

# **USE OF HVDC MULTI TERMINAL OPTIONS FOR FUTURE UPGRADE OF THE NATIONAL GRID**

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## 1 The Multi-terminal HVDC options

Conventionally, High Voltage Direct Current (HVDC) transmission is used for the efficient transmission of electricity from one point to another, using an ac/dc converter at each end of the link. It is possible to design a HVDC transmission system with more than two terminals (i.e. a Multi-terminal Link) provided that ac/dc converters are installed at all terminals. The viability of multi-terminal HVDC transmission or distribution largely depends on the technology employed in the conversion process.

We are in a transition period between the long serving Line Commutated Conversion (LCC) technology and a fast developing Self-Commutating Conversion alternative. The new technology offers much greater flexibility for multi-terminal HVDC, but has some limitations in its application to high voltage bulk power transmission. I will start by briefly presenting the main differences between the conventional and new conversion alternatives.

### 1.1 Conventional Current Source Conversion(CSC)

Conventional HVDC Transmission uses the CSC concept, whereby the dc current flow is unidirectional and the power direction is changed reversing the dc voltage. It suits the thyristor switch and is still the only practical solution for large power transmission. The Cook Strait link, was one of the pioneering schemes based on the CSC principle and has been a considerable technical and financial success. This was to be expected considering the factors that led to the need of an inter-island link.

The extension of the CSC technology to multi-terminal HVDC has been discussed for over four decades, the interest peaking in the 1980's, both by academic researchers and the power industry. However, only one fully multi-terminal scheme was constructed for commercial operation. Its object was to convert the Hydro-Quebec-New England link (commissioned in 1986) into a five terminal scheme with the addition of three further terminals. However, the original two terminal link (between Des Cantons and Comerford) was never integrated into the multi-terminal DC network because of anticipated performance problems. No other (higher than three) multi-terminal scheme has been considered since then based on the CSC technology. Accepting that three terminals is the only practical multi-terminal option, when at the planning stage a third terminal extension is to be made in the future, this must be taken into account in the initial cost comparison between the ac and dc alternatives, because the tapping is equivalent to reducing the transmission distance, which makes the dc solution less competitive.

Normally the power rating of a proposed third terminal tap is relatively small compared with the main transmission link and, therefore, the high transmission

voltages of the bipolar interconnection will require expensive converter equipment for a parallel connected third terminal. To try and reduce the cost, consideration has been given to the use of series, rather than parallel, tapping of the additional terminal. There have been many contributions on the series tapping concept to show that it is technically feasible, but none has been built so far.

A recent variation of the conventional CSC technology is Capacitor Commutated Conversion (CCC), a configuration based on the use of series capacitors on the converter ac side. This addition practically eliminates the need for reactive power compensation and reduces the risk of commutation failures. These features are very attractive for a third terminal extension, as the latter will normally operate as an inverter and feed a weaker ac system. CCC fits easily with existing converter arrangements, such as those of the inter-island link. The CCC technology has already been implemented in the 1000 MW Garabi interconnection between Argentina and Brazil, commissioned in the year 2000.

## 1.2 Self-commutating Voltage Source Conversion (VSC)

The availability of self-commutating power semiconductors has in the past decade permitted the development of a more controllable VSC Transmission technology, where the dc voltage is unidirectional and the change of power direction implemented by dc current reversal. Commercially developed by ABB under the name of HVDC Light, this technology is already used in seven schemes (two of them, the Direct and Murray links, in Australia). The converters use transistor-type switches (IGBTs) and operate under Pulse Width Modulation (PWM) control, a technique that provides an almost sinusoidal ac terminal voltage, fully controllable in magnitude and phase and, therefore, permits independent control of the reactive power at each terminal. While these conditions are perfectly suited to multi-terminal DC, the use of low level (two or three levels) and high frequency conversion implemented by transistor switches imposes severe limitations on the transmission voltage (which is currently limited to 150 kV) and are, thus, unlikely to replace the present thyristor technology for large power transmission. Its dependence on cable transmission is a further severe limitation, both in terms of cost and reliability (the operation of the Direct Link in Australia has been restricted due to the number of cable joint faults). The vulnerability of the transistor valves to large voltage surges on the one hand and the difficulty of clearing dc short circuits on the other (as the diodes continue conducting the fault current until the fault is cleared by circuit breaker action on the ac side), has so far detracted from the use of overhead transmission. As a result, all the VSC multi-terminal applications being discussed relate to medium voltage dc grids interconnecting different alternative energy sources (such as wind farms, solar etc.) with local loads and the Distribution system.

## 2 Multi-terminal HVDC in New Zealand?

The state of VSC development (explained in the previous section) is unlikely to permit the power ratings required for the reinforcement of the New Zealand grid at this stage and, thus, if the multi-terminal concept is to be considered, it will have to be based on the present CSC thyristor technology.

However, as pointed out in earlier sections, multi-terminal HVDC is likely to be restricted to three terminals. Therefore, considering the flexibility required in future grid expansion, the latter is likely to be in the form of AC transmission lines. If multi-terminal HVDC is to be used for power transmission in the New Zealand National Grid it should be limited to a very small number of purpose built links. Some likely examples are discussed in the following sections.

### 2.1 South Island

The existence of dc transmission in the South Island provides the base for a possible multi-terminal development and, therefore, the addition of a dc tap to Christchurch is an option. However, as explained in (1.1) above, the following issues need to be addressed and satisfactorily resolved if this option is to be implemented:

- The power involved should be sufficiently high to justify the cost of conversion at  $\pm 350$  kV for the Christchurch terminal.
- The requirement of dc switching equipment to swap the Christchurch poles during power reversals between the two main converter stations.
- The requirement of dc switching equipment for isolation of dc faults (to disconnect the faulty feeder following disturbances) to reduce the impact of a fault on power transmission between the healthy terminals.
- The reduction in the level of power that can be transferred to the North Island.

Another example relates to the possible use of coal power generation in the south of the island to transmit power to the Auckland region. The transmission system could be built as a three terminal link, tapped either at Christchurch, as an alternative to the solution discussed above, or at Haywards. Since the generation would not be hydro based, and the link would be dedicated to Auckland, this alternative is not affected by the dry year constraint and can be considered “firm”, subject, of course, to the availability of the generation plant.

### 2.2 North Island-With reference to the existing dc link

Consideration has already been given to a possible non-multi-terminal solution, in which one of the poles would bypass Hayward and a new single pole line built to the North, but the low reliability of supply by the single pole is likely to be unacceptable.

In the absence of dc transmission in the North Island there is less justification for the development of multi-terminal dc of the conventional type. There is the possibility of extending the present HVDC scheme north as a multi-terminal link, with a tap at Haywards for the Wellington region. However, if the three terminal constraint is to be respected, that would prevent a similar tap to Christchurch in the South. Presumably the rating of the Wellington tap would also be relatively small and the comments made for the Christchurch link would apply equally here. Further, extending the existing HVDC link to Auckland is unlikely to provide the required supply security to the Auckland area during the dry years in the South Island.

### **2.3 North Island- With reference to the Whakamaru-Otahuhu connection**

None of the reasons favouring the use of conventional dc transmission appear to apply to this interconnection. The distance is short (and would be even shorter if an intermediate third terminal was considered), the frequency and frequency control are common to both terminals as they are both part of a common grid, etc. The financial benefit of a potential staged development of a dc bipolar scheme over an alternative 400 kV ac line is probably overstated. The main saving in this respect would be the cost of the second stage converters, as the complete transmission system, whether ac or dc, would presumably be constructed in the first stage to reduce the transmission losses. Regarding the ac options, the transmission efficiency would be substantially better in the case of a 400 kV ac system with respect to the continuation of the 220 kV transmission, because the power losses reduce in proportion to the square of the voltage. The transmission efficiency of the 400 kV line would be comparable to that of the single pole 350 kV dc link alternative. Moreover the development of the 400 kV ac system could also be staged, by installing only half rated transformers at the initial stage. This would have the added benefit of halving the cost of the spare transformer capacity needed for supply reliability. Thus the adoption of a three terminal dc link of the conventional type for the Whakamaru-Auckland system would be a very costly solution with limited flexibility for future transmission expansion.

On the other hand, as has been explained above, the more flexible PWM multi-terminal alternative is not really a contender for the large power rating involved. Apart from the components (particularly the cable) costs, the switching (due to high frequency) and transmission (due to the high current) losses would be extremely high.

## **3 Suggested approach to future HVDC developments**

As explained earlier we are at a point of considerable change in the DC Transmission technology. Heavy investment in IGBT (transistor based) technology is currently favouring this device at the expense of the IGCT (thyristor based) alternative. For high voltage applications, however, there are still problems with the IGBT due to stray inductances and diode reverse recoveries and, thus, at

this stage it is not clear to what extent the fast switching capability can be exploited, as the resulting voltage spikes may exceed the allowable limits. The commonly used argument that the IGBT will eventually catch up with the ratings of the thyristor types appears to have no foundation, because the latter are also continuing to improve.

I do not think that the PWM IGBT VSC technology will eventually compete in the high voltage and large power transmission area. The future of large power HVDC transmission is likely to continue being point to point and thyristor based, but not necessarily restricted to Line Commutated or Voltage Source Conversion. The continued development of a PWM technology for larger voltage and power ratings is being strongly challenged at the moment, with many alternative proposals in the form of efficient multi-level converter configurations, both of the VSC and CSC types based on self-commutating thyristor switches. These configurations are gradually simplifying their structure and increasing their control flexibility. Our team at Canterbury is very much at the centre of these developments (an indication of our credibility in this respect is the award by the IEE last year of the 2004 Generation, Transmission and Distribution prize for our paper entitled 'Multilevel voltage re-injection- A new concept in high voltage source conversion').

New Zealand's previous commitment to dc (with the Cook Strait scheme), was an obvious decision, as there was no practical economic ac alternative at the time. However, the case for further dc, and particularly the multi-terminal option, is far from obvious at the moment and I would suggest a prudent "wait and see" policy in this respect.