Presented at Distribution 2000 Conference,
Brisbane, Australia, November 1999

Network interconnection using HVDC Light

Authors

Anthony S Cook, TransÉnergie, Australia Pty. Ltd, Brisbane, Qld., Australia 4000

Mike Wyckmans, ABB Transmission and Distribution Limited, Vic 3140, Australia

Lars Weimers, ABB Power Systems, HVDC Division, SE-771 80 Ludvika, Sweden

Kjell Eriksson, ABB Power Systems, HVDC Division, SE-771 80 Ludvika, Sweden

Abstract

The HVDC Light is an electric power transmission technology for small and medium size transmissions. This technology is well suited for connection of networks that otherwise are difficult or impossible to interconnect. Accurate control of the transmitted active power and independent control of the reactive power in the connected ac networks contribute to this as will be exemplified.

HVDC Light is designed as standard units between 5 and 150 MW and are built in movable housings. This together with the above technical characteristics make them suitable for power exchange as a business concept and even opens up possibilities for leasing of transmission units.

Keywords

Transmission, HVDC Light, deregulation, electricity market, controllability.

1.0 Introduction

Governments world-wide are increasingly using competition in the electricity industry as a means of achieving cost effective outcomes, and the Australian National Electricity Code constantly stresses the importance to the National Electricity Market of competitive, market-oriented outcomes. However, while competition in the generation sector is now well established, to date the achievement of market outcomes in the provision of network services has been ignored or neglected. This situation is largely due to outdated assumptions regarding economies of scale and scope and the inevitability of loop flow. These assumptions have hindered the deployment of advanced technologies, including HVDC Light. Such technologies will greatly facilitate market-driven network services, and over time will produce the same effects in the network sector that the introduction of gas turbine and combined cycle technology has produced in the generation sector, where competition is now taken for granted.

This paper first reviews the historical role of network services. It then outlines how competitive power markets have changed that role, and the basis for competition in the provision of network services. The HVDC Light technology is described in some detail. The part that technologies such as HVDC Light will play in the development of competitive network services is discussed. The discussion is illustrated through the Directlink project, which is based on the HVDC Light technology.

2.0 The Provision and Role of Network Services

The introduction of competitive power markets has added considerable complexity to the provision of network services and thereby changed the fundamental role of network services.

Historically, the role of the vertically integrated utility was to plan the development of the power system for reliable and secure operation. In that regulated environment the utility planned both new generation and network services. New generation was designated as base load, intermediate or peaking plant, based on its position in the merit order. With the level of operation of each generation facility known in advance with reasonable certainty it was relatively straightforward for the utility to provide sufficient network capacity consistent with that level of operation.

With the advent of competition in the generation sector Independent Power Producers (IPPs) plan new generation facilities in response to market forces. In such an environment the network service provider has little or no information regarding the location or level of operation of generation facilities, and therefore the required level of network service. To further complicate matters the required level of network service is a random variable determined by the power market in response to generator bids.

The role of network services has also changed as a result of the introduction of competitive power markets. Whereas historically the role of network services was to play a passive role transporting power from generation facilities to the load center, network services are now seen as actively competing with generation. The debate over the South Australia New South Wales Interconnection (SANI) is a good illustration. If SANI was to be constructed remote generators in New South Wales would have direct access to the South Australian market, and be able to compete with local South Australian generators to supply the South Australian load. In that case SANI is equivalent to a 'virtual generator' located in South Australia.

The basic issue with SANI was who should pay for new network services. That is, should generators receive the benefits of access to the South Australian market at no cost, while consumers receive little or no benefits but incur the bulk of the costs? A related issue is whether network service providers should receive essentially risk free regulated returns on investments that are competing in the energy market.

The Australian response to these issues has been to further examine the competitive provision of network services.

3.0 Competition in Network Services

The National Electricity Code defines both 'regulated'and 'non-regulated' network services.

Provided the network service is 'justified' under the terms of the Code, the owners of a regulated network service receive a fixed, annual revenue from their investment. On the other hand the owners of a non-regulated network service must earn their revenue in the market by charging market participants who use that network service. Non-regulated network services do not need to be justified under the Code.

As a first step in the provision of competitive 'non-regulated' network services the National Electricity Code Administrator (NECA) developed the Safe Harbour Provisions for Entrepreneurial Interconnectors (SHPs). The SHPs recognise that network services do not just play a passive role transporting power, rather that they can actively participate in the power market.

The SHPs define the conditions under which network services can compete in the power market. The SHPs as presently drafted are quite restrictive, and should be treated as only the first step towards competitive network services; it is NECA's intention to further expand the SHPs. In order to meet the SHPs a network service must satisfy a number of conditions, including:

- The service must comprise a single two-terminal element of at least 30 MW capacity that directly connects networks in different price regions.
- The flow through the service must be independently controllable if the service forms part of any network loop.
- The service manager will be required to pay for identifiable services dedicated to supporting the use of the service.

In return for satisfying these conditions the network service owner can become an active player in the spot market in competition with other links (either regulated or non-regulated) and supply and demand-side alternatives. The principle source of income for the owner of a non-regulated network service is the spot price differential between the terminals. Other potential revenue sources arise through the deferment of the installation of regulated network services, and the provision of ancillary services.

The Directlink project being developed jointly by the New South Wales distributor NorthPower and the Canadian utility Hydro-Quebec will be the first non-regulated network service. The HVDC Light technology ensures that Directlink will satisfy NECA's Safe Harbour Provisions.

4.0 What is HVDC Light ?

HVDC Light is a DC transmission technology which consists of two elements: converter stations and a pair of cables. The converter stations are voltage source converters (VSCs) employing state of the art turn on/turn off IGBT power semiconductors. No communications links are required between the converter stations In addition HVDC Light does not rely on the AC network's ability to keep the voltage and frequency stable. This gives additional flexibility regarding the location of the converters in the AC system.

HVDC Light systems are designed for capacities of up to 150 MVA and for DC voltages up to ±150 kV. A 65 MVA station employs a +/-80 kV voltage.

The HVDC Light design is based on a modular concept with a number of standardised sizes. Most of the equipment is installed in enclosures at the factory, which makes the field installation and commissioning short and efficient. The standardised design allows for delivery times as short as 12 months.

Fig. 1
Preinstallation of Gotland HVDC Light

The stations are designed to be unmanned and are virtually maintenance free. Operation can be carried out remotely or could even be automatic based on needs of the interconnected ac networks.

Maintenance requirements are determined by movable equipment eg the conventional ac breakers and the pumps and fans in the cooling system.

The HVDC Light technology itself is designed to be environmentally friendly. Since power is transmitted via a pair of underground cables there is no visual impact, no ground current and the electromagnetic fields from the cables cancel each other.

The stations are compact and need little space (a 65 MVA station occupies an area of approx. 800 sq. metres). The appearance can easily be adapted to local environmental requirements.

In addition, HVDC Light is a technology that offers the possibility of replacing polluting technology (eg diesel) by environmentally friendly energy over the transmission network.

Fig. 2
Ploughing of cable, normally at a depth of 50-70 cm.

4.1 HVDC Light Cables

The HVDC Light extruded cable is the outcome of a comprehensive development program, where space charge accumulation, resistivity and electrical breakdown strength were identified as the most important material properties when selecting the insulation system. The selected material gives cables with high mechanical strength, high flexibility and low weight. Extruded HVDC Light cables systems in bipolar configuration have both technical and environmental advantages. The cables are small yet robust and can be installed by ploughing, making the installation fast and economical.

5.0 HVDC Light Characteristics

5.1 Controllability

The HVDC Light converter station output is determined electronically by control of a high frequency, kHz range pulse width modulation (PWM). Control of the PWM makes it possible to create any phase angle or amplitude within ratings. Control signals to a converter can almost instantaneously change the output voltage and current to the ac network. Operation can take place in all four quadrants of the real - reactive power plane i.e. active power transmission in either direction can be combined with generation or consumption of reactive power.

From the system viewpoint an HVDC Light installation corresponds to an electrical machine without inertia. It can operate as a generator or motor and be changed between these states.

These features mean that active power can be controlled to match the changing needs of a consumer or distributor (by power order changes or by frequency control). Power can also be controlled to match an agreed power contract.

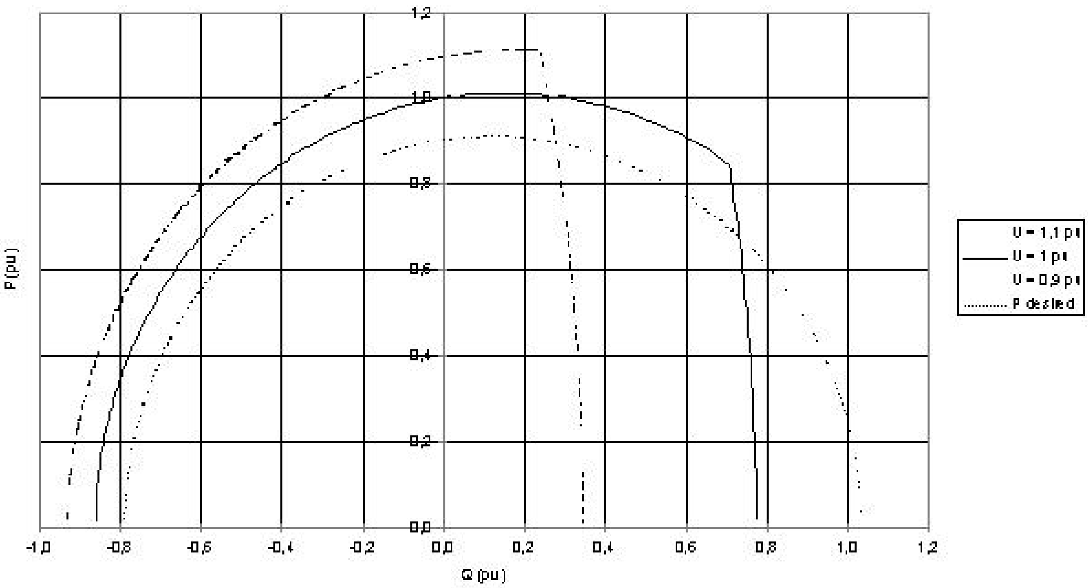

Fig. 3
PQ diagram, station 1, rectifier

5.2 Reactive power support and control

Reactive power generation and consumption of an HVDC Light converter can be used for compensating the needs of the connected network within the rating of a converter. As the rating of the converters is based on maximum currents and voltages the reactive power capabilities of a converter can be traded against the active power capability. The combined active /reactive power capabilities can most easily be seen in a P-Q diagram (positive Q is fed to the ac network).

5.3 Power Quality

The reactive power capabilities of HVDC Light can be used to control the ac network voltages, and thereby contribute to an enhanced power quality.

In the presence of a fault which would normally lead to an AC voltage decrease the converter can be rapidly deblocked and assist with voltage support to avoid severe disturbances in local industries that are sensitive to voltage dips.

The response time for a change in voltage is 50 ms ie for a step order change in the bus voltage the new setting is reached within 50 ms. With this speed of response HVDC Light will be able to control transients and flicker up to around 3 Hz, thereby helping to keep the AC bus voltage constant.

6.0 Experience to Date

6.1 Operational Experience and Marketing

The operational experience to date is based on results from two projects viz

- the Hellsjön 3 MW demonstration project, which has been in operation since March 1997, and
- the 65 MVA Gotland project, which was commissioned in July 1999.

Performance to date is as expected; the test results show that HVDC Light is a transmission technology that has come of age.

The market response for HVDC Light since it was introduced in May 1997 has been enormous; thus far 3 HVDC Light and 3 SVC Light contracts has been awarded to ABB.

One of the driving forces behind the interest in HVDC Light is the worldwide deregulation of electricity markets. HVDC Light is suitable for projects up to 200 MW and has a competitive edge with short delivery times and the simplified permitting process since cables are used instead of over-head lines.

Table 1

HVDC Light and SVC Light projects

Project	Size, MVA	Distance, km	In service
Hagfors	22 (0-44 MVAr)	N/A	99-05
Gotland	60	70	99-07
Directlink	180	65	99-12
Tjæreborg	8	4	00-03
RWE Energie	19 (0-38 MVAr)	N/A	00-06

7.0 Applications

HVDC Light can be employed to best advantage in the following circumstances.

- Supply of isolated loads
  That is, supply to a distant town, mine or island or even a production platform in the sea needing power from the mainland.
- Asynchronous grid connection
  A connection between two networks with different frequencies. An asynchronous connection can also be used to safeguard the power quality of a sensitive load.
- Infeed of small generation
  HVDC Light can be used to transmit power from isolated generation to a grid or to a separate load. Such infeed could be from wind, hydro, tidal, solar etc without affecting the power quality of the receiving network.

- DC grids
  HVDC Light is an excellent component for multi-terminal connections, paralleling and for constructing dc grids.

Two important features of HVDC Light are:

- the ability to transmit power over a long distance with a complete underground connection, and
- the controllability of reactive power individually for the two converter stations combined with active power control. This gives power quality advantages.

Fig. 4
Directlink map

8.0 Directlink

Directlink is a 180 MVA HVDC Light project that will link the regional electricity markets of New South Wales and Queensland. Directlink will be a non-regulated project, operating as a generator by delivering energy to the highest value regional market. By directly participating in the spot market Directlink will earn a market-based return for its owners. That return could include substantial revenues during periods of scarcity in either Queensland or New South Wales, when the market clearing price could rise to as much as $5,000/MWhr.

Some of the Directlink capacity may be sold through financial hedging instruments eg capacity rights. These instruments would shift risks and returns between the project's owners and users, permitting both parties to better hedge their financial profile.

Directlink employs the HVDC Light technology, the development advantages of which include:

- In order to facilitate permitting the HVDC Light cable will be installed along existing rights of way for its entire 65 km route, with a substantial portion underground.
- The flow of energy over HVDC Light facilities can be precisely defined and controlled, thereby meeting NECA's Safe Harbour Provisions. The ability to control power flow over the facility also means that the capacity rights required for fully commercial network service are readily defined.
- The Voltage Source Converter terminals can act independently of each other to provide ancillary services (such as var support) in the weak networks to which Directlink connects.
- The use of the HVDC Light technology will greatly reduce the Directlink construction and commissioning period. Rapid response to market conditions must be a feature of market-driven transmission projects.

9.0 Conclusions

It is widely recognised that the role of network services has changed as a result of the introduction of competitive power markets. HVDC Light is a new DC transmission technology that has important advantages for application in competitive markets. These advantages include its modularity, standardised design leading to short delivery times, and compact stations and cables reducing environment impacts and controllability giving possibilities to match the power need and/or to control the voltage in the network. These features mean that HVDC Light facilities can be installed quickly in response to competitive market signals.

10 References

[1] Asplund, G, Eriksson, K, Svensson, K: "DC Transmission based on Voltage Source Converters", Cigré SC14 Colloquium on HVDC and FACTS in South Africa, 1997.

[2] Asplund, G, Eriksson, K, Drugge, B: "Electric power transmission to distant loads by HVDC Light", Distribution 2000, Sidney, Australia, 1997.

[3] Asplund, G, Eriksson, K, Jiang, H, Lindberg, J, Pålsson, R, Svensson, K: "DC Transmission Based on Voltage Source Converters", Cigré Conference, Paris, France, 1998.