder of the surge arresters will be installed in the remaining three years of the program.

For further information, please contact Sandra Jones at 604-623-4315 or by e-mail at bchydroregulatorygroup@bchydro.com.

Yours sincerely,



Joanna Sofield
Chief Regulatory Officer

gd/rh

Enclosure

Business Case



**Overvoltage Mitigation for Events Caused by
Contact Between Transmission and Distribution
Conductors**

January 2011

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1 Executive Summary

The installation of distribution underbuild on transmission lines has been common practice at BC Hydro over the last several decades. The practice allows for infrastructure that would otherwise require two separate overhead pole lines to be installed on the same structures, thus reducing capital installation costs, reducing right-of-way requirements, and minimizing impacts to communities and landowners. However, associated with this installation is the possibility that the two circuits, of different voltages, can come into contact with each other, introducing temporary overvoltages (**TOVs**) on the distribution system that may impact BC Hydro's customers.

The frequency of reported TOV occurrences has increased in the last few years. Ten incidents have occurred since December 25, 2008. Due to the increasing number of occurrences and increasing number of customers experiencing damage during these latest incidents, BC Hydro investigated mitigation measures to reduce the impact of these events. Based on tests performed by Powertech Labs Inc. (Powertech) and the corresponding study conducted by BC Hydro Distribution Engineering, the application of Station-Class surge arresters has been found to provide a reasonable amount of protection at a reasonable cost. This option was considered along with several other alternatives for system wide mitigation of TOVs. The alternatives considered included:

Alternative	Description	Capital (\$M)	OMA / Year (\$000)	PV Cost over 30 Years (\$M)
1	Do nothing ¹	0	160.0	2.20
2	Fast-track installation of Station Class surge arresters to limit overvoltages	2.67	33.8	2.91
3	Increased application of Distribution Class surge arresters to limit overvoltages	3.40	24.0	3.45
4	Installation of Station-Class surge arresters coordinated with transmission line refurbishment and maintenance over the next 5 years	2.12	32.9	2.24
5	Relocation of existing distribution underbuild to a separate pole line	169.50	640.0	133.56

Based on the evaluation of the alternatives, it is recommended that Station Class surge arresters be installed on distribution circuits that are underbuilt on transmission lines in coordination with planned transmission line refurbishment and maintenance over the next five years (Alternative 4). For lines where no maintenance or upgrade work is planned, Alternative 4 includes the installation of Station Class surge arresters over the next two years. The work will be prioritized so that all lines that have experienced recent incidents or are otherwise considered to be at higher risk will be addressed over the next two years. The advantage of coordinating with other transmission work is reduced costs and efficiency in executing the work. This alternative will help to mitigate the impact of TOVs, but will not completely eliminate the risk of transmission to distribution line contacts.

The impact of this recommendation would be the installation of an estimated 1,410 Station Class surge arresters in approximately 610 locations (400 3-phase and 210 single phase) throughout B.C. at an estimated present value cost of \$2.24 million.

BC Hydro will re-allocate funds within existing budgets to accommodate these expenditures. In order to complete the project, a high level estimate of 3,200 power line technician (PLT) hours would be required to install arresters over the next two years in approximately 305 locations where no other transmission work is planned. This work volume represents a

¹ This alternative takes no specific action from the distribution perspective. Transmission initiatives such as ongoing refurbishments and maintenance will, over time, improve clearances and reduce but not eliminate the probability of transmission to distribution line contact.

3-PLT crew for nine months, which is considered to be achievable using either BC Hydro crews and/or contractors. The remaining arresters would be installed over five years in conjunction with planned transmission work programs.

2 Issue Definition

2.1 Description of the Problem

The practice of installing distribution underbuild on 60 kV transmission lines is common within the BC Hydro service area, and has been applied as an efficient way of installing two circuits without the need for a second separate pole line, thus reducing initial capital cost and impact on communities. The practice of installing transmission and distribution circuits on the same pole line is also common throughout North America. This construction method carries with it the possibility that the two circuits can contact each other during events such as a motor vehicle accident, a tree falling on the line, conductor sag caused by thermal loading, or an accumulation of snow and ice on the wires.

It should be recognized that electrical contact can be established between circuits without actual physical contact of the conductors. When the physical distance between conductors of different voltages is reduced to below the insulation strength of the air gap, electrical flashover can occur. When conductors are in motion, the air gap distances between conductors can change so that when an electrical flashover occurs, the arcing fault will move within the span.

During an investigation of a recent transmission and distribution line contact, a survey of other North American utilities was conducted and it was found that although many utilities practiced installing distribution underbuild on transmission lines, very few had implemented mitigation measures to reduce the risk of over-voltage. One utility, Dominion Virginia Power, has installed Station Class arresters to mitigate the effects of transmission to distribution line contacts². BC Hydro's recent experience has shown a need to consider such mitigation measures and therefore a project was initiated to study the performance of Station Class surge arresters for installation on sections of distribution underbuild. A study performed by Powertech (Appendix C) and a corresponding study conducted by BC Hydro Distribution

² Overvoltage Protectors – A Novel Concept for Dealing With Overbuilt Distribution Circuits by Daniel J. Ward, IEEE paper 0885-8977 published in the IEEE Transactions on Power Delivery, Volume 25, No. 3, July 2010.

Engineering determined that the application of Station Class surge arresters provide a reasonable amount of protection at a reasonable cost.

When a transmission and distribution circuit contact each other, a temporary overvoltage (**TOV**) event occurs. This TOV event may be two to five times the regular voltage in magnitude. The time duration of the TOV event will always be greater than a few cycles³, and will depend on the protection settings of the fastest device that interrupts the fault⁴. As the amount of energy imposed on a power system during a fault situation is directly proportional to the time duration of the fault, the amount of energy imposed on the distribution circuit during a TOV event is greater than what any distribution-rated overvoltage protection equipment is designed to protect against.

For temporary type faults between transmission and distribution conductors (e.g., galloping conductors⁵, falling branches) customers would experience only one TOV event for the original contact. For permanent type faults, (i.e. tree on lines) customers will usually be exposed to more than one TOV as they will experience a TOV from the original contact, an automatic reclose as programmed into the protection device, and often a supervisory reclose as given by an operator at the Control Centre. BC Hydro is reviewing and revising its practice regarding reclosing on 60 kV circuits with distribution underbuild to limit the number of reclosing operations and thereby reduce the impacts of TOV⁶.

Distribution Class surge arresters have existed for a long time, but their intention is to protect the power system from very short duration voltage “surges”⁷, such as lightning strikes. Although these surges can be of very great magnitude, their time duration is very short (less than 0.3 ms for lightning) resulting in fault energy levels that conventional Distribution Class surge arresters are capable of diverting, thereby mitigating their impact on the system.

³ On a 60 Hz system, one cycle = 16.7 ms in duration.

⁴ An abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential.

⁵ Chaotic bouncing of the lines usually caused by heavy ice and snow loads dropping away from the lines. It can also occur in high wind situations.

⁶ Reclosing policy for transmission lines is specified in Operating Order 1T-29A, which is being revised to limit reclosing on 60 kV lines with underbuild.

⁷ Voltage transient.

Under normal operation, surge arresters are designed to provide a low impedance path to ground whenever the circuit voltage exceeds a certain level (voltage surge). This effectively limits the voltage and diverts energy away safely. Under short duration voltage “surge” conditions, the arrester returns to a high impedance state once the circuit voltage returns to normal. However, under longer duration voltage surges such as a TOV, the energy threshold of the arrester could be exceeded and the arrester could fail permanently into short-circuit mode and keep the circuit grounded even when the circuit voltage attempts to return to normal.

Distribution Class surge arresters are designed with a self-disconnect mechanism that removes a failed arrester that is in a short circuit mode from service after the fault is cleared by an upstream device. This means that reclosing attempts to re-energize the circuit will be successful as the arrester will be, in effect, removed from the line and the circuit will no longer be grounded. However, the overvoltage protection originally provided by that arrester would also be removed.

Station Class surge arresters do not have this self-disconnect mechanism; therefore a failed arrester will continue to provide a low-impedance path to ground and protect the circuit from further TOV events. Reclose attempts will not be successful until the arrester is manually disconnected from the line.

The risk of transmission line contact with distribution underbuild has always existed. However, the number of incidents regarding TOVs has increased significantly in the last few years, with ten incidents occurring since December 2008. The increased rate of occurrence may be due to a variety of factors, such as changing weather patterns, increased thermal loading of the upper circuit, or inadequate transmission to distribution clearances. The impact of TOV incidents on customers has also increased due to the amount of sensitive consumer electronic equipment used in homes. This combination of higher impact and increased frequency has driven the need to address TOV issues resulting from transmission line contacts with distribution underbuild.

2.2 Business Risks

The following is a summary of business risks associated with distribution underbuild:

Safety

TOV events could potentially damage customer equipment which may result in hazardous situations. A second safety risk is to BC Hydro's workers. If a distribution line crew is performing any work on the distribution circuit that is contacted by a transmission circuit, the distribution line crew will also be exposed to the TOV. This overvoltage could exceed the level of protection provided by distribution voltage rated tools. Although the time duration at this higher voltage would be very short, it would be enough to cause serious consequences to any affected worker.

Financial

BC Hydro has been exposed to an increasing number of claims resulting from overvoltage events. As governed by the section 9.7 of the Electric Tariff, BC Hydro is not legally obligated to accept claims for damage unless there is wilful misconduct on the part of any BC Hydro employees.

While the Tariff protects BC Hydro against claims, BC Hydro has responded to a number of events by making payment to customers in response to TOVs. These cash payouts, coupled with internal investigation costs and community relations effort could be in the order of a hundred thousand dollars or more per year depending on the number of customer claims, nature of the event(s) and number of events.

Reputational

BC Hydro's reputation suffers when a TOV occurs and customer equipment is damaged. This reputational impact is compounded when customers become aware that their claims can be denied because no wilful misconduct was found on BC Hydro's part and therefore BC Hydro is not liable for the damaged equipment.

3 Background and Context

BC Hydro performed an analysis to quantify the total amount of underbuild BC Hydro has in its system, and to look at the historical pattern at which contacts occurred between the transmission and distribution conductors resulting in TOV. The results show that there are approximately 830 km of three-phase and 450 km of single-phase underbuild in BC Hydro's

system, meaning approximately 2.7 per cent of the total 48,128 km of overhead distribution lines are installed as underbuild. The analysis also indicated that there have been 10 contacts between transmission and distribution conductors that have resulted in overvoltages since December 2008.

The most recent incidents are listed in the following table:

Incident	Date	Location	Type
1	Aug. 19, 2010	Maple Ridge	due to 60 kV crossarm failure
2	July 15, 2010	Belcarra	due to a tree falling on both transmission and distribution lines,
3	July 5, 2010	Nakusp	due to a tree coming down on the transmission and distribution line,
4	Dec. 16, 2009	Quesnel	due to suspected conductor jump or galloping
5	Nov. 17, 2009	Whonnock	due to a fallen tree
6	Nov. 17, 2009	Fraser Lake	due to suspected conductor jump or galloping
7	Nov. 16, 2009	Vanderhoof	due to suspected conductor jump or galloping
8	June 30, 2009	Lake Cowichan	due to transmission vegetation work
9	Jan. 5, 2009	Mission	due to conductor jump or galloping
10	Dec. 25, 2008	Belcarra	due to conductor jump or galloping,

The rate of reported TOV events has increased significantly and requires appropriate mitigation measures. The potential mitigation measures for various causes of TOV can be summarized as follows:

Cause	Potential Mitigation		
	Temporarily de-energize 60 kV	Increase Transmission to Distribution Clearance	Install Arrester
Maintenance (e.g.vegetation trim)	X		X
Snow/ice jump		X	
Galloping		X	
Motor Vehicle Collision			X
Tree contact			X
60 kV equipment failure			X

There has been one incident related to planned tree trimming but since it is rarely possible or prudent to de-energize a transmission line for vegetation work, the installation of surge arresters would mitigate the impact of this type of contact incident. Existing vegetation management programs are in place to manage trees in the right of way, but tree contacts from trees outside the right of way and wind-blown branches cannot be totally eliminated. The issues of conductor jump and galloping will be addressed over time as the 60 kV system is refurbished. But even when clearance between the 60 kV and underbuild is sufficient, TOV could occur as a result of motor vehicle accidents, trees/branches coming into contact with lines, and 60 kV equipment failure (considered to be rare, especially as the lines are maintained to current standards).

Surge arresters can mitigate TOV incidents and should be deployed in conjunction with other preventive measures such as planned work procedures and line upgrades.

4 Alternatives – Description, Analysis, and Recommendation

The following section discusses five alternatives, as follows:

Alternative 1: Do nothing and maintain the status quo;

Alternative 2: Install Station Class surge arresters over next two years;

Alternative 3: Install Additional Distribution Class surge arresters;

Alternative 4: Install Station Class surge arresters coordinated with other planned work; and

Alternative 5: Relocate the underbuild to new distribution pole lines.

The discussion pertaining to each alternative includes a description of the work required, the major benefits and drawbacks, the present value cost of each alternative, and a risk evaluation in which risks were assessed in accordance with the BC Hydro Corporate Risk Matrix which uses a scale of one to six with one being the least risk and six being high risk (see Appendix B).

4.1 Description of Alternatives

Alternative 1: Do Nothing and maintain status quo

Description: Alternative 1 is a continuation of the status quo (from the distribution perspective) and provides no additional protection to customers and customer equipment from impacts caused by contact between transmission and distribution conductors. BC Hydro will respond to individual events on a case by case basis and perform investigations as warranted. Although ongoing transmission refurbishing and maintenance programs will improve clearance issues over time, it is still expected that transmission to distribution contacts will continue to occur.

Major Benefits: Avoidance of distribution capital investment and resource assignments associated with any implementation or distribution program.

Major Drawbacks: BC Hydro will continue to experience TOVs, posing risk to customer equipment. Most contacts will likely require technical investigations impacting internal resources. BC Hydro is exposed to adverse reputational impact and declining customer satisfaction. There is a risk of losing public confidence due to taking no action while being aware of a potential hazard and available reasonable solutions.

Risks: Project Risk: There is no capital project involved in this alternative, therefore there are no associated project risks.

Safety Risk: In the event that a TOV occurs while a worker is in contact with the distribution line or a customer is in contact with an impacted piece of equipment, injuries with a consequence severity of S5⁸ could occur. However, it is judged that the frequency of such an occurrence is low at an L4 level, resulting in a safety risk of four (moderate-high) using the BC Hydro Corporate Risk Matrix (see Appendix B).

Reputation Risk: Should TOV events continue without any corrective action, customers may lose trust in BC Hydro. Therefore the consequence severity of this is considered to be S5. Given the number of events over the past two years, the frequency of occurrence of this is judged to be L6, resulting in a risk level of five (high) using the BC Hydro Corporate Risk Matrix.

Financial Costs: BC Hydro will continue to use internal labour to perform investigation reports. The cost of the previous investigations ranged from approximately \$25,000 to \$50,000 per incident. However, the cost of future investigations is expected to be lower due to the work done to date on previous incidents. Further, it is expected that although 2009 may have been an anomaly, the annual rate of occurrences will be approximately four events per year. Assuming an upper investigation cost of \$15,000 and four occurrences per year, approximate costs of

⁸ References to S_ and L_ relate to BC Hydro's Corporate Risk matrix (see Appendix B).

\$60,000 annually would be incurred. Annual cash payouts to impacted customers are estimated to be approximately \$100,000. Based on the above the following costs are expected to be incurred:

Item	Cost
Incident investigation	\$60,000/year
Equipment Replacement	\$0/year
Incremental OMA	\$0/year
Cash Payouts to customers	\$100,000
Present Value over 30 years	\$2.20M ⁹

Alternative 2: Install Stations-Class Surge Arresters

Description: Alternative 2 involves installing sets of Station Class surge arresters along every underbuild in BC Hydro’s service area, using a spacing of at least one set every 2 km¹⁰. For lines that are less than 2 km in length, a set would be installed at each end of the underbuild. Faulted Circuit Indicators (**FCIs**) would be installed at every arrester to visually indicate to crews which arresters have faulted and need to be replaced, speeding up restoration efforts.

Major Benefits: Station Class surge arresters can provide a low impedance path to ground in less than one cycle thus significantly reducing the time duration that customers are exposed to TOVs, and limiting damage to customers’ equipment. Unlike Distribution Class arresters, Station Class arresters do not have a self-disconnect mechanism. Therefore, should an arrester fail during a TOV event, the distribution line will remain grounded for any reclose attempts which helps to ensure that reclose attempts do not cause any further damage.

Major Drawbacks: Although a Station Class arrester may potentially withstand several TOV events, should the arrester happen to fail during a temporary fault between transmission and distribution, the non-self

⁹ See Appendix A for details.

¹⁰ See report “Surge Arrester Testing At Powertech on 20 and 21 August 2009” attached in Appendix C.

disconnecting characteristic of a Station Class arrester would result in a permanent outage for the customers affected. This would require line crews to patrol the line and remove the surge arrester from service before the line could be re-energized. FCIs will help with identifying the location of the shorted arrester, but there is a maintenance cost to maintain the FCI battery. The impact on reliability due to the failing of Station Class arresters to short circuit mode as a result of transmission to distribution line contact is conservatively estimated to be approximately an additional 2,000 customer interruptions per year and 6,000 customer hours lost¹¹. This amounts to a 0.06 per cent increase in customer interruptions and 0.08 per cent increase in customer hours lost for the BC Hydro system¹². This small incremental impact on reliability is considered acceptable in order to mitigate the potential safety and damage hazard posed by TOV events in a cost effective manner.

Risks:

Project Risk: As with the introduction of any standard or operational changes, change management and field acceptance of these procedures needs to be managed to avoid project delays.

Safety Risk: The installation of Station Class surge arresters would reduce the consequence severity from S5 to S3 reducing the residual inherent safety risk to two (low) as compared to four in Alternative 1.

Reputation Risk: It is anticipated that installation of Station Class surge arresters would result in only a limited number of customers experiencing impacts of TOVs, reducing the risk to two (low) from five, when compared with Alternative 1.

¹¹ Assumes estimate of 2000 customer affected, and a 3 hour restoration time to locate and remove the Station-Class surge arrester from service. Also assumes 4 TOV incidents a year, only one of which would cause an incremental impact on reliability due to an arrester failing in short-circuit to ground mode for a temporary 60kV to underbuild contact.

¹² Based on F2010 numbers for customer interruptions and customer hours lost.

Financial Costs: Based on a maximum spacing of 2 km per set of arresters for 830 km of 3-ph lines and 450 km of 1-ph lines, and taking into account that not every underbuild is 2 km in length, it is estimated that 435 3-phase arrester sets and 235 1-phase arresters will need to be installed. Some pole replacements to taller poles would be required to accommodate some arrester installations, resulting in early renewal of assets at a cost of about \$167,000 (based on approximately 10 per cent of poles replaced on average five years early). The cost of any other upgrade work that is typically undertaken when working on a structure is not included in this analysis. Similar to Alternative 1, it is expected that the annual rate of occurrence will be four events per year, resulting in four arrester failures per year at a cost of \$700 each. Further it is assumed that the engineering effort required for incident investigation will be reduced to \$5,000 since identifying the location of the fault would be aided by FCI indications. Based on this, the following costs are expected to be incurred:

Item	Cost
435 3-ph arresters sets	\$4,450 per set → \$1.94M
235 1-ph arresters	\$2,400 per install → \$0.56M
Pole Replacements	\$0.167M
Incident Investigation	\$20,000/year ¹³
Equipment Replacement	\$2,800/year
FCI Battery Maintenance	\$11,050/year
Cash Payouts to customers	low
Present Value over 30 years	\$2.91M ¹⁴

Alternative 3: Install Additional Distribution Class Surge Arresters

Description: Alternative 3 involves the installation of Distribution Class surge arresters at strategic points along the circuit. As protection would be

¹³ Assumes 4 incidents per year, \$5,000 investigation cost per incident.

¹⁴ See Appendix A for details.

needed against the initial contact, the automatic reclose and any supervisory reclose on the 60 kV circuits, the spacing pattern would be up to three sets of arresters for every 2 km. Based on the review and revised practice regarding reclosing on 60 kV circuits with distribution underbuild, limited reclosing will take place therefore two sets of arresters would be required every 2 km.

Major Benefits:

Materials already exist in stores throughout province. Crews are familiar with installing and maintaining Distribution Class surge arresters. Reliability would not be negatively affected due to the self-disconnect mechanism resulting in no permanent outages for temporary faults.

Major Drawbacks:

The self-disconnecting mechanism on Distribution Class surge arresters means the circuit will be re-energized and crews will have no obvious indication that arresters have failed. Customers will experience a brief overvoltage (approximately one cycle while waiting for nearest arrester to fail to short-circuit mode) on the original contact and on reclose. In areas with low transmission fault currents, the 60 kV circuit breaker could take a relatively long time to clear the fault, causing numerous surge arresters to fail during each of the original overvoltage and reclose attempts, possibly eliminating the surge protection on the distribution line. As a result, there is still a possibility of TOV under this option. Further, every affected district will need to perform regularly planned inspections on all surge arresters to check for failures caused by TOVs so that protection is maintained. Distribution Class arresters are not designed to mitigate transmission induced TOVs and will be subject to failures. However, the failure mode of distribution arresters is such that fragments are well contained thereby avoiding the risk of a public safety hazard.

Risks:

Project Risk: No major project risks are anticipated with this alternative.

Safety Risk:

The installation of Distribution Class arresters will mitigate impacts of some TOV events, but the disconnect feature of the arresters may also leave some circuits unprotected. This makes this alternative better than Alternative 1, but not as good as Alternative 2. The consequence severity is judged to be S4 resulting in a residual safety risk of three (moderate) when compared with Alternative 1 (see Appendix B).

Reputation Risk: Although the potential for TOV exists, the impact would be limited to a smaller number of customers. The consequence severity therefore is judged to be S1 resulting in the reduction in the residual reputational risk to two (low) from five when compared with Alternative 1.

Financial Costs:

Based on having two sets of arresters installed every 2 km (as compared to one in Alternative 2) it is estimated that 870 3-phase arrester sets and 470 1-phase arresters will need to be installed. Some pole replacements would be required to accommodate the arresters, resulting in early renewal of assets at a cost of about \$335,000 (the cost of any other upgrade work that is typically undertaken when working on a structure is not included in this analysis). Similar to Alternative 1 and 2, it is expected that the annual rate of occurrence will be four events per year. In this alternative, however, it is expected that eight arrester failures will occur per year at a cost of \$500 each. The investigation costs would remain similar to those in Alternative 2 (\$5,000) since identifying the location of the fault would be aided by the location of failed surge arresters. Based on this, the following costs are expected to be incurred:

Item	Cost
870 3-ph arresters sets	\$2,500 per set → \$2.18M
470 1-ph arresters	\$1,900 per install → \$0.89M
Pole Replacements	\$0.335M
Incident Investigation	\$20,000/year
Equipment Replacement	\$4,000/year
Incremental OMA	low
Cash Payouts to customers	low
Present Value over 30 years	\$3.45M ¹⁵

Alternative 4: Install Station Class Surge Arresters Coordinated with Other Planned Work

Description: Alternative 4 is similar to Alternative 2 but is implemented over a longer time frame to coordinate with planned maintenance and upgrade work on the 60 kV system.

Major Benefits: By installing the Station Class surge arresters as part of other planned work the labour cost will be greatly reduced since the crew will have already travelled to the site and will be set up to work on the pole. In addition to the cost saving the work will also be done more efficiently by doing all required work on a pole at the same time. Furthermore, fewer arresters will need to be installed in locations where the line is upgraded to achieve sufficient clearance and the risk of contact from other causes is judged to be very low – e.g. locations where there are no trees or low risk of vehicle accidents. By coordinating the work, pole replacements to taller poles will also be reduced compared to Alternative 2. Current upgrade procedures include detailed engineering and transmission line design on each span of the transmission and underbuild, which provides a better margin than relying on prescriptive “standard” separation distances at the pole. The upgrade work will also consider

¹⁵ See Appendix A for details.

design innovations such as the installation of phase spacers where appropriate to maintain line separation.

Major Drawbacks:

This option would take up to five years to implement, however the work will be prioritized so that all lines that have experienced recent incidents or are otherwise considered to be higher risk will be addressed over the next two years. As in Alternative 2, the non-self disconnecting characteristic of a Station Class arrester would result in more permanent outages as a result of TOV incidents, with a slightly smaller impact on reliability since fewer arresters would be installed.

Risks:

Project Risk: As with the introduction of any standard or operational changes, change management and field acceptance of these procedures needs to be managed to avoid project delays.

Safety Risk: The residual safety risk of this option would be similar to Alternative 2.

Reputation Risk: The residual reputational risk of this alternative would be similar to Alternative 2.

Financial Costs:

It is estimated that 50 per cent of the arresters proposed in Alternative 2 can be installed at a reduced labour cost by coordinating with other work. It is also estimated that fewer arresters will need to be installed in locations where the line is upgraded to achieve sufficient clearance and the risk of contact from other causes is judged to be very low. If it is assumed that 10 per cent fewer arresters would be installed compared to Alternative 2, the following costs are expected to be incurred:

Item	Cost
400 3-ph arresters sets	200 at \$4,450, and 200 at \$3,450 → \$1.58M
210 1-ph arresters	105 at \$2,400 and 105 at \$2,050 → \$0.467M
Pole Replacements	\$0.076M
Incident Investigation	\$20,000/year
Equipment Replacement	\$2,800/year
FCI Battery Maintenance	\$10,100/year
Cash Payouts to customers	low
Present Value over 30 years	\$2.24M ¹⁶

Alternative 5: Build Exclusive Distribution Pole Lines

Description: Alternative 5 involves physically separating the transmission and distribution lines by building exclusive pole lines for the distribution line. Occasional underbuild on transmission poles would still be required for line crossings in order to serve customers.

Major Benefits: This option would all but eliminate the number of TOVs as the only exposure areas would be at the tap poles which are required for crossings.

Major Drawbacks: Significant capital investment is required. This alternative requires additional pole lines on the opposite side of the street or alternate distribution routing. This effects aesthetics negatively and adds to maintenance and operations costs. Finding appropriate right-of-ways could also be an issue in some areas. The volume and scope of work would put a strain on resources and require eight to 10 years to implement.

Risks: Project Risk: Building exclusive pole lines in geographically harsh and/or remote areas would be difficult and could add significantly to project cost.

¹⁶ See Appendix A for details.

Safety Risk: Separation of the lines would all but eliminate the potential of line contact reducing the frequency of occurrence to L0 with a corresponding reduction of the safety risk to one (low) from four when compared with Alternative 1 (see Appendix B).

Reputation Risk: The cost of this alternative is high resulting in potential impact on rates and associated customer complaints. The consequence severity of this alternative is judged to be S3 resulting in a residual reputational risk of three (moderate) compared to five in Alternative 1.

Financial Costs: Assuming that additional right-of-ways are readily available for a separate distribution pole line, the following costs are expected to be incurred using very high level estimates:

Item	Cost
New Distribution Lines	\$150,000/km for 3 ph and \$100,000/km for 1 ph → \$170M
Incident Investigation	\$0/year
Equipment Replacement	\$0/year
Incremental OMA	\$500/km @ 100% of 1280km → \$640,000/year
Cash Payouts to customers	\$0
Present Value over 30 years	\$133.6M ¹⁷

4.2 Analysis of Alternatives

A structured decision making approach was undertaken to determine the most appropriate solution to the issue of TOV caused by transmission to distribution line contacts based on financial, environmental and social impacts. The details of this analysis are as follows.

¹⁷ See Appendix A for details.

4.2.1 Financial Analysis

Alternative	Description	Capital (\$M)	OMA / Year (\$000)	PV Cost over 30 Years (\$M)
1	Do nothing ¹⁸	0	160.0	2.20
2	Fast-track installation of Station Class surge arresters to limit overvoltages	2.67	33.8	2.91
3	Increased application of Distribution Class surge arresters to limit overvoltages	3.40	24.0	3.45
4	Installation of Station-Class surge arresters coordinated with transmission line refurbishment and maintenance over the next 5 years	2.12	32.9	2.24
5	Relocation of existing distribution underbuild to a separate pole line	169.50	640.0	133.56

Alternative 5 is prohibitive at a cost of \$133 million. Alternatives 1 and 4 are essentially the same cost, but Alternative 4 achieves maximum benefits by coordinating the arrester installation with other planned work.

4.2.2 Environmental Analysis

Alternatives 1 to 4 will have negligible environmental impact as they involve either doing nothing or installing equipment on existing poles along existing rights-of-way. Alternative 5, to build exclusive pole lines, would have a high environmental impact due to the additional right of way requirements which are estimated to be over 1000 hectares.

4.2.3 Social Analysis

As highlighted by previous incident investigations, TOV events can have a negative impact on customer equipment and could potentially impact safety of the crews and public. As outlined by the Powertech tests and the corresponding study conducted by Distribution Engineering, it is possible to limit the extent of damages caused by these events through the installation of surge arresters. Alternative 1 does not address the issues of safety and could have significant reputational impacts. Although Alternative 5 would eliminate virtually all incidents, the significant cost of this option could have a negative effect on the ratepayer and

¹⁸ This alternative takes no specific action from the Distribution perspective. Transmission initiatives such as ongoing refurbishments and maintenance will, over time, improve clearances and reduce but not eliminate the probability of transmission to distribution line contact.




community impacts as a result of increased infrastructure. Alternative 3 would provide some level of protection against TOVs but would require regular inspections to ensure that installed surge arresters have not failed and self disconnected from the system. Alternative 4 provides the greatest protection against TOVs at the lowest cost and would be seen as the most desirable from a social perspective.

4.3 Summary of Analysis

The comparison of each option based on several factors is outlined in the table below.

Objective	Criteria	Measures (unit)	Alt. 1 – Do Nothing	Alt. 2 – Station-Class surge arresters	Alt. 3 – Distribution-Class surge arresters	Alt. 4 – Station class arrester & other work	Alt. 5 – Exclusive Pole Lines
Cost	Total Capital and OMA	PV (\$)	\$2.20 M	\$2.91 M	\$3.45 M	\$2.24 M	\$133.6 M
Safety	Public – potential injury due to failed equipment	1-6 scale, 1 is best, based on BCH risk matrix	4	2	3	2	1
Reputation	BCH loss of reputation for managing responsibilities well	1-6 scale, 1 is best, based on BCH risk matrix	5	2	2	2	3
Environment	Disturbed Land	Relative	Low	Low	Low	Low	High
	GHG emissions from vehicles	Relative	Low	Low	Moderate - Low	Low	High

Legend:

-  Relatively EQUAL to recommended alternative
-  Relatively BETTER than recommended alternative
-  Relatively WORSE than recommended alternative

4.4 Recommendation and Implementation

It is recommended that Alternative 4, installation of Station Class surge arresters over five years coordinated with other planned transmission capital and maintenance work, be adopted. Specifically, the planned maintenance and upgrade programs would be reprioritized so that lines with potential transmission to distribution line contacts are upgraded first thereby correcting any clearance issues and at the same time installing surge arresters where deemed to still be required. This may take up to five years, but the benefits of coordinating the work in terms of efficiency and cost savings offset the extra time needed. Simultaneously, for underbuilds with no planned maintenance and upgrade work on the transmission circuit, surge arresters will be installed over a two year period to mitigate against potential TOV's.

Station Class arresters will largely mitigate the damage due to TOVs. A full inventory of all underbuilds is presently being created with the length, number and type of customers, and condition of each underbuild to prioritize the order for the maintenance and upgrade work and for the Station Class arrester installation.

Business Case

Overvoltage Mitigation for Events Caused by Contact Between Transmission and Distribution Conductors



Appendix

A

Present Value Cost Analysis

**Business Case - Overvoltage Mitigation
Appendix A**

PV Analysis

	Capital (\$ K)	OMA (\$ K/year)	\$M PV
Alt. 1 Do Nothing	\$0	\$160.00	\$2.20
Alt. 2 Stations SA	\$2,667	\$33.85	\$2.91
Alt. 3 Distribution SA	\$3,403	\$24.00	\$3.45
Alt. 4 Stn SA & other work	\$2,123	\$32.90	\$2.24
Alt. 5 Exclusive Lines	\$169,500	\$640.00	\$133.56

<u>Year</u>	<u>Do Nothing Alternative 1</u>	<u>Stations SA Alternative 2</u>	<u>Distribution SA Alternative 3</u>	<u>Stn Arrester & Other Work Alternative 4</u>	<u>Exclusive Lines Alternative 5</u>
1	\$160,000	\$1,367,475	\$1,725,500	\$457,600	\$17,590,000
2	\$160,000	\$1,367,475	\$1,725,500	\$457,600	\$17,590,000
3	\$160,000	\$33,850	\$24,000	\$457,600	\$17,590,000
4	\$160,000	\$33,850	\$24,000	\$457,600	\$17,590,000
5	\$160,000	\$33,850	\$24,000	\$457,600	\$17,590,000
6	\$160,000	\$33,850	\$24,000	\$32,900	\$17,590,000
7	\$160,000	\$33,850	\$24,000	\$32,900	\$17,590,000
8	\$160,000	\$33,850	\$24,000	\$32,900	\$17,590,000
9	\$160,000	\$33,850	\$24,000	\$32,900	\$17,590,000
10	\$160,000	\$33,850	\$24,000	\$32,900	\$17,590,000
11	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
12	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
13	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
14	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
15	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
16	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
17	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
18	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
19	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
20	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
21	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
22	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
23	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
24	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
25	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
26	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
27	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
28	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
29	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
30	\$160,000	\$33,850	\$24,000	\$32,900	\$640,000
PV(5.88%)	\$2,230,943	\$2,921,160	\$3,459,413	\$2,253,584	\$134,389,586
PV(6.0%)	\$2,202,373	\$2,910,998	\$3,449,874	\$2,241,854	\$133,562,967
PV(8.0%)	\$1,801,245	\$2,759,282	\$3,304,412	\$2,066,085	\$120,940,861

Notes

Alt 1 assumes 4 incidents per year @ \$15k/each, 1 claim per year offers \$100k compensation

Alt 2 assumes 4 incidents per year, 1 arrester damaged per incident, \$700 replacement costs/each, \$5k investigation cost per incident

Alt 3 assumes 4 incidents per year, 2 arresters damaged per incident, \$500 replacement costs/each, \$5k investigation cost per incident

Alt 4 assumes 4 incidents per year, 1 arrester damaged per incident, \$700 replacement costs/each, \$5k investigation cost per incident

Alt 5 assumes \$500/km maintenance costs for 1280 km

FCI battery replacement cost is \$100 every 5 years per 3-ph set, \$50 every 5 years per 1-ph set.

Business Case

Overvoltage Mitigation for Events Caused by Contact Between Transmission and Distribution Conductors



Appendix

B

Risk Analysis

Risk Analysis

BC Hydro Corporate Risk Matrix											
FREQUENCY OF OCCURRENCE (YEARLY)	FREQUENCY OF OCCURRENCE	L9	L8	L7	L6	L5	L4	L3	L2	L1	L0
$f \geq 10^2$	At least 100 times every year	3	4	5	6	6	6	6	6	6	6
$10^1 \leq f < 10^2$	At least 10 times every year	3	3	4	5	6	6	6	6	6	6
$10^0 \leq f < 10^1$	At least once every year	2	3	3	4	5	6	6	6	6	6
$10^{-1} \leq f < 10^0$	At least once every 10 years	2	2	3	3	4	5	6	6	6	6
$10^{-2} \leq f < 10^{-1}$	At least once every 100 years	1	1	2	3	3	4	5	6	6	6
$10^{-3} \leq f < 10^{-2}$	At least once every 1,000 years	1	1	1	2 & 4	2 & 4	ALT3	ALT1	5	6	6
$10^{-4} \leq f < 10^{-3}$	At least once every 10,000 years	1	1	1	2	2	3	3	4	6	6
$10^{-5} \leq f < 10^{-4}$	At least once every 100,000 years	1	1	1	2	2	2	3	4	6	6
$10^{-6} \leq f < 10^{-5}$	At least once every 1,000,000 years	1	1	1	1	2	2	2	3	6	6
$f < 10^{-6}$	Less than once every 1,000,000 years	1	1	1	1	1	ALT5	2	2	6	6
CONSEQUENCE SEVERITY											
		S0	S1	S2	S3	S4	S5	S6	S7		
Safety	Worker	Near Miss	First Aid	Treatment by Medical Professional	Temporary Disability	Permanent Disability	Permanent Disability	Facility	Multiple Facilities		
	Public	None	Near Miss	First Aid	Treatment by Medical Professional	Temporary Disability	Permanent Disability	Facility	Multiple Facilities		
Environmental *		Almost zero impact	Low impact	Moderate impact	Moderate to High impact	High impact	Very high impact	Extreme impact			
	Financial	<\$10K	\$10K to \$100K	\$100K to \$1M	\$1M to \$10M	\$10M to \$100M	\$100M to \$1B	\$1B to \$10B	> \$10B		
Reliability	Supply	None	Limited complaints to company or shareholder	Negative local profile	Small but vocal minority of customers critical	Many customers critical	Loss of trust - strategic change immediately required and/or shareholder	Loss of consent to operate			
	Customer	None	< 5K customer hours lost per event	NA	Require voluntary load reduction	Localized load shedding	Significant load shedding required	ERC load shedding spreads to WECC	50M to 500M customer hours lost per event	> 500M customer hours lost per event	

* Additional criteria available to determine Consequence Severity. Question? Contact BC Hydro Enterprise Risk or visit http://bchydro.com/insights/enterprise_risk_framework.html Date: June 30, 2018

How to interpret the matrix: The columns represent the severity of the consequence associated with the risk, in this case the risk of 60 kV to underbuild contact. The consequences can be related to safety, environmental, financial, reputational or reliability. Here the safety factor is shown as it is the highest risk factor (reputational risk was also evaluated). The rows represent the estimated frequency of occurrence for the indicated consequence. For example, Alternative 1 (ALT1 - Do Nothing) has a consequence of S5 that is estimated to occur once every 1000 years so the frequency is L4. The corresponding cell in the matrix has a risk ranking of four, which is relatively high risk on a scale where one represents the lowest and six represents the highest risk.

Business Case

Overvoltage Mitigation for Events Caused by Contact Between Transmission and Distribution Conductors



Appendix

C

Surge Arrester Testing At Powertech on 20 and 21, August, 2009

SURGE ARRESTER TESTING AT POWERTECH ON 20 AND 21 AUGUST 2009

Prepared by: Mike Wyndham and Raj Dhrochand

Date Revised: 03 March 2010

1. Summary

The tests were split into two separate groups, namely:

- a) Day 1: Short-circuit current tests (in accordance with IEEE C62.11) to simulate the effects of multiple 20 kA reclose operations on the arrester, primarily to confirm if the arrester will remain intact and not fragment.
Note: IEEE C62.11 standard requires only one pressure relief test at arrester's maximum fault current rating.
- b) Day 2: Overvoltage tests to simulate the effects of the 69 kV line making contact with the under-built 25 kV and 12.5 kV lines for multiple reclose operations, and the effects of these over-voltages on secondary equipment (meters, power bars, and LCD computer monitors). This test demonstrates the failure mode and rate (magnitude and time duration) of the surge arresters upon excessive overvoltage stress from a typical 69kV source.

Three manufacturers' arresters, ABB, Cooper and Ohio Brass (Hubbell) were subjected to the above tests. All the station class arresters passed three 20kA short-circuit tests and remained intact during the reclose operations. The station class arresters successfully prevented high over-voltages from being impressed on the secondary side of the distribution transformers. In addition, the surge protected power bars fitted between the electricity meters and the computer monitors protected the latter from failure.

2. Arresters Tested

Table 1 – List of Arrester Types Tested

No	Make	Model	Cat/Style Number	Class	Rating	MCOV	Pressure Relief Class
1	ABB	XPS	Q018SA015A	Station	18 kV	15.3 kV	80 kA rms
2	ABB	XPS-HE	P018SA015A	Station	18 kV	15.3 kV	65 kA rms
3	ABB	XPS	Q009SA008A	Station	9 kV	7.65 kV	80 kA rms
4	Cooper	VariSTAR	UH0180151445A11	Station	18 kV	15.3 kV	80 kA rms
5	Cooper	VariSTAR	UX0180151445A11	Station	18 kV	15.3 kV	80 kA rms
6	Ohio Brass	PVN	314015	Station	18 kV	15.3 kV	80 kA rms
7	Ohio Brass	PVI-LP	300815	Intermediate	18 kV	15.3 kV	40 kA rms
8	Ohio Brass	PDV-100 Optima	213715	Distribution	18 kV	15.3 kV	10 kA rms
9	Ohio Brass	PDV-100 Optima	213708	Distribution	9 kV	7.65 kV	10 kA rms



Figure 1 – Station Class Arresters Used During the Tests

SURGE ARRESTER TESTING AT POWERTECH ON 20 AND 21 AUGUST 2009

3. Meters Tested

Table 2 – List of Meters Tested (left to right of Figure 2)

Meter #	Manufacturer	Type	Design	Ratings
1	Itron Centron	C1S	Solid-state electronic	0.5 – 200 A, 240 V, 1-phase
2	Elster	R1S	Solid-state electronic	1 – 200 A, 240 V, 1-phase
3	iCON Sensus	Isa1	Solid-state electronic	1 – 200 A, 240 V, 1-phase
4	GE Tantalus	i-210	Solid-state electronic	2 – 200 A, 240 V, 1-phase
5	ABB	D5S	Ferraris-disc	2 – 200 A, 240 V, 1-phase



Figure 2 – Meters Subjected to the Over-Voltage Tests

4. Test Sequence and Measured Values

4.1 Short-Circuit Tests



Figure 3 – Test Set-Up for Short Circuit Tests

SURGE ARRESTER TESTING AT POWERTECH ON 20 AND 21 AUGUST 2009

The arresters were pre-failed using low current as required by the test standard and then immediately subjected to the following short-circuit currents:

- a) 20 kA for 400 ms (simulate 69 kV auto-reclose);
- b) 20 kA for 100 ms (simulate 8 kA, 4-shot, auto-reclose of the distribution system); and
- c) 20 kA for 200 ms (simulate a 69 kV manual reclose initiated by the control centre operator).

4.2 Condition of Surge Arresters after Short Circuit Currents.

Test #	Arrester	Ejected Parts Within Enclosure	Pass/Fail
1	ABB, 18 kV, 80 kA	Small piece of housing	Pass
2	Cooper, 18 kV, 80 kA (UX)	Molten Al + pieces of housing	Pass
3	Ohio Brass, 18 kV, 80 kA	Large pieces of housing	Pass
4	ABB, 18 kV, 65 kA	Small pieces of housing	Pass
5	Cooper, 18 kV, 80 kA (UH)	Large pieces of housing	Pass
6	Ohio Brass, 18 kV, 40 kA	Failed catastrophically. Large piece outside enclosure	Fail
7	Ohio Brass, 9 kV, 10 kA	Failed. Line lead blown clear	Fail

Note: Only test #6 resulted in a large piece of housing being ejected outside of the wooden enclosure.

4.3 Over-Voltage Tests

The initial tests were conducted with the station class arresters in parallel with the distribution class arresters. Only two computer monitors were connected to the secondary side as shown in **Figure 4**. The series of final tests were conducted with only the distribution class arresters in circuit and with five computer monitors connected to each of the meters.

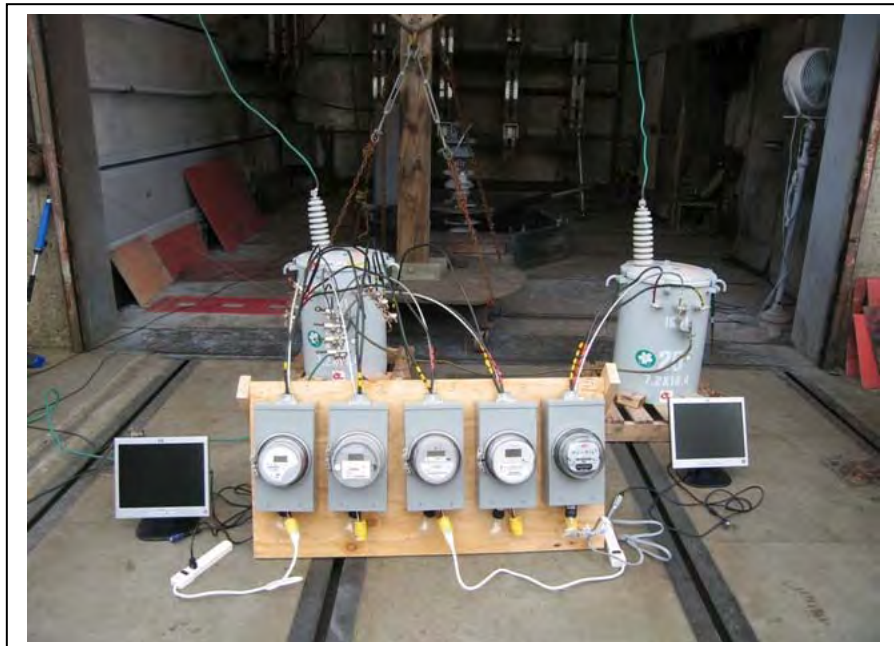


Figure 4 – Initial Test Set-Up for Over-Voltage Tests

SURGE ARRESTER TESTING AT POWERTECH ON 20 AND 21 AUGUST 2009



Figure 5 – Final Test Set-Up for Over-Voltage Tests

The arresters (which were not pre-failed) and secondary equipment were subjected to the following over-voltages, applied to the primary side of the distribution transformers:

- a) 42 kV for 200 ms (simulate 1st 69 kV fault and line trip);
- b) 42 kV for 200 ms (simulate 69 kV auto-reclose); and
- c) 42 kV for 200 ms (simulate a 69 kV manual reclose initiated by the control centre operator).

Note: The applied primary over-voltage value of 42 kV = $(69 \text{ kV}/\sqrt{3}) \times 1.05$. The additional 5% allows for voltage fluctuations caused by sudden load shedding and allows for tap changer operations.

4.4 Measured Values During Over-Voltage (OV) Tests

Test #	Arrester	Secondary Peak Voltage (SV) and Duration of Peak Voltage(D)						Extent of Damage to Secondary Equipment
		OV1-SV	OV1-D	OV2-SV	OV2-D	OV3-SV	OV3-D	
1 ⁽¹⁾	Ohio Brass, 18 kV, 40 kA	280 V	6.05ms	N/A	N/A	N/A	N/A	No damage
2 ⁽¹⁾	Ohio Brass, 18 kV, 80 kA	322 V	16.6ms	102 V	-(⁴)	108 V	-(⁴)	No damage
3 ⁽¹⁾	ABB, 18 kV, 65 kA	274 V	9.45ms	22 V	-(⁴)	27.5 V	-(⁴)	No damage
4 ⁽¹⁾	Cooper, 18 kV, 80 kA (UH)	293 V	8.8ms	28 V	-(⁴)	25 V	-(⁴)	No damage
5 ⁽²⁾	Ohio Brass, 9 kV, 80 kA	293 V	4.0ms	171 V	-(⁴)	161 V	-(⁴)	No damage
6 ⁽²⁾	ABB, 9 kV, 80 kA	288 V	3.7ms	31 V	-(⁴)	25 V	-(⁴)	No damage
7 ⁽²⁾	Cooper, 9 kV, 80 kA (UH)	311 V	5.0ms	43 V	-(⁴)	27 V	-(⁴)	No damage
8 ⁽³⁾	Ohio Brass, 9 kV, 10 kA	323 V	3.0ms	N/A	N/A	N/A	N/A	Monster power bar
9 ⁽³⁾	Ohio Brass, 9 kV, 10 kA	302 V	1.9ms	N/A	N/A	N/A	N/A	None
10 ⁽³⁾	Ohio Brass, 9 kV, 10 kA	300 V	1.2ms	N/A	N/A	N/A	N/A	Belkin power bar failed
11 ⁽³⁾	No arresters	340 V	41.5ms	N/A	N/A	N/A	N/A	Refer to 5.2 c)

- Note**
1. Test conducted in parallel with 18 kV Ohio Brass PDV-100 Optima distribution arresters. Two LCD computer monitors connected to the secondary, namely one to meter 1 via Belkin surge-protected power bar and the other directly connected to meter 5.
 2. Test conducted in parallel with 9 kV Ohio Brass PDV-100 Optima distribution arresters. Two LCD computer monitors were connected to the secondary, namely one monitor to meter 1 via Belkin surge-protected power bar and the other directly connected to meter 5.
 3. Tests conducted with three 9 kV distribution class arresters connected in parallel on the primary side of the distribution transformers. Five LCD computer monitors were connected to each of the meters via various types of surge-protected power bars, except for the Ferraris-disc meter 5, which had a direct connection.
 4. Duration of over-voltage is negligible and was not formally recorded.

SURGE ARRESTER TESTING AT POWERTECH ON 20 AND 21 AUGUST 2009

5. Observations and Analyses

5.1 Short-Circuit Tests

a) Compliance with IEEE Standard

Each station class arrester met the requirements of IEEE C62.11 as:

- i) there was no violent shattering;
- ii) no parts of the arrester were found outside the enclosure (up to 60 g permitted); and
- iii) the arrester self-extinguished open flames within 2 min after the end of the test.

b) Extent of Damage (Dependent on Housing Design)

The pre-failing procedure produced more “damage” (swelling and distortion) to the composite housing material on the Ohio Brass and Cooper arresters. The ABB arresters showed the least amount of “damage”. Hence, the ABB arresters performed better after the short-circuit tests in terms of the extent of damage to the composite housing and the volume of ejected parts.

5.2 Over-Voltage Tests

a) Speed of Operation of Station Class Compared to Distribution Class

When the distribution class arresters of the same voltage ratings were installed in parallel with the station class arresters with higher energy capabilities, the station class arresters still failed first thermally into a short circuit mode. This is attributed to the station class arrester having a lower protective characteristic than the distribution class so that it absorbed the majority of the voltage suppression current duties.

b) Effectiveness of Station Class Arresters

Based on the over-voltage magnitude and operating times, station class surge arresters were highly effective in limiting the temporary (less than one cycle) over-voltages of transmission system contacts on the customer side of the transformer. The station class arresters limited the duration of the overvoltage on the secondary side of the transformer proportionally to the arrester protective level for less than once cycle and near 20 to 30 V (peak) thereafter on the first contact with transmission voltage. After the first contact, no further over-voltages are created on the secondary of the transformer regardless of the number of contacts that might occur.

NOTE: Station class arresters are not equipped with a self-disconnecting device to isolate the arrester after a failure. The failed arrester must be manually disconnected.

c) Extent of Damage to Electronics after Each 69 kV Contact with Three Distribution Arresters in Parallel

- i) After the first distribution arrester operated, the Monster power bar failed.
- ii) After the second distribution arrester operated, no meter, power bar or LCD monitor failed.
- iii) After the third distribution arrester operated, the Belkin power bar failed.

NOTE: The distribution arresters are equipped with a self-disconnecting device to isolate the arrester after failure. In practice, with parallel connections the arrester closest to the transmission contact is expected to fail with each successive contact.

d) Extent of Damage to Electronics without Surge Arresters on the Primary side of the Transformer

The final test was undertaken with no primary arresters. The short-circuit current was reduced to 1 kA for five cycles on the primary side. The outcome of the test was as follows:

- i) Cut-out operated protecting the transformer on the left of **Figure 5**.
- ii) Internal fault detector operated on the transformer on the left of **Figure 5**.
- iii) Electronic iCON meter and meter base cover blew out (third meter from left).
- iv) Electronic GE Tantalus meter failed internally (fourth meter from left).
- v) All power bars with surge protection failed.
- vi) LCD monitor connected to Ferraris-disc meter (on extreme right of **Figure 5**) failed.
- vii) Filament in the incandescent lamp connected to Ferraris-disc meter (on extreme right of **Figure 5**) was open-circuited.

SURGE ARRESTER TESTING AT POWERTECH ON 20 AND 21 AUGUST 2009

6. Recommendations

- 6.1 Install station class arresters on all under-built circuits, with one set between switching/isolation points.
- 6.2 If the switching points are more than 2 km apart and there are distribution transformers or cable dips within these points, install station class arresters every 2 km.
- 6.3 Install the arresters at poles without equipment to minimise collateral damage to adjacent equipment, due to relatively large space of hot ionized gases (plasma) around the failed arrester and short-duration fire.
- 6.4 Wire appropriately sized leads to the arresters, to withstand the short-circuit currents and/or match the size of the overhead line conductors.
- 6.5 Specify the same voltage rating for station class arresters as existing distribution class arresters, as station class operate first when connected in parallel to the distribution class arresters
- 6.6 Do not apply secondary arresters as it is not necessary and impracticable, in terms of locating, removing and replacing large numbers of these arresters.
- 6.7 Fit Faulted Circuit Indicators to each lead to the arrester to provide a visible indication of a failed arrester, which requires removal and replacement, following a contact incident.
- 6.8 Make customers aware of the need to fit surge-protected power bars to protect their sensitive electronic devices.

Annex – List of Equipment Used

Equipment	Make and Model	Technical Information
Monitors	Hewlett Packard 20555 SH249 L1502, Model No. PE1234, product No. P9617D	Flat panel monitor, input voltage: 100-240 V, 50-60 Hz
Transformers	Cam Tran Co Ltd NKCA900-20	Dual voltage 14,400/7,200 V; 120/240 V; 25 kVA; Z = 1.8 %
Power bars	Belkin Surge Master F5 CO47tt2PK	312 J
	Monster PowerProtect AV600 SurgeGuard	420 J
	Monster Digital Power Center 700	2,160 J, audible alarm to notify failure/operation
	Powertap 31F8, Model DX-D111	Unknown