

# Summary of Electric Transmission Assessment Report

*January 2010*

## **Assessment and Analysis of the State-Of-the-Art High-Voltage Electric Transmission Systems with Specific Focus on High-Voltage Direct Current (HVDC), Underground or Other New or Developing Technologies**

*Prepared by Stantec, Areva and Power Delivery Consultants for the Alberta Department of Energy, October 2009*

### **About the Study**

An assessment and analysis of high-voltage electric power transmission systems was conducted for the Alberta Department of Energy (ADOE) by Stantec Consulting Ltd. (Stantec), with assistance from AREVA T&D, Power Delivery Consultants (PDC), ABB, and Siemens AG Energy Sector. The study was intended to provide factual information on power transmission system alternatives for potential application in Alberta.

### **Central Conclusions**

The study concluded that overhead high-voltage alternating current (HVAC) transmission lines provide a good balance from a cost and technical perspective. This technology will likely remain the main option for power transmission. High voltage direct current (HVDC) transmission systems provide benefits such as: significantly less right of way than for an equivalent capacity HVAC transmission line, reduced land impact, efficient control of power flows and lower overall cost compared to a HVAC transmission system for longer transmission distances. New technologies for HVDC are continually evolving and may be considered for specialized applications. Underground transmission – be it alternating current (AC) or direct current (DC) – is expensive, but it may be an option for shorter distances in areas such as densely populated urban and commercial regions where there is limited right-of-way for overhead transmission. The longest 500 kilovolt (kV) HVAC underground transmission system, currently in operation, is approximately 40 km and is located in Japan.

### **Background**

The backbone of Alberta's electric power system is a network of transmission lines or "grid" that carries electricity over long distances at high voltage. Substations near power plants facilitate the movement of energy onto the grid, and substations near populated areas (or "loads") transfer the energy into local distribution networks that function at lower voltage levels.

No significant high-voltage transmission line projects have been undertaken in Alberta in the last two decades. The demand for power in the province has escalated substantially over the same period. Additional high-voltage transmission capacity offers Alberta the promise of: enhancing the reliability of the transmission system (i.e. keeping the lights on); helping sustain economic growth; enabling efficient use of renewable energy; minimizing land use impacts; and reducing energy losses associated with transmission. As technology evolves, there are new technologies becoming available for power transmission. This study aimed to better inform the selection of high-voltage transmission system alternatives, through objective consideration of:

- Overhead and underground transmission;
- Transmission via AC and DC; and,
- New and developing power transmission technologies.

## Overhead and Underground Transmission

High-voltage overhead transmission is the prevalent means of power transmission in Alberta and in North America today. Electricity travels through a metal conductor, most often aluminum. The air enveloping the transmission line insulates the conductor from the ground. Porcelain, glass or polymer units are used to support the line and insulate the conductor from the tower structure.



Power can also be transmitted underground, although only a small fraction of high-voltage transmission has been constructed in this fashion to date. Underground transmission power cables are insulated with a medium (oil, paper, polymers or even compressed gas) and set in a duct, tunnel, or thermal backfill material.

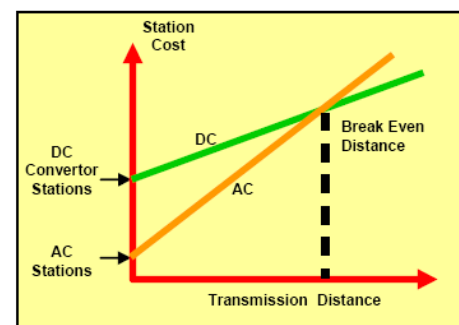


High-voltage overhead transmission is much less expensive to build and much quicker to repair than underground transmission, but it requires wider "right-of-ways." A right-of-way is the strip of land needed to locate, build, operate and maintain a transmission line or cable. There is also the question of environmental impact. High-voltage underground transmission is not without its environmental impact, but it has seen increasing application in densely populated urban and commercial areas where there is limited right-of-way. Public concerns have also been expressed regarding radio interference, audible noise, corrosion effects, electric fields and electromagnetic fields associated with high-voltage overhead lines.

## Transmission via AC and DC

DC is the oldest transmission method we know – Italian-born physicist Alessandro Volta achieved the first transmission of electricity by linking positively-charged and negatively-charged connectors and driving an electrical charge through them in the early 1800s – but AC has long-since assumed prevalence. Electricity must be transmitted and distributed at high voltages, but is required to be transformed to lower voltages to be used by consumers. Because of this, AC has been adopted for use throughout the world because of the ease and efficiency by which it can be transformed from one voltage to another.

Although transforming DC voltage levels is much more complex, DC can be a more economic way to move electricity over long distances; a HVDC system can carry greater power per conductor than an equivalent HVAC system, resulting in greater power per transmission line. At the sending end of a HVDC transmission line or cable, a station is required to convert AC into DC. A similar station is required at the receiving end to convert DC back to AC so it can be transmitted and distributed to where it will be used. The chart on the right illustrates that DC's higher station costs



reduce its transmission cost advantages over short distances. Today, HVDC's main applications are for efficient bulk power transfer, point-to-point, over longer distances, using overhead lines or submarine cables. HVDC is also employed for interconnection of asynchronous regions (e.g. the Alberta and Saskatchewan grids).

### **New and Developing Power Transmission Technologies**

This study gave consideration to developing technologies for HVDC transmission. Voltage Source Converter (VSC) HVDC overhead transmission is an advancement on the traditional method of HVDC transmission. VSC itself is not new, but the recent availability of high-voltage, high-power transistors now permit the additional features provided by this technology to be used for HVDC transmission. VSC technology may also have application in HVDC underground transmission. Another technology considered was "ultra-high-voltage direct current" (UHVDC) overhead line technology. Any voltage level of 600 kV or higher is classified as UHV. UHVDC is like HVDC in concept and differs only in its voltage level. A system has just been completed in China that operates at 800 kV.

### **Criteria for Comparison**

This study compared the following technologies believed to have potential application in Alberta:

1. Conventional overhead HVAC transmission lines;
2. Underground HVAC transmission cables;
3. Combinations of HVAC overhead and underground transmission;
4. HVDC systems; and,
5. New and developing technologies.

The following criteria were employed in these comparisons:

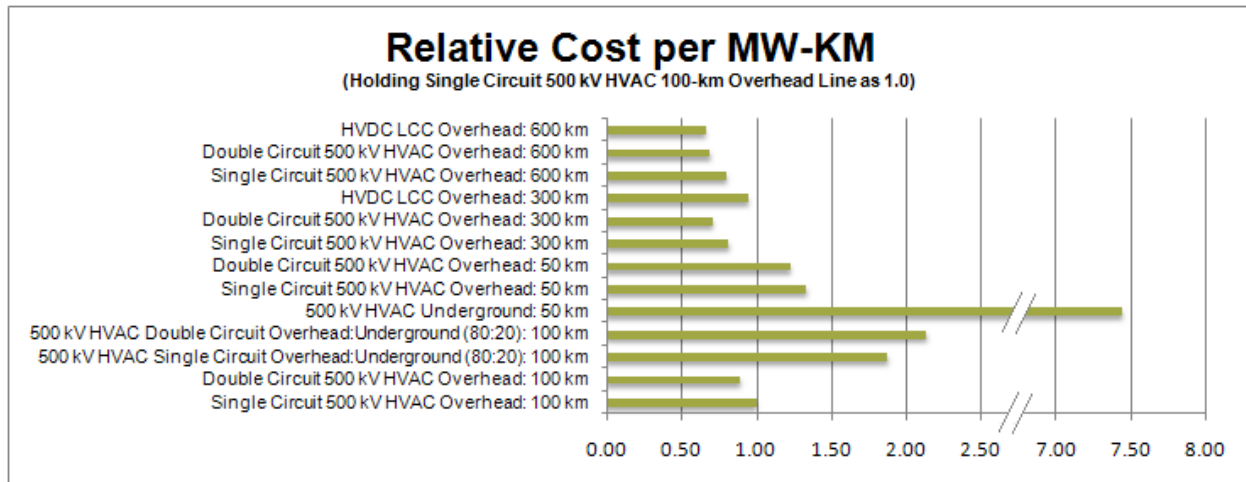
- Power transmission capabilities and voltage levels;
- Length of a transmission line or cable;
- Technology;
- Environmental concerns;
- Cost; and,
- Reliability, efficiency, performance, and operational features

Cost summaries were developed for 50-km, 100-km, 300-km, and 600-km transmission line scenarios where applicable.<sup>1</sup> Scenarios assumed a 500-kV line.<sup>2</sup> A chart portraying the estimated installed costs for each technology option – relative to the installed cost of a single circuit 500 kV HVAC overhead transmission – follows:

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<sup>1</sup> The cost estimates in this study are indicative only; they are based on numerous assumptions. They do not incorporate land costs, which vary across the province. Actual costs are application-specific and are verified during the detailed design stage, when many of the design criteria decisions are made.

<sup>2</sup> In Alberta, 69/72 kV, 138/144 kV, 240 kV and 500 kV are the transmission voltages currently in use. Distribution systems operate at lower voltages, normally less than, or equal to, 25 kV.



Relative costs of transmission technologies compared to a single circuit 500 kV HVAC 100-km overhead line. (Note: Relative costs are indicative only and will vary depending upon the actual design requirements and costs at time of construction.)

Advantages, disadvantages and the study’s overall conclusion for each technology option are identified in the section that follows. Criteria by which the options were compared are examined in greater detail in main body of this report.<sup>3</sup>

### 1. Conventional Overhead HVAC Transmission

The advantages and disadvantages of conventional overhead HVAC transmission can be summarized as follows:

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<ul style="list-style-type: none"> <li>▪ Standard construction in North America – proven technology</li> <li>▪ Lower cost than alternative technologies</li> <li>▪ Increased capacity by double circuit at low incremental cost</li> <li>▪ Easily interconnected into the power system</li> <li>▪ Good reliability</li> <li>▪ Easy and quick to repair</li> <li>▪ Easy to dismantle and completely restore the environment at the end of its service</li> </ul>	<ul style="list-style-type: none"> <li>▪ Visual impact</li> <li>▪ Longer distances may require reactive power compensation, i.e. intermediate station with Flexible AC Transmission Systems (FACTS) device</li> <li>▪ Concerns about AC electromagnetic field (EMF)</li> </ul>

To date in Alberta all 500 kV transmission lines are overhead HVAC lines, constructed with conventional steel lattice towers, insulators and wire. At 500 kV HVAC, an overhead transmission line can be built to support either a single circuit, or two circuits which is commonly called a double circuit transmission line. A double circuit line costs less to install than two single circuit lines and can double transmission capacity over a single circuit line while only slightly expanding the right-of-way. A double circuit line does require a higher transmission tower than a single circuit line.

<sup>3</sup> Detailed electrical modeling studies or simulations, which shed light on how the electric system will “behave” and if it will operate in a stable and predictable manner, will assist in verifying the feasibility of integrating various types of high-voltage apparatus or technology within existing systems. These modeling studies were not part of this report.

The study's conclusion is that overhead transmission lines are a good balance from a cost perspective. For power transmission distances in the shorter to medium range, 500 kV HVAC overhead transmission lines with the use of FACTS technologies will remain the central option. For higher capacity and longer transmission distances, the use of HVDC transmission should be considered.

## 2. Underground HVAC Transmission

The advantages and disadvantages of underground HVAC transmission can be summarized as follows:

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<ul style="list-style-type: none"> <li>▪ Low visual impact, except for transition stations, reactor stations and link boxes</li> <li>▪ Very few weather-related outages</li> <li>▪ Applications in densely populated urban and commercial areas where right-of-way is limited for overhead</li> </ul>	<ul style="list-style-type: none"> <li>▪ Few 500 kV underground cables in service in the world – lack of operational experience – the longest 500 kV HVAC cable link is 40 km</li> <li>▪ Need for reactive power compensation – additional shunt reactor stations at short intervals (10 to 30 km)</li> <li>▪ Difficult to repair</li> <li>▪ Need 100% redundancy (duplication of cables)</li> <li>▪ Very high cost</li> <li>▪ Difficult to dismantle and restore the natural environment</li> <li>▪ Heat emission from cables may reduce capacity</li> </ul>

Alberta does not currently have a 500 kV HVAC underground transmission cable installation. The highest voltage for an underground cable system that is operational in Alberta is 240 kV, and these lines are few in number. These 240 kV cable installations pass through densely populated urban areas in cities where there is no available right-of-way for an overhead transmission line.

The technology for manufacturing 500 kV underground cables and their associated splices is a relatively recent development in the transmission industry. The first installation of a 500 kV cable was completed in Japan in 1999. Because repair time in the event of a cable failure can take up to two months, system reliability can only be assured by doubling the number of cables installed; this adds significantly to the cost of underground transmission.

The study's conclusion with respect to HVAC underground cable transmission is that it has potential application for short distances (less than 50 km) where overhead transmission cannot be accommodated such as in densely populated urban and commercial areas with limited right-of-way for overhead transmission. For longer underground transmission distances, the overall investment and operational costs will be less if an HVDC solution is used.

## 3. Combinations of HVAC Overhead and Underground Transmission

The advantages and disadvantages of combination overhead/underground HVAC transmission can be summarized as follows:



<ul style="list-style-type: none"> <li>▪ Low visual impact for the underground cable segment</li> </ul>	<ul style="list-style-type: none"> <li>▪ Visual impact of overhead line segments and transition stations</li> <li>▪ Very high cost for the underground cable segment</li> <li>▪ Large transition stations are needed to place lines from overhead to underground and vice versa</li> <li>▪ Construction difficulties at underground cable crossings of natural and manmade obstacles</li> <li>▪ Heat emission from the underground cables</li> <li>▪ Long repair time on cable segment of the line</li> <li>▪ The reduced capacity of the underground cable segment reduces the capacity of the overall line</li> </ul>
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Alberta has only one 240 kV AC transmission installation where part of the transmission is an overhead line and part is underground cable. Two overhead lines, one starting at the Petrolia Substation the other starting at the Ellerslie Substation, convert to underground cables at the Argyll Transfer Station in Edmonton. These underground cables then end at the Bellamy Terminal Station near downtown Edmonton. Large transition stations are also required at the point on the route where the overhead line converts to underground cable and again to convert the underground back to the overhead line.

The conclusion of this study with respect to the combined overhead-underground HVAC transmission option is that, while not a simple solution, it can be possible where the substantially increased cost of the project can be justified. The solution is generally workable for transmission lines that enter into densely populated urban and commercial areas where there is limited right-of-way. Two parallel cable systems must be constructed to ensure continued operation due to the considerable time to repair if one of the cables break.

#### 4. HVDC Systems

##### 4.1 HVDC Overhead Transmission

The advantages and disadvantages of HVDC overhead transmission can be summarized as follows:



<ul style="list-style-type: none"> <li>▪ High capacity bulk power transfer</li> <li>▪ Maximizes transmission capacity with reduced right-of-way and lower transmission cost than HVAC</li> <li>▪ Less visual impact when compared to HVAC lines</li> <li>▪ Optimal power flow can be achieved</li> <li>▪ Lower transmission losses</li> <li>▪ Able to control power flow and direction</li> <li>▪ Converter stations can be built in stages, reducing the initial cost impacts (expandable)</li> <li>▪ HVDC link can interconnect asynchronous networks, e.g. Alberta - Saskatchewan power grids</li> </ul>	<ul style="list-style-type: none"> <li>▪ High cost of converter stations</li> <li>▪ Expensive to make taps: to take power out of a point-to-point scheme along its length</li> </ul>
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Conventional HVDC (HVDC Line Commutated Converter (LCC)), systems are specialized types of transmission systems. The main application for this technology is for applications where there is a requirement to transmit large quantities of power over longer distances. The cost for an overhead HVDC transmission line is significantly less than its HVAC counterpart; however, the costs of the converter stations at each end of the transmission line are high and increase the total cost of HVDC transmission systems.

The conclusion of this study with respect to 500 kV HVDC LCC overhead transmission is that, for the transmission of bulk power at longer distances, it has a lower cost than a comparable HVAC option. For shorter transmission distances, the HVDC option may be preferred due to its ease of efficient control of power flow, in situations where asynchronous systems have to be connected, where flexibility is needed for increasing power capacity (expandable) in the future, or in cases where environmental concerns weigh more heavily.

#### ***4.2 HVDC Underground Transmission***

There are no underground applications of conventional 500 kV HVDC technology due to the type of cable currently available. The only application of cable systems with conventional HVDC technology is the use of submarine cable for crossing large bodies of water. As this cable technology continues to evolve, this method may be an option for future underground applications. The conclusion of this study with respect to conventional HVDC underground transmission is that it is not currently practicable.

### **5. New and Developing Technologies**

#### ***5.1 HVDC Overhead Transmission (HVDC Voltage Source Converter (VSC))***

The advantages and disadvantages of HVDC VSC overhead transmission can be summarized as follows:

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<ul style="list-style-type: none"> <li>▪ Can accommodate multi-terminal operation</li> <li>▪ Less visual impact when compared with HVAC lines</li> <li>▪ Reduced right-of-way</li> <li>▪ Reduced operating voltages</li> <li>▪ Continuously variable power from full power in one direction to full power in reverse</li> <li>▪ VSC has no reactive power demand</li> <li>▪ Area required for VSC converter is less than for LCC</li> </ul>	<ul style="list-style-type: none"> <li>▪ No commercial operation to date – first overhead transmission link using this technology will be in service in 2010</li> <li>▪ Due to very high cost of converter stations, this alternative is considered only for relatively long transmission distances</li> <li>▪ Available VSC converter power ratings are less than for LCC</li> <li>▪ Higher converter losses than for LCC</li> </ul>

HVDC VSC overhead transmission systems are not in commercial operation to date. The first application of VSC technology with an overhead transmission line is scheduled to be commissioned in 2010. VSC-based HVDC demonstrates characteristics similar to HVDC based on LCC.

The conclusion of this study with respect to HVDC VSC overhead transmission is that in the future this technology will be used for overhead transmission voltages up to about 640 kV, for bipole power ratings up to 2,400 megawatts (MW).

### 5.2 HVDC VSC Underground Transmission

The advantages and disadvantages of HVDC VSC underground transmission can be summarized as follows:

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<ul style="list-style-type: none"> <li>▪ Less visual impact when compared with HVAC cable lines</li> <li>▪ Low operating voltages</li> <li>▪ Practically no charging current during steady state operation</li> <li>▪ Easy transport of cables, can be spliced using pre-molded joints</li> <li>▪ Very small DC magnetic field for closely laid opposite pole cables</li> <li>▪ Compact VSC converter dimensions</li> </ul>	<ul style="list-style-type: none"> <li>▪ High cost</li> <li>▪ Very low capacity – power transmission rating of HVDC extruded polymer cables is limited: currently in range of 200-400 MW</li> <li>▪ Higher converter cost when compared to LCC</li> <li>▪ Higher converter power losses</li> <li>▪ Complete loss of transmission if one cable or one leg of converter of VSC bipolar goes out of service</li> </ul>

Keeping in mind the limitations of HVAC power cables and HVDC mass impregnated (MI) cables for underground application, the use of HVDC cables with extruded polymer insulation may be the only technical solution for long distance electric power transmission where undergrounding is required along the complete route. HVDC cables with VSC converters currently in service can transmit relatively small amounts of power (in the range of 200-400 MW).

The conclusion of this study with respect to HVDC VSC underground cable transmission is that while its practical application is currently limited, in the future it may eventually find application at voltages up to about 400 kV and power levels up to 1,500 MW.

### 5.3 UHVDC LCC Overhead Transmission

The advantages and disadvantages of UHVDC LCC overhead transmission can be summarized as follows:

+	-
<ul style="list-style-type: none"> <li>▪ Very high capacity</li> <li>▪ Less visual impact when compared with HVAC lines</li> <li>▪ Reduced right-of-way, lower losses over long distances</li> <li>▪ No limitation on distance due to stability constraints</li> <li>▪ No reactive power demand at intermediate points</li> <li>▪ Potential solution for very long distance bulk power transmission (greater than 600 km)</li> </ul>	<ul style="list-style-type: none"> <li>▪ Very limited commercial operation to date</li> <li>▪ Visual impact</li> <li>▪ Due to high cost of converter stations, this alternative is considered only for very long transmission distances</li> <li>▪ Large amount of power concentrated in one line</li> <li>▪ Technology cannot be applied in Alberta</li> </ul>



The first UHVDC LCC system has just been commissioned in China.. The main application of the UHVDC LCC is when there is a requirement to transmit very large amounts of power (up to 6,400 MW) over very long distances. Because of this, UHVDC LCC technology will only be used in very large electrical systems.

The conclusion of this study with respect to UHVDC LCC overhead transmission is that the Alberta interconnected system is not of a sufficient size to warrant deployment of UHVDC LCC overhead transmission.

### *Summary and Conclusions*

The study was intended to generate factual information on power transmission system alternatives for potential application in Alberta. This study aimed to better inform the selection of available transmission system alternatives, through objective consideration of:

- Transmission overhead and underground
- Transmission via alternating current and direct current
- New and developing power transmission technologies

Overhead transmission is the prevalent means of power transmission in Alberta – and in North America – today. It is much less expensive to build and much quicker to repair than underground transmission, but it requires wider right-of-ways. Conventional AC overhead transmission is a practical technology for shorter and medium transmission distances.

With respect to the combined overhead-underground HVAC transmission option, while not a simple solution, it can be possible where the substantially increased cost of the project can be justified. It may be a viable option for transmission lines that enter into densely populated urban and commercial areas where there is limited right-of-way for overhead transmission. Two parallel cable systems must be constructed to ensure reliable operation due to the considerable time to repair when one of the cables break. This ensures that the line will continue in operation during repairs.

For longer transmission distances, the use of high-voltage HVDC transmission should be considered. HVDC can be a more economic way to move electricity over longer distances; a HVDC system can carry greater power per conductor than an equivalent AC system, resulting in greater capacity per transmission line. Today, HVDC's main applications are for efficient bulk power transfer, point-to-point, over longer distances, using overhead lines.

Other technologies, including HVDC VSC and UHVDC LCC, continue to be developed but are not practicable in Alberta at this time.

*Glossary of Terms*

Active power	Active power is useable power that can perform real work (e.g. light, motion, and heat).
Alternating current (AC)	AC is current that flows alternately in one direction and then in the reverse direction. In North America, the standard for alternating current is 60 complete cycles each second, 60 Hertz.
Cable splice	A cable splice is a joint made by connecting (splicing) two cable ends.
Direct current (DC)	DC is current that flows continuously in the one direction. The current supplied by a battery is DC.
Electromagnetic induction	Electromagnetic induction is a phenomenon that occurs when a voltage is induced across a conductor situated in a time-varying magnetic field.
Flexible AC transmission systems (FACTS)	FACTS are power electronic based systems that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability.
Grid	The grid is a network of transmission and distribution lines that deliver power from generation to load
Jointing bay	A jointing bay is a structure where cable splices are housed.
Link box	A link box is usually placed near a jointing bay and contains removable links that allow portions of the underground cable to be isolated.
Load	Loads are entities that consume electrical energy.
Electrical losses	Electrical losses occur when current flows through a conductor and is met by resistance. As current flows through a conductor, electrons collide with particles within the conductor. This collision releases energy in the form of heat and is called an electrical loss.
Magnetic field	A magnetic field is a physical field produced by magnetic materials and moving electrical charges.
Reactive power	Reactive power is unusable power that flows between inductors and capacitors, and is required in certain case such as startup of electrical motors.
Submarine cables	Submarine cables are power cables designed specifically for underwater use.
Transition station	A transition station is a station in which overhead transmission lines are connected to underground transmission cables.