Evolution of Application Considerations for BC Hydro 500 kV Line Protections

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Abstract

This paper summarizes the major application considerations for BC Hydro 500 kV line protections, with an emphasis on how these protection requirements are realised on a modern multifunction distance relay. It reviews BC Hydro 500 kV transmission line protection principles in several major aspects, such as line tripping, automatic reclose, pole disagreement, breaker failure, alarms, etc. This paper will then highlight the implementations of these protection requirements into a multifunction distance relay, with detailed descriptions and logic diagrams.

Finally there will be brief discussions on some special protection applications for several 500 kV lines, where there are three line circuit breakers, series capacitors, lines with submarine cables, etc.

I. INTRODUCTION

A. BC Hydro 500 KV System

The BC Hydro high-voltage transmission system consists of 18,286 kilometres of transmission lines, operating at voltages from 60 kV to 500 kV. The transmission network includes 33 wholely owned 500 kV circuits and three 500 kV interconnections with other utilities.

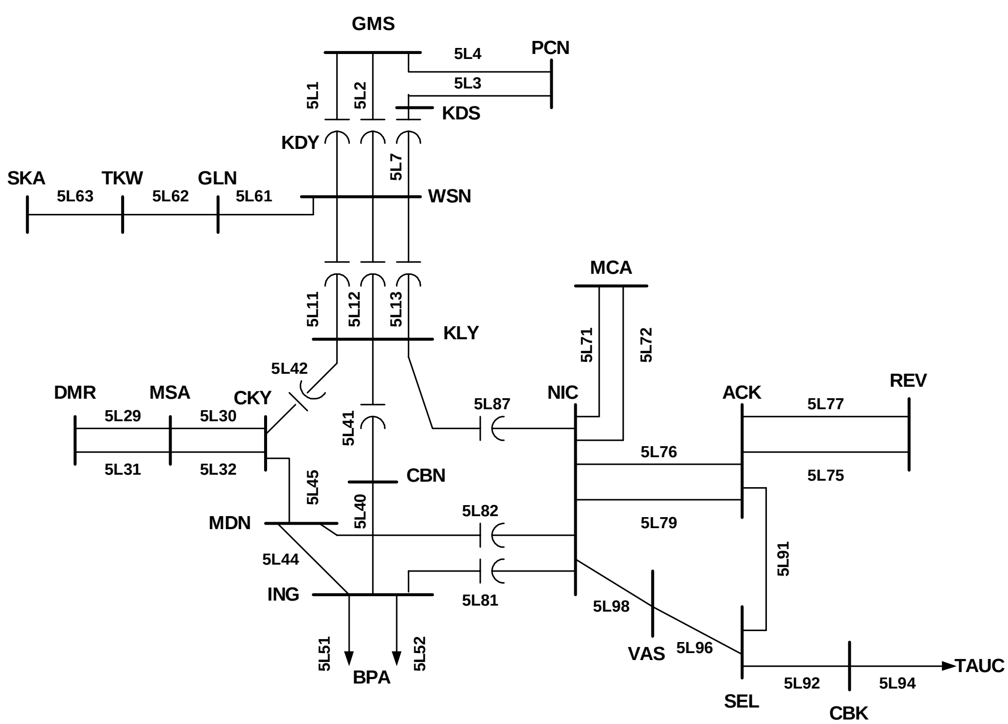

Fig. 1. BC Hydro 500 kV system

The BC Hydro 500 kV bulk transmission network connects the major generators in the Northern and South Interior regions of the province with the major load centres in heavily populated southwest B.C.

Previous WPRC papers have described some of the special problems encountered on some circuits and been solved with the first protection systems applied to circuits 5L61, 5L62 and 5L63 [1], and circuits 5L71, 5L72, 5L81 and 5L82 [2].

The BC transmission system is interconnected to Alberta by two 138-kV lines and one 500-kV line and to the United States by two 500-kV and two 230-kV lines.

B. BC Hydro 500 kV System Protection Replacement Program

The majority of the B.C. 500 kV transmission system was built in the 1960's and 1980's, and is reaching the limits of its capability in many areas, including its protection system. From the late 1990's, BC hydro began to replace the existing electromechanical relays on its 500 kV lines by microprocessor-based relays. In the first few years of the replacement, several single function digital relays were used to realize different functions in line protection, such as distance protection, reclose protection, breaker failure protection, etc. Since 2001, BC Hydro began to use a new type of multifunction distance relay and have applied it on nineteen of its 500 kV transmission lines.

C. Focus of Present Paper

The present paper is focused on the application considerations of multifunction distance relays on these 500 kV lines. It describes first some common protection functions, which are applied to almost all the 500 kV lines. These common protection requirements define the 500 kV lines trip and reclose operation modes, the protection system operation speed and their sensitivity for various kind of faults on the lines. Breaker failure protections and stub line protection are briefly introduced. Three specially designed pole disagreement protections, which are applied on all the 500 kV lines, are described in detail. Then, some special protection functions are discussed for their applications on selected 500 kV lines. These protection systems with special functions include the protection of a line terminal with three circuit breakers, lines with or near series capacitors and lines with submarine cables. Finally, some other considerations for the protections on several 500 kV lines are briefly mentioned.

II. COMMON PROTECTION REQUIREMENTS

For all these BC Hydro 500 kV transmission lines, the line protection consists of identical primary and standby systems (excepting minor setting differences between systems). Use of identical primary and standby protection systems result in increased security as well as lower costs. Dependability concerns due to common mode principle failure are addressed by extensive model power system tests for each unique application [3, 4]. Some common protection requirements are detailed in the following paragraphs.

A. Trip / Reclose Modes

Many of the applications require single phase tripping and reclosing (SPTR) for single line to ground faults (SLG faults), and three phase tripping (3PT) and reclose for multi phase faults. Specifically when SPTR is applied, the following five trip / reclose modes are provided:

Mode 1:
- Any Fault => 3 Phases Trip => No reclose

Mode 2:
- Any Fault => 3 Phases Trip => Reclose Only SLG Fault

Mode 3:
- Any Fault => 3 Phases Trip => 3 Phases Reclose

Mode 4:

- SLG Fault => Single Phase Trip => Single Phase Reclose
- Other Faults => 3 Phases Trip, No Reclose

Mode 5:

- SLG Fault => Single Phase Trip => Single Phase Reclose
- Other Faults => 3 Phases Trip => 3 Phases Reclose

The protection systems are normally operated in Mode 5, but the other modes may be applicable in certain circumstances. Furthermore, automatic reclose is blocked if the trip or transfer trip is initiated from the following protection functions:

- Breaker failure protection
- Pole disagreement protection
- System overvoltage protection
- Time delayed channel independent ground overcurrent protection or phase distance protection
- Switch on to fault (SOTF)
- Line open-end keying
- Other special protection functions for some lines

B. Speed / Sensitivity

The mandatory requirements for the relay scheme's maximum operating times, including communication time (if applicable), are as follows:

Fault Type	**Ground Resistance**	**Speed**	**Fault Location**
Multi phase	NA	1 cy	< 25% from line terminal.
Multi phase	NA	2 cy	> 25% from line terminal
SLG	0 – 50 Ω	2 cy	0-100% line
SLG	50 – 100 Ω	4 – 5 cy	0-100% line
SLG	100 – 200 Ω	7 cy	0-100% line
SLG	200 – 300 Ω	20 cy	0-100% line

The above speed / sensitivity requirements are also applicable when the system is weak or opens at one line terminal.

Note that BC Hydro has unusually stringent requirements for sensitivity. These are due to the lack of shield wires on the transmission circuits and high tower footing resistances. When SPTR is applied, the requirement for correct phase selection and tripping applies to SLG faults with 300 ohms or more.

C. Breaker Failure Protection

In BC Hydro applications, breaker failure protection is aimed at failure to interrupt fault current. It is initiated by all protective zones on either side of the circuit breaker (i.e., lines, buses, transformers, and reactors, etc.). It trips the adjacent protection zones and sends direct transfer trip to the remote terminals of the affected lines.

D. Stub Line Protection

Stub line protection is required for some line terminals where the voltage transformers are located on the line side of the line disconnect switches.

E. Pole Disagreement Protection

Pole disagreement may happen when a circuit breaker closes or opens. Usually, pole discordance logic is used to detect pole disagreement by comparing the status of circuit breaker auxiliary contacts in each phase. Circuit breaker main contacts are connected by insulating rods to the operating mechanism. However, discordance logic based on auxiliary switches may fail to identify a presence of pole disagreement in the event of a broken connection between the operating mechanism and the main contacts. Such failures did happen on BC Hydro 500 kV circuit breakers. In more than one case the sustained unbalance current flowing due to undetected pole disagreement resulted in unexpected and undesirable operation of the sensitive ground fault protection mentioned in Section II.B above. Thus, more sophisticated pole disagreement protections are required to be realized on new 500 kV line protections even though discordance relays are also applied on circuit breaker control.

F. Open Terminal Transfer Trip Keying

The long EHV circuits on the BC Hydro system result in significant levels of voltage rise on the open terminal when one terminal of a line is opened (due to the large amount of line capacitance). To reduce the duration of the overvoltage, the remote terminal of an EHV circuit is usually automatically opened when one end is manually opened. The line protection applications are configured to provide this automatic opening of the other end when one terminal is opened under no-fault conditions.

III. REALIZATION OF THE COMMON PROTECTION REQUIREMENTS

BC Hydro uses one type of modern multifunction transmission line protection system to realize its new line protections. This system has ultra-high-speed (subcycle) operation elements and protection logic processors. By carefully applying these protection elements and user designed logics, the new line protections satisfy the above mentioned common protection requirements.

A. Trip Elements

As described in section II, five trip / reclose modes are required for the protection system. A four position selector switch is used to select the trip / reclose modes 2 to 5, This switch asserts one of four discrete inputs of the relay. A separate switch is connected to a fifth discrete relay input. This second switch is used for the trip / reclose mode 1 to control automatic reclose ON/OFF.

Appropriate relay elements are chosen for the implementation of various internal trip logics, such as unconditional trip, direct trip / direct transfer trip, switch-onto-fault trip as well as communications-assisted trip, etc. The details of the definitions of these trip elements are explained below.

1. Unconditional trip

The unconditional trip logic determines which elements trip unconditionally. These unconditional trip elements are user defined as shown in the logic diagram of Figure 2.

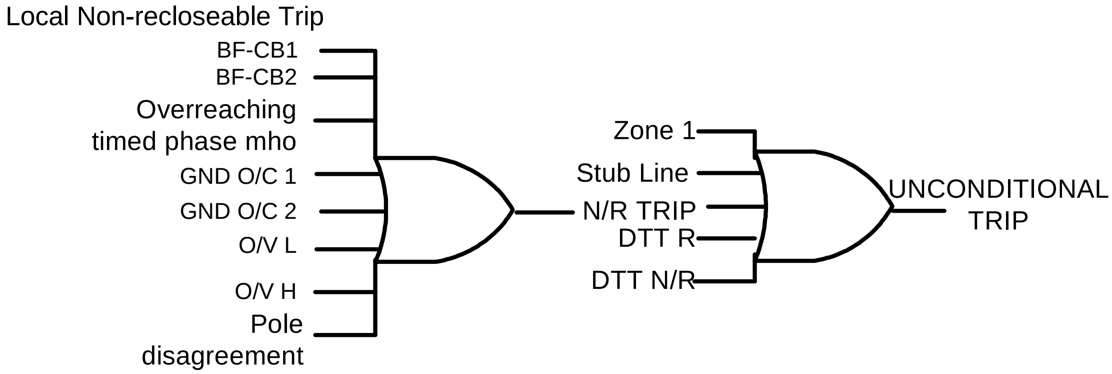

Fig. 2. Unconditional Trip Logic

The instantaneous zone 1 trip consists of zone 1 Mho phase element and ground distance element which are usually set at about 80% of line impedance. The overreaching timed phase mho reach is usually set at about 150% of the line impedance. Note that as discussed in Section III.A.2 (following), this is not the same mho element that is used in the permissive overreaching transfer trip logic. In fact, the forward looking Zone 4 element in the multifunction relay is used for the typical timed Zone 2 application. Direct tripping timed overreaching ground distance elements are not used, because of the difficulty of coordinating with ground time overcurrent functions on other nearby circuits.

For some line terminals where the voltage transformers are located on the line side of the line disconnect switches, stub line protection are applied which are initiated from phase current detection while the relative line switches are open.

Internal breaker failure (BF) functions are used to realize BF protections. Local line terminal breaker failures initiate non-reclosable three phase trip (N/R trip). N/R trip is also caused by some slower protection elements, such as overreaching, time delayed phase Mho distance element or channel independent ground time overcurrent elements (GND O/C 1 and GND O/C 2). The trip caused by these slower protection elements usually means the failure of communication channel. Over-voltages (O/V) on the protected line trip the line with different time delays for low or high O/V limit (O/V L/H). For operation and maintenance purpose, three kinds of pole disagreement protections have been developed in the new 500 kV line protections and are described later. One of the pole disagreement protections initiates a N/R trip.

Unconditional Trip may also be initiated by Direct Transfer Trips (DTT) from remote terminal. DTT are segregated into two types: the first one will not block auto-reclose of the line (DTT-R) while another will block auto-reclose of the line (DTT-N/R). A non-reclosable three phase transfer trip (DTT–N/R) is initiated whenever the terminal is opened manually, or a local non-reclosable three phase trip (N/R Trip) described above activates.

2. Communications-Assisted Trip

Permissive Overreaching Transfer Tripping (POTT) with echo logic scheme is used in all the 500 kV lines. The communications-assisted trip is initiated first, as shown in Figure 3, by zone 2 Mho phase and ground distance elements. It should be noted that these zone 2 elements are usually set much longer than the conventional 125%-150% of the protected line impedance. Typically, the minimum setting is 200% of the protected line impedance and on shorter lines, the reach may be increased to several multiples of the line impedance. Such long reaches are used to improve the speed of response of digital distance measurement. Load blinding features are applied where necessary to make these elements immune to load or satisfy the North American Electric Reliability Corporation (NERC) loadability requirements.

To detect high impedance SLG, residual and negative sequence directional overcurrent elements are also used to initiate the communications-assisted trip. To avoid mis-operation of these sensitive overcurrent elements caused by unbalances after single phase open (SPO), these elements are cut off at the instant of single phase trip (SPT) or during single phase open. Tripping by these sensitive elements may also be delayed slightly for extra security.

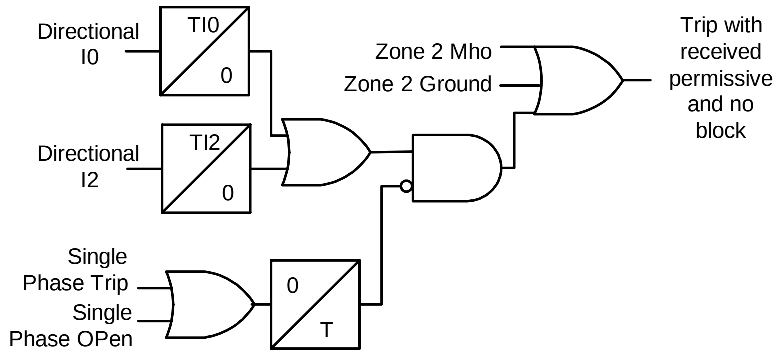

Fig. 3. Communications-Assisted Trip Initiation

A permissive trip is sent to the remote terminal when the permissive trip output of Figure 3 is initiated and the current reversal blocking logic is not asserted. This will activate the relay internal KEY element.

Furthermore, undelayed, sensitive residual and negative sequence directional overcurrent elements (Directional I2/I0) also send a permissive trip signal. Undelayed keying of permissive trip by the sensitive elements helps accelerate clearing of all unbalanced faults whether or not they are high impedance. These sensitive overcurrent elements are supervised by the same current reversal logic that supervises the permissive trip output of Figure 3.

A permissive trip signal is also keyed by any local three phase trip. This allows faster permissive tripping at the remote terminal than would be achieved by the direct transfer trip function that usually has a small security delay included.

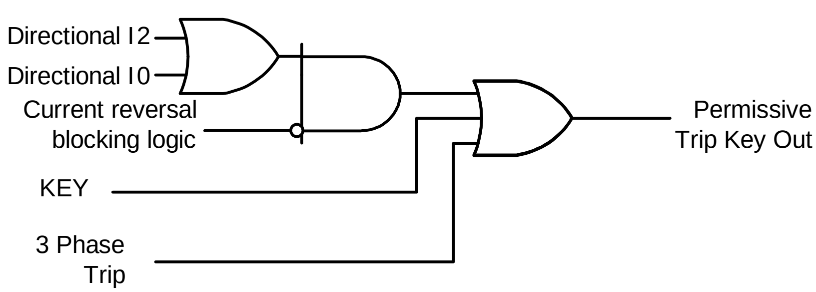

Fig. 4. Permissive Trip Send

Conventional POTT echo logic [5] is also always applied to improve the sensitivity for high resistance SLG faults that might be sensed at one terminal but not at the other. Due to the ratio of current contributions from one end to the other for fault not at the electrical centre, one terminal is often not able to detect high resistance faults and is thus considered “weak”.

3. Switch on to Fault Trip

Switch on to fault (SOTF) protection is used to trip a line terminal when a faulted line is energized. The specific trip elements are shown in Figure 5. They consist of the same Zone 4 elements that are used for timed overreaching protection as discussed in Section III.A.1. In the SOTF application, the phase distance elements are not time delayed as in the unconditional tripping application. As is normally the case for protection with line connected voltage transformers, special attention is paid to close-in three phase faults where the polarizing voltage may be too low for dependable operation of a directional distance element. Phase over-current functions (Ph. O/C) is also used to initiate the SOTF trip for close-in three phase faults. This over-current element is supervised by an undervoltage element (U/V SUPN) to allow the setting to be applied without concern about loadability. NERC regulations allow SOTF current detectors to be set independent of loadability considerations as long as they are supervised by voltage detectors set lower than 70% of nominal voltage [7].

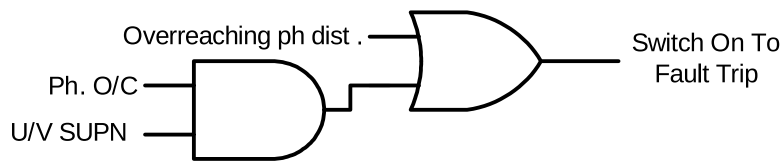

Fig. 5. Switch on to Fault Trip

4. Phase Segregated Direct Transfer Trip

As shown in Figure 6, whenever there is a single phase trip at one line terminal, a phase segregated direct transfer trip will be sent to the remote terminal and trips the remote terminal. This is an important supplement to minimize the operating time of the protection at the remote terminal that may not be sensitive enough to operate for a resistive SLG fault near the local terminal. In such cases the POTT echo function allows the stronger terminal to trip and the phase segregated direct transfer trip clears the weaker terminal without having to rely on sequential sensing of the resistive fault.

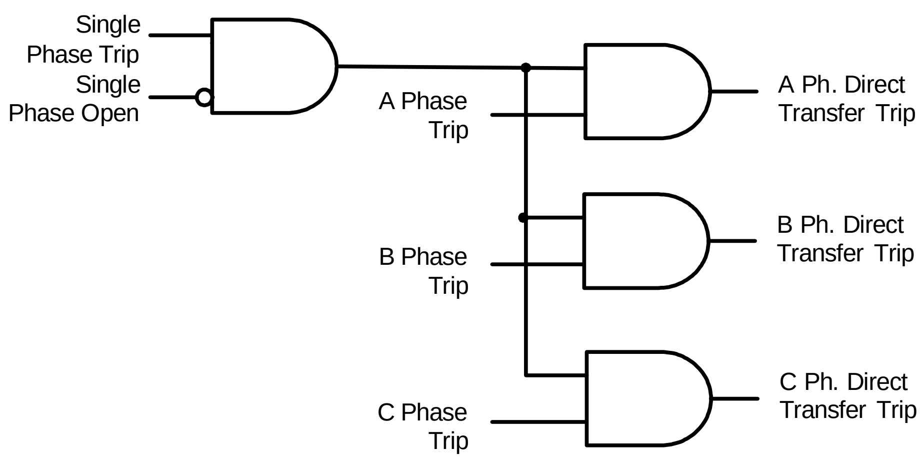

Fig. 6 Direct Transfer Trip

5. Phase Segregated Direct Trip

In order to ensure phase segregated tripping under conditions of high load and high fault resistance, the manufacturer's built-in phase selection logic is supplemented with additional custom logic. As shown in Figure 7, negative sequence and zero sequence directional over-current elements are used with internally derived faulted phase selection logic to provide phase selective tripping. This custom logic provides phase selective tripping even under heavy load conditions that might have otherwise caused a multiphase fault to have been declared.

As shown in Figure 7, the phase segregated received direct transfer trip also initiates a local phase selective trip.

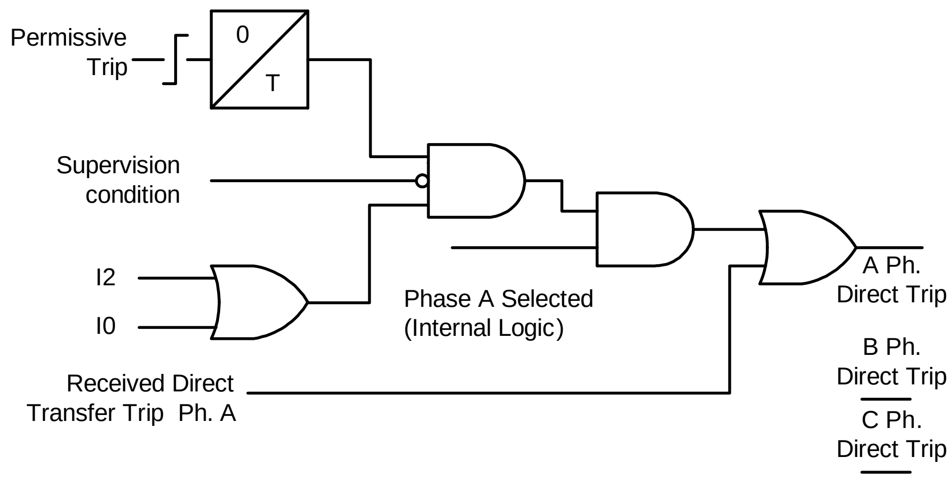

Fig. 7. Direct Trip

6. Non-reclosable Three Phase Direct Transfer Trip

A line terminal will send to remote terminal a non-reclosable three phase transfer trip whenever the terminal opens (as noted in Section II.F) or a local non-reclosable three phase trip (described in the trip logic shown in Figure 2) activates.

B. Reclose Control

As described in section III.A, two switches provide the reclose mode and ON/OFF controls.

BC Hydro uses the internal auto-reclose scheme of the multifunction line protection system to realize the reclose control for its 500 kV lines. The dedicated but complex internal auto-reclose scheme provides the base to design the specific reclose control. Many logic equations in the auto-reclose scheme are carefully user programmed, such as the equations for single-phase / three-phase enable, lead / follow breaker choice, unlatch of breakers, reclose supervisions and reclose drive to lockout, etc.

As an example, Figure 8 describes the user programmed logic for recloser drive to lockout. When the relay receives a local non-reclosable three phase trip (N/R Trip) or a remote non-reclosable transfer trip (N/R TT), it will drive reclose to lockout. The logic also demonstrates the conditions to drive reclose to lockout in different A/R modes. In A/R mode 1, there is no auto-reclose for any fault. For A/R mode 2, a multiphase fault in the protected line will drive auto-reclose to lockout. For A/R mode 4, a multiphase fault in the protected line will lead to 3PT and drive auto-reclose to lockout.

It should be noted that, many of the auto-reclose functions are manufacturer pre-determined. The protection engineer should look into these functions carefully to determine any need for additional user-defined logic for specific applications. For example, in Figure 8, a special user-defined logic is added when relay works on A/R mode 5. This is due to the need to drive auto-reclose to lockout when an evolving fault happens during single-phase reclose reclaim period (after the close order has been issued, but before the reclose cycle has reset).

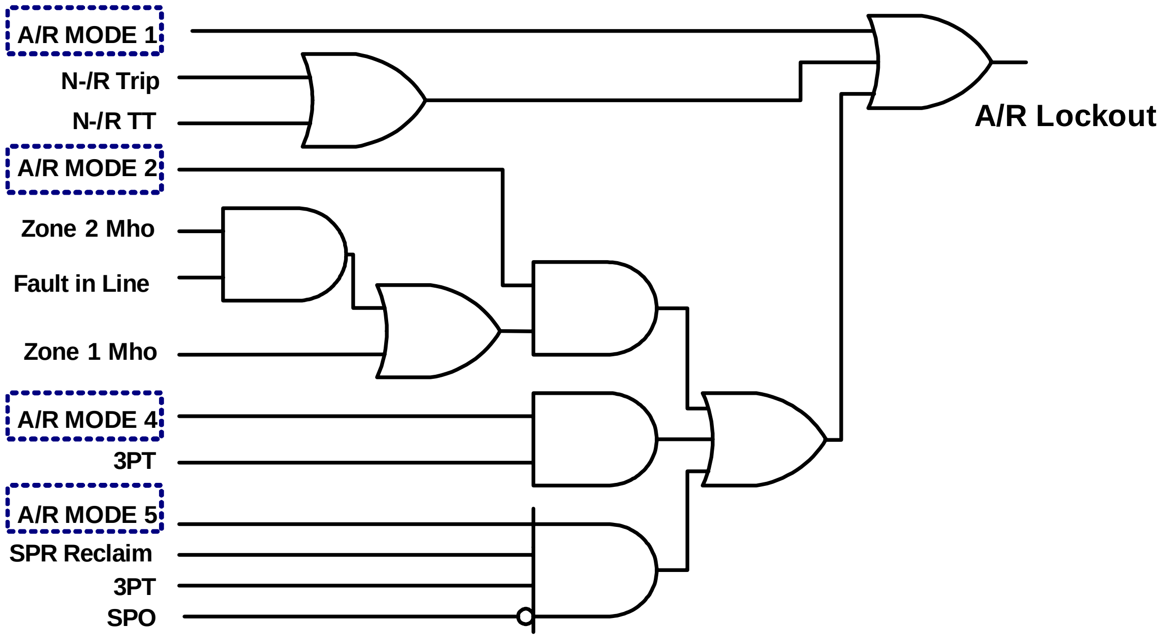

Fig. 8 Auto-Reclose Lockout

BC Hydro also follows certain specific philosophies in the initiation and blocking of automatic reclose. All functions that trip the line terminal will initiate reclose (even the non-recloseable trip functions). In addition to initiating reclose, the non-recloseable functions will also lockout the reclose function. The reasoning behind this logic is for simplicity, to avoid the need to discriminate between reclose initiation functions. It is considered that if a non recloseable trip signal is present to initiate reclose in the digital logic, the same signal will also drive the recloser to lockout reliably through the same digital logic.

Since the automatic reclosing function is important to the reliability of the transmission system, it is implemented in both the primary and standby protections. However to avoid the possibility of two independent close signals causing a problem, if the primary reclose function is in a reclose cycle, it will drive the standby reclose function to lockout. If the primary protection is not working then its reclose function will also not be working and the reclose function in the standby protection will operate to maintain the reliability of the transmission network. This “drive to lockout” feature from the primary to standby protection is one of the few differences in settings between the primary and standby protections.

C. Pole Disagreement Protections

As described in section II, pole disagreement protections are required for BC Hydro’s 500 kV lines. Special logic functions are designed to detect pole disagreement and to realize three kinds of pole disagreement protections.

1. Detection of Pole Disagreement

Each terminal of BC Hydro’s 500 kV lines is usually connected to two circuit breakers (CB1 and CB2). For pole disagreement detection, special protection and automation logic is user designed as shown in Figure 9. To detect a pole disagreement on any circuit breaker, several conditions should be satisfied. First, the relay should detect a loss of current in at least one pole of that circuit breaker. Then, there should be enough zero sequence current passing the circuit breaker. That means the loss of phase current is not caused by all three poles open or low load. Also, the relay should not detect any line phase is open and system voltage is normal. That shows that the loss of phase current is not caused by a line fault. When all these conditions are satisfied and after a short time delay, pole disagreement is declared. The short time delay T1 should be coordinated longer than the time between auto reclose of the first and second breakers on the line terminal to avoid undesired operation during single phase reclose before both breakers are reclosed.

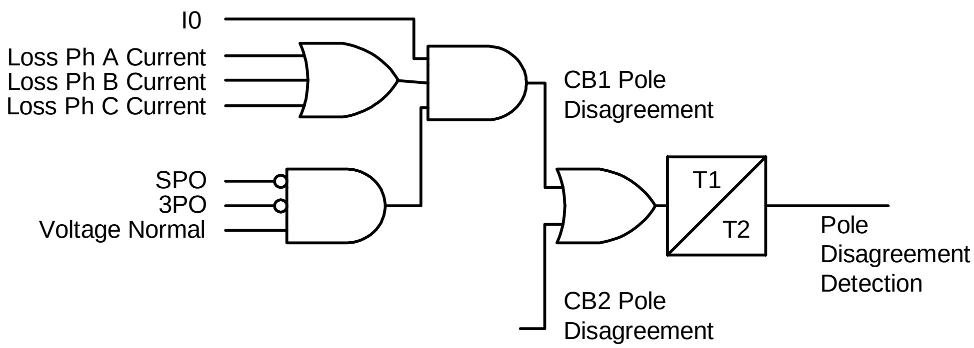

Fig. 9 Pole Disagreement Detection

This pole disagreement detection logic is applied to three applications of pole disagreement protections described in the following section.

2. Pole Disagreement Protections

Three applications of pole disagreement protections are applied on BC Hydro's 500 kV lines.

The first application is for a normally "closed" line terminal. This is the case when pole disagreement is declared while the two line circuit breakers are supposed to be "closed" according to auxiliary switch position indication. In this situation, an alarm is sent out 2 seconds after the pole disagreement declaration. The logic diagram is shown in Figure 10.

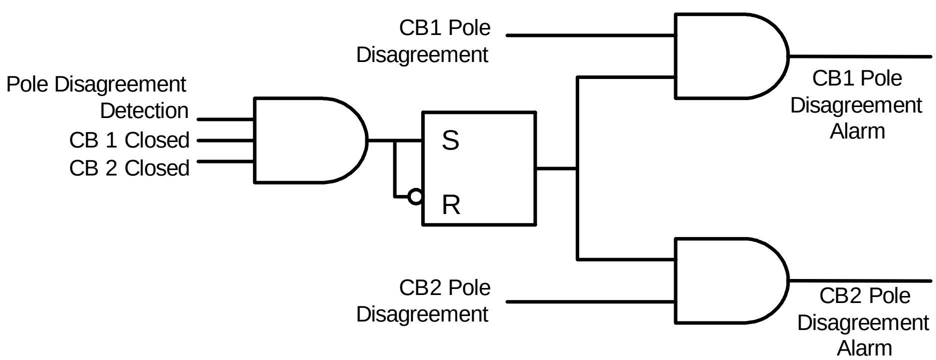

Fig. 10 Pole Disagreement Protection 1

The second application is applied after a single pole auto-reclose (SPR). As shown in Figure 11, during the SPR reclaim period, pole disagreement on any circuit breaker will lead to its three phase trip. This provides fast three phase tripping of a breaker which fails to reclose a single open phase.

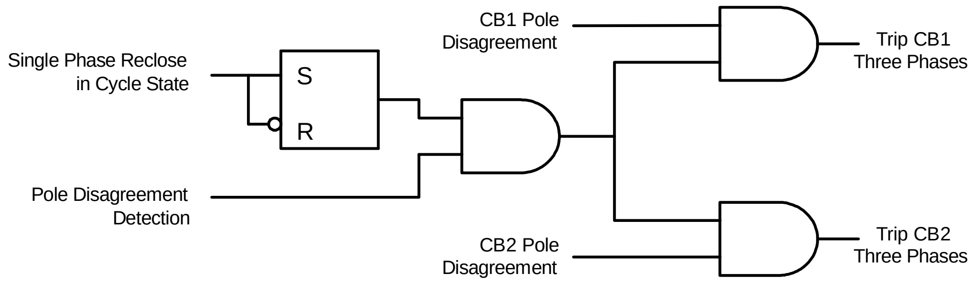

Fig. 11 Pole Disagreement Protection 2

Figure 12 shows the third application of pole disagreement protection. When one circuit breaker has just been opened and pole disagreement is declared for another circuit breaker, we trip three phases of the line and send non-reclosable DTT to remote terminal.

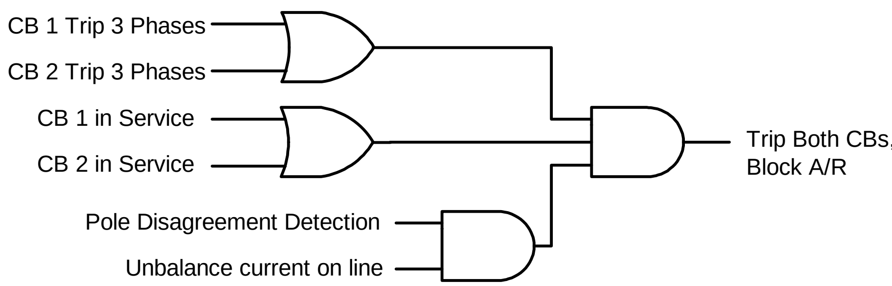

Fig. 12 Pole Disagreement Protection 3

IV. REALIZATION OF SOME SPECIAL PROTECTION REQUIREMENTS

During last six years, protections have been replaced on nineteen BC Hydro 500 kV lines using the multifunction distance relay. Some of the lines presented some special protection challenges in addition to the above-mentioned common requirements. These special cases include line terminals with three circuit breakers, lines with or near series capacitors, etc.

A. Protections of Line Terminal With Three Circuit Breakers

BC Hydro 500 kV Lines with three circuit breakers connected on each line are indicated in Figure 13.

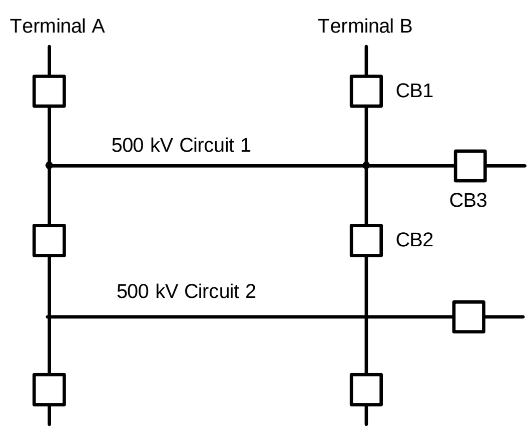

Fig. 13 Line Terminal with Three Circuit Breakers

Internally, the multifunction distance relay used by BC Hydro is designed for two circuit breakers application. In case with three circuit breakers, at terminal B, circuit breaker CB1 is assigned as first breaker for auto-reclose and CB2 second one. Their trip and reclose controls are realized in the multifunction distance relay by a way similar to other line breakers mentioned above. For the third circuit breaker, CB3 here, the control of its trip and reclose are user defined and carefully programmed.

Figure14 and Figure 15 show the user programmed trip logic and reclose logic for CB3. First, it is tripped whenever the relay issues an internal trip. It will also be tripped when the auto-reclose of both CB1 and CB2 are locked out. CB3 will also be three phase tripped if its reclose is not successful ten cycles after receiving a reclose order. If a fault occurs within nine seconds after CB3 is closed and the line switch closed, CB3 will be three phase tripped without auto-reclose. CB3 is usually auto-reclosed with the second circuit breaker CB2.

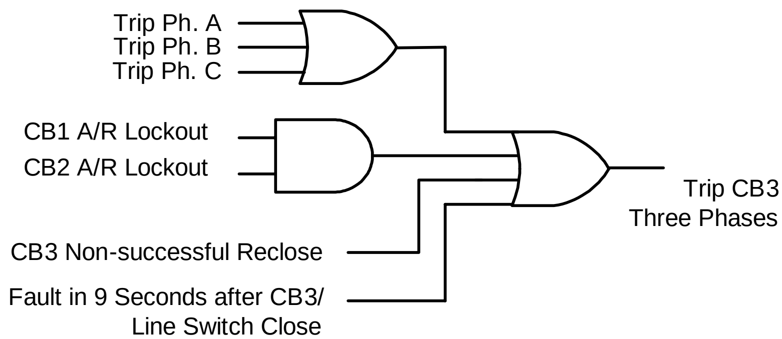

Fig. 14 Third Circuit Breaker Trip Control

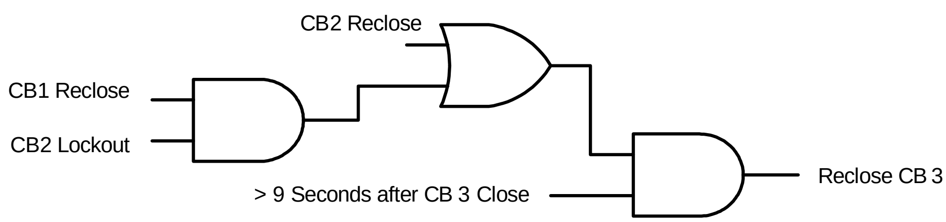

Fig. 15 Third Circuit Breaker Reclose Control

B. Protections of Lines With or Near Series Capacitors

Series compensations are applied on several BC Hydro 500 kV lines. This section will discuss the protections of two lines, one has series capacitor on it, and another is near to series capacitor.

1. Line With Series Capacitors

One of BC Hydro's 500 kV lines is compensated by series capacitors as shown in Figure 16. Capacitive reactance Xc is 51% of line impedance ZL. The capacitor bank is located at one third of the line distance from Terminal B. To prevent damage caused by overvoltages resulting from fault current, metal oxide varistors (MOVs) bypass protection is applied to the series capacitors.

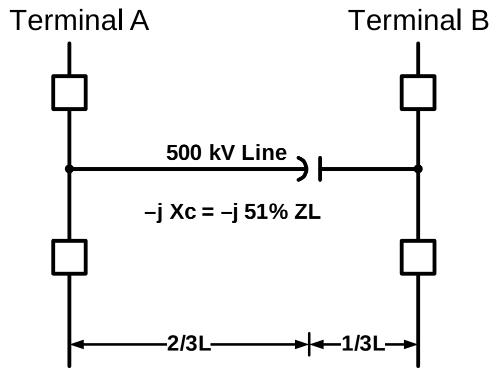

Fig. 16 Line with Series Capacitor

Since the capacitive reactance is in series with the transmission line inductive reactance, one of the protection problems is distance relay overreach. Generally, to overcome the overreach problem, internal series compensation logic provided in the relay may be used, or zone 1 settings at both line terminals may be reduced. From model power system tests of this line, it is found that using built-in logic will slow down the trip of zone 1 fault by about half a cycle. So reduced zone 1 settings are applied here.

This line is operated at single phase trip and reclose mode. Tripping or reclose of any phase by line protection will lead to bypass or insertion of series capacitors on that phase. As mentioned in Section III, negative sequence and zero sequence current elements are used to detect single line to ground faults. Since phase unbalances may occur after bypassing any one phase, the sensitive negative sequence and zero sequence currents elements in the line protection should be blocked after any bypassing.

2. Line Near to Series Capacitors

In another application, 500 kV Line 1 has no series capacitors on line, but the series capacitors are located just beyond its Terminal B and on adjacent 500 kV Line 2 as shown in Figure 17. Both lines have the same line impedance ZL. Capacitive reactance Xc is 100% of line impedance ZL. Air gap bypass protection is applied on these series capacitors.

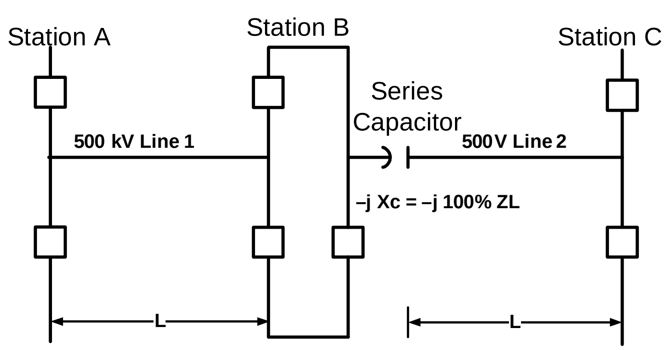

Fig. 17 Line Near to Series Capacitor

For a fault on 500 kV Line 2, the Line 1 terminal A will see it as an internal fault since the series capacitors completely compensate its line reactance. Any effort to reduce zone 1 settings will not help us to overcome the distance relay overreach problem. Thus the internal series compensation logic in the relay is used although it reduces the tripping speed by about half a cycle.

Line 1 is operated in three phase trip and reclose mode. Tripping or reclose of three phases by line protection will lead to bypass or insertion of series capacitors on all three phases. On both terminals, internal CVT (Capacitor Voltage Transformer) transient detection logic is enabled although there is no CVT transient problem on the line. During the model power system tests (MPST) of BC Hydro's 500 kV lines, it was found that this CVT logic is quite helpful for avoiding trips caused by transient conditions. Also, the MPST show that the CVT logic causes a much shorter time delay on zone 1 distance elements tripping than the delays anticipated before tests.

C. Protections of Lines With Submarine Cables

Two 500 kV Parallel Lines from Terminal A to Terminal B have some submarine cables sections as shown in Figure 18.

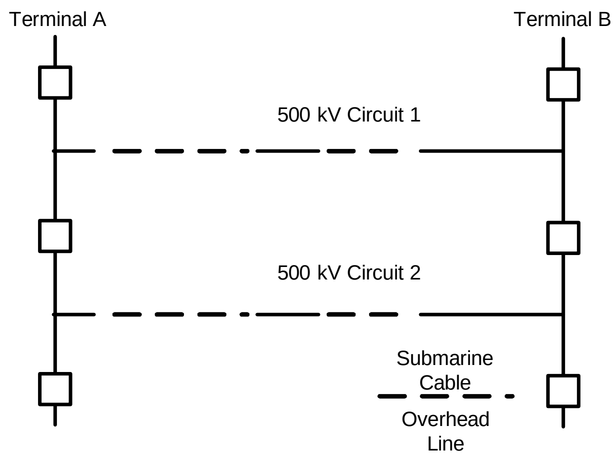

Fig. 18 500 kV Lines with Submarine Cables

The combination of submarine cable and overhead line presents some unusual challenges to protection relays in addition to above mentioned common protection requirements.

Three phase auto-reclose on those two lines uses parallel line power supervision instead of the traditional parallel line current supervision. This is due to the large amount of line charging current that might flow when the shunt reactors are out of service (for instance during heavy load flow). Three phase auto-reclose is blocked when the parallel line is out of service. Both single phase and three phase recloses of the follow terminal (Terminal A) are supervised by voltage restoration on each phase. To avoid reclose for a conductor to sheath fault on cable sections, Zone 5 quadrilateral elements at Terminal A are programmed to detect such a fault and send a non-reclosable transfer trip to the remote Terminal B. Furthermore, voltage recovery logic is applied at Terminal B to detect a possible conductor to sheath fault on cable sections. Based on EMTP studies, for cable fault, recovery of the faulted phase voltage is deemed to be very low during the open phase period. In contrast, if faulted phase voltage reaches a certain value in a defined period, the fault is deemed to be in an overhead line section. This voltage recovery condition is applied to supervise auto reclosing of the lead terminal, here Terminal B, of the lines with submarine cables.

The normally applied negative sequence directional control for ground faults is replaced in these two lines with zero sequence voltage control. It is observed that the contributions of zero sequence current from Terminal A to single line to ground faults are relatively much higher than is the case for the negative sequence current. To supplement the zero sequence overcurrent level detectors, negative sequence overcurrent level detectors are also applied for enhancing dependability.

The long length of submarine cable results in a very significant distortion of fault currents and voltages and consequently presents great challenges to determine the relay settings. For example, it was observed that there was considerable instability in the mho element measurement looking from Terminal A towards faults on the Terminal B bus. The zone 1 settings were finally determined during model power system tests after 50 or more different types of remote bus faults of various types and point on wave switchings.

D. Overview of Other Considerations on 500 kV Line Protections

This section will mention briefly other considerations for the protection replacements on some of the 500 kV lines.

1. Out of Step Protection

Both out of step tripping and out of step blocking are applied on one 500 kV line to separate the generation from the main 500 kV grid or keep local load center connected to the main 500 kV grid when out of step occurs [4].

2. Cross Country Fault Protection

Some of BC Hydro's 500 kV parallel lines have suffered mis-operations because of simultaneous single line to ground faults on both of the parallel lines. Cross country fault protections, internal to the distance relays, are applied on these parallel lines.

3. Secondary Arc Extinction Detection Logic

Secondary arc may occur after single phase trips of some of our 500 kV lines where shunt reactors are not available. To speed up the single phase reclose and avoid reclose before arc extinction, a user defined secondary arc extinction detection logic was developed and applied in the reclose control of these lines [6].

4. Overvoltage Protections

BC Hydro's generation centers are relatively far away from the consumer load centers. Some of the 500 kV lines cross quite long distances. Overvoltages are a concern especially during light load conditions. On BC Hydro 500 kV lines, two levels of overvoltage limits are usually applied with different tripping times. These overvoltage elements block auto-reclose after tripping three phases.

5. Special Protection Schemes or Load Shedding Inputs/Outputs

The line terminal open logic within the BC Hydro's 500 kV line protections are also used as a part of its special protection schemes or load shedding schemes. For example, if one terminal of these lines trips and opens for any reason, the remote terminal will be opened by a transfer trip. The opening of some of the 500 kV lines may cause concerns on transient and/or dynamic stability of the system. So for these 500 kV lines, two separate pulses of 6 cycle duration will be initiated from primary and standby line protection relays respectively for generation shedding, or for other RAS actions, such as reactive switching or line switching. It may also lead to load shedding in some cases. The inputs/outputs which are used in special protection schemes are conspicuously marked as "RAS Related Input/Output" in the DC drawings and on the relay panels.

6. Protection Logic Diagram

In complex schemes with many user defined logic elements, a logic diagram becomes more and more necessary. The logic diagram provides main important information, such as inputs/output assignments, CT/VT data, trip logics, reclose logics and other user defined logics. The internal functions of the relay are listed in the logic diagram without any details. An overview of the layout of such a logic diagram is shown in Figure 19.

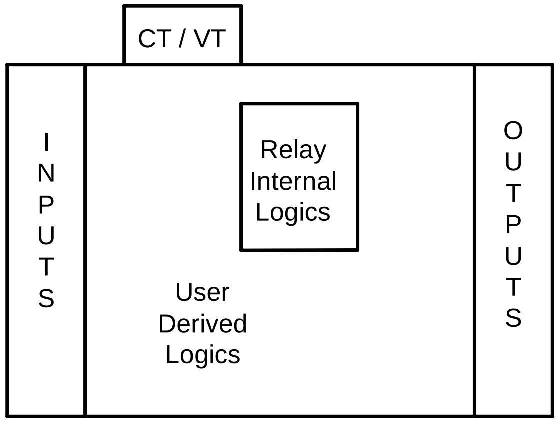

Fig. 19 Protection Logic Diagram Demonstration

7. Continuous Improvement of BC Hydro's 500 kV Line Protections

As one of the first users of this particular multifunction distance relay, BC Hydro's 500 kV line protections are in a continuous improvement process. First, the multifunction distance relay itself is improving since its release six years ago. Also, our own understanding of the relay and experience on the operation are improving.

V. CONCLUSIONS

Modern multifunction distance relays provide a platform to realize dedicated and complex transmission line protections. This paper summarizes the main considerations for applying them on BC Hydro's 500 kV lines. Although it is not possible to discuss in detail all the protection elements in one paper, the authors do wish that this paper will aid others in development of EHV transmission protection applications.

VI. REFERENCES

1. Brian Avent, "Protection for the B.C. Hydro North Coast 500 kV Intertie", Proceedings of the 6th Western Protection Relay Conference, Spokane, WA, October, 1979.

2. Maurice Lefrancois, "A Segregated Phase Comparison System with Special Features for High Tower Footing Resistance", Proceedings of the 5th Western Protection Relay Conference, Sacramento, CA, October, 1978..

3. Charles Henville, Ralph Folkers, Allen Hiebert, and Rudi Wierkx, "Dynamic Simulations Challenge Protection Performance", Proceedings of the 30th Western Protection Relay Conference, Spokane, WA, October, 2003.

4. Frank Plumptre, Stephan Brettschneider, Allen Hiebert, Michael Thompson and Mangapathirao "Venkat" Mynam, "Validation of Out-of-Step Protection with a Real Time Digital Simulator". Proceedings of the 33rd Western Protection Relay Conference, Spokane, WA, October, 2006.

5. IEEE Standard C37.113-1999, "IEEE Guide for Protective Relay Applications to Transmission Lines", Clause 5.2.4.7 - Directional Comparison Hybrid (unblocking scheme with echo logic).

6. Armando Guzman, Joe Mooney, Gabriel Benmouyal, Normann Fischer, "Transmission Line Protection System for Increasing Power System Requirements", Proceedings of the 29th Western Protection Relay Conference, Spokane, WA, October, 2002.

7. NERC Publication “Switch-Onto-Fault Schemes in the Context of Line Relay Loadability” Online ftp://www.nerc.com/pub/sys/all_updl/pc/spctf/SOTF_Tech_Doc_6-07-06_(2).pdf

Biographies

Xing Chen received his Master’s degree and Bachelor’s degree in Electrical Engineering from Electric Power Research Institute and Tsinghua University in 1985 and 1988 respectively. From 1988 to 1992, he worked as engineer in Electric Power Research Institute. Then, he joined the University of Montreal and obtained his Ph.D degree in Electrical Engineering in 2000. From 1996 to 2005, He was with Cegertec Inc., as a consultant engineer. He was involved in power system engineering, protection design and electrical maintenance services. Since 2005, he has been with BC Hydro as a Senior Engineer in Protection Planning. Dr. Chen is a registered Professional Engineer in the provinces of Quebec and British Columbia. He is involved as a corresponding member in WECC Relay Work Group.

Frank Plumptre graduated from the University of Calgary with a B. Sc. in Electrical Engineering in 1975. He has over 30 years experience in the field of protective relaying and is presently a Specialist Engineer with B C Hydro. He is a member of the IEEE Power System Relay Committee (PSRC past chair of the Awards and Recognition Chair of the PSRC.) and is chair of the Substations Subcommittee in that organization, Plus is active in several working groups. Most recently chair of K13 Series Capacitor Protection and successful publication of the IEEE GUIDE On ‘Protection of Transmission Line Series Capacitors’. Also involved as a corresponding member in several CIGRE work groups.

Charlie Henville received a BA and MA from Cambridge University in England in 1969 and 1974, respectively, and the MEng. from the University of BC in 1996. He has more than 30 years of experience with protection engineering. In 2005 he retired from BC Hydro as a principal engineer. He is now president of his own engineering consulting firm (Henville Consulting Inc). He is a fellow of the IEEE and chairman of the IEEE Power System Relay Committee (PSRC).

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