ABB Response
August 20, 2009

Stantec Consulting
Request for HVDC Information
on behalf of Alberta Department of Energy

Background

Stantec has been awarded a study by the Alberta Department of Energy, to study and compare all of the available technologies for the transmission of bulk electrical power within the province of Alberta. In particular we have been requested to compare the following technologies:

- 500 kV AC overhead lines
- 500 kV AC underground cables
- HVDC in the conventional LCC with overhead lines
- HVDC in the conventional LCC with underground cables
- HVDC in VSC with overhead lines (in all HVDC voltages available)
- HVDC in VSC with underground cables (in all HVDC voltages available)
- FACTS systems
- Other technologies

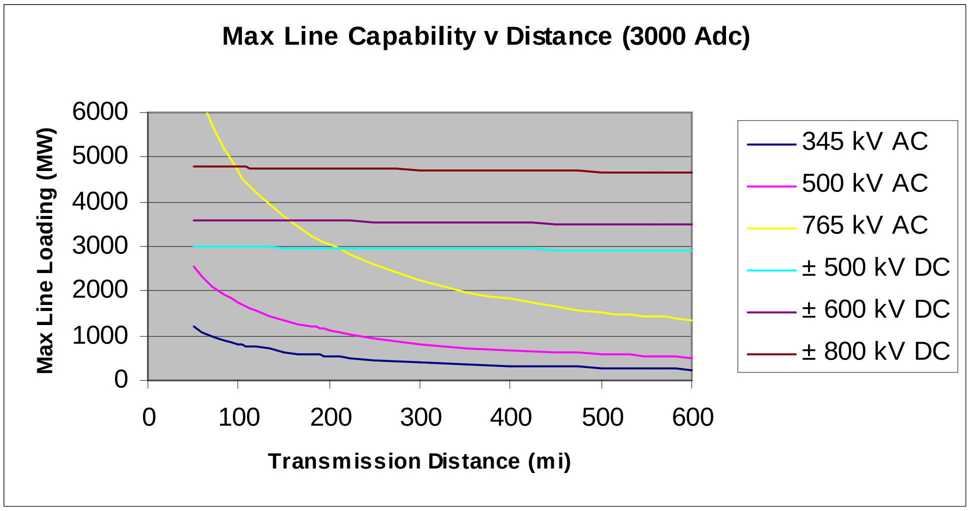
Since your firm is a supplier of HVDC systems, we would request that you provide information to Stantec with respect to the HVDC systems described above, including approximate or budgetary prices and the power transmission capabilities. We would like to include your information into our report. Stantec can provide the transmission line and transmission cable information required.

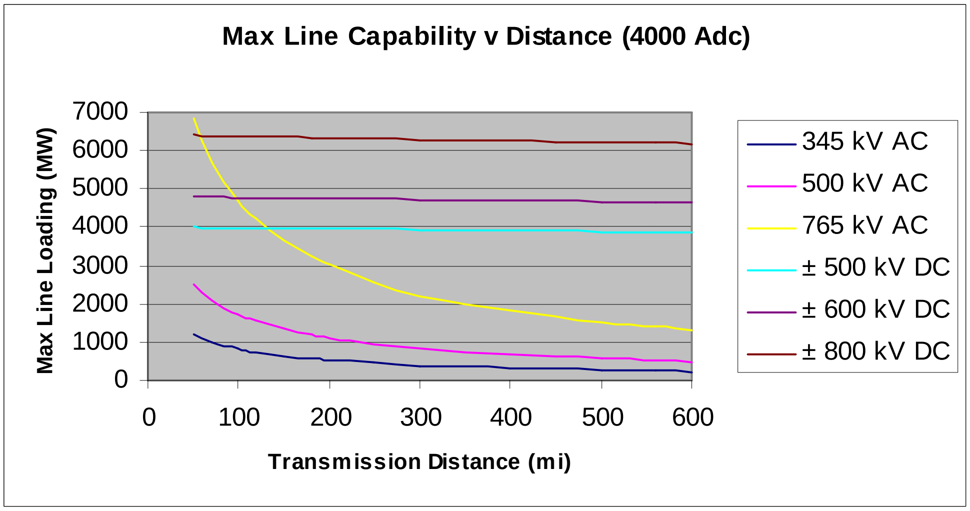
In addition we request any current information that you may have regarding:

- For proven HVDC technology, how many installations of the various types do you have installed worldwide
- Does your firm currently have any HVDC orders placed, especially for "cutting edge" systems for the various HVDC systems or "other technology" including FACTs systems, if so can you provide some details
- Within a 5 year time period, does your firm expect to be bringing new technology or systems to the market, and to provide some details of the possible offering

Power Transmission Capabilities

EHV AC and Conventional HVDC with OVHD lines:
The following sets of curves compare power transmission capability versus distance as a function of voltage for EHV AC and conventional HVDC transmission lines for two different available dc current ratings, 3000 A and 4000 A. The EHV AC transfer ratings versus distance are based on St. Clair loadability curves.[1]





The HVDC lines use a bipolar configuration with two independent circuits. HVDC converter overloads of approximately twenty-five percent, 25%, are possible. The transfer capability of the AC lines can be increased by the addition of series compensation or by intermediate switching stations with shunt compensation.

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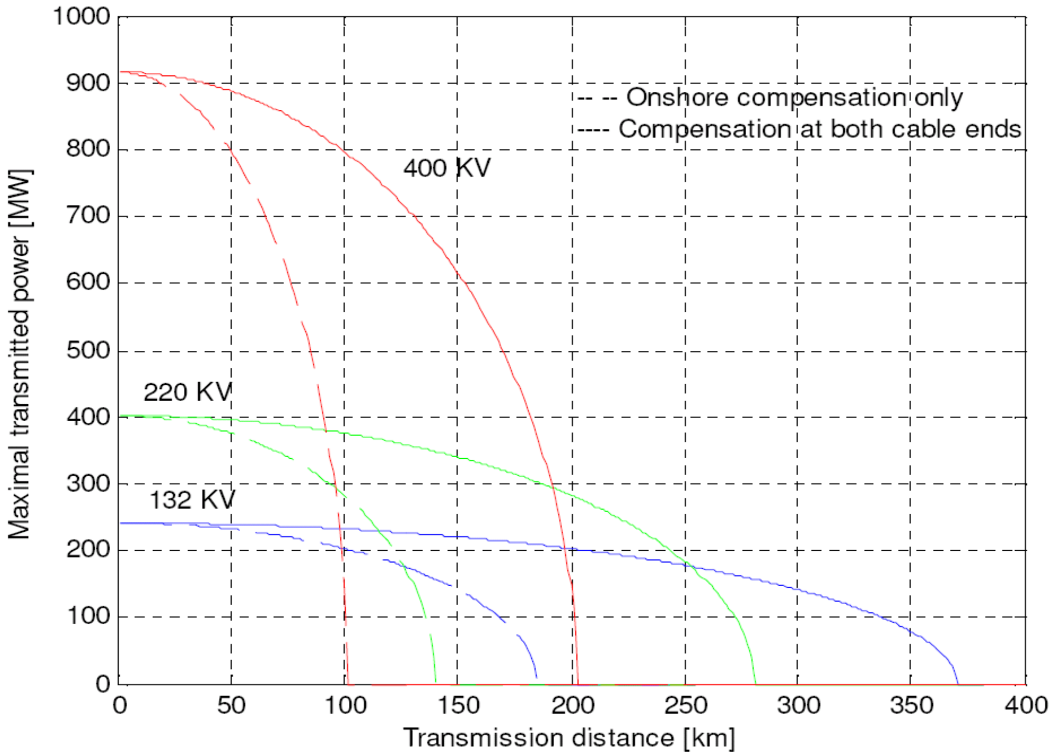
[1] "Analytical Development of Loadability Characteristics for EHV and UHV Transmission Lines," Dunlop, Gutman, and Marchenko, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-98, No. 2 March/April 1979.

AC Underground Cables:

The following set of curves depicts typical transfer capability for AC cables as a function of voltage and distance[2]. The drop off in transfer capability with distance for a given ampacity is due to the cumulative effect of charging current. There is no such effect for HVDC cables. These curves are indicative since cable capacitance varies with its physical characteristics such as type and thickness of insulation material, conductor size etc.



Conventional Mass-Impregnated, Lapped-Paper HVDC Cables:

Conventional HVDC cables are comprised of mass-impregnated, lapped-paper insulation. These cables have been used mainly for submarine cable applications at DC transmission voltages up to 500 kV and power ratings up to 800 MW. Cable joints are mostly made at the factory where the cable is loaded unto a turntable on a cable laying vessel for transport and laying. Such cables are not conducive for long-distance, underground cable applications due to transport limitations and amount of time and skilled craftsmen needed to make field joints.

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[2] Economic Comparison of HVAC and HVDC Solutions for Large Offshore Wind Farms under Special Consideration of Reliability, KTH Electrical Engineering, Royal Institute of Technology, Department of Electrical Engineering, Stockholm 2005, Master's Thesis X-EtS/ESS-0505

HVDC Light Extruded Polymer Cables:

Extruded HVDC Light cables with polymer insulation are available for both land and sea applications. These cables are much more conducive for land cable applications since they can be more easily transported on cable drums and can be spliced using pre-molded cable joints. HVDC Light land cables are currently available in voltages up to 400 kV dc. HVDC Light sea cables are currently available in voltages up to 320 kV dc.

More information on ABB high voltage cables, including reference lists, can be found at http://www.abb.com/cables

HVDC Converter Technology:

ABB offers conventional HVDC converter technology with line-commutated, thyristor valves and HVDC Light converter technology with self-commutated, IGBT valves. Conventional HVDC converters are available at voltages up to 800 kV and continuous current ratings up to 4000 A dc. HVDC Light converters are currently available at voltages up to +/- 320 kV and continuous current ratings of up to 1880 A dc. HVDC Light can be used for overhead transmission voltages up to +/- 640 kV for bipolar power ratings up to 2400 MW.

More information on ABB HVDC technology, including reference lists, can be found at http://www.abb.com/hvdc

FACTS:

The ABB FACTS portfolio includes series compensation, thyristor-controlled series compensation (TCSC), static var compensator (SVC) and static synchronous compensators (STATCOM).

More information on ABB FACTS technologies, including reference lists, can be found at http://www.abb.com/facts

HVDC Budgetary Prices:

Over the last several years, ABB has provided various budgetary EPC price estimates for HVDC and HVDC Light converter stations and cables to several different Alberta Transmission Facilities Owners (TFOs), either directly or via their consulting firms. The TFO’s have added other owner costs, e.g. land, permitting, transmission lines, interconnection costs, overheads, profits, and taxes to develop their total project cost estimates. We ordinarily only provide detailed budgetary estimates to potential customers. EPC estimates by themselves may be misleading since they are not total project costs.

HVDC Reference Lists:

Links for downloading the latest available HVDC and HVDC Light Project Reference Lists can be found in the lower right-hand column at:

http://www.abb.com/industries/us/9AAF400191.aspx

HVDC Projects Underway:

A list of HVDC and HVDC Light projects currently underway can be found in the right-hand column at:

http://www.abb.com/industries/us/9AAF400191.aspx

FACTS Projects Reference Lists:

Links to FACTS projects for series and shunt compensation respectively can be found by way of the following link:

http://www.abb.com/facts

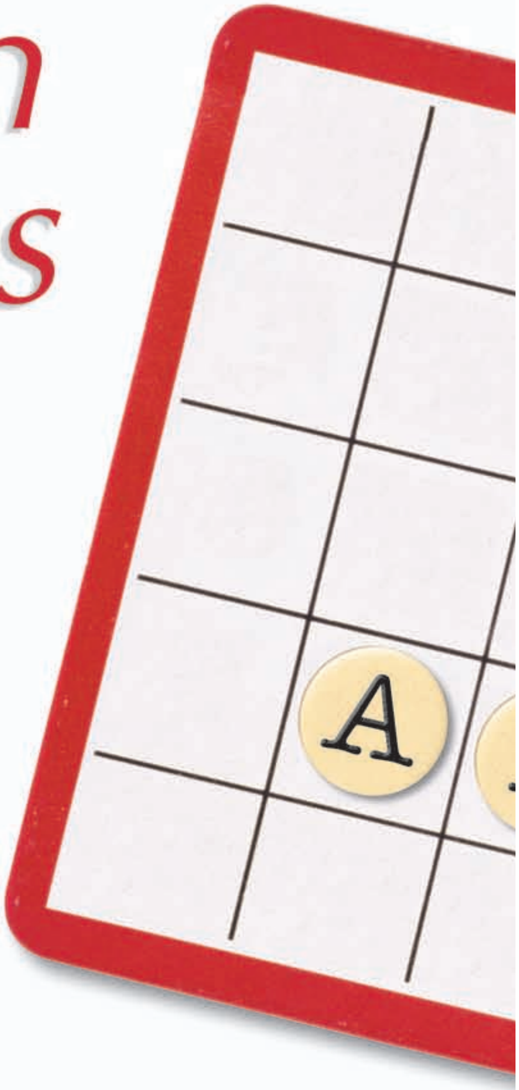
Future Offerings:

The trend toward higher voltage and power ratings for conventional HVDC, HVDC Light and extruded AC and HVDC cables will continue. HVDC Light conversion efficiencies will also continue to improve. In the near future HVDC Light can be used for underground transmission at voltages up to +/- 400 kV dc and power levels up to 1500 MW per circuit.

Paper title: The ABCs of HVDC Transmission Technology

The ABCs of HVDC Transmission Technologies

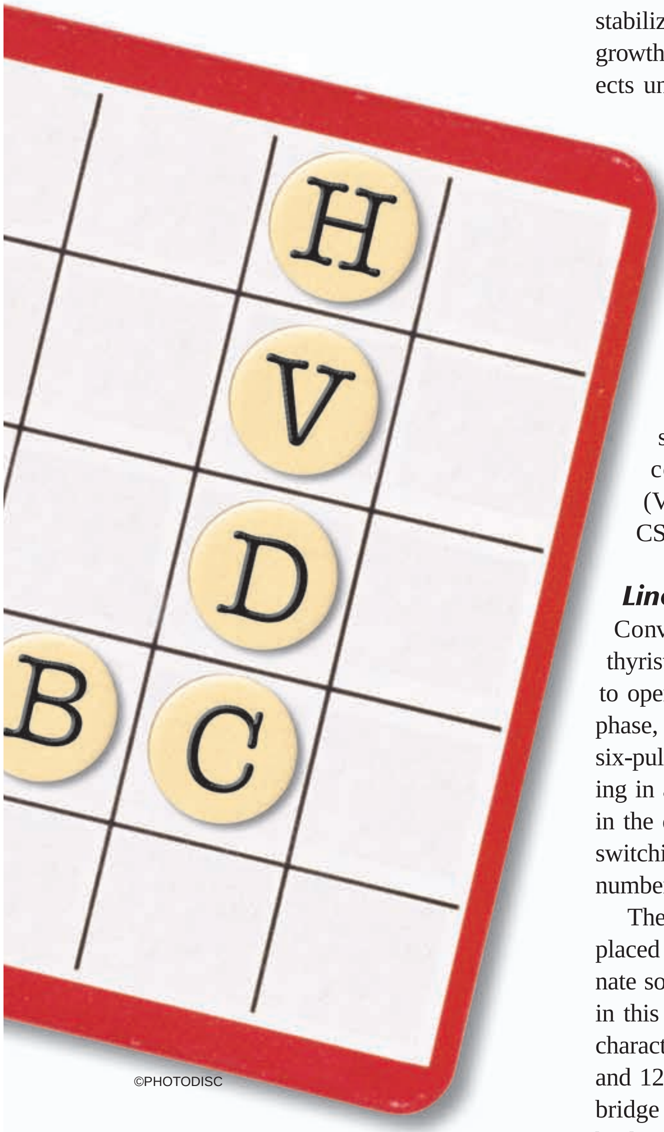
An Overview of High Voltage Direct Current Systems and Applications



by Michael P. Bahrman and Brian K. Johnson

1540-7977/07/$25.00©2007 IEEE

HIGH VOLTAGE DIRECT CURRENT (HVDC) TECHNOLOGY HAS characteristics that make it especially attractive for certain transmission applications. HVDC transmission is widely recognized as being advantageous for long-distance bulk-power delivery, asynchronous interconnections, and long submarine cable crossings. The number of HVDC projects committed or under consideration globally has increased in recent years reflecting a renewed interest in this mature technology. New converter designs have broadened the potential range of HVDC transmission to include applications for underground, offshore, economic replacement of reliability-must-run generation, and voltage stabilization. This broader range of applications has contributed to the recent growth of HVDC transmission. There are approximately ten new HVDC projects under construction or active consideration in North America along with many more projects underway globally. Figure 1 shows the Danish terminal for Skagerrak's pole 3, which is rated 440 MW. Figure 2 shows the ±500-kV HVDC transmission line for the 2,000 MW Intermountain Power Project between Utah and California. This article discusses HVDC technologies, application areas where HVDC is favorable compared to ac transmission, system configuration, station design, and operating principles.



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Core HVDC Technologies

Two basic converter technologies are used in modern HVDC transmission systems. These are conventional line-commutated current source converters (CSCs) and self-commutated voltage source converters (VSCs). Figure 3 shows a conventional HVDC converter station with CSCs while Figure 4 shows a HVDC converter station with VSCs.

Line-Commutated Current Source Converter

Conventional HVDC transmission employs line-commutated CSCs with thyristor valves. Such converters require a synchronous voltage source in order to operate. The basic building block used for HVDC conversion is the three-phase, full-wave bridge referred to as a six-pulse or Graetz bridge. The term six-pulse is due to six commutations or switching operations per period resulting in a characteristic harmonic ripple of six times the fundamental frequency in the dc output voltage. Each six-pulse bridge is comprised of six controlled switching elements or thyristor valves. Each valve is comprised of a suitable number of series-connected thyristors to achieve the desired dc voltage rating.

The dc terminals of two six-pulse bridges with ac voltage sources phase displaced by 30° can be connected in series to increase the dc voltage and eliminate some of the characteristic ac current and dc voltage harmonics. Operation in this manner is referred to as 12-pulse operation. In 12-pulse operation, the characteristic ac current and dc voltage harmonics have frequencies of $12n \pm 1$ and $12n$, respectively. The 30° phase displacement is achieved by feeding one bridge through a transformer with a wye-connected secondary and the other bridge through a transformer with a delta-connected secondary. Most modern HVDC transmission schemes utilize 12-pulse converters to reduce the harmonic filtering requirements required for six-pulse operation; e.g., fifth and seventh on the ac side and sixth on the dc side. This is because, although these harmonic currents still flow through the valves and the transformer windings, they are

180° out of phase and cancel out on the primary side of the converter transformer. Figure 5 shows the thyristor valve arrangement for a 12-pulse converter with three quadruple valves, one for each phase. Each thyristor valve is built up with series-connected thyristor modules.

Line-commutated converters require a relatively strong synchronous voltage source in order to commutate. Commutation is the transfer of current from one phase to another in a synchronized firing sequence of the thyristor valves. The three-phase symmetrical short circuit capacity available from the network at the converter connection point should be at least twice the converter rating for converter operation. Line-commutated CSCs can only operate with the ac current lagging the voltage, so the conversion process demands reactive power. Reactive power is supplied from the ac filters, which look capacitive at the fundamental frequency, shunt banks, or series capacitors that are an integral part of the converter station. Any surplus or deficit in reactive power from these local sources must be accommodated by the ac system. This difference in reactive power needs to be kept within a given band to keep the ac voltage within the desired tolerance. The weaker the ac system or the further the converter is away from generation, the tighter the reactive power exchange must be to stay within the desired voltage tolerance. Figure 6 illustrates the reactive power demand, reactive power compensation, and reactive power exchange with the ac network as a function of dc load current.

figure 1. HVDC converter station with ac filters in the foreground and valve hall in the background.

figure 2. A ±500-kV HVDC transmission line.

Converters with series capacitors connected between the valves and the transformers were introduced in the late 1990s for weak-system, back-to-back applications. These converters are referred to as capacitor-commutated converters (CCCs). The series capacitor provides some of the converter reactive power compensation requirements automatically with load current and provides part of the commutation voltage, improving voltage stability. The overvoltage protection of the series capacitors is simple since the capacitor is not exposed to line faults, and the fault current for internal converter faults is limited by the impedance of the converter transformers. The CCC configuration allows higher power ratings in areas were the ac network is close to its voltage stability limit. The asynchronous Garabi interconnection between Brazil and Argentina consists of 4 × 550 MW parallel CCC links. The Rapid City Tie between the Eastern and Western interconnected systems consists of 2 × 100 MW parallel CCC links (Figure 7). Both installations use a modular design with converter valves located within prefabricated electrical enclosures rather than a conventional valve hall.

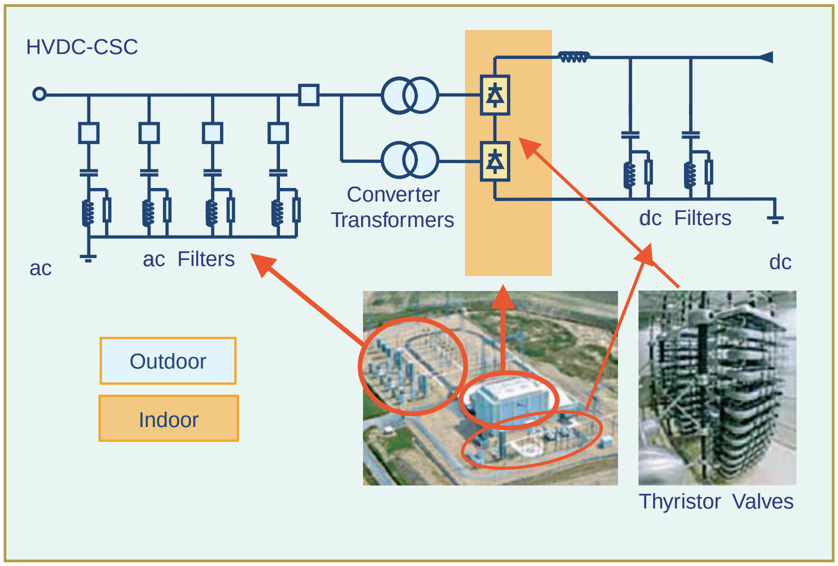

figure 3. Conventional HVDC with current source converters.

Self-Commutated Voltage Source Converter

HVDC transmission using VSCs with pulse-width modulation (PWM), commercially known as HVDC Light, was introduced in the late 1990s. Since then the progression to higher voltage and power ratings for these converters has roughly paralleled that for thyristor valve converters in the 1970s. These VSC-based systems are self-commutated with insulated-gate bipolar transistor (IGBT) valves and solid-dielectric extruded HVDC cables. Figure 8 illustrates solid-state converter development for the two different types of converter technologies using thyristor valves and IGBT valves.

HVDC transmission with VSCs can be beneficial to overall system performance. VSC technology can rapidly control both active and reactive power independently of one another. Reactive power can also be controlled at each terminal independent of the dc transmission voltage level. This control capability gives total flexibility to place converters anywhere in the ac network since there is no restriction on minimum network short-circuit capacity. Self-commutation with VSC even permits black start; i.e., the converter can be used to synthesize a balanced set of three phase voltages like a virtual synchronous generator. The dynamic support of the ac voltage at each converter terminal improves the voltage stability and can increase the transfer capability of the sending- and receiving-end ac systems, thereby leveraging the transfer capability of the dc link. Figure 9 shows the IGBT converter valve arrangement for a VSC station. Figure 10 shows the active and reactive power operating range for a converter station with a VSC. Unlike conventional HVDC transmission, the converters themselves have no reactive power demand and can actually control their reactive power to regulate ac system voltage just like a generator.

HVDC Applications

HVDC transmission applications can be broken down into different basic categories. Although the rationale for selection of HVDC is often economic, there may be other reasons for its selection. HVDC may be the only feasible way to interconnect two asynchronous networks, reduce fault currents, utilize long underground cable circuits, bypass network congestion, share utility rights-of-way without degradation of reliability, and to mitigate environmental concerns. In all of these applications, HVDC nicely complements the ac transmission system.

Long-Distance Bulk Power Transmission

HVDC transmission systems often provide a more economical alternative to ac transmission for long-distance bulk-power delivery from remote resources such as hydroelectric developments, mine-mouth power plants, or large-scale wind farms. Higher power transfers are possible over longer distances using fewer lines with HVDC transmission than with ac transmission. Typical HVDC lines utilize a bipolar configuration with two independent poles, one at a positive voltage and the other at a negative voltage with respect to ground. Bipolar HVDC lines are comparable to a double circuit ac line since they can operate at half power with one pole out of service but require only one-third the number of insulated sets of conductors as a double circuit ac line. Automatic restarts from temporary dc line fault clearing sequences are routine even for generator outlet transmission. No synchro-checking is required as for automatic reclosures following ac line faults since the dc restarts do not expose turbine generator units to high risk of transient torque amplification from closing into faults or across high phase angles. The controllability of HVDC links offer firm transmission capacity

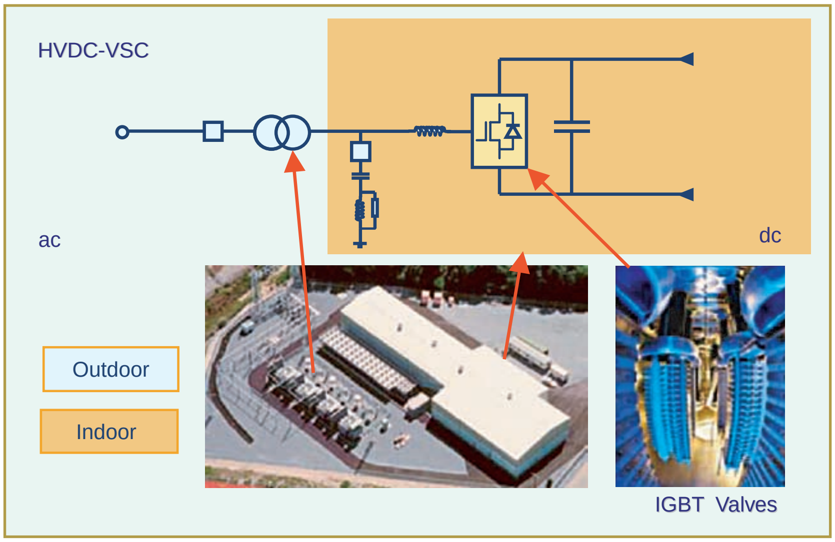

figure 4. HVDC with voltage source converters.

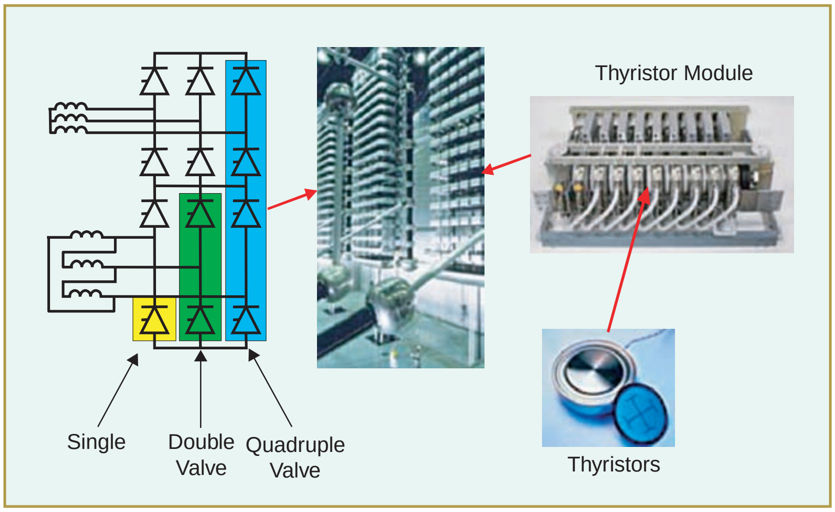

figure 5. Thyristor valve arrangement for a 12-pulse converter with three quadruple valves, one for each phase.

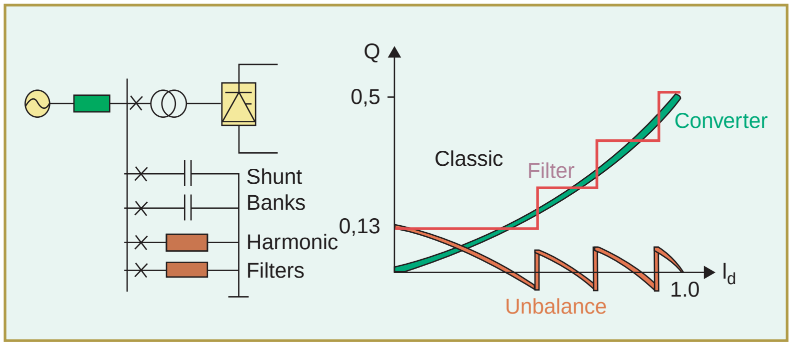

figure 6. Reactive power compensation for conventional HVDC converter station.

without limitation due to network congestion or loop flow on parallel paths. Controllability allows the HVDC to "leap-frog" multiple "choke-points" or bypass sequential path limits in the ac network. Therefore, the utilization of HVDC links is usually higher than that for extra high voltage ac transmission, lowering the transmission cost per MWh. This controllability can also be very beneficial for the parallel transmission since, by eliminating loop flow, it frees up this transmission capacity for its intended purpose of serving intermediate load and providing an outlet for local generation.

Whenever long-distance transmission is discussed, the concept of "break-even distance" frequently arises. This is where the savings in line costs offset the higher converter station costs. A bipolar HVDC line uses only two insulated sets of conductors rather than three. This results in narrower rights-of-way, smaller transmission towers, and lower line losses than with ac lines of comparable capacity. A rough approximation of the savings in line construction is 30%.

Although break-even distance is influenced by the costs of right-of-way and line construction with a typical value of 500 km, the concept itself is misleading because in many cases more ac lines are needed to deliver the same power over the same distance due to system stability limitations. Furthermore, the long-distance ac lines usually require intermediate switching stations and reactive power compensation. This can increase the substation costs for ac transmission to the point where it is comparable to that for HVDC transmission.

For example, the generator outlet transmission alternative for the ±250-kV, 500-MW Square Butte Project was two 345-kV series-compensated ac transmission lines. The 12,600-MW Itaipu project has half its power delivered on three 800-kV series-compensated ac lines (three circuits) and the other half delivered on two ±600-kV bipolar HVDC lines (four circuits). Similarly, the ±500-kV, 1,600-MW Intermountain Power Project (IPP) ac alternative comprised two 500-kV ac lines. The IPP takes advantage of the double-circuit nature of the bipolar line and includes a 100% short-term and 50% continuous monopolar overload. The first 6,000-MW stage of the transmission for the Three Gorges Project in China would have required 5 × 500-kV ac lines as opposed to 2 × ±500-kV, 3,000-MW bipolar HVDC lines.

Table 1 contains an economic comparison of capital costs and losses for different ac and dc transmission alternatives for a hypothetical 750-mile, 3,000-MW transmission system. The long transmission distance requires intermediate substations or switching stations and shunt reactors for the ac alternatives. The long distance and heavy power transfer, nearly twice the surge-impedance loading on the 500-kV ac alternatives, require a high level of series compensation. These ac station costs are included in the cost estimates for the ac alternatives.

It is interesting to compare the economics for transmission to that of transporting an equivalent amount of energy using other transport methods, in this case using rail transportation of sub-bituminous western coal with a heat content of 8,500 Btu/lb to support a 3,000-MW base load power plant with heat rate of 8,500 Btu/kWh operating at an 85%

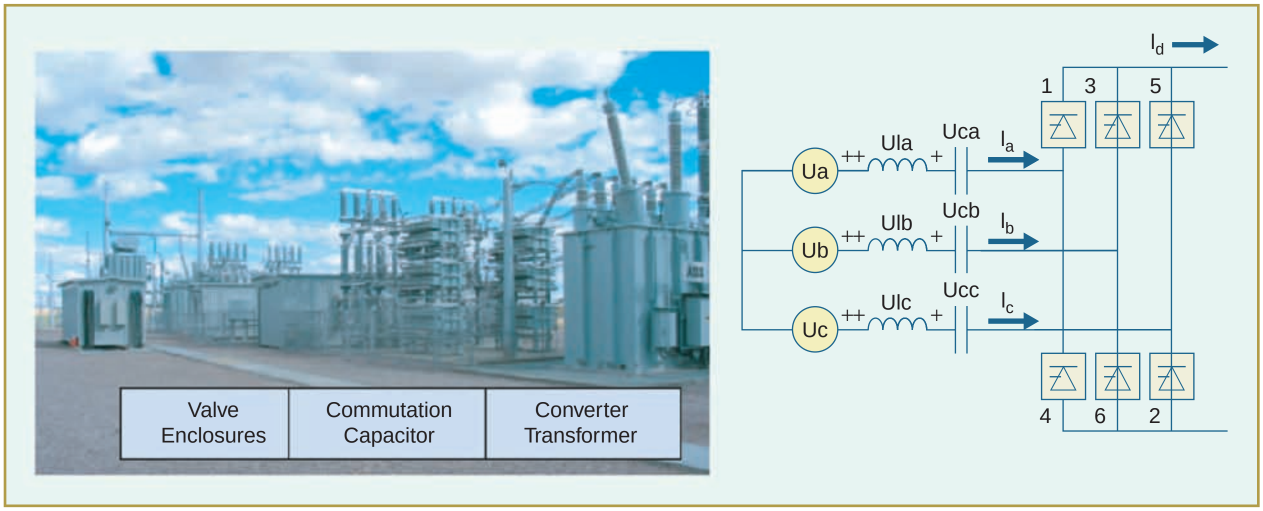

figure 7. Asynchronous back-to-back tie with capacitor-commutated converter near Rapid City, South Dakota.

load factor. The rail route is assumed to be longer than the more direct transmission route; i.e., 900 miles. Each unit train is comprised of 100 cars each carrying 100 tons of coal. The plant requires three unit trains per day. The annual coal transportation costs are about US$560 million per year at an assumed rate of US$50/ton. This works out to be US$186 kW/year and US$25 per MWh. The annual diesel fuel consumed in the process is in excess of 20 million gallons at 500 net ton-miles per gallon. The rail transportation costs are subject to escalation and congestion whereas the transmission costs are fixed. Furthermore, transmission is the only way to deliver remote renewable resources.

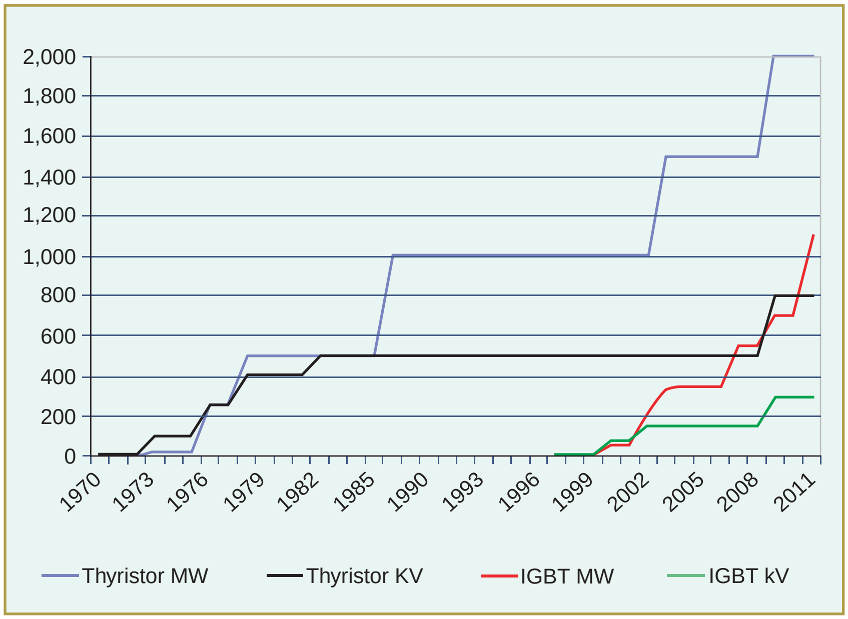

figure 8. Solid-state converter development.

Underground and Submarine Cable Transmission

Unlike the case for ac cables, there is no physical restriction limiting the distance or power level for HVDC underground or submarine cables. Underground cables can be used on shared rights-of-way with other utilities without impacting reliability concerns over use of common corridors. For underground or submarine cable systems there is considerable savings in installed cable costs and cost of losses when using HVDC transmission. Depending on the power level to be transmitted, these savings can offset the higher converter station costs at distances of 40 km or more. Furthermore, there is a drop-off in cable capacity with ac transmission over distance due to its reactive component of charging current since cables have higher capacitances and lower inductances than ac overhead lines. Although this can be compensated by intermediate shunt compensation for underground cables at increased expense, it is not practical to do so for submarine cables.

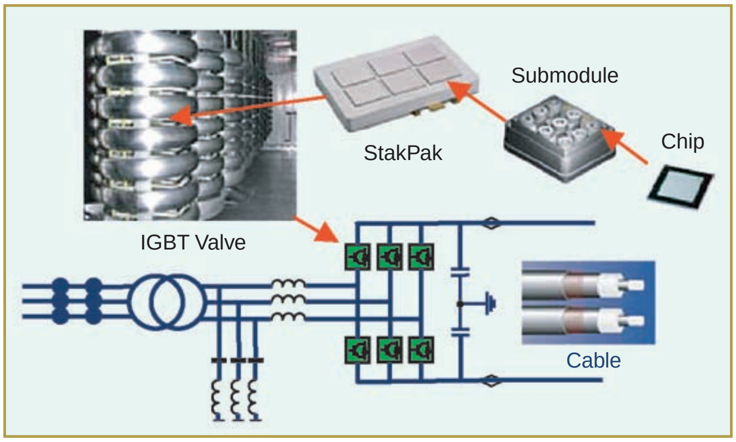

figure 9. HVDC IGBT valve converter arrangement.

For a given cable conductor area, the line losses with HVDC cables can be about half those of ac cables. This is due to ac cables requiring more conductors (three phases), carrying the reactive component of current, skin-effect, and induced currents in the cable sheath and armor.

With a cable system, the need to balance unequal loadings or the risk of postcontingency overloads often necessitates use of a series-connected reactors or phase shifting transformers. These potential problems do not exist with a controlled HVDC cable system.

Extruded HVDC cables with prefabricated joints used with VSC-based transmission are lighter, more flexible, and easier to splice than the mass-impregnated oil-paper cables (MINDs) used for conventional HVDC transmission, thus making them more conducive for land cable applications where transport limitations and extra splicing costs can drive up installation costs. The lower-cost cable installations made possible by the extruded HVDC cables and prefabricated joints makes long-distance underground transmission economically feasible for use in areas with rights-of-way constraints or subject to permitting difficulties or delays with overhead lines.

Asynchronous Ties

With HVDC transmission systems, interconnections can be made between asynchronous networks for more economic or reliable system operation. The asynchronous interconnection allows interconnections of mutual benefit while providing a buffer between the two systems. Often these interconnections use back-to-back converters with no transmission line.

Asynchronous HVDC links act as an effective "firewall" against propagation of cascading outages in one network from passing to another network.

Many asynchronous interconnections exist in North America between the Eastern and Western interconnected systems, between the Electric Reliability Council of Texas (ERCOT) and its neighbors, [e.g., Mexico and the Southwest Power Pool (SPP)], and between Quebec and its neighbors (e.g., New England and the Maritimes). The August 2003 Northeast blackout provides an example of the "firewall" against cascading outages provided by asynchronous interconnections. As the outage expanded and propagated around the lower Great Lakes and through Ontario and New York, it stopped at the asynchronous interface with Quebec. Quebec was unaffected; the weak ac interconnections between New York and New England tripped, but the HVDC links from Quebec continued to deliver power to New England.

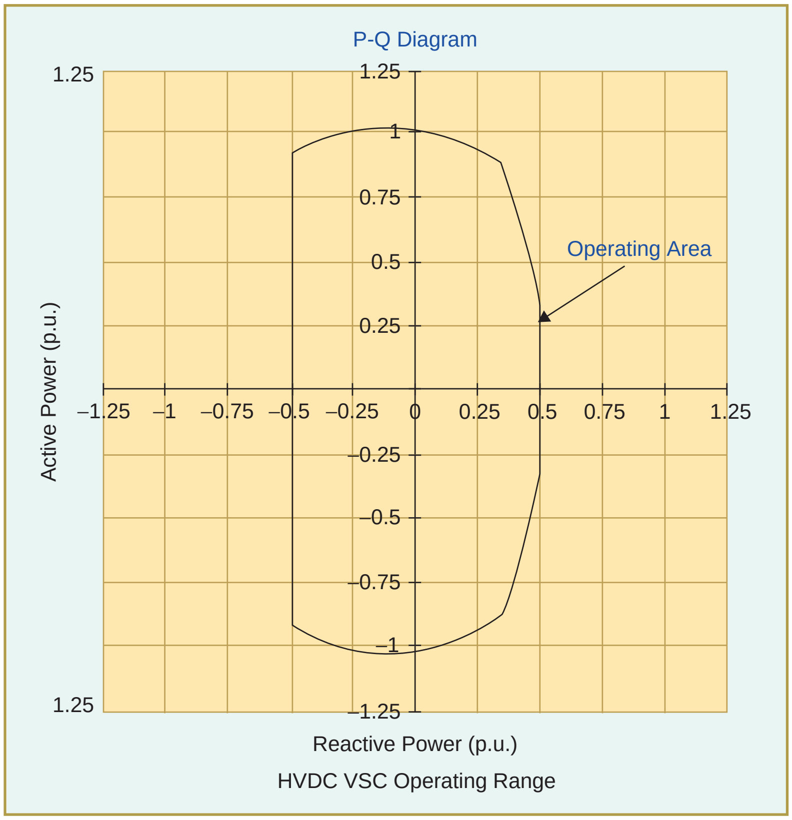

figure 10. Operating range for voltage source converter HVDC transmission.

Regulators try to eliminate "seams" in electrical networks because of their potential restriction on power markets. Electrical "seams," however, serve as natural points of separation by acting as "shear-pins," thereby reducing the impact of large-scale system disturbances. Asynchronous ties can eliminate market "seams" while retaining natural points of separation.

Interconnections between asynchronous networks are often at the periphery of the respective systems where the networks tend to be weak relative to the desired power transfer. Higher power transfers can be achieved with improved voltage stability in weak system applications using CCCs. The dynamic voltage support and improved voltage stability offered by VSC-based converters permits even higher power transfers without as much need for ac system reinforcement. VSCs do not suffer commutation failures, allowing fast recoveries from nearby ac faults. Economic power schedules that reverse power direction can be made without any restrictions since there is no minimum power or current restrictions.

figure 11. VSC power supply to Troll A production platform.

Offshore Transmission

Self-commutation, dynamic voltage control, and black-start capability allow compact VSC HVDC transmission to serve isolated loads on islands or offshore production platforms over long-distance submarine cables. This capability can eliminate the need for running expensive local generation or provide an outlet for offshore generation such as that from wind. The VSCs can operate at variable frequency to more efficiently drive large compressor or pumping loads using high-voltage motors. Figure 11 shows the Troll A production platform in the North Sea where power to drive compressors is delivered from shore to reduce the higher carbon emissions and higher O&M costs associated with less efficient platform-based generation.

Large remote wind generation arrays require a collector system, reactive power support, and outlet transmission. Transmission for wind generation must often traverse scenic or environmentally sensitive areas or bodies of water. Many of the better wind sites with higher capacity factors are located offshore. VSC-based HVDC transmission allows efficient use of long-distance land or submarine cables and provides reactive support to the wind generation complex. Figure 12 shows a design for an offshore converter station designed to transmit power from offshore wind generation.

Multiterminal Systems

Most HVDC systems are for point-to-point transmission with a converter station at each end. The use of intermediate taps is rare. Conventional HVDC transmission uses voltage polarity reversal to reverse the power direction. Polarity reversal requires no special switching arrangement for a two-terminal system where both terminals reverse polarity by control action with no switching to reverse power direction. Special dc-side switching arrangements are needed for polarity reversal in a multiterminal system, however, where it may be desired to reverse the power direction at a tap while maintaining the same power direction on the remaining terminals. For a bipolar system this can be done by connecting the converter to the opposite pole. VSC HVDC transmission, however, reverses power through reversal of the current direction rather than voltage polarity. Thus, power can be reversed at an intermediate tap independently of the main power flow direction without switching to reverse voltage polarity.

Power Delivery to Large Urban Areas

Power supply for large cities depends on local generation and power import capability. Local

table 1. Comparative costs of HVDC and EHV AC transmission alternatives.

	DC Alternatives				AC Alternatives			Hybrid AC/DC Alternative		
Alternative	+ 500 Kv Bipole	2 x + 500 kV 2 bipoles	+ 600 kV Bipole	+800 kV Bipole	500 kV 2 Single Ckt	500 kV Double Ckt	765 kV 2 Singl Ckt	+ 500 kV Bipole	500 kV Single Ckt	Total AC + DC
Capital Cost										
Rated Power (MW)	3000	4000	3000	3000	3000	3000	3000	3000	1500	4500
Station costs including reactive compensation (M$)	$420	$680	$465	$510	$542	$542	$630	$420	$302	$722
Transmission line cost (M$/mile)	$1.60	$1.60	$1.80	$1.95	$2.00	$3.20	$2.80	$1.60	$2.00	
Distance in miles	750	1,500	750	750	1,500	750	1,500	750	750	1,500
Transmission Line Cost (M$)	$1,200	$2,400	$1,350	$1,463	$3,000	$2,400	$4,200	$1,200	$1,500	$2,700
Total Cost (M$)	**$1,620**	**$3,080**	**$1,815**	**$1,973**	**$3,542**	**$2,942**	**$4,830**	**$1,620**	**$1,802**	**$3,422**
Annual Payment, 30 years @ 10%	$172	$327	$193	$209	$376	$312	$512	$172	$191	$363
Cost per kW-Yr	$57.28	$81.68	$64.18	$69.75	$125.24	$104.03	$170.77	$57.28	$127.40	$80.66
Cost per MWh @ 85% Utilization Factor	$7.69	$10.97	$8.62	$9.37	$16.82	$13.97	$22.93	$7.69	$17.11	$10.83
Losses @ full load	193	134	148	103	208	208	139	106	48	154
Losses at full load in %	6.44%	3.35%	4.93%	3.43%	6.93%	6.93%	4.62%	5.29%	4.79%	5.12%
Capitalized cost of losses @ $1500 kW (M$)	$246	$171	$188	$131	$265	$265	$177	$135	$61	$196
Parameters:										
Interest rate %	10%									
Capitalized cost of losses $/kW	$1,500									

Note:
AC current assumes 94% pf
Full load converter station losses = 0.75% per station
Total substation losses (transformers, reactors) assumed = 0.5% of rated power

generation is often older and less efficient than newer units located remotely. Often, however, the older, less-efficient units located near the city center must be dispatched out-of-merit because they must be run for voltage support or reliability due to inadequate transmission. Air quality regulations may limit the availability of these units. New transmission into large cities is difficult to site due to right-of-way limitations and land-use constraints.

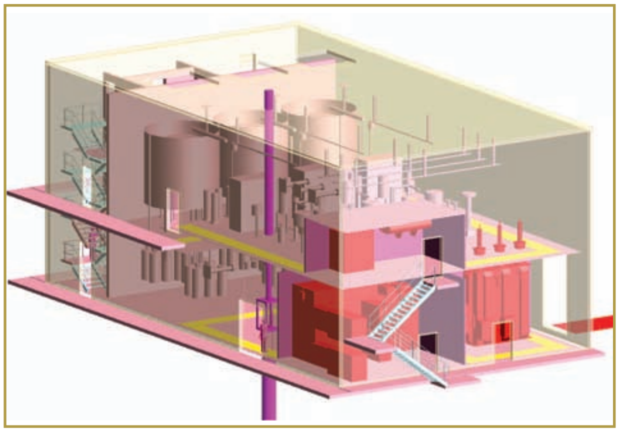

figure 12. VSC converter for offshore wind generation.

Compact VSC-based underground transmission circuits can be placed on existing dual-use rights-of-way to bring in power as well as to provide voltage support, allowing a more economical power supply without compromising reliability. The receiving terminal acts like a virtual generator delivering power and supplying voltage regulation and dynamic reactive power reserve. Stations are compact and housed mainly indoors, making siting in urban areas somewhat easier. Furthermore, the dynamic voltage support offered by the VSC can often increase the capability of the adjacent ac transmission.

System Configurations and Operating Modes

Figure 13 shows the different common system configurations and operating modes used for HVDC transmission. Monopolar systems are the simplest and least expensive systems for moderate power transfers since only two converters and one high-voltage insulated cable or line conductor are required. Such systems have been used with low-voltage electrode lines and sea electrodes to carry the return current in submarine cable crossings.

In some areas conditions are not conducive to monopolar earth or sea return. This could be the case in heavily congested

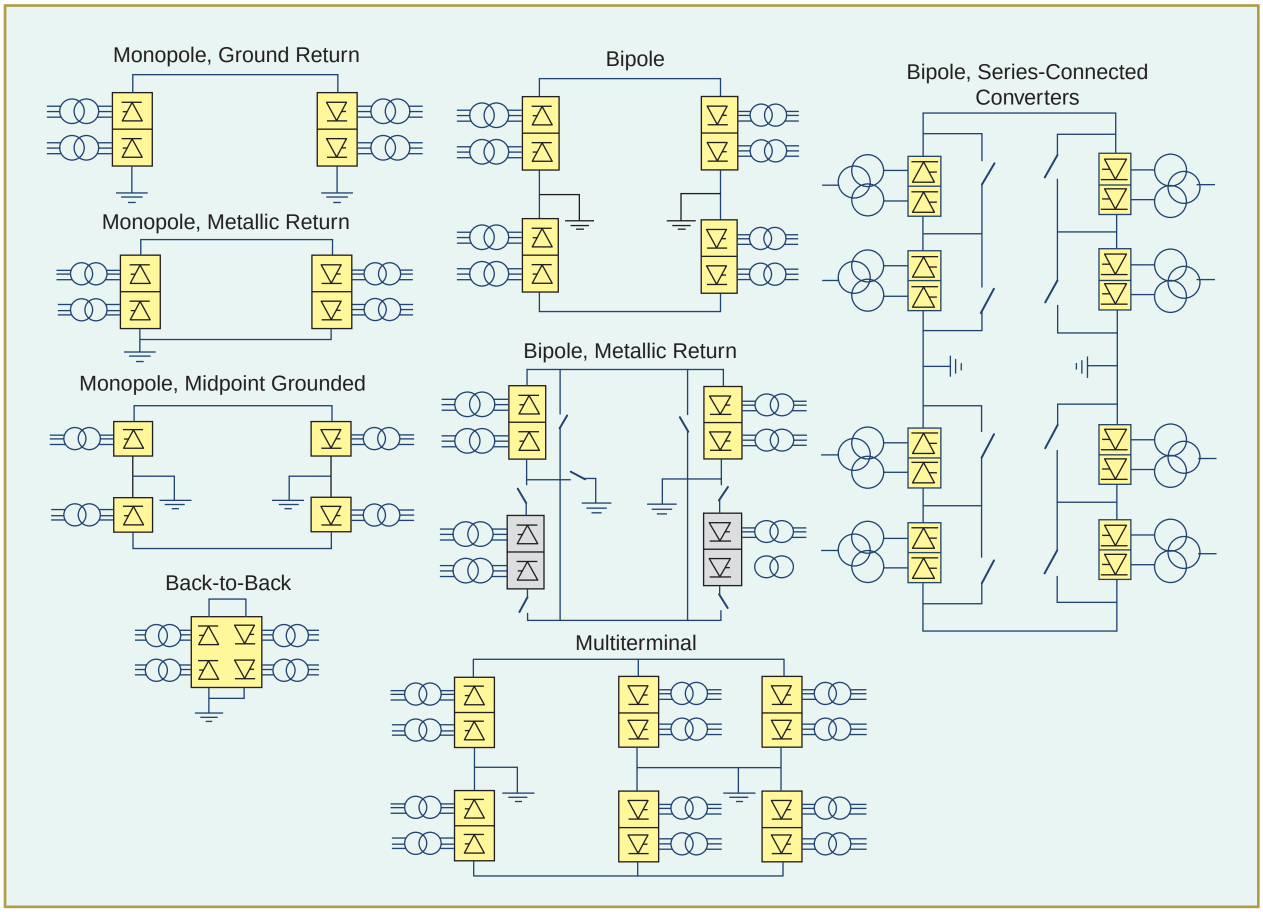

figure 13. HVDC configurations and operating modes.

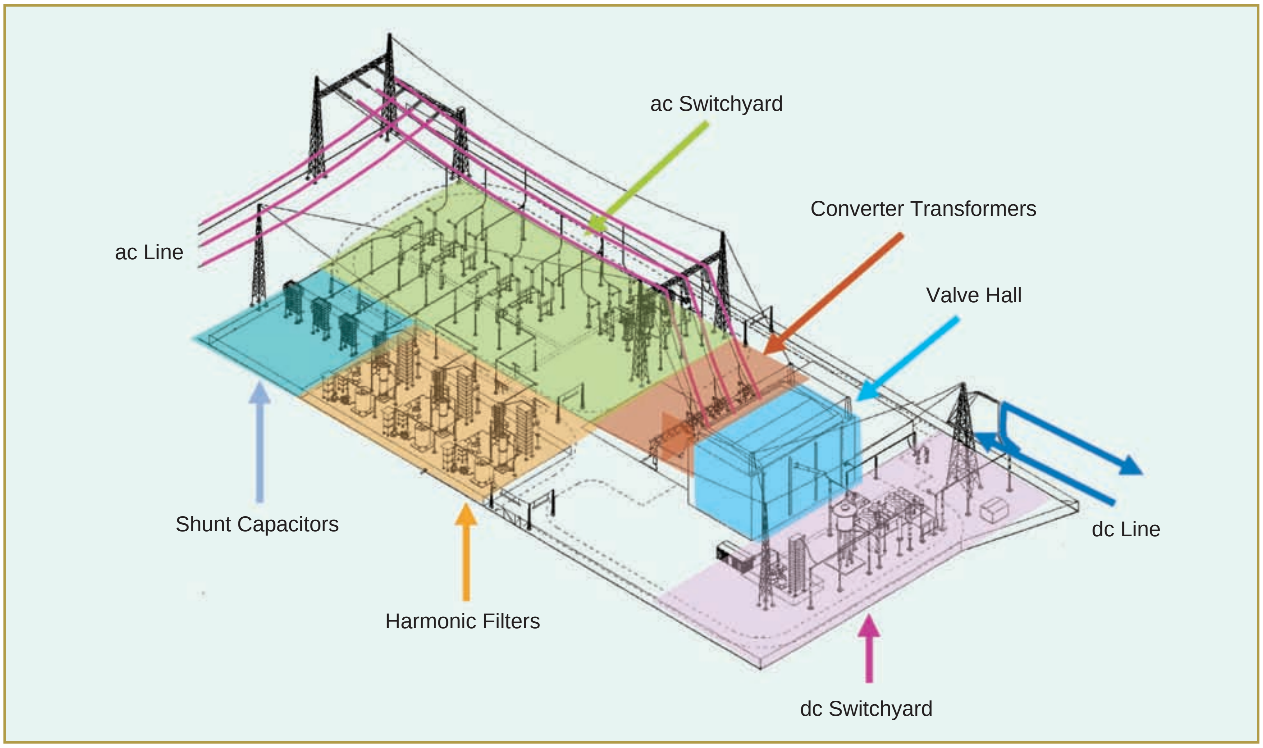

figure 14. Monopolar HVDC converter station.

areas, fresh water cable crossings, or areas with high earth resistivity. In such cases a metallic neutral- or low-voltage cable is used for the return path and the dc circuit uses a simple local ground connection for potential reference only. Back-to-back stations are used for interconnection of asynchronous networks and use ac lines to connect on either side. In such systems power transfer is limited by the relative capacities of the adjacent ac systems at the point of connection.

As an economic alternative to a monopolar system with metallic return, the midpoint of a 12-pulse converter can be connected to earth directly or through an impedance and two half-voltage cables or line conductors can be used. The converter is only operated in 12-pulse mode so there is never any stray earth current.

VSC-based HVDC transmission is usually arranged with a single converter connected pole-to-pole rather than pole-to-ground. The center point of the converter is connected to ground through a high impedance to provide a reference for the dc voltage. Thus, half the converter dc voltage appears across the insulation on each of the two dc cables, one positive the other negative.

The most common configuration for modern overhead HVDC transmission lines is bipolar with a single 12-pulse converter for each pole at each terminal. This gives two independent dc circuits each capable of half capacity. For normal balanced operation there is no earth current. Monopolar earth return operation, often with overload capacity, can be used during outages of the opposite pole.

Earth return operation can be minimized during monopolar outages by using the opposite pole line for metallic return via pole/converter bypass switches at each end. This requires a metallic-return transfer breaker in the ground electrode line at

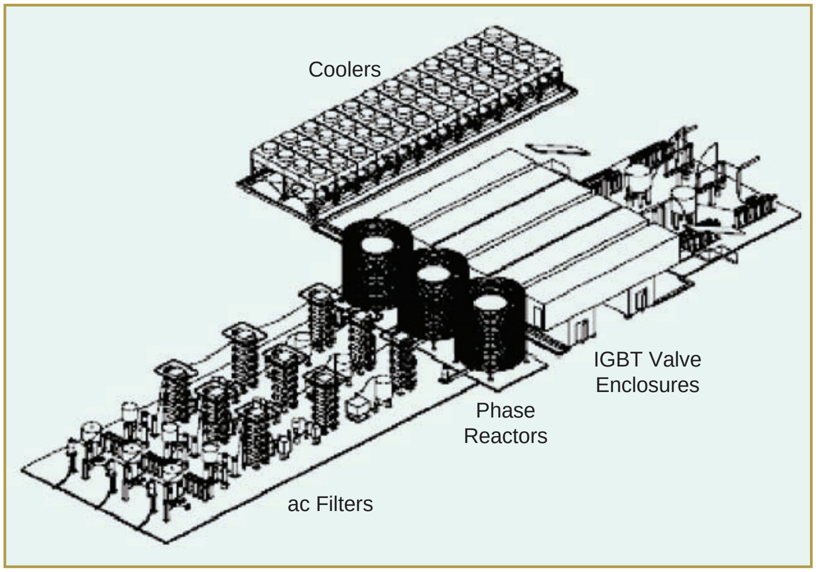

figure 15. VSC HVDC converter station.

one of the dc terminals to commutate the current from the relatively low resistance of the earth into that of the dc line conductor. Metallic return operation capability is provided for most dc transmission systems. This not only is effective during converter outages but also during line insulation failures where the remaining insulation strength is adequate to withstand the low resistive voltage drop in the metallic return path.

For very-high-power HVDC transmission, especially at dc voltages above ±500 kV (i.e., ±600 kV or ±800 kV), series-connected converters can be used to reduce the energy unavailability for individual converter outages or partial line insulation failure. By using two series-connected converters per pole in a bipolar system, only one quarter of the transmission capacity is lost for a converter outage or if the line insulation for the affected pole is degraded to where it can only support half the rated dc line voltage. Operating in this mode also avoids the need to transfer to monopolar metallic return to limit the duration of emergency earth return.

Station Design and Layout

Conventional HVDC

The converter station layout depends on a number of factors such as the dc system configuration (i.e., monopolar, bipolar, or back-to-back), ac filtering, and reactive power compensation requirements. The thyristor valves are air-insulated, water-cooled, and enclosed in a converter building often referred to as a valve hall. For back-to-back ties with their characteristically low dc voltage, thyristor valves can be housed in prefabricated electrical enclosures, in which case a valve hall is not required.

To obtain a more compact station design and reduce the number of insulated high-voltage wall bushings, converter transformers are often placed adjacent to the valve hall with valve winding bushings protruding through the building walls for connection to the valves. Double or quadruple valve structures housing valve modules are used within the valve hall. Valve arresters are located immediately adjacent to the valves. Indoor motor-operated grounding switches are used for personnel safety during maintenance. Closed-loop valve cooling systems are used to circulate the cooling medium, deionized water or water-glycol mix, through the indoor thyristor valves with heat transfer to dry coolers located outdoors. Area requirements for conventional HVDC converter stations are influenced by the ac system voltage and reactive power compensation requirements where each individual bank rating may be limited by such system requirements as reactive power exchange and maximum voltage step on bank switching. The ac yard with filters and shunt compensation can take up as much as three quarters of the total area requirements of the converter station. Figure 14 shows a typical arrangement for an HVDC converter station.

VSC-Based HVDC

The transmission circuit consists of a bipolar two-wire HVDC system with converters connected pole-to-pole. DC capacitors are used to provide a stiff dc voltage source. The dc capacitors are grounded at their electrical center point to establish the earth reference potential for the transmission system. There is no earth return operation. The converters are coupled to the ac system through ac phase reactors and power transformers. Unlike most conventional HVDC systems, harmonic filters are located between the phase reactors and power transformers. Therefore, the transformers are exposed to no dc voltage stresses or harmonic loading, allowing use of ordinary power transformers. Figure 15 shows the station arrangement for a ±150-kV, 350 to 550-MW VSC converter station.

The IGBT valves used in VSC converters are comprised of series-connected IGBT positions. The IGBT is a hybrid device exhibiting the low forward drop of a bipolar transistor as a

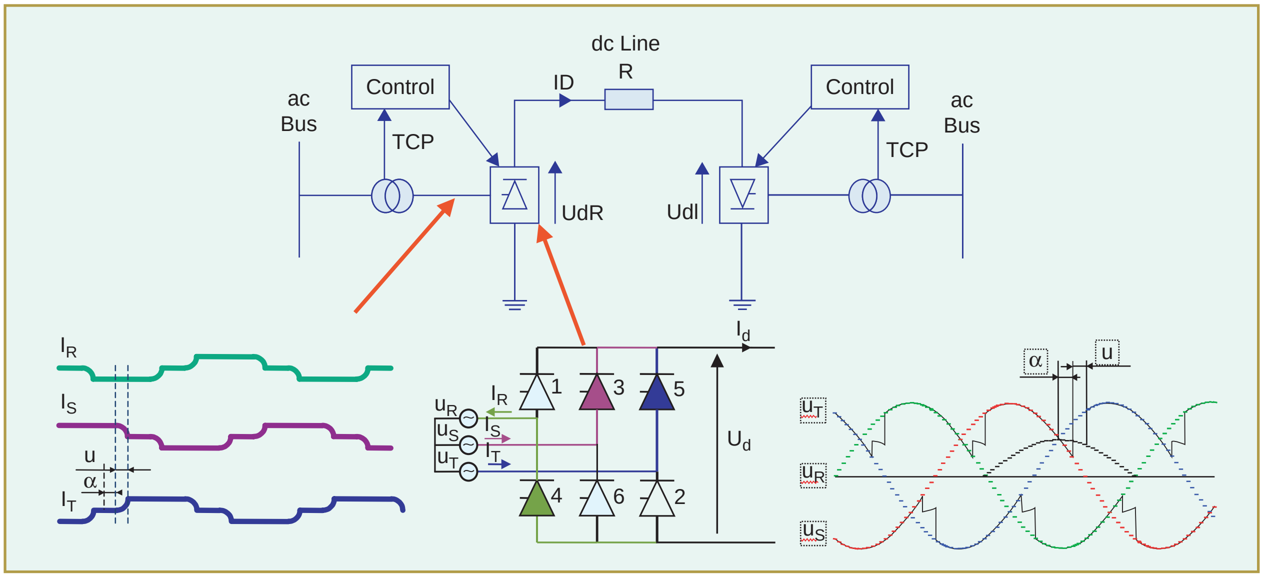

figure 16. Conventional HVDC control.

conducting device. Instead of the regular current-controlled base, the IGBT has a voltage-controlled capacitive gate, as in the MOSFET device.

A complete IGBT position consists of an IGBT, an antiparallel diode, a gate unit, a voltage divider, and a water-cooled heat sink. Each gate unit includes gate-driving circuits, surveillance circuits, and optical interface. The gate-driving electronics control the gate voltage and current at turn-on and turn-off to achieve optimal turn-on and turn-off processes of the IGBTs.

To be able to switch voltages higher than the rated voltage of one IGBT, many positions are connected in series in each valve similar to thyristors in conventional HVDC valves. All IGBTs must turn on and off at the same moment to achieve an evenly distributed voltage across the valve. Higher currents are handled by paralleling IGBT components or press packs.

The primary objective of the valve dc-side capacitor is to provide a stiff voltage source and a low-inductance path for the turn-off switching currents and to provide energy storage. The capacitor also reduces the harmonic ripple on the dc voltage. Disturbances in the system (e.g., ac faults) will cause dc voltage variations. The ability to limit these voltage variations depends on the size of the dc-side capacitor. Since the dc capacitors are used indoors, dry capacitors are used.

AC filters for VSC HVDC converters have smaller ratings than those for conventional converters and are not required for reactive power compensation. Therefore, these filters are always connected to the converter bus and not switched with transmission loading. All equipment for VSC-based HVDC converter stations, except the transformer, high-side breaker, and valve coolers, is located indoors.

HVDC Control and Operating Principles

Conventional HVDC

The fundamental objectives of an HVDC control system are as follows:

1) to control basic system quantities such as dc line current, dc voltage, and transmitted power accurately and with sufficient speed of response
2) to maintain adequate commutation margin in inverter operation so that the valves can recover their forward blocking capability after conduction before their voltage polarity reverses
3) to control higher-level quantities such as frequency in isolated mode or provide power oscillation damping to help stabilize the ac network
4) to compensate for loss of a pole, a generator, or an ac transmission circuit by rapid readjustment of power
5) to ensure stable operation with reliable commutation in the presence of system disturbances
6) to minimize system losses and converter reactive power consumption
7) to ensure proper operation with fast and stable recoveries during ac system faults and disturbances.

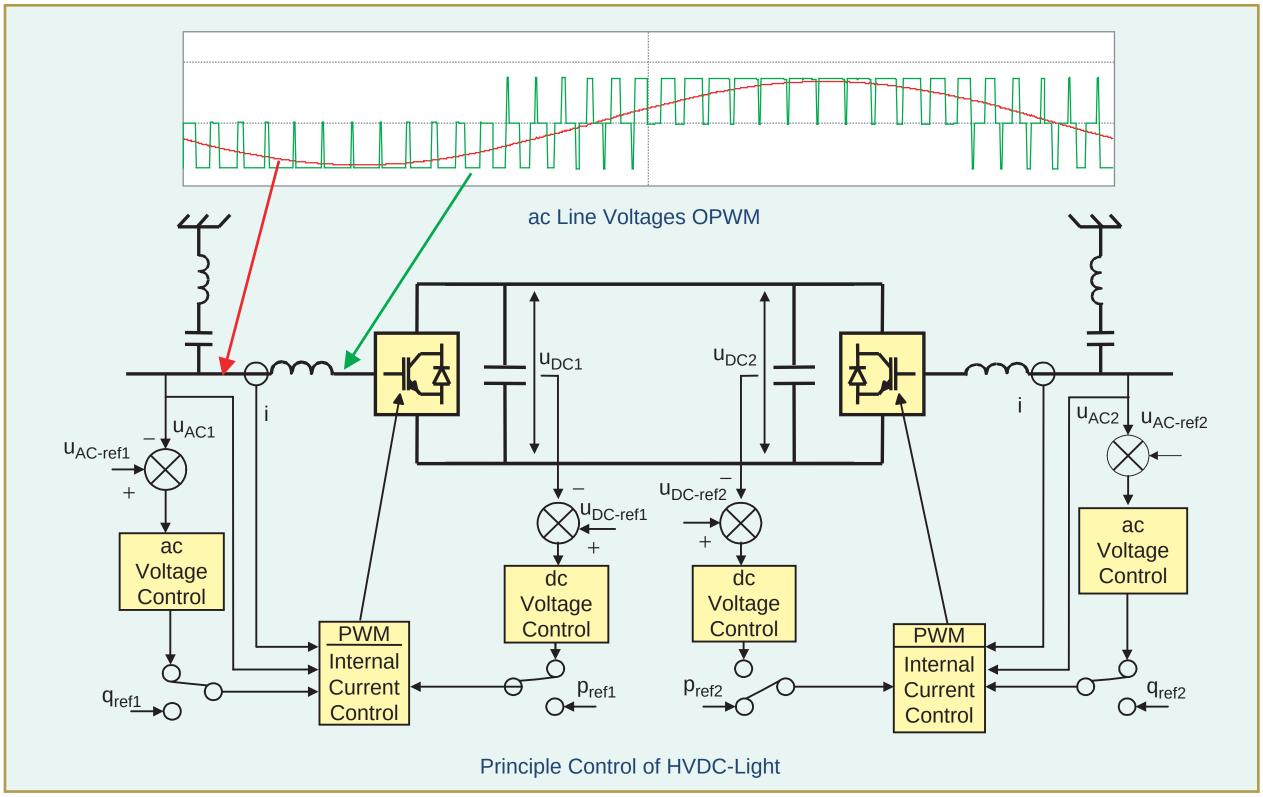

figure 17. Control of VSC HVDC transmission.

For conventional HVDC transmission, one terminal sets the dc voltage level while the other terminal(s) regulates the (its) dc current by controlling its output voltage relative to that maintained by the voltage-setting terminal. Since the dc line resistance is low, large changes in current and hence power can be made with relatively small changes in firing angle (alpha). Two independent methods exist for controlling the converter dc output voltage. These are 1) by changing the ratio between the direct voltage and the ac voltage by varying the delay angle or 2) by changing the converter ac voltage via load tap changers (LTCs) on the converter transformer. Whereas the former method is rapid the latter method is slow due to the limited speed of response of the LTC. Use of high delay angles to achieve a larger dynamic range, however, increases the converter reactive power consumption. To minimize the reactive power demand while still providing adequate dynamic control range and commutation margin, the LTC is used at the rectifier terminal to keep the delay angle within its desired steady-state range (e.g., 13–18°) and at the inverter to keep the extinction angle within its desired range (e.g., 17–20°), if the angle is used for dc voltage control or to maintain rated dc voltage if operating in minimum commutation margin control mode. Figure 16 shows the characteristic transformer current and dc bridge voltage waveforms along with the controlled items Ud, Id, and tap changer position (TCP).

VSC-Based HVDC

Power can be controlled by changing the phase angle of the converter ac voltage with respect to the filter bus voltage, whereas the reactive power can be controlled by changing the magnitude of the fundamental component of the converter ac voltage with respect to the filter bus voltage. By controlling these two aspects of the converter voltage, operation in all four quadrants is possible. This means that the converter can be operated in the middle of its reactive power range near unity power factor to maintain dynamic reactive power reserve for contingency voltage support similar to a static var compensator. It also means that the real power transfer can be changed rapidly without altering the reactive power exchange with the ac network or waiting for switching of shunt compensation.

Being able to independently control ac voltage magnitude and phase relative to the system voltage allows use of separate active and reactive power control loops for HVDC system regulation. The active power control loop can be set to control either the active power or the dc-side voltage. In a dc link, one station will then be selected to control the active power while the other must be set to control the dc-side voltage. The reactive power control loop can be set to control either the reactive power or the ac-side voltage. Either of these two modes can be selected independently at either end of the dc link. Figure 17 shows the characteristic ac voltage waveforms before and after the ac filters along with the controlled items Ud, Id, Q, and Uac.

Conclusions

The favorable economics of long-distance bulk-power transmission with HVDC together with its controllability make it an interesting alternative or complement to ac transmission. The higher voltage levels, mature technology, and new converter designs have significantly increased the interest in HVDC transmission and expanded the range of applications.

For Further Reading

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A. Ekstrom and G. Liss, "A refined HVDC control system," *IEEE Trans. Power Systems*, vol. PAS-89, pp. 723–732, May-June 1970.

Biographies

Michael P. Bahrman received a B.S.E.E. from Michigan Technological University. He is currently the U.S. HVDC marketing and sales manger for ABB Inc. He has 24 years of experience with ABB Power Systems including system analysis, system design, multiterminal HVDC control development, and project management for various HVDC and FACTS projects in North America. Prior to joining ABB, he was with Minnesota Power for 10 years where he held positions as transmission planning engineer, HVDC control engineer, and manager of system operations. He has been an active member of IEEE, serving on a number of subcommittees and working groups in the area of HVDC and FACTS.

Brian K. Johnson received the Ph.D. in electrical engineering from the University of Wisconsin-Madison. He is currently a professor in the Department of Electrical and Computer Engineering at the University of Idaho. His interests include power system protection and the application of power electronics to utility systems, security and survivability of ITS systems and power systems, distributed sensor and control networks, and real-time simulation of traffic systems. He is a member of the Board of Governors of the IEEE Intelligent Transportation Systems Society and the Administrative Committee of the IEEE Council on Superconductivity. p&e

Michael Bahrman P.E., ABB Grid Systems, WECC Transmission Planning Seminar, February 2-3, 2009

HVDC Transmission

An economical complement to ac transmission

HVDC Transmission
Agenda:

Role of FACTS & HVDC

Transfer limitations

AC v DC comparisons

Technology

Economics

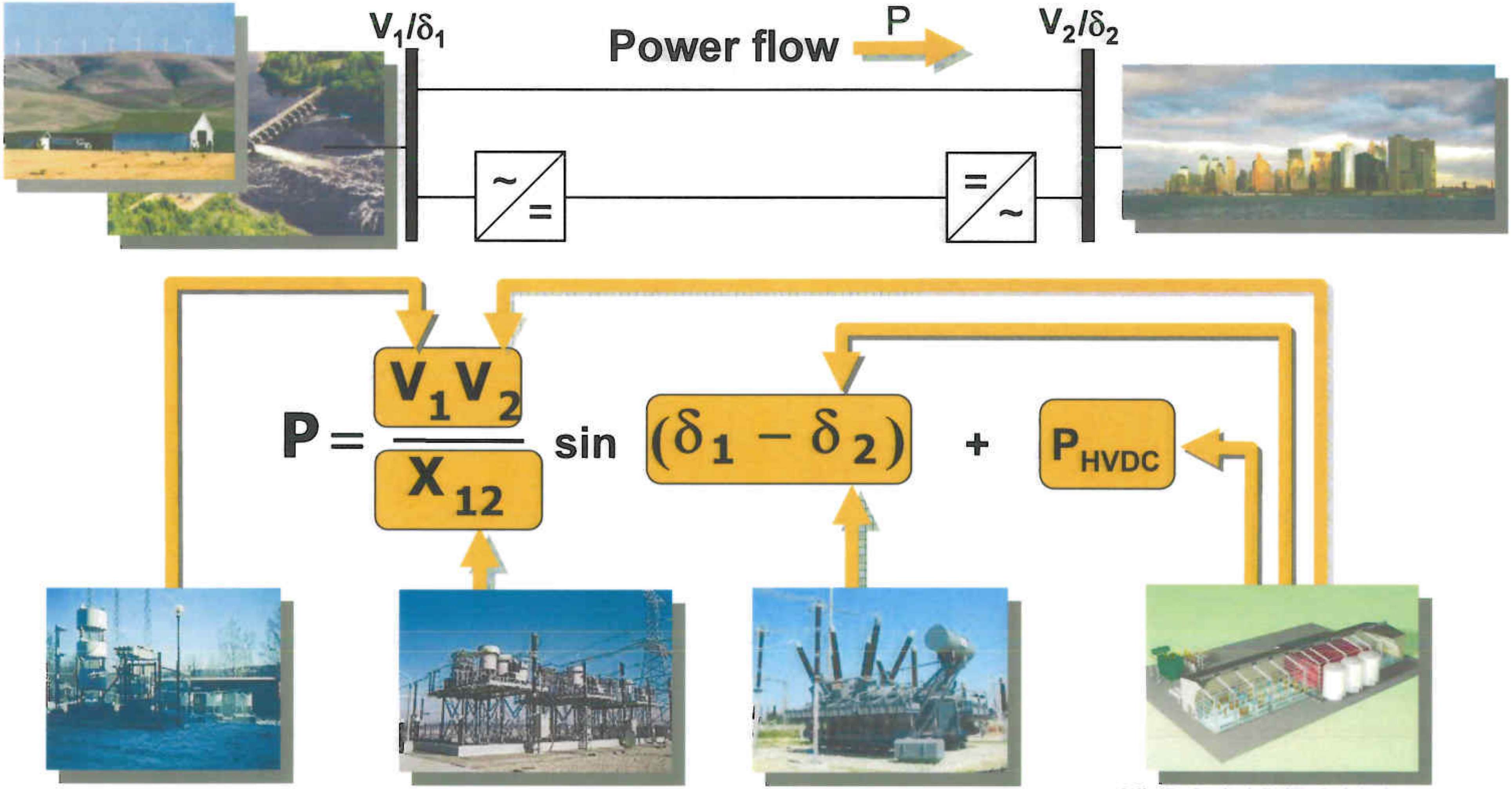
Efficiency

Reliability

Summary

Discussion (extra supporting and background slides)

Ways to boost or control a corridor's power flow
Role of FACTS & HVDC



$$P = \frac{V_1 V_2}{X_{12}} \sin(\delta_1 - \delta_2) + P_{HVDC}$$

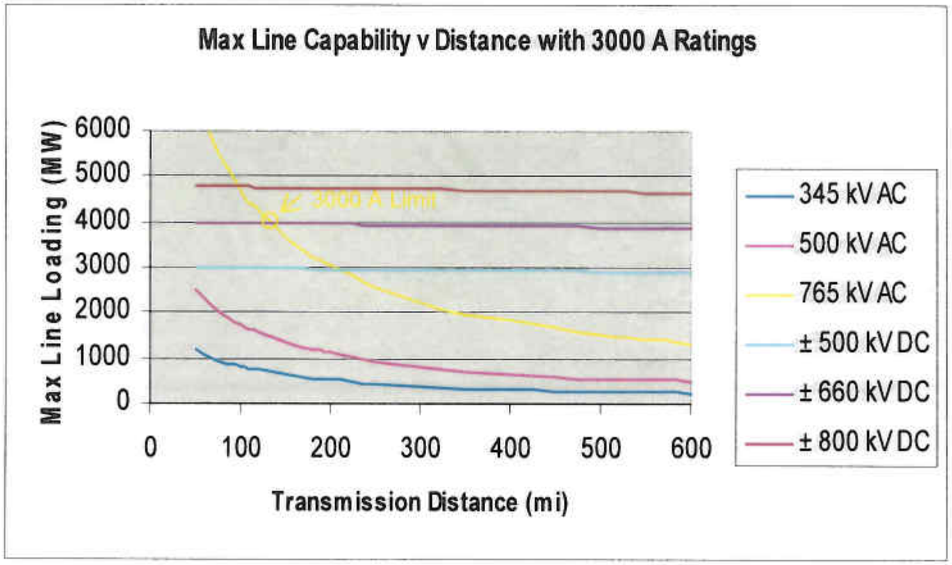
SVC & STATCOM
Boost or control ac voltage (V), dynamic reactive reserve

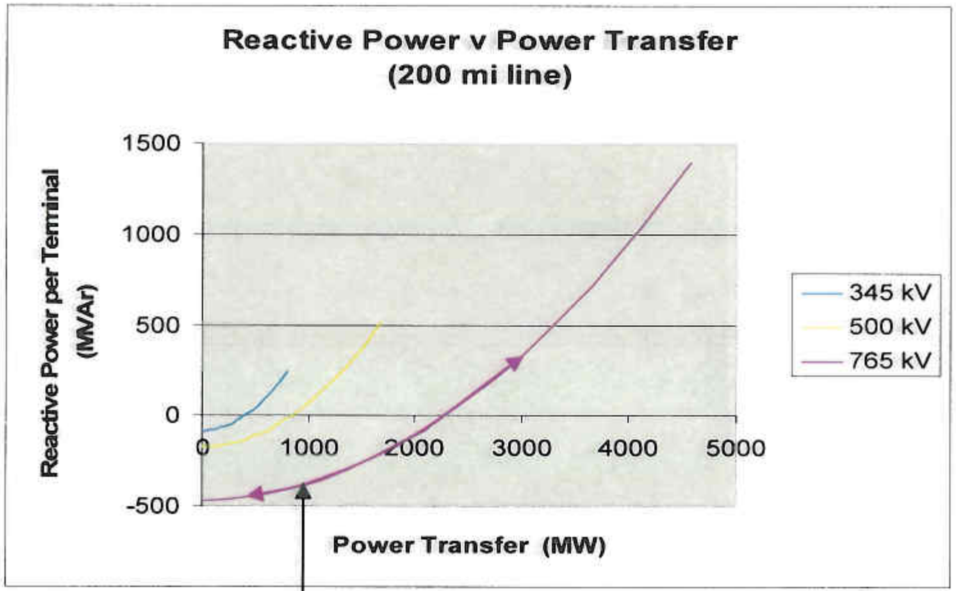
SC & TCSC – Boost Voltage (V), Reduce line reactance (X), limited by voltage profile

Phase Shifting Xfmrs -
Regulate phase angle (δ), limited by MVA, angular range

HVDC & HVDC Light -
Control power flow (P) and ac voltage (V), leverage ac cap by dynamic Q

Transmission line delivery capability v distance
AC line capacity diminishes with distance*


Max Line Capability v Distance with 3000 A Ratings


Reactive Power v Power Transfer (200 mi line)

Reactive power variation per 100 mi, 0.2-1.3 SIL

AC line distance effects:

- Intermediate switching stations, e.g. every ~200-250 mi max line segment length due to TOV, TRV, voltage profile
- Lower stability limits (voltage, angle)
- Increase stability limits & mitigate parallel flow with FACTS: SVC & SC
- Higher reactive demand with load
- Higher charging at light load
- Parallel flow issues more prevalent

DC line distance effects:

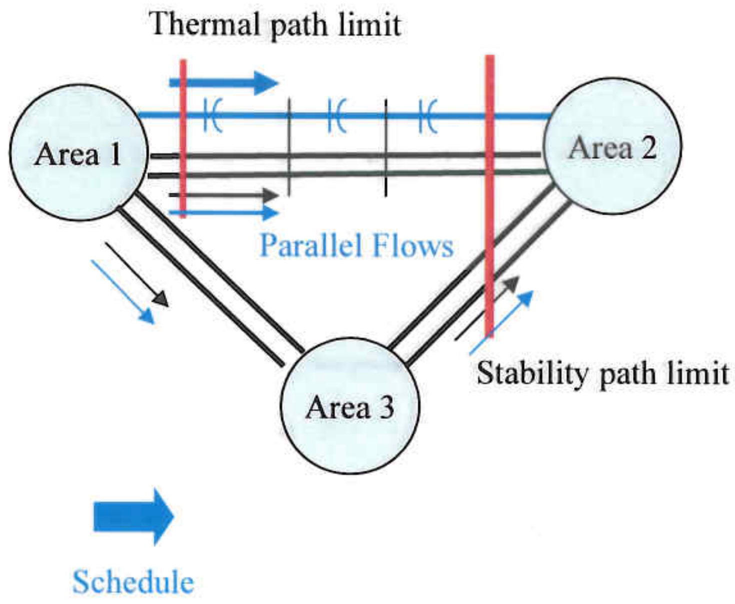
- No distance effect on stability (voltage, angle)
- No need for intermediate stations
- No parallel flow issues due to control
- Minor change in short circuit levels
- No increase in reactive power demand

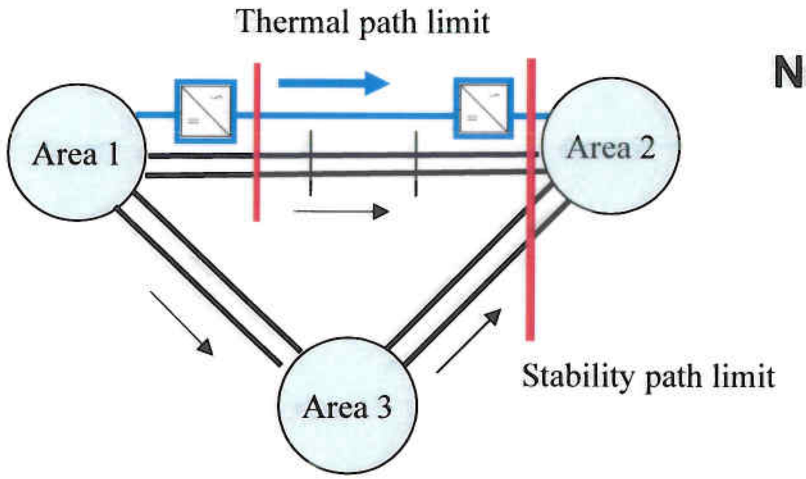
* Loadings per St Clair curve

Characteristics of HVDC Transmission

- Controllable - power injected where needed, supplemental control, e.g. damping, freq control
- Bypass congested circuits – no inadvertent flow
- Higher power, fewer lines, no intermediate S/S needed
- Lower losses
- Facilitates integration of remote diverse resources with less impact on existing grid
- Two circuits on less expensive line
- No stability distance limitation
- Reactive power demand limited to terminals independent of distance
- Narrower ROW, no EMF constraints
- No limit to underground or sea cable length
- Asynchronous, ‘firewall’ against cascading outages

Distance effects
AC v DC





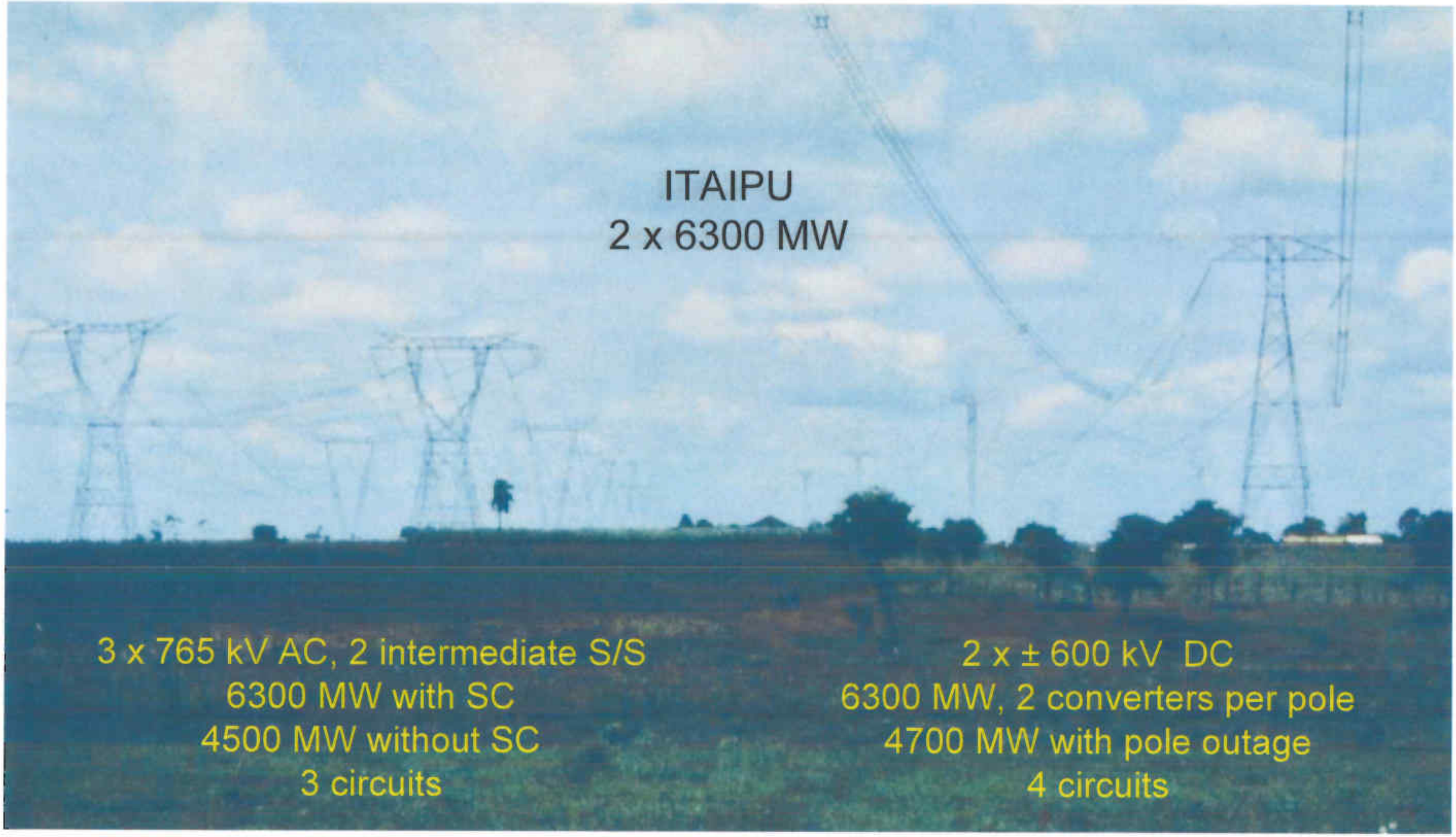
New AC line:

- Need for intermediate switching stations – the longer the line the more intermediate S/S
- Lower stability limits with longer distance
- Higher reactive power demand with heavy load, higher reactive power surplus at light load
- Parallel flow issues: cumulative, more prevalent and widespread for longer transfer distances
- Increase stability limits & mitigate parallel flow with series compensation (FACTS)
- Thermal limit remains the same

New DC line:

- No distance effect on stability
- Raise stability limit (voltage, angle)
- No need for intermediate stations
- No parallel flow issues due to control
- No increase in short circuit levels
- No increase in reactive power demand

Itaipu transmission example, 900 km (550 mi)
3 x 765 kV ac lines with SC = 2 x ± 600 kV HVDC lines
Each HVDC line costs ~ 70% of AC line cost

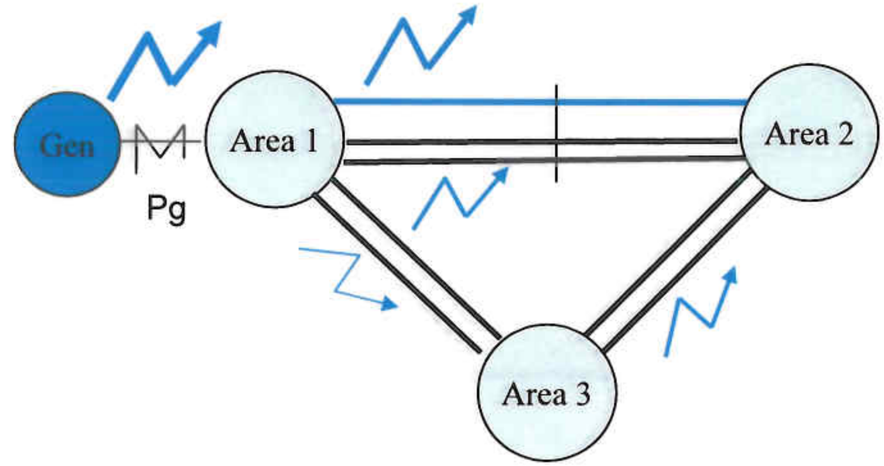


ITAIPU
2 x 6300 MW

3 x 765 kV AC, 2 intermediate S/S
6300 MW with SC
4500 MW without SC
3 circuits

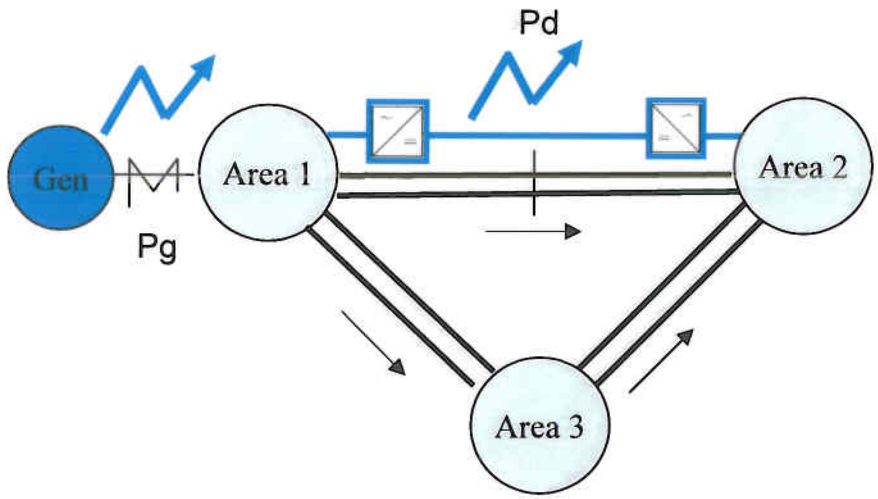
2 x ± 600 kV DC
6300 MW, 2 converters per pole
4700 MW with pole outage
4 circuits

Indirect v direct control – AC v DC



AC Transmission:

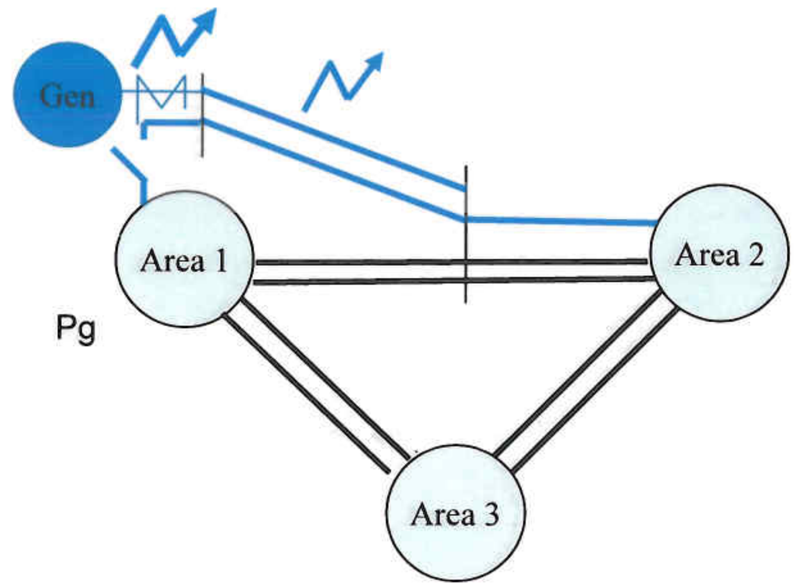
- Power flow from generation distributes per line characteristics (impedance) & phase angle (generation dispatch)
- Variable generation gives variable flow on all intermediate paths
- Transfer may be limited due to congestion
- New resources add cumulatively clogging existing paths, usurping original purpose
- Flow controlled indirectly by generation dispatch

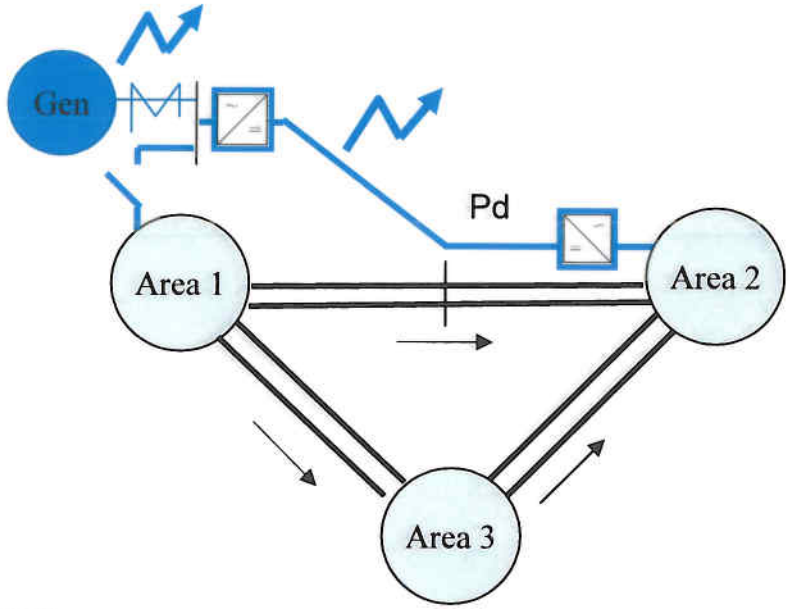


HVDC Transmission:

- Controlled power flow adds flexibility, independent of phase angle
- Operational examples: Pd = Σ Pg + P schedule, Pd = k * Pg
- Permits optimal power flow, e.g. lower losses, transmission reserve margin
- Bypasses congestion
- Off-loads parallel paths

Isolated or radial operation – AC v DC





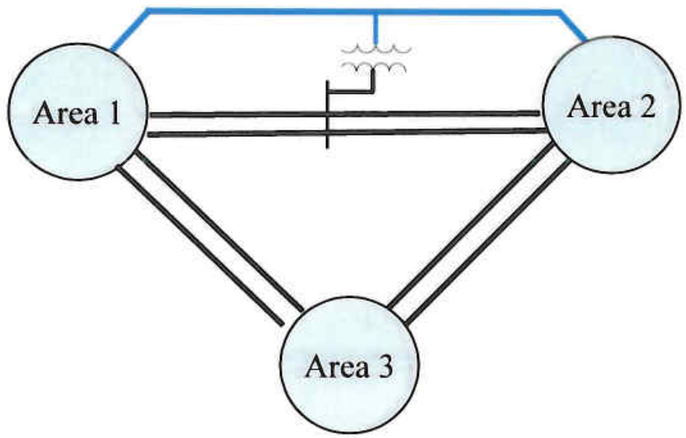
AC Transmission:

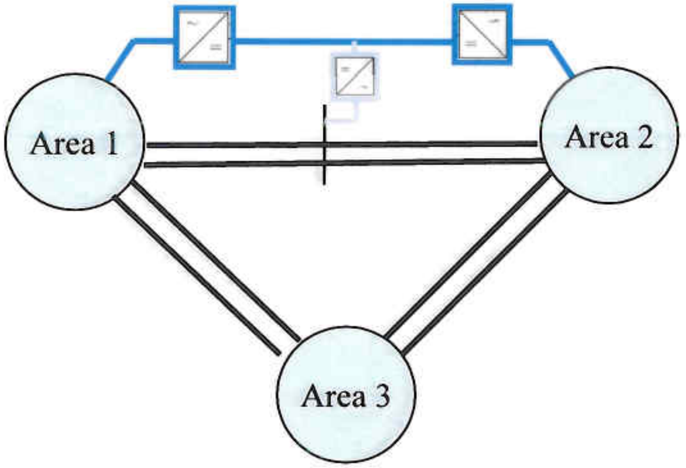
- Isolated operation may present stability problem
- More generator outlet lines may be required for stability
- SSR more likely if series compensation used, requires lower comp level or TCSC
- Auto-reclosing problematic due to stability or transient torque fatigue stress
- Induction generator instability possible issue with series compensation

HVDC Transmission:

- Bipolar line provides two circuits
- Auto-reclosing reduced risk of transient torque amplification – soft restarts possible
- Synchronous or asynchronous operation – some issues with ind gen with conventional HVDC but not VSC HVDC
- Isolated operation OK, may require SSTI mitigation for some generators

Tapping – AC v DC





AC Tap

- Add substation equipment and transformers if different voltage levels
- May exacerbate parallel flow issues

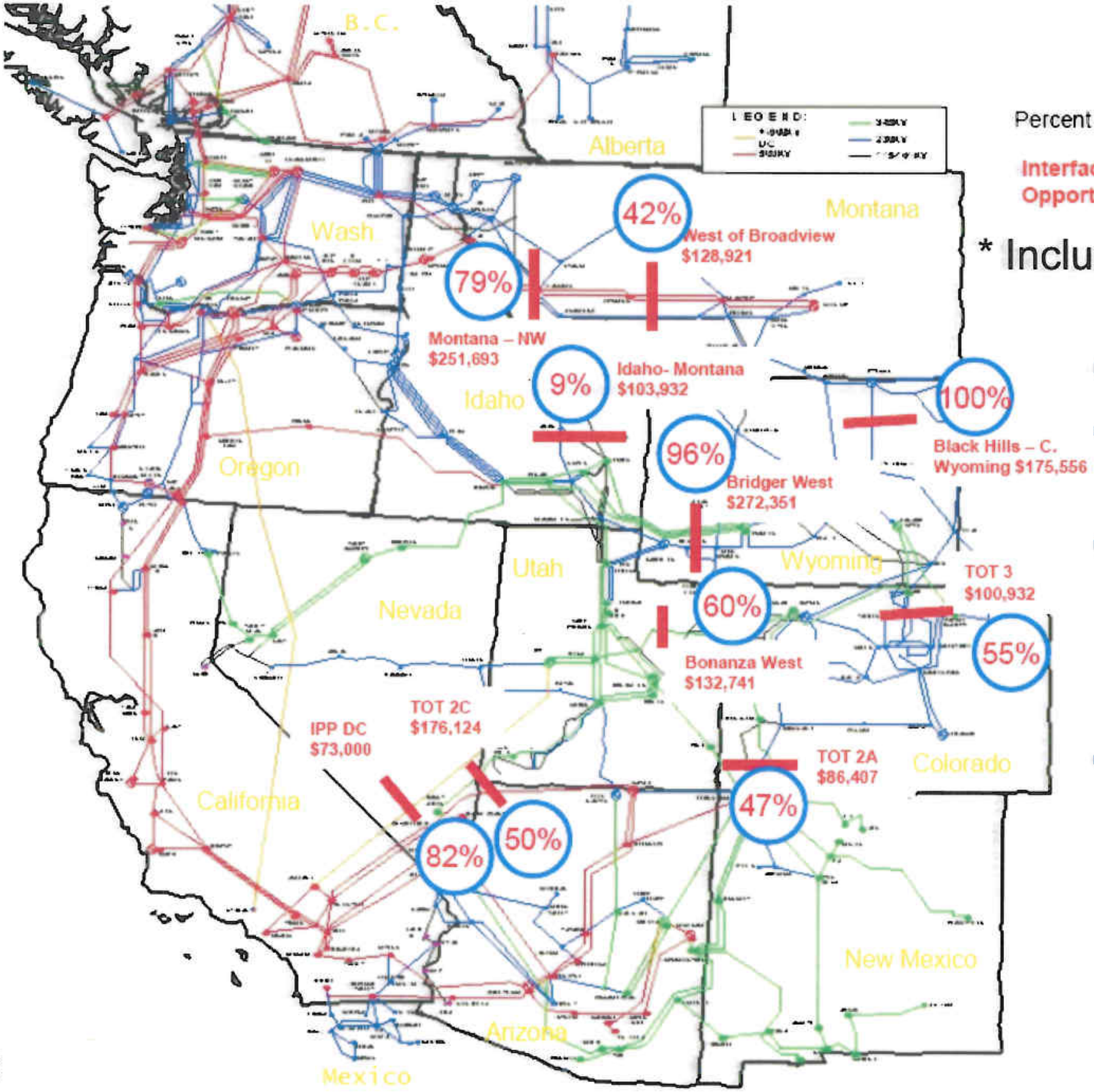
HVDC Tap

- Electronic clearing of dc line faults
- Fast isolation of faulty converters
- Reactive power compensation required
- Momentary interruption due to ac fault at tap
- Limitations on tap rating, location and recovery rate due to voltage stability with weak systems
- Power reversal requires polarity reversal

HVDC Light Tap

- No momentary interruption to main power transfer due to ac fault at tap
- Less limitations on tap rating and location
- No reactive power constraints, improved voltage stability
- DC breaker may be needed for faster dc line fault clearing in some applications
- Power reversal at tap by current reversal

Path congestion RMATS 2013 11,700*MW Alt 4 generation



%

Percent of Time at Binding Limit

Interface Name

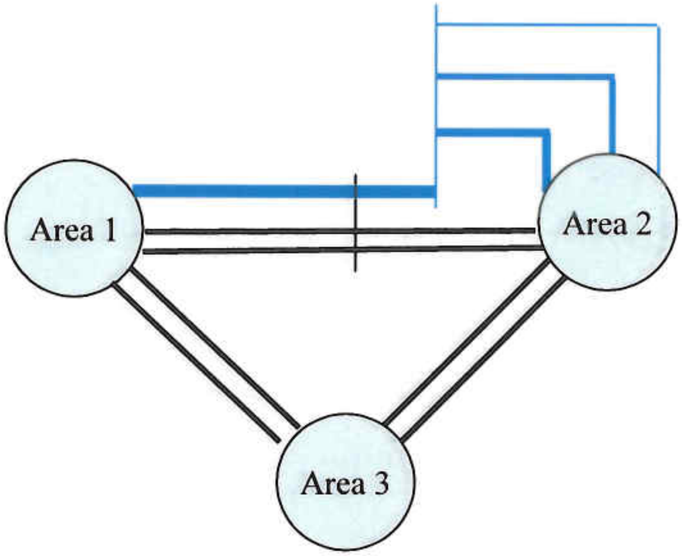
Opportunity Cost/Savings ($) per incremental MW

* Includes 7800 MW for Export

- Multiple path limits |
- Percentage of time ○ each path is congested
- The longer the ac transmission, the more path limits are affected, flows are cumulative
- DC bypasses multiple congestion points implies transfer capacity is more firm

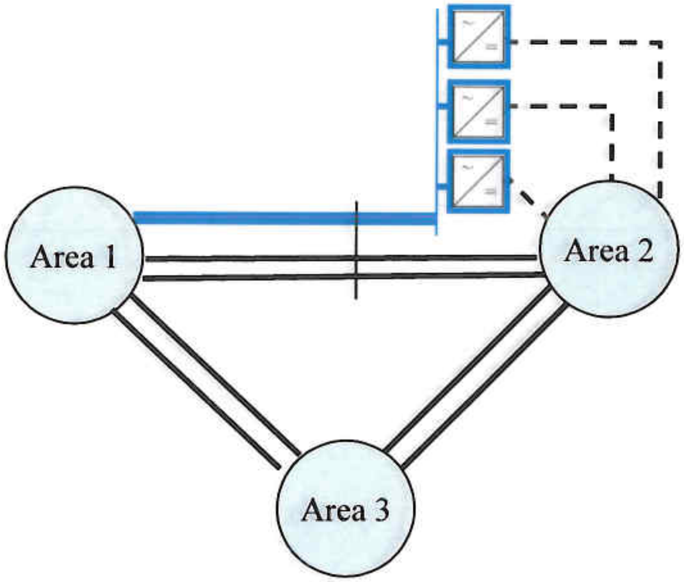
ABB

Grid Extenders



AC extenders:

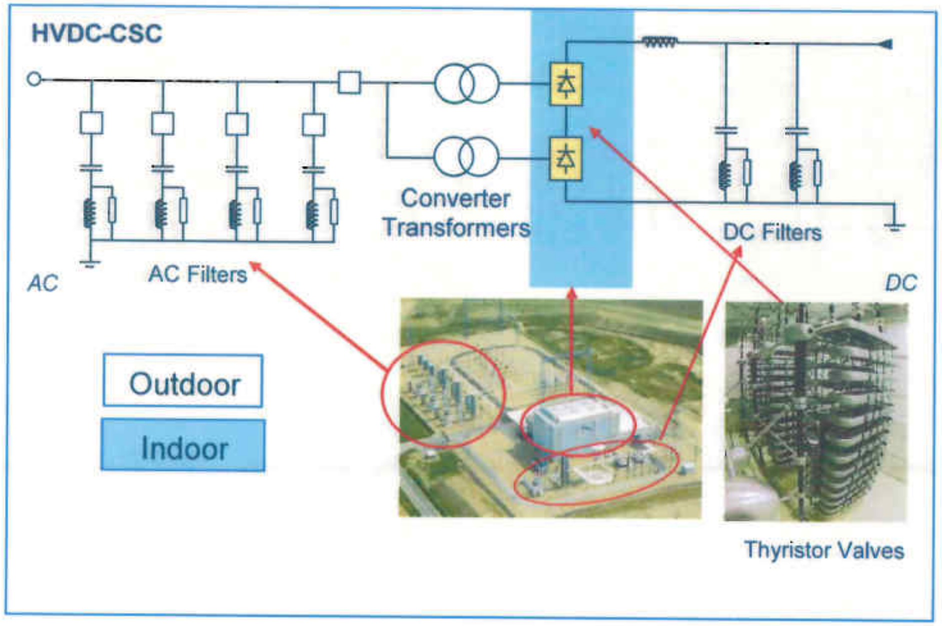
- No control of power injection distribution
- Potential for unequal utilization and local congestion without phase shifters
- Reactive power compensation required for light & heavy load conditions
- No inherent voltage support
- Increases fault current duties
- Increased right-way-requirements

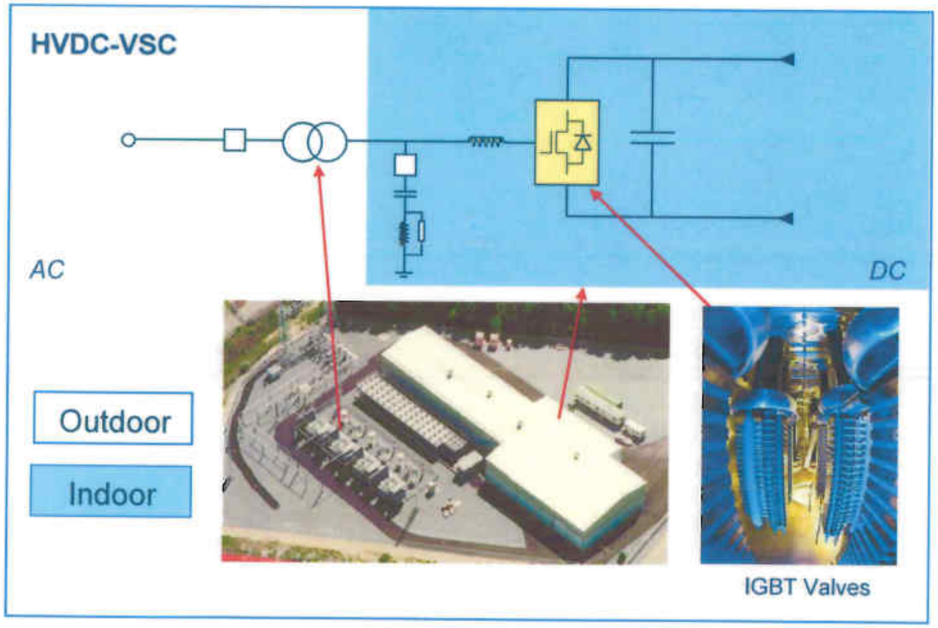


HVDC Light extenders:

- Delivers bulk power allocation to selected distribution substations in congested area
- Provides dynamic voltage support (virtual generators), enhancing capability of ac system
- Doesn't increase fault current duties
- Allows shared use of narrow rights-of-way
- Stealthy and healthy – can be U/G, low dc EMF

Core HVDC technologies





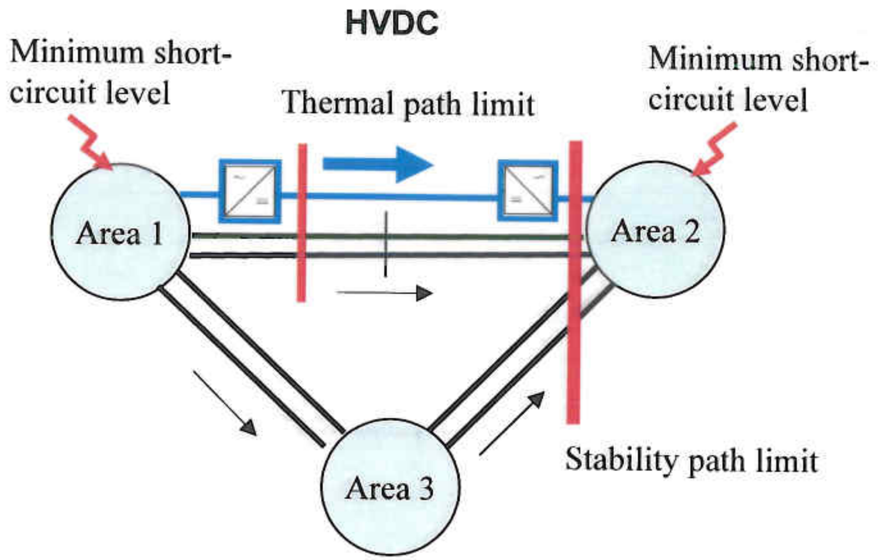
HVDC Classic

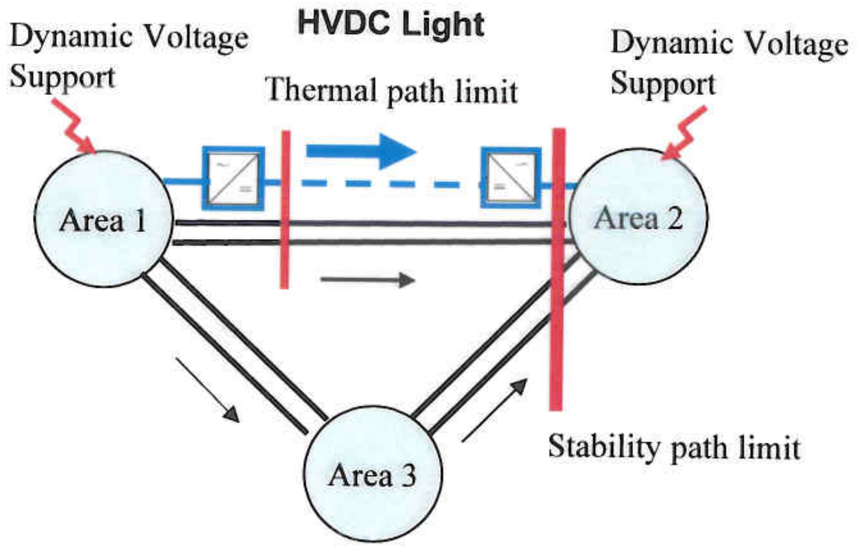
- Current source converters
- Line-commutated thyristor valves
- Requires 50% reactive compensation (35% HF)
- Converter transformers
- Minimum short circuit capacity > 2x converter rating, > 1.3x with capacitor commutation

HVDC Light

- Voltage source converters (VSC)
- Self-commutated IGBT valves
- Requires no reactive power compensation (~15% HF)
- Virtual generator at receiving end: P,Q
- Standard transformers
- Weak system, black start
- Radial wind outlet regardless of type of wind T-G, off-shore or isolated
- U/G or OVHD

Transmission expansion – HVDC & HVDC Light





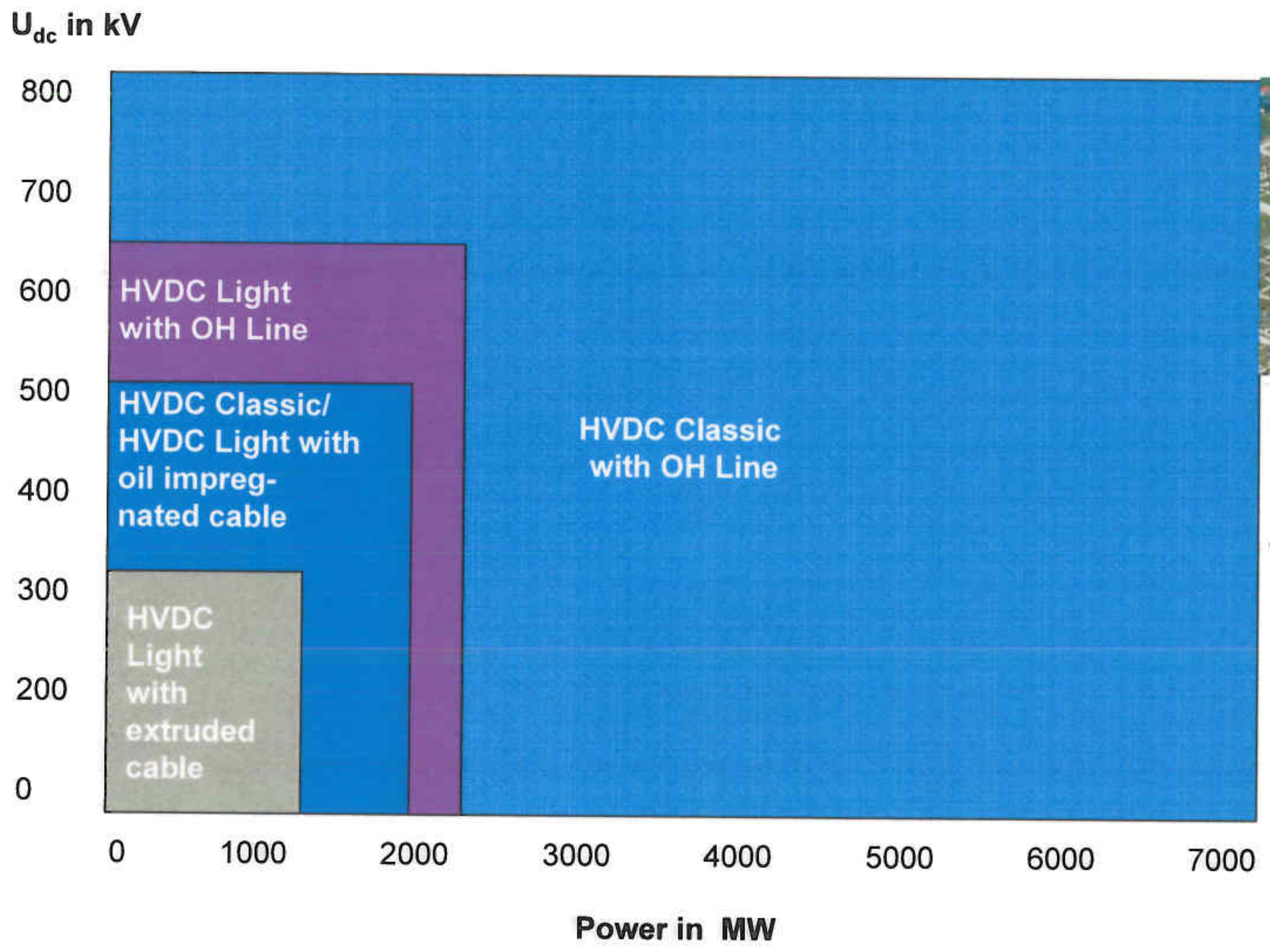
Conventional HVDC:

- Minimum short circuit level restriction ($S_{MVA} > 2 \times Pd$)
- Induction wind generation contributes 50-70% of synchronous to S_{MVA}
- Reactive power demand at terminals ($Q \sim= 0.5 \times Pd$)
- Reactive compensation at terminals
- Higher ratings, greater economies of scale

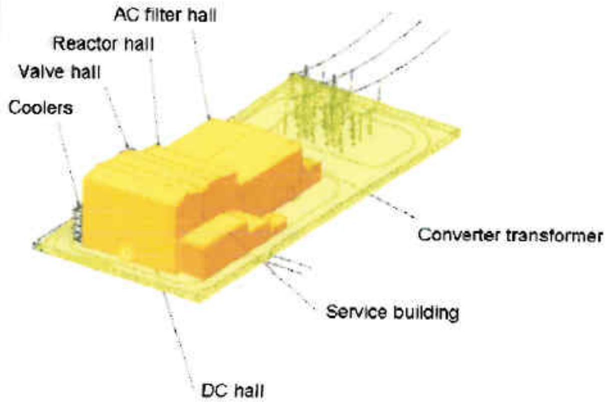
HVDC Light:

- No minimum short circuit levels
- No reactive power demand
- Dynamic reactive voltage support (virtual generator, $Q \sim= 0.5 \times Pr$)
- Leverage capacity by ac voltage support
- Conducive for but not limited to underground cable transmission

HVDC Light® or HVDC Classic
Ratings range for underground and overhead

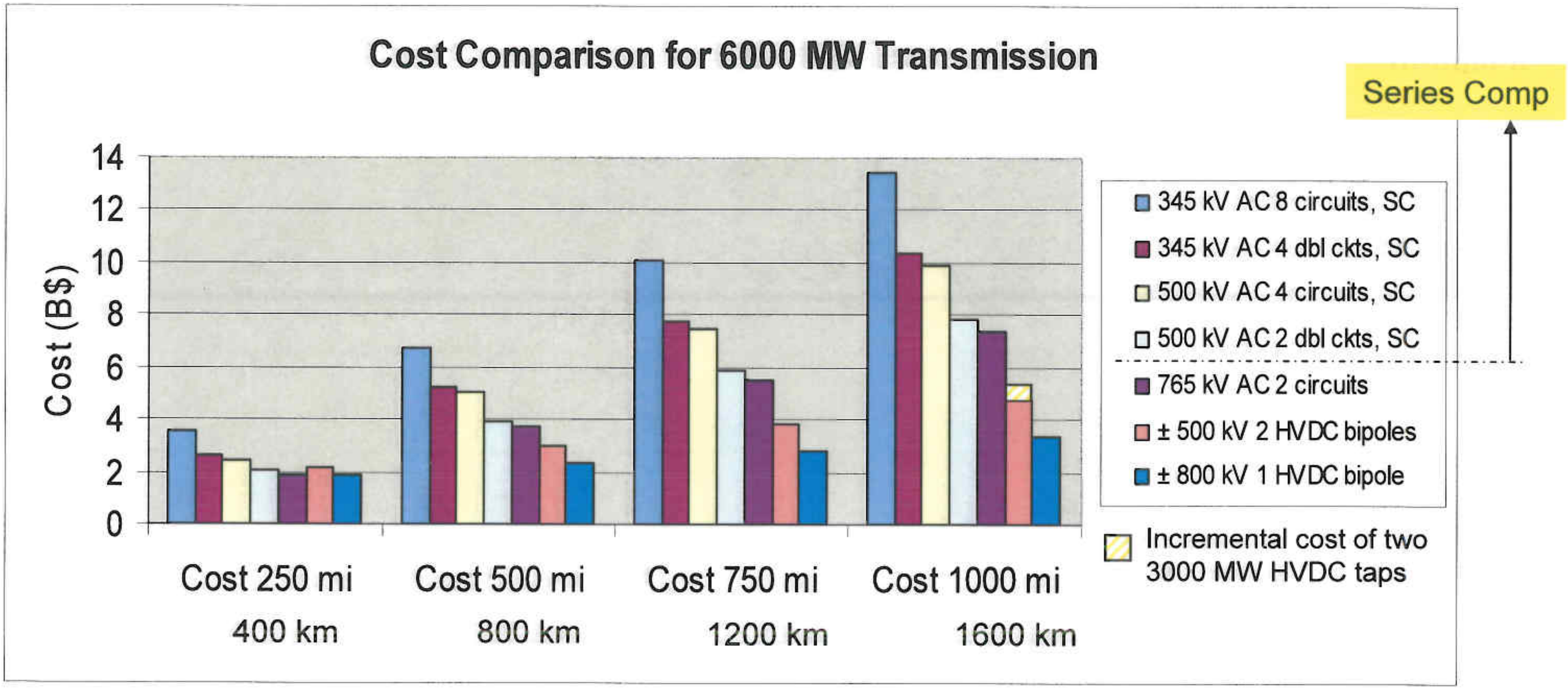


± 500 kV, 3300 MW HVDC



± 320 kV, 1200 MW HVDC

Comparative costs for 6000 MW transmission Intermediate S/S and reactive comp every 250 miles

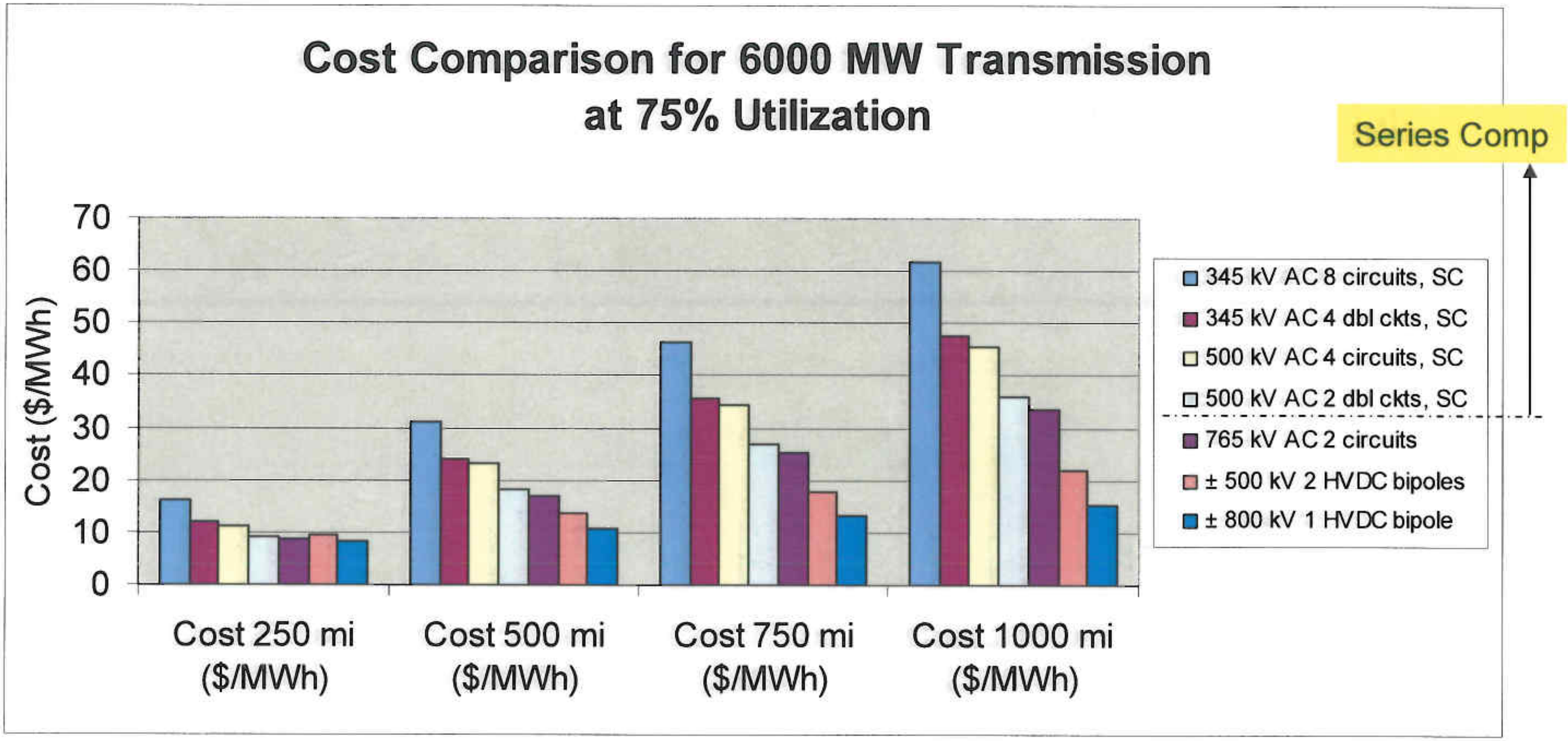


Cost Comparison for 6000 MW Transmission

Notes:

- Series compensated ac lines loaded to ~ 2 x SIL,
- 765 kV loaded to ~ 1.3 x SIL or ~ steady state stability limit for 200 mi line segment per St Clair curve
- Transmission line and substation costs based on Frontier Line transmission subcommittee, NTAC and ERCOT CREZ unit cost data.
- Lines loaded to their steady state stability limits – no stability margin

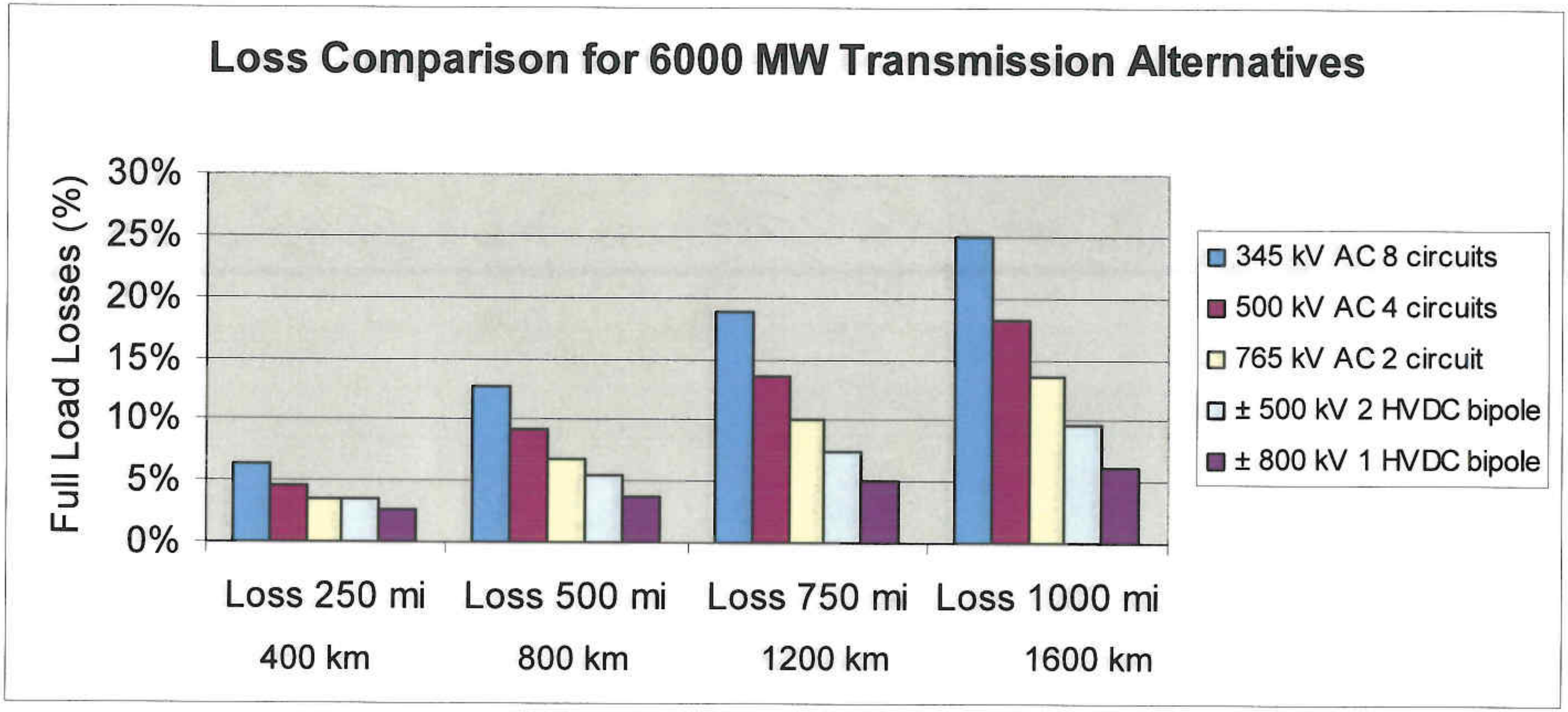
Comparative delivery costs for 6000 MW transmission IOU financing, no incentives, 75% utilization



Notes:

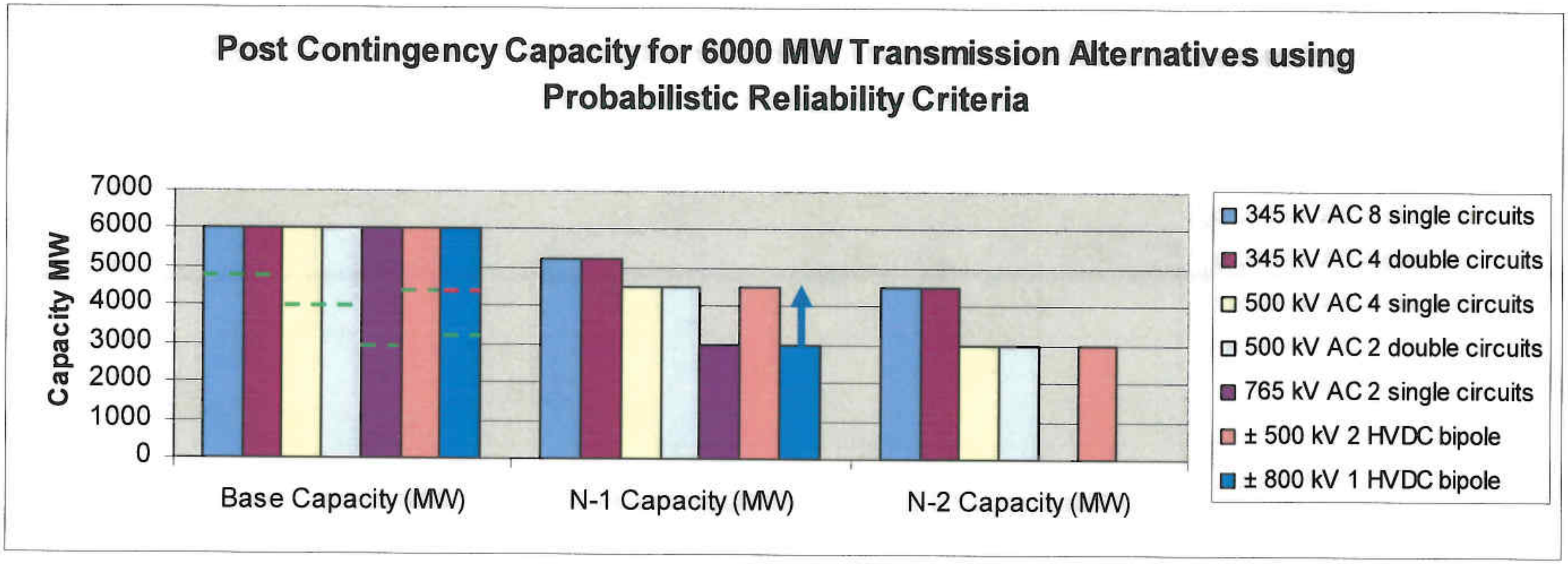
- Series compensated ac lines loaded to ~ 2 x SIL,
- 765 kV loaded to ~ 1.3 x SIL or ~ steady state stability limit for 200 mi line segment per St Clair curve
- Transmission line and substation costs based on Frontier Line transmission subcommittee, NTAC and ERCOT CREZ unit cost data.

Transmission alternatives loss comparison: 6000 MW Line losses + converter and S/S losses @ full load



Note: AC and DC line conductors chosen for comparable current densities, higher no. conductor bundles for higher voltage. Corona losses not included.

Post-contingency capacity – 6000 MW base
Margins: RAS/SPS, reduced severe weather limits?



Post Contingency Capacity for 6000 MW Transmission Alternatives using Probabilistic Reliability Criteria

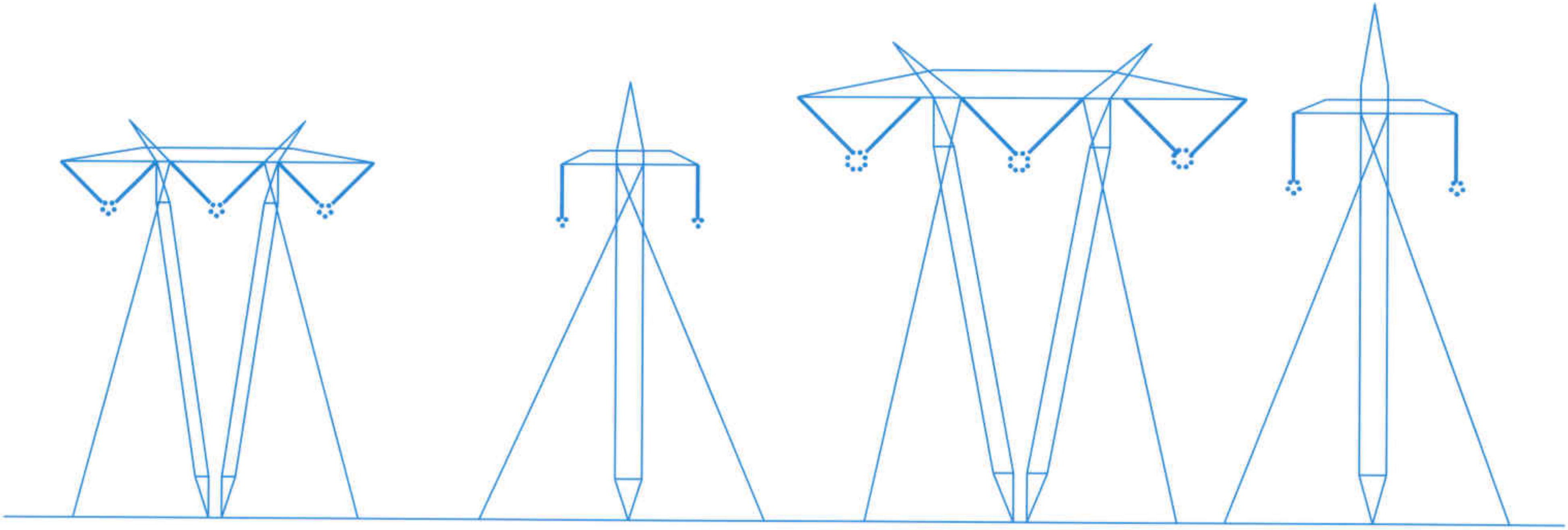
N-1 = Loss of one AC circuit or one HVDC pole, converter ↑, excludes loss of tower
N-2 = Loss of two AC circuits, two HVDC poles, includes loss of tower (Class C)

Note: Capacity indicated is for lines loaded to their steady state stability limits – no margin

- - - Plausible transfer limits with stability margins for N - 1

- - - ↑ Plausible transfer limits with stability margins for N – 1, if loss of single 400 kV converter or degraded insulation is treated probabilistically as N – 1

UHV AC and DC line comparison
AC lines loaded to 1.3 x SIL limit for 200 mi segment



800 kV	± 600 kV	1000 kV	± 800 kV
1 circuit	2 circuits	1 circuit	2 circuits
3000 MW	4000 MW	5600 MW	6400 MW
200 mi	1000 mi ±	200 mi	1000 mi ±

Overall comparison of HVDC and EHVAC lines

Line insulation

- Clearance requirements are more critical with EHVAC/UHVAC
- More stringent demands on HVDC insulators (creepage length)

Corona effects

- Larger conductor bundles are needed with EHVAC/UHVAC

Effect of high altitudes

- Higher clearances and larger conductor bundles required for AC
- Larger relative increase in air clearance required for HVDC

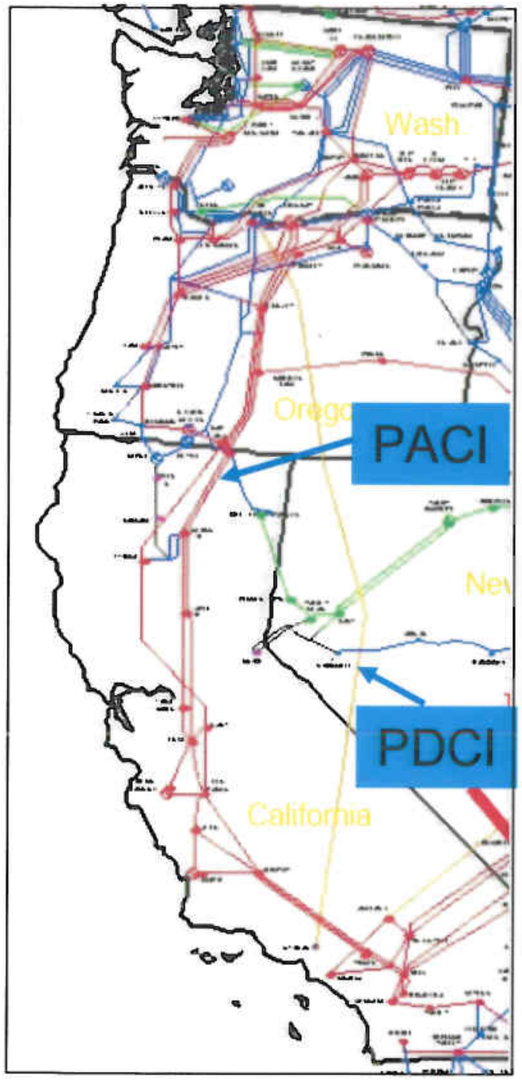
Mechanical load

- Conductor load on tower is considerably lower with HVDC

Overall cost aspects

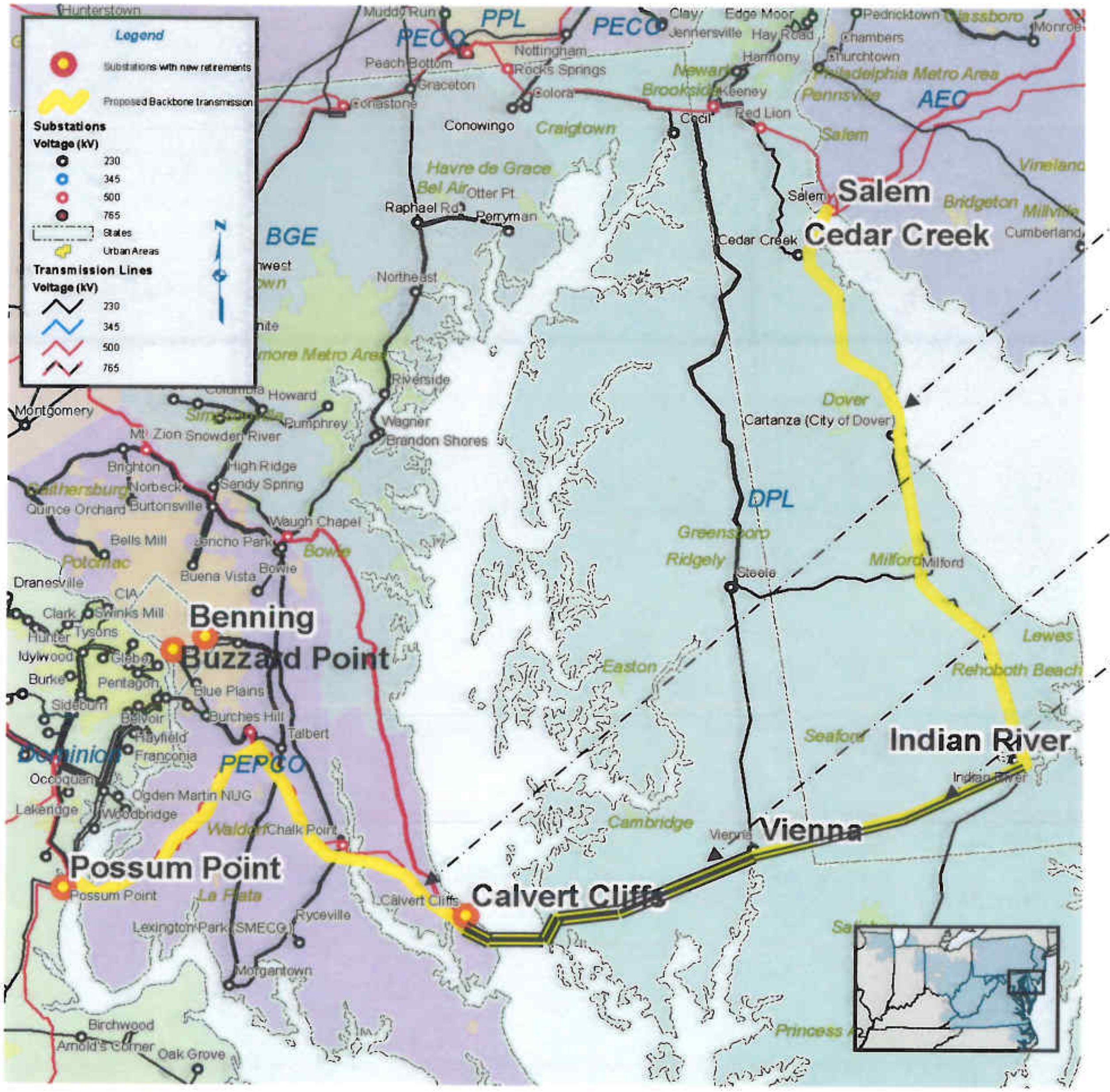
- Lower investment costs for HVDC lines
- Cost advantage of HVDC is more pronounced at higher voltages and higher altitudes

Pacific AC and DC Interties: PACI and PDCI
Hybrid 2 x 500 kVac with SC and ± 500 kV HVDC



- Hybrid: two multi-segment, series-compensated AC lines plus one bipolar DC link
- Combines local N-S access with parallel bypass for greater operational flexibility and efficiency
- Links diverse resources - hydro in the Pac NW, thermal in the SW
- Seasonal load diversity between N and S
- PACI upgraded to ~50% higher current rating in late '90's through early '00's
- PDCI upgrades: 1440->1600->2000->3100 MW
- Combined IOU and public power development
- Nearly 4 decades of providing value to operation of the western interconnected system

PHI Mid-Atlantic Power Pathway (MAPP) Project
3x1000MW DC/AC hybrid proposed, approved by PJM



Single circuit 500 kV ac overhead line segment additions:

Indian River – Salem (last stage)

\+

Possum Point – Calvert Cliffs

Controllable HVDC 640 kV dc cable or dc cable/overhead line staged circuit additions:

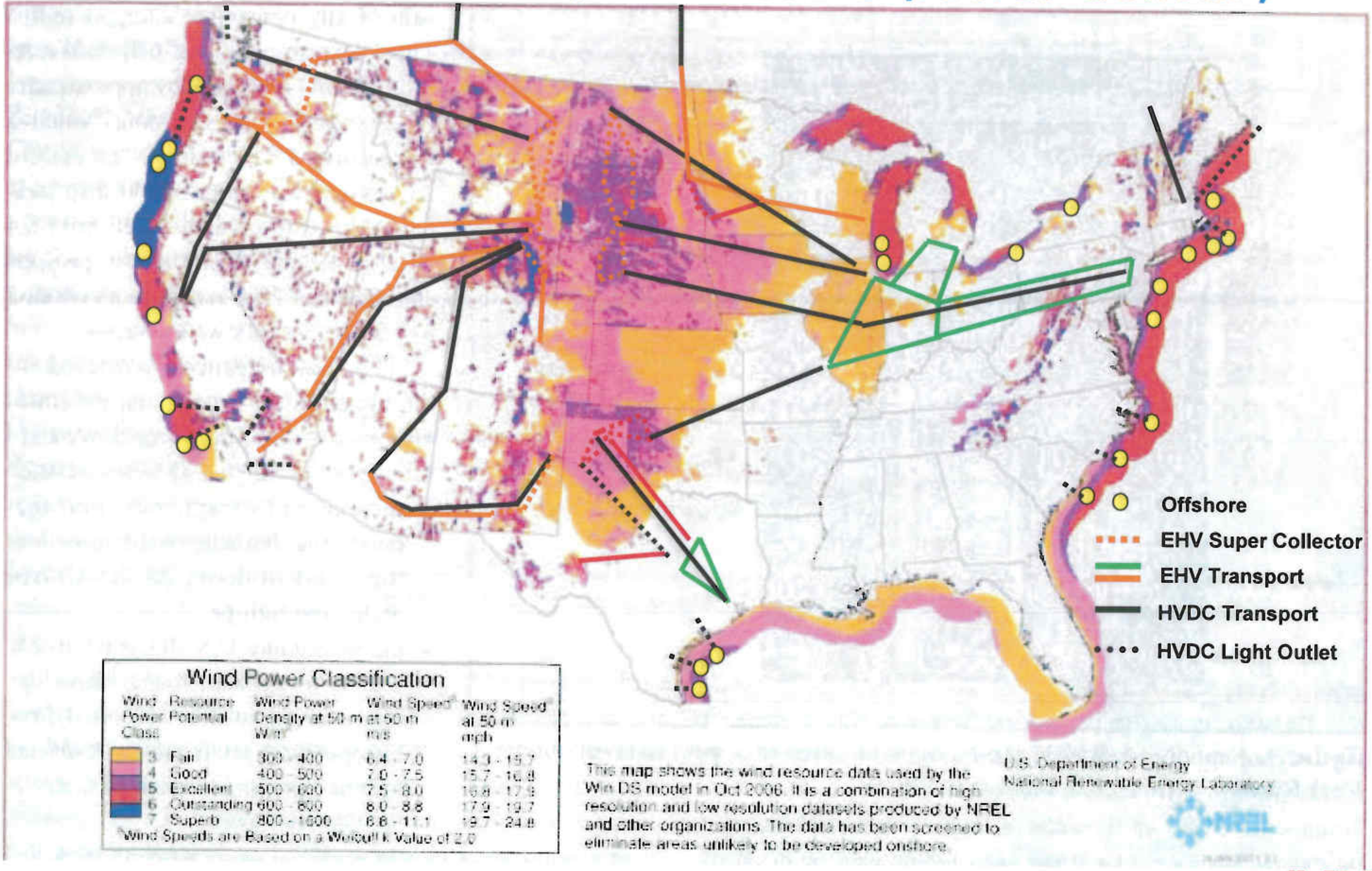
Calvert Cliffs – Vienna,
1 x 1000 MW, ±320 kV VSC dc

\+

Calvert Cliffs – Indian River,
2 x 1000 MW, ±320 kV VSC dc

Note: Studies showed an all 500 kV ac alternative does not load up beyond 1200 MW even with largest available phase angle regulator (PAR).

Accessible US wind resources lower 48 states
Super collectors and hybrid AC/DC power delivery



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed* at 50 m m/s	Wind Speed* at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

*Wind Speeds are Based on a Weibull k Value of 2.0

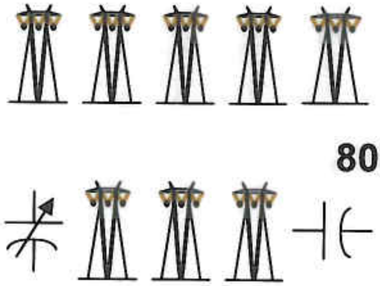
This map shows the wind resource data used by the Win DS model in Oct 2006. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data has been screened to eliminate areas unlikely to be developed onshore.

U.S. Department of Energy
National Renewable Energy Laboratory

Long distance bulk power transmission - 6000 MW
AC, DC or hybrid connection ?

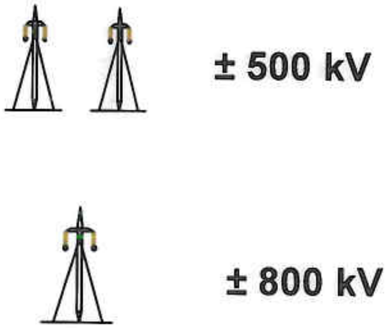
AC **HVAC interconnections**

- **FACTS** - fewer lines, improved voltage profile



HVDC more economical for longer distances (>400 km) or higher ratings (>2000 MW)

DC



- **Capex** – fewer lines, reduced line cost
- **Opex** – reduced losses over longer distances, lower O&M
- **Capacity** – 3000 to 6400 MW per bipolar line
- **Reliability** – double circuit lines, can operate with reduced capacity, e.g. converter outage or degraded insulation
- **Flexibility** – controllability, bypass congestion, firm, frees up capacity on parallel paths, asynchronous possible
- **Environmental** – reduced ROW, dc magnetic fields, lower losses, less material

Underground, offshore, island or isolated wind farms AC or DC connection ?

AC **HVAC connections**

- **FACTS** – absorb excess charging, voltage control

HVDC Light (VSC technology) economical for longer distances (>50 km) or higher ratings (>300 MW)

DC

- **Capex** – fewer cables, reduced cable cost, smaller footprint
- **Opex** – reduced power losses over long distances
- **Capacity** - several wind farms connected to a “plug at sea”
- **Reliability** – grid code compliance, ride through, frequency & voltage control, stability, black start capability
- **Flexible** – real and reactive power controllability, enables U/G or OVHD connection to main AC grid, allows connection of simpler more efficient wind plant designs
- **Environmental** – reduced trenching, canceling dc magnetic fields, no oil in XLPE cable, less material, lower losses

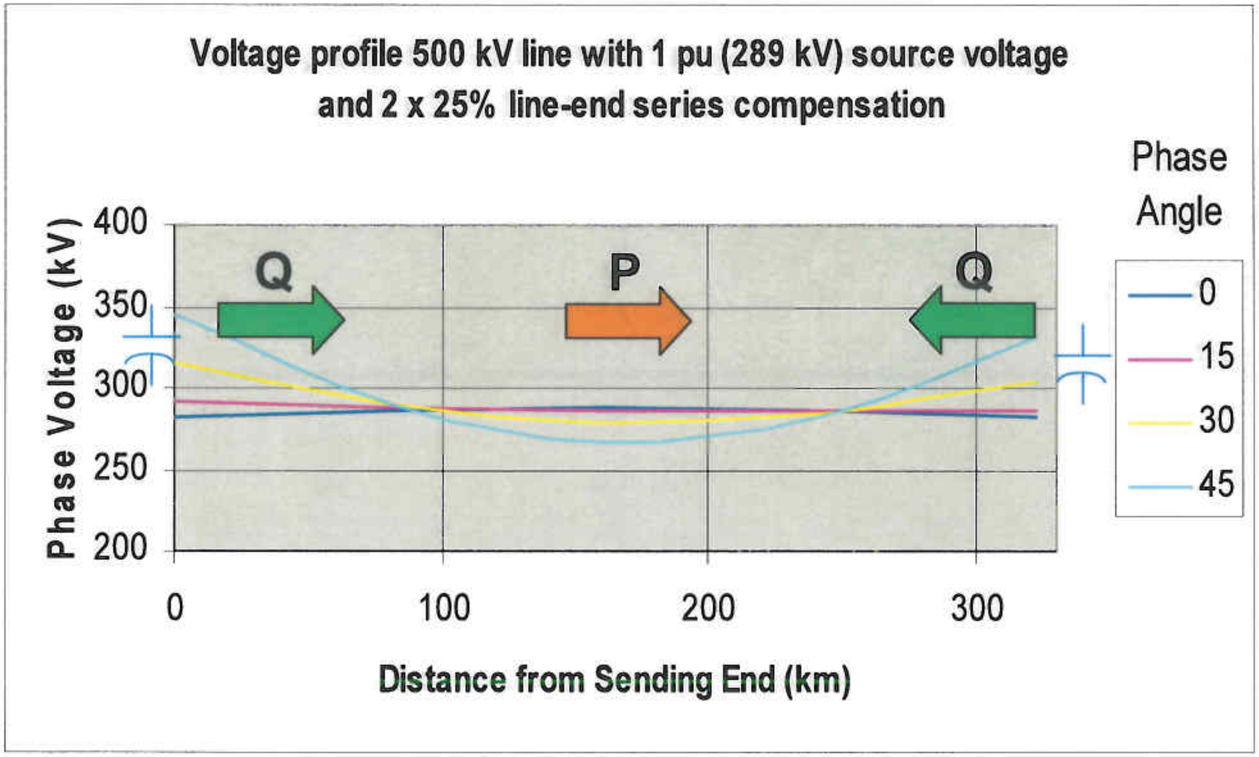
Summary

- Choice of transmission technology exists
- HVDC and FACTS reduce the number of lines for lower cost transmission
- HVDC adds operational flexibility for generator outlet transmission and for interconnections thereby complementing the AC system
  - Fewer, less-expensive, double-circuit lines
  - Bypass congestion, reduced parallel flow issues
  - Controllable and firm
- HVDC transmission is more efficient for longer distances, e.g. > 250 mi
- Cost of tapping is higher with HVDC, some system location restrictions may apply, less restriction with HVDC Light
- Hybrid AC/DC systems provide both local access and transport functions
- HVDC can operate and be financed on a stand-alone project basis enabling more economic integration of diverse capacity into a smarter grid with more efficient use of capital

Power and productivity
for a better world™

ABB

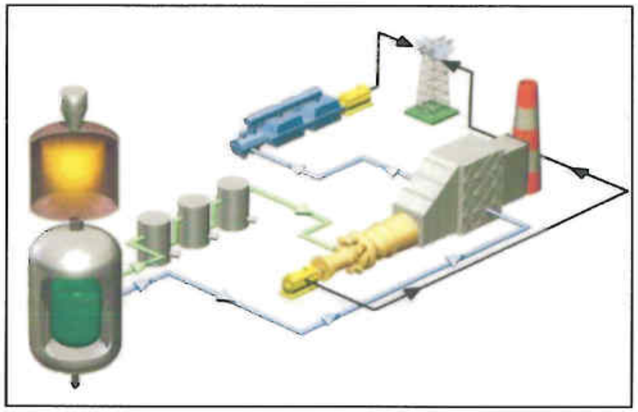
Voltage profile for a 320 km (200 mi) line 25% series compensation at each end



30 degrees ~ 1200 MVA
45 degrees ~ 3000 MVA

- Series capacitor banks can boost voltage, reduce effective line impedance and partially meet reactive power demand
- Voltage profile along the line can limit the maximum practical transfer limit
- Voltage profile affected by series capacitor bank(s) location

Power plants of the future
Improvements in both wind & conventional generation



- Diversity of wind plants across a reasonably sized balancing area
- Firming up power supply with other forms of power production to increase realizable wind penetrations
- Controlled ramp rates for wind plants to match load profile and ramp rates of other generation assets – number of wind machines and pitch control
- Faster ramp rates for new versions of traditional generation to better match wind resources
- Net reduction in emissions
- Integrated system operation with hydro resources and pumped storage to minimize wind spillage where feasible
- Controllable transmission enables smart grid operational strategies

Existing HVDC technology and associated constraints

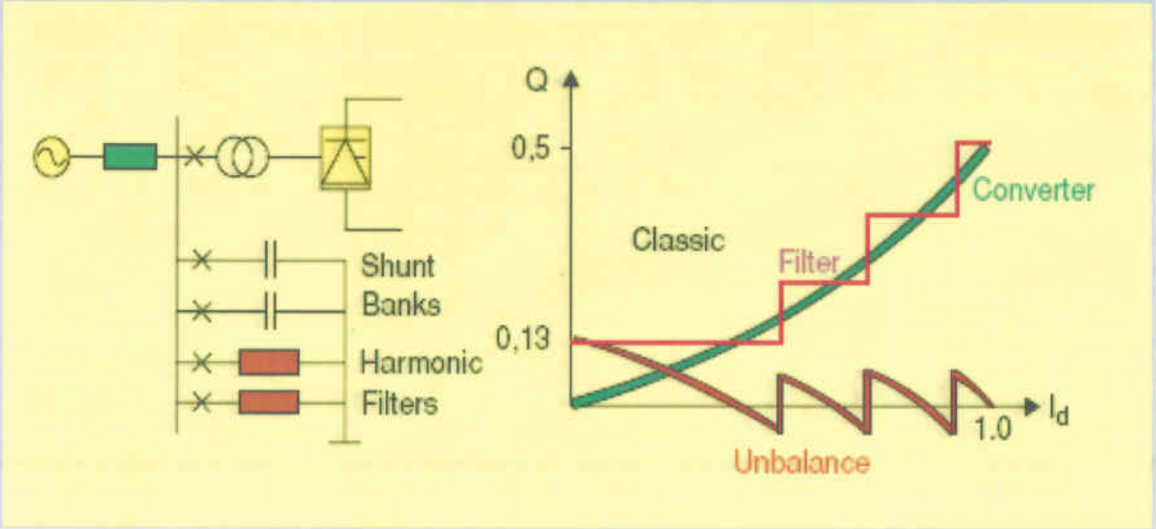
HVDC Ratings

- Up to 3000 – 4000 A dc per converter,
- Up to 1600 – 2400 MW per converter
- 400, 500, 800 kV dc per pole, 900 kV dc converter used for symmetrical monopole (e.g. NorNed ± 450 kV)
- Parallel or series converters for staging or expansion
- Transformer transport limitations may affect configuration

HVDC Light VSC Ratings

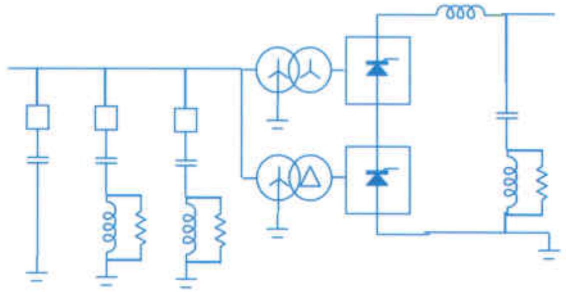
- 1200 MW, 1880 A at 640 kV (± 320 kV) per converter
- Up to 320 kV for cable systems (± 320 kV)
- Up to 2400 MW for bipolar overhead line systems at ± 640 kV, proportionally less at lower transmission voltages

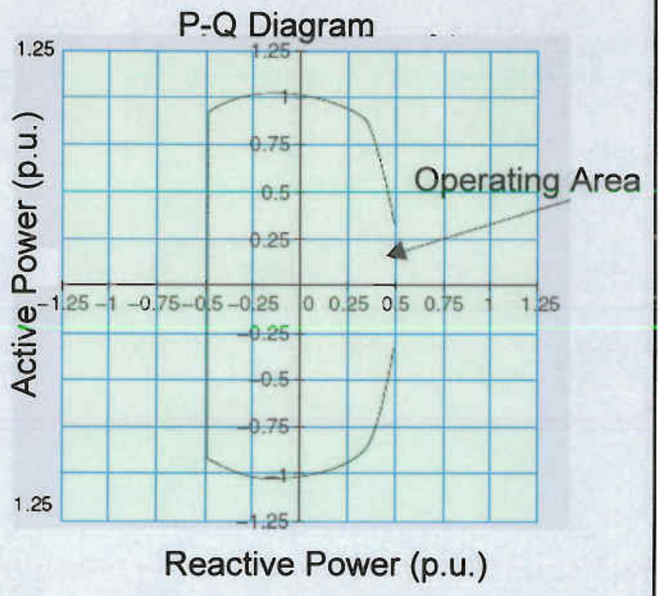
Comparison of Reactive Power Characteristics



HVDC Classic:

~ reactive compensation by switched filters and shunt capacitor banks

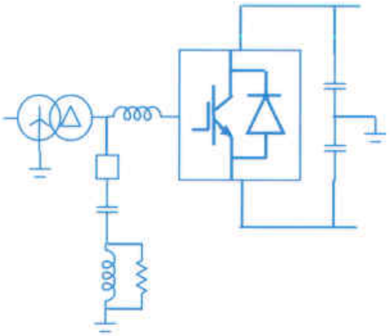




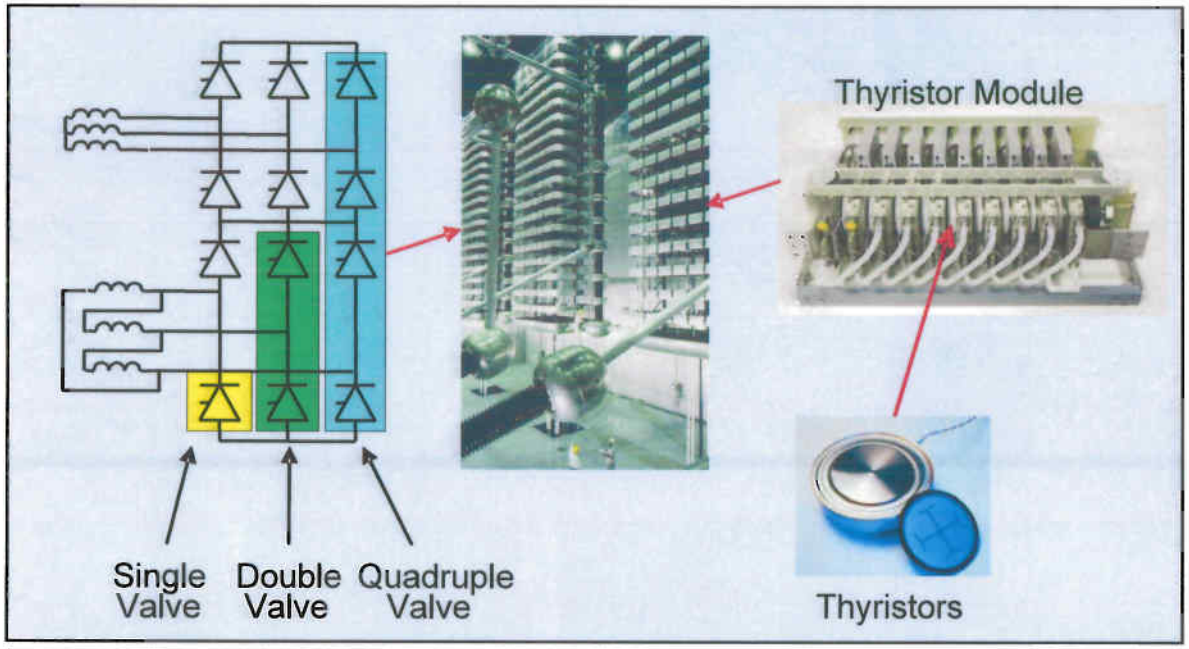
HVDC VSC Operating Range

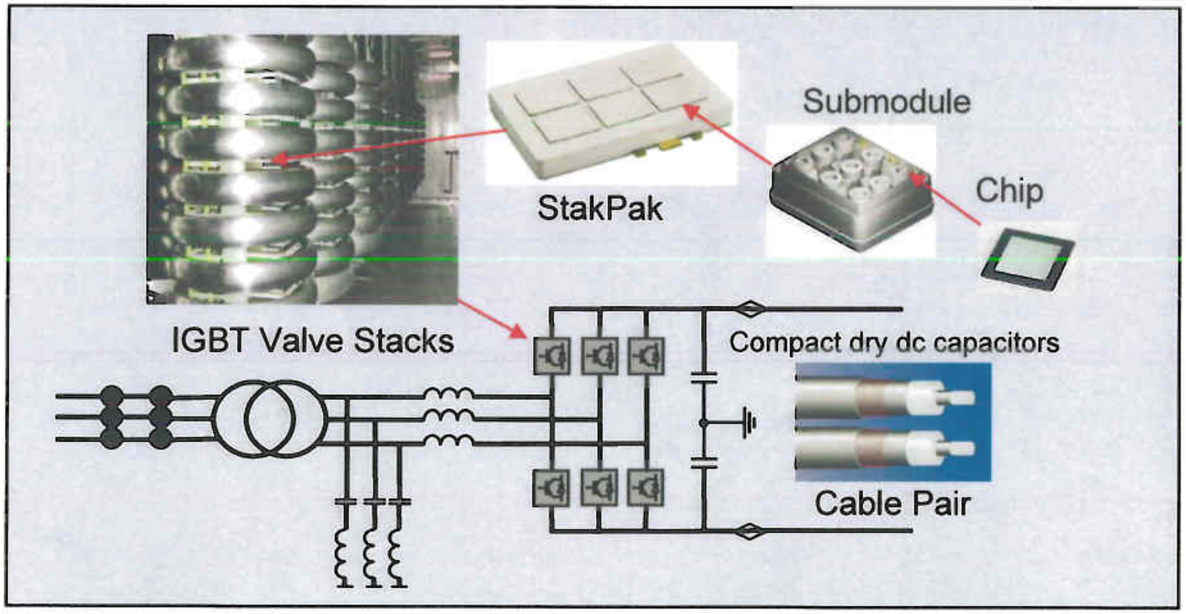
HVDC Light:

No reactive compensation necessary, STATCOM with dynamic range ~ 0.5Pd/+0.5Pd MVar below 90% power



HVDC Converter Arrangements





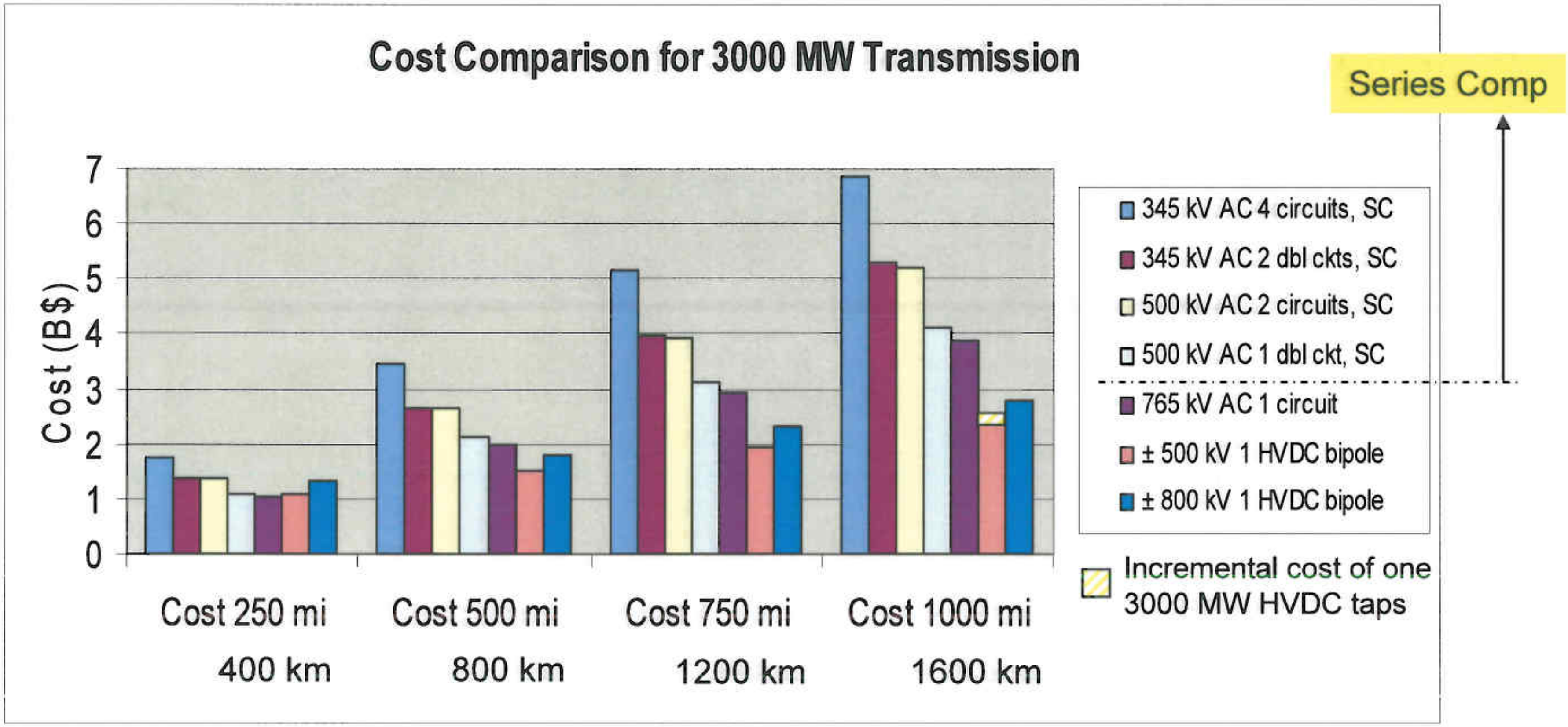
HVDC Classic

- Thyristor valves
- Thyristor modules
- Thyristors
- Line commutated

HVDC Light

- IGBT valves
- IGBT valve stacks
- StakPaks
- Submodules
- Self commutated
- Compact dry dc capacitors

Comparative costs for 3000 MW transmission Intermediate S/S and reactive comp every 400 km



Notes:

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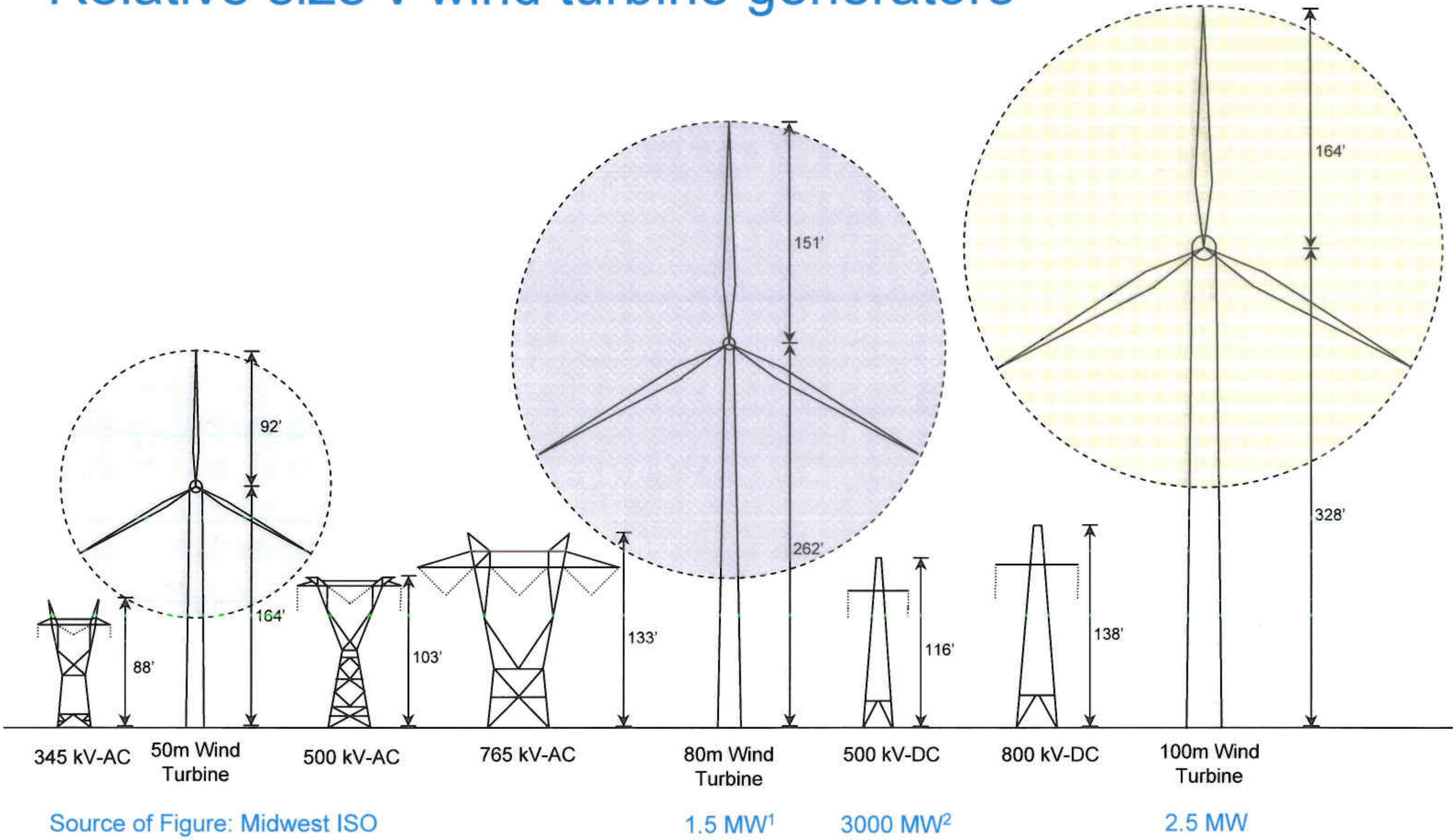
- 765 kV loaded to ~ 1.3 x SIL or ~ steady state stability limit for 200 mi line segment per St Clair curve
- Transmission line and substation costs based on Frontier Line transmission subcommittee, NTAC and ERCOT CREZ unit cost data.
- Lines loaded to their steady state stability limits – no stability margin

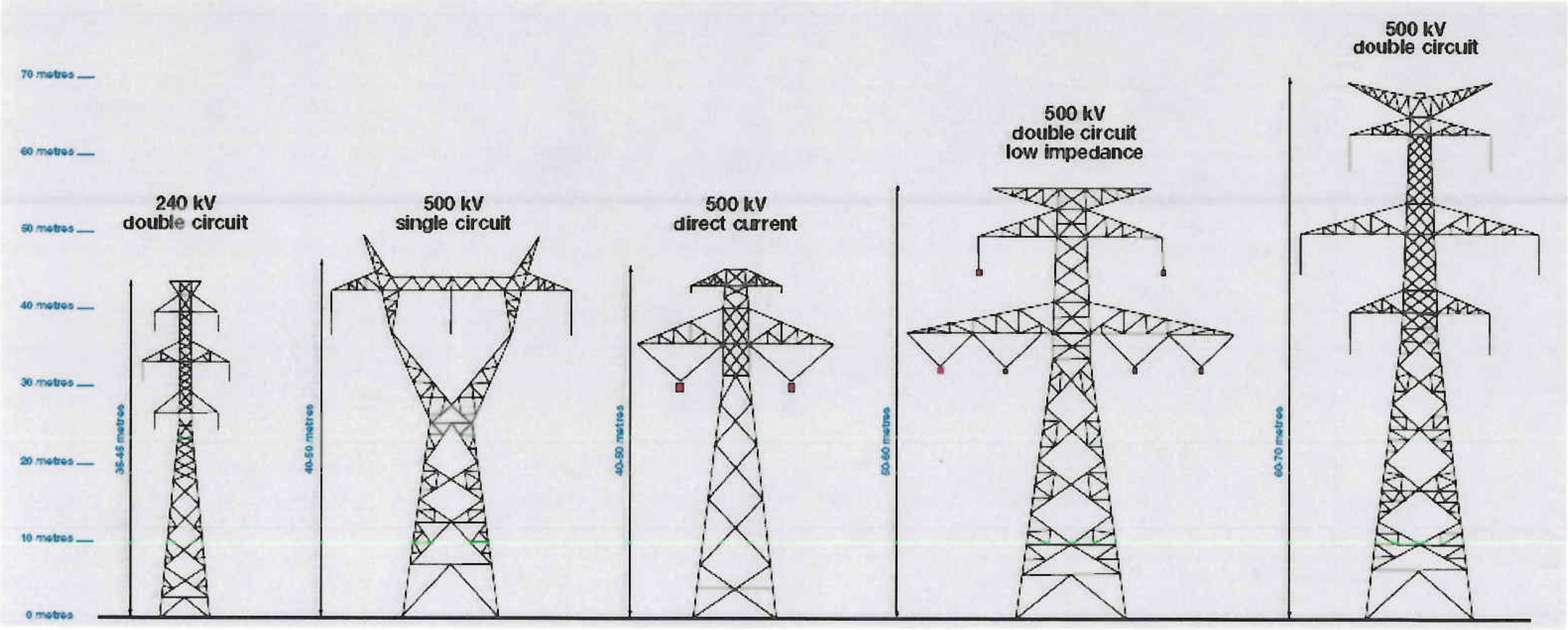
EHV AC and HVDC line comparison
Relative size v wind turbine generators



Source of Figure: Midwest ISO

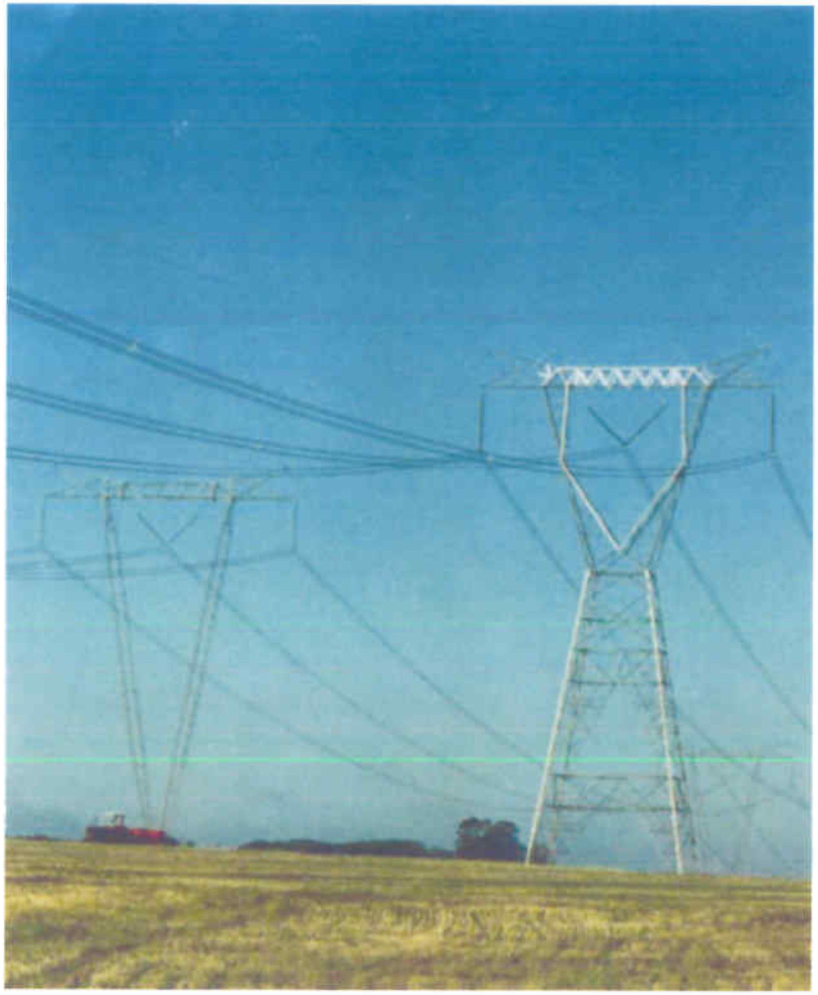
[1] Footprint of 3000 MW Wind Plant = 180,000 A per NREL unit spacing (5-10 x blade diameter)
[2] ROW for 3000 MW, 1000 mi HVDC T-Line, 150' R/W width = 18,000 A

EHV AC and HVDC line comparison
Relative sizes



Source: Alberta ESO

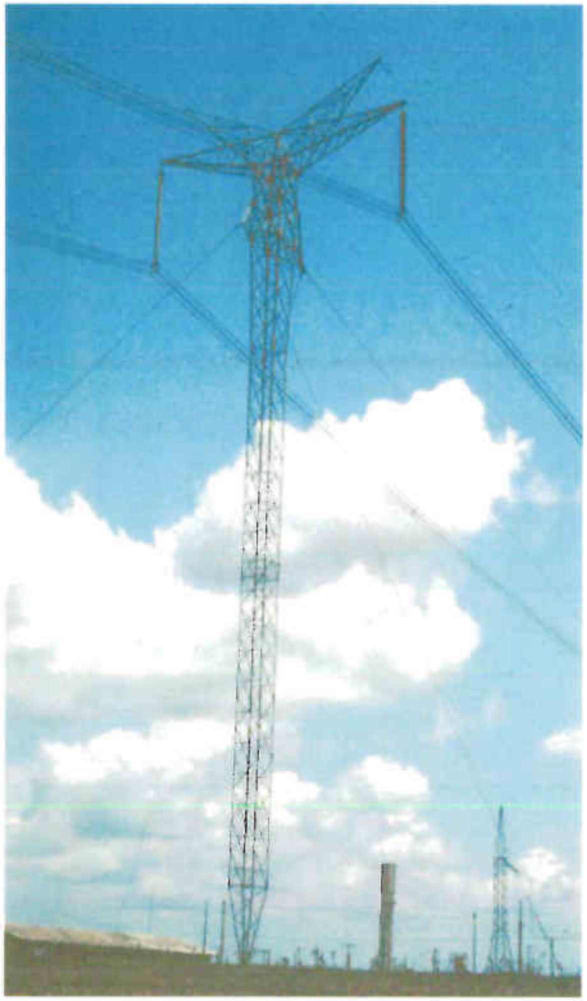
Itaipu 765 kVac transmission lines



Line 1. 891 km	1982, 86,
Line 2. 891 km	1989
Line 3. 915 km	1999, 00, 01

- About 70% Guyed Vee
- Average weight 8500 kg, guyed
- Self supporting, weight 14000 kg
- 15.80 m Phase spacing, guyed
- 14.30 m Phase spacing, self support
- Conductor 4xBluejay 564 mm^2 ACSR
- 450 mm subconductor spacing
- 35 Insulators
- 95 m RoW one line
- 178 m RoW two lines

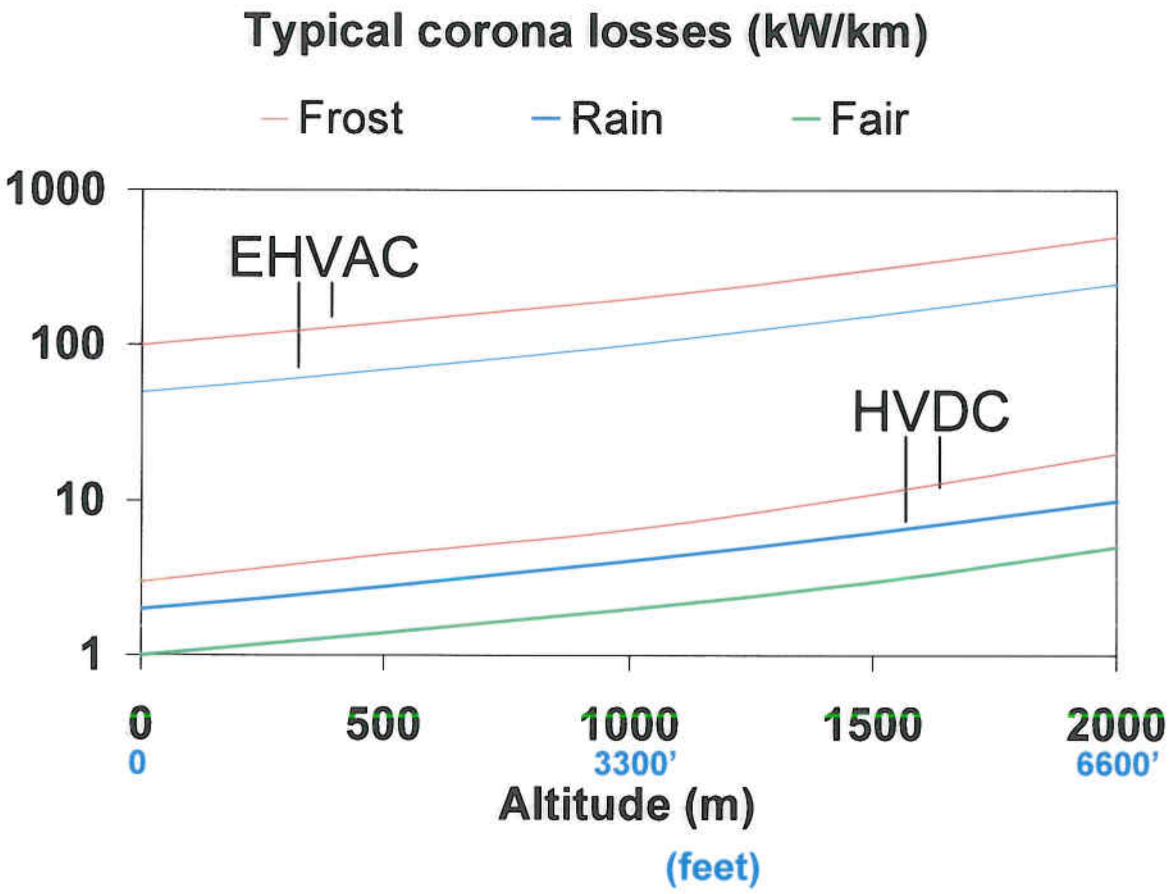
Itaipu ± 600 kV HVDC transmission lines



Bipole 1	792 km	1984
Bipole 2	820 km	1987

- About 80% Guyed Mast
- Average weight 5000 kg, guyed
- Self supporting, weight 9000 kg
- Conductor 4xBittern 644 mm² 45/7ACSR
- 450 mm subconductor spacing
- 32 Insulators 510 mm creep, 27 mm/kV
- 16.40 m pole spacing
- 72 m RoW per circuit

Power losses, corona, AN, RI v altitude
Corona higher during foul weather with EHV AC



EHVAC

- Resistive losses
- Corona losses
- Effect of altitude

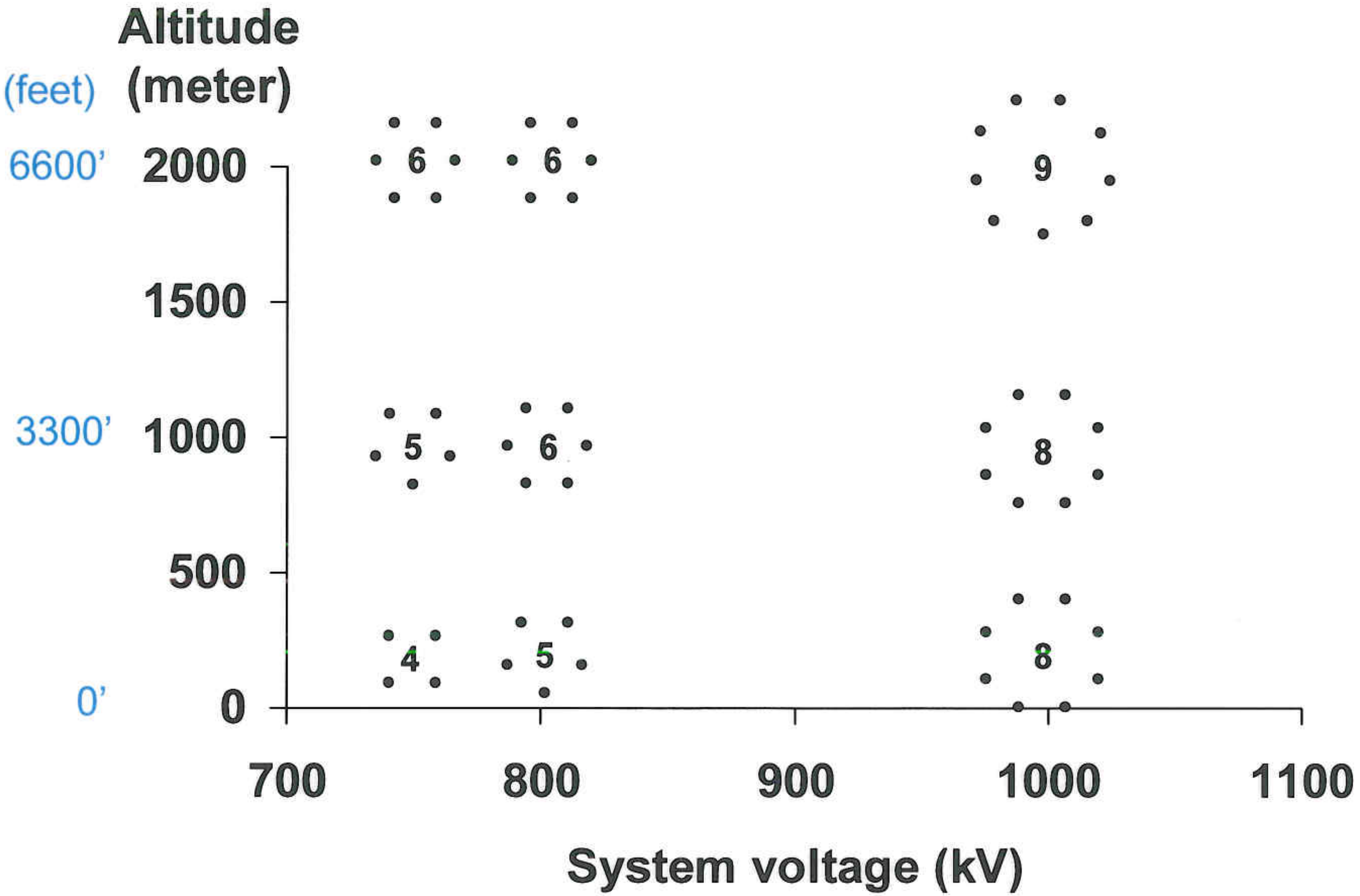
HVDC

- Resistive losses
- Corona losses
- Effect of altitude

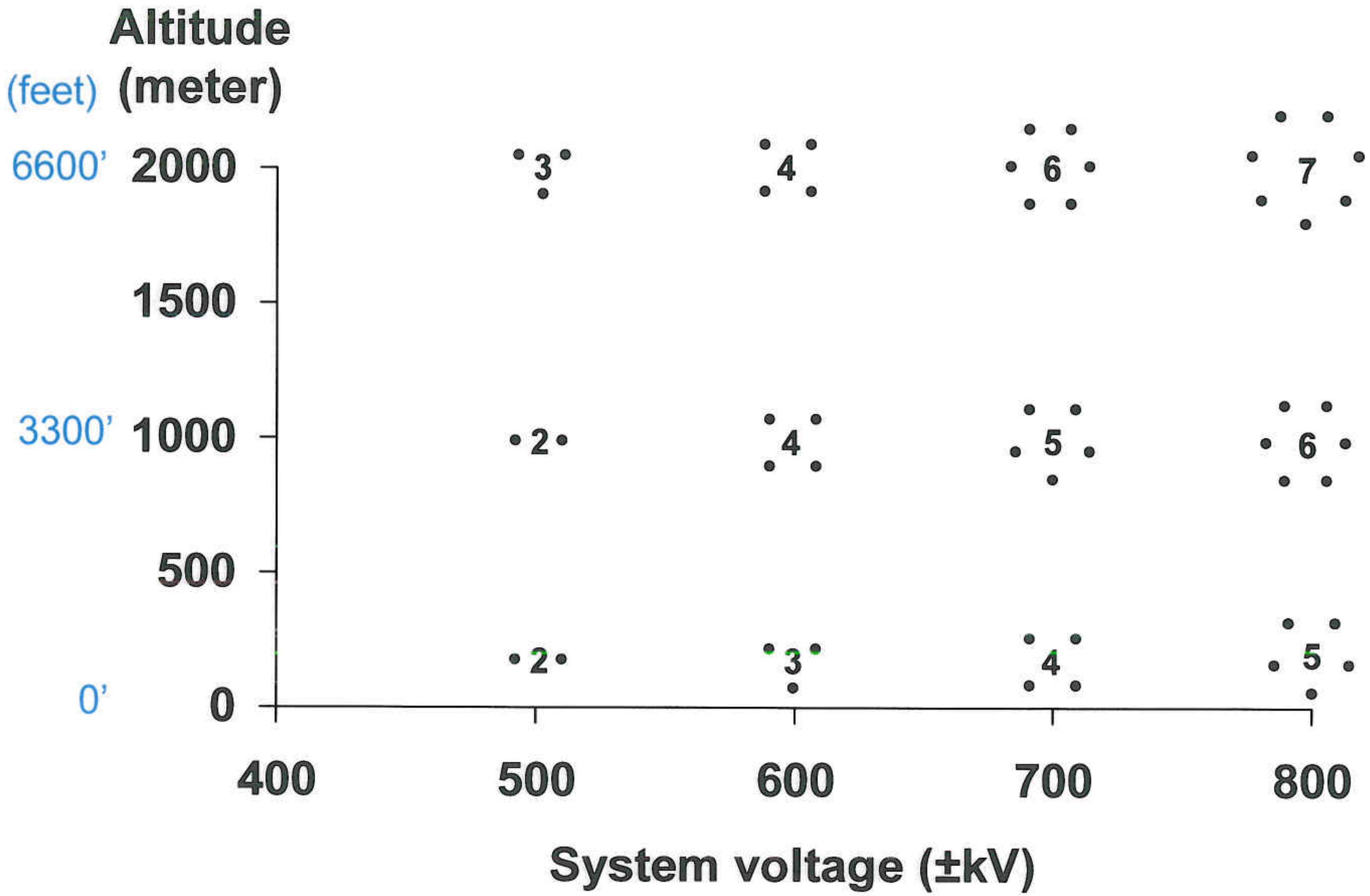
Comparison HVDC-EHVAC

- Corona losses of HVDC lines are less sensitive to variations in weather conditions

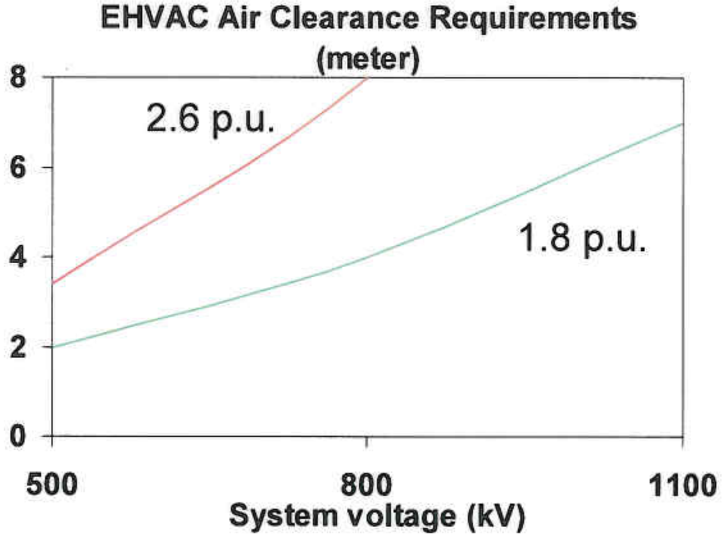
UHVAC conductor bundles for AN = 50-55 dBA

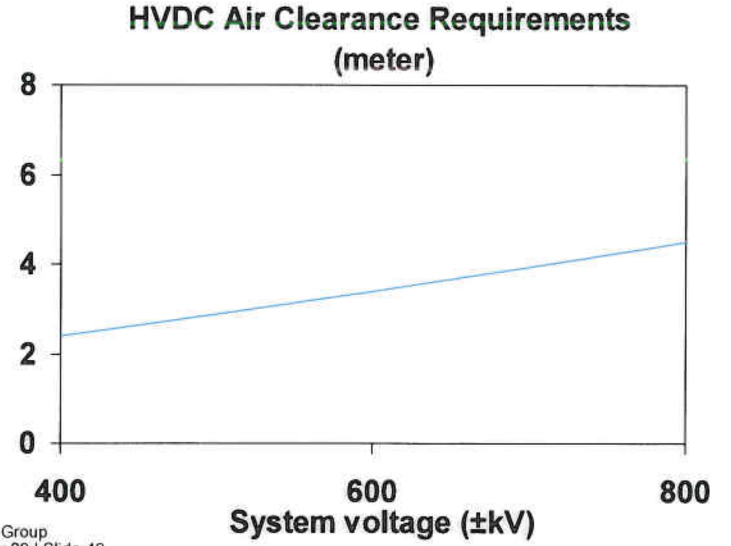


HVDC conductor bundles for AN = 40-45 dBA



Air clearance requirements v voltage AC and DC


EHVAC Air Clearance Requirements (meter)


HVDC Air Clearance Requirements (meter)

EHVAC

- Switching overvoltages
- (Lightning overvoltages)

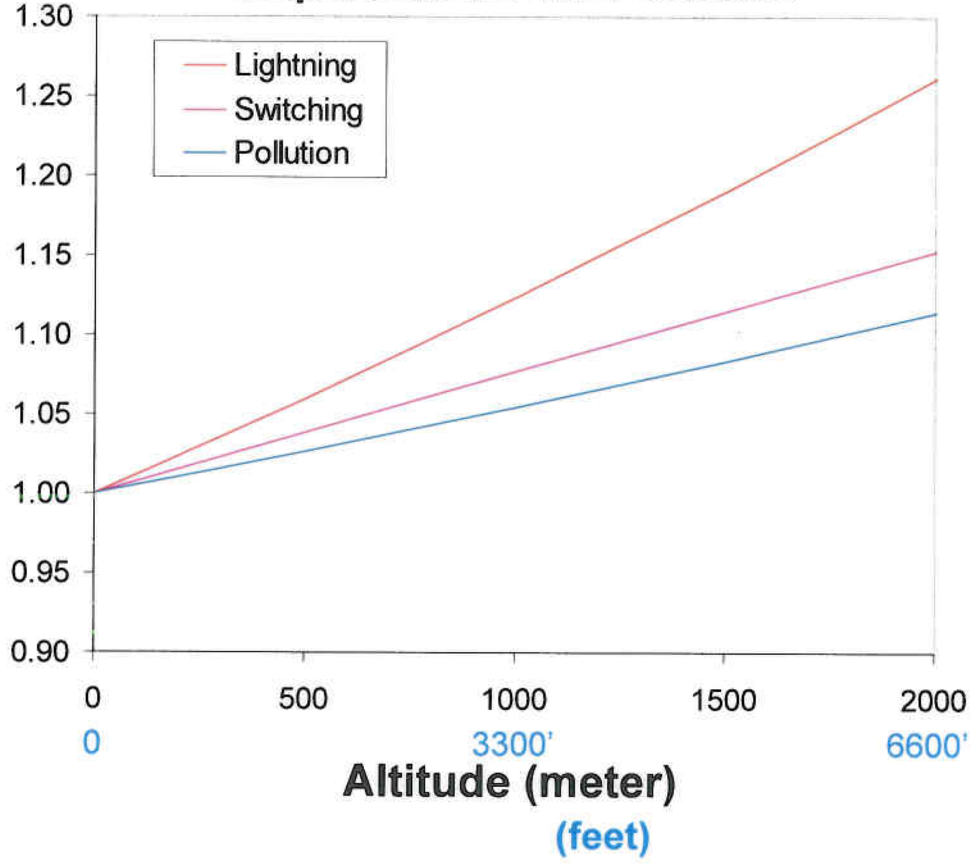
HVDC

- (Switching overvoltages)
- Lightning overvoltages

Comparison HVDC-EHVAC

- Air clearance requirements are significantly lower for HVDC lines

Effect of altitude on insulation performance


Relative increase in insulation requirements with altitude

EHVAC

- Air clearances (switching overvoltages)
- Line insulators (pollution)

HVDC

- Air clearances (lightning overvoltages)
- Line insulators, creepage length ~27 mm/kV agricultural area (pollution dependent)

Comparison HVDC-EHVAC

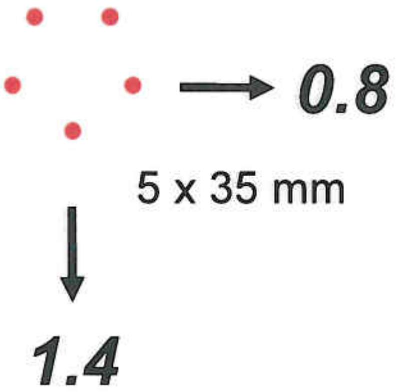
- Air clearance requirements for HVDC lines are more sensitive to the effect of altitude

Total conductor load on tower (kN/m)
Lower mechanical loading means lower cost towers

EHVAC 500 kV

3 conductors

800 kV

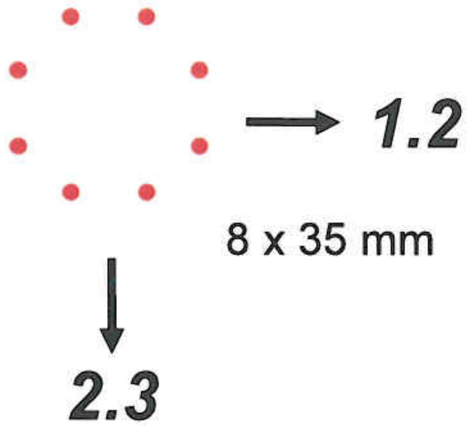


0.8

5 x 35 mm

1.4

1000 kV



1.2

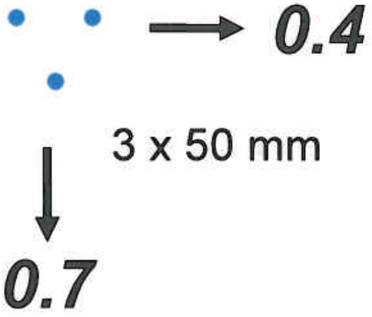
8 x 35 mm

2.3

HVDC ± 500 kV

2 conductors

± 600 kV

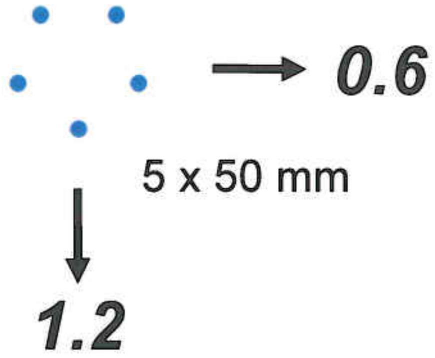


0.4

3 x 50 mm

0.7

± 800 kV

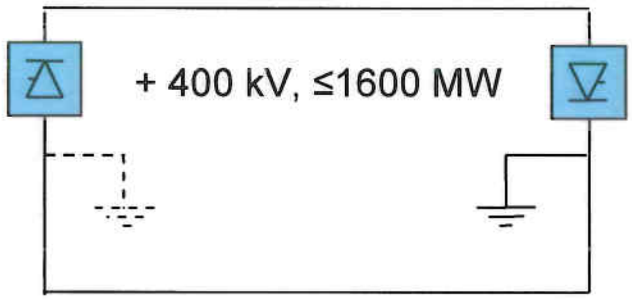


0.6

5 x 50 mm

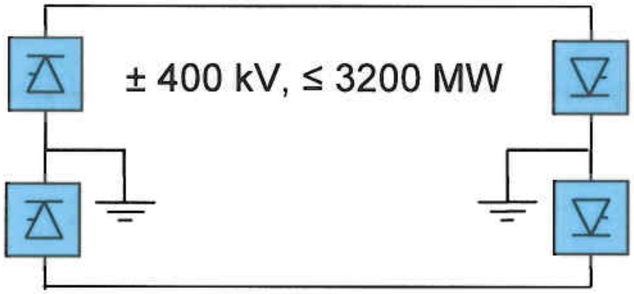
1.2

Staged transmission expansion HVDC scenario



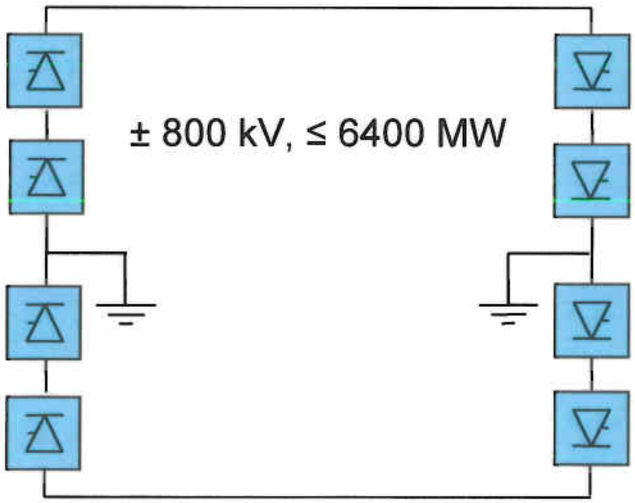
Stage 1:

- Build bipolar transmission line
- Insulate one pole to 400 kV, second pole as neutral
- Add up to 1600 MW converter at each end



Stage 2:

- Raise insulation on second pole to 400 kV
- Add up to 1600 MW converter at each end on second pole

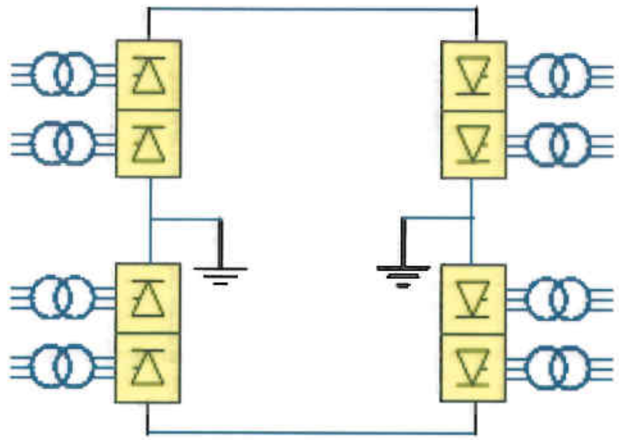


Stage 3:

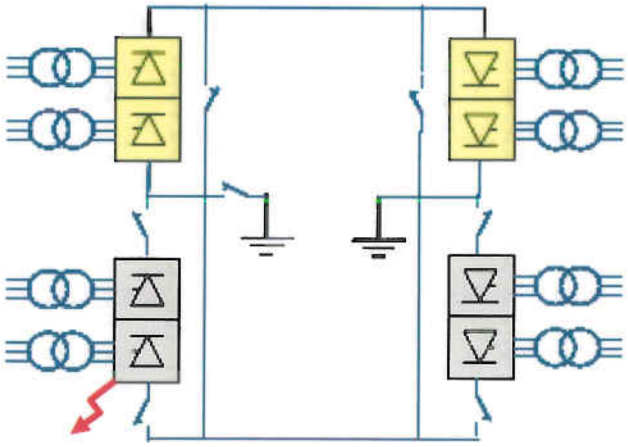
- Raise insulation on both poles to 800 kV
- Add up to 1600 MW series-connected converter at each end on each pole
- Power doubled, no increase in losses
- Can operated at 75% capacity with converter outage or degraded line insulation
- Parallel converters also possible

HVDC Bipole – contingency operation

Bipole

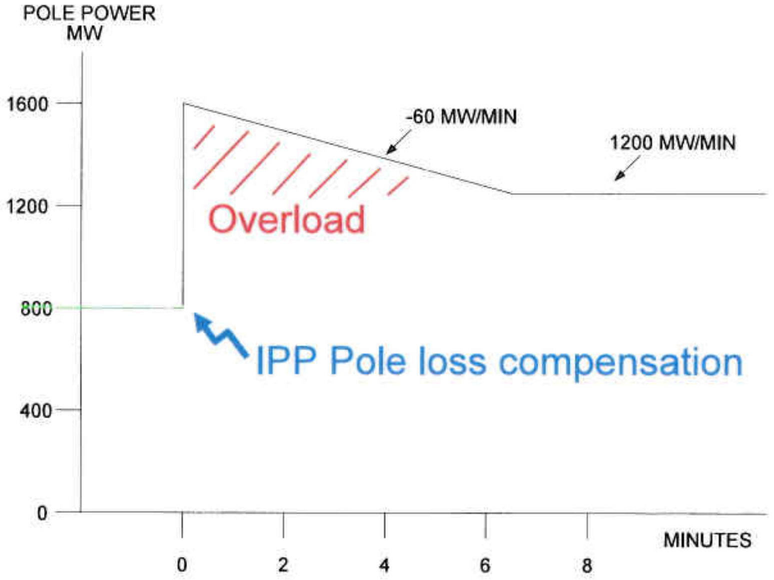


Bipole, Metallic Return

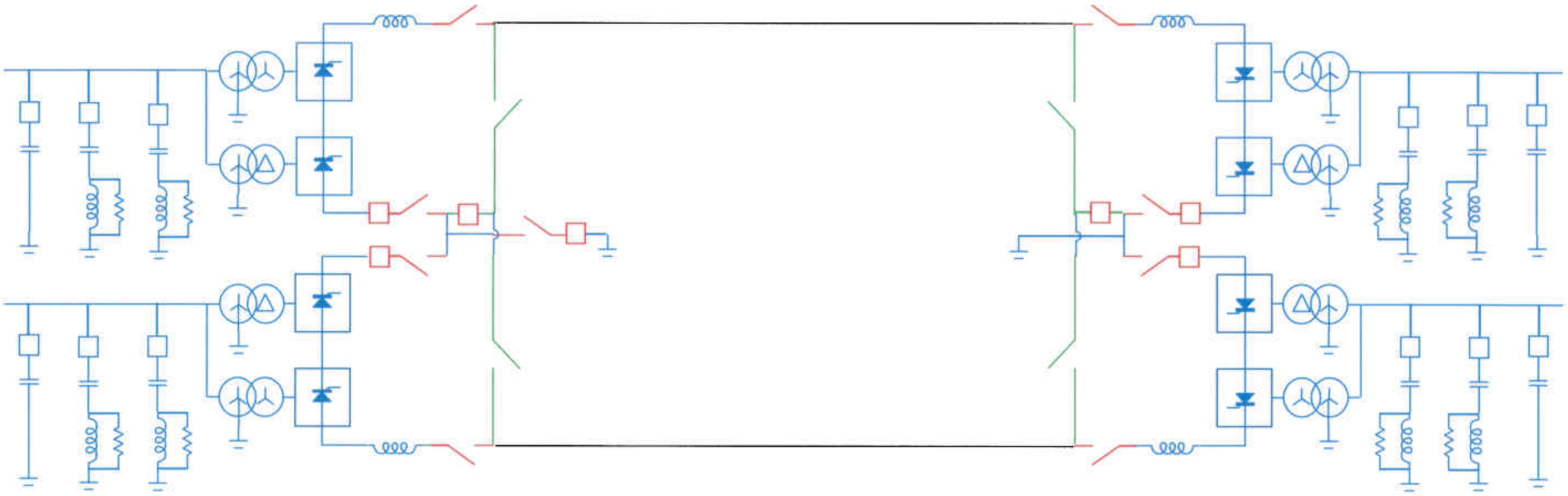


DC Transmission:

- Similar to double circuit ac line
- Pole loss compensation
- Higher overloads may be possible depending on nominal rating, ambient, time
- Can operate with reserve capacity
- Compensation for parallel or series converters
- Metallic return switching post contingency
- Can compensate for parallel ac or dc lines

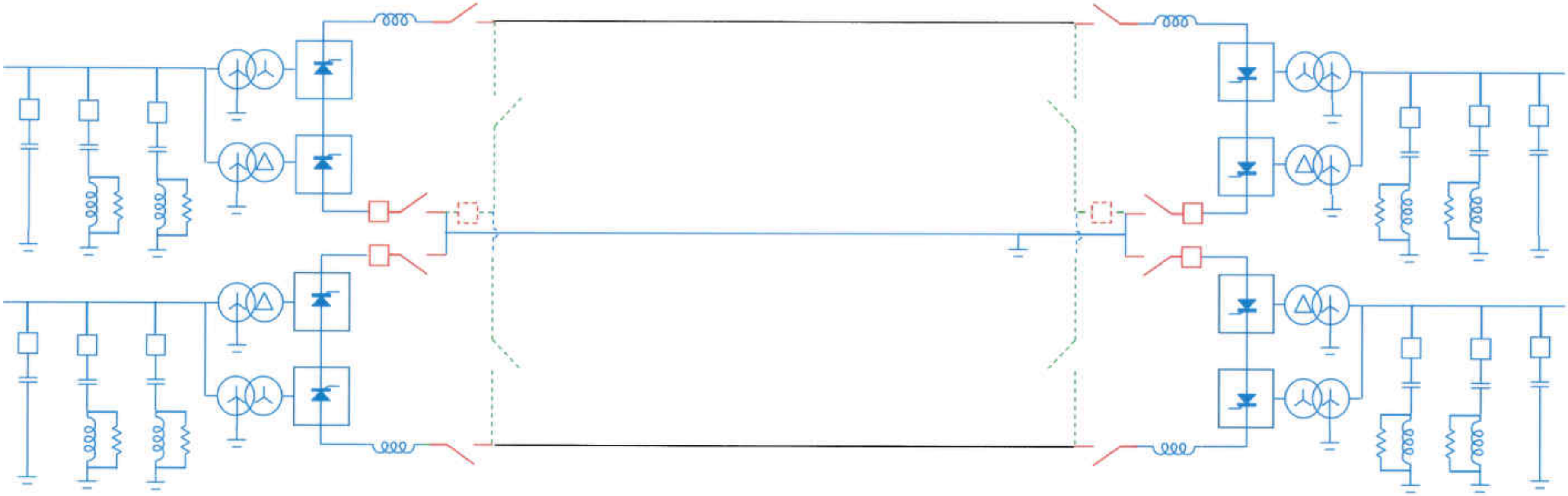


HVDC in bipolar operation
Bipole with metallic return switching provision



- DC disconnect, closed
- DC disconnect, open
- 🟥 DC breaker, closed
- 🟩 DC breaker, open

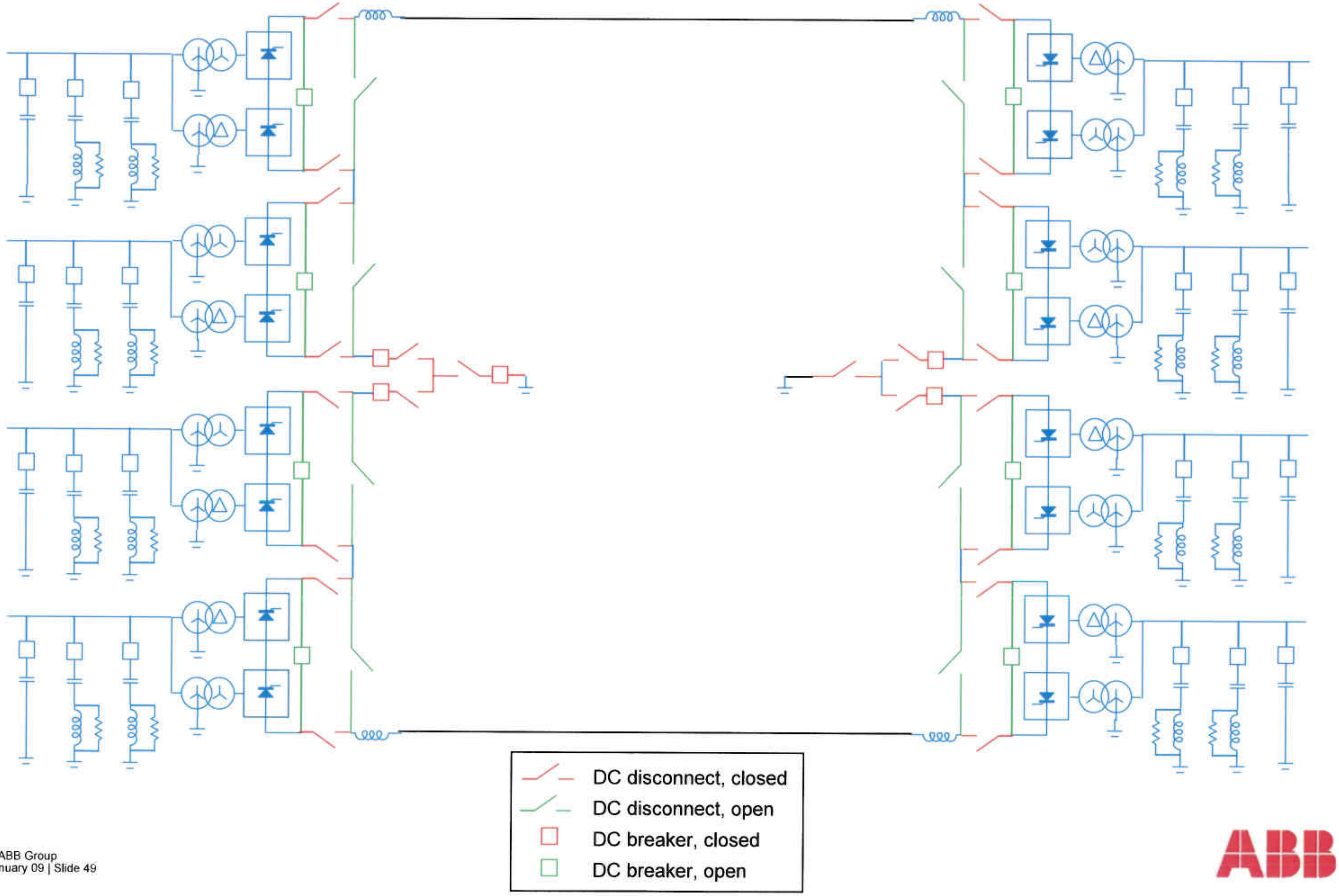
HVDC bipole
with metallic neutral + optional metallic return switch



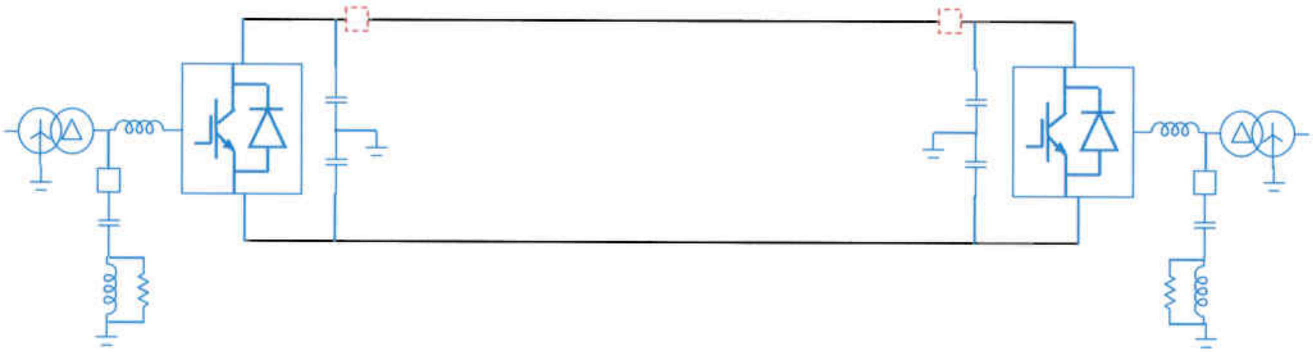
- DC disconnect, closed
- DC disconnect, open
- 🟥 DC breaker, closed
- 🟩 DC breaker, open

Continuous metallic neutral: thermally rated only, could be high-temperature, low-sag conductor to reduce weight

HVDC bipole
with independent series-connected 12p converters

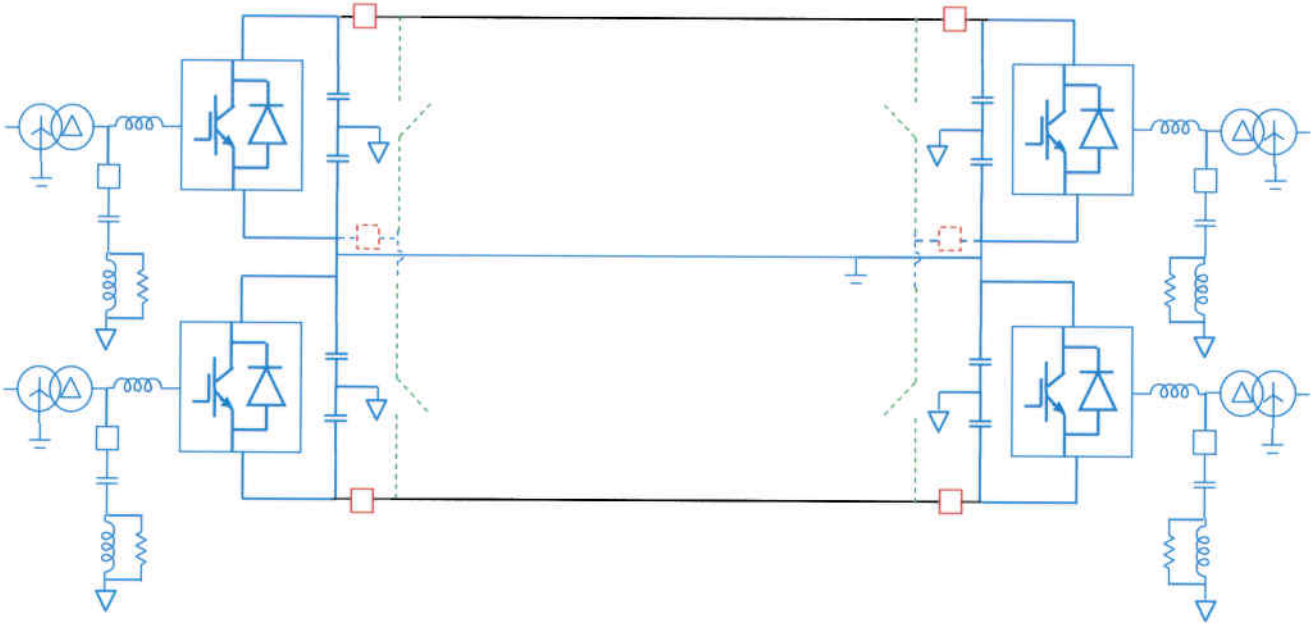


HVDC Light
Symmetric monopole – cable or overhead



- DC disconnect, closed
- DC disconnect, open
- □ DC breaker, closed
- □ DC breaker, open

HVDC Light bipole
with metallic neutral, optional metallic return switch



- ⟋ DC disconnect, closed
- ⟋ DC disconnect, open
- 🟥 DC breaker, closed
- 🟩 DC breaker, open

System Performance for Temporary Faults
HVDC and HVDC Light

AC System Fault at HVDC Rectifier End

- HVDC - temporary reduction in DC power commensurate with voltage depression during the fault, recoveries slower for weaker inverter ac system
- HVDC Light – similar except faster recoveries possible with weaker inverter ac system

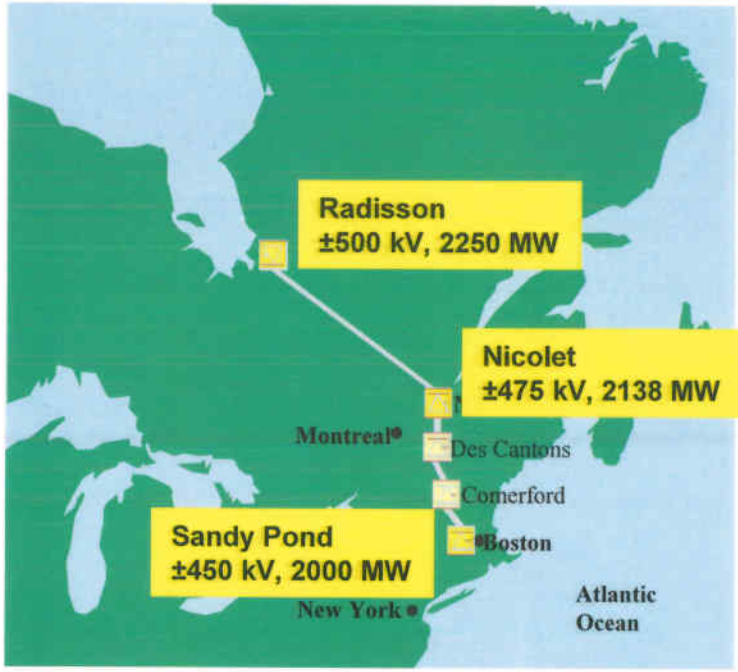
AC System Fault at HVDC Inverter End

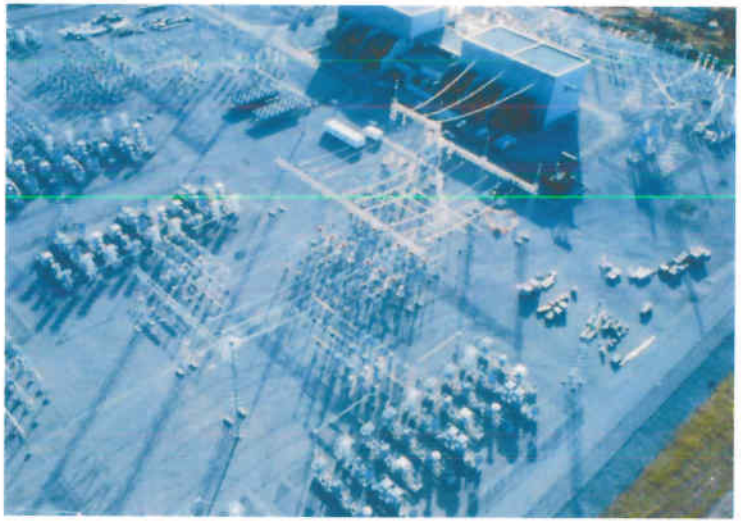
- HVDC - temporary interruption in DC power during the fault, commutation failure at leading edge of fault, recovery rate ac system dependent
- HVDC Light – temporary reduction in DC power commensurate with voltage depression during the fault, no commutation failures, faster recoveries with weaker ac systems

DC Line Temporary Fault

- HVDC - temporary interruption in DC power on faulted pole during the fault + 200 ms deionization time before restart, fault cleared electronically
- HVDC Light – temporary interruption in DC power during fault + 200 ms deionization time, fault cleared by dc and/or ac breakers, auto-restart time ~ 500 ms total

Quebec - New England Ph II HVDC Multiterminal

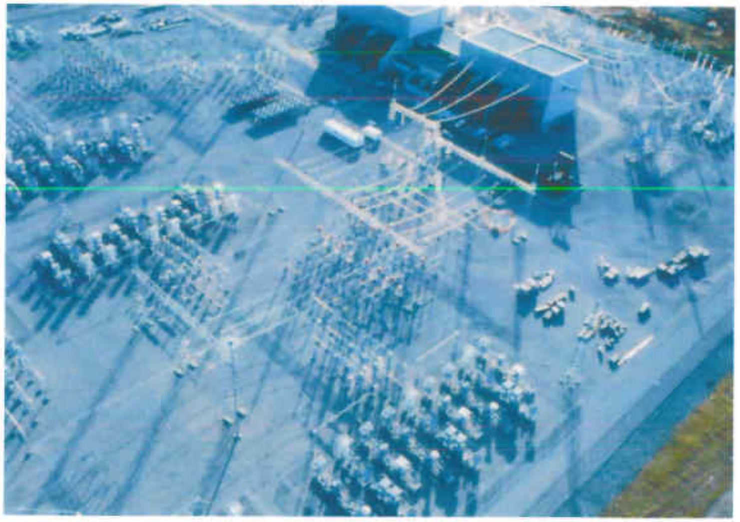


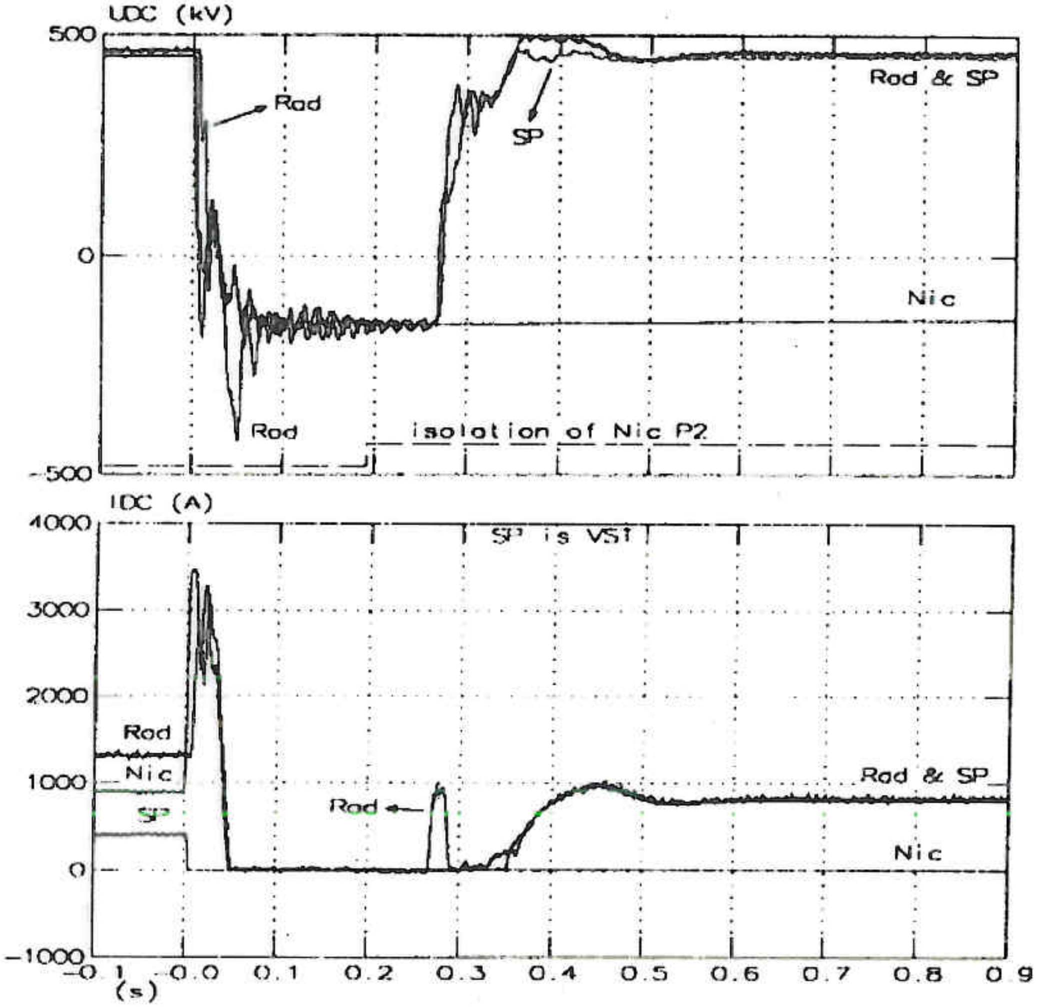


Radisson Converter Station

- Ratings:
  - Radisson: ±500 kV, 2250 MW
  - Nicolet: ±475 kV, 2138 MW
  - Sandy Pond: ±450 kV, 2000 MW
- Line length: 1500 km
- Application: Hydro generation outlet
- System voltages: 315, 230 and 345 kV
- In operation: 1990 - 1992
- Customers: Hydro-Quebec, New England Hydro
- Bidirectional for export or import
- Asynchronous interconnection
- Isolated radial or parallel system operation at Radisson
- 10 year firm energy contract with price indexed to avoided cost

Quebec-New England Phase 2
Protective Isolation of Nicolet as inverter with telecom





Protective isolation of Nicolet pole 2 as inverter
Pole 2 quantities plotted,
Pole 1 transmission unaffected

ICNIRP EMF guidelines for general public exposure

Table 7. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values).[a]

DC

AC

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields, perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.

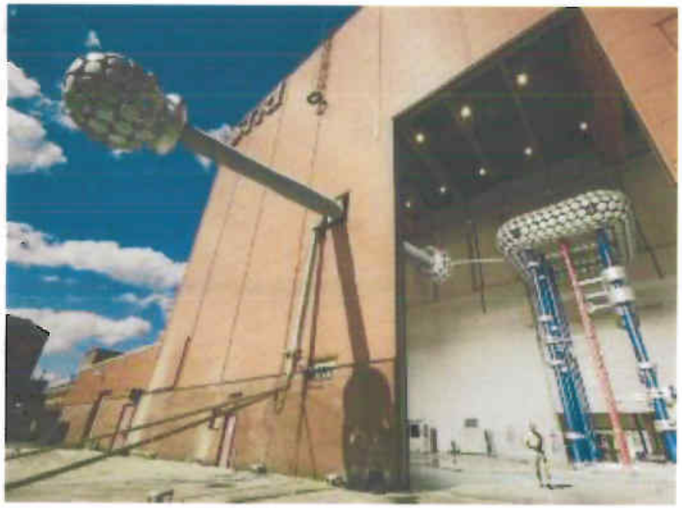
Magnetic & electric fields
AC and DC general public exposure guidelines

- Difference between AC- and DC-fields (essential difference in acceptance level)
- No magnetic induction from DC-field
- ICNIRP (International Commission on Non-Ionizing Radiation Protection 1998) Maxima guidelines for continuous exposure of general public: 40,000 μT for static (DC) v. 83 μT for 60 Hz AC magnetic fields; 10 kV/m for static (DC) v 4.17 kV/m for 60 Hz AC electric fields
- New limits for countries or jurisdictions adopting the "precautionary principle", e.g., Holland and Sweden, Max. 0.40 μT for 50 Hz AC, applying same principle to static magnetic fields would result in criterion of 40 μT
- Earth magnetic field ≈ 50 μT
- Very small DC-field in vicinity of two cables laid close together with opposite current directions

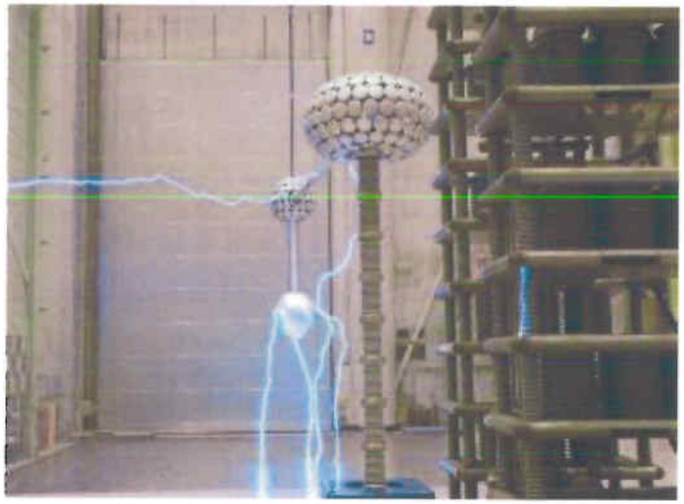
http://www.icnirp.de/documents/emfgdl.pdf
http://www.emfs.info/issue_ExposureLimits.asp#eurec

800 kV UHVDC (Ultra High Voltage Direct Current)

UHVDC test laboratory at ABB



Valve hall clearance testing

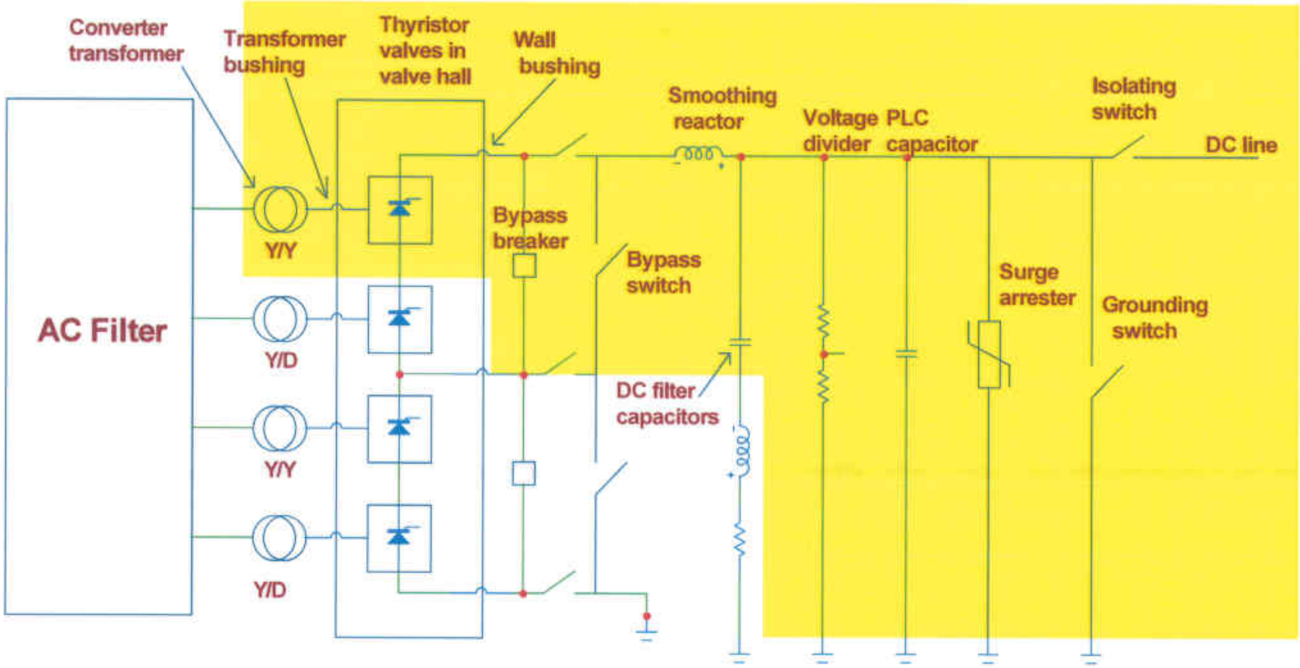


- For long distance bulk power transmission
- Up to 9000 MW on one transmission line
  - Increased energy efficiency
  - 30% less losses and
  - 30% less costs

Compared to today's 500 or 800 kV AC

- UHVDC is making environmental friendly, very remote located, hydro generation accessible in China and India
- Potential markets: China, India, Brazil, NA, and southern Africa

800 kV, 4800-6400 MW HVDC Transmission



🟨 Pole equipment exposed to 800 kV dc

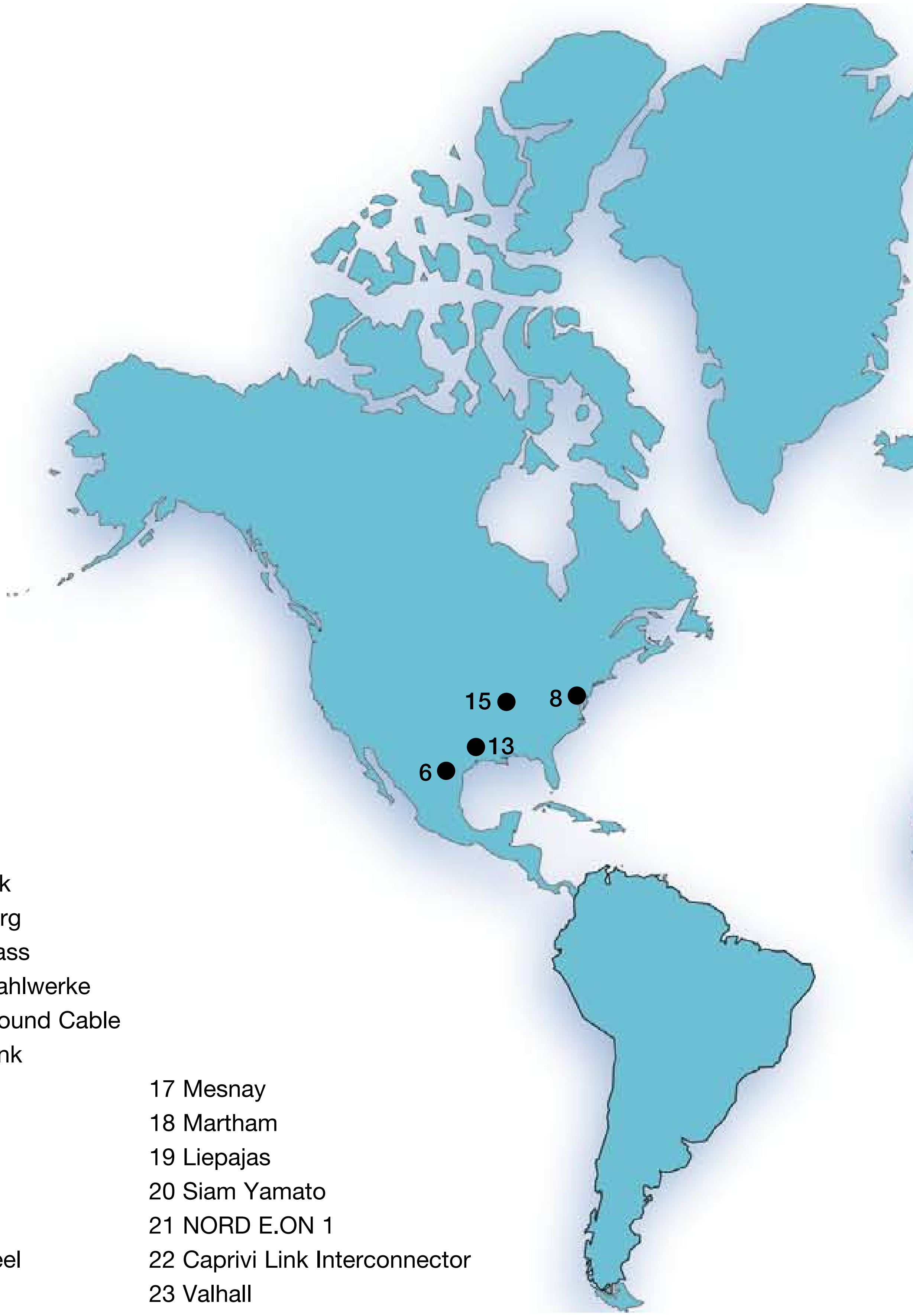
Long term test circut for 800 kV HVDC

± 800 kV, 6400 MW (4 x 1600) HVDC Link

± 800 kV HVDC converter station
4 x 1600 MW

HVDC & SVC Light - Reference list

ABB HVDC & SVC Light Projects Worldwide



1 Hällsjön
2 Hagfors
3 Gotland
4 Directlink
5 Tjæreborg
6 Eagle Pass
7 Moselstahlwerke
8 Cross Sound Cable
9 Murraylink
10 Polarit
11 Evron
12 Troll A
13 Holly
14 Estlink
15 Ameristeel
16 ZPSS
17 Mesnay
18 Martham
19 Liepajas
20 Siam Yamato
21 NORD E.ON 1
22 Caprivi Link Interconnector
23 Valhall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SCHEME	1. HÄLLSJÖN HVDC Light	2. HAGFORS SVC Light	3. GOTLAND HVDC Light
Commissioning year	**1997**	**1999**	**1999**
Power Transmitted, MW	**3**	**-**	**50**
Direct voltage, kV	**±10**	**-**	**±80**
Converters per station	**1**	**1**	**1**
Direct voltage per converter, kV	±10	-	±80
Direct current, A	150	-	360
Reactive power range, MVAr	±3	0 - 44	+50/-55
Converter station location and AC grid voltage	Hällsjön, 10 kV, 50 Hz Grängesberg, 10 kV, 50 Hz	Hagfors, 36 kV, 50 Hz	Näs, 77 kV, 50 Hz Bäcks, 77 kV, 50 Hz
Length of overhead DC line, km	**10**	**-**	**-**
Cable arrangement	**-**	**-**	**Bipolar**
Length of cable route, km	**0.2**	**-**	**70**
Grounding of the DC circuit	**-**	**-**	**-**
AC grids at both ends	Synchronous	-	Synchronous
Control	Active and reactive power	Steel, reactive power, flicker mitigation	Active and reactive power, AC voltage
Emergency change of power flow	-	-	-
Main reason for choosing VSC system	Pilot system	Flicker mitigation	Wind power, environmental, controllability
Owner	**VB Elnät, SWEDEN**	**Uddeholm, SWEDEN**	**GEAB, SWEDEN**
Main supplier of converter equipment	ABB	ABB	ABB

4. DIRECTLINK HVDC Light	**5. TJÆREBORG** HVDC Light	**6. EAGLE PASS** HVDC Light	**7. MOSELSTAHLWERKE** SVC Light
2000	**2000**	**2000**	**2000**
3 x 60	**7.2**	**36**	**-**
±80	**±9**	**-**	**-**
3	**1**	**2**	**1**
±80	±9	-	-
375	358	-	-
+90/-165	-3/+4	±36	0 - 38
Terranora, 110 kV, 50 Hz Mullumbimby, 132 kV, 50 Hz	Enge, 10.5 kV, 50 hz Tjæreborg, 10.5 kV, 50 Hz	Eagle Pass, 138 kV, 60 Hz	Trier, 20 kV, 50 Hz
-	**-**	**-**	**-**
Bipolar	**Bipolar**	**-**	**-**
65	**4.4**	**0 (Back to Back)**	**-**
-	**-**	**-**	**-**
Asynchronous (when delivered)	Synchronous / asynchronous	Asynchronous	-
Active and reactive power, AC voltage	Active and reactive power, AC voltage, variable frequency control	Active and reactive power, AC voltage	Steel, reactive power, flicker mitigation
-	-	Runback implemented	-
Energy trade, environment, controllability	Wind power, environment, controllability	AC voltage support (SVC operation), power exchange	Flicker mitigation
TransEnergy, USA North Power, AUSTRALIA	**Eltra, DENMARK**	**AEP, USA**	**RWE Energie, GERMANY**
ABB	ABB	ABB	ABB

SCHEME	8. CROSS SOUND CABLE HVDC Light	9. MURRAYLINK HVDC Light	10. POLARIT SVC Light
Commissioning year	**2002**	**2002**	**2002**
Power Transmitted, MW	**330**	**220**	**-**
Direct voltage, kV	**±150**	**±150**	**-**
Converters per station	**1**	**1**	**1**
Direct voltage per converter, kV	±150	±150	-
Direct current, A	1200	739	-
Reactive power range, MVAr	±150	+140 / -150	0 - 164
Converter station location and AC grid voltage	New Haven, 345 kV, 60 Hz Shoreham, 138 kV, 60 Hz	Berri, 132 kV Red Cliffs, 220 kV	Tornio, 33 kV, 50 Hz
Length of overhead DC line, km	**-**	**-**	**-**
Cable arrangement	**Bipolar**	**Bipolar**	**-**
Length of cable route, km	**40**	**180**	**-**
Grounding of the DC circuit	**-**	**-**	**-**
AC grids at both ends	Synchronous	Synchronous	-
Control	Active and reactive power, AC voltage	Active power and AC voltage	Steel, reactive power, flicker mitigation
Emergency change of power flow	Runback implemented	Runback implemented	-
Main reason for choosing VSC system	Energy trade, controllability	Energy trade, environment, controllability	Very high flicker mitigation, compactness
Owner	**TransEnergie US, USA**	**TransEnergie US, USA**	**AvestaPolarit Stainless Oy, FINLAND**
Main supplier of converter equipment	ABB	ABB	ABB

11. EVRON SVC Light	**12. TROLL A** HVDC Light	**13. HOLLY** SVC Light	**14. ESTLINK** HVDC Light	**15. AMERISTEEL** SVC Light
2003	**2005**	**2004**	**2006**	**2006**
-	**2 x 41**	-	**350**	-
-	**±60**	-	**±150**	-
1	**2**	**1**	**1**	**1**
-	-	-	±150	-
-	400	-	1230	-
±17	Troll A: NA Kollsnes: +24/-20	+110 / -80	±125	±32
Evron, 90 kV, 50 Hz	Troll A, 56 kV Kollsnes, 132 kV	Austin, 138 kV, 60 Hz	Espoo, 400 kV, 50 Hz Harku, 330 kV, 50 Hz	Charlotte, 13.2 kV, 60 Hz
-	-	-	-	-
-	**Bipolar**	-	**Bipolar**	-
-	**67**	-	**105**	-
-	-	-	-	-
-	-	-	Asynchronous	-
Railway, load balancing, active filtering	Motordrive and VHV motor, AC voltage, frequency control	Reactive power	Active and reactive power, AC voltage, frequency control, damping control	Steel, reactive power, flicker mitigation
-	-	-	Runback implemented, black start	-
Active filtering	Platform electrification, environment, CO_2-tax	Voltage support, compactness	Energy trade, AC voltage contol	Flicker mitigation
SNCF/RTE, FRANCE	**Statoil, NORWAY**	**Austin Energy, USA**	**Nordic Energy Link AS, ESTONIA**	**Gerdau Ameristeel, USA**
ABB	ABB	ABB	ABB	ABB

SCHEME	**16. ZPSS** SVC Light	**17. MESNAY** SVC Light	**18. MARTHAM** SVC Light	**19. LIEPAJAS** SVC Light
Commissioning year	**2006**	**2008**	**2009**	**2009**
Power Transmitted, MW	**-**	**-**	**-**	**-**
Direct voltage, kV	**-**	**-**	**-**	**-**
Converters per station	**1**	**1**	**1**	**1**
Direct voltage per converter, kV	-	-	-	-
Direct current, A	-	-	-	-
Reactive power range, MVAr	±82	±15	±0.6	±164
Converter station location and AC grid voltage	Ziangjiagang, 35 kV, 50 Hz	Jura Mesnay, 63 kV, 50 Hz	Martham, 11 kV, 50 Hz	Liepaja, 33 kV, 50 Hz
Length of overhead DC line, km	**-**	**-**	**-**	**-**
Cable arrangement	**-**	**-**	**-**	**-**
Length of cable route, km	**-**	**-**	**-**	**-**
Grounding of the DC circuit	**-**	**-**	**-**	**-**
AC grids at both ends	-	-	-	-
Control	Steel, reactive power, flicker mitigation	Railway, load balancing, active filtering	Active and reactive power	Steel, reactive power, flicker mitigation
Emergency change of power flow	-	-	-	-
Main reason for choosing VSC system	Flicker mitigation	Active filtering	Voltage support	Flicker mitigation
Owner	**ZPSS, CHINA**	**SNCF/RTE, FRANCE**	**EDF Energy, UK**	**Liepajas Metalurgs, LATVIA**
Main supplier of converter equipment	ABB	ABB	ABB	ABB

20. SIAM YAMATO SVC Light	21. NORD E.ON 1 HVDC Light	22. CAPRIVI LINK HVDC Light	23. VALHALL HVDC Light
2009	2009	2009	2010
-	400	300	78
-	±150	350	150
1	1	1	1
-	±150	350	75
-	1200	857	573
±120	±150	± 200	Valhall: 110 transient Lista: +10/-10
Bangkok, 22 kV, 50 Hz	Diele, 380 kV, Borkum 2, 170 kV	Zambezi, 330 kV, 50 Hz Gerus, 400 kV, 50 Hz	Lista, 300 kV Valhall, 11 kV
-	-	970	-
-	Bipolar	-	Coaxial
-	203	-	292
-	-	Earth electrode	-
-	Asynchronous	Synchronous	50 Hz, 60 Hz isolated
Steel, reactive power, flicker mitigation	Active and reactive power, AC voltage, frequency control	Active power, AC voltage, frequency control	AC voltage, frequency control
-	Runback implemented	Runback implemented, power supply of black network	-
Flicker mitigation	Offshore wind, power to shore	Energy trade, energy import, weak AC networks	Platform electrification, environment, CO_2-tax
Siam Yamato Steel, THAILAND	E.ON Netz, GERMANY	NamPower, NAMIBIA	BP, NORWAY
ABB	ABB	ABB	ABB

Elanders, 2007, Västerås

POW-0027 Rev. 7

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Elanders, Västerås 2008

POW-0013 Rev. 7

HVDC Classic - Reference list

Thyristor valve projects and converter station upgrades

ABB HVDC Classic Projects Worldwide

Thyristor valve projects

1 Gotland
2 Skagerrak 1 & 2
3 Cahora Bassa
4 Inga-Shaba
5 CU-project
6 Nelson River 2
7 Itaipu
8 Gotland 2
9 Dürnrohr
10 Pacific Intertie Upgrading
11 Châteauguay
12 Intermountain
13 Highgate
14 Blackwater
15 Vindhyachal
16 Broken Hill
17 Gotland 3
18 Rihand-Delhi
19 Konti-Skan 2
20 Quebec - New England
21 Fenno-Skan
22 Pacific Intertie Expansion
23 Gezhouba - Shanghai
24 New Zealand
25 Skagerrak 3
26 Baltic Cable
27 Kontek
28 Chandrapur Padghe
29 Leyte - Luzon
30 SwePol
31 Brazil-Argentina Interconnection 1
32 Italy-Greece
33 Three Gorges - Changzhou
34 Brazil-Argentina Interconnection 2
35 Three Gorges - Guangdong
36 Rapid City DC Tie
37 Vizag II
38 Three Gorges - Shanghai
39 NorNed
40 Sharyland
41 SAPEI
42 Outaouais
43 Xiangjiaba - Shanghai
44 Lingbao II Extension project
45 Fenno-Skan 2
46 Hulunbeir - Liaoning

HVDC Classic upgrades

U1 Skagerrak 1 & 2
U2 New Zealand DC Hybrid Link
U3 - U5 CU-project
U6 Square Butte HVDC Scheme
U7 Pacific HVDC Intertie, Sylmar Replacement Project
U8 Skagerrak 1 & 2
U9 Cahora Bassa, Apollo Upgrade
U10 Blackwater
U11 Châteauguay
U12 Intermountain Upgrade

SCHEME	**1. GOTLAND**	**2. SKAGERRAK 1 & 2**	**3. CAHORA BASSA**	**4. INGA-SHABA**	**5. CU-PROJECT**	**6. NELSON RIVER 2**	**7. ITAIPU**
Commissioning year	**1970**	**1976-1977**	**1977/1979**	**1982**	**1978**	**1978/1985**	**1984-1985/1987**
Power transmitted, MW	**(20) + 10**	**500**	**1930**	**560**	**1000**	**2000**	**3150 + 3150**
Direct voltage, kV	**(100) + 50**	**±250**	**±533**	**±500**	**±400**	**±500**	**±600**
Converters per station	**(2) + 1**	**2**	**8**	**2**	**2**	**4**	**4 + 4**
Direct voltage per converter, kV	50	250	133	500	400	250	300
Direct current, A	200	1000	1800	560	1250	2000	2610
Reactive power supply	Capacitors Synchronous condensers	Capacitors Synchronous condensers	Capacitors	Capacitors Synchronous condensers	Capacitors Power generator	Capacitors	Capacitors Synchronous condensers
Converter station location and AC grid voltage	Västervik, 130 kV Visby, 70 kV	Kristiansand, 275 kV Tjele, 150 kV	Songo, 220 kV Apollo, 275 kV	Inga (Zaire River), 220 kV Kolwezi (Shaba), 220 kV	Coal Creek, 235 kV Dickinson, 350 kV	Henday, 230 kV Dorsey, 230 kV	Foz do Iguaçu, 500 kV Ibiuna, 345 kV
Length of overhead DC line	–	113 km	1420 km	1700 km	687 km	940 km	785 and 805 km, respectively
Cable arrangement	**1 cable, ground return**	**1 cable per pole**	**–**	**–**	**–**	**–**	**–**
Cable route length	**96 km**	**127 km**	**–**	**–**	**–**	**–**	**–**
Grounding of the DC circuit	**For full current in two sea electrode stations**	**For full current in two ground electrode stations**	**For full current in two ground electrodes**	**For full current in two ground electrode stations**	**For full current in two ground electrode stations (intermittent)**	**For full current in two electrode stations**	**For full current in two ground electrode station per bipole**
AC grids at both ends	Asynchronous	Asynchronous	Asynchronous	Asynchronous	Synchronous	Asynchronous	Foz do Iguaçu, 50 Hz Ibiuna, 60 Hz
Control	Constant frequency on Gotland	Constant power in either direction	Constant power	Constant power or constant frequency in Shaba	Constant power, damping control	Constant power	Constant power, damping control
Emergency change of power flow	–	On manual or automatic order to preset value	–	–	–	–	–
Main reason for choosing HVDC system	Long sea crossing, frequency control	Sea crossing	Long distance	Long distance	Distance, environment, stability benefits	Long distance	Long distance, 50/60 Hz conversion
Power company	**Statens Vattenfallsverk, Sweden**	**Statkraft, Norway and Elsam, Denmark**	**Hidroelectrica de Cahora Bassa, Mocambique and Electricity Supply Commission, South Africa**	**SNEL, DR Congo**	**CPA, USA and UPA, USA**	**Manitoba Hydro, Canada**	**FURNAS, Brazil**
Main supplier of converter equipment	ABB	ABB	ABB/Siemens/AEG	ABB: Converters, controls, system responsibility GE: Transformers, filters synchronous condensers	ABB	ABB/Siemens/AEG	ABB

SCHEME	8. GOTLAND 2	9. DÜRNROHR	10. PACIFIC INTERTIE UPGRADING	11. CHÂTEAUGUAY	12. INTERMOUNTAIN	13. HIGHGATE	14. BLACKWATER
Commissioning year	**1983**	**1983**	**1985**	**1984**	**1986**	**1985**	**1985**
Power transmitted, MW	**130**	**550**	**(1600) + 400**	**2 x 500**	**1920**	**200**	**200**
Direct voltage, kV	**150**	**145**	**±500**	**2 x 140.6**	**±500**	**57**	**56.8**
Converters per station	**1**	**2**	**(6) + 2**	**4**	**2**	**2**	**2**
Direct voltage per converter, kV	150	145	100	140.6	500	57	56.8
Direct current, A	914	3790	2000	2 x 3600	1920	3600	3600
Reactive power supply	Capacitors Synchronous condenser	Capacitors	Capacitors	Capacitors and SVC	Capacitors	Capacitors	Capacitors
Converter station location and AC grid voltage	Västervik, 130 kV Visby, 70 kV	Dürnrohr, 420 kV CSSR side, 420 kV	Celilo, 230 kV Sylmar, 230 kV	Hydro-Queb. side, 315 kV U.S. side, 120 kV	Intermountain, 345 kV Adelanto, 500 kV	Highgate North, 120 kV Highgate South, 115 kV	New Mexico side, 345 kV Texas side, 230 kV
Length of overhead DC line	7 km	Back-to-back	1360 km	Back-to-back	785 km	Back-to-back	Back-to-back
Cable arrangement	**1 cable, ground return**	**–**	**–**	**–**	**–**	**–**	**–**
Cable route length	**96 km**	**–**	**–**	**–**	**–**	**–**	**–**
Grounding of the DC circuit	**For full current in two sea electrode stations**	**One point grounded**	**For full current in one ground and one sea electrode station (intermittent)**	**One point grounded**	**For full current in two ground electrode stations (intermittent)**	**One point grounded**	**One point grounded**
AC grids at both ends	Asynchronous	Asynchronous	Synchronous	Asynchronous	Synchronous	Asynchronous	Asynchronous
Control	Constant frequency on Gotland	Constant power in either direction	Constant power in either direction and small signal modulation	Constant power	Constant power, damping control	Constant power in either direction	Constant power, reactive power control
Emergency change of power flow	–	–	On manual or automatic order to preset values	–	–	Automatic power reduction triggered by AC-signal	–
Main reason for choosing HVDC system	Long sea crossing	Asynchronous link	Long distance, rapid control	Asynchronous link	Long distance	Asynchronous link	Asynchronous link
Power company	**Statens Vattenfallsverk, Sweden**	**Österreichische Elektrizitatswirtschafts AG, Austria**	**Bonneville Power Administration, USA and The Department of Water and Power of the City of Los Angeles, USA**	**Hydro-Quebec, Quebec, Canada**	**Intermountain Power Agency, USA Agent: The Department of Water and Power of the City Los Angeles, USA**	**Vermont Electric Power Company Inc., USA**	**Public Service Company of New Mexico USA**
Main supplier of converter equipment	ABB	ABB/Siemens/AEG	ABB	ABB/Siemens	ABB	ABB	ABB

SCHEME	15. VINDHYACHAL	16. BROKEN HILL	17. GOTLAND 3	18. RIHAND-DELHI	19. KONTI-SKAN 2	20. QUEBEC – NEW ENGLAND	21. FENNO-SKAN
Commissioning year	**1989**	**1986**	**1987**	**1990**	**1988**	**1990-1992**	**1989**
Power transmitted, MW	**2 x 250**	**40**	**130**	**1568**	**300**	**2000 (Multiterminal)**	**500**
Direct voltage, kV	**70**	**8.3**	**150**	**±500**	**285**	**±450**	**400**
Converters per station	**2 + 2**	**2**	**1**	**2**	**1**	**2**	**1**
Direct voltage per converter, kV	70	8.3	150	500	285	450	400
Direct current, A	3600	2400	914	1568	1050	2200	1250
Reactive power supply	Capacitors	Capacitors Synchronous condenser	Capacitors Synchronous condenser	Capacitors	Capacitors	Capacitors	Capacitors
Converter station location and AC grid voltage	Northern system, 400 kV Western system, 400 kV	22 kV 6.9 kV	Västervik, 130 kV Visby, 70 kV	Rihand, 400 kV Dadri, 400 kV	Lindome, 130 kV Vester Hassing, 400 kV	Radisson, 315 kV Sandy Pond, 345 kV Nicolet, 230 kV	Dannebo, 400 kV Rauma, 400 kV
Length of overhead DC line	Back-to-back	Back-to-back	7 km	814 km	61 km	1480 km	33 km
Cable arrangement	**–**	**–**	**1 cable**	**–**	**1 cable**	**–**	**1 cable**
Cable route length	**–**	**–**	**96 km**	**–**	**88 km**	**–**	**200 km**
Grounding of the DC circuit	**One point grounded**	**Mid-point grounded**	**For full current in two sea electrode stations**	**For full current in two ground electrode stations (intermittent)**	**For full current in two sea electrode stations**	**All stations grounded by totally three electrode stations**	**For full current in two sea electrode stations**
AC grids at both ends	Asynchronous	Asynchronous	Asynchronous	Synchronous	Asynchronous	HQ synchronous NEH asynchronous	Synchronous
Control	Constant power in either direction, damping control	Constant 40 Hz frequency	Constant frequency on Gotland	Constant power, damping control	Constant power in either direction	Multiterminal, constant power control, frequency control	Constant power, damping control
Emergency change of power flow	Automatic power reduction triggered by AC signal	–	–	On manual or automatic order	On manual or automatic order to preset value	Isolation of Radisson from the AC system at severe AC disturbances	–
Main reason for choosing HVDC system	Asynchronous link	Frequency control	Long sea crossing	Long distance, stability	Sea crossing, asynchronous link	Asynchronous link	Sea crossing
Power company	**National Thermal Power Corporation, India**	**Southern Power Corporation, Australia**	**Statens Vattenfallsverk, Sweden**	**National Thermal Power Corporation, India**	**Statens Vattenfallsverk, Sweden and Elsam Denmark**	**Hydro Quebec, Quebec, Canada and New England Hydro Transmission Electric Company Inc., USA**	**Statens Vattenfallsverk, Sweden and Imatran Voima Oy, Finland**
Main supplier of converter equipment	ABB	ABB	ABB	BHEL, India, main contractor ABB subcontractor to BHEL under licence agreement	ABB	ABB	ABB

SCHEME	22. PACIFIC INTERTIE EXPANSION	23. GEZHOUBA – SHANGHAI	24. NEW ZEALAND DC HYBRID LINK	25. SKAGERRAK 3	26. BALTIC CABLE	27. KONTEK	28. CHANDRAPUR – PADGHE
Commissioning year	**1989**	**1989**	**1991-1992**	**1993**	**1994**	**1995**	**1998**
Power transmitted, MW	**1100**	**1200**	**560**	**440**	**600**	**600**	**1500**
Direct voltage, kV	**±500**	**±500**	**-350**	**350**	**450**	**400**	**±500**
Converters per station	**(8) + 2**	**2**	**1**	**1**	**1**	**1**	**2**
Direct voltage per converter, kV	500	500	350	350	450	400	500
Direct current, A	1100	1200	1600	1260	1364	1500	1500
Reactive power supply	Capacitors	Capacitors	Capacitors Synchronous condensor	Capacitors Synchronous condensor	Capacitors	Capacitors	Capacitors
Converter station location and AC grid voltage	Celilo, 500 kV Sylmar, 230 kV	Gezhouba, 500 kV Nan Qiao, 230 kV	Benmore, 220 kV Haywards, 220 kV	Kristiansand, 300 kV Tjele, 400 kV	Kruseberg, 400 kV Herrenwyk, 380kV	Bjæverskov, 400 kV Bentwisch, 400 kV	Chandrapur, 400 kV Padghe, 400 kV
Length of overhead DC line	1360 km	1000 km	575 km	113 km	12 km	–	736 km
Cable arrangement	**–**	**–**	**2 cables + 1 spare**	**1 cable**	**1 cable**	**1 cable**	**–**
Cable route length	**–**	**–**	**42 km**	**127 km**	**261 km**	**170 km (120 km under ground)**	**–**
Grounding of the DC circuit	**For full current in one ground and one sea electrode station (intermittent)**	**For full current in two ground electrode stations**	**For full current in one ground and one sea electrode station**	**For full current in two ground electrode stations**	**For full current in two sea electrodes**	**For full current in two sea electrodes**	**For full current in two electrode stations**
AC grids at both ends	Synchronous	Asynchronous	Asynchronous	Asynchronous	Asynchronous	Asynchronous	Synchronous
Control	Constant power in either direction and small signal modulation	Constant power, reactive power control	Constant power, frequency and damping control	Constant power in either direction	Constant power, frequency and damping control	Constant power, frequency and damping control	Constant power, frequency and damping control
Emergency change of power flow	On manual or automatic order to preset value	On manual or automatic order to preset value	Frequency control of isolated Wellington area	On manual or automatic order to preset value	On manual or automatic order to preset value	On manual or automatic order to preset value	On manual or automatic order
Main reason for choosing HVDC system	Long distance, rapid control	Long distance, stability benefits	Long distance including sea crossing	Sea crossing	Sea crossing	Sea crossing asynchronous systems	Long distance, stability
Power company	**Bonneville Power Administration, USA and The Department of Water and Power of the City of Los Angeles, USA**	**Central China Electric Power Administration, China and East China Electric Power Administration, China**	**Trans Power New Zealand Ltd., New Zealand**	**Statnett, Norway and Elsam, Denmark**	**Baltic Cable AB, Sweden**	**Elkraft, Denmark VEAG, Germany**	**Maharashtra State Electricity Board, India**
Main supplier of converter equipment	ABB	ABB/Siemens	ABB	ABB	ABB	ABB	ABB/BHEL

SCHEME	29. LEYTE-LUZON	30. SWEPOL	31. BRAZIL-ARGENTINA INTERCONNECTION 1	32. ITALY-GREECE	33. THREE GORGES – CHANGZHOU	34. BRAZIL-ARGENTINA INTERCONNECTION 2	35. THREE GORGES – GUANGDONG
Commissioning year	**1997**	**1999**	**2000**	**2000**	**2003**	**2002**	**2004**
Power transmitted, MW	**440**	**600**	**2 x 550**	**500**	**3000**	**2 x 550**	**3000**
Direct voltage, kV	**350**	**450**	**±70**	**400**	**±500**	**±70**	**±500**
Converters per station	**1**	**1**	**2 + 2**	**1**	**2**	**2 x 2**	**2**
Direct voltage per converter, kV	350	450	70	400	500	70	500
Direct current, A	1260	1330	3930	1250	3000	3930	3000
Reactive power supply	Capacitors	Capacitors	Capacitors	Capacitors	Capacitors	Capacitors	Capacitors
Converter station location and AC grid voltage	Ormoc, 230 kV, Naga, 230 kV	Stärnö, 400 kV Slupsk, 400 kV	Garabi, Brazil, 525 kV Argentina, 500 kV	Galatina, 400 kV Arachthos, 400 kV	Longquan, 500 kV Zhengping, 500 kV	Garabi, Brazil, 525 kV Argentina, 500 kV	Jingzhou, 500 kV Huizhou, 500 kV
Length of overhead DC line	433 km	–	Back-to-back	110 km	890 km	Back-to-back	940 km
Cable arrangement	**1 cable + 1 spare**	**1 cable + 2 cables for the return current**	**–**	**1 land and 1 sea cable**	**–**	**–**	**–**
Cable route length	**19 km**	**230 km**	**–**	**200 km (40 km + 160 km)**	**–**	**–**	**–**
Grounding of the DC circuit	**For full current in two sea electrodes**	**For current in two sea electrodes**	**Midpoint grounded no ground current**	**For full current in two sea electrode stations**	**For full current in two ground electrode stations (intermitted)**	**Midpoint grounded no ground current**	**For full current in two ground electrode stations (intermitted)**
AC grids at both ends	Asynchronous	Asynchronous	Brazil, 60 Hz Argentina, 50 Hz	Asynchronous	Asynchronous	Brazil, 60 Hz Argentina, 50 Hz	Asynchronous
Control	Constant power, frequency control	Power control, emergency power control	Constant power	Constant power	Constant power	Constant power	Constant power
Emergency change of power flow	On manual or automatic order to preset value	On automatic order to set values	On automatic order to preset values	Frequency control	–	On automatic order to preset values	–
Main reason for choosing HVDC system	Long distance including sea crossing	Long distance and sea crossing	Different AC system frequences	Sea crossing	Long distance Asynchronous networks	Different AC system frequences	Long distance Asynchronous networks
Power company	**National Power Corporation Manila, Philippines**	**SwePol Link AB, Sweden**	**CIEN a company of the Endesa Group**	**ENEL Italy and PPC Greece**	**China Power Grid Development Co Ltd China**	**CIEN a company of the Endesa Group**	**State Power Corporation of China**
Main supplier of converter equipment	ABB	ABB	ABB	ABB	ABB	ABB	ABB

SCHEME	**36. RAPID CITY DC TIE**	**37. VIZAG II**	**38. THREE GORGES - SHANGHAI**	**39. NORNED**	**40. SHARYLAND**	**41. SAPEI**	**42. OUTAOUAIS**
Commissioning year	**2003**	**2005**	**2007**	**2007**	**2007**	**2008**	**2009**
Power transmitted, MW	**2 x 100**	**500**	**3000**	**700**	**150**	**1000**	**1250**
Direct voltage, kV	**±13**	**±88**	**±500**	**±450**	**±21**	**±500**	**±87.5**
Converters per station	**2 + 2**	**1 + 1**	**2**	**1**	**1 + 1**	**2**	**2**
Direct voltage per converter, kV	26	176	500	900	42	500	175
Direct current, A	3930	2860	3000	780	3600	1000	3600
Reactive power supply	Capacitors	Capacitors	Capacitors	Capacitors	Capacitors	Capacitors	Capacitors
Converter station location and AC grid voltage	Rapid City, South Dakota, USA, 230 kV both sides	Visakhapatnam, India, 400 kV both sides	Yidu, 500 kV Huaxin, 500 kV	Eemshaven, 400 kV Feda, 300 kV	Sharyland, Texas, USA, 138 kV both sides	Fiume Santo, 400 kV Latina, 400 kV	Outaouais, Quebec Quebec side, 315 kV Ontario side, 240 kV
Length of overhead DC line	Back-to-back	Back-to-back	1059 km	–	Back-to-back	–	Back-to-back
Cable arrangement	**–**	**–**	**–**	**2 x 450 kV cables**	**–**	**2 cables**	**–**
Cable route length	**–**	**–**	**–**	**560 km**	**–**	**420 km (sea) + 15 km (land)**	**–**
Grounding of the DC circuit	**Midpoint grounded no ground current**	**Midpoint grounded no ground current**	**For full current in two ground electrode stations (intermittent)**	**Midpoint grounded 12-pulse converter in Eemshaven. No ground current.**	**Midpoint grounded no ground current**	**For full current in two sea electrode stations**	**Midpoint grounded no ground current**
AC grids at both ends	Asynchronous	Asynchronous	Asynchronous	Asynchronous	Asynchronous	Asynchronous	Asynchronous
Control	Power Control, emergency power control voltage control	Power Control, frequency control voltage control	Constant power	Constant power. Reactive/AC-voltage control. Frequency dependant power control. Power swing damping control.	Constant power.	Frequency control on Sardinia	Constant power. Frequency dependant power control. Power swing damping control.
Emergency change of power flow	–	–	–	–	–	–	Runback control.
Main reason for choosing HVDC system	Asynchronous networks	Asynchronous networks	Long distance. Asynchronous networks	Long distance submarine crossing. Asynchronous networks	Asynchronous networks	Long distance submarine crossing.	Asynchronous networks
Power company	**Basin Electric Power Cooperative and Black Hills Power & Light, USA**	**Powergrid Corporation of India Ltd.**	**State Grid Corporation of China**	**Statnett, Norway TenneT, The Netherlands**	**Sharyland Utilities, USA**	**Terna, Italy**	**Hydro Quebec, Quebec, Canada**
Main supplier of converter equipment	ABB	ABB	ABB - Chinese Consortium	ABB	ABB	ABB	ABB

SCHEME	43. XIANGJIABA - SHANGHAI	44. LINGBAO II EXTENSION PROJECT	45. FENNO-SKAN 2	46. HULUNBEIR - LIAONING			
Commissioning year	**2010-2011**	**2009**	**2011**	**2009**			
Power transmitted, MW	**6400**	**750**	**800**	**3000**			
Direct voltage, kV	**±800 kV**	**168 kV**	**500 kV**	**±500 kV**			
Converters per station	**4**	**2**	**1**	**2**			
Direct voltage per converter, kV	400	168	500	500			
Direct current, A	4000	4500	1600	3000			
Reactive power supply	Capacitors	Capacitors	Capacitors	Capacitors			
Converter station location and AC grid voltage	Fulong: 525 kV Fengxian: 515 kV	Huazhong: 500 kV Xibei: 330 kV	Finnböle: 400 kV Rauma: 400 kV	Yimin: 500 kV Mujia: 500 kV			
Length of overhead DC line	2071 km	Back-to-back	70 km (Swedish side) 33 km (Finnish side)	920 km			
Cable arrangement	**–**	**–**	**–**	**–**			
Cable route length	**–**	**–**	**200 km**	**–**			
Grounding of the DC circuit	**For full current in two electrode stations**	**One point grounded**	**Grounded neutral. Common neutrals and electrodes with Fenno-Skan 1.**	**For full current in two ground electrode stations (intermittent)**			
AC grids at both ends	Synchronous	Asynchronous	Synchronous	Asynchronous			
Control	Constant power, frequency and damping control	Constant power, frequency control	Constant power, damping control	Constant power			
Emergency change of power flow	On manual or automatic order	–	On manual order to preset value	–			
Main reason for choosing HVDC system	Long distance	Asynchronous networks	Long distance submarine crossing.	Long distance. Asynchronous networks			
Power company	**State Grid Corporation of China**	**State Grid Corporation of China**	**Fingrid, Finland and Svenska Kraftnät, Sweden**	**State Grid Corporation of China**			
Main supplier of converter equipment	ABB/Siemens	ABB/XPR/XJ/ CEPRI/TBEA/XB/Sifang	ABB	ABB/XPR/XJ/TBEA/NARI			

HVDC converter station upgrades

SCHEME (*)	Commissioning year		Power MW	Scope	Power company
	Original plant	Upgrade			
U1. SKAGERRAK 1 & 2 (2.)	1976 - 77	1991	500	Replacement of valve control and valve electronics.	Elsam, Denmark, Statkraft, Norway
U2. NEW ZEALAND DC HYBRID LINK (mercury arc valves)	1965	1992	2 x 500	Paralleling of mercury-arc poles. Total replacement of control system	Trans Power New Zealand Ltd., Wellington, New Zealand
U3. CU-PROJECT (5.)	1978	2001	1000	Replacement of valve control and valve electronics.	Great River Energy, MN, USA
U4. CU-PROJECT (5.)	1978	2002	1000	Voltage upgrade ±10 kV (2.5 %), + 25 MW.	Great River Energy, MN, USA
U5. CU-PROJECT (5.)	1978	2004	1025	Control and protection upgrade.	Great River Energy, MN, USA
U6. SQUARE BUTTE HVDC SCHEME (Originally built by General Electric)	1977	2004	500	Control and protection upgrade.	Minnkota Power Coop., Grand Forks, ND, Minnesota Power, Duluth, MN, USA
U7. PACIFIC HVDC INTERTIE, SYLMAR SYLMAR REPLACEMENT PROJECT (22.)	1970, 1985, 1989	2004	3100	Re-building of the Sylmar East converter station from 1,100 to 3,100 MW.	The Department of Water and Power of the City of Los Angeles, CA, USA
U8. SKAGERRAK 1 & 2 (2.)	1976 - 77	2007	2 x 250	Control and protection upgrade.	Energinet.dk, Denmark, Statnett, Norway
U9. CAHORA BASSA, APOLLO UPGRADE (3.)	1977-79	2008	1920	New outdoor valves, AC filters. Control and protection system.	ESKOM, South Africa
U10. BLACKWATER (14.)	1985	2009	200	Valve cooling and control and protection system upgrade.	Public Service Company of New Mexico (PNM), USA
U11. CHÂTEAUGUAY (11.)	1984	2009	2 x 500	Control and protection system upgrade.	Hydro-Québec, Canada
U12. INTERMOUNTAIN POWER PROJECT (12.)	1986	2010	2 400	Control and protection system upgrade, additional AC filters and cooling system	Intermountain Power Agency with Los Angeles Department of Water and Power, USA

* Figures in brackets refer to the project in the main table.

ABB pioneered the use of series capacitors in electric power systems in the late 1940s. The ABB series capacitors have a well proven design and have over the years demonstrated extraordinarily good reliability. This is essential as the installations are unmanned and often located in remote areas far away from service centres.

ABB's success in the series compensation field is best illustrated by the confidence in our solutions evidenced by customers. Today, 287 installations located all over the world are in service or under construction. This represents 84900 Mvar, equal to 48% of the world total.

ABB Series Capacitor projects Worldwide

Customer	Location	System Voltage	Rated Power	Protection Scheme *)	Order year
ISOLUX/CYMI/CTEEP - Ribeiro Goncalves	Brazil	500 kV	891 Mvar	MOV	2008
HYDRO ONE - Nobel II	Canada	500 kV	750 Mvar	FPD	2008
HYDRO ONE - Nobel I	Canada	500 kV	750 Mvar	FPD	2008
FINGRID - Toumela	Finland	400 kV	300 Mvar	FPD	2008
FINGRID - Asmuti	Finland	400 kV	370 Mvar	FPD	2008
CFE - Donato Guerra I	Mexico	400 kV	232 Mvar	FPD	2008
CFE - Donato Guerra II	Mexico	400 kV	232 Mvar	FPD	2008
CFE - Donato Guerra III	Mexico	400 kV	232 Mvar	FPD	2008
Eskom - Iziko Seremula	South Africa	400 kV	2200 Mvar	FPD	2008
FPLE - Horse Hollow	USA	345 kV	400 Mvar	MOV	2008
Furnas - Rio Verde 1	Brazil	220 kV	34 Mvar	FPD	2007

***) SG: Single-gap**
DG: Dual-gap
FPD: CapThor
MOV: Metal Oxide Varistor
SiC: Silicon carbide Varistor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
Furnas - Rio Verde 2	Brazil	220 kV	34 Mvar	FPD	2007
Furnas - Itumbiara	Brazil	220 kV	37 Mvar	FPD	2007
Ukrenego - Dzjankoj	Ukraine	330 kV	189 Mvar	FPD	2007
PG&E - Vaca Dixon Upgrade II	USA	500 kV	384 Mvar	MOV	2007
Idaho Power - Three Mile Knoll	USA	345 kV	465 Mvar	MOV	2007
Salt River Project - Silverking	USA	500 kV	314 Mvar	FPD	2007
Salt River Project - Coronado	USA	500 kV	314 Mvar	FPD	2007
Abengoa SA - Itacaiunas	Brazil	500 kV	431 Mvar	SG	2006
Hydro Quebec - Des Hetres	Canada	230 kV	108 Mvar	FPD	2006
Power Grid India - Ranchi I	India	400 kV	398 Mvar	FPD	2006
Power Grid India - Ranchi II	India	400 kV	398 Mvar	FPD	2006
San Diego Gas&Electric - Imperial Valley East Upgrade	USA	500 kV	150 Mvar	MOV	2006
Abengoa SA - S.João do Piaui	Brazil	500 kV	374 Mvar	MOV	2005
Abengoa SA - Ribeiro Goncalves	Brazil	500 kV	425 Mvar	MOV	2005
Abengoa SA - Ribeiro Goncalves	Brazil	500 kV	462 Mvar	MOV	2005
Eskom - Cape Strengthening Komsberg No.1	South Africa	400 kV	704 Mvar	MOV	2004

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
Eskom - Cape Strengthening Bacchus No.1	South Africa	400 kV	248 Mvar	MOV	2004
Eskom - Cape Strengthening Proteus No.1	South Africa	400 kV	229 Mvar	MOV	2004
Eskom - Cape Strengthening Komsberg No.2	South Africa	400 kV	656 Mvar	MOV	2004
PG&E - Midway, phase 3	USA	500 kV	503 Mvar	MOV	2004
Electricity of Vietnam - Tan Dinh	Vietnam	500 kV	101 Mvar	MOV	2004
Transener S.A. - 3rd&4th Line SC Extension	Argentina	500 kV	580 Mvar	MOV	2003
Power Grid Corp. of India - Raipur Rourkela 2	India	400 kV	394 Mvar	MOV	2003
Power Grid Corp. of India - Raipur-Rourkela 1	India	400 kV	394 Mvar	MOV	2003
Power Grid Corp. of India - Raipur-Rourkela 1 TCSC	India	400 kV	59 Mvar	MOV	2003
Power Grid Corp. of India - Raipur Rourkela 2 TCSC	India	400 kV	59 Mvar	MOV	2003
SCECO - SCECO East	Saudi Arabia	380 kV	588 Mvar	MOV	2003
SCECO - SCECO East	Saudi Arabia	230 kV	189 Mvar	MOV	2003
SCECO - SCECO East	Saudi Arabia	380 kV	495 Mvar	MOV	2003
SCECO - SCECO East	Saudi Arabia	380 kV	495 Mvar	MOV	2003

***) SG: Single-gap MOV: Metal Oxide Varistor**
DG: Dual-gap SiC: Silicon carbide Varistor
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
PG&E - Vaca Dixon Upgrade	USA	500 kV	384 Mvar	MOV	2003
Idaho Power Company - Goshen SC	USA	345 kV	380 Mvar	MOV	2003
Nevada Power - McCullough	USA	500 kV	452 Mvar	MOV	2003
San Diego Gas & Electric - Imperial Valley	USA	550 kV	307 Mvar	MOV	2003
Hydro Quebec - Bergeronnes extension	Canada	760 kV	516 Mvar		2002
BC Hydro - McLeese 2 Refurb.	Canada	500 kV	616 Mvar	MOV	2002
BC Hydro - McLeese 1 Refurb.	Canada	500 kV	616 Mvar	MOV	2002
PG&E - PG&E Alliance Fas 2	USA	500 kV	503 Mvar	MOV	2002
PG&E - PG&E Alliance Fas 2	USA	500 kV	503 Mvar	MOV	2002
PG&E - PG&E Alliance Fas 2	USA	500 kV	544 Mvar	MOV	2002
PG&E - PG&E Alliance Fas 2	USA	500 kV	544 Mvar	MOV	2002
Eletronorte - North - North East III	Brazil	500 kV	315 Mvar	MOV	2001
Eletronorte - North - North East III	Brazil	500 kV	435 Mvar	MOV	2001
Eletronorte - North - North East III	Brazil	500 kV	279 Mvar	MOV	2001
Eletronorte - North - North East III	Brazil	500 kV	435 Mvar	MOV	2001

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
PG&E - Table Mountain 2	USA	500 kV	444 Mvar	MOV	2001
PG&E - Table Mountain 1	USA	500 kV	444 Mvar	MOV	2001
PG&E - Gates 3	USA	500 kV	544 Mvar	MOV	2001
PG&E - Gates 4	USA	500 kV	544 Mvar	MOV	2001
PG&E - Gates 2	USA	500 kV	584 Mvar	MOV	2001
PG&E - Round Mountain 2	USA	500 kV	444 Mvar	MOV	2001
PG&E - Round Mountain 1	USA	500 kV	444 Mvar	MOV	2001
PG&E - Gates 1	USA	500 kV	584 Mvar	MOV	2001
Enelven - 400 kV Series Compensation Project	Venezuela	400 kV	2096 Mvar	MOV	2001
Eneleven - El Tablazo 1	Venezuela	400 kV	126 Mvar	MOV	2001
Enelven - Yaracuy 2	Venezuela	400 kV	197 Mvar	MOV	2001
Enelven - El Tablazo 3	Venezuela	400 kV	126 Mvar	MOV	2001
Eneleven - Yaracuy 1	Venezuela	400 kV	197 Mvar	MOV	2001
Enelven - El Tablazo 2	Venezuela	400 kV	126 Mvar	MOV	2001
Transener - Recreo	Argentina	500 kV	245 Mvar	MOV	2000
NCEPG - Dafang SC	China	500 kV	744 Mvar	MOV	2000
SOGEM - Mali-Senegal, Kayes	Mali	225 kV	22,5 Mvar	MOV	2000
SOGEM - Mali-Senegal, Matam	Mali	225 kV	45 Mvar	MOV	2000

***) SG: Single-gap**
DG: Dual-gap
FPD: CapThor
MOV: Metal Oxide Varistor
SiC: Silicon carbide Varistor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
Trönder Energi - Trönder Energi	Norway	22 kV	1 Mvar	MOV	2000
Virginia Power Co. - Midlothain MINICAP	USA	34 kV	9 Mvar		2000
Enelven - La Paz MINICAP	Venezuela	24 kV	1 Mvar		2000
Transener - Recreo	Argentina	500 kV	240 Mvar	MOV	1999
SOGEM - Mali-Senegal Dagana	Mali	225 kV	45 Mvar	MOV	1999
Idaho Power Company - Ontario	USA	230 kV	135 Mvar	MOV	1999
Transener - 4th line	Argentina	500 kV	430 Mvar	MOV	1998
Furnas - Ivaipora	Brazil	800 kV	1056 Mvar	MOV	1998
Western Power - Bullabulling	Australia	33 kV	10 Mvar	MOV	1997
Eletronorte - N/S Intertie-Imperatriz	Brazil	500 kV	161 Mvar	MOV	1997
Eletronorte - N/S Intertie-Miracena	Brazil	500 kV	161 Mvar	MOV	1997
Eletronorte - N/S Intertie-Marabá	Brazil	500 kV	348 Mvar	MOV	1997
Eletronorte - N/S Intertie-Colinas	Brazil	500 kV	322 Mvar	MOV	1997
Eletronorte - N/S Intertie-Imperatriz TCSC	Brazil	500 kV	107 Mvar	MOV	1997
PG & E - Round Mountain North	USA	500 kV	770 Mvar	MOV	1997
Colbun SA - Colbun	Chile	230 kV	504 Mvar	MOV	1996

***) SG: Single-gap**
DG: Dual-gap
FPD: CapThor
MOV: Metal Oxide Varistor
SiC: Silicon carbide Varistor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
Båkab Energi AB - Granbo Minicap	Sweden	22 kV	4,6 Mvar	MOV	1996
Svenska Kraftnät - Isovaara	Sweden	400 kV	500 Mvar	MOV	1996
TRANSENER S.A. - Retrofit	Argentina	500 kV	1280 Mvar	MOV	1995
BC-Hydro - Chapman-Retrofit Control	Canada		0 Mvar		1995
Hydro-Quebec - Wenindji - Minicap	Canada	25 kV	3,4 Mvar	MOV	1995
BC Hydro - McLeese	Canada	500 kV	605 Mvar	MOV	1993
Hydro-Quebec - Chamouch. Nord II	Canada	800 kV	243 Mvar	MO	1991
Hydro-Quebec - Abitibi II	Canada	800 kV	397 Mvar	MOV	1991
Hydro-Quebec - Chamouch. Nord I	Canada	800 kV	243 Mvar	MOV	1991
Hydro-Quebec - Abitibi I	Canada	800 kV	397 Mvar	MOV	1991
Hydro-Quebec - Abitibi III	Canada	800 kV	397 Mvar	MOV	1991
Hydro-Quebec - Chamouch. Nord III	Canada	800 kV	243 Mvar	MOV	1991
Landsvirkjun - Holar	Iceland	132 kV	43 Mvar	MOV	1991
SSPB - Stöde	Sweden	400 kV	493 Mvar	MOV	1991
SSPB - Tandö	Sweden	400 kV	554 Mvar	MOV	1991
Hydro-Quebec - Arnaud Sud III	Canada	800 kV	363 Mvar	MOV	1990
Hydro-Quebec - Arnaud Sud I	Canada	800 kV	363 Mvar	MOV	1990

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
Hydro-Quebec - Bergeronnes II	Canada	800 kV	238 Mvar	MOV	1990
Hydro-Quebec - Bergeronnes III	Canada	800 kV	238 Mvar	MOV	1990
Hydro-Quebec - Saguenay Nord	Canada	800 kV	238 Mvar	MOV	1990
Hydro-Quebec - Arnaud Nord II	Canada	800 kV	363 Mvar	MOV	1990
Hydro-Quebec - Arnaud Nord III	Canada	800 kV	363 Mvar	MOV	1990
Hydro-Quebec - Perigny	Canada	800 kV	238 Mvar	MOV	1990
Hydro-Quebec - Bergeronnes I	Canada	800 kV	238 Mvar	MOV	1990
Hydro-Quebec - Arnaud Nord I	Canada	800 kV	363 Mvar	MOV	1990
Hydro-Quebec - Arnaud Sud II	Canada	800 kV	363 Mvar	MOV	1990
SSPB - Djurmo EK2	Sweden	400 kV	538 Mvar	MOV	1990
Hidronor - Choele Choel II	Argentina	500 kV	170 Mvar	MOV	1989
Hidronor - Choele Choel IV	Argentina	500 kV	170 Mvar	MOV	1989
Hidronor - Olavarria II	Argentina	500 kV	135 Mvar	MOV	1989
Hidronor - Olavarria IV	Argentina	500 kV	135 Mvar	MOV	1989
Hidronor - Olavarria III	Argentina	500 kV	245 Mvar	MOV	1989
Hidronor - Choele Choel I	Argentina	500 kV	215 Mvar	MOV	1989
Hidronor - Choele Choel III	Argentina	500 kV	180 Mvar	MOV	1989

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	Location	System Voltage	Rated Power	Protection Scheme *)	Order year
Hidronor - Olavarria I	Argentina	500 kV	245 Mvar	MOV	1989
Furnas - Ivaipora V	Brazil	800 kV	1017 Mvar	DG	1989
Swedish State Power B. - Djurmo EK4	Sweden	400 kV	603 Mvar	MOV	1989
AEP - Kanawha River	USA	345 kV	788 Mvar	MOV	1989
Tucson Gas - Vail II	USA	345 kV	102 Mvar	SG	1988
El Paso Electric - Luna, N. Mexico	USA	345 kV	123 Mvar	SG	1988
Furnas - Ivaipora I	Brazil	800 kV	1017 Mvar	DG	1987
Furnas - Itabera I	Brazil	800 kV	1242 Mvar	SG	1987
Furnas - Itabera II	Brazil	800 kV	1242 Mvar	SG	1987
Furnas - Ivaipora IV	Brazil	800 kV	1056 Mvar	DG	1987
Furnas - Ivaiopra II	Brazil	800 kV	1017 Mvar	DG	1987
Furnas - Ivaipora III	Brazil	800 kV	1056 Mvar	DG	1987
Eade - Apartado	Colombia	110 kV	16 Mvar	SG	1987
TEK - Bolu	Turkey	380 kV	256 Mvar	MOV	1987
TEK - Sincan I	Turkey	380 kV	190 Mvar	MOV	1987
TEK - Sincan II	Turkey	380 kV	190 Mvar	MOV	1987
TEK - Kayabasi I	Turkey	380 kV	207 Mvar	MOV	1986
TEK - Kayabasi III	Turkey	380 kV	207 Mvar	MOV	1986
TEK - Kayabasi II	Turkey	380 kV	207 Mvar	MOV	1986
Hydro-Quebec - Joutel	Canada	120 kV	25 Mvar	SG	1985

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
Hydro-Quebec - Kamouraska I	Canada	315 kV	192 Mvar	MOV	1985
Hydro-Quebec - Kamouraska II	Canada	315 kV	192 Mvar	MOV	1985
Hydro-Quebec - Kamouraska III	Canada	315 kV	192 Mvar	MOV	1985
Hydro-Quebec - Kamouraska IV	Canada	315 kV	192 Mvar	MOV	1985
NVE - Evje	Norway	300 kV	432 Mvar	MOV	1985
NVE - Arendal	Norway	300 kV	234 Mvar	MOV	1985
SDG&E - Imper. Valley II	USA	500 kV	150 Mvar	MOV	1984
SDG&E - Imper. Valley I	USA	500 kV	150 Mvar	MOV	1984
BPA - Garrison IV	USA	500 kV	281 Mvar	MOV	1983
PG&E - Table Mountain III	USA	500 kV	600 Mvar	MOV	1983
BPA - Garrison III	USA	500 kV	281 Mvar	MOV	1983
BPA - Garrison I	USA	500 kV	281 Mvar	MOV	1983
PG&E - Vaca Dixon	USA	500 kV	384 Mvar	MOV	1983
PG&E - Table Mountain IV	USA	500 kV	384 Mvar	MOV	1983
PG&E - Tesla	USA	500 kV	600 Mvar	MOV	1983
BPA - Garrison II	USA	500 kV	281 Mvar	MOV	1983
CFE - Temascal I	Mexico	400 kV	259 Mvar	DG	1982
CFE - Temascal II	Mexico	400 kV	259 Mvar	DG	1982

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
BPA - Columbia II	USA	500 kV	276 Mvar	MOV	1981
BPA - Columbia I	USA	500 kV	276 Mvar	MOV	1981
CFE - Minatitlan I	Mexico	400 kV	37 Mvar	SG	1980
CFE - Minatitlan II	Mexico	400 kV	37 Mvar	SG	1980
CFE - Coatzacoalcos	Mexico	400 kV	37 Mvar	SG	1980
CFE - Tecali I	Mexico	400 kV	66 Mvar	DG	1980
CFE - Puebla II	Mexico	400 kV	244 Mvar	DG	1980
CFE - Puebla I	Mexico	400 kV	244 Mvar	DG	1980
CFE - Tecali II	Mexico	400 kV	142 Mvar	DG	1980
TEK - Nevsehir II	Turkey	400 kV	164 Mvar	DG	1979
TEK - Nevsehir I	Turkey	400 kV	164 Mvar	DG	1979
TEK - Seydisehir	Turkey	400 kV	65 Mvar	DG	1979
TEK - Osmaniye	Turkey	400 kV	65 Mvar	DG	1979
PP&L - Midpoint	USA	500 kV	603 Mvar	SG	1978
PP&L - Burns	USA	500 kV	603 Mvar	SG	1978
CFE - Durango	Mexico	230 kV	78 Mvar	SG	1977
CFE - Culican	Mexico	230 kV	78 Mvar	SG	1977
TG&E - McKinley II	USA	345 kV	78 Mvar	SG	1977
USBR - Archer	USA	230 kV	63 Mvar	SG	1977
USBR - Ault	USA	345 kV	97 Mvar	SG	1977
TG&E - McKinley I	USA	345 kV	78 Mvar	SG	1977

***) SG: Single-gap MOV: Metal Oxide Varistor**
DG: Dual-gap SiC: Silicon carbide Varistor
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
ESCOM - Luckhoff II	South Africa	400 kV	246 Mvar	SG	1976
Hidronor - Henderson I	Argentina	500 kV	182 Mvar	SG	1975
Hidronor - Puelches II	Argentina	500 kV	182 Mvar	MOV	1975
Hidronor - Henderson II	Argentina	500 kV	182 Mvar	MOV	1975
Hidronor - Puelches I	Argentina	500 kV	182 Mvar	SG	1975
ESCOM - Kronos	South Africa	400 kV	137 Mvar	SG	1975
ESCOM - Aires	South Africa	400 kV	137 Mvar	SG	1975
ESCOM - Helios	South Africa	400 kV	137 Mvar	SG	1975
ESCOM - Aurora	South Africa	400 kV	137 Mvar	SG	1975
ESCOM - Juno	South Africa	400 kV	137 Mvar	SG	1975
Arizona Public Service - Saguaro	USA	500 kV	105 Mvar	SG	1975
Arizona Public Sevice - Cholla III	USA	500 kV	105 Mvar	SG	1975
PP&L - Jim Bridger I	USA	345 kV	178 Mvar	SG	1975
PP&L - Jim Bridger III	USA	345 kV	178 Mvar	SG	1975
PP&L - Jim Bridger II	USA	345 kV	178 Mvar	SG	1975
ESCOM - Nestor II	South Africa	400 kV	212 Mvar	SG	1974
Bl. Hills P&L - Spearfish	USA	230 kV	80 Mvar	SG	1974
USBR - Mead	USA	345 kV	110 Mvar	SG	1974
TG&E - Greenlee	USA	345 kV	158 Mvar	SG	1974
Utah P&L - Goshen	USA	345 kV	178 Mvar	SG	1974

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	Location	System Voltage	Rated Power	Protection Scheme *)	Order year
USBR - Liberty	USA	345 kV	110 Mvar	SG	1974
Bl. Hills P&L - Hot Springs	USA	230 kV	106 Mvar	SG	1974
Idaho Power Company - Kinport	USA	345 kV	178 Mvar	SG	1974
Idaho Power Company - Borah	USA	345 kV	178 Mvar	SG	1974
TG&E - Vail	USA	345 kV	56 Mvar	SG	1974
ESCOM - Victoria II	South Africa	400 kV	222 Mvar	SG	1973
ESCOM - Luckhoff II	South Africa	400 kV	246 Mvar	SG	1973
ESCOM - Luckhoff I	South Africa	400 kV	246 Mvar	SG	1973
ESCOM - Victoria I	South Africa	400 kV	222 Mvar	SG	1973
Arizona Public Service - Westwing I	USA	500 kV	104 Mvar	SG	1973
Arizona Public Service - Westwing II	USA	500 kV	104 Mvar	SG	1973
NVE - Majavatn	Norway	275 kV	115 Mvar	SG	1972
ESCOM - Komsberg I	South Africa	400 kV	315 Mvar	SG	1972
ESCOM - Nestor III	South Africa	400 kV	212 Mvar	SG	1972
ESCOM - Komsberg II	South Africa	400 kV	315 Mvar	SG	1972
ESCOM - Nestor I	South Africa	400 kV	212 Mvar	SG	1972
SSPB - Stöde	Sweden	400 kV	500 Mvar	SG	1972
TEK - Kayseri I	Turkey	400 kV	116 Mvar	DG	1972
TEK - Kayseri II	Turkey	400 kV	116 Mvar	DG	1972
PG&E - Midway III	USA	500 kV	322 Mvar	SG	1972

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
SCE - Vincent	USA	500 kV	286 Mvar	SG	1972
LADWP - Victorville	USA	500 kV	264 Mvar	SG	1971
LADWP - McCallough II	USA	500 kV	314 Mvar	SG	1971
Arizona Public Service - Navajo II	USA	500 kV	201 Mvar	SG	1971
Arizna Public Service - Navajo III	USA	500 kV	201 Mvar	SG	1971
Arizona Public Service - Moenkopi IV	USA	500 kV	109 Mvar	SG	1971
Arizona Public Service - Pinnacle Peak III	USA	345 kV	133 Mvar	SG	1971
LADWP - McCallough I	USA	500 kV	314 Mvar	SG	1971
Arizona Public Service - Moenkopi III	USA	500 kV	109 Mvar	SG	1971
Arizona Public Service - Pinnacle Peak IV	USA	345 kV	133 Mvar	SG	1971
Arizona Public Service - Navajo I	USA	500 kV	20 Mvar	SG	1971
USBR - Flagstaff I	USA	345 kV	121 Mvar	SG	1968
USBR - Pinnacle Peak II	USA	345 kV	121 Mvar	SG	1968
USBR - Flagstaff II	USA	345 kV	121 Mvar	SG	1968
USBR - Pinnacle Peak I	USA	345 kV	121 Mvar	SG	1968
SSPB - Tandö	Sweden	400 kV	600 Mvar	SG	1967
Idaho Power Company - Boise Bench III	USA	230 kV	137 Mvar	SG	1967

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
Idaho Power Company - Boise Bench II	USA	230 kV	137 Mvar	SG	1967
Idaho Power Company - Boise Bench I	USA	230 kV	137 Mvar	SG	1967
Idaho Power Company - Boise Bench IV	USA	230 kV	137 Mvar	SG	1967
CADAFE - Bolivar II	Venezuela	230 kV	41 Mvar	SG	1967
CADAFE - Barbacoa I	Venezuela	230 kV	54 Mvar	SG	1967
CADAFE - Barbacoa II	Venezuela	230 kV	54 Mvar	SG	1967
CADAFE - Bolivar I	Venezuela	230 kV	41 Mvar	SG	1967
BPA - Bake Oven II	USA	500 kV	153 Mvar	SG	1966
BPA + PP&L - Malin I	USA	500 kV	184 Mvar	SG	1966
BPA - Bake Oven III	USA	500 kV	153 Mvar	SG	1966
PG&E - Round Mountain I	USA	500 kV	243 Mvar	SG	1966
PG&E - Table Mountain I	USA	500 kV	162 Mvar	SG	1966
PG&E - Midway I	USA	500 kV	324 Mvar	SG	1966
SCE - Eldorado	USA	500 kV	283 Mvar	SG	1966
Arizona Public Service - Moenkopi I	USA	500 kV	199 Mvar	SG	1966
BPA + PG&E - Ft Rock I	USA	500 kV	232 Mvar	SG	1966
Arizona Public Service - Four Corners	USA	500 kV	152 Mvar	SG	1966

***) SG: Single-gap**
DG: Dual-gap
FPD: CapThor
MOV: Metal Oxide Varistor
SiC: Silicon carbide Varistor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
BPA + PG&E - Sand Springs II	USA	500 kV	232 Mvar	SG	1966
BPA + PG&E - Ft Rock II	USA	500 kV	232 Mvar	SG	1966
Arizona Public Service - Moenkopi II	USA	500 kV	199 Mvar	SG	1966
BPA + PG&E - Sycan II	USA	500 kV	232 Mvar	SG	1966
PG&E - Midway II	USA	500 kV	324 Mvar	SG	1966
BPA + PP&L - Malin II	USA	500 kV	194 Mvar	SG	1966
PG&E - Table Mountain II	USA	500 kV	162 Mvar	SG	1966
PG&E - Round Mountain II	USA	500 kV	243 Mvar	SG	1966
BPA + PG&E - Sand Springs I	USA	500 kV	232 Mvar	SG	1966
BPA + PG&E - Sycan I	USA	500 kV	232 Mvar	SG	1965
BPA - Bake Oven I	USA	500 kV	153 Mvar	SG	1965
SSPB - Vittersjö II	Sweden	400 kV	802 Mvar	SG	1964
Idaho Power Company - Midpoint II	USA	230 kV	83 Mvar	SG	1964
Idaho Power Company - Midpoint I	USA	230 kV	83 Mvar	SG	1964
Idahow Power Company - Midpoint I	USA	230 kV	83 Mvar	SG	1964
Arizona Public Service - Cholla I	USA	345 kV	204 Mvar	SG	1962
Arizona Public Service - Cholla II	USA	345 kV	204 Mvar	SG	1962

***) SG: Single-gap** **MOV: Metal Oxide Varistor**
DG: Dual-gap **SiC: Silicon carbide Varistor**
FPD: CapThor

Customer	**Location**	**System Voltage**	**Rated Power**	**Protection Scheme *)**	**Order year**
SSPB - Djurmo II	Sweden	400 kV	600 Mvar	SG	1961
PP&L - Walla Walla	USA	230 kV	114 Mvar	SG	1961
SSPB - Haverö II	Sweden	400 kV	155 Mvar	SG	1958
SSPB - Kättbo	Sweden	400 kV	216 Mvar	SG	1957
SSPB - Vittersjö I	Sweden	400 kV	305 Mvar	SG	1953
SSPB - Djurmo I	Sweden	400 kV	213 Mvar	SG	1952
SSPB - Haverö I	Sweden	400 kV	200 Mvar	SG	1952
BPA - Rocky Ford	USA	230 kV	81 Mvar	SG	1949
BPA - St Andrews	USA	230 kV	48 Mvar	SG	1949
SSPB - Alfta	Sweden	230 kV	31 Mvar	SG	1948
BPA - Chekalis	USA	230 kV	24 Mvar	SG	1948

Number of installations: 285 Total installed power: 84 866 Mvar

***) SG: Single-gap MOV: Metal Oxide Varistor**
DG: Dual-gap SiC: Silicon carbide Varistor
FPD: CapThor

ABB carries a long and pioneering tradition in the static var compensation (SVC / SVC Light) field, with commercial SVC's in use in electrical power systems since the early 1970s. Since then, our success in the SVC / SVC Light field has best been illustrated by the confidence in our solutions evidenced by customers. Today, 489 installations located all over the world are in service or under construction. This represents 69800 Mvar, equal to 54% of the world total.

ABB SVC projects Worldwide

Customer -Project	Location	System Voltage	Rated Power Controlled Mvar	Application	Order year
VISA Steel Ltd. - EAF SVC	India	33 kV	135 () Mvar	EAF	2009
Danieli - UNI Steel, SVC-LIGHT	Kuwait	33 kV	164 () Mvar	EAF	2009
CFE - El Palmar	Mexico	230 kV	200 () Mvar	Utility	2009
Tung Ho Steel Enterprise - Tao Yuan Plant	Taiwan	33 kV	165 () Mvar	EAF	2009
Danieli - GHC2, SVC-LIGHT	Un. Arab Emirate	33 kV	164 () Mvar	EAF	2009
ONCOR - Renner II	USA	138 kV	565 () Mvar	Utility	2009
Smorgon Steel - SVC Smorgon Steel	Australia	22 kV	115 () Mvar	EAF	2008
HYDRO ONE - Kirkland Lake	Canada	115 kV	200 () Mvar	Utility	2008
ALTALINK - Langdon	Canada	240 kV	500 () Mvar	Utility	2008
Pilsen Steel - SVC - Q	Czech Republic	22 kV	70 () Mvar	EAF	2008
Beshay Steel - ESISCO II	Egypt	33 kV	195 () Mvar	EAF	2008
SALEM STEEL - SAIL SVC	India	33 kV	60 () Mvar	EAF	2008
Danieli Steel - AMET (Russia)	Italy	33 kV	150 () Mvar	EAF	2008
Duferdofin - Duferdofin	Italy	30 kV	175 () Mvar	EAF	2008

Customer -Project	Location	System Voltage	Rated Power Controlled Mvar	Application	Order year
LS Industrial Systems - SVC for Kotobuki	Japan	22 kV	80 () Mvar	EAF	2008
Liepajas Metalurgs - SVC LIGHT	Latvia	33 kV	164 () Mvar	EAF	2008
Arcelor Mittal - Mittal Steel (F10095)	Mexico	69 kV	225 () Mvar	Power Quality SVC	2008
Koniambo Nickel - SAS SVC - Q	New Caledonia	63 kV	200 () Mvar	EAF	2008
KOSCO Steel - KOSCO Steel	S.Korea	33 kV	140 () Mvar	EAF	2008
LKAB - F10090	Sweden	6 kV	35 () Mvar	Mine Hoists	2008
Hai-Kwang Enterprice Co. - Hai-Kwang (F10078)	Taiwan	23 kV	65 () Mvar	Power Quality SVC	2008
Lo Toun Steel & Iron Works Ltd - Lo Toun (F10088)	Taiwan	23 kV	125 () Mvar	Power Quality SVC	2008
MMK - Atakas	Turkey	35 kV	330 () Mvar	EAF	2008
Oncor - Parkdale SVC 2	USA	138 kV	565 () Mvar	Utility	2008
AEP - Rio Pecos	USA	69 kV	90 () Mvar	Utility	2008
ONCOR - Renner I	USA	138 kV	565 () Mvar	Utility	2008
NSTAR - Barnstable SVC	USA	115 kV	225 () Mvar	Utility	2008
PG&E - Humboldt	USA	60 kV	75 () Mvar	Utility	2008
Oncor - Parkdale SVC 1	USA	138 kV	565 () Mvar	Utility	2008
Powerlink - Woolooga SVC	Australia	275 kV	450 () Mvar	Utility	2007
Western Power - Southern Terminal SVC	Australia	132 kV	300 () Mvar	Utility	2007
Mineracao - Onca Puma SVC 1	Brazil	35 kV	140 () Mvar	EAF	2007
Mineracao - Onca Puma SVC 2	Brazil	35 kV	140 () Mvar	EAF	2007
Manitoba Hydro - Birchtree SVC	Canada	230 kV	225 () Mvar	Utility	2007
Beshay Steel - ESISCO I	Egypt	33 kV	195 () Mvar	EAF	2007

Customer -Project	Location	System Voltage	Rated Power Controlled Mvar	Application	Order year
SNCF - Jura Mountains SVC LIGHT	France	63 kV	15 () Mvar	Utility	2007
EdF - Martham SVC Light	Great Britain	11 kV	10 () Mvar	Utility	2007
EdF Energy/Powerlink - London Underground - Wood Green	Great Britain	11 kV	33 () Mvar	Utility	2007
Jindal Steel & Power - Jindal SVC	India	33 kV	200 () Mvar	EAF	2007
Bhushan Steel - Bhushan Steel	India	33 kV	185 () Mvar	EAF	2007
Luz y Fuerza - La Paz	Mexico	400 kV	600 () Mvar	Utility	2007
Statnett - Tunnsjödal	Norway	420 kV	500 () Mvar	Utility	2007
Statnett - Viklandet	Norway	420 kV	500 () Mvar	Utility	2007
Statnett - Hasle Upgrade	Norway	420 kV	360 () Mvar	Utility	2007
Pervoural'sk - Pervoural'sk SVC	Russia	35 kV	110 () Mvar	EAF	2007
ESKOM - Hydra I Upgrade	South Africa	400 kV	300 () Mvar	Utility	2007
ESKOM - Hydra II Upgrade	South Africa	400 kV	300 () Mvar	Utility	2007
ESKOM - Perseus I Upgrade	South Africa	400 kV	300 () Mvar	Utility	2007
ESKOM - Perseus II Upgrade	South Africa	400 kV	300 () Mvar	Utility	2007
ESKOM - Poseidon Upgrade	South Africa	400 kV	300 () Mvar	Utility	2007
Siam Yamato Steel - Siam Yamato Steel, SVC Light	Thailand	22 kV	120 () Mvar	EAF	2007
ICDAS - ICDAS SVC	Turkey	35 kV	300 () Mvar	EAF	2007
CEMTAS - Cemtas SVC	Turkey	35 kV	35 () Mvar	EAF	2007
Emirate Steel - Emirate Steel	Un. Arab Emirate	33 kV	65 () Mvar	EAF	2007
First Energy - Atlantic Upgrade	USA	230 kV	130 () Mvar	Utility	2007

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
CMC Steel Group - CMC	USA	13 kV	40 () Mvar	EAF	2007
NICSIC - NICSIC	Yugoslavia	35 kV	90 () Mvar	EAF	2007
Elektranet - South East SVC 1 Upgrade	Australia	275 kV	130 () Mvar	Utility	2006
Elektranet - South East SVC 2 Upgrade	Australia	275 kV	130 () Mvar	Utility	2006
MRM Gerdau Ameristeel - Gerdau SVC	Canada	14 kV	80 () Mvar	EAF	2006
Bao-Steel - Bao Steel SVC	China	33 kV	180 () Mvar	EAF	2006
NSC-TISCO - TISCO SVC	China	35 kV	100 () Mvar	EAF	2006
ISA - Cano Limon SVC	Colombia	35 kV	84 () Mvar	Utility	2006
Corus UK - Port Talbot SVC 2 Upgrade	Great Britain	11 kV	42 () Mvar	Rolling mill	2006
Halyvourgiki - Halyvourgiki	Greece	22 kV	115 () Mvar	EAF	2006
Ramsharup - Ramsharup SVC	India	33 kV	80 () Mvar	EAF	2006
CFE - Culiacan	Mexico	230 kV	200 () Mvar	Utility	2006
PEME - SSSRM SVC	Oman	33 kV	75 () Mvar	EAF	2006
SEC - Jeddah-Faisaliyah SVC	Saudi Arabia	110 kV	660 () Mvar	Utility	2006
SEC - Jeddah-Jamia SVC	Saudi Arabia	110 kV	660 () Mvar	Utility	2006
SEC - Jeddah Medinah SVC	Saudi Arabia	110 kV	660 () Mvar	Utility	2006
P Madrid - P Madrid SVC	Spain	30 kV	120 () Mvar	EAF	2006
Siderurgica Balboa - Balboa SVC	Spain	33 kV	200 () Mvar	EAF	2006
Bergara - Bergara SVC	Spain	30 kV	120 () Mvar	EAF	2006
Siderugica Balboa - Balboa DC Furnace SVC	Spain	20 kV	80 () Mvar	EAF	2006

Customer -Project	Location	System Voltage	Rated Power Controlled Mvar	Application	Order year
El Fouladh - El Fouladh SVC	Tunisia	11 kV	45 () Mvar	EAF	2006
Yazici Steel - Yazici Steel SVC	Turkey	32 kV	100 () Mvar	EAF	2006
PHI - Dennis SVC	USA	230 kV	250 () Mvar	Utility	2006
AEP - Bluff Creek SVC	USA	35 kV	90 () Mvar	Utility	2006
XCEL Energy - Tuco SVC	USA	230 kV	200 () Mvar	Utility	2006
Nucor Steel - Nucor Upgrade	USA	35 kV	108 () Mvar	EAF	2006
DUKE POWER - Beckerdite SVC	USA	100 kV	400 () Mvar	Utility	2006
Tucson Electric Power - Tucson SVC	USA	138 kV	275 () Mvar	Utility	2006
Alleghny Power - Black Oak SVC	USA	500 kV	720 () Mvar	Utility	2006
Belgo - Belgo Piracicaba	Brazil	33 kV	140 () Mvar	EAF	2005
Trans-Elect Inc. - Puerto Montt SVC	Chile	220 kV	110 () Mvar	Utility	2005
Voest Alpine - ZPSS - SVC Light	China	35 kV	164 () Mvar	EAF	2005
Corus UK - Port Talbot SVC 1 Upgrade	Great Britain	11 kV	42 () Mvar	Rolling mill	2005
Insig - Barsoo	Iran	33 kV	105 () Mvar	EAF	2005
Alfa Acciai - Alfa Acciai	Italy	22 kV	163 () Mvar	EAF	2005
GSW - GSW	Spain	30 kV	145 () Mvar	EAF	2005
Nervacero - Nervacero	Spain	32 kV	140 () Mvar	EAF	2005
Tung Ho - Tung Ho DC-EAF	Taiwan	22 kV	90 () Mvar	EAF	2005
Colakoglu - Colakoglu	Turkey	35 kV	310 () Mvar	EAF	2005
AEP - Mc Camey - Crane	USA	69 kV	90 () Mvar	Utility	2005
Gerdau Ameristeel - Gerdau Ameristeel Charlotte SVC Light	USA	13 kV	64 () Mvar	EAF	2005

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
AEP - Mc Camey - Dilley	USA	69 kV	90 () Mvar	Utility	2005
AEP - Mc Camey - Airline	USA	69 kV	90 () Mvar	Utility	2005
Powerlink Queensland - Woree	Australia	132 kV	230 () Mvar	Utility	2004
Carinox - Carinox	Belgium	33 kV	190 () Mvar	EAF	2004
Outokumpu - Outokumpu	Finland	20 kV	140 () Mvar	Rolling mill	2004
RTE - Plaine Haute	France	225 kV	150 () Mvar	Utility	2004
RTE - Poteau Rouge	France	225 kV	300 () Mvar	Utility	2004
CFE - Pidiregas 806	Mexico	400 kV	390 () Mvar	Utility	2004
CFE - Pie de la Cuesta	Mexico	230 kV	200 () Mvar	Utility	2004
CFE - Cerro de Oro	Mexico	400 kV	600 () Mvar	Utility	2004
CFE - Moctezuma	Mexico	230 kV	390 () Mvar	Utility	2004
Deacero Celaya - Deacero Celaya	Mexico	35 kV	140 () Mvar	Power Quality SVC	2004
VAI Technika - MMK	Russia	35 kV	180 () Mvar	Power Quality SVC	2004
VAI Technika - MMK	Russia	35 kV	180 () Mvar	Power Quality SVC	2004
CERN - Cern SVC	Switzerland	18 kV	150 () Mvar	Utility	2004
GVEA Alaska - Jarvis Creek	USA	138 kV	44 () Mvar	Utility	2004
Danieli - BH Steel	Yugoslavia	35 kV	120 () Mvar	EAF	2004
Trans Grid - Sydney West	Australia	330 kV	380 () Mvar	Utility	2003
EASRCO - EASRCO	Egypt	33 kV	160 () Mvar	EAF	2003
ERAMET - Nouvelle Caledonie	New Caledonia	63 kV	64 () Mvar	EAF	2003
PG&E - Potrero SVC	USA	115 kV	340 () Mvar	Utility	2003
Allegheny-Ludlum - Allegheny-Ludlum	USA	25 kV	110 () Mvar	EAF	2003
Austin Energy - Holly - SVC Light	USA	138 kV	200 () Mvar	Utility	2003

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
Nanjing Iron & Steel Ltd - Nisco	China	33 kV	88 () Mvar	EAF	2002
LES - CTRL II Singlewell 3	Great Britain	25 kV	45 () Mvar	Utility	2002
LES - CTRL II Barking 2	Great Britain	25 kV	45 () Mvar	Utility	2002
LES - CTRL II Barking 1	Great Britain	25 kV	45 () Mvar	Utility	2002
POSCO - SMP III Pohang	S.Korea	22 kV	120 () Mvar	EAF	2002
CELSA - CELSA	Spain	25 kV	135 () Mvar	EAF	2002
Arcelor - Olaberria	Spain	30 kV	150 () Mvar	EAF	2002
CELSA - CELSA	Spain	25 kV	135 () Mvar	EAF	2002
ICDAS - ICDAS	Turkey	35 kV	180 () Mvar	EAF	2002
ALZ - ALZ via Voest Alpine	Belgium	32 kV	140 () Mvar	EAF	2001
Meishan Steel - Meishan 2	China	30 kV	22 () Mvar	EAF	2001
Taiyuan I&S - Taiyuan I	China	35 kV	40 () Mvar	EAF	2001
AvestaPolarit - Tornio - SVC Light	Finland	33 kV	164 () Mvar	EAF	2001
LES - CTRL II- Singlewell 4	Great Britain	25 kV	45 () Mvar	Utility	2001
Ferriere Nord / ITSAE - Ferriere Nord	Italy	21 kV	90 () Mvar	EAF	2001
CFE-Comisión Federal de Electricidad - Camargo	Mexico	230 kV	250 () Mvar	Utility	2001
CFE-Comisión Federal de Electricida - Durango	Mexico	230 kV	200 () Mvar	Utility	2001
PG & E - Newark	USA	230 kV	300 () Mvar	Utility	2001
Connectiv - Cardiff N.Jersey	USA	230 kV	250 () Mvar	Utility	2001
Cascade Steel - Cascade Steel	USA	34 kV	90 () Mvar	EAF	2001
LES - CTRL - Singlewell 1	Great Britain	25 kV	45 () Mvar	Utility	2000

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
LES - CTRL - Singlewell 2	Great Britain	25 kV	45 () Mvar	Utility	2000
SPL - London Underground - Neasden 2	Great Britain	22 kV	60 () Mvar	Utility	2000
SPL - London Underground - Neasden 3	Great Britain	22 kV	60 () Mvar	Utility	2000
SPL - London Underground - Neasden 1	Great Britain	22 kV	60 () Mvar	Utility	2000
LES - CTRL - Sellindge Load balancer	Great Britain	33 kV	252 () Mvar	Utility	2000
SPL - London Underground - Greenwich	Great Britain	22 kV	60 () Mvar	Utility	2000
SPL - London Underground - Bethnal Green	Great Britain	22 kV	60 () Mvar	Utility	2000
Antamina - Vizcarra	Peru	220 kV	135 () Mvar	Utility	2000
CERN - CERN SVC	Switzerland	18 kV	150 () Mvar	Utility	2000
Kaptan Demir Celik - Kaptan	Turkey	33 kV	100 () Mvar	EAF	2000
Diler Demir Celik - Diler Demir Celik	Turkey	33 kV	100 () Mvar	EAF	2000
Powerlink - Braemar	Australia	275 kV	230 () Mvar	Utility	1999
Powerlink - Blackwall	Australia	275 kV	300 (300) Mvar	Utility	1999
RWE Energie - RWE SVC Light	Germany	20 kV	38 (38) Mvar	EAF	1999
NamPower - AUAS	Namibia	400 kV	330 (330) Mvar	Utility	1999
Aceralia Co, Siderurgica - Aceralia	Spain	30 kV	72 (72) Mvar	EAF	1999
Vattenfall AB - Hofors	Sweden	33 kV	105 (105) Mvar	EAF	1999
CSW - Eagle Pass BtB	USA	138 kV	50 (50) Mvar	Utility	1999
Connectiv - Indian River, Delaware	USA	230 kV	250 (250) Mvar	Utility	1999

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
Black & Veatch, Connectiv - Nelson, Delaware	USA	138 kV	250 (250) Mvar	Utility	1999
IPSCO - IPSCO	Canada	15 kV	75 (75) Mvar	EAF	1998
Panzhihua Iron & Steel - Panzhihua 2	China	11 kV	55 (55) Mvar	Rolling mill	1998
EDF/SNCF - SVC Light Evron	France	90 kV	36 () Mvar	Utility	1998
Schwermetall Halbzeugwerk - Schwermetall Halbzeugwerk	Germany	10 kV	24 (24) Mvar	Rolling mill	1998
CFE - Güemez	Mexico	400 kV	300 (300) Mvar	Utility	1998
CFE - Texcoco	Mexico	400 kV	300 (300) Mvar	Utility	1998
CFE - Nizuc	Mexico	115 kV	101 (101) Mvar	Utility	1998
CFE - Topilejo	Mexico	400 kV	300 (300) Mvar	Utility	1998
POSCO - Kwang Yang Minimill II	S.Korea	22 kV	83 (83) Mvar	Rolling mill	1998
POSCO - Kwang Yang Minimill III	S.Korea	22 kV	83 (83) Mvar	Rolling mill	1998
POSCO - Kwang Yang Minimill IIII	S.Korea	22 kV	83 (83) Mvar	Rolling mill	1998
POSCO - Kwang Yang Minimill I	S.Korea	22 kV	83 (83) Mvar	Rolling mill	1998
KEPCO - Seo-Daegu	S.Korea	345 kV	200 (200) Mvar	Utility	1998
Anyang Iron & Steel Co. - Anyang	China	33 kV	50 (50) Mvar	EAF	1997
Megasteel - Megasteel	Malaysia	33 kV	190 (190) Mvar	EAF	1997
Megasteel - Megasteel	Malaysia	33 kV	95 (95) Mvar	EAF	1997
Megasteel - Megasteel	Malaysia	33 kV	46 (46) Mvar	Rolling mill	1997
Namakwa Sands - Namakwa Steel	South Africa	33 kV	80 (80) Mvar	EAF	1997
Uddeholm Tooling - Hagfors SVC Light	Sweden	11 kV	44 (44) Mvar	EAF	1997
JISCO - JISCO	China	10 kV	30 (30) Mvar	Power Quality SVC	1996
CFE - Escarcega	Mexico	230 kV	200 (200) Mvar	Utility	1996

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
CFE - Xul Ha	Mexico	115 kV	50 (50) Mvar	Utility	1996
Saldanha Steel - Saldanha Steel	South Africa	33 kV	60 (60) Mvar	Rolling mill	1996
Saldanha Steel - Saldanha Steel	South Africa	33 kV	165 (165) Mvar	EAF	1996
SSAB - Borlänge	Sweden	11 kV	55 (55) Mvar	Rolling mill	1996
UMC - Union Metal	Thailand	22 kV	60 (60) Mvar	EAF	1996
Virginia Power - Colington	USA	115 kV	108 (108) Mvar	Utility	1996
Nucor, Nebraska - Nucor	USA	35 kV	106 (106) Mvar	EAF	1996
Sonelgaz - Bechar II	Algeria	220 kV	50 (50) Mvar	Utility	1995
Sonelgaz - Naama	Algeria	220 kV	50 (50) Mvar	Utility	1995
Sonelgaz - Behar I	Algeria	220 kV	50 (50) Mvar	Utility	1995
Marcial Ucin - Aciérie de l'Atlantique	France	32 kV	120 (120) Mvar	EAF	1995
MEM/ETECEN - Peru	Peru	60 kV	60 (60) Mvar	Utility	1995
MEM/ETECEN - Peru	Peru	138 kV	50 (50) Mvar	Utility	1995
Hanbo Steel - Dangjin-Kun	S.Korea	33 kV	80 (80) Mvar	EAF	1995
Hanbo Steel - Dangjin-Kun	S.Korea	33 kV	80 (80) Mvar	EAF	1995
Hanbo Steel - Dangjin-Kun	S.Korea	33 kV	80 (80) Mvar	EAF	1995
Hanbo Steel - Dangjin-Kun	S.Korea	33 kV	80 (80) Mvar	EAF	1995
Hanbo Steel - Dangjin-Kun	S.Korea	33 kV	80 (80) Mvar	EAF	1995
SCECO C - Riyadh I	Saudi Arabia	380 kV	150 (150) Mvar	Utility	1995
SCECO C - Riyadh II	Saudi Arabia	380 kV	150 (150) Mvar	Utility	1995
SSAB - Oxelösund	Sweden	21 kV	72 (72) Mvar	Rolling mill	1995
Nakornthai Strip Mill - NSM-Chonburi	Thailand	33 kV	160 (160) Mvar	EAF	1995
Nakornthai Strip Mill - NSM-Chonburi	Thailand	33 kV	55 (55) Mvar	Rolling mill	1995

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
LANL - Los Alamos	USA	115 kV	150 (150) Mvar	Utility	1995
Tuscaloosa Steel - Tuscaloosa	USA	35 kV	110 (110) Mvar	EAF	1995
FURNAS - Barro Alto	Brazil	230 kV	350 (350) Mvar	Utility	1994
HQ - La Verendrye II ext.	Canada	735 kV	220 (220) Mvar	Utility	1994
HQ - Chibougamau II ext.	Canada	735 kV	220 (220) Mvar	Utility	1994
HQ - La Verendrye I ext.	Canada	735 kV	220 (220) Mvar	Utility	1994
HQ - Chibougamau I ext.	Canada	735 kV	220 (220) Mvar	Utility	1994
Panzhihua Iron & Steel - Panzhihua	China	11 kV	20 (20) Mvar	Rolling mill	1994
NGC - Hams Hall	Great Britain	13 kV	60 (60) Mvar	Utility	1994
NGC - Coventry	Great Britain	13 kV	60 (60) Mvar	Utility	1994
NGC - Penn	Great Britain	13 kV	60 (60) Mvar	Utility	1994
NGC - Oldbury	Great Britain	13 kV	60 (60) Mvar	Utility	1994
Salem Steel Plant - Salem	India	33 kV	20 (20) Mvar	Rolling mill	1994
Statnett - Kristiansand	Norway	300 kV	400 (400) Mvar	Utility	1994
Voest-Alpine - Posco	S.Korea	22 kV	120 (120) Mvar	EAF	1994
North Star - West Coast Steel plant	USA	35 kV	95 (95) Mvar	EAF	1994
ZESA - Insukamini	Zimbabwe	330 kV	300 (300) Mvar	Utility	1994
HQ - Chamouchouane I ext.	Canada	735 kV	220 (220) Mvar	Utility	1993
HQ - Chamouchouane II ext.	Canada	735 kV	220 (220) Mvar	Utility	1993
Huanghai Iron & Steel - Yantai	China	35 kV	45 (45) Mvar	EAF	1993
Meishan Metallurg. Corp. - Meishan	China	10 kV	45 (45) Mvar	Rolling mill	1993
Nisco - Yazd	Iran	33 kV	115 (115) Mvar	Rolling mill	1993
Columbus Joint Venture - Middelburg	South Africa	33 kV	85 (85) Mvar	Rolling mill	1993

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
Columbus Joint Venture - Middelburg	South Africa	33 kV	165 (165) Mvar	EAF	1993
Chin Tai Steel Enterpr. - Kaohsiung	Taiwan	22 kV	75 (75) Mvar	EAF	1993
Siam Iron & Steel - Bangkok	Thailand	11 kV	50 (50) Mvar	EAF	1993
EGAT - Bang Saphan	Thailand	230 kV	350 (350) Mvar	Utility	1993
ICDAS - Istanbul II	Turkey	35 kV	105 (105) Mvar	EAF	1993
TAVINIR - Omedieh Iran	Iran	420 kV	300 (300) Mvar	Utility	1992
Statnett - Sylling	Norway	400 kV	320 (320) Mvar	Utility	1992
North. States Power - Forbes S/S	USA	500 kV	200 (200) Mvar	Utility	1992
B.C. Hydro - Dunsmuir	Canada	132 kV	300 (300) Mvar	Utility	1991
CISPC - Fuzhou	China	35 kV	60 (60) Mvar	EAF	1991
Ferdofin - Brescia	Italy	16 kV	110 (110) Mvar	EAF	1991
Natsteel - Singapore	Singapore	22 kV	58 (58) Mvar	Power Quality SVC	1991
TKI I - Elbistan	Turkey	20 kV	20 (20) Mvar	Power Quality SVC	1991
TKI III - Elbistan	Turkey	6 kV	10 (10) Mvar	Power Quality SVC	1991
TKI II - Elbistan	Turkey	20 kV	20 (20) Mvar	Power Quality SVC	1991
AEA - Daves Creek	USA	115 kV	35 (35) Mvar	Utility	1991
AEA - Soldatna	USA	115 kV	110 (110) Mvar	Utility	1991
Nucor - Blytheville AR III	USA	34 kV	195 (195) Mvar	EAF	1991
BPA - Maple Valley	USA	230 kV	650 (650) Mvar	Utility	1991
BPA - Keeler	USA	230 kV	650 (650) Mvar	Utility	1991
Nucor - Blytheville Ar IV	USA	34 kV	65 (65) Mvar	Rolling mill	1991
Marienhuette - Graz	Austria	20 kV	45 (45) Mvar	EAF	1990
Metaldom - Santo Domingo	Dominica	34 kV	55 (55) Mvar	Power Quality SVC	1990
Stadtwerke - Bremen	Germany	33 kV	110 (110) Mvar	Rolling mill	1990

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
NTPC - Kanpur 2	India	400 kV	280 (280) Mvar	Utility	1990
NTPC - Kanpur 1	India	400 kV	280 (280) Mvar	Utility	1990
Arvedi - Cremona	Italy	22 kV	65 (65) Mvar	EAF	1990
NEB - Kl North 1	Malaysia	275 kV	200 (200) Mvar	Utility	1990
NEB - Kl North 2	Malaysia	275 kV	200 (200) Mvar	Utility	1990
Antara Steel - Pasir Gudang	Malaysia	33 kV	110 (110) Mvar	EAF	1990
NEB - Yong Peng	Malaysia	275 kV	200 (200) Mvar	Utility	1990
Soinco S.A.C.I. - Tintaya	Peru	138 kV	15 (15) Mvar	Utility	1990
KIA - Kunsan	S.Korea	22 kV	90 (90) Mvar	EAF	1990
Avesta AB - Avesta	Sweden	10 kV	40 (40) Mvar	Power Quality SVC	1990
Siam Construction Steel - Rayong	Thailand	22 kV	110 (110) Mvar	EAF	1990
NTS Steel Groups - Chonburi	Thailand	22 kV	110 (110) Mvar	EAF	1990
Cucurova IIA - Izmir	Turkey	35 kV	110 (110) Mvar	EAF	1990
Cucurova IIB - Izmir	Turkey	35 kV	110 (110) Mvar	EAF	1990
Keystone Steel and Wire - Peoria	USA	34 kV	165 (165) Mvar	EAF	1990
Kremikovtzy - Sofia	Bulgaria	35 kV	110 (110) Mvar	EAF	1989
Lenin Steel Works - Pernik III	Bulgaria	35 kV	30 (30) Mvar	EAF	1989
Wuyang Steelworks - Wuyang	China	35 kV	100 (100) Mvar	EAF	1989
Tianjim Seamless Tube - Tianjin	China	33 kV	120 (120) Mvar	EAF	1989
Bohai Aluminium - Bohai	China	10 kV	36 (36) Mvar	Rolling mill	1989
Shiu Wing Steel - Hong Kong	Hong Kong	35 kV	30 (30) Mvar	EAF	1989
Kang Won Industries - Pohang	S.Korea	22 kV	115 (115) Mvar	EAF	1989
Sid Mendes Junior - Juiz De Fora II	Brazil	22 kV	30 (30) Mvar	EAF	1988

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
Furnas - Barro Alto	Brazil	230 kV	55 (55) Mvar	Utility	1988
HQ - Chamouchouane II	Canada	735 kV	445 (445) Mvar	Utility	1988
HQ - Chamouchouane I	Canada	735 kV	445 (445) Mvar	Utility	1988
Sydney Steel - Sydney, N. Scotia	Canada	35 kV	140 (140) Mvar	EAF	1988
North-East El. Power Adm. - Shenyang China	China	500 kV	550 (550) Mvar	Utility	1988
First Heavy Mach. Works - Qiqihar	China	35 kV	40 (40) Mvar	EAF	1988
Sammi Steel -	S.Korea	30 kV	80 (80) Mvar	EAF	1988
Posco Iron & Steel - Pohang	S.Korea	22 kV	105 (105) Mvar	EAF	1988
Kosice Steelworks - Kosice	Slovakia	110 kV	25 (25) Mvar	Power Quality SVC	1988
Smedjebacken - Boxholm - Smedjebacken	Sweden	20 kV	7 (7) Mvar	EAF	1988
Ekinciler - Iskenderun	Turkey	32 kV	80 (80) Mvar	EAF	1988
MEPCO - Chester	USA	345 kV	550 (550) Mvar	Utility	1988
Tippins/Sydney Steel - Nova Scotia Can.	USA	35 kV	140 (140) Mvar	EAF	1988
Jersey Central P&L - Atlantic	USA	230 kV	130 (130) Mvar	Utility	1988
Marion Steel - Marion, Ohio	USA	14 kV	50 (50) Mvar	EAF	1988
Eletronorte - Coxipo	Brazil	230 kV	120 (120) Mvar	Utility	1987
Eldor Mines - Saskatchewan	Canada	35 kV	18 (18) Mvar	Rolling mill	1987
Acc. Di Terni - Terni	Italy	15 kV	72 (72) Mvar	EAF	1987
Mining Corporation - Maymyo Burma	Myanmar	33 kV	15 (15) Mvar	EAF	1987
Ensidesa - Aviles	Spain	14 kV	36 (36) Mvar	Rolling mill	1987
EGAT - Tha Tako 2	Thailand	500 kV	150 (150) Mvar	Utility	1987
EGAT - Tha Tako 1	Thailand	500 kV	150 (150) Mvar	Utility	1987
Kroman - GEBZE	Turkey	35 kV	45 (45) Mvar	EAF	1987

Customer -Project	Location	System Voltage	Rated Power Controlled Mvar	Application	Order year
Nucor Steel - Indiana	USA	35 kV	80 (80) Mvar	Rolling mill	1987
Empire Detroit - Mansfield	USA	35 kV	90 (90) Mvar	EAF	1987
Nucor Steel - Indiana	USA	35 kV	140 (140) Mvar	EAF	1987
QEC - Nebo	Australia	275 kV	340 (340) Mvar	Utility	1986
Lenin Steel Works - Pernik II	Bulgaria	35 kV	30 (30) Mvar	EAF	1986
Energoimpex - Dobrudja II	Bulgaria	400 kV	100 (100) Mvar	Utility	1986
DOFASCO - Hamilton II	Canada	14 kV	30 (30) Mvar	Rolling mill	1986
DOFASCO - Hamilton III	Canada	14 kV	30 (30) Mvar	EAF	1986
GISW - Guangzhou	China	35 kV	35 (35) Mvar	EAF	1986
Guangdong Gen. Pow. Co. - Jiang Men	China	500 kV	180 (180) Mvar	Utility	1986
CNMIEC - Zhengzhou	China	500 kV	135 (135) Mvar	Utility	1986
CNTIC - Hebei	China	6 kV	13 (13) Mvar	Rolling mill	1986
CNTIC - Dalian	China	500 kV	105 (105) Mvar	Utility	1986
Beltrame - Vicenza	Italy	35 kV	110 (110) Mvar	EAF	1986
Arbed - Dudelange	Luxembourg	37 kV	32 (32) Mvar	EAF	1986
Tamsa - Veracruz	Mexico	33 kV	100 (100) Mvar	Power Quality SVC	1986
Mining Corp. - Maymyo	Myanmar	33 kV	15 (15) Mvar	EAF	1986
NSPB - Nedre Rössåga	Norway	300 kV	320 (320) Mvar	Utility	1986
NSPB - Verdal	Norway	300 kV	320 (320) Mvar	Utility	1986
Electrolima II - Lima	Peru	60 kV	60 (60) Mvar	Utility	1986
Electrolima I - Lima	Peru	60 kV	90 (90) Mvar	Utility	1986
BMZ - Zhlobin III	Russia	10 kV	20 (20) Mvar	Rolling mill	1986
BMZ - Zhlobin IV	Russia	33 kV	15 (15) Mvar	EAF	1986
BMZ - Zhlobin II	Russia	10 kV	20 (20) Mvar	Rolling mill	1986
CEB - Chunnakam	Sri Lanka	132 kV	20 (20) Mvar	Utility	1986

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
CEB - Galle	Sri Lanka	132 kV	20 (20) Mvar	Utility	1986
SSPB - Stenkullen	Sweden	400 kV	400 (400) Mvar	Utility	1986
SSPB - Hamra	Sweden	400 kV	400 (400) Mvar	Utility	1986
Diler - GEBZE	Turkey	35 kV	20 (20) Mvar	EAF	1986
NYSEG - Fraser New York	USA	345 kV	625 (625) Mvar	Utility	1986
Niagara Mohawk - Leeds	USA	345 kV	570 (570) Mvar	Utility	1986
WAPA - Fargo	USA	14 kV	65 (65) Mvar	Utility	1986
Sidetur - Barquisimeto	Venezuela	30 kV	30 (30) Mvar	EAF	1986
Zelezarna Jesenice - Jesenice	Yugoslavia	35 kV	125 (125) Mvar	EAF	1986
Val Sina - Luanda	Angola	15 kV	9 (9) Mvar	EAF	1985
QEC - Grantliegh	Australia	132 kV	51 (51) Mvar	Utility	1985
ECNSW - Broken Hill I	Australia	220 kV	50 (50) Mvar	Utility	1985
ECNSW - Broken Hill II	Australia	220 kV	50 (50) Mvar	Utility	1985
QEC - Gregory	Australia	132 kV	51 (51) Mvar	Utility	1985
QEC - Blackwater	Australia	132 kV	51 (51) Mvar	Utility	1985
SECV - Kerang	Australia	220 kV	75 (75) Mvar	Utility	1985
QEC - Dingo	Australia	132 kV	69 (69) Mvar	Utility	1985
QEC - Coppabella	Australia	132 kV	93 (93) Mvar	Utility	1985
QEC - Oonooie	Australia	132 kV	93 (93) Mvar	Utility	1985
QEC - Mt McLaren	Australia	132 kV	51 (51) Mvar	Utility	1985
SECV - Horsham	Australia	220 kV	75 (75) Mvar	Utility	1985
QEC - Moranbah	Australia	132 kV	93 (93) Mvar	Utility	1985
QEC - Dysart	Australia	132 kV	69 (69) Mvar	Utility	1985
Energoimpex - Dobrudja I	Bulgaria	400 kV	100 (100) Mvar	Utility	1985
Iton Seine - Bonnieres	France	20 kV	50 (50) Mvar	EAF	1985
TNEB - Madurai	India	132 kV	15 (15) Mvar	Utility	1985

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
TNEB - Singaropet	India	132 kV	15 (15) Mvar	Utility	1985
TNEB - Trichur	India	132 kV	15 (15) Mvar	Utility	1985
Acciaierie Galtarossa - Verona	Italy	30 kV	60 (60) Mvar	EAF	1985
Acciaierie Tanaro - Lesegno	Italy	30 kV	40 (40) Mvar	EAF	1985
Sectretariate of Electricity S.O.E - Sebha II Libya	Libya	220 kV	90 (90) Mvar	Utility	1985
Com.de Aguas del Valle de Mexico, CAVM - S.E Planta Bombeo No.3	Mexico	115 kV	40 (40) Mvar	Utility	1985
Norsk Jernverk - Mo I Rana	Norway	23 kV	85 (85) Mvar	Power Quality SVC	1985
PUB - Kallang Basin	Singapore	230 kV	50 (50) Mvar	Utility	1985
PUB - Labrador	Singapore	230 kV	100 (100) Mvar	Utility	1985
SSPB - Oxelösund	Sweden	132 kV	25 (25) Mvar	Utility	1985
EGAT - Chumphon	Thailand	115 kV	80 (80) Mvar	Utility	1985
Kansas Gas & El Co - Gordon Evans	USA	138 kV	300 (300) Mvar	Utility	1985
Kansas Gas & El Co - Murray Gill	USA	138 kV	225 (225) Mvar	Utility	1985
YGEC Alsthom - Sanaa	Yemen	132 kV	30 (30) Mvar	Utility	1985
Lenin Steel Works - Pernik I	Bulgaria	38 kV	45 (45) Mvar	EAF	1984
Alberta Power - Bonnyville	Canada	144 kV	50 (50) Mvar	Utility	1984
Usinor - Dunkerque	France	90 kV	66 (66) Mvar	Rolling mill	1984
Com.de Aguas del Valle de Mexico, CAVM - S.E Planta Bombeo No. 4 Mexico	Mexico	115 kV	40 (40) Mvar	Utility	1984
Com.de Aguas del Valle de Mexico, CAVM - S.E Planta Bombeo No.5 Mexico	Mexico	115 kV	30 (30) Mvar	Utility	1984
SCECO E - Shedgum	Saudi Arabia	380 kV	200 (200) Mvar	Utility	1984

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
SCECO E - Faras	Saudi Arabia	380 kV	200 (200) Mvar	Utility	1984
ULCO - Kimberley	South Africa	11 kV	6 (6) Mvar	Rolling mill	1984
ULCO - Kimberley	South Africa	11 kV	6 (6) Mvar	Rolling mill	1984
ULCO - Kimberley	South Africa	11 kV	6 (6) Mvar	Rolling mill	1984
Siderurgica Sevillana - Sevilla	Spain	16 kV	60 (60) Mvar	EAF	1984
Avesta AB - Degerfors	Sweden	20 kV	60 (60) Mvar	EAF	1984
Cukorova - Izmir III	Turkey	35 kV	80 (80) Mvar	EAF	1984
HABAS - Izmir	Turkey	35 kV	60 (60) Mvar	EAF	1984
Cukorova - Izmir IV	Turkey	35 kV	80 (80) Mvar	EAF	1984
Tucson Electr Power Co - Tucson Arizona	USA	11 kV	30 (30) Mvar	Utility	1984
Transalta Utilit. Corp. - Langdon Alberta	Canada	240 kV	500 (500) Mvar	Utility	1983
British Steel - Port Talbot II	Great Britain	11 kV	42 (42) Mvar	Rolling mill	1983
British Steel - Port Talbot I	Great Britain	11 kV	42 (42) Mvar	Rolling mill	1983
Halyps - Volos	Greece	20 kV	32 (32) Mvar	EAF	1983
New Zealand Steel - South Auckland	New Zealand	33 kV	30 (30) Mvar	EAF	1983
ICDAS - Istanbul I	Turkey	35 kV	30 (30) Mvar	EAF	1983
Colakoglu Metalurji - Gebze	Turkey	35 kV	40 (40) Mvar	EAF	1983
Metas - Izmir	Turkey	35 kV	40 (40) Mvar	EAF	1983
Smorgons Cons Ind - Victoria	Australia	22 kV	49 (49) Mvar	EAF	1982
Sid Mendes Junior - Juiz de Fora I	Brazil	22 kV	45 (45) Mvar	EAF	1982
HQ - Chibougamau II	Canada	735 kV	445 (445) Mvar	Utility	1982
HQ - Chibougamau I	Canada	735 kV	445 (445) Mvar	Utility	1982
DOFASCO - Hamilton I	Canada	14 kV	60 (60) Mvar	Rolling mill	1982
HQ - Chateauguay II	Canada	120 kV	270 (270) Mvar	Utility	1982

Customer -Project	Location	System Voltage	Rated Power Controlled Mvar	Application	Order year
HQ - La Verendrye II	Canada	735 kV	445 (445) Mvar	Utility	1982
HQ - La Verendrye I	Canada	735 kV	445 (445) Mvar	Utility	1982
Rourkela Steel - Rourkela II	India	7 kV	7 (7) Mvar	Rolling mill	1982
Rourkela Steel - Rourkela I	India	7 kV	13 (13) Mvar	Rolling mill	1982
BMZ - Zhlobin	Russia	33 kV	120 (120) Mvar	EAF	1982
Marcial Ucin - Azpeitia	Spain	30 kV	45 (45) Mvar	EAF	1982
Plains Electr G&T Coop - Clapham New Mex	USA	13 kV	50 (50) Mvar	Utility	1982
Tucson Electr Power Co - Tucson Arizona	USA	11 kV	30 (30) Mvar	Utility	1982
Westingh Transp Div - West Mifflin Penn	USA	4 kV	10 (10) Mvar	Power Quality SVC	1982
Timken Company - Canton Ohio	USA	35 kV	85 (85) Mvar	EAF	1982
SEGBA - Rodriguez II	Argentina	500 kV	320 (320) Mvar	Utility	1981
SEGBA - Rodriguez I	Argentina	500 kV	320 (320) Mvar	Utility	1981
SECV - Rowville II	Australia	220 kV	160 (160) Mvar	Utility	1981
SECV - Rowville I	Australia	220 kV	160 (160) Mvar	Utility	1981
HQ - Chateauguay	Canada	120 kV	270 (270) Mvar	Utility	1981
HQ - Chateauguay	Canada	120 kV	270 (270) Mvar	Utility	1981
Algoma Steel Corp - Sault Ste Marie	Canada	12 kV	20 (20) Mvar	Power Quality SVC	1981
Les Mines Seleine - Dauphine, Que	Canada	1 kV	1 (1) Mvar	Rolling mill	1981
Bokaro Steel - Bokaro I	India	11 kV	30 (30) Mvar	Rolling mill	1981
Bokaro Steel - Bokaro III	India	11 kV	23 (23) Mvar	Rolling mill	1981
Bokaro Steel - Bokaro II	India	11 kV	23 (23) Mvar	Rolling mill	1981
S.O.E. - SEBHA I	Libya	220 kV	90 (90) Mvar	Utility	1981
SOE - Tripoli	Libya	230 kV	50 (50) Mvar	Utility	1981
SOE - Tripoli	Libya	230 kV	50 (50) Mvar	Utility	1981

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
S.O.E. - SEBHA II	Libya	220 kV	90 (90) Mvar	Utility	1981
SOE - Tripoli	Libya	230 kV	50 (50) Mvar	Utility	1981
SOE - Tripoli	Libya	230 kV	50 (50) Mvar	Utility	1981
NSPB - Röd	Norway	420 kV	500 (500) Mvar	Utility	1981
Edelca - San Geronimo	Venezuela	765 kV	580 (580) Mvar	Utility	1981
Edelca - La Horqueta	Venezuela	765 kV	580 (580) Mvar	Utility	1981
Mining Companies - Mining Shovel Drives	Brazil	1 kV	600 (600) Mvar	Power Quality SVC	1980
CNTIC - Wu Han II	China	500 kV	120 (120) Mvar	Utility	1980
CNTIC - Wu Han I	China	500 kV	120 (120) Mvar	Utility	1980
CERN - CERN	France	18 kV	19 (19) Mvar	Utility	1980
Tavanir - Omedieh	Iran	420 kV	300 (300) Mvar	Utility	1980
NISIC - AHWAZ I	Iran	30 kV	150 (150) Mvar	EAF	1980
NISIC - AHWAZ III	Iran	30 kV	150 (150) Mvar	EAF	1980
NISIC - AHWAZ II	Iran	30 kV	150 (150) Mvar	EAF	1980
Amalgamated Steel - Kuala Lumpur	Malaysia	15 kV	50 (50) Mvar	EAF	1980
CFE - Puebla	Mexico	230 kV	200 (200) Mvar	Utility	1980
CFE - Temascal	Mexico	400 kV	600 (600) Mvar	Utility	1980
CAVM - S. E. Planta 4	Mexico	115 kV	40 (40) Mvar	Utility	1980
CFE - Acatlan	Mexico	400 kV	200 (200) Mvar	Utility	1980
CAVM - S. E. Planta 3	Mexico	115 kV	40 (40) Mvar	Utility	1980
CAVM - S. E. Planta 5	Mexico	115 kV	30 (30) Mvar	Utility	1980
Ajaokuta Steel Mill - Ajaokuta I	Nigeria	11 kV	7 (7) Mvar	Rolling mill	1980
Ajaokuta Steel Mill - Ajaokuta II	Nigeria	11 kV	9 (9) Mvar	Rolling mill	1980
NSPB - Kvandal	Norway	420 kV	320 (320) Mvar	Utility	1980
NSPB - Hasle	Norway	420 kV	360 (360) Mvar	Utility	1980
OEMK - Kursk II	Russia	110 kV	90 (90) Mvar	EAF	1980

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
OEMK - Kursk I	Russia	110 kV	90 (90) Mvar	EAF	1980
Hidro Nitro Espanola - Monzon	Spain	66 kV	24 (24) Mvar	EAF	1980
SSPB - Hagby	Sweden	220 kV	400 (400) Mvar	Utility	1980
Cathedral Bluffs Shale - Rifle Colorado	USA	13 kV	15 (15) Mvar	Power Quality SVC	1980
VEB Kaltwalswerk - Oranienburg	Germany	15 kV	10 (10) Mvar	Rolling mill	1979
Swedish Steel - Borlänge	Sweden	10 kV	30 (30) Mvar	Rolling mill	1979
Cukorova - Izmir I	Turkey	35 kV	25 (25) Mvar	EAF	1979
Cukorova - Izmir II	Turkey	35 kV	25 (25) Mvar	EAF	1979
Structural Metals Inc - Seguin Texas	USA	13 kV	60 (60) Mvar	EAF	1979
Bethlehem Steel Co - Johnstown Penns	USA	35 kV	125 (125) Mvar	EAF	1979
Bethlehem Steel Co - Johnstown Penns	USA	35 kV	125 (125) Mvar	EAF	1979
EPRI Contract - Butte Montana	USA	12 kV	9 (9) Mvar	Power Quality SVC	1979
Halyvourgia Thessalias - Volos	Greece	15 kV	25 (25) Mvar	EAF	1978
ESKOM - Ferrum	South Africa	132 kV	30 (30) Mvar	Utility	1978
SSPB - Slite	Sweden	6 kV	10 (10) Mvar	Rolling mill	1978
Publ Serv of New Mexico - Farmington N Mex	USA	11 kV	30 (30) Mvar	Utility	1978
AEP - Beaver Creek	USA	138 kV	250 (250) Mvar	Utility	1978
Lukens Steel Co - Coatesville Penns	USA	14 kV	100 (100) Mvar	EAF	1978
Florida Steel Corp - Croft N C	USA	13 kV	60 (60) Mvar	EAF	1978
Publ Serv of New Mexico - Farmington N Mex	USA	11 kV	30 (30) Mvar	Utility	1978
SNS - El Hadjar	Algeria	63 kV	42 (42) Mvar	EAF	1977
Vitkovice - Ostrava	Czech Republic	22 kV	40 (40) Mvar	EAF	1977

Customer -Project	**Location**	**System Voltage**	**Rated Power Controlled Mvar**	**Application**	**Order year**
VEB Stahl und Walzwerk - Brandenburg	Germany	30 kV	100 (100) Mvar	EAF	1977
FMI - Delta Steel I	Nigeria	33 kV	121 (121) Mvar	EAF	1977
FMI - Delta Steel III	Nigeria	33 kV	121 (121) Mvar	EAF	1977
FMI - Delta Steel II	Nigeria	33 kV	121 (121) Mvar	EAF	1977
Funasa - Guayaquil	Ecuador	27 kV	4 (4) Mvar	EAF	1976
Barata - Surabaya	Indonesia	6 kV	4 (4) Mvar	EAF	1976
EDS - Damaskus	Syria	66 kV	35 (35) Mvar	Utility	1976
Minn Power Light - Duluth Minnesota	USA	14 kV	40 (40) Mvar	Utility	1976
El Fouladh - El Fouladh	Tunisia	11 kV	11 (11) Mvar	EAF	1975
DFDSV - Frederiksvaerk	Denmark	30 kV	65 (65) Mvar	EAF	1974
DFDSV - Frederiksvaerk	Denmark	30 kV	65 (65) Mvar	EAF	1974
Outokumpu - Torneå	Finland	20 kV	47 (47) Mvar	Power Quality SVC	1974
SKF Steel - Haellefors	Sweden	33 kV	40 (40) Mvar	EAF	1974
Ameron Steel & Wire - Etiwanda Calif	USA	33 kV	65 (65) Mvar	EAF	1974
Halmstads Järnverk - Halmstad	Sweden	20 kV	35 (35) Mvar	EAF	1973
ISCOR - Vanderbijlpark	South Africa	30 kV	48 (48) Mvar	Rolling mill	1972
Smedjebackens Valsverk - Smedjebacken	Sweden	20 kV	35 (35) Mvar	EAF	1972
Auburn Steel - Auburn New York	USA	14 kV	35 (35) Mvar	EAF	1972
Norsk Jernverk - Bergen	Norway	10 kV	5 (5) Mvar	Rolling mill	1971
Domnarvets Jernverk - Borlänge	Sweden	20 kV	60 (60) Mvar	EAF	1970

Number of installations: 484 Total installed power: 69 175 Mvar