Control of Switching Overvoltages and Transient Recovery Voltages for Hydro-Québec 735-kV Series-Compensated Transmission System

Q. Bui-Van, A. Lecompte, N. Leblanc and P. Larivière

Abstract – This paper summarizes results of transient simulation studies assessing transmission line insulation coordination and the performance of line circuit breakers that are to be used in the Hydro-Québec 735-kV series-compensated system. The effectiveness of permanently connected surge arresters at line ends to control switching overvoltages along 735-kV lines has been confirmed. The characteristics of transient recovery voltages during a line fault clearing, a line charging current breaking as well as an out-of-phase current interruption were thoroughly analyzed. Finally, the effects of mitigation measures on transient recovery voltages such as fast by-passing of series-capacitor banks, metal-oxide varistors across circuit breaker terminals, were also investigated in order to optimize performance requirements for 735-kV line circuit breakers.

***Keywords* – Fault Transients, Switching Overvoltages (SOV), Transient Recovery Voltages (TRV), Circuit Breakers (CB), Series Compensation (SC), Series-Capacitor Banks (SCB), Substation Surge Arresters (SA), Line-end Surge Arresters (LSA), Metal-Oxide Varistors (MOV)**

I. INTRODUCTION

As Fig. 1 illustrates, the Hydro-Québec 735-kV transmission system is a long radial network. The three main generating centers, the 8100-MW Manic-Outardes complex, the 15600-MW James Bay complex and the 5600-MW Churchill Falls complex, are located approximately 400 km to 1000 km north of the two main load centers, Montréal and Québec City. In the beginning of the 1990s, 32 series capacitor banks (SCB) having a total reactive power of 11200 Mvar were implemented at 11 different 735-kV substations. In the foreseeable future, Hydro-Québec intends to implement series compensation (SC) extensively in this system in order to minimize the number of new 735-kV lines, which would be required for the integration of new remote generating plants. It is well known that the presence of series compensation increases switching overvoltages (SOV) on transmission lines during line fault clearings and transient recovery voltages (TRV) on line circuit breakers (CB) [1], [2].

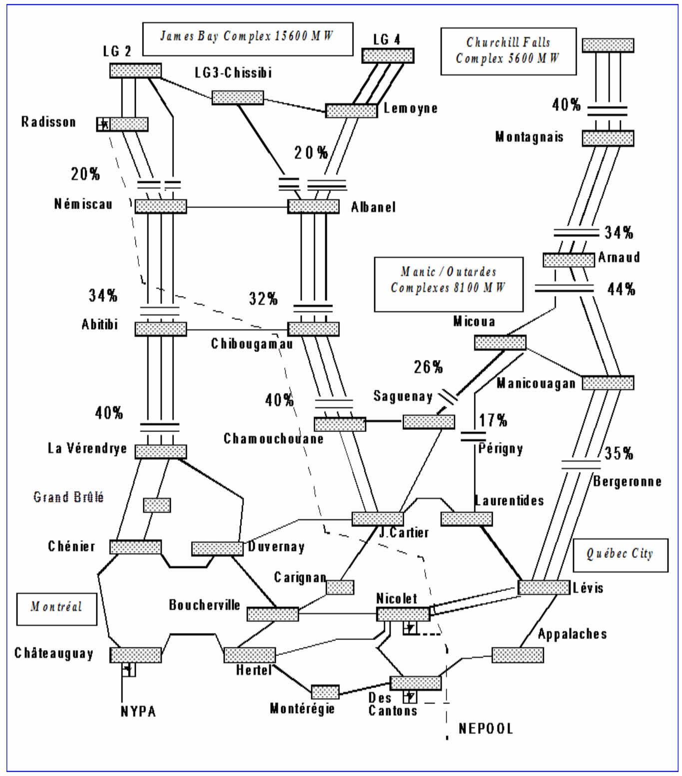

Fig. 1: Hydro-Québec 735-kV series-compensated system.

Therefore, exhaustive transient simulation studies were conducted in order to assess the transmission line insulation coordination and to optimize the performance of line CB that are to be used in the Hydro-Québec 735-kV series-compensated system. For the interpretation of study results, the p.u. values are based on the Φ-to-ground voltage of 600-kV peak (i.e. 735 kV rms Φ-to-Φ voltage $\frac{\sqrt{2}}{\sqrt{3}}$).

II. EQUIVALENT SYSTEM FOR TRANSIENT SIMULATION

In general, SOV and TRV studies involve numerous statistical simulations due to the random nature of these transient phenomena. The use of the detailed network entailed very long simulation times. Therefore, a reduced equivalent system including all the 735-kV substations, as illustrated in Fig. 1, was developed using the detailed peak-load 2006-2007 Hydro-Québec network set up on EMTP-RV [3]. In order to preserve the system steady state conditions, the network frequency dependency as well as the system dynamic behavior, the simplified approach described in [4] was applied for synthesizing sub-transmission systems that are connected

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to HV or LV sides of 735-kV substations. As illustrated in Fig. 2, the representative frequency responses at Chibougamau 735 kV show that there is a good agreement between the detailed and the reduced equivalent networks. Furthermore, the load flow solutions for the detailed and the reduced networks also indicate that the discrepancies in power flows and voltages are generally less than 1%.

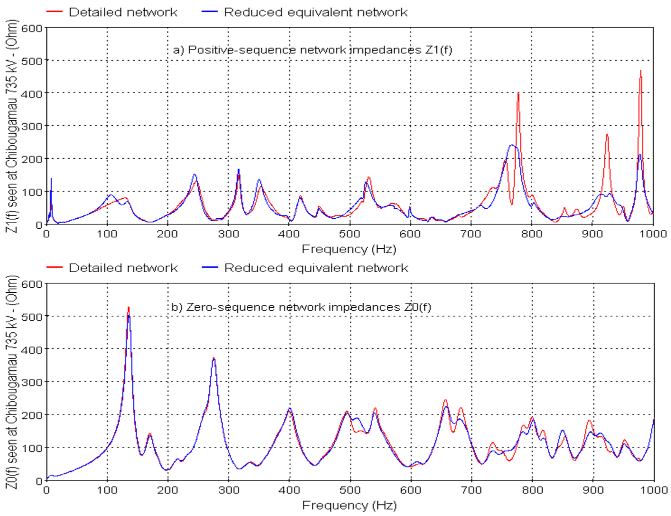

Fig. 2: Frequency responses at Chibougamau 735 kV of the detailed and the reduced networks

III. SOV on Series-Compensated Lines Due to Fault Clearings

Line fault clearings could produce high SOV along series-compensated lines. The statistical simulations of SOV along two typical series-compensated 735-kV lines Chibougamau (CHB)-Chamouchouane (CHM) and Abitibi (ABI)-La Vérendrye (LVD) were performed with the same fault locations, fault clearing conditions and other study parameters as those considered for the TRV study (see Fig. 3 and section IV–A).

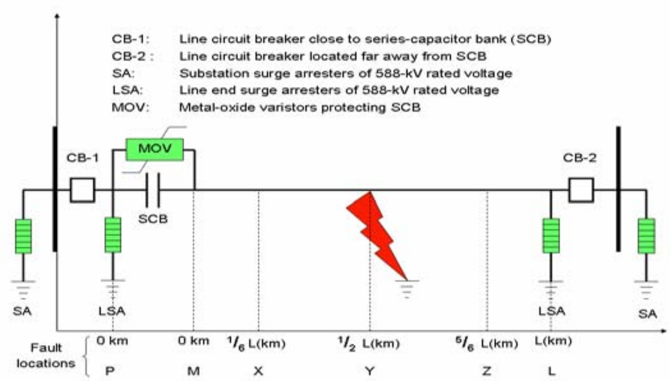

Fig. 3: Fault locations along the typical series-compensated lines for SOV and TRV studies

A. SOV without line-end surge arresters (LSA)

Simulation results indicated that severe SOV on the two typical series-compensated lines occurred during a Φ-to-Φ ungrounded fault at location (P). Without the presence of LSA, the maximum SOV along the CHB-CHM line reached 3.10 p.u. whereas the maximum SOV along the ABI-LVD line was 3.50 p.u., as shown in Fig. 4a and 4.b.

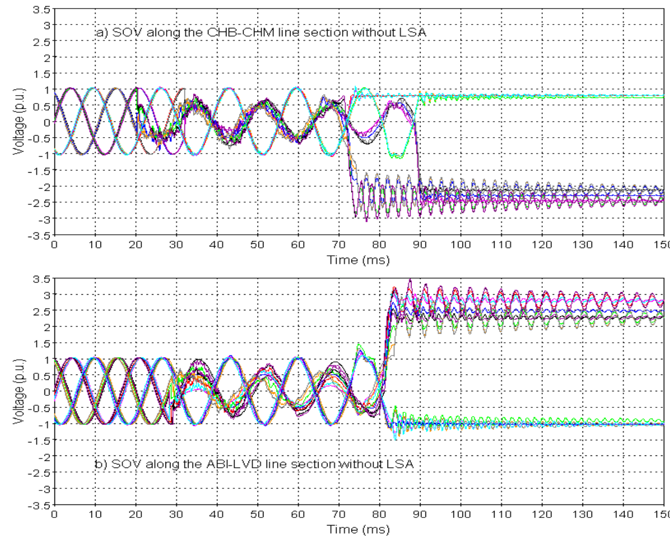

Fig. 4: SOV along the CHB-CHM and ABI-LVD lines during a Φ-to-Φ ungrounded fault at location (P) – Without LSA

These SOV are much higher than the 2.30-p.u. switching impulse withstand level (SIWL) of 735-kV line insulation. In order to reduce SOV stresses on line insulation it is therefore, recommended to implement LSA at both line ends, as illustrated in Fig. 3.

B. SOV with LSA implemented at both line ends

SOV on the CHB-CHM and ABI-LVD lines were also analyzed with the presence of 588-kV rated voltage LSA at both line ends. As shown in Fig. 5a and 5b, SOV have effectively been limited by LSA to their switching surge protective level (1140 kV or 1.90 p.u.). Along the CHB-CHM and ABI-LVD lines, the maximum SOV could respectively reach 2.20 p.u. and 2.30 p.u. because of limited protective zones offered by LSA. These SOV stresses are considered acceptable for 735-kV line insulation (SIWL = 2.30 p.u.).

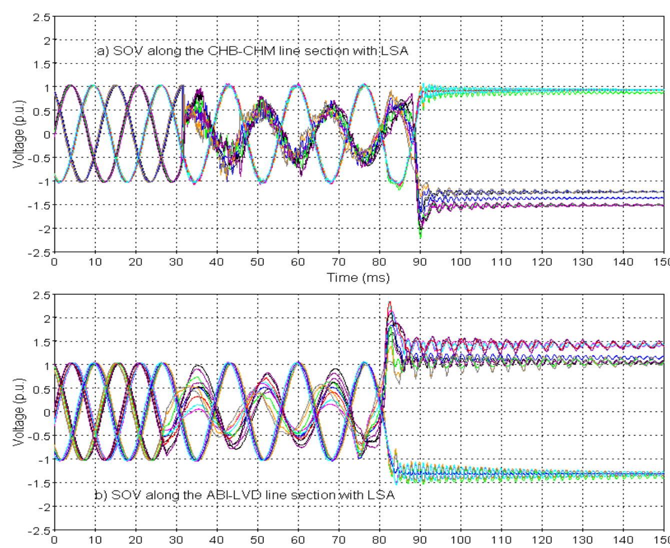

Fig. 5: SOV along the CHB-CHM and ABI-LVD lines during a Φ-to-Φ ungrounded fault at location (P) – With LSA at both line ends

Furthermore, the presence of LSA at both line ends brings about significant reduction of TRV on line CB. These results are also corroborated by those obtained in [2].

IV. TRV on Series-Compensated Line CB

The characteristics of TRV on series-compensated line CB were thoroughly investigated for the following conditions:

- a line fault clearing;
- an out-of-phase current breaking and
- a line charging current interruption.

A. *TRV during a line fault clearing*

Two typical series-compensated 735-kV lines - CHB-CHM and ABI-LVD - were selected for the simulation of TRV on line CB. Table I summarizes the characteristics of these lines.

Table I
Characteristics of the Selected Series-Compensated Lines

Line	Length L(km)	SCB rated Characteristics	MOV protective level
CHB-CHM	200	25 Ω - 1800 A	159.1 kV peak
ABI-LVD	287	34 Ω - 2600 A	312.5 kV peak

Furthermore, to determine the representative TRV, the following study parameters have been analyzed:

- *Four types of fault (Φ-to-ground, 2Φ-to-ground, Φ-to-Φ ungrounded and 3Φ-to-ground)* were considered in this study according to the fault occurrences observed on the Hydro-Québec 735 kV network over the last 20 years (Table II) [5].

Table II
Annual Fault Occurrences on the Hydro-Québec 735-kV network

Type of fault	Annual occurrences	No. of faults per 100 km-line per year
Φ-to-ground	38.3	0.33953
2Φ-to-ground	1.43	0.01267
Φ-to-Φ ungrounded	2.21	0.01959
3Φ-to-ground	0.48	0.00425
3Φ ungrounded	no occurrence	

- *Six fault locations (P, M, X, Y, Z and L)* along the typical series-compensated lines were simulated, as illustrated in Fig. 3.
- *Statistical tests* involving 100 fault initiations and clearings per test were performed to obtain representative TRV for each type of fault at each fault location. Random faults were initiated over one cycle of system frequency (60 Hz) using a uniform distribution. The time delays for fault clearing orders to CB-1 and CB-2 were randomly generated using a Gaussian distribution. These random time delays were also based on fault locations along the line, typical line protection times and a minimum CB mechanical time of 20 ms. Table III summarizes the fault initiation time and the time delays associated to CB-1 and CB-2 used in the present study.

Furthermore, dispersion time delays between the three poles of CB-1 and CB-2 were also randomly generated according to a Gaussian distribution with the standard deviation of σ = 1.33 ms.

Table III
Fault Initiation Time and Time Delays Associated to CB-1 and CB-2

Fault location	Fault initiation time (ms)	Time delays to CB-1 (ms)		Time delays to CB-2 (ms)	
		T p	T m	T p	T m
P, M	25 ± 8.3	23.0 ± 10	20	36.5 ± 7.5	20
L	25 ± 8.3	36.5 ± 7.5	20	23.0 ± 10	20
X, Y, Z	25 ± 8.3	36.5 ± 7.5	20	36.5 ± 7.5	20

Tp = Typical line protection times; Tm = minimum CB mechanical time

A.1. Simulation results

- *Representative TRV on line CB.* Since LSA are required at both line ends to control SOV along the two typical series-compensated lines (see section III-B), the TRV on line CB were therefore, evaluated with the presence of LSA as illustrated in Fig. 3. Table IV summarizes, for each type of fault, the representative TRV on CB-1 and CB-2 of the two typical series-compensated 735-kV lines CHB-CHM and ABI-LVD. The fault locations associated to these TRV were also indicated in this Table IV.

Table IV
Representative TRV on CB-1 and CB-2 with LSA

Line	Type of fault	TRV on CB-1 in p.u. - (fault loc.)	TRV on CB-2 in p.u. - (fault loc.)
CHB-CHM	Φ-to-grd.	1.74 - (L)	1.84 - (P)
	2Φ-to-grd.	2.61 - (L)	2.65 - (P)
	Φ-to-Φ ungrd.	2.91 - (L)	**2.94 - (P)**
	3Φ-to-grd.	2.85 - (L)	2.81 - (P)
ABI - LVD	Φ-to-grd.	2.09 - (L)	1.89 - (P)
	2Φ-to-grd.	2.99 - (L)	2.79 - (P)
	Φ-to-Φ ungrd.	2.85 - (L)	2.84 - (P)
	3Φ-to-grd.	**3.06 - (L)**	2.77 - (P)

The maximum TRV on the CB-2 of the CHB-CHM line caused by a Φ-to-Φ ungrounded fault at location (P) is illustrated in Fig. 6a whereas Fig. 6b shows the maximum TRV on the CB-1 of the ABI-LVD line due to a 3Φ-to-ground fault at location (L).

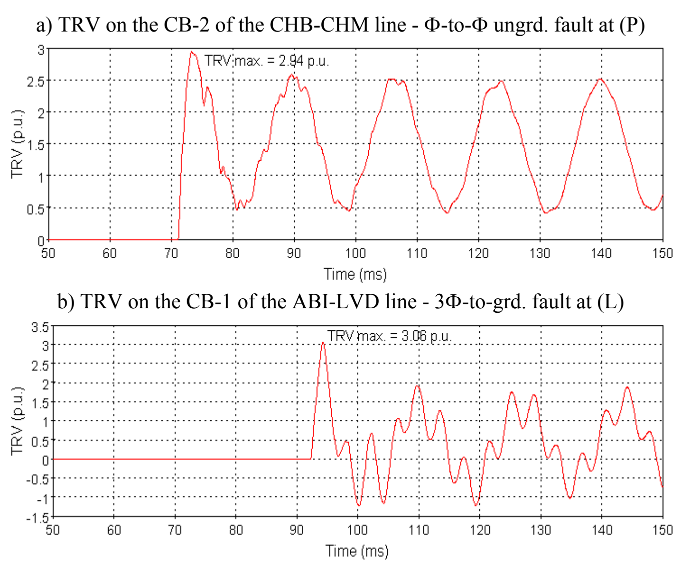

Fig. 6: Maximum TRV on the two typical series-compensated lines

• *Rate of rise of TRV (RRTRV).* The analysis of numerous TRV waveforms has indicated that RRTRV are generally less than 1.0 kV/µs.

• *Symmetrical currents interrupted by CB-1 and CB-2* of the two typical series-compensated lines CHB-CHM and ABI-LVD varies depending on types of fault and fault locations along these lines. TABLE V summarizes simulation results of maximum interrupted symmetrical currents for four types of fault. It should be mentioned, from TABLE IV and TABLE V, that the maximum TRV on CB-1 and CB-2 are generally associated with interrupted symmetrical currents less than 10 kA rms.

TABLE V
SYMMETRICAL CURRENTS INTERRUPTED BY LINE CB OF THE TWO TYPICAL SERIES-COMPENSATED LINES CHB-CHM AND ABI-LVD

Line circuit breaker	Max. symmetrical current (kA rms) to be interrupted by line CB during a fault at location:					
	P	M (*)	X	Y	Z	L
CB-1	14.7	15.3	13.0	7.5	4.3	2.6
CB-2	3.2	2.2	3.8	5.5	10.6	17.5

(*) With SCB by-passed

A.2. TRV values specified by IEC for 800-kV class CB

The IEC 62271-100:2001 including its related amendments has specified various TRV and RRTRV values according to test duties performed on CB. TABLE VI summarizes these specifications for an 800-kV CB with the rated short-circuit current interrupting capability of 40 kA rms.

TABLE VI
IEC 62271-100 SPECIFICATIONS FOR AN 800-KV – 40 KA CB

Test duty	Rated symmetrical current (kA rms)	TRV in (p.u./600kV)	RRTRV in (kV/µs)
T100	40	1.98	2.0
T60	24	2.12	3.0
T30	12	2.18	5.0
T10	4	2.50	7.0
OP1-OP2 (*)	10 (**)	2.72	1.54

(*) OP1-OP2: Out-of-phase current test duties; (**) Rated out-of-phase current

Moreover, with the first-pole-to-clear factor of 1.3 applied for short-circuit current test duties, the IEC specifications for 800-kV class CB do not cover TRV stresses during Φ-to-Φ ungrounded or 3Φ ungrounded faults. Furthermore, the IEC 800-kV class CB has a rated line charging current breaking of 900 A rms associated with a maximum recovery voltage of 3.05 p.u. = 1.4 x 2 x (800/735).

The simulation results of the two typical series-compensated lines indicated that RRTRV are generally less than 1.0 kV/µs and that severe TRV stresses are generally associated with interrupted symmetrical currents less than 10 kA rms. It is therefore suggested to use the TRV withstand of 2.72 p.u., which is specified for out-of-phase current test duties, as reference level to assess the suitability of IEC 800-kV class CB for 735-kV series-compensated lines. With respect to this reference level, it can be seen that without applying any mean for TRV reduction, the IEC 800-kV class CB is not adequate to cover TRV stresses on the CB-1 and CB-2 of the typical 735-kV series-compensated lines (TABLE IV vs. TABLE VI). As a consequence, up to now special CB with higher TRV withstand levels than those of the IEC 800-kV class CB have been implemented on 735-kV series-compensated lines.

A.3. Effects of fast by-passing of SCB on TRV

With the recent development of a new fast protective device (FPD) for HV series capacitors, it becomes very attractive to apply fast by-passing of SCB to reduce TRV stresses on line CB during line fault clearings. A pilot installation of FPD with the maximum by-pass time of 5 ms from receiving an external close signal has been in service since October 2003 at the Kamouraska SCB in the Hydro-Québec 315-kV sub-transmission system [6]. The follow up of this installation as well as detailed prototype tests should be done in order to verify the performance and the reliability of FPD before its application in the Hydro-Québec 735-kV series-compensated system.

The design principle of SCB fast by-passing for TRV reduction, as illustrated in Fig. 7, consists of sending simultaneously a line trip signal to line circuit breaker and a by-pass signal to FPD whenever a line fault is detected by local line protection systems. Given that the speed of FPD is much faster than that of line CB (maximum of 5 ms for FPD vs. minimum of 20 ms for line CB) it is possible to by-pass SCB well in advance of the line circuit breaker opening. Consequently, the TRV across the breaker will be similar to switching the line without any SCB.

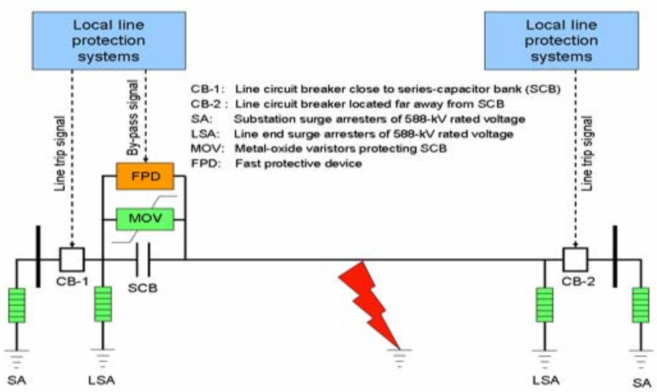

Fig. 7: Design principle of SCB fast by-passing for TRV reduction

Statistical simulations of various types of fault at different fault locations along the two typical series-compensated lines CHB-CHM and ABI-LVD were also performed with the application of the above mentioned SCB fast by-passing.

Simulation results indicated that the fast by-passing of SCB allowed reducing TRV during 2Φ-to-ground and 3Φ-to-ground faults below the reference withstand level of the IEC 800-kV class CB, as an example illustrated in Fig. 8.

For the Φ-to-Φ ungrounded faults, even with the application of SCB fast by-passing, TRV stresses on CB-1 and CB-2 still statistically exceed the reference withstand level of the IEC 800-kV class CB, as an example shown in Fig. 9.

Since the effects of Φ-to-Φ ungrounded faults on the system stability are much less severe compared to those of 2Φ-to-ground or 3Φ-to-ground faults, low risks of exceeding withstand level would be acceptable. Based on the annual Φ-to-Φ ungrounded fault occurrences (TABLE II), the results of statistical simulations and the line lengths, the calculated mean times between two occurrences of exceeding withstand level (MTBEW) of the IEC 800-kV class CB were respectively 900 years and 690 years for the two typical series-compensated lines CHB-CHM and ABI-LVD. These MTBEW are still acceptable with respect to the performance criterion of MTBEW ≥ 500 years being adopted for Hydro-Québec 735-kV line CB.

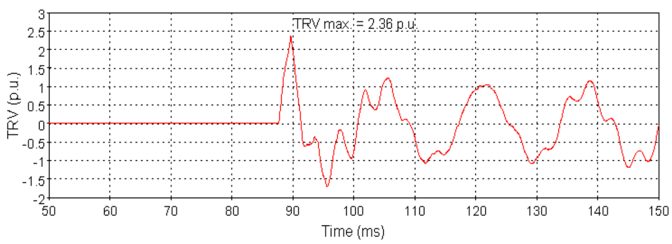

Fig. 8: Max. TRV on CB-1 of the ABI-LVD line during a 3Φ-to-ground fault at location (L) – With SCB fast by-passing

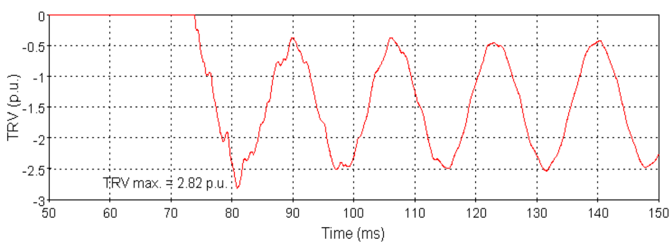

Fig. 9: Max. TRV on CB-2 of the CHB-CHM line during a Φ-to-Φ ungrounded fault at location (P) – With SCB fast by-passing

A.4. Effects of metal-oxide varistors (MOV)

The MOV connected in parallel with the contacts of series-compensated line CB have been successfully applied for many years in the Turkish 420-kV grid [1]. For the application on the Hydro-Québec 735-kV line CB, the effects of the two following MOV across CB terminals were analyzed (TABLE VII):

TABLE VII
CHARACTERISTICS OF MOV ACROSS 735-KV CB TERMINALS

Characteristics	MOV-1	MOV-2
Rated voltage	1105 kVrms	884 kVrms
Maximum continuous operating voltage (MCOV)	884 kVrms	707.2 kVrms
Switching surge protective level at 2 kA, 30/60 µs	2142 kVp or 3.56 p.u.	1714 kVp or 2.86 p.u.
Withstand to 60-Hz voltage beats when CB is open and energized at both terminals	continuously	≈ 200 s

Although the MOV-1 could withstand continuously to power frequency voltage beats when CB is open and energized at both terminals, it obviously offers no reduction on TRV since its switching surge protective level of 3.56 p.u. is much higher than the maximum prospective TRV (without MOV) during a line fault clearing. Therefore, the use of MOV-1 for TRV reduction was discarded.

As indicated in Fig. 10a and 10b, the presence of MOV-2 allows reducing the TRV on CB-1 and CB-2 below the reference withstand level of the IEC 800-kV class CB. However, in order to ensure a safe operation of MOV-2, an automatic or manual opening of adjacent disconnect switches is necessary within 200 s following the CB opening. This operation would not be safe under adverse icing conditions during winter time in Québec. As a consequence, the solution of MOV-2 across CB terminals has not been considered for the Hydro-Québec 735-kV series-compensated system.

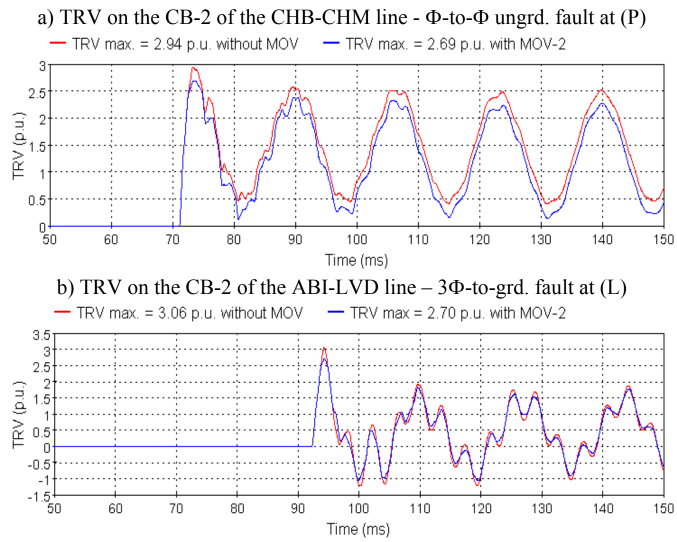

Fig. 10: Effects of MOV-2 on TRV stresses

B. TRV due to out-of-phase clearing and line charging current interruption

It was demonstrated in [7] that an extreme disturbance in the Hydro-Québec 735-kV series-compensated system, which includes several transmission corridors of 1000 km length, can cause a loss of synchronism with distant generating centers, leading to a full load rejection by the simultaneous opening of several line circuit breakers under out-of-phase conditions.

Following a full load rejection, large temporary overvoltages (TOV) due to the Ferranti effect appear on long unloaded line that are still connected to generators. The uses of switchable 484-kV rated surge arresters in combination with the fast removal of unloaded lines from generators by overvoltage protections allow a reduction of the magnitude as well as the duration of TOV. As a consequence, line CB in this system are subjected to severe TRV stresses due to out-of-phase clearing and unloaded line de-energization under high TOV.

Without applying any mitigation measure, the maximum TRV due to out-of-phase clearing and the maximum TRV during unloaded line de-energization could respectively reach 3.30 p.u. and 3.45 p.u. (Fig. 11a and 11b), which obviously exceed the IEC specifications for 800-kV class CB. Since these TRV stresses could appear on 735-kV lines with or without series compensation, fast by-passing of SCB would not be effective for the reduction of these types of TRV. In this case, the presence of MOV-2 across CB terminals would allow reducing these TRV below the withstand levels of the IEC 800-kV class CB (Fig. 11a and 11b). However, as discussed earlier, the solution of MOV-2 across CB terminals has not been considered for 735-kV series-compensated lines because of the necessity of opening adjacent disconnect switches shortly after the CB opening.

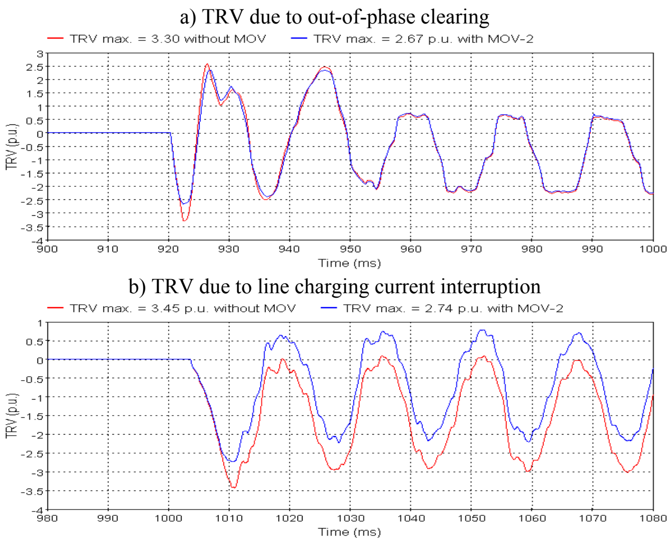

Fig. 11: Maximum TRV on 735-kV line CB due to out-of-phase clearing and line charging current interruption – With and without MOV-2

V. Conclusions

Exhaustive transient simulation studies were conducted for assessing the 735-kV line insulation coordination and the performance of line circuit breakers that are to be used in the Hydro-Québec 735-kV series-compensated system. In light of these study results, the following main conclusions could be drawn:

- The implementation of LSA at both line ends allows efficiently limiting SOV along 735-kV lines to an acceptable level for their insulation. These LSA bring about significant reduction of TRV on line CB during line fault clearings.
- Without applying any other mean for further TRV reduction, TRV stresses on 735-kV series-compensated line CB exceed the withstand levels of the IEC 800-kV class CB. As a consequence, up to now special CB with higher TRV withstand levels than those of the IEC 800-kV class CB have been implemented on 735-kV series-compensated lines.
- The SCB fast by-passing allows reducing TRV to a level similar to switching the line without any SCB. This action would make the use of the IEC 800-kV class CB acceptable for clearing faults on 735-kV series-compensated lines. However, the follow up of the pilot installation at Kamouraska 315-kV SCB as well as detailed prototype tests should be done in order to verify the performance and the reliability of FPD before its application in the 735-kV series-compensated system.
- Although MOV with appropriate switching surge protective level across CB terminals were proven to be very efficient for limiting TRV, this solution has not been considered for the 735-kV series-compensated system because of the requirement of opening disconnect switches, which can be difficult under adverse icing conditions during winter time in Québec.

VI. References

[1] F. Iliceto, F. M. Gatta, E. Cinieri and G. Asan, "TRVs across Circuit Breakers of Series Compensated Lines. Status with Present Technology and Analysis for the Turkish 420 kV Grid," *IEEE Trans. Power Delivery*, vol. 7, no. 2, *pp., 757-766, Apr. 1992.*

[2] B. Khodabakhchian, S. Breault, E. Portales, H. Huynh and Y. Hotte, "TRV and the Non-Zero Crossing Phenomenon in Hydro-Québec Projected 735 kV Series Compensated System," *CIGRE 1992 Session*, *paper no. 13-303.*

[3] L. Gérin-Lajoie, J. Mahseredjian and B. Khodabakchian, "Large Network Simulation Using EMTP-RV at Hydro-Québec," *EMTP-RV Newsletter, Vol. 1, No. 3, December 2006.*

[4] Q. Bui-Van and F. Beauchemin, "Simplified Approach for Synthesizing Frequency Dependent Network Equivalents Including Dynamic Behavior of Large Power Transmission Systems," *paper no. 001 presented at IPST'05 in Montréal, Québec, Canada, June 2005.*

[5] G. Trudel, J.-P. Gingras and J.-R. Pierre, "Designing a Reliable Power System – The Hydro-Québec's integrated Approach," *Proceedings of IEEE, Vol. 93, No. 5, May 2005.*

[6] J. Redlund, J. Fecteau, L. Paulsson and L.-P. Rollin, "A New Fast Protective Device for High Voltage Series Capacitors," *paper no. 1-4244-0493-2/06 presented at PES General Meeting in Montréal, Québec, Canada, June 2006.*

[7] Q. Bui-Van and M. Rousseau, "Control of Overvoltages on Hydro-Québec 735-kV Series-Compensated System during a Major Electro-mechanical Transient Disturbance," *paper no. 014 presented at IPST'01 in Rio de Janeiro, Brazil, June 2001.*

VII. Biographies

Que Bui-Van has received B. A. Sc. in electrical engineering from École Polytechnique de Montréal in 1975. He has been with Systems Studies, Hydro-Québec TransÉnergie since his graduation. Mr. Bui-Van has been working on HV/EHV equipment specifications, lightning performance of transmission lines, insulation coordination of HV/EHV AC/DC power cables and GIS. He was responsible of electrical performance specifications for power cables from 25 kV to 345 kV used in Hydro-Québec power system. Mr. Bui-Van has been involved in several system studies for the implementation of special surge protective devices, static var compensators, series compensation and HVDC interconnections in Hydro-Québec 735-kV transmission system. During the 1990s, he has also been involved in several system studies for international power system projects. Mr. Bui-Van is the Chairman of the Canadian Subcommittee on IEC/TC28: Insulation Coordination, an active member of the CIGRÉ WG A3.13: Changing Network Conditions and System Requirements as well as a Registered Professional Engineer in the Province of Québec.

Audrey Lecompte has graduated from Institut en Génie de l'Énergie Électrique – Université Laval in 2006. During this year, Ms. Lecompte has joined Systems Studies, Hydro-Québec TransÉnergie for a short training period. She is now an engineer with Systems Studies, Hydro-Québec TransÉnergie involving in studies of control and protection systems.

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