CIGRE-151 **2019 CIGRE Canada Conference**
Montréal, Québec, September 16-19, 2019

Reactive Power Planning Strategy for the BC Hydro Transmission System

YANSONG LENG, PAUL HORAN, MING ZOU, WAH SHUM
BC Hydro
Canada

SUMMARY

In British Columbia (BC) the power system topology was and still is largely influenced by the geographical makeup of the province. Extremely long electrical highways (500 kV transmission network) connect the generation (sending end) rich regions of the Northern Interior (NI) and Southern Interior East (SIE) to the main load centers (receiving end) in the Lower Mainland (LM) and Vancouver Island (VI). Approximately 80% of BC Hydro's total generation is located in the NI and SIE regions and approximately 70% of BC hydro's total load is located in the LM and VI regions. The result is extremely long heavily loaded 500 kV transmission lines supplying a very large load. Therefore, reactive power planning is an integral part of planning the receiving end transmission system because it is critical for maintaining steady state control of voltage, reducing losses, controlling the level of temporary over voltage and improving transient and voltage stability which lends to a wider operational margin.

Reactive power planning for the 500 kV transmission systems began over 40 years ago and it coincided with the build out of the 500 kV bulk transmission system. The strategy behind reactive power planning for the sending end and 500 kV transmission network is less complicated and is well defined within BC Hydro. The sending end requires minimum reactive power compensation because the high side voltage can be regulated by the local generation and the strong 500 kV transmission network was planned with series compensation and shunt reactors to increase transfer capability and control the voltage respectively. Based on current long term transmission planning studies it is not anticipated that the strategy for the sending end and 500 kV transmission network will need to change. The strategy behind reactive power planning for the receiving end transmission system is more complicated from a technical and implementation point of view.

This paper includes a brief description of the BC Hydro 500 kV transmission system, the BC Hydro system performance requirements, proposed reactive power reinforcement project, a summary of the existing BC hydro receiving end reactive compensation equipment and a discussion about the evolution of the BC Hydro receiving end reactive power planning strategy in the context of the receiving end transmission system development to date and into the future.

Transmission planning studies have identified that the BC Hydro receiving end transmission system is forecasted to be constrained. This is a result of continued load growth in the main load centres, existing reactive power equipment reaching end of life and a lack of local generation support. There

Yansong.leng@bchydro.com

are also constraints on developing the receiving end transmission system due to social, environmental and capital budget reduction commitments.

The result is an optimization in approach to the strategy BC Hydro has for planning and installing reactive power compensation at the receiving end transmission system. The objective of BC Hydro reactive power planning at the receiving end of the transmission system is to maintain reliable transmission system operation and to meet NERC and WECC transmission system voltage performance requirements under system normal and contingency conditions with minimum capital investment.

KEYWORDS

Reactive power planning, strategy, VAR, synchronous condensers, voltage stability

I. INTRODUCTION

Reactive power planning of a transmission system is an integral part of the transmission planning process and is critical for steady state control of voltage, improving transient and voltage stability, reducing losses and controlling the level of temporary over voltage and facilitating a wider operational margin.

To achieve the aforementioned conditions, reactive power planning also assesses the most optimum equipment and locations to install e.g. series capacitors, shunt reactors, shunt capacitors, Static Var Compensator (SVC), synchronous condensers and the replacement of aging VAR equipment.

Previously, considerable efforts were undertaken for reactive power planning, this included developing new computations algorithms, methodologies, principles and software optimization programs [1-8]. However, there is minimum discussion about the strategy of reactive power planning adopted in utility. In BC Hydro, the multiple million dollar investment of reactive power equipment is driven by the planning strategy. Therefore, it is necessary to discuss the reactive power planning strategy.

In this paper, the development of the strategy used in reactive power planning on the receiving end of the BC Hydro transmission system is described. The planning of reactive power supply for a given power system can only be viewed properly in the context of the characteristics and the performance requirements of that system. It is appropriate, therefore, to describe briefly the BC Hydro system in terms of its, generation and load distribution, its existing transmission network and its performance requirements of reliability and economy before proceeding with a discussion of strategy development.

II. DESCRIPTION OF BC HYDRO 500 KV TRANSMISSION SYSTEM

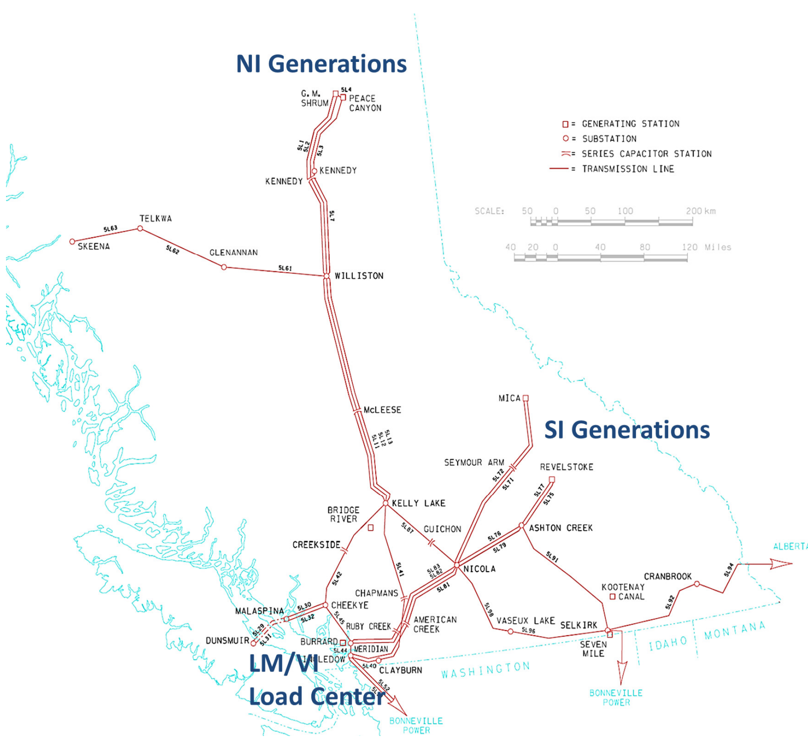

Fig 1: BC Hydro 500 kV Transmission System

Figure 1 shows an overview of the existing BC Hydro 500 kV transmission system and interconnections with the United States and neighboring province Alberta. The majority of BC Hydro loads, approximately over 70% of the total amount, are in Lower Mainland (LM) and Vancouver Island (VI) areas -so called receiving end of the system. LM area consists of two sub-regions – M region and F region.

The major generation resources, approximately over 80% of the total amount, are in the remote parts of BC, the Peace River generations in the North East of BC and the Columbia River generations in the South East part of BC - so called sending end of the system.

The Northern Interior and Southern Interior 500 kV transmission systems are joined together by a 500 kV line in the Central Interior and interconnect to LM/VI load centers via the five Interior to Lower Mainland 500 kV transmission lines. The power generated from the two remote major generation clusters are transferred to the major load centers via the 500 kV backbone transmission system. There are four 500 kV substations in LM and one 500 kV substation in VI to serve the loads.

III. BC HYDRO SYSTEM PERFORMANCE REQUIREMENTS

The basic principles of reactive power planning on the BC Hydro system must follow the overall transmission planning philosophy involved, i.e. the objectives and criteria for system performance. The objective of transmission planning for the BC Hydro system is aimed to plan and design a safe and reliable transmission system and in compliance with North American Electric Reliability Corporation (NERC) transmission planning (TPL) standards [9], and meet Western Electricity Coordinating Council (WECC) performance criteria [10] and BC Hydro transmission planning criteria.

BC Hydro reactive power planning aims to ensure system voltages are planned and operated within pre-defined limits to maintain system reliability and stability during system normal operating conditions and following system disturbances. In the planning and operating horizon, sufficient reactive resources need to be available to meet performance requirement under contingencies, ranging from winter/summer peak load conditions to light load conditions. Capital investment projects are developed to install new reactive power sources to serve load growth and replace aging VAR equipment through consistent, cost effective, sustainable, operation flexible, coordinated and efficient approaches.

In additional to the requirement identified by NERC reactive power planning [11] and WECC voltage stability guide [12], BC Hydro steady-state voltages at all distribution substation load buses must meet the following limit:

- Above 1.0 p.u. of system nominal voltage under single-contingency conditions

IV. BC HYDRO RECEIVING END REACTIVE COMPENSATION EQUIPMENT SUMMARY

The voltage level, type and location of reactive power sources used to mitigate VAR deficiency is driven by system characteristics, environmental and capital budget considerations. In the current BC Hydro receiving end system, a combination of shunt equipment including SVC, synchronous condensers and synchronous generators is operated to alleviate under-voltage and over-voltage conditions and ensure reliable pre-contingency and post-contingency voltage levels and robust system response following disturbances.

a. Voltage Level

BC Hydro reactive compensation devices are installed from 12/25 kV distribution voltage level to 500 kV transmission voltage level in the current transmission system.

b. Types and Locations

- **Series Capacitor Banks**
  To increase power transfer capability and improve system performance, approx. 50% series compensation has been applied on all 500 kV transmission lines from the Interior to the Lower Mainland. Since series compensation is more related to real power planning, it will not be discussed in detail in this paper.

- **Switched/fixed Shunt Reactors**
  To control steady state, temporary and switching over-voltages BC Hydro installed shunt reactors from transformer tertiary voltage levels to 500 kV. The switched shunt reactors will not be discussed in detail in this paper because it is equipment insulation coordination related.

- **Switched/fixed Shunt Capacitor Banks**
  BC Hydro installed approx. 2,000 MVArs of shunt capacitor banks at the receiving end of the transmission system. Approx. 1,000 MVArs of 230 kV shunt capacitors (8 units) were installed at two major 500 kV substations – 5A and 5B in the LM for 500 kV line contingency conditions. Approx. 150 MVArs of 138 kV shunt capacitor banks were installed with four synchronous condensers in VI to support transmission system voltage under various system conditions. The remaining shunt capacitors were mainly on 12/25 kV distribution voltage level installed within substations. Some distribution voltage level capacitors were installed on the feeders to avoid substation expansion.

- **Synchronous Condensers**
  There are a total of eight synchronous condensers which serve the following purposes:
  - Four condensers (2 x +100/-79 MVArs and 2 x +55/-50 MVArs) were installed on VI side of a HVDC system between LM and VI to contribute short-circuit capacity in the 1960s and 1970s.
  - Four condensers (4 x +100/-50 MVArs) were initially gas fired turbine generators in 2S station interconnecting to 5A 500 kV substation in LM area. With the retirement of the Gas fired generation in 1990s, 4 out of 6 generation units were converted to synchronous condensers to provide voltage support to the 500 kV transmission system for 500 kV line contingencies.

- **Static Var Compensator**
  One +165/-135 MVArs SVC was installed in the early 1990s at a 500 kV substation in VI for a double 500 kV line contingency condition to prevent VI transmission system from voltage collapse.

- **Synchronous Generator**
  There are approx. 2,000 MW of dependable synchronous generators operated in LM and VI at receiving end of BC hydro transmission system, which is capable of providing voltage support under system normal or contingency conditions.

c. Sizing

BC Hydro generally has standard sizes for shunt capacitor banks at different voltage levels at the receiving end of the transmission system. The exception to this is in some remote areas of BC with weak system strength or long radial lines. In these instances BC Hydro has installed non-standard size for shunt capacitors. All standard sizes for shunt capacitor banks are summarized as follows:

- 230 kV shunt capacitor bank standard is 125 MVArs
- 138 kV shunt capacitor bank standard is between 20 and 40 MVArs
- 60 kV shunt capacitor bank standard is 10 or 20 MVArs

- 25/12kV shunt capacitor bank standard is 10 or 20 MVArs

The size of synchronous condensers, SVC and generators are determined on case by case basis.

d. Operating Mode

With the exception of some small distribution shunt capacitors and HVDC filter capacitors which are fixed type, the majority of the shunt capacitors are switchable and capable to be operated either by AutoVar control schemes or supervisory control.

V. BC HYDRO REACTIVE POWER PLANNING AT THE RECEIVING END OF THE SYSTEM

The objective of BC Hydro reactive power planning at the receiving end of the transmission system is to maintain reliable transmission system operation and to meet NERC and WECC transmission system voltage performance requirements under system normal and contingency conditions with minimum capital investment.

The major principles of BC Hydro reactive power planning at the receiving end of the transmission system are as follows:

- Each transmission system (such as LM and VI) should be properly planned so that the system will be adequately compensated locally for system normal and contingency conditions to avoid reactive power transfer over long distances.
- Each voltage level of the transmission system should be properly planned to ensure each level has an adequate amount of reactive power reserved for system normal and single contingency conditions. There should be minimum reactive power penetration between different voltage levels.

a. Previous Strategy

In the 1980s BC Hydro developed a reactive power planning strategy using the above objectives and principles. The strategy at the receiving end has two layers of reactive power compensation: At 500 kV level and at distribution voltage level as shown in the Figure 2.

The regional transmission systems, 230 kV, 138 kV and 60 kV in the LM, between 500 kV system and distribution system had sufficient capacity for real power transfer and adequate reactive power reserves because of the lower load levels and several underground 230 kV cables installed in M region of LM. Therefore, the previous strategy did not require reactive power compensation equipment in between 500 kV and distribution voltage levels at the receiving end.

There are two major types of reactive power reinforcement projects implemented in the LM and VI based on the above strategy:

- From early 1980s until early 2000s, BC Hydro installed eight 230 kV shunt capacitor banks at the 5A and 5B 500 kV substations (four units at each substation for a total of 1,000 MVArs) to provide centralized voltage support to the 500 kV transmission system for 500 kV line contingency conditions. The reason 230 kV shunt capacitors were chosen instead of 500 kV shunt capacitor banks was because the technology of the 230 kV shunt capacitors was more mature at that time and the neighboring utilities already had operational experience with 230 kV shunt capacitor banks since the 1980s. The VAR losses crossing the step-up transformers were considered.

- In the early 1990s, BC Hydro implemented VAR optimization projects in the LM and VI which involved the installation of shunt capacitor banks at 12 and 25 kV voltage levels at distribution substations to meet load growth. The optimization purpose of this was to provide local VAR compensation, increase overall receiving end system load power factor and reduce VAR losses at minimum capital cost. For substations where did not have enough space, the designated shunt capacitors were installed on distribution feeders outside the substations to avoid station expansion. A total of 800 MVArs distribution shunt capacitor banks have been in service in the LM and VI system.

The 500 kV and distribution layers reactive power planning strategy worked effectively in the past 40 years to meet the planning objectives and principles.

As load demand continuously grows, transmission planning studies have identified that the receiving end transmission system is forecasted to be constrained. The previous strategy is no longer adequate and the strategy has been optimized to meet the increased load supply demand while fitting in with the overall transmission planning strategy. The following has contributed to the needs to update the previous strategy:

- The 500 kV bulk transmission system requires more VAR support than before because it is heavily loaded during peak load operation period under contingency conditions.
- The 230 kV shunt capacitor banks at 5A and 5B and the four synchronous condensers at 2S which were originally designed for 500 kV transmission line contingencies are now provides voltage support to regional system during system normal conditions.
- Regional 60 kV and 230 kV transmission networks are approaching their thermal and voltage supply limits, half a century after they were built.
- No new transmission line and reactive power compensation projects to reinforce the regional transmission system were implemented in the past 20 years.

b. <u>Continuous Strategy Development</u>

The result is an optimization in approach to the previous strategy BC Hydro has for planning and installing reactive power compensation at the receiving end transmission system. To address regional (230 kV, 138 kV and 60 kV) transmission system as well as the 500 kV transmission system constraints, centralized VAR compensation is considered as the most economical solution for the receiving end transmission system. The reactive power compensation optimizations are as follows:

- Add a third layer of VAR compensation at 230 kV voltage level and plan the VAR compensation in the long term planning horizon until the 230 kV system becomes saturated.
- Within the 230 kV layer, VAR compensation will be further optimized into two sub-regions M and F to resolve local system constraints.
- Gradually phase out the existing feeder capacitors and replace them with 230 kV shunt capacitors.
- No 60 kV shunt capacitors will be planned because the existing 60 kV transmission system in LM area is planned to be gradually phased out in future.

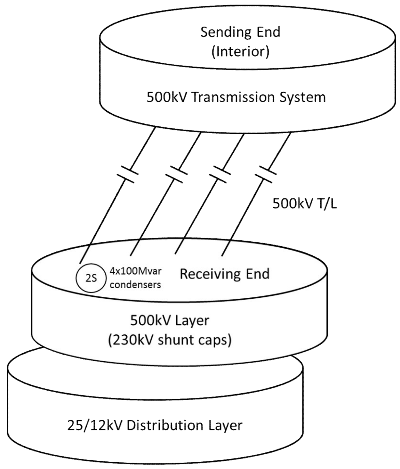

Fig 2: BC Hydro Receiving End Strategy Diagram (Previous)

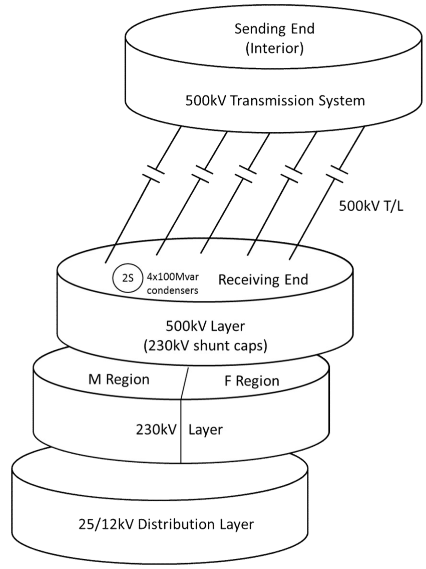

Fig 3: BC Hydro Receiving End Strategy Diagram (Optimized)

The introduction of one more voltage layer of VAR compensation as shown in Fig. 3 defers new line reinforcement investment.

Recently, a reactive power reinforcement project was initiated based on the optimized strategy. The proposed project background, system constraints, study findings, alternatives and potential project scope are as follows:

- **Project Background**
  Synchronous condensers at 2S station in M region are reaching end-of-life and BC Hydro is considering retiring four condensers and replacing them with other type of reactive power equipment or to re-invest in the same location and continue its operation to meet transmission system requirement.
- **System Constraints**
  During the annual NERC Transmission Planning assessment, system performance violations were identified in the F regional system under single contingency conditions. There is an opportunity to optimize the VAR compensation by relocating VAR equipment from the current 2S location to the F region so that the VAR equipment can provide reactive power support to the 230 kV F regional system during line and transformer contingency conditions and to the 500 kV bulk system for 500 kV line contingency conditions.

- **Study Findings**
  System studies including steady state power flow, PV analysis, QV analysis [13] [14] and transient stability were performed and the study recommendations were as follows:
  - The need of fast transient dynamic VAR equipment has not been observed.
  - A total of 500 MVArs switched shunt capacitor banks are required to replace 2S 4 x +100 MVArs synchronous condensers
  - Additional 250 MVArs switched shunt capacitor banks are required in F region to meet the system performance requirement.

- **Alternatives**
  After optimization studies, the reactive compensation device location, voltage level and size were determined and three alternatives were selected for the next stage of the project lifecycle. The project scope of one of the alternatives is as follows and shown in the Fig.4:
  - Install 1 x 250 MVArs 500 kV Switched Shunt Capacitor at 5B 500 kV substation

- Install 4 x 125 MVArs 230 kV Switched Shunt Capacitors in three substations in F region.
- Install 2 x 132 MVArs 230 kV shunt reactors at 230 kV buses of substation 5B

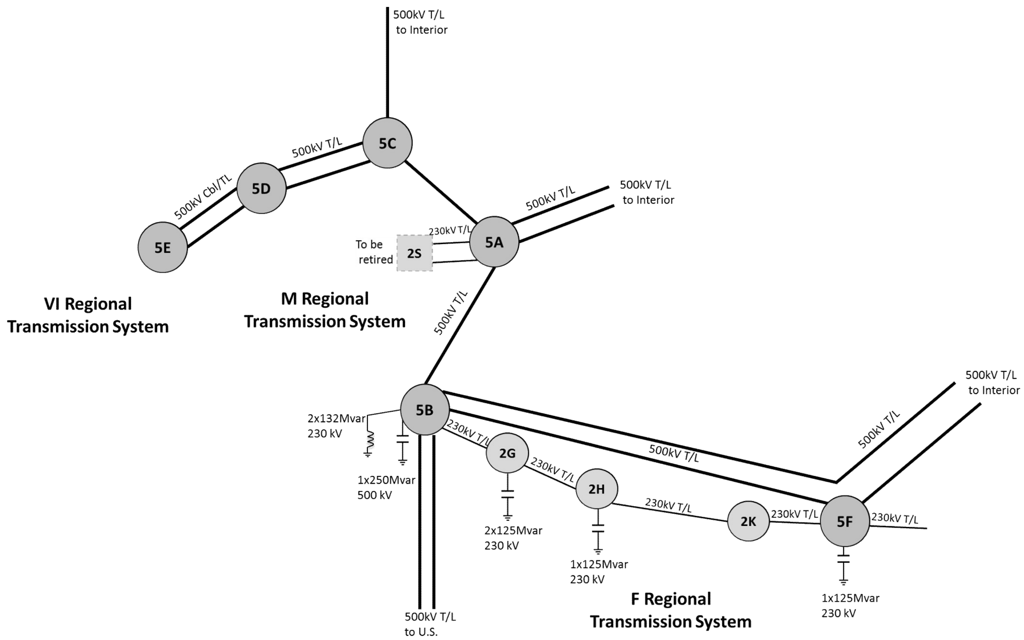

Fig.4 Proposed Reactive Power Reinforcement Project

VI. CONCLUSION

The planning of reactive power sources on the receiving end of the BC Hydro transmission system takes into account reliability, operating and economic factors. The previous planning strategy worked efficiently in the past 40 years. However, it will no longer meet the future reliability supply requirement. The strategy was further optimized to meet planning requirements in the long term planning horizon and a project is being implemented.

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