Solving the challenges of successfully delivering BESS projects in competitive electricity markets

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***Abstract*—The Hornsdale Power Reserve (HPR) project, consists of a 100 MW Battery Energy Storage System (BESS) in South Australia and was delivered in a period of under 100 days The HPR project has proven to be a commercial success and a critical part of the Australian National Electricity Market (NEM) providing energy, contingency and regulation services and a critical part of that regions power system protection scheme. Many renewable generators have since identified opportunities to implement BESS projects for additional revenue streams and capture the energy that would be foregone due to system curtailments. However, many of these new potential projects have either failed to materialize, been reduced in scope or have been delayed.**

If the Hornsdale BESS project was so successful in such a short delivery time, why have subsequent projects proven to be either too great a financial risk or have been difficult to implement?

Some of the existing problems had been already identified during the HPR implementation but a number of other factors have since emerged that have significantly increased the complexity of these new BESS projects and resulted in either the project abandonment, restrictions or costly delays. Many of the factors that are restricting the potential implementation of BESS projects are not technical. All of the existing battery projects that have been successfully delivered since the HPR project have been from large organizations that have experience with the complexities of power systems and functional trading and operations teams.

BESS installations are a critical missing part of the power system to allow for large proportions of renewable energy in Australia and for many other international markets, but what is required to make these projects a success?

The rapid pace of development of power technology is much faster than the reform processes of market rules and operations. There has been a huge increase in the number of individual generator stakeholders in the market, especially with new renewable generation projects. Market reform is becoming increasingly difficult to achieve with an uneasy balance between incumbent financial interests and fair and efficient market design that matches the reality of the dynamic power system.

It is imperative that the renewable industry can successfully implement BESS projects and that these projects are successful. By mitigating the technical and non-technical risks and by the adoption of reliable and proven systems, it is possible for small and large renewable generators to develop new revenue sources in energy and ancillary service markets by delivering successful BESS projects and participate in the realization of the goal of 100% renewable generation power systems.

Keywords— battery systems; NEM; market design; market reform

I. Introduction

The Australian National Electricity Market (NEM) is an interconnected power system across Australia's eastern and south-eastern seaboard and is dispatched on a 5 minute basis in a co-optimised energy and ancillary service market. Since about 2015, the NEM has experienced an unparalleled growth of renewable generation at many locations within the existing transmission grid system that have never before had transmission assets [1]. The number of new generation projects has created many challenges for the system operator, the Australian Energy Market Operator (AEMO) in managing the new generation applications, integrating the renewable generation into the existing power system and maintaining system security.

The Hornsdale Power Reserve (HPR) Battery Energy Storage System (BESS) was successfully implemented into the South Australian (SA) region of the NEM and since the start of operation, a large number of delivered and proposed BESS projects have commenced in all of the regions of the NEM. However, the implementation of BESS projects in the NEM presents a number of challenges to cope with existing market limitations, connection issues and project financing.

II. The Hornsdale Power Reserve Project

A. *The motivation for the HPR project*

The blackout that occurred in the South Australian (SA) region on the 28 September 2016 due to a severe weather event and issues with the operation of the generation and power system [2] resulted in the creation of the Hornsdale Power Reserve (HPR) project. The SA region in the NEM at the time of the blackout had a high level of penetration of renewable energy and had recently experienced the retirement of a large coal power plant, thereby producing a more vulnerable regional power system with a relatively low amount of inertia. The business cost of the blackout in the SA region has been estimated to be $367 million [3] and had an immediate and significant political response both locally and federally, with blame being quickly apportioned to renewable generation shortly after the blackout in the absence of any real evidence at that time.

After the SA blackout in September 2016, but before the commencement of the HPR project, the SA region had another serious system security incident on 3 March 2017 when there was an explosion of a Capacitor Voltage Transformer (CVT) in the switch yard of the Torrens Island Power station resulting in the trip of three units (3 x 130 MW) and the trip of the nearby Pelican Point Power Station generating (220 MW) due to over current protection on that generator [4].

The loss of gas generation in the region was compensated for in the short term by increased flows across the Victoria–SA interconnector where the interconnector was run over the allowed power flow for a short period of time and therefore just managed to prevent another blackout in the SA region. Also, during the 2016/2017 summer season, the SA region experienced blackouts due to storms in December 2016 and involuntary load shedding in February 2017 due to the lack of reserves and lack of contract gas at Pelican Point Power Station.

The serious consequences of the blackout, the vulnerability of the region's power system and the lack of reserve conditions created an environment of rare alignment of political, business and social interests to work together to rectify the serious power issues in the region. The common goals and determination to address the issues were the key element in ensuring the delivery of the BESS by the 1st December 2017, prior to the summer season and the ultimate successful implementation of the HPR project.

B. *Implementing the project*

The Hornsdale Power Reserve (HPR) BESS is located near Jamestown, north of Adelaide in South Australia and is currently the largest utility-scale storage device operating in the world. HPR is rated at 100 MW discharge and 80 MW charge, with a storage capacity of 129 MWh [1].

To meet the generation deadline, it was necessary to have many tasks running in parallel including all of the site works, installation of the battery hardware, integration into the existing switchyard systems, controls development and testing of all of the integrated systems.

Apart from the physical delivery of the BESS equipment, all of the market and connection agreements had to be developed during the project, as there were few precedents of any significant BESS projects in the Australian NEM. HARD software had the role of designing, developing and implementing the operations and trading systems for the HPR project that could incorporate optimised energy and ancillary service offers and provide the market integration services and also display a trading and operations user interface to monitor the operations and allow for intervention when required under direction or other circumstances.

Since the implementation of the HPR project, many of the financial details of the project that were confidential during the project have subsequently been published [5]. The total capital cost of the HPR project was €56 million ($AUS 96 million) with 70 MW of the batteries capacity to be dedicated to the South Australian governments System Protection Scheme for a fee of $AUS 4 million per annum over 10 years. The remaining 30 MW capacity of the battery and about 90MWh of storage, is able to be traded in the merchant market, selling electricity on to the wholesale market by time-shifting the output of wind, or by arbitraging spikes in prices. The HPR project also trades in the Frequency Control and Ancillary Services market (FCAS).

The HPR BESS commenced generation in the market in late November 2017 and had an immediate impact on the market providing essential energy and ancillary services on the 30 November 2017 where it significantly reduced the need for gas generation in the state and lowered prices significantly.

C. *Performance of the HPR project*

Since the start of generation in December 2017 the HPR BESS has captured a significant share of the FCAS market in the NEM and had a material impact of energy and FCAS pricing in the NEM. In 2018, the 100MW/129MWh Tesla big battery, which cost $96 million to build, pulled in revenue of €18 million ($A29 million), and its margins were excellent, delivering earnings before interest, depreciation, and tax (EBITDA) of €14.2 million ($A22.8 million at then exchange rates) with the addition of $AUS 4 million from the state government for "grid security" services and earning the rest of its money from FCAS and arbitrage [6].

It has been estimated that the HPR project has resulted in savings to consumers of $AUS 40 to $AUD 50 million in its first year of operation by lowering costs, particularly in the frequency control market, but also in the wholesale energy price.

However, in recent months, the HPR proportion of the FCAS market, that was around 10% of the NEM market, is starting to be affected by the competition of the two other completed BESS projects in Victoria and does demonstrate the lack of depth and liquidity in the NEM FCAS markets.

III. NEW AND POTENTIAL BESS PROJECTS

A. *New BESS NEM projects*

Since the start of the HPR, other renewable and vertically integrated generation companies have started to evaluate and consider the implementation of BESS projects in the NEM (Table 1), as distinct from BESS projects in the Western Australia Market (WEM) or for grid forming applications in isolated power systems.

Apart from the HPR project, that had a very different funding model using private equity and the guarantee of money from the State government, most of the proposed BESS projects have had some degree of financial support from the Australian Renewable Energy Agency (ARENA), a government agency with the purpose to accelerate Australia's shift to affordable and reliable renewable energy.

Recent projects have attempted to deliver projects fully private funding with no explicit government support and it is anticipated that, unless there is some novel project capabilities or new technology to justify the need for ARENA funding, future BESS projects will not continue to be able to access this source of government funding.

There are a number of other BESS projects under consideration for the NEM that have not been publicly announced that are under consideration and yet to reach financial close. It is difficult to estimate the exact number as these projects are strictly confidential at this critical stage of development, but to the author's direct knowledge, there are at least 10 other projects under active development, although it is not expected that all of these projects will be viable and progress to the construction stage.

B. *BESS revenue models*

Since the start of HPR, many other generation companies have started to evaluate and consider BESS projects and determine if they are financially viable.

BESS systems are technically capable of providing many useful and diverse services in both the transmission and distribution power systems [31].

Potential sources of BESS revenue are:

- Direct off-taker energy payments through a Power Purchase Agreement (PPA),

TABLE I. PUBLICLY ANNOUNCED NEM BESS PROJECTS

BESS project	Location	Company	Size	Funding	Generation
Hornsdale Power Reserve [7, 8]	Jamestown SA	Neoen / Tesla	100 MW / 129 MWh	SA Gov / private	1 Dec 2017
Dalrymple ESCRI battery [9, 10, 11]	Yorke Peninsula SA	ElectraNet / AGL	30 MW / 8 MWh	ARENA / private	Apr 2019
Gannawarra Solar Farm [12, 13, 14]	Kerang VIC	Edify & Wirsol	25 MW / 50 MW	ARENA / private	Oct 2018
Bungama Project [15]	Port Pirie SA	EPS Energy	140 MW / 560 MWh	private	2021
Robertson Solar Project [16, 17]	Roberston SA	EPS Energy	250 MW / 1000 MWh	private	End 2019
Solar River Project [18]	South Australia	Alinta Energy	100 MW / 300 MWh	ARENA / private	1st Qtr 2021
Lincoln Gap wind farm BESS [19, 20]	Lincoln Gap SA	Nexif / Fluence	10 MW / 10 MWh	private	May 2020
Energy Australia [21, 22]	Ballarat Vic	Spotless / Downer	30 MW / 30 MWh	ARENA / private	May 2020
Playford Utility Battery (PUB) [23]	Port Pirie SA	Simec Energy	100 MW / 100 MWh	ARENA / private	May 2020
Bulgana Green Energy Hub [24]	Stawell, Vic	Neoen	20 MW / 34 MWh	private	Dec 2019
Lake Bonney Wind Farm [25]	Lake Bonney SA	Infigen Energy	25 MW / 52 MWh	ARENA / private	Sep 2019
Mt Stuart Power Station [26, 27]	North Queensland	Origin Energy	4 MW / 4 MWh	private	May 2019
Snowtown [28]	mid-north SA	Tilt	21 MW / 26 MWh	ARENA / private	2021
Kennedy Energy Park [29, 30]	North Queensland	Windlab	2 MW / 4 MWh	ARENA / private	Sep 2019

- Revenue via energy payments, including energy arbitrage and time shifting,
- Revenue via availability payments – capacity contracts, upgrade deferral & resiliency,
- Ancillary services – Frequency response, regulation, voltage support, load following, ramp rate control & black start services, and
- Demand charge reduction and backup power.

Presently, only the energy, frequency regulation and contingency services are presently part of the NEM design and are part of the NEM Dispatch Engine (NEMDE) co-optimised 5-minute clearing process. Other required ancillary services in the NEM that are not part of the dispatch process are contracted on an annual basis through an auction process.

As discussed in the context of the revenue performance of the HPR project, the markets for FCAS services in the NEM are illiquid and therefore prices will be dramatically affected with each new entrant into those markets. The six contingency markets in the NEM are split into 6, 60 second and 5 minute raise and lower service categories that were based on the technical capability of the generation assets at the time of the design of the FCAS markets about 20 years ago, namely coal plants, hydro and fast start gas turbine generators. BESS generators are capable of delivering responses in these markets that are much faster than the minimum 6 second market and so therefore have no exploitable advantage in the market and yet they can provide a very useful response to frequency deviations that are especially valuable in regions with high levels of renewable generation.

The author has contributed to an earlier paper that considers the design of a market-based frequency control solution that dynamically calculates the quantities and timing of FCAS in a manner that is both feasible using current dispatch engines and is also technologically neutral. Market signals could therefore encourage appropriate investment and innovation in technologies such as BESS and other potential fast response generators [32].

Conversely, as generators, such as coal power plants are retired, the portfolio of the existing generators age and become less reliable and economically unviable to maintain, there will be an increased demand for the fast response contingency services that will be expected to conversely increase the demand and prices for these services.

Many of the listed BESS potential sources of revenue are not currently supported directly by the NEM market design but could be exploited through the use of direct contracted services with network service providers. BESS generators can provide the means of augmenting existing transmission assets or enabling the deferment of capital works to enhance capacity of distribution assets such as overloaded sub-stations, transformers or distribution lines in a potentially cost-effective manner. Transmission and distribution assets in the NEM are managed in a highly regulated segment of the market with mandated independence from the generation and retail participants and so the use of BESS technology for these distribution network applications is still at an early stage.

C. *Issues with BESS projects*

Understandably there is limited information available on the reasons for delays for the connection and first generation of many of the recent BESS projects. The Lake Bonney project which is implementing a 25 MW / 52 MWh BESS in the SA region was initially expected to be operational in Feb 2019 but is yet to start generation and is now expected to generate in the September 2019 quarter [25].

The reasons for the delay of the Lake Bonney project have been stated as being due to continuing studies between Infigen, the market operator and the network service provider in relation to finalising connection and access to the electricity grid.

Similarly, the Kennedy Energy Park project, which includes a BESS and other renewable generators, was meant to be generating in January 2019 and is now due to start operations in September 2019 citing grid connection problems [29].

The ability to complete renewable and BESS project connections has proven to be a significant problem in the NEM, possibly due to the difficulties in conducting detailed dynamic power system models in a rapidly changing NEM power system. The large number of new projects and the limited technical resources available are leading to capacity issues causing connection costs and delays and causing cost blowouts for many projects throughout the NEM and threatening the financial viability of some of the large renewable contractors [33].

IV. The Need for Market Reform

The NEM is currently undergoing the most significant transformation of the electricity grid since its formation due to the introduction of large numbers of new generators in new locations with new technologies. The overdue need for market reform is now the critical factor limiting the integration of any new power system technology, including BESS projects.

A. Establishment of the NEM

It is instructive to consider the environment of the creation of the NEM as an example of how significant market reform can be achieved and identify the differences in the current environment compared to the early 1990s [34].

The establishment of the NEM was the result of a an industry commission report that concluded that the individual State responsibilities for electricity supply was an inefficient economic process and was leading to a great financial burden for some of the States and that there was potential for significant improvements in the National Gross Domestic Product (GDP) through reform and increased competition. The National Grid Development Council (NGMC) was established in 1991 and at the time there was a rare alignment of bi-partisan State and Federal political support and industry willingness to reform the electricity market.

The key lessons from the electricity market reform process were:

- The material problems were defined, and clear reform objectives were set,
- Reform took high-level political drive; provision of time, energy and, according to many reform participants, financial incentives,
- Strategies were developed to enhance confidence in the reforms,
- Strong and appropriate support structures were established with key stakeholder participation,
- The pace of the reform allowed for effective consultation across all stakeholders, and
- Getting the industry structures right was key for effective competition.

B. Issues with the NEM market

Whilst significant and long-lasting reform was achieved with the original creation of the NEM market, there were some issues created that have now made further market reform difficult. As part of the market design process, there were many compromises necessary due to the Information Technology capabilities of the time and the lack of competitive market experience of the participants.

The most important compromise that was made during the design process was the adoption of regional pricing and dispatch, where the regions were mostly defined along the lines of State boundaries connected by inter-connectors, whose arbitrary electrical boundaries are increasingly becoming irrelevant, in contrast to a possible adoption of a full nodal pricing design that was used in the, albeit much smaller and simpler, New Zealand electricity market.

With no dynamic power flow model incorporated into the NEM dispatch process, NEMDE uses a vast system of constraint equations, yearly averaged marginal loss factors, leading to a less efficient use of the transmission network.

Also, the locational pricing signals for new generation assets, presently consisting of renewable generation and BESS projects, are indistinct, as accurate forecasts of marginal loss factors are very difficult to produce due to the lack of forward notice of new generation projects, lack of precedents and changing load profiles through industrial rationalisation [33].

Other “temporary” market compromises such as FCAS causer pays calculations, thirty-minute settlements and generic constraints have out stayed their usefulness or applicability. As an example, the FCAS causer pays factors continue to be inappropriately applied to participants that were never considered in the original calculation design, such as renewable generators, and these generators continue to have to deal with the substantial adverse financial consequences [36].

Probably the most worrying aspect of continuing NEM development is that in Version 01 of the original NEM rules (NEMMCO was the system operator in the early stages of the NEM and was later replaced by AEMO) [37]:

3.8.1 Central Dispatch

… (f) NEMMCO must investigate from time to time:

1) the scope for further development of the *dispatch algorithm* beyond the minimum requirements specified in clause 3.8.1(b); and

(2) the sufficiency of the *dispatch algorithm* in meeting the minimum requirements specified in clause 3.8.1(b),

Later versions of the code removed the word **must** and replaced it with **may.**

It is the lack of continual review and market development by any market regulatory body that has led to a stagnation of the NEM design and, without the drive to continuously improve the design and ensure that the physics of the electrical system more closely matches the economics. No significant efficiency improvements have been made to the original market design since the original establishment of the market and the introduction of competitive FCAS markets in 2001 [38].

C. Proposed market rule changes

To meet the changing nature of the electricity system and the introduction of a greater proportion of renewable generation and new BESS projects, a number of market rule changes are presently being considered. It should be noted that the progress of many of the proposed rule changes has been difficult due to the wide consultative approach and the many and varied financial interests of the incumbent market participants.

The market reforms being implemented or under consideration are:

- Five minute settlement
- Wholesale demand response mechanism
- Integration of storage
- Integration of hybrid generation

Five minute settlement has been approved by the AEMC and a timetable has been established for introduction of five minute settlement in 2021 [39], thereby removing a market anomaly where the high price signals in a single dispatch interval were averaged over the thirty minute trading interval and generation that occurred after the price signal could still benefit from the high dispatch interval prices. Generators that are capable of generating at short notice, such as BESS, should greatly benefit from this rule change.

The AEMC has presently produced a draft determination for a wholesale demand response mechanism [40] and it is expected that rule changes will soon be submitted to facilitate the integration of BESS in the NEM within the present NEM market design [41].

Recognition of a renewable hybrid generator class, where curtailed renewable energy can be captured in a BESS, is presently only supported in the NEM if that generator registers as a single dispatched generator where the responsibility to meet dispatch targets for every dispatch interval is borne by that generator. Other possible dispatch classes for a mix of renewable generation and BESS are presently being considered.

D. The need for market reform

Whilst the proposed market rule changes do potentially improve the market design and help to facilitate the integration of renewable and BESS technology into the existing NEM design, they do little to improve the fundamental basis of the NEM market. Incorporating a network power flow model, dynamic losses and nodal pricing into the NEM dispatch process will ensure that the economic signals match more closely the physics of the power system and ensure that the transmission and distribution systems are more effectively used and improve the overall efficiency of the market [38]

The present means of piecemeal rule changes for individually identified deficiencies in the NEM will improve the integration process for BESS, effective demand response and renewable projects, but due to the wide range of different participants with varied interests, including retail, vertically integrated utilities with large market power, incumbent generators and large numbers of renewable generators, there are limits to the nature of the reforms that could ever be implemented in a reasonable timeframe, if ever.

Reference [37] has an excellent summary of many of the problems with the present NEM market and considers many of the issues discussed in this paper in the wider context of the present regulatory governance, the partisan political environment and divisive and inconsistent nature of National climate policy.

The Council of Australian Governments (COAG) has recently established an Energy Security Board (ESB) with a responsibility to propose a new market design for implementation in 2025 [42].

"The optimal market design will not only need to deliver lowest-cost power and other services on a day-to-day, minute-to-minute basis, but also be capable of sending appropriate signals for timely investment and disinvestment and give investors confidence in their ability to make a risk-adjusted return on investments"

At present no reports or proposals have been published by the ESB, but it is hoped that many of the significant market reform proposals, such as the incorporation of a network power flow model, dynamic losses and nodal pricing into the NEM dispatch process are given serious consideration and form part of the proposed new market design for 2025.

CONCLUSIONS

Significant electricity market reform can provide new entrants and existing participants with the locational price signals required to ensure that investment and operational decisions meet the needs of the electricity market and consumers and help to provide the necessary financial returns for participants.

The integration of new technology into the power system, such as BESS and renewable technologies, is presently challenging due to new technological capability and improved economics outpacing the market reform process by many years. The past lack of review and continuous improvement of the entire electricity dispatch process has resulted in an electricity market that now does not meet the needs of either the participants, new entrants or consumers.

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