ROBINSON BOWMAKER PAUL

Modelling the Market Impact of Battery Storage in Asia-Pacific Electricity Markets

ROBINSON BOWMAKER PAUL

Executive Summary

How will widespread introduction of storage technology affect generation assets? The complexities of wholesale energy markets can lead to non-obvious outcomes.

In this paper, we present the results of simulations to forecast the wholesale market impact of battery storage on several classes of conventional generation, in terms of market prices received, market dispatch, and hence revenue. We present the results of this analysis across in three different Asia-Pacific markets (Australia's NEM, the Philippines WESM and Singapore's NEMS), each with different market fundamentals and storage quantity scenarios. From this, we draw out key risks and opportunities for energy market investors in the region.

We find that in markets experiencing volatile market prices, a large battery storage facility can significantly reduce market prices. In such situations, there is a net transfer of wealth from generators to consumers and battery owners. However, the magnitude of a specific generator's loss is very dependent on factors such as the type of generator and its location in a constrained transmission network. This is a potential loss that generators should plan to mitigate. Possible hedges include investing in storage projects and baseload generation.

In a market that is free of transmission constraints, generation shortages and volatile market prices, the impact of battery storage on wholesale energy market outcomes is likely to be minimal, and energy price arbitrage alone will not provide sufficient return on capital outlay.

KAPAIA PROJECT (13MW/52MWH)
KAUAI, HAWAII, USA

1. Introduction

Recent years have seen significant penetration of renewable generation in many markets. This has been driven by a combination of rapidly decreasing costs, environmental concerns and government policy. The intermittency of most renewable sources places greater demand on conventional thermal peaking generators to compensate and help maintain grid stability.

Energy storage technologies support the integration of renewable generation onto the grid, and provide support for the transmission and distribution systems. The cost of grid-scale and end-user energy storage is decreasing rapidly, along a similar trajectory to the recent history of renewable generation. Therefore, it is reasonable to expect significant penetration of storage technology in the grid in the future. This could occur both as grid-scale storage, and aggregated end-user (e.g. domestic) storage. This can be expected to occur within the economic lifetime of generation assets that are currently being planned, and could well happen within the lifetime of assets that are currently in service.

How will widespread introduction of storage technology affect generation assets? The complex interactions between storage and intermittent renewables, multiple types of conventional generation, transmission constraints and ancillary service requirements can lead to non-obvious energy market outcomes.

In this paper, we present the results of simulations to forecast the energy market impact of storage on several classes of conventional generation, in terms of market prices received, market dispatch, and hence revenue and profitability. We present the results of this analysis for three Asia-Pacific markets, each with different market fundamentals and storage quantity scenarios. From this, we draw out key risks and opportunities for energy market investors in the region.

2. Simulation Methodology

To quantify the impact of grid-scale storage, we have used a simulation model of the target markets to forecast the market outcomes under scenarios with and without the additional storage.

The model used is WEMSIM (Wholesale Electricity Market Simulation), a proprietary model used by Robinson Bowmaker Paul (RBP) to provide market analysis to support power market transactions and reforms. WEMSIM simulates the dispatch of thermal and renewable generators in a nodal wholesale market environment, given forecast demand and fuel prices, and subject to transmission system constraints and generation plant characteristics.

As a result, plant dispatch, nodal prices and other market outcomes can be simulated under storage- and no-storage scenarios, and the results compared to determine the impact of the storage.

For this study, we are simulating a single representative year for each scenario.

3. Simulations

3.1 Simulation 1: The South Australian Grid-Connected Battery Storage Project

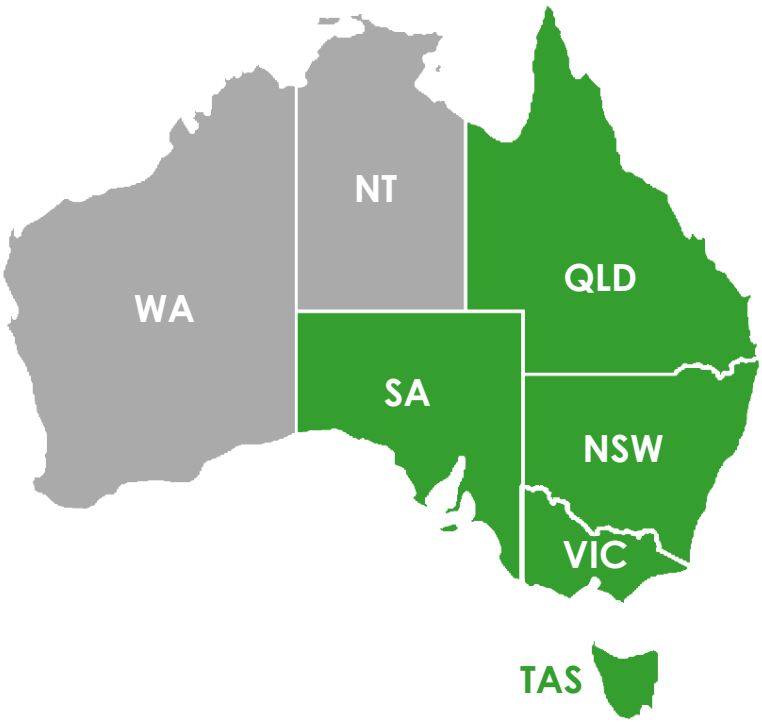
3.1.1 Introduction

Our first simulation focusses on the South Australia region of Australia's National Electricity Market (NEM). The NEM covers Australia's western states of Queensland, New South Wales, Victoria, Tasmania, and South Australia (SA).

SA is particularly prone to volatility and periods of high pricing, and last year suffered an extensive system blackout. This has been blamed in part on the large quantity of intermittent renewable generation, particularly wind, that has entered the market in recent years. This is exacerbated by the constrained interconnections with the rest of the NEM system. One of the SA Government's responses has been to issue a tender for the supply of 100 MW of grid-connected battery storage[1]. The tender received over 90 proposals in the first round, demonstrating the significant commercial interest in implementing grid battery storage.

One response to the tender proposes a total of 600MWh storage capacity with 200MW maximum output. The proponent has indicated that this project would go ahead regardless of whether it wins the tender, and has already secured land. We have chosen to simulate a system of this capacity as an example of the scale of facility likely to enter the SA system.

The SA region is interconnected with, and is part of the wider NEM market, so this simulation involves modelling the entire NEM market. The results presented below focus on the SA region, though we have included some out-of-state coal-fired generation in results for illustrative purposes.



[1] http://www.renewablessa.sa.gov.au/news/south-australian-grid-connected-battery-storage-project

3.1.2 Results

Table 1 presents summary results from this simulation on SA-wide outcomes. These results show that:

- The presence of the battery storage facility reduces time-weighted average prices (i.e. a simple average of prices across the year) by AUD2.83/MWh, or a 3.5% reduction on the no-battery scenario price.
- Similarly, the load-weighted average price is reduced by AUD6.05/MWh, or 5.9%. This figure is larger because the price reductions are greater at times of peak load.
- These price reductions result in a net saving of AUD87m in wholesale energy cost for SA electricity consumers
- Conversely, SA generators lose AUD127m in wholesale market revenue.
- The battery facility makes AUD41m in wholesale market revenue through the arbitrage in market prices

In summary, these results show a significant transfer of wealth from generators to consumers and the owner of the battery storage facility.

Table 1. South Australia summary results

Result	No Battery	Battery	Difference	
Time-weighted average price (AUD/MWh)	$80.01	$77.17	-$2.83	-3.5%
Load-weighted average price (AUD/MWh)	$102.16	$96.11	-$6.05	-5.9%
Total consumer cost (MM AUD)	$1,447.0	$1,359.6	-$87.33	-6.0%
Total generator market revenue (MM AUD)	$1,406.4	$1,279.1	-$127.36	-9.1%
Battery market revenue (MM AUD)	$-	$40.9	$40.93	

Figure 1 compares the price duration curve for the SA region with and without the battery storage facility. This shows the expected general pattern of reduced prices at peak times while the battery is discharging and increased prices at off-peak times while the battery is charging.

However, this is not universally true; there are some times when the battery scenario price is higher that the non-battery scenario price even though prices are above average. The main reason for this is that the battery does not have the capacity to optimize over the entire year; Its charge-discharge cycle is measured in hours up to a day. As a result, there will be times when it is optimal to charge at above-average prices to be able to prevent even higher prices or unserved energy shortly afterwards.

Figure 1. South Australia price duration curve comparison

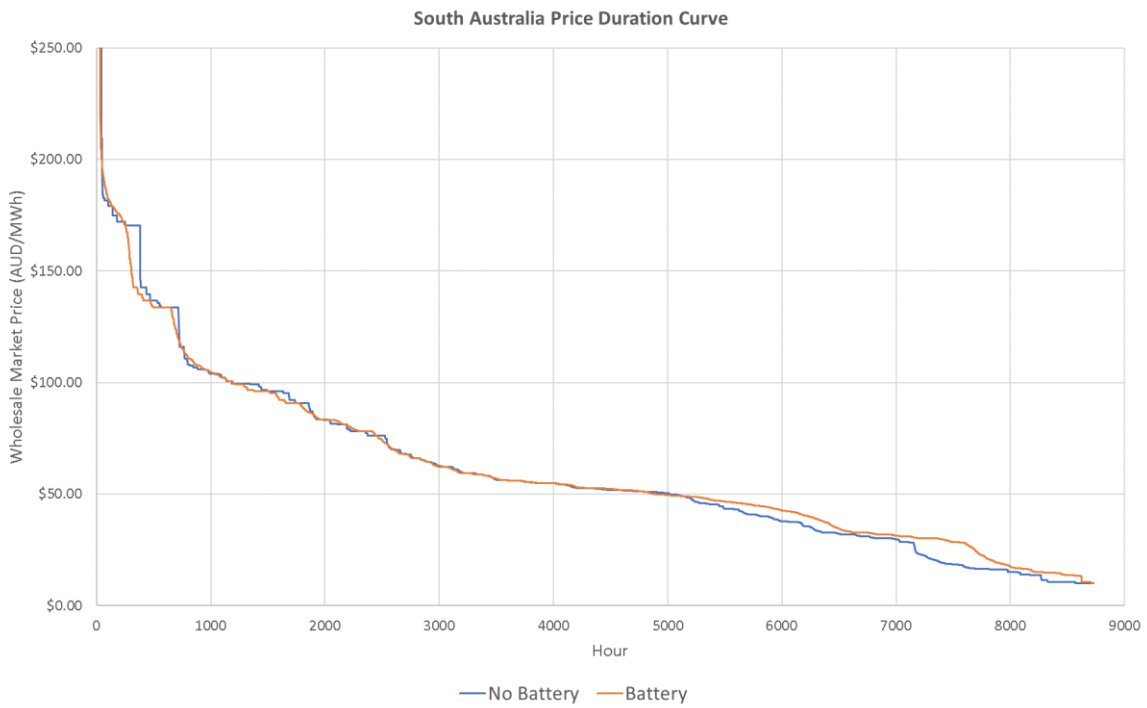


Figure 2 shows the impact of the battery on an average daily generation profile. The storage facility causes an increase in generation during the off-peak periods when it is charging its batteries, and a decrease in generation during peak periods when it is supplying energy to the grid.

Figure 2. Average daily generation profile

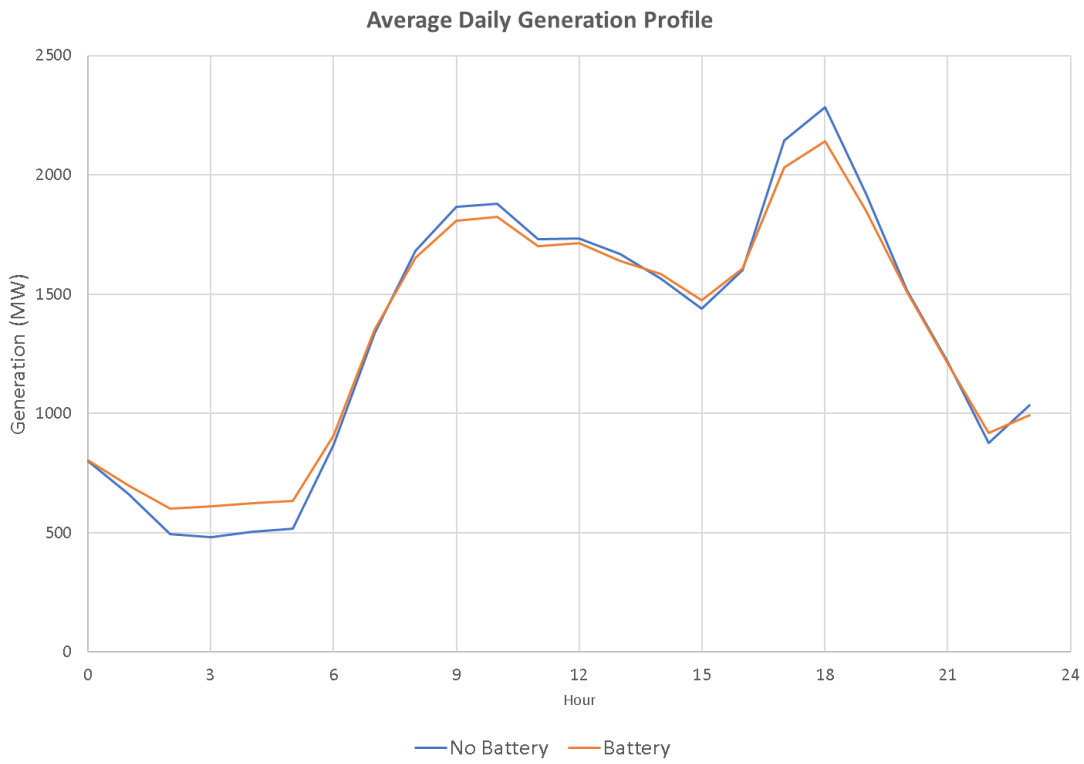


Table 2 and Table 3 provide the GWh generation and market revenue results of this simulation for the main classes of generation capacity in SA.

Table 2. SA generation results (GWh)

Generation type	No Battery	Battery	Difference	
Gas Turbine	93.6	55.9	-37.68	-40.3%
Wind	5167.3	5190.3	23.05	0.4%
CCGT	987.7	598.7	-389.02	-39.4%
Black Coal ST	2582.3	2713.6	131.25	5.1%
Gas ST	1930.1	1566.6	-363.54	-18.8%

Table 3. SA market revenue results (Million AUD)

Generation type	No Battery	Battery	Difference	
Gas Turbine	143,212	110,956	-32,255	-22.5%
Wind	415,688	400,121	-15,567	-3.7%
CCGT	162,493	104,918	-57,574	-35.4%
Black Coal ST	270,153	294,325	24,172	8.9%
Gas ST	414,876	327,812	-87,064	-21.0%

These results show that:

- As expected, the utilisation of gas turbine peakers is significantly reduced, as the battery takes over their roles in meeting rapid changes in demand.
- Less expected is the reduction in utilisation of mid-merit gas-fired combined-cycle gas turbines (CCGTs) and stream turbines (STs). This is due to the battery enabling better use of the interconnectors to bring in lower priced out-of-state generation.
- Wind generators see a small improvement in utilisation as the batteries enable better integration and reduce curtailment.
- Baseload coal-fired generation (from out of state) sees a small increase in utilisation as it provides the generation to charge the batteries
- Overall, there is a reduction of generation from within the state of SA due to the better utilisation of the interconnectors
- Gas-fired peakers, CCGTs and STs all see significant reductions in market revenue with their reduced utilisation and overall lower market prices
- Despite their slightly higher utilisation, wind generators see a drop in revenue due to the overall lower market prices
- Coal generators see an increase in revenue due to the increased load and higher prices when the batteries are charging.

3.1.3 Conclusion

The commissioning of a large battery storage facility in a market with volatile prices such as SA can significantly reduce market prices. While it is expected that peaking plant would see a drop in dispatch and revenue, our modelling shows that mid-merit plant can also be negatively affected. Baseload plant, however, will experience a rise in utilisation and off-peak prices that can more than offset the overall lower market prices.

Overall, these results represent a transfer of wealth from generators to consumers and the owners of the battery storage projects. Given that the SA government is actively tendering for storage capacity, generators need to plan to offset this potential loss. Investing in battery storage projects is one possible hedge against this potential loss.

3.2 Simulation 2: Grid Storage in the Philippines' Visayas Grid

3.2.1 Introduction

The Visayas region of the Philippines is an archipelago of islands to the south of Luzon. It is connected to the main grid of Luzon via a series of subsea interconnectors. The limited capacity of these interconnectors and a deficit of generation capacity in the region has led to high and volatile prices, and unserved energy.

The conventional solution to this problem would be to encourage additional thermal generation build, with the associated pollution/emissions and fuel costs, or the relatively expensive option of upgrading the Visayas grid.

Another option would be to install grid-connected battery storage in the Visayas. This would improve the reliability of supply and lower peak prices by making better use of the existing generation capacity, and reduce the reliance on supply from Luzon. Several such projects have been proposed, but none have yet come to fruition.

For this simulation, we have assumed a 300MWh/100MW storage facility, located in the central Visayas island of Cebu. This does not represent a particular project, but indicates the capacity required to make a significant impact. The base scenario assumes a load and generation capacity situation in which significant load shedding is occurring (0.18% of total demand).

3.2.2 Results

Table 4 presents summary results from this simulation for generators and consumers in Cebu. These results show that:

- The presence of the battery storage facility reduces time-weighted average prices by USD68.77/MWh, or a 34% reduction on the no-battery scenario price, by reducing the prevalence of high prices driven by generation shortages and reducing the use of high-priced peaker generators.
- Similarly, the load-weighted average price is reduced by USD56.56/MWh, or 31%. Note that load-weighted average prices are lower than time-weighted prices in this simulation, as high prices are largely driven by planned outages of generation plant (rather than peak loads), which are scheduled to occur during low loads
- Load shedding is cut by two thirds
- These price reductions result in a net saving of USD74m in wholesale energy cost for Cebu electricity consumers
- Conversely, Cebu generators lose USD35m in wholesale market revenue.
- The battery facility makes USD34m in wholesale market revenue through the arbitrage in market prices

Again, these results show a significant transfer of wealth from generators to consumers and the owner of the battery storage facility.

Table 4. Cebu summary results

Result	No Battery	Battery	Difference	
Time-weighted average price (USD/MWh)	$112.89	$103.60	-$9.29	-8.2%
Load-weighted average price (USD/MWh)	$120.45	$108.88	-$11.57	-9.6%
Load shedding (% of total demand)	0.18%	0.06%	-0.13%	-69.0%
Total Consumer cost (MM USD)	$772.93	$698.66	-$74.27	-9.6%
Total generator market revenue (MM USD)	$524.55	$489.72	-$34.83	-6.6%
Battery market revenue (MM USD)	0	$34.23	$34.23	

Figure 3 compares the price duration curve of the main Cebu market node with and without the battery storage facility. This shows the expected reduction in prices during peak periods when the battery is discharging, and higher prices during off-peak periods when the battery is charging. This is the expected outcome.

Figure 3. Cebu price duration curve comparison

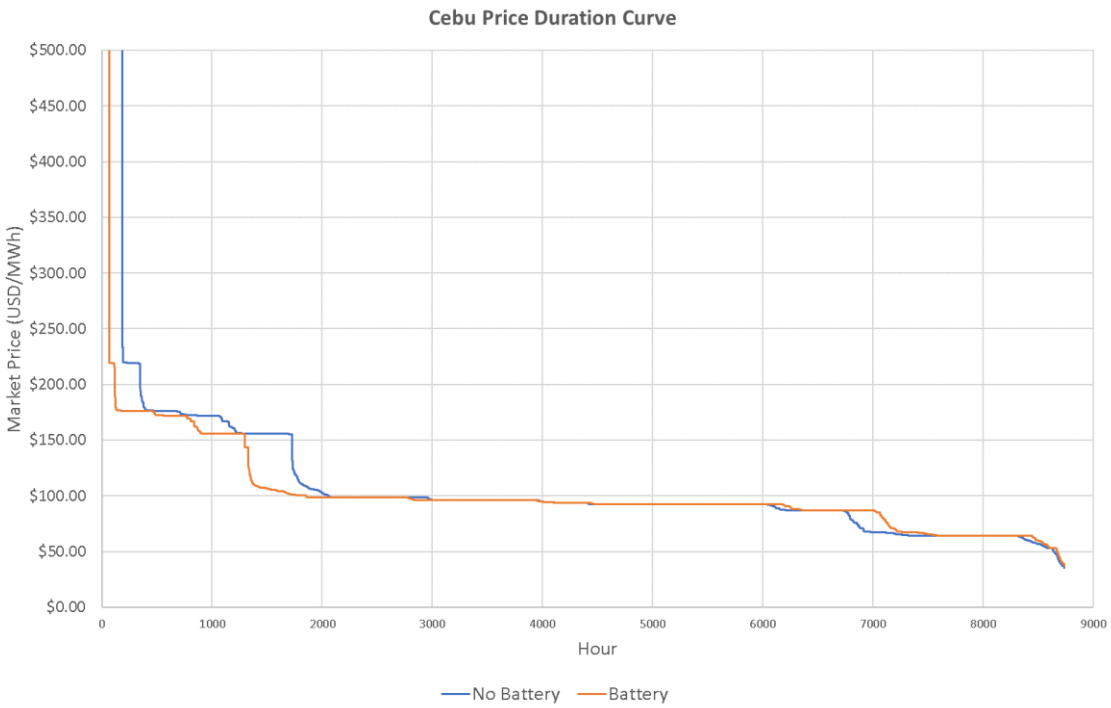


Table 5 and Table 6 provide the GWh generation and market revenue results of this simulation for the types of generation capacity in the Visayas region.

Table 5. Visayas generation results (GWh)

Generation type	No Battery	Battery	Difference	
Biomass	408.8	408.8	0.0	0.0%
Coal (Low Grade)	1,593.6	1,582.6	-11.0	-0.7%
Coal	4,559.5	4,627.4	67.9	1.5%
Diesel	203.5	133.8	-69.6	-34.2%
Geothermal	2,404.3	2,406.7	2.4	0.1%
Hydro	177.4	177.4	0.0	0.0%
Solar	69.0	69.0	0.0	0.0%
Wind	211.9	211.9	0.0	0.0%

Table 6. Visayas market revenue results (Million USD)

Generation type	No Battery	Battery	Difference	
Biomass	20,805.6	20,786.0	-19.6	-0.1%
Coal (Low Grade)	199,010.0	178,390.1	-20,619.9	-10.4%
Coal	375,603.4	366,377.4	-9,226.0	-2.5%
Diesel	57,199.1	30,957.3	-26,241.8	-45.9%
Geothermal	145,876.4	145,731.2	-145.2	-0.1%
Hydro	14,950.8	13,892.7	-1,058.2	-7.1%
Solar	3,506.5	3,502.0	-4.5	-0.1%
Wind	10,443.8	10,432.5	-11.3	-0.1%

These results show that:

- The only class of generator that has its utilisation significantly reduced by the battery is the diesel-fired peakers, which are the highest-priced generators in the region.
- Coal-fired generators, which provide the baseload generation in the region, see an increase in generation as they charge the batteries in off-peak periods.
- Overall, generation in the region is reduced slightly, as the battery enables better use of the interconnector with Luzon
- There is a significant reduction in revenue for thermal and hydro generators due to the lowered market prices
- Diesel peakers take an extra reduction in revenue as their dispatch is reduced in addition to the lower market prices
- Biomass, Geothermal, Solar and Wind do not see significant reductions in revenue, as they are located at market nodes that are insulated from the reduced prices by transmission constraints.

3.2.3 Conclusion

Regions experiencing load shedding, high prices and grid constraints may well consider battery storage as an alternative to investing in additional generation or transmission upgrades. These results show that battery storage can be an effective alternative.

As for the SA simulation, there is a net transfer of wealth from generators to consumers and battery owners. However, in a constrained transmission network, the magnitude of a generator's loss is very dependent on factors such as the type of generator and its location.

BANGUI WIND FARM (33MW)
ILOCOS NORTE, PHILIPPINES

3.3 Simulation 3: Solar PV and Grid Storage in the Singapore NEMS

3.3.1 Introduction

The following simulation serves as a counterpoint to the above scenarios. The Singapore market is characterised by very flat pricing and no significant transmission constraints. This is the result of an excess of capacity, consisting largely of very similar gas-fired CCGTs. A significant capacity of older steam turbine and gas turbine facilities are also held in reserve. As such, the case for grid-scale storage is not as strong as the previous two scenarios.

In 2014, the Singapore government announced the intention to raise the adoption of solar power to 350MW by 2020. As of the first quarter of 2017, Singapore has 99MW of grid-connected solar PV systems.

While the grid could likely cope with this quantity of intermittent generation without the addition of storage, adding storage would be in line with Singapore's history of extremely risk averse development of the power system. Indeed, the Energy Market Authority have launched a pilot program for the introduction of grid storage.

For this simulation, we have assumed a 600MWh/200MW battery storage facility, located centrally on the 230kV grid. This does not represent any specific project, but is representative of a large grid-scale project. The 350MW of solar capacity is present in both scenarios.

3.3.2 Results

Table 7 provides the Singapore-wide summary results from this simulation. These results show that:

- There is negligible impact on market prices
- There is also negligible impact on total consumer energy cost or overall generator revenue
- The battery storage facility makes just over SGD 1 million from market price arbitrage. This would, by itself, be a poor return on an SGD 300-500 million investment. The facility would need to get its primary income by providing reserve and system support services.

Table 7. Singapore summary results

Result	No Battery	Battery	Difference	
Time-weighted average price (SGD/MWh)	140.02	139.99	-$0.03	-0.02%
Load-weighted average price (SGD/MWh)	139.98	139.96	-$0.02	-0.02%
Total Consumer cost (MM SGD)	7,828.87	7,827.56	-$1.30	-0.02%
Total generator market revenue (MM SGD)	7,943.49	7,942.64	-$0.85	-0.01%
Battery market revenue (MM SGD)	0	$1.05	$1.05	

Figure 4 compares the price duration curve of the Singapore market price with and without the battery storage facility. This again shows that the storage facility has very little impact on market prices, due to the already very flat shape of the existing price curve.

Figure 4. Singapore price duration curve comparison

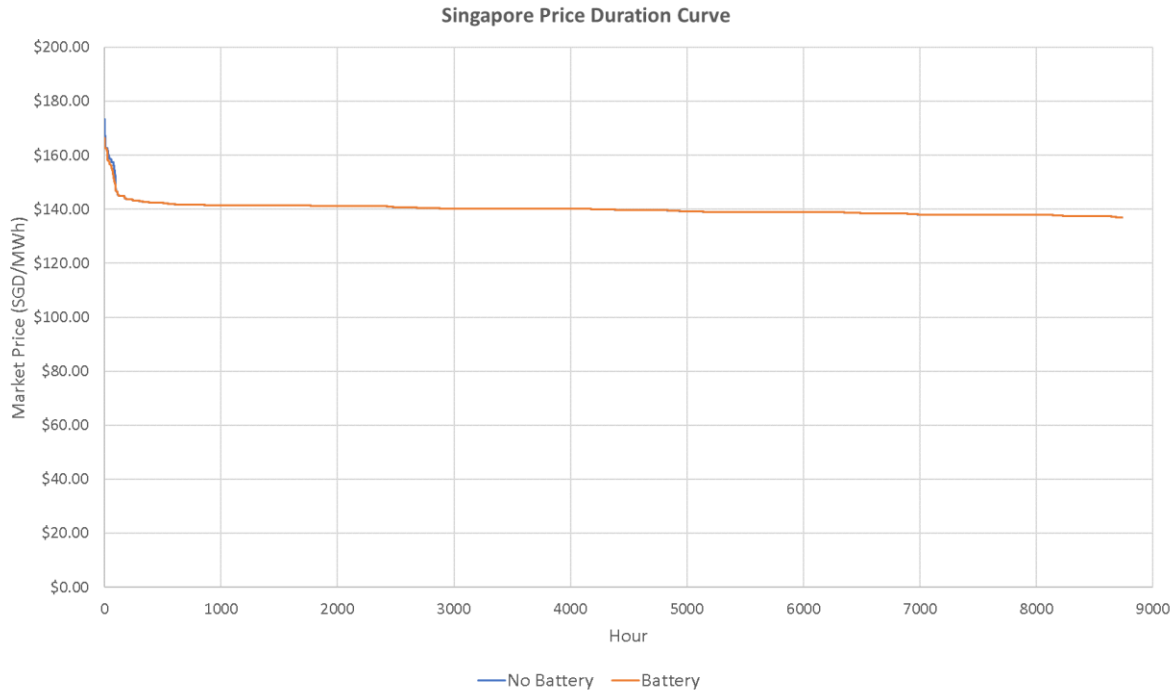


Table 8 and Table 9 provide the GWh generation and market revenue results of this simulation for each type of generation capacity in Singapore.

Table 8. Singapore generation results (GWh)

Generation type	No Battery	Battery	Difference	
CCGT	55,935.9	55,938.9	3.0	0.01%
OCGT	0.0	0.0	0.0	
ST	692.8	690.1	-2.7	-0.39%
Solar	689.8	689.8	0.0	0.00%
Other	61.6	61.5	-0.1	-0.19%

Table 9. Singapore market revenue results (SGD Million)

Generation type	No Battery	Battery	Difference	
CCGT	7,742.9	7,741.5	-1.4	-0.02%
OCGT	0.0	0.0	0.0	
ST	95.7	95.3	-0.5	-0.48%
Solar	96.1	96.1	0.0	-0.01%
Other	8.8	8.8	0.0	-0.57%

As expected, the differences between the no-battery and battery scenarios are minor:

- There is a small shift of generation from the Steam Turbines (STs), which are setting the peak market prices, to the CCGTs, which will be providing the generation to charge the batteries
- Each class of generation sees a drop in revenue due to the slightly lower market prices, but in all cases the drop is less than 1%.

3.3.3 Conclusion

In a market that is free of transmission constraints, generation shortages and volatile market prices, such as Singapore, the impact of battery storage on wholesale energy market outcomes is likely to be minimal.

ROBINSON BOWMAKER PAUL

4. Conclusions

In markets experiencing volatile market prices (whether as the result of generation shortages, constrained grids, or a peaky demand curve and diverse generation fleet), a large battery storage facility can significantly reduce market prices. It is a given that peaking plant would see a drop in dispatch and revenue, however mid-merit plant can also be negatively affected. Whether baseload plant will experience increased utilisation and off-peak prices to offset the overall lower market prices depends on the dynamics of the particular market.

In such situations, there is a net transfer of wealth from generators to battery owners, and a larger one from generators to consumers. The magnitude of a generator's loss is very dependent on factors such as the type of generator and its location in a constrained transmission network. This is a potential loss that generators should plan to mitigate. Possible hedges against this loss include investing in storage projects and baseload generation.

In a market that is free of transmission constraints, generation shortages and volatile market prices, the impact of battery storage on wholesale energy market outcomes is likely to be minimal.

If you need an independent, expert view on the outlook for your energy market assets, we'd be happy to help. Please get in touch.

Richard Bowmaker
richard.bowmaker@rbp.consulting
+64 4 4965630
+64 21 1352526

Tim Robinson
tim.robinson@rbp.consulting
+64 4 4965619
+64 21 576483

Images: p2 Tesla. stock.adobe.com: p1 eyematrix p4 soonthorn, p5 Alois, p10 sean heatley, p11/16 bonilla1879 p15 PerfectLazyBones, p17 SeanPavonePhoto, p19 Teppakorn

ROBINSON BOWMAKER PAUL
Level 8
104 The Terrace
Wellington 6011
NEW ZEALAND

@RBPEnergy
rbp.consulting