28 February 2018

Integrated System Plan Committee
Australian Energy Market Operator
Level 22, 530 Collins Street
Melbourne VIC 3000

Re: Integrated System Plan Consultation Submission

We appreciate the opportunity to make a submission to the Australian Energy Market Operator's (AEMO) consultation regarding the Integrated System Plan (ISP). We also welcome the initiative from AEMO to request feedback from the greater community of the proposed ISP.

This is a submission on behalf of the real-time digital simulation laboratory at UNSW Sydney (RTS@UNSW). Our detailed response to questions 4.1 – 4.4 of the consultation document can be found in the attached document at the end of this letter.

We are happy to address any further questions and discuss and matters associated with this submission either via e-mail (g.konstantinou@unsw.edu.au) or by phone (02) 9385 7405.

Yours Sincerely

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Submission to the Integrated System Plan Consultation

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Introduction

A long-term integrated transmission network plan is critical in order to meet *i)* security of supply, *ii)* system reliability and *iii)* network resilience targets. This plan becomes even more pivotal as the amount of synchronous generation in the network decreases while asynchronous generation, predominantly through power electronics interfaced systems, increases in the network.

The development of the integrated system plan (ISP) should consider not only import and export needs of regions[1] but do so in a highly controllable, flexible and well-regulated manner. The ISP should not serve as a short-term, minimum current cost plan but provide a backbone for ever-changing needs of the transmission system.

We believe that a bold outlook for the future and "higher-cost/higher-flexibility" solutions that incorporate modern technologies and experiences/lessons from other countries should be considered. These solutions for the ISP should breach through the current state barriers to deliver the required targets across the whole national electricity market (NEM).

Question 4.1: Have the right transmission options been identified for consideration in the ISP?

The ISP identifies most of the important transmission development option based on upgrading or augmenting the existing ac systems in the NEM. However, the ISP does not explicitly consider high-voltage direct current (HVDC) transmission systems as a credible solution with the exclusion of the Tasmania - Victoria interconnection with a potential second HVDC link. We believe that alternative approaches based on HVDC technology should be analysed and considered as options both for particular proposed projects as well as for coordinated development and enhancement of the existing network.

As we analyse later, such HVDC systems - especially those based on voltage-source modular multilevel converters (VSC / MMC, [1]) - can provide novel solutions to a power system that incorporates asynchronous power-electronics interfaced sources such as solar photo-voltaic (PV) and wind energy systems.

The technology, despite its higher cost, provides a well-proven solution to several transmission network issues beyond bulk transfer of power over long distances. VSC-based HVDC systems not only include the advantages of classical line-commutated converters (LCCs) HVDC solutions,

[1] We choose to refer to regions rather than states to include future renewable energy zones (REZ) as well as areas that may serve as "energy storage".

but also provide greater flexibility and/or functionality as they are capable of:

- Operating under low short-circuit ratios (suited to weaker grids, such as connection of offshore/onshore renewables or systems with high penetration of asynchronous generation).
- Providing dynamic reactive power for voltage regulation independently at each terminal.
- Quickly adjusting real and reactive power flow in response to system contingencies.
- "Firewalling" one ac system so that disturbances do not spread to an adjacent system.
- Providing a variety of power quality support functions such as *i)* frequency stabilisation, *ii)* artificial fast frequency response, *iii)* power oscillation damping, and *iv)* black-start capabilities.

In terms of VSC-based HVDC, MMCs [1] are used for converter station terminals in the majority of projects completed in the last 5 years or currently under construction. On top of the advantages of VSC-HVDC, MMC-based HVDC transmission offers modularity, scalability, and expandability to wide power and voltage ratings [2, 3, 4]. Other modular multilevel VSC topologies such as full-bridge based MMC, hybrid MMC and alternate arm converter (AAC) [5] that include fault-tolerant submodules [6], provide the dc-fault ride through (FRT) capability to the dc power systems where ratings and the cost of dc-breakers can be reduced.

VSC-HVDC is well-suited in the formation of multi-terminal dc (MTDC) transmission systems, with long-term benefits especially in the areas of flexible integration of distributed energy sources. Some examples of HVDC projects that have been developed and commissioned in the last 3 years with functions and applications relevant to the current ISP are given below:

The INELFE Project - Expansion of the France-Spain Interconnection (2015)

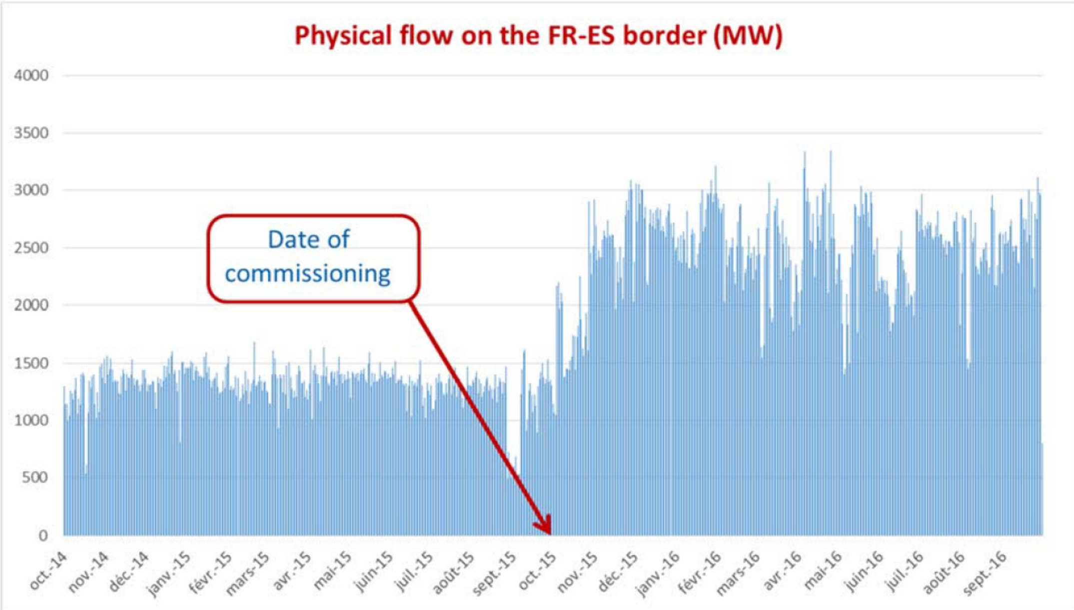
Until 2015 the Spain-France interconnection consisted of four ac lines (last line was built in 1982), with a total commercial exchange capacity of 1400 MW [7]. The goal of the HVDC project was to enhance the power transfer capacity between the two countries [8]. The interconnection is composed of 2 (MMC-based VSC) HVDC links and has rated transmission capacity of 1000 MW per link ($\pm$300 MVAr), dc voltage of $\pm$320 kV, and connecting to 400 kV ac grids. The transmission distance is 64.5 km[2].

VSC-HVDC systems using MMCs had been selected for this project due to the dynamic performance, power flow control requirements, and the low ac short-circuit ratio of the France-Spain system [7]. The very fast control and protective intervention capabilities of the power converters provide a high level of stability in the transmission system, which primarily serves to reduce grid faults and disturbances in the three-phase ac network. This significantly increases supply reliability for utility companies and power customers.

Moreover, this technology allows to include continuous reactive power compensation independent of the energy transmission in the Réseau Transport d'Électricité (RTE) and Red Eléctrica de España (REE) grids as well as a rapid reversal of energy flow (possible in 150 ms) in the event of a grid disturbance. Last but not least, the black-start capability function makes it possible for the HVDC transmission system to restart the affected power grid as quickly as possible [9]. The HVDC project has assisted the Spain - France interconnection not only by providing a new

[2]It should be noted that the transmission distance in this project is significantly smaller to typical "break-even" distances when simply comparing ac against dc systems (see for example page 8 of [10]). These distances are typically calculated to 500 km for overhead lines and 50-100 km for undersea cables based on LCC-HVDC technology. In this case, connection with ac-lines was already available and the additional flexibility offered by the HVDC system appears to justify the additional expenditure.

path for power flow but also through ancillary functions for the parallel ac lines between the two countries [11, 12]. After the commissioning of the new interconnection, physical exchanges have increased considerably also allowing flexible control and greater variations (Figure 1 [11]).



Energy exchanges (TWh) at the French – Spanish Border	ES ⇨ FR	FR ⇨ ES	Total
One year before commissioning (from 05/10/14 to 04/10/15)	1.44	6.58	**8.02**
One year after commissioning (from 05/10/15 to 04/10/16)	2.81	12.36	**15.17**

Figure 1: Power transfer (in MW) in the HVDC Spain-France interconnection (from [11]).

The Luxi hybrid back-to-back project: Asynchronous Connection of Yunnan with the South China Grid (2017)

China Southern Power Grid (CSG) developed the Luxi hybrid back-to-back (BTB) interconnector aiming not only to improve the grid security but also to improve the delivery capacity of hydropower plants in the south-west of China to the main load centres in the south [13], [14]. Traditional alternatives based on ac technology were considered during the first steps of the project. However, analysis on the network showed that a synchronous connection between the grids increases the risk of cascading failures in both networks so an HVDC connection was the preferable choice [13].

The BTB interconnector separates Yunnan grid and the main grid, to form two asynchronous grids within the China Southern Grid. The back-to-back system has a total transmission capacity of 3000 MW (three connection units rated at 1000 MW each). One of the connection units adopts VSC-HVDC (at $\pm$350 kV) [15] while the other two employ the conventional LCC-HVDC technology (at $\pm$160 kV) [16].

The Nan'ao VSC-MTDC project: Multi-terminal Integration of Wind Power (2013 & 2017)

The Nan'ao VSC-MTDC showcases the potential of "small" MTDC systems for the integration of renewable energy [17]. It was developed, initially in 2013 as a three-terminal network, currently being augmented with dc-breakers and with the potential for a fourth terminal in the future [18]. This China South Grid project allows existing and future wind power generated on Nan'ao island to be fed into the regional power grid, both to safeguard future energy supply and to support the transition from coal towards renewable sources [17, 19]. The multi-terminal VSC-HVDC system consists of three converter stations at different locations, connected by a combination of subsea dc cable, land dc cable and overhead dc line, as shown in Figure 2. The dc voltage is ±160 kV and the rated powers are 200 MW, 100 MW and 50 MW (station 1, station 2 and station 3, respectively)[3]. The converter station is connected to the 110 kV ac system.

Figure 2: Nan'ao multi-terminal VSC-HVDC project (from [20]).

HVAC, conventional HVDC and VSC-based HVDC were possible options. However, VSC-HVDC offers better transmission efficiency, flexible and independent power control, reactive power compensation, and unlimited terminal configurations. Therefore, a multi-terminal VSC-HVDC system was the preferable alternative to connect wind generation from the island of Nan'ao to the mainland of China [19].

Question 4.2 How can the coordination of regional transmission planning be improved to implement a strategic long-term outcome?

The introduction of REZs as part of the ISP is a great step towards a top-down coordinated development of large-scale renewable energy across the NEM. A similar coordinated approach should be taken in transmission system planning in order to ensure network reliability, security, and quality of supply to customers/users considering costs and benefits from transmission system upgrades. An approach that prioritises multiple least-regret options may potentially lead to an overall regrettable solution in the long term.

Long-term planning with appropriate consideration for the future needs and capabilities of the transmission system, plays a major role in identifying which approach is the best credible option to achieve the policy objectives of affordability, reliability, security and robustness. A couple of examples are discussed below, in which the long-term planning considering VSC-based HVDC developments may be a potentially credible solution.

[3] Although, the Nan'ao VSC-MTDC project can be treated as a demonstration project of MTDC potential, it shows that multiple small converters of a few hundred MW rated power can be considered in network planning and development of flexible multiterminal networks. This is highly promising considering the future potential of medium voltage (± 100 kV) dc (MVDC) grids for such solutions.

1. **Bass Strait interconnection – renewable and distributed sources:** The current ISP includes one additional HVDC link between Tasmania and Victoria as part of the proposed system augmentations considering two possible paths between Tasmania and the mainland. A direct point-to-point approach limits the possibility of interconnection of wind generation in either King Island, the Furneaux Group or both; REZs identified in the same report amongst the highest wind energy resource areas in the country. An alternative approach to the proposed systems should also consider an MTDC grid that includes some or all of the above areas both with the aim of increasing the transmission capacity as well as increasing the injection of high-quality renewable resources to the NEM and flexibly transferring power to Tasmania for storage purposes. The Nan'ao project described in the previous section can serve as an example of renewable and distributed sources integration of an MTDC using VSC-HVDC technology.
2. **Increasing interconnection from South Australia to the Eastern and Northern States:** A centrally managed MTDC system connecting the South Australia (SA), Eastern, and/or Northern States can offer long-term benefits in the context of the ISP for the Australian Network. This can include load areas, REZs and areas with energy storage potential in multiple configurations. Rather than a single project, one of more MTDCs can be gradually developed with a primary focus on areas where an HVDC connection can reinforce existing transmission systems and alleviate transmission congestion. We also envisage that these systems would be of ratings in the hundreds of MWs up to 1 GW rather than larger HVDC systems. The INELFE HVDC project offers a great example of such application.
3. **Two Asynchronous Sections of the NEM:** The projects that have been included in the ISP assume a NEM that maintains all its ac interconnections between existing states. However, greater numbers of asynchronous generation in certain parts of the network should make us challenge the way we approach the operation and planning of the current system. With greater penetration of wind power in SA, an asynchronous interconnection between the area and the rest of the NEM can be considered through back-to-back HVDC systems. Such approach will provide greater flexibility in managing the networks of both areas, allowing for example the SA network to operate with different set of standards in times of higher renewable penetration without impacting on the rest of the NEM. The Luxi BTB system can provide a variety of lessons for such an approach.

Question 4.3: What are the biggest challenges to justifying augmentations which align to an over-arching long-term plan? How can these challenges be met?

We find that the key challenge in justifying augmentations that align to a bold and future-proof overarching long-term plan is the proper attribution of value to the additional functions that can be provided by technologies not currently explicitly considered in the ISP consultation document (e.g. ancillary functions, frequency support, etc). This is particularly important in the case of VSC-HVDC transmission systems where a justification of the additional cost, compared to LCC-HVDC and traditional ac transmission, is required. This lack of value, especially in contingency events or when the resilience of the network is challenged, puts more expensive but more capable solutions at a great disadvantage. A second challenge we identify is the alignment of existing proposals and connection applications in the NEM[4] with the recommended REZs that are outlined in the ISP consultation document.

[4] These projects are currently more than sufficient to cover the renewable energy targets.

Question 4.4: Is the existing regulatory framework suitable for implementing the ISP?

A regulatory framework must provide sufficient signals that incentivise appropriate, timely and efficient investments in transmission projects. In long-term integrated system planning, it is critical to make decisions considering the whole NEM and not only transmission upgrades linked to specific regional and state priorities. Experience in other systems [21] has demonstrated that a market based approach might not always be optimal, in certain cases leading to underinvestment, reliability and security of supply issues. A process that aligns future project to the development of an integrated NEM should be considered. The same applies to the approval of new large-scale renewable energy projects, which when done at a state level and without consideration of the greater plan, can lead to suboptimal development of REZs and also sub-optimal network augmentation in certain areas.

We also find that a regulatory framework - especially regarding revenue streams - should consider the special requirements in the operation of an MTDC system. This is necessary in order to avoid cases where single point-to-point HVDC links would provide a preferable revenue stream for a given operator over participation to an MTDC system.

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