Submission No 235

INQUIRY INTO FEASIBILITY OF UNDERGROUNDING THE TRANSMISSION INFRASTRUCTURE FOR RENEWABLE ENERGY PROJECTS

Organisation: Amplitude Consultants

Date Received: 14 July 2023

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14 July 2023

The Hon Emily Suvaal
Committee Chair,
Parliament of New South Wales

RE: Inquiry into the feasibility of undergrounding the transmission infrastructure for renewable energy projects

Dear Ms. Suvaal,

I thank you for the opportunity to present this submission to the Inquiry into the feasibility of undergrounding the transmission infrastructure for renewable energy projects, as detailed in the Terms of Reference which was adopted on 22 June 2023.

Background of Author

My background and experience in relation to long distance HVDC transmission projects is summarised in the bio provided in Attachment 1.

I am the co-founder and Managing Director of Amplitude Consultants Pty Ltd, an Australian-based engineering consulting company that provides specialist consulting services to clients involved in the transmission and distribution of electricity. Our key areas of expertise are in the fields of HVDC power transmission, high voltage land and submarine cables, power electronics and Flexible AC Transmission Systems (FACTS), AC power transmission and distribution and renewable energy project connection. Amplitude has established offices in Brisbane, Darwin, Singapore and Wellington (New Zealand) and close to 40 staff. One of the specialty areas we are well known for is our experience and expertise in long distance HVDC projects – our nine-person HVDC team, based in Australia, New Zealand and Singapore can boast almost 90 years of experience in HVDC and power electronics projects, with projects completed or currently underway in Australia, New Zealand, USA, Canada, China, South Africa and Mozambique.

In my own experience, I have worked almost exclusively on HVDC, power electronic and high voltage cables for the last 24 years of my 30+ year career. This includes roles during the design, manufacture, construction, commissioning and operation of both the HVDC converters and the underground and/or subsea cables for Directlink (NSW), Murraylink (Victoria/SA), Basslink (Victoria, Tasmania) and Trans Bay Cable (California, USA), and leading recent concept and early development activities for HVDC projects under development in Australia. Most recently, I have led a number of AC vs HVDC and overhead vs underground engagements, including the development of up-to-date cost estimates, for proposed transmission lines in Australia, including proposed alternatives to AC overhead transmission and grid connection options for proposed offshore and remote renewable energy projects. I have led a number of international working groups with CIGRE and IEC on the topic of HVDC transmission.

HVDC Cables and Australia – Historical Context

It is important to understand Australia's role in the early development of voltage source converter (VSC) and HVDC polymer cable technology.

There are effectively two main types of HVDC converter technology in use today – line commutated converters (LCC) and voltage source converters (VSC). LCC converters utilise thyristor valves as the main power electronic switching device to achieve the conversion between AC and DC (and back again). VSC converters are self-commutating, meaning they switch on and off insulated gate bipolar transistors (IGBTs) to build or generate AC and DC waveforms. These technologies have various pros and cons, however without going into detail, I am of the view that it is highly likely that the HVDC technology selected for any transmission project in Australia will be VSC technology. This is mainly because VSC systems can operate and perform better under relatively "weak" (or weakening) AC network conditions, can provide "grid firming" support and can provide fast reactive support services to the AC networks.

With the development of the VSC technology, it became possible to utilise polymer underground or subsea cables, similar to the AC XLPE cables that are in use throughout Australia today, on these projects. These cables can be lighter, easier to install and can tolerate higher conductor temperatures – meaning that more power can be transmitted for the same size cable than other HVDC cable technologies in use.

A lot of people are unaware that one of the very first VSC and HVDC polymer cable systems commissioned in the world was the Directlink HVDC system between Mullumbimby to Terranora, both in NSW. This system is nominally rated at 180MW and has a route length of approximately 56 km. I was the deputy project manager, project engineer and commissioning engineer for the owners during the design, construction and commissioning of that project and I know that the primary reason for adopting the new HVDC technology and using cables was because of the difficulties that would be faced to connect an overhead transmission line between these locations, due to terrain, environmental and public opposition concerns. We were able to find a route for the cables using a combination of private land, existing rail corridor and road reserve. The project was installed and commissioned successfully over 23 years ago and remains the first interconnector in the world to utilise the new (at the time) VSC and HVDC polymer cable technology.

Shortly after the success of the technology on Directlink, the Murraylink project commenced. This was specified as a 220 MW interconnector between Red Cliffs in Victoria and Berri in South Australia, utilising VSC and HVDC polymer technology (higher power and voltages than Directlink) for a route length of approximately 180 km. The project was put into service in 2002, almost 21 years ago. The VSC technology and underground cables were selected mainly due to concerns in getting approvals for overhead transmission lines through the Murray-Sunset national park. We found a route mostly utilising road reserve and some private land and staying within a 4 m construction corridor. Horizontal directional drilling was employed for particularly environmentally sensitive areas, including the Murray River and the Lyrup Flats. The impact on the environment was so minimal that the project won a Case Earth Award in 2002, under the category of "environmental management of construction projects – covering measures taken to minimise environmental impacts during the construction phase of a project'. This outcome contradicts many claims that underground cable projects have a greater adverse impact on the environment.

As a younger engineer at the time, I remember thinking how this technology could revolutionise long distance power transmission, with the potential to reduce if not eliminate the need for large high voltage transmission lines and towers and allow the transmission network to develop with minimal impact on communities and the environment. I was also very proud that Australia was leading this technology development and setting a new benchmark for the rest of the world to follow. That was over 20 years ago, and very little else of its kind has been done in Australia since.

One key takeaway from both Directlink and Murraylink is that for long distance underground cable projects, innovation can be applied to select a route and to work within a construction corridor, even though it may appear challenging. In recent years, I have seen long distance underground projects assessed and costed based on construction methods applied to shorter cable installations in built up areas, which do not take into account such innovations that can be applied.

Meanwhile, other countries have observed these early projects, and other projects that came shortly after and, with vendors developing the technology to improve performance, have adopted the VSC HVDC/polymer cable technology for many of their recent long distance transmission projects.

Comparison of AC and HVDC Technology

There are pros and cons with the use of both AC and HVDC technology for high power transmission interconnection. The best technology to select is often dependent on the specific application. The selection of voltage source converter (VSC) technology would be likely for most applications in the NEM, due to anticipated lower system strength, mostly because of the increase in inverter-based renewable energy generation. Table 1 provides a high-level comparison of AC and VSC HVDC technologies for the purpose of power transmission. Colour coding is provided as a visual indication only – green means a pro/benefit and red means a con/disadvantage.

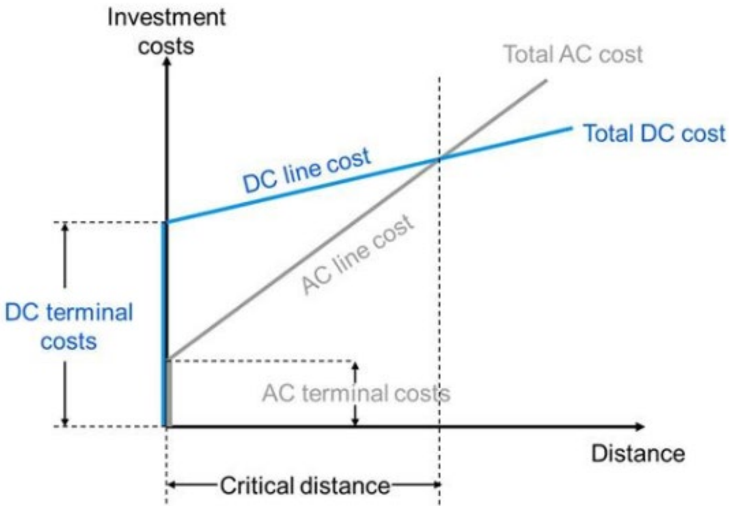
Table 1 - Comparison of AC and HVDC Power Transmission Technologies

Parameter	AC	VSC HVDC
Controllability	Low	High
Losses – Substation/Converters	Lower	Higher
Losses – Lines/Cables	Higher	Lower
Inherent Voltage Support Capability	Not available	Available
Underground Cable Capability	At a distance >50km and at higher voltage, requires substantial reactive compensation along the route	No practical limit on distance, fewer cables
Tap Off Points Along Route	Unlimited, relatively low cost	Limited to a few, high cost
Substation/Converter Station Footprint	Smaller	Larger
Overhead Line	Larger towers	Smaller towers
Easement Width for Overhead Lines	Larger	Smaller
Visual Impact of Overhead Lines	Greater	Lesser

From Table 1, it can be seen that VSC HVDC transmission has a number of technical advantages over AC transmission, including controllability, lower losses on the transmission lines, inherent voltage support capability and no need for reactive compensation stations for underground cables. Conversely, AC transmission will have lower losses in the terminals (substations), relatively easier/less expensive to tap in along the route and a smaller footprint for the substation. Compared to AC options, VSC HVDC transmission can be superior in terms of environmental impact and aesthetics because the use of underground cables becomes more viable.

In general, the total cost per MW of an HVDC interconnector becomes more economical against an AC option as the route length of the interconnector increases. This is often represented generically in the form of a set of curves, with one example shown in Figure 1. This curve shows the relatively high terminal and converter cost versus the relatively lower AC substation cost. However, the gradient of the lines in this graph indicates that the cost per kilometre of the transmission circuits (overhead lines or cables) is generally much less for HVDC systems than for AC. This is due mainly to the physically smaller towers, sub-components and easement required for the same MW level of power transmission. Where these intersect is the "breakeven" or "critical" distance, beyond which the cost of HVDC transmission becomes more economical.

Figure 1 - Comparison of AC and HVDC cost vs Distance[1]



The determination of the critical distance depends on many factors of the particular project, including HVDC technology, HVDC configuration, power transfer and DC voltage level. Also, this comparison really only works when comparing two overhead options or two underground options (i.e., not one overhead option versus an underground option). For overhead transmission lines, this breakeven distance can be many hundreds of kilometres. Comparing HVDC and AC underground options, this distance can be less than 100 km.

[1] Image from www.medium.com/predict/future-of-electricity-transmission-is-hvdc-9800a545cd18

Comparison of Underground and Overhead Transmission Systems

In June 2021, Amplitude published a report for the Moorabool Shire Council, titled "Western Victorian Transmission Network Project, High-Level HVDC Alternative Scoping Report". This report is available in the public domain[2].

In this report, Amplitude was asked to assess various impacts for the four potential transmission options, namely:

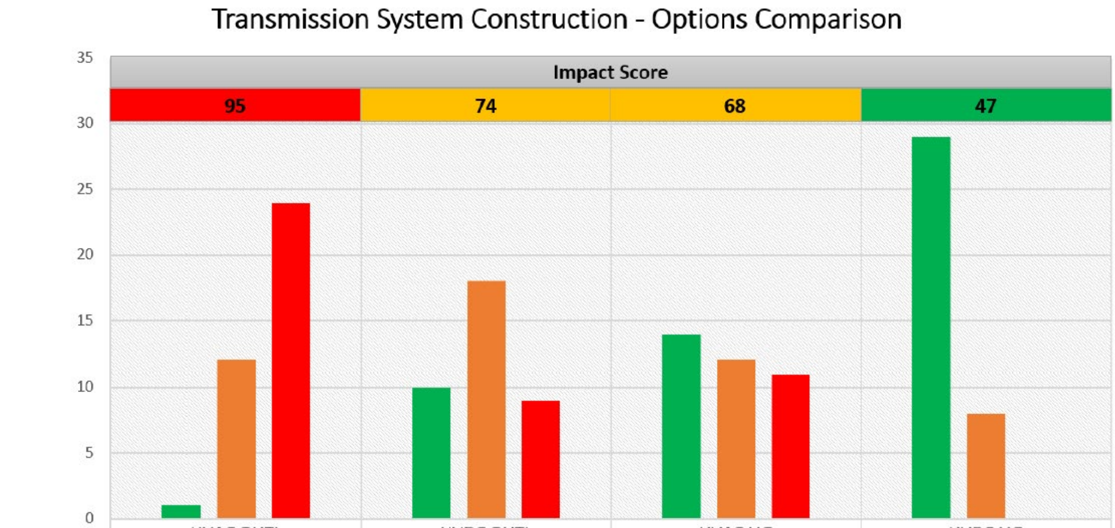
- AC overhead transmission (HVAC OHTL);
- HVDC overhead transmission (HVDC OHTL);
- AC underground transmission (HVAC UG); and
- HVDC underground transmission (HVDC UG).

A total of thirty-seven criteria were provided for assessment, which included broad topics such as land disturbance, environmental impacts, land use, technical and various risks. The outcomes are presented in Appendix B of the report. For each criterion, some commentary is provided in that report for each of the four options, and the four options were ranked – green (1) being the best performance of the four options, red (3) the worst performance and orange (2) for those options in the middle. This traffic light and numbering systems allows for some high-level view of overall performance of each of the four options to be presented as shown in Figure 2.

While we understand that the commentary and the assignment of colours and numbers can be arbitrary, the figure presented here shows a divide between AC overhead options and HVDC underground options in terms of these criteria and impacts on the topics covered by these criteria. HVDC underground options scored the highest (best performing) in 29 out of the 37 criteria, whereas AC overhead transmission scored the highest only one time. Conversely AC overhead transmission scored the worst in 24 out of the 37 criteria, whereas the HVDC underground did not score the worst in any of the criteria.

[2] https://www.moorabool.vic.gov.au/files/content/public/about-council/large-projects-impacting-moorabool/western-victoria-transmission-network-project-western-renewables-link/wvtnp-high-level-hvdc-alternative-scoping-report.pdf

Figure 2 – Comparison of HVDC and AC, Underground and Overhead Transmission for Select Criteria



	HVAC OHTL	HVDC OHTL	HVAC UG	HVDC UG
Low	1	10	14	29
Moderate	12	18	12	8
High	24	9	11	0

Assessments such as these remain critical when assessing the viability of underground cables for transmission projects in Australia. There are certain applications where such an assessment should be taken into account and where the use of HVDC underground cables may prove to be the best outcome for the project. However, I understand that this is not the case for every application.

During recent work, we have been made aware of the use of "triple bottom line" assessments. These assessments focus on social, environmental and financial factors. The cost of transmission projects in Australia are only assessed on one of these three factors i.e., financial. PwC UK published the outcomes of one example of the application of the triple bottom line approach on a proposed new transmission line in the UK[3]. A few quotes from this document relevant to this discussion are provided below:

- "*We found that the biggest negative impacts from the line were from its impact on the landscape, on local historic sites and on local tourism. And, that these impacts would all have been even bigger if the original plan had gone ahead – particularly the impact on landscape*."
- "*We found that the impacts on landscape and historic sites, which were avoided by re-routing or undergrounding the line, or dismantling other lines nearby, were valued the most by people*."

The report determined that the value to society (value of social, environmental and economic benefits) for each 1 GBP spent on mitigation measures, was between GBP 2.90 and GBP 3.70.

It is my view that this type of assessment should be applied to transmission projects in Australia.

[3] PwC UK Report, "Accounting for the triple bottom line of capital projects. How a major energy provider values its total impact" located at https://www.pwc.co.uk/sustainability-climate-change/assets/sse-accounting-for-triple-bottom-line-capital-projects.pdf

Addressing Concerns Raised on Underground Cables

As previously mentioned, I have been involved in a number of AC vs HVDC, overhead vs underground assessment projects over the past few years, and therefore have been heavily involved in the detailed comparison of the relative pros and cons and the cost to manufacture, install and commissioning HVDC and AC underground and subsea cables in Australia. The following summarises my views based on this experience, and my experience in key roles for every HVDC long distance underground cable project installed in Australia.

The following information is provided to address some statements about underground cables that I have read or heard in the media or elsewhere in the public domain, which are mostly negative towards underground cable projects.

HVDC Underground Projects Are Not "Ten Times the Cost" of The AC Overhead Equivalent

A statement I have seen and heard many times is that undergrounding power transmission projects costs more than ten times the AC overhead lines. I expect that the genesis of such a statement is likely based on early work comparing AC overhead transmission with AC underground transmission. However please note that:

1. AC underground cables require reactive compensation (large reactors) to operate and the higher the voltage of the cable and the longer the distance, the greater these requirements become. At the AC voltage levels required for high-power transmission (e.g., 330 kV or 500 kV), at certain distances along the route, reactive compensation stations may need to be installed. All of this increases the overall cost of the underground cable option. <u>HVDC underground cable projects do not require any reactive compensation.</u>
2. For the equivalent level of power transfer, an AC underground cable option would require significantly more cables to be installed than the HVDC underground cable equivalent, which increases the total amount of cable as well as the number and width of cable trenching required.
3. As mentioned previously, underground cable projects can be costed based on short length cable projects in built up areas and can ignore the innovations and associated efficiencies that are typically applied to long distance projects.

From my own experiences in developing costing, and even in light of recent increases in the cost of both HVDC technology and associated underground cables, it is my view that a properly considered, long distance (i.e., greater than 200-300 km), point to point <u>HVDC underground alternative can be between two and four times the cost of an AC overhead equivalent project</u>, and this is without considering impacts of a triple bottom line assessment on the AC overhead equivalent project.

At a Certain Distance the HVDC Underground Equivalent Will Have Lower Electrical Losses

The comparison of losses for AC and HVDC options for a transmission project would look something similar to the curves shown in Figure 2. This is because the HVDC converter stations will have (relatively) higher losses than the AC substation equivalent. However, the line losses (i.e., the electrical losses along the underground cables) will be significantly lower per kilometre for HVDC than for AC. This means that at a certain distance, the loss "savings" in the cable losses will offset the additional costs in the converter stations, and beyond that lead to overall lower electrical losses for the HVDC solution.

Amplitude has presented an example comparison of the electrical losses of a HVDC underground option with the AC overhead line equivalent in the report for Moorabool Shire[4]. In this report, we demonstrate that for an equivalent 2.26 GW and 88 km transmission project, the electrical losses at maximum power for the AC overhead transmission option is three times that of the equivalent HVDC underground cable option.

Underground Cable Projects Do Not Require Two Months to Repair

I have heard it stated that underground cable projects require up to two months to repair in the event of a cable fault.

Firstly, it is important to understand that while an underground cable fault may take some time to locate and repair, the frequency of such failures will be lower than the overhead case. A properly designed and managed HVDC project of a few hundred kilometres may have one of these faults every 10-20 years, as evidenced by the performance of Murraylink (which was the world's longest underground cable for over 15 years). The HVDC system can be designed with the appropriate redundancy to manage the outage of the relevant part of the system while repairs are underway.

Based on my experience in the capacity of Operations and Maintenance manager for both Directlink and Murraylink, and setting up and preparing the appropriate emergency response plans, it is my view that for an underground HVDC project with a well written emergency response plan, key equipment such as fault locating equipment purchased and with short term availability contracts with key service providers (excavators, personnel, jointers from overseas) in place – a cable fault location and repair should take no more than a few weeks. I would expect any prudent operator to have all of these in place.

It is also often argued that cable repair jointers will need to be flown in from overseas to repair the cable and that these personnel are in high demand. While the latter is true, this statement is mostly correct for subsea cables. For land cables, it is expected that local experienced HV jointers would be trained and qualified on the new cable joints. We did this in Australia for both Directlink and Murraylink. While these are smaller cables and lower voltages, the point is when we installed these cables in the late 1990s and early 2000s, nobody was qualified in Australia to perform these joints. Knowing some of the very good Australian cable jointers and companies around, I see no reason to expect that personnel qualified on 500 kV or 330 kV AC joints could not be trained and qualified on 320 kV or 525 kV DC polymer cables.

HVDC Underground Cables Do Not "Sterilise" the Land Above Them

The topic of what having cables underground does to the land directly above them and the limitations of land use in their vicinity has been brought up recently in the media.

The reality is that once cables are installed and the land remediated (typically within months of completion of the work) – it is hard to see where the cables are. Having been directly involved in the

[4] https://www.moorabool.vic.gov.au/files/content/public/about-council/large-projects-impacting-moorabool/western-victoria-transmission-network-project-western-renewables-link/wvtnp-high-level-hvdc-alternative-scoping-report.pdf

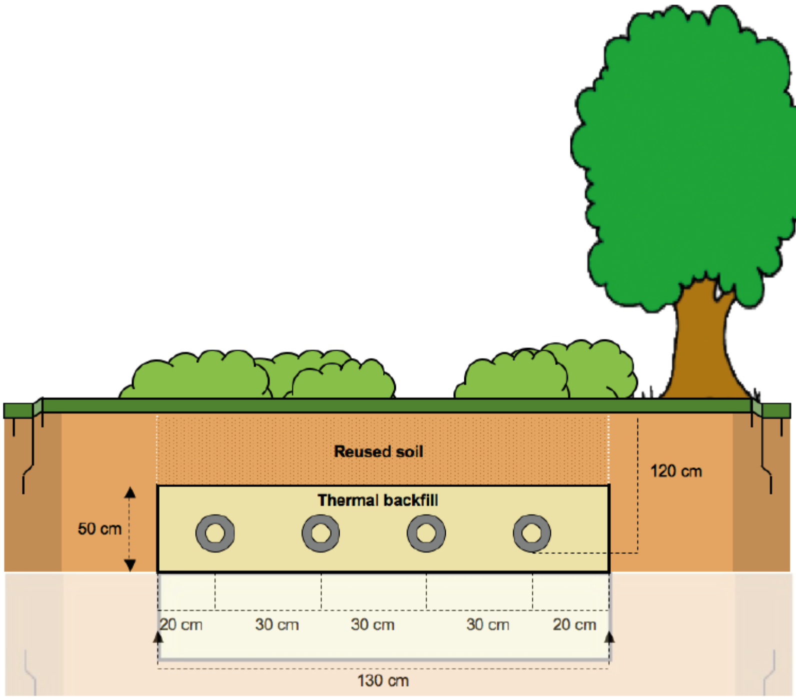
location of such cables I can say with experience that the land above is not “sterilised” as has been stated by others.

While the validity of this statement could be verified by simply driving to the locations of the Australian underground HVDC cables, there are also a number of references available in the public domain to support this. One example is a report by Europacable[5]. Quoting directly from this report:

“The only restriction on the use of land over an undergrounded section is that no deeply rooted trees may be planted within the corridor width plus a margin of about 2 meters to prevent root encroachment into the cable trench. Apart from that there are no limitations to cultivation, including agricultural farming.”[6]

The report includes the diagram shown in Figure 3, repeated for convenience, which shows a 320 kV, 2 GW HVDC system.

Figure 3 – Cable Trench Profile Showing Limited Impact on Surface for 2 GW, 320 kV HVDC System[7]



In terms of environment, one benefit of the underground cables is the reduced easement requirements compared to extra high voltage AC overhead transmission lines. While AC overhead transmission lines need to be installed in straight lines between towers and will require more towers on non-linear routes, underground cables have the flexibility to be able to have the trench/route installed around bends, diverting around sensitive areas and can be installed below major obstacles using horizontal directional drilling. This provides some flexibility when selecting a route, making relatively narrow road reserves and corridors viable options for cable routing. In the case of

[5] Europacable report, “An Introduction to High Voltage Direct Current (HVDC) Underground Cables”, October 2011 (https://europacable.eu/wp-content/uploads/2021/01/Introduction_to_HVDC_Underground_Cables_October_2011_.pdf)
[6] Ibid, Page 8.
[7] Ibid, Page 7.

Murraylink, we were able to install the cables within the firebreaks along fencing (on the road reserve side) for a significant length of the route and were able to bend the trench/route around trees to avoid cutting them down. This is why Murraylink won the Case Earth Award in 2002.

Another point to make is that much of what is said against underground cables in relation to environment is what happens during construction. The reality is that a cable construction front is only at one location for a few weeks (before moving on to the next section), and then immediately remediated. It can take up to 6 months to reinstate vegetation. After this, the land repairs quickly and for the rest of the life of the asset (40 years +) there is virtually no impact on the environment except to maintain access tracks in areas not accessible by existing roads.

HVDC as an Alternative to AC Power Transmission

When considering HVDC options for proposed AC transmission network projects, it is not always simply the case of replacing the proposed line with an HVDC system of similar rating and performance. The additional functionality of HVDC systems, such as controllability of active and reactive power and the inherent reactive power capability, could lead to the application of different performance standards and planning criteria. For example, HVDC systems can be readily controlled during transient network disturbance events, and making use of this capability could reduce pre-contingent limitations or criteria that would ordinarily be applied to an AC transmission line.

In May 2021, I co-authored an opinion piece in Energy Source and Distribution magazine[8], titled "Is Australia ready for HVDC Transmission Superhighways?". In this article, we explore the concept of using long distance, point-to-point HVDC systems to shunt large amounts of power from concentrated sources of renewable energy (such as renewable energy zones or large RE projects) directly to the largest concentration of load (e.g., a capital city or major industrial precinct). If this concept were to be adopted, more "traditional" AC transmission planning concepts, such as the need for another substation to "tie into" the line, would no longer be of concern. In this case, the new "shunt" should free up congestion in existing AC transmission networks, which could be used for such tie-ins if required.

"*The implementation of such "transmission superhighways" could allow the bulk of the generation to get to the major load centres directly with lower losses, while leaving the parallel AC transmission network with less congestion to allow generation and loads to "tap in" along the way*."

The most common argument against HVDC systems is that it is "not possible" to tap into the line along the way. This is not entirely true – it is possible, it just involves the addition of another converter station which tends to not be economically viable. However, when one considers the use of a point-to-point HVDC link as described above, there will be no need to tap in, as the nearby AC transmission networks could be freed of congestion and in any case, the new HVDC link will likely be rated for the full power/load requirements, so there may not be any capacity to tap into anyway.

The philosophy expressed above is being considered I the same way in Germany, as the translated quote below attests to:

"*Three-phase lines are integrated into the network differently than DC lines: while three-phase transmission lines are connected to the rest of the network like a freeway with many on- and off-ramps*

[8] Energy Source & Distribution Magazine, May/Jun 2021, Page 41.

(this is why it is also referred to as a meshed network), DC lines are similar to flight connections from A to B (so-called point -to-point connection).”[9]

Projects in Other Countries

As mentioned previously, while Australia was one of the first countries to adopt the VSC technology and use of long-distance cables for transmission, the technology has developed significantly and other countries have embraced this technology. We know that there are a number of very large power, long distance transmission projects in other countries using VSC technology and underground cables. Some of these projects are underground due to the requirements or regulations in that country whereas others are either changed to underground, or originally proposed as underground in the face of public opposition to the overhead transmission lines. Information on these projects is readily available online, however some examples are provided below.

In Germany, an Act entered into force during December 2015 with the following two relevant points:

1. *“For major electricity highways (=new ultra-high voltage direct current transmission lines), the Act gives priority to underground cables as a principle in federal planning.*
2. *In the case of alternating current (AC) cables, the number of pilot routes using underground cables and the criteria to be met were expanded.”*[10]

The source goes on to say, in the case of point 1 above, “*Where major electricity highways are concerned (= new ultra-high voltage direct current transmission lines), the Act will give priority to underground cables as a principle in federal planning. Overhead cables will only be used exceptionally in certain cases, e.g. in order to protect the natural environment. To put it simply, this means that there will be an absolute ban (sic) overhead cables being used wherever people live. So overhead cables can only be used in very strict exceptions.”*[11]

Generally, Germany has adopted the “point to point transmission” approach for getting power from renewable sources to major load centres and where these are deemed to be HVDC, then the project must be underground. There are a number of long-distance underground HVDC projects under construction in Germany meeting these requirements, including Suedlink (4 GW, 525 kV, 750 km underground cables) and SuedOstlink (2 GW, 525 kV, 270 km underground cable).

The requirement in Denmark is that since November 2008, “all new transmission lines above 100 kV shall be underground cables”[12].

In the USA, the SOO Green project is a 2 GW, 525 kV with an underground cable route length of just over 563 km. The project was required to go underground “*due to public opposition in the Midwest and an Illinois court rejection*”[13]. As an underground cable project, the SOO Green project route is now able to run in an existing rail system right of way, avoiding sensitive wildlife habitats and to avoid

[9] https://www.bmwk.de/Redaktion/DE/Artikel/Energie/stromnetze-und-netzausbau-regulierung-rahmenbedingungen.html
[10] https://www.bmwk.de/Redaktion/EN/FAQ/Underground-cables/faq-underground-cables.html
[11] Ibid.
[12] Norstrat, “Nordic power road map 2050: Strategic choices towards carbon neutrality, D4.1.R Institutional grid review”, sourced at: https://www.sintef.no/globalassets/project/norstrat/d4.1-institutional-grid-review.pdf , Page 17.
[13] https://www.renewableenergyworld.com/policy-regulation/quick-fix-why-ferc-should-approve-the-soo-green-transmission-project/#gref

damaging the natural landscape. This is an example of the flexibility in routing that HVDC underground cables can provide, as explained earlier in this submission.

We have access to project information for a number of other long distance transmission projects in other parts of the world. We would be happy to present more of these to the Inquiry if requested.

Closing Remarks

I appreciate the opportunity to be able to present this submission.

As an expert in the field of HVDC transmission projects and as one of the few with direct experience in the installation, commissioning, operation and maintenance of such HVDC undergrounding projects in Australia and overseas, I would appreciate the opportunity to make a presentation to the Inquiry on these matters.

Yours faithfully,

Mr Leslie Neil Brand
FIEAust, RPEQ, CPEng
Managing Director
Amplitude Consultants Pty Ltd

Attachment 1 – Profile

Leslie (Les) Neil Brand
Managing Director

Profile

Les Brand (FIEAust, CPEng, RPEQ) is an experienced electrical engineer with over 30 years of experience in the transmission and distribution industry in Australia, Asia and the USA. He has held senior and executive roles within the power transmission and distribution sectors, including utilities, consultancies and private companies. He is the Managing Director of Amplitude Consultants Pty Ltd, a company he co-founded in 2015, and a Director of CIGRE Australia.

Les has held key and senior technical roles for numerous HVDC interconnection projects including Directlink (Australia), Murraylink (Australia), Basslink (Australia) and Trans Bay Cable (California, USA). During these projects, Les held responsibilities either directly or indirectly related to the HVDC cables, both underground (land) and subsea cables. For all three Australian HVDC projects (Directlink, Murraylink and Basslink), Les has continued to support these projects during their operating and maintenance cycles and various upgrades to these facilities.

Les is the co-founder of Amplitude Consultants Pty Ltd, an Australian-born engineering consultancy headquartered in Brisbane, Australia and with permanent offices established in Darwin, Singapore and Wellington (New Zealand). Amplitude's key speciality areas include HVDC, underground and subsea cables (both AC and DC cables). Since its inception in 2015, Amplitude has undertaken various projects involving long distance land and subsea HVDC and AC cables and systems. Recent project include a number of HVDC vs AC, underground vs overhead studies for various interconnectors, renewable energy and offshore wind projects in Australia, SE Asia and New Zealand. These engagements have included the determination of scope and cost estimation for AC substations, HVDC converters and HVDC/AC overhead lines and cables.

During these activities, Les has established and developed strong relationships with HVDC vendors and AC and HVDC cable suppliers and gained an understanding of the state of the market for HVDC converter stations and associated cables.

Les is heavily involved in volunteer technical activities associated with HVDC projects on the international stage, including with CIGRE and the IEC. Les was the convenor of the CIGRE Australian Panel for HVDC and Power Electronics (B4), was the convenor of the international working group B4.63 "Commissioning of VSC HVDC Systems" and is the current convenor of CIGRE WG B4.90 "Operation and Maintenance of HVDC and FACTS Facilities". Les is also the convenor of Joint Maintenance Team 7 (JMT 7) of IEC Technical Committee 99 responsible for the revision of IEC TS 61936-2 "Power installations exceeding 1kV AC and 1.5kV DC. – Part 2: DC". This standard defines the installation, safety and maintenance requirements of safety systems for HVDC facilities. Les is presently leading a section of the CIGRE HVDC Green Book being developed, which includes chapters on the modelling, analysis, testing, commissioning and operation of HVDC systems.

Les was a recipient of the National Professional Electrical Engineer of the Year award with Engineers Australia for 2020 and received the CIGRE Pioneer e-session Achievement Award for SC B4 (DC and Power Electronics) in 2021.

Amplitude CONSULTANTS

Leslie (Les) Neil Brand

Managing Director

Relevant Key Roles Held:

- Directlink HVDC Project (NSW, Australia)
  - Senior Project Engineer.
  - Commissioning Engineer.
- Murraylink HVDC Project (VIC/SA, Australia)
  - Project Manager.
  - Commissioning Manager.
  - O&M and Trading Manager.
- Basslink HVDC Project (TAS/VIC, Australia)
  - Project Inspector, Technical
- Transbay Cable HVDC Project (California, USA)
  - Owner's Engineer
  - Subsea Cable Installation Manager
  - O&M Manager
- Ceres HVDC Project (SA, Australia)
  - Owner's Engineer and Technical Advisor
- Directlink and Murraylink Control and Protection Replacements (Australia)
  - Owner's Engineer and Project Manager

Industry Involvement, Awards and Recognition

- Fellow, Engineers Australia (FIEAust)
- Chartered Professional Engineer, Engineers Australia (CPEng)
- Registered Professional Engineer of Queensland (RPEQ)
- Registered Professional Engineer of Victoria
- National Professional Engineers Register, Australia (NPER) – Electrical
- Director, CIGRE Australia
- Convener of CIGRE Working Group B4.90 "Operation and maintenance of HVDC and FACTS Facilities" (ongoing)
- Convener of CIGRE AP (Australian Panel) B4 Panel "HVDC and Power Electronics" (2013-2019)
- Convener of CIGRE Working Group B4.63 "Commissioning of VSC HVDC Schemes" (2013-2017)
- Convener, IEC TC99 / JMT 7 – IEC TS 61936-2 "Power installations exceeding 1kV AC and 1.5kV DC – Part 2: DC."
- National Professional Electrical Engineer of the Year 2020 (Engineers Australia)
- CIGRE Pioneer 2020 e-session Achievement Award for SC B4 (2021)