Implementation of remedial action schemes to mitigate temporary over voltage (TOV) - lessons learned

Wah Shum　　　Ming Zou　　　Yansong Leng

***Abstract*—Temporary Overvoltage is a well-known phenomenon by the utilities. Traditional way to control the TOV is to install shunt reactors to properly compensate the system. In recently years, utilities have been trying to reduce the capital cost of the new transmission projects. Remedial Action Scheme (RAS) has been adopted to control the TOV and reduce the project cost in some utilities instead of installing the expensive shunt reactors. However, lessons learned that RAS should be carefully designed and combined with other schemes such as overvoltage relays, equipment such as sacrificial surge arrestors to mitigate the TOV.**

***Keywords*: Temporary over voltage, remedial action scheme, back feeding and over voltage relay.**

I. INTRODUCTION

TEmporary overvoltage (TOV) defined by IEEE is an oscillatory phase to ground or phase-to phase overvoltage that is at a given location of relative long duration(seconds, even minutes) and that is undamped or only weakly damped [1]. TOV are dependent on a number of important factors [2]:

- System characteristics: short circuit power, line length,
- System conditions and operating procedures
- Sequence of events leading to TOV

The important TOV causes are listed as follows

- Fault application
- Load rejection
- Line energizing
- Line dropping and fault clearing
- Reclosing
- Transformer energizing
- Parallel line resonance
- Uneven Breaker poles
- Ferroresonance
- Backfeeding

Other than the installation of the shunt reactors to control the TOV, other economic means such as using remedial action schemes (RAS) [3]and Surge arresters [4][5] to control the TOV have been developed and applied in the utilities.

Wah Shum is the manager of Transmission system planning department, Integrated planning, British Columbia Hydro, Canada; Ming Zou and Yansong Leng work in Transmission system planning, Integrated planning, British Columbia Hydro, Canada (email: ming.zou@bchydro.com).

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This paper presents a TOV phenomenon that was foreseen when planning a new 112 km 230 kV transmission system to supply an area in the east of South Interior, British Columbia, Canada (hereafter referred to as “area UCV”) and a similar approach [5] to control the TOV. Area UCV was supplied by a 129 km single radial 60 kV transmission line and load growth along the radial system exceeded the system supply limit in 2012. A new 230 kV transmission line was planned to supply the area load after 2012. In the transmission planning study stage, potential TOV was identified under a special system configuration because of the backfeeding. A cost effective technical solution–RAS with surge arrestors was selected to mitigate the potential TOV problem and secure the system supply. 2 years after the new 230 kV system was in service, the TOV indeed happened during one of the disturbance events because of many unexpected factors of the RAS, system equipment and the system conditions.

A. *Pre-2012 230-60 kV system*

Area UCV was supplied by a 129 km single-circuit radial 60 kV transmission line 6LB. The radial transmission system was supplied by a 230/60 kV system substation SD2. Supply to the SD2 is facilitated by another single-circuit 230 kV transmission line approximately 128 km in length from a 500/230 kV system substation SS1. The transmission system configurations including a number of substations with the 2012 peak loads to be cited in this paper are illustrated in Fig. 1 (area UCV is in the dash line). SS1 also connects to SD2 via a 137 km long 60 kV line 60LA.

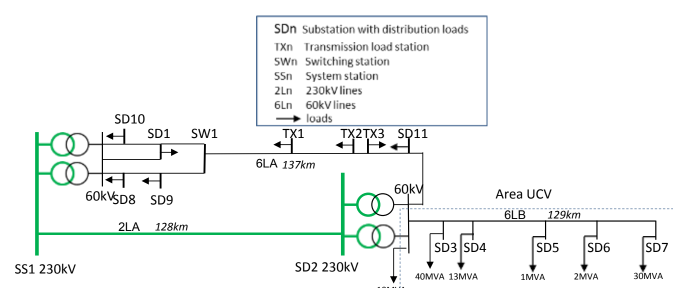

Fig. 1: Transmission system one line diagram – pre 2012

B. *Post-2012 230 kV system*

Transmission planning studies identified that, with the forecasted load growth in area UCV, by 2012, the 60 kV radial transmission system 6LB supplying SD3, SD4, SD5, SD6 and SD7 will not meet the load growth requirements. Various alternatives including 230 kV, 138 kV and 60 kV supply were proposed and evaluated and a 230 kV alternative was finally selected to meet the long term load supply demand in the area UCV. The proposed new 230 kV system with a new 230 kV line -2LB, a new230/60 kV substation SS2 is shown in the Fig. 2.

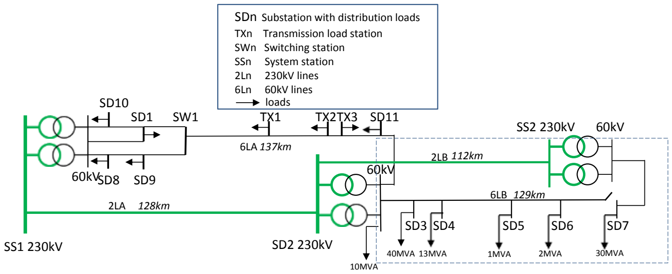

Fig. 2: Transmission system one line – post 2012

The scopes of the new project are as follows:

- Construct a new 230/60 kV substation SS2 close to station SD7 with 2x 230/64.5 kV On Load Tap Change (LTC) transformers
- Construct a new 112 km 230 kV line 2LB from SD2 to SS2.
- Construct a new 5 km short 60 kV line between SS2 and SD7
- The previous 60 kV line supplying SD7 from SD2 60 kV bus will be open at SD7.
- SD7 distribution loads will be supplied by the new 230 kV system via the 112 km 230 kV line to offload 6LB.

Fig. 3 shows the system parameters of new transmission line and transformers added to the previous system.

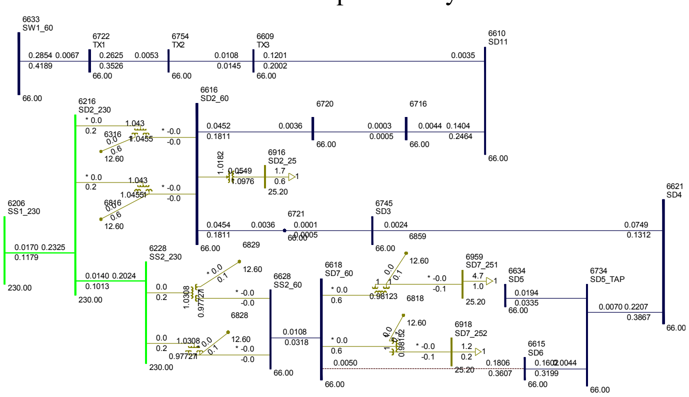
Fig. 3: Transmission system parameters

II. TOV CONCERNS AND MITIGATIONS

A. *Reactive compensation consideration*

The charging of the new 112 km 230 kV line is approximately 20 MVAr at 230 kV. To compensate this additional Var, a 15 MVAr 230 kV or 60 kV shunt reactor was considered and the estimated cost was between $5 and $10 million at the time. System planning studied two scenarios during light summer (LS) load period without the additional reactor:

- SS1 system station is a 500/230 kV step-down substation. There are two 512.5/242 kV auto transformers with a tapping range of (+/- 2 x 2.5%). The current tap position is on the maximum buck position 538.1 kV to ensure the 230 kV bus voltage is regulated between 230 kV and 242 kV during year round under system normal conditions, the 230 kV bus voltage at SS2 will not exceed 248.5 kV and with the 230/60 kV LTC transformers at SS2 and 60/25 kV LTC transformers at distribution station SD7, the distribution customer voltage will be regulated within acceptable range below 1.05 p.u.
- Under some contingency cases such as during shunt reactors maintenance at SS1, if the system substation SS1 230 kV bus voltage cannot be regulated below 242 kV because of the high 500 kV bus voltage, SD7 substation can be switched back to the previous
- 60 kV system from SD2 and the new 230 kV transmission system can be de- energized.

Therefore, to reduce the overall project cost, reactor compensation was not considered.

B. *TOV scenario*

If there are Single Phase to Ground (SPG) faults on 2LA and 2LB, faulted phase will be tripped within 6 cycles. In 1 second, faulted phase will be reclosed, if the faults are temporary, the system will be restored. If the faults are permanent, three- phase will be tripped.

One system configuration was identified in the planning study that may potentially result in TOV.

During LS load period, if there are permanent 1 – phase, 2-phase or 3-phase faults happen on the line 2LA, the 2LA will be tripped, 6LA will be backfeeding line 2LB, station SS2 and SD7 via two 230/60 kV step-down transformers at SD2. Because of the weak source system (the fault level at SW1 60 kV bus is 430 MVA), the uncompensated long 230 kV line and small load current (less than the 230 kV line charging current), there will be severe TOV on the line 2LB and 6LB and the substations supplied by 6LB, SD2 , SS2 and SD7 stations. The post contingency steady-state power flow results after any automatic system voltage regulating devices including transformer tap and shunt capacitor banks which were assumed to have operated show potentially excessive TOV along the system. PSS/E [6] simulation results-Root Mean Square in p.u./kV are summarized in the following table after the loss of 2LA as well as shown in Fig. 4 with pre contingency system power flow simulation results and Fig. 5 with post contingency power flow simulation results.

TABLE 1: BUS VOLTAGE - PSS/E SIMULATION RESULTS

60 kV bus name	SW1	SD2	SD7
Voltage in p.u./RMS(kV)	1.018/67.2	1.163/76.8	1.137/75.1
230 kV bus name	SD2	SS2	
Voltage in p.u./RMS(kV)	1.29/297	1.31/301	
25 kV bus name	SD7		
Voltage in p.u./RMS(kV)	1.07/27		

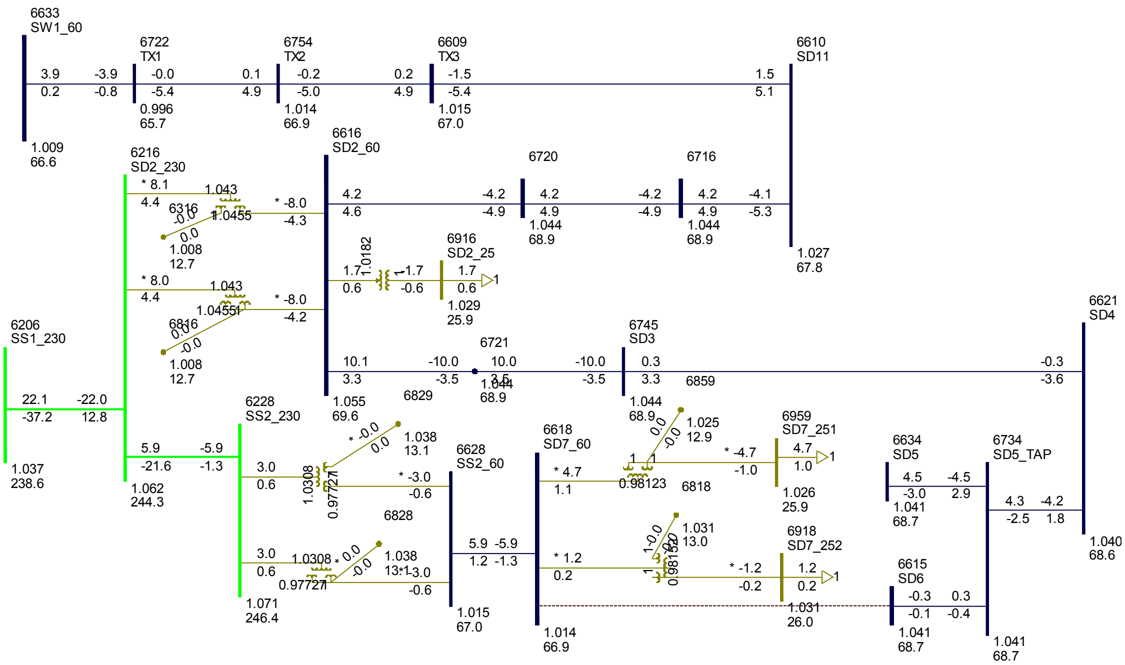

Fig. 4: System power flow simulation results pre-fault

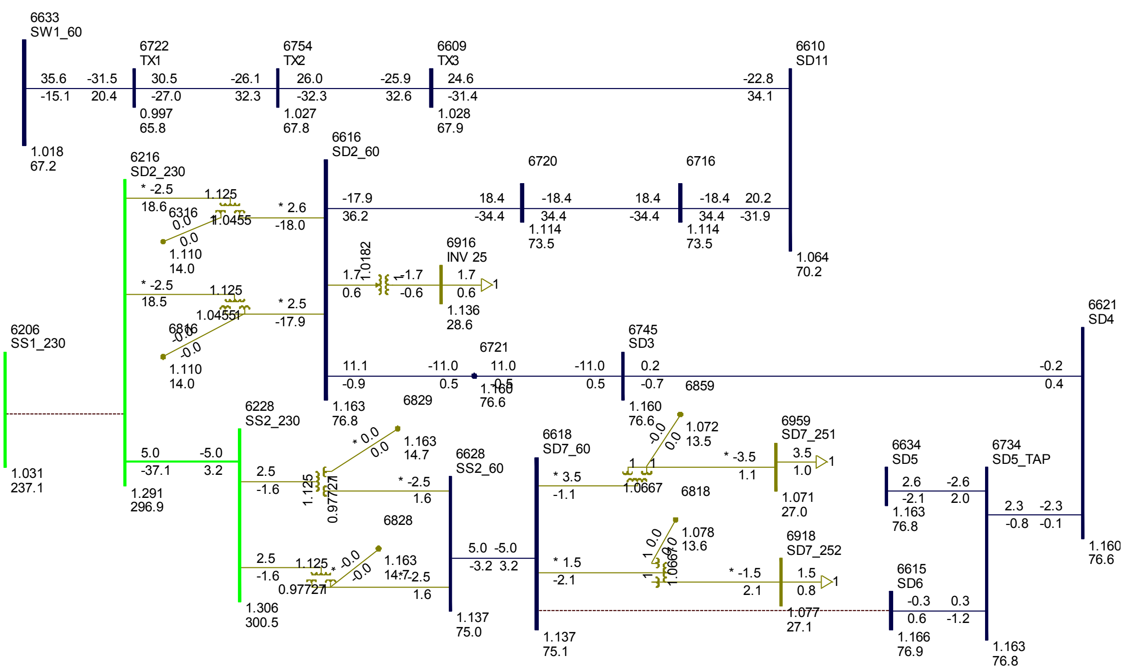

Fig. 5: System power flow simulation results post-fault

To mitigate the above TOV, a remedial action scheme is proposed to send a Direct Transfer Trip (DTT) signal to open 2LB 3-pole on SS2 station side after 2LA is tripped and trip 6LA and 6LB on SD2 side to avoid the 6LA backfeeding the 230 kV and 6LB system.

Furthermore, one sacrificial 230 kV surge arrestor was installed on each side of 2LB at station SD2 and SS2 to protect the system equipment from the TOV in case if the RAS fails.

The new 230 kV line and the NEW 230/60 kV substation have been in service since 2012.

III. THE DISTURBANCE EVENT AND TOV

A. The disturbance event

On Friday, June 20, 2014 at 6:53:00 pm, there was a temporary C phase to ground fault on 2LA. After 6 cycles, C phase was tripped on both SS1 and SD2 sides. Within 1 second, SS1 station side C phase of 2LA was successfully reclosed but the 230 kV Circuit Breakers on SD2 side of 2LA did not reclose and were eventually driven to lock out and tripped 3 phases at SD2.

The logic designed for the RAS is that, only for 3-pole tripping on 2LA will send a DTT to transfer trip 3-pole of 2LB at SS2 and 6LA and 6LB at SD2. In this case, 2LA 3-pole is still closed on SS1 side. Therefore, DTT signals were not sent out.

The pre-fault 2LA line loading is approximately 20 MW and 2LB line loading is approximately 5 MW. The pre-fault 6LA from SW1 to SD2 is less than 2 MW. The system is light loaded.

Excessive TOV (Up to 300 kV on 230 kV system and 79 kV on 60 kV system) were built up on line 2LB, 60LB, at station SD2 and SS2 when back feeding from 6LA via 2 step-down transformers at SD2. Operators responded in 10 minutes after the TOV were built up and tripped the 2LB manually. Sacrificial 230 kV surge arrestors on both sides of 2LB did not operate.

The recorded bus voltages at a number of stations were shown in Fig. 6, Fig. 7, Fig. 8 and Fig. 9.

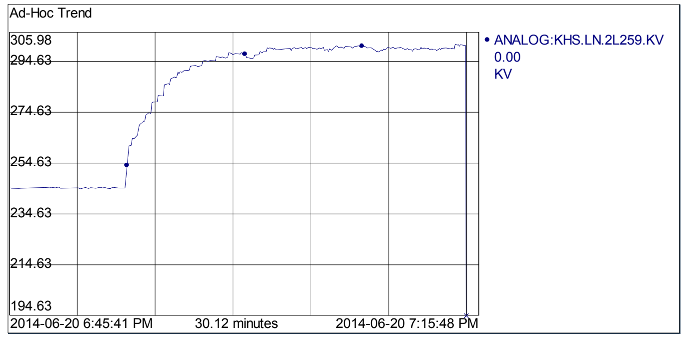

Fig. 6: Recorded RMS value of the 230 kV bus voltage at SS2 station

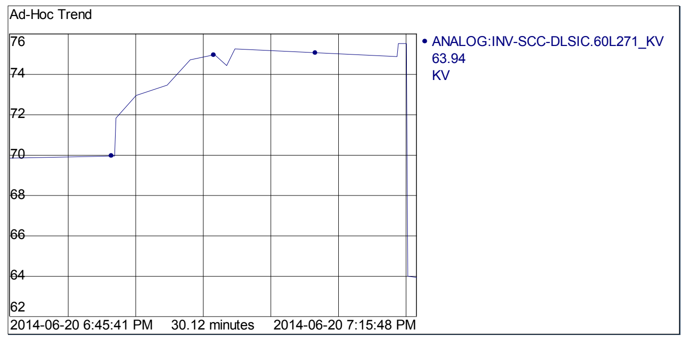

Fig.7: Recorded RMS value of the 60 kV bus voltage at SD2 station

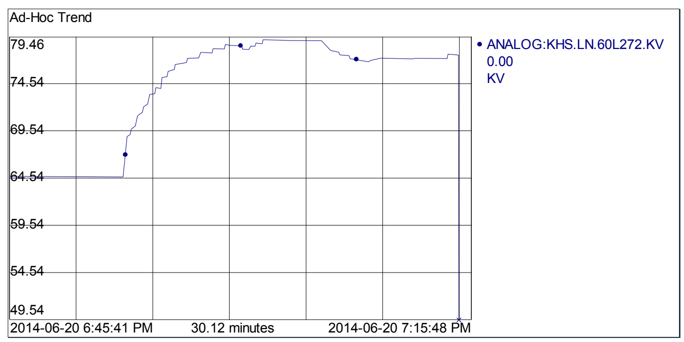

Fig.8: Recorded RMS value of the 60 kV bus voltage at SS2 station

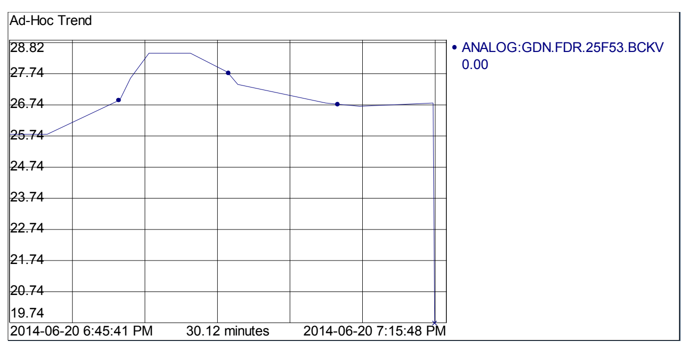

Fig.9: Recorded RMS value of the 25 kV bus voltage at SD7 station

From the recorded data, 230 kV bus voltage on SS2 side reached at 301 kV, 60 kV bus voltage on SS2 side reached at 77.5 kV, 60 kV bus voltage on SD2 side reached at 75.5 kV, 15 minutes after the C- phase fault on 2LA was cleared. 25 kV distribution bus voltage at SD7 reached at 26.7 kV. All the distribution bus voltage at SD3, SD4, SD5, and SD6 were about 1.06 p.u. No equipment damage was reported either on BC Hydro side or customer side. The observed TOV values approximately matched the PSS/E offline simulation results.

B. What went wrong

- The protection communication channels did not work properly.
- SD2 230 kV CB wired wrongly result in that they cannot close when in a single pole open state.
- Sacrificial 230 kV surge arrestors did not operate
- RAS logic did not cover CB failure scenario

IV. LESSONS LEARNED

After the event, BC Hydro set up a team to analyze the event and found out that using RAS alone to mitigate TOV has the following risks:

- RAS schemes may not cover all the operating scenarios.
- Protection communication channels could go wrong.
- CB may not act properly.

And made following corrections:

- SD2 230 kV CBs were re-wired to sure they can close when in a single pole open state
- 1.15 p.u. 30-second over voltage PN on both side of 2LA and 2LB were added
- Whenever, SD2 side 2LA is opened 3-pole, a DTT signal is sent to SD2 2LB to trip 2LB 3-pole.

V. CONCLUSIONS

TOV caused by backfeeding is a well-known phenomenon. Using RAS to mitigate the TOV is an economic solution but with the certain risks. RAS schemes should be designed with care to cover as many operating scenarios as possible and tested properly. RAS should only be used when combining with other schemes such as over voltage relay and properly specified sacrificial surge arrestors to ensure that the system equipment will be protected properly from TOV impacts.

VI. REFERENCES

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[6] PSS/E Program Operation Manual (POM)