WESTERN POWER DISTRIBUTION
INNOVATION

British Solar Renewables

NEXT GENERATION NETWORKS

Solar Storage Dissemination Webinar

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Webinar Contents

- Project overview
- Results for each use case
- Overall project conclusions
- Q&A

The project was funded by the Network Innovation Allowance (NIA), to investigate revenue streams available to Energy Storage Developers and grid services that could be offered to DNOs.

The project was split into three phases:

Procure, Build and Connect

The tender process was technology-agnostic, with particular weighting given to the round trip efficiency of the storage system. The size of 300kW was chosen as the smallest sized battery that could still have the required effects on the grid at 11kV.

- 11kV connection
- 1.5MWp 0.99MWAC solar park
- FiT subsidy unaffected

Operate and Test

The testing regime was delayed and interrupted by software bugs and teething troubles, which reduced the seasonal variation of the tests. However, these were corrected and the battery proved its reliability with tests 7 days a week during late 2017.

- 9 use cases
- Real-world test data
- Future revenue streams
- Inform the DSO transition

Removal, Sale and Reinstatement

It is believed that this is the only second-hand sale of a battery of this scale in the UK, and it is unprecedented for the assets of a NIA project to be sold at the end of the trial. While no longer brand new, the battery had a proven track record of reliability from the later part of the testing regime, providing reassurance for bidders.

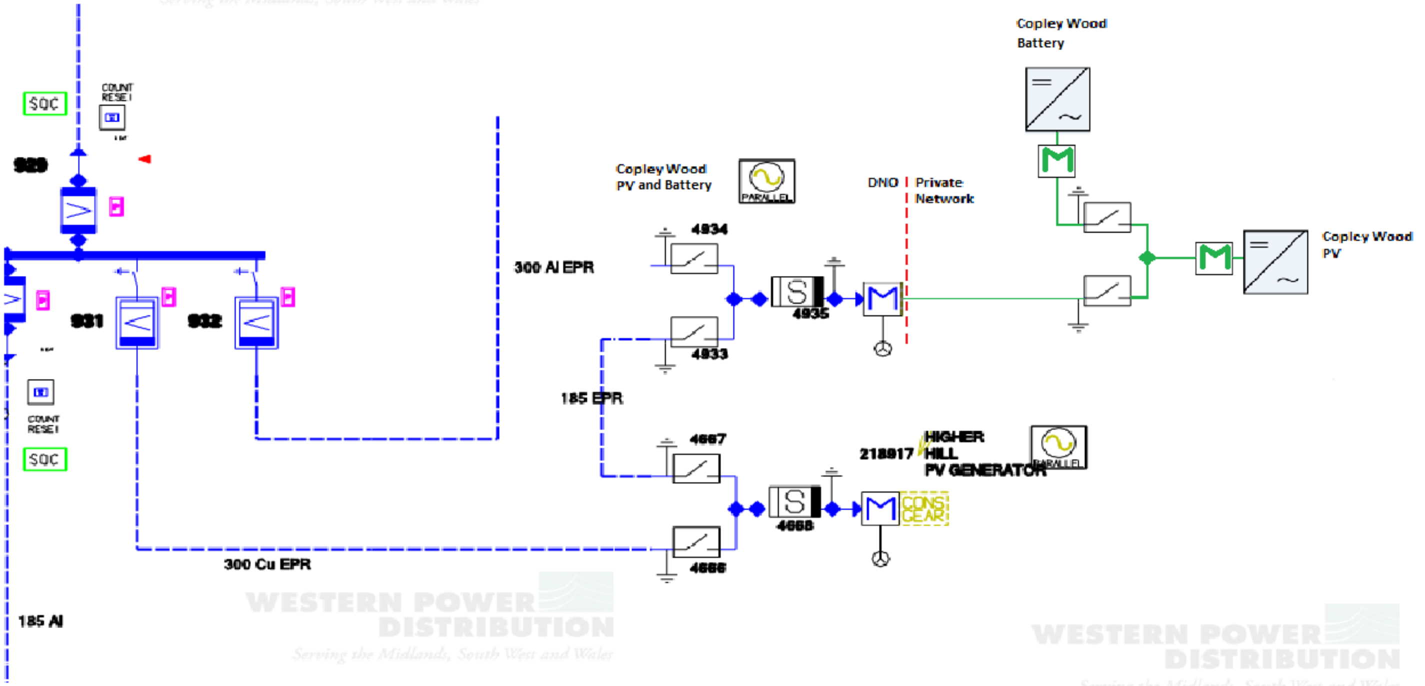
- First sale of its type in the UK
- Gain value for consumers by reducing the cost of the trial
- Provide extra learning

The Battery

- Lithium Ion Iron Phosphate Cells
- 300 kW nominal (310kW inverter)
- 658kWh nominal (actual initial capacity >700kWh)
- Single 40 ft container
- Two hour depth

The Solar Park and Battery Layout

The Connection for the Battery



The Use Cases

Use Case	Notes on Testing	Results
Arbitrage	Easy to implement testing of simple timed arbitrage. More accurate price-triggered arbitrage was beyond the scope of this project.	Real-world results provided little to no revenue due to existing contractual agreements. Results based on simulated prices significantly more promising.
Peak demand limiting	Easy to monitor effectiveness on this feeder due to the Argand monitoring system installed in WPD's substation. The export could have been triggered by a signal in a similar way to local demand peak lopping.	The results in WPD's analogues are impossible to see, but the Argand monitoring shows the reduction of load on the 11kV feeder. This use case requires specific network conditions and constraints to be cost effective.
Local demand profile matching	Twice the complexity as this use case introduces an external trigger, which needed programming separately. However, exciting to see the potential for communication between different energy assets	Highly reliable response to external trigger, meaning not only a success for this use case but a variety of other future scenarios
Low demand grid voltage support	Another simple testing regime: schedule the battery to import power overnight. It was expected that the clean feeder would allow the effect to be shown more clearly.	The unpredictability of the live substation, including the potential changing of an automated tap changer, coupled with the relatively small size of the battery, means any effect is difficult to see.

The Use Cases

Use Case	Notes on Testing	Results
Voltage control by reactive power	Setting up the testing was more complex than with other use cases, as a control slope percentage had to be calculated for the input. This could have been made simpler by allowing maximum and minimum voltages to be set instead.	The battery was able to affect the power factor seen by the network while the solar park was exporting, but the battery size was too small to have an effect on the voltage.
PV export limiting	This is the use case everyone wants to test as soon as combined solar and storage is mentioned. The algorithm made this easy to test, but predicting levels of solar generation was a big challenge.	Accurate response from the battery even during large swings of solar generation, although speed of response would need to be improved in a commercial project
Variable PV export limiting	This was to demonstrate a flexible peak lop level, but due to the way the testing works it is functionally the same as standard peak lopping	See above
Ramp Rate Control	It was sometimes challenging to select days with a fast enough change in generation to trigger the ramp rate control.	Days which had a fast enough ramp rate showed that the control method was very effective, and could smooth power output onto the grid
Multiple Battery Systems	It was not possible to investigate the impact of multiple systems on the network as only one battery was installed for the trial.	The interference this use case was to investigate is unlikely to occur, as batteries performing the same function are usually centrally controlled.

The Base Case

- ‘Default’ business case at the time of the trail: FFR and Capacity Market Auction
- Two rates calculated, one for 2016, one for 2018, showing how the market has changed
- 2018 hourly rate used during most of analysis as most relevant
- Constantly evolving market has reduced relevance of FFR, but still used as a constant to compare against and income level for viability.
- 2016 rate doesn’t include Capacity Market derating, while 2018 does.
- Calculated specifically as an hourly rate for this battery (310kW, 2 hours)

2016 Baseline Price: £7.31 per hour

Capacity market derating: 2 hour storage gives 64.79%

2018 Baseline Price: £2.79 per hour

Arbitrage

- Simplest of the use cases
- Originally expected to be always viable every day
- Relies on access to the variability of the energy market
- Most obvious candidate for being outsourced
- Couldn't generate a profit with existing agreements
- Likely to be the new base case going forwards due to declining FFR prices
- Constant revenue source, but unpredictable

Couldn't compete with FFR in 2016

Partially location-agnostic: grid charges are still variable

Every technology is chasing the price peaks

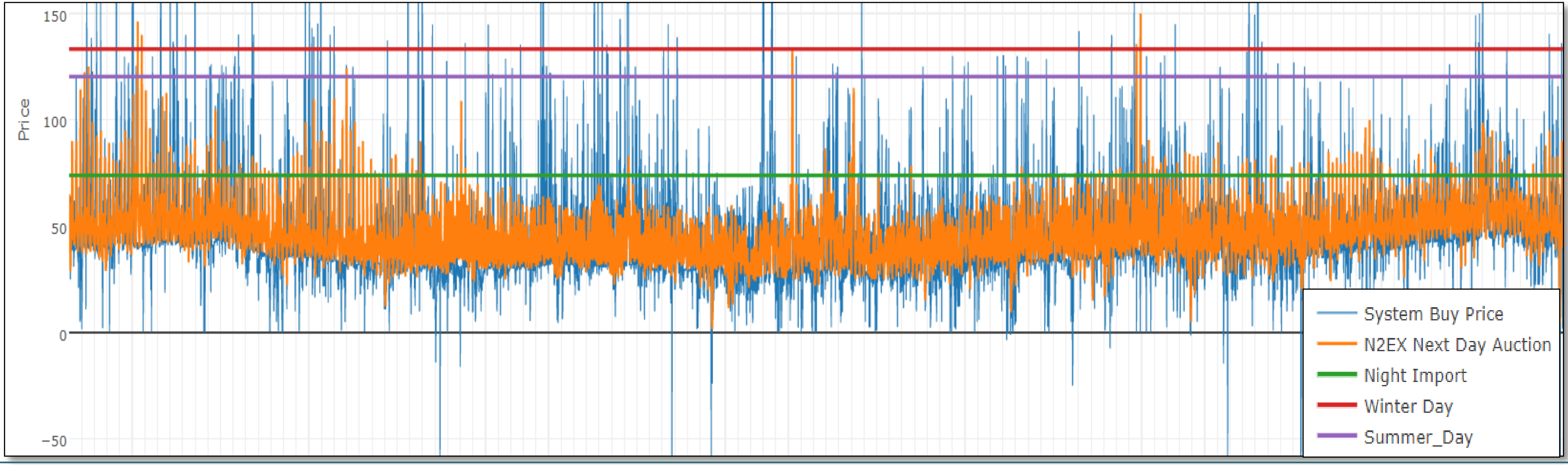
Arbitrage – Requirement for Virtual PPA

This graph demonstrates the power prices available to the park, as well as the system price. It shows the difference in variability of the markets.

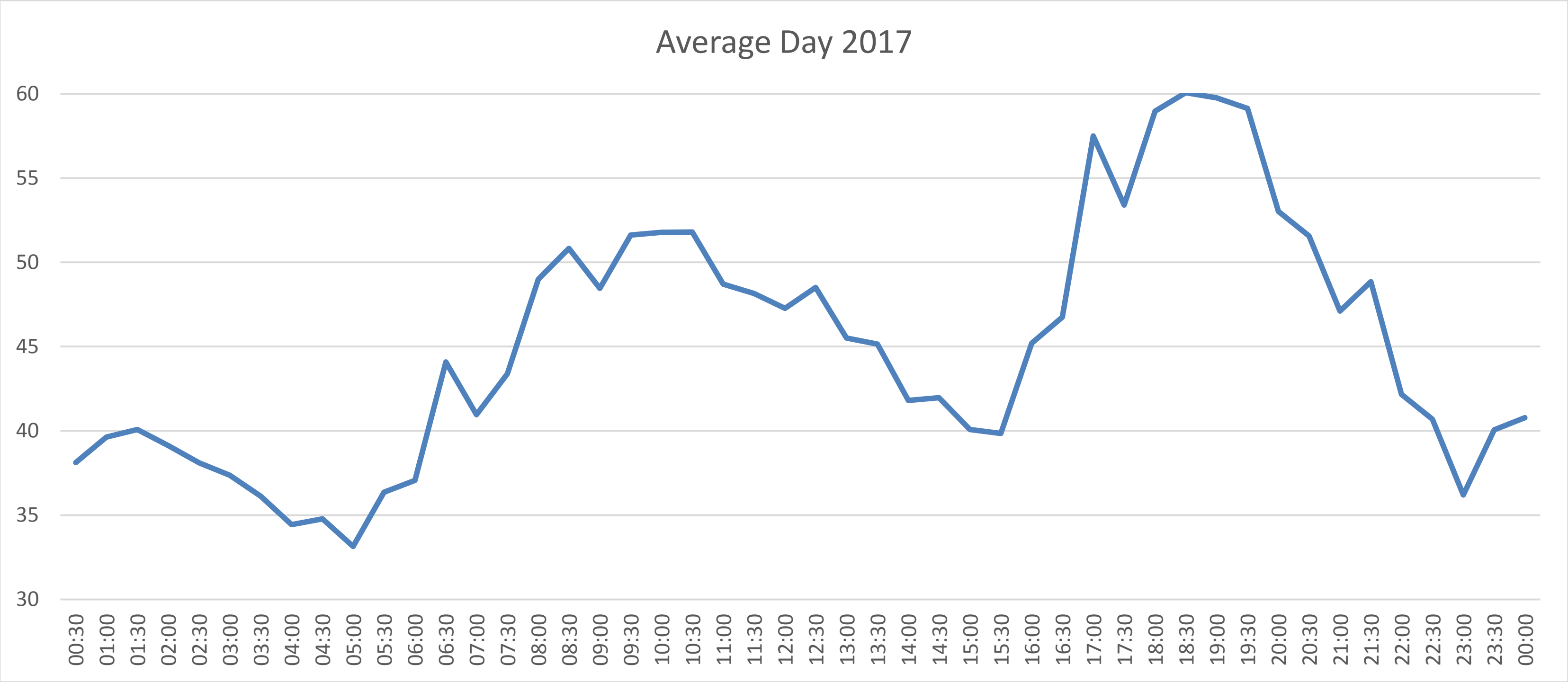
Import Virtual PPA includes:
- System price
- Supplier profit margin
- AAHEDC
- DUoS
- 7% system losses

Export Virtual PPA includes:
- System price
- Supplier profit margin
- AAHEDC
- Red DUoS credit
- 7% system losses credit
- BSuOS and RC credit

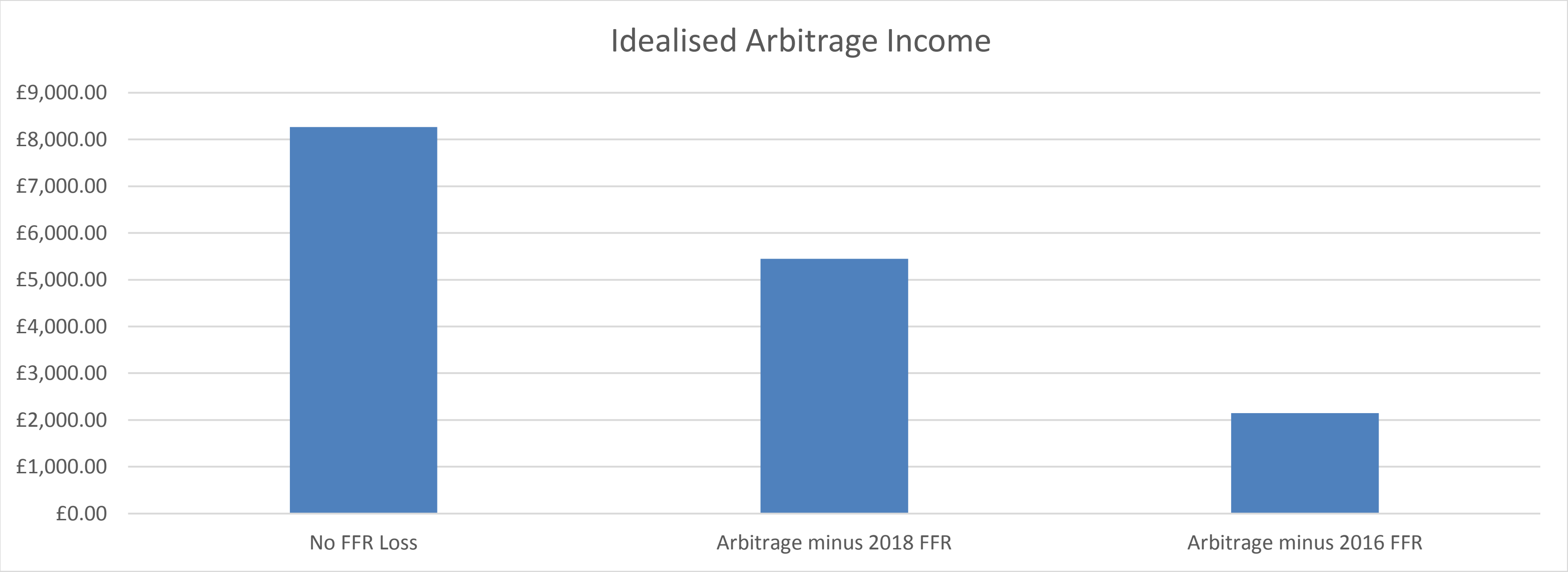
Virtual PPA excludes:
- CCL
- FiT
- CfD
- Capacity Market
- ROC



N2EX Export Price Average



A simulation based on a virtual PPA was run for the year 2017. The simulation was idealised, meaning that each arbitrage opportunity was captured, although this is impossible to predict in actual operation.



Arbitrage

DATETIME	Arbitrage Income	Low_FFR (2018)	Arbitrage Loss	High_FFR (2016)	Arbitrage Loss
31/01/2017	£828.42	£2,075.76	-£1,247.34	£5,438.64	-£4,610.22
28/02/2017	£589.45	£1,874.88	-£1,285.43	£4,912.32	-£4,322.87
31/03/2017	£623.88	£2,075.76	-£1,451.88	£5,438.64	-£4,814.76
30/04/2017	£568.83	£2,008.80	-£1,439.97	£5,263.20	-£4,694.37
31/05/2017	£1,376.53	£2,075.76	-£699.23	£5,438.64	-£4,062.11
30/06/2017	£707.58	£2,008.80	-£1,301.22	£5,263.20	-£4,555.62
31/07/2017	£697.22	£2,075.76	-£1,378.54	£5,438.64	-£4,741.42
31/08/2017	£578.37	£2,075.76	-£1,497.39	£5,438.64	-£4,860.27
30/09/2017	£642.17	£2,008.80	-£1,366.63	£5,263.20	-£4,621.03
31/10/2017	£660.46	£2,075.76	-£1,415.30	£5,438.64	-£4,778.18
30/11/2017	£407.96	£2,008.80	-£1,600.84	£5,263.20	-£4,855.24
31/12/2017	£585.12	£2,075.76	-£1,490.64	£5,438.64	-£4,853.52
Total	£8,265.97	£24,440.40	-£16,174.43	£64,035.60	-£55,769.63

Arbitrage Conclusions

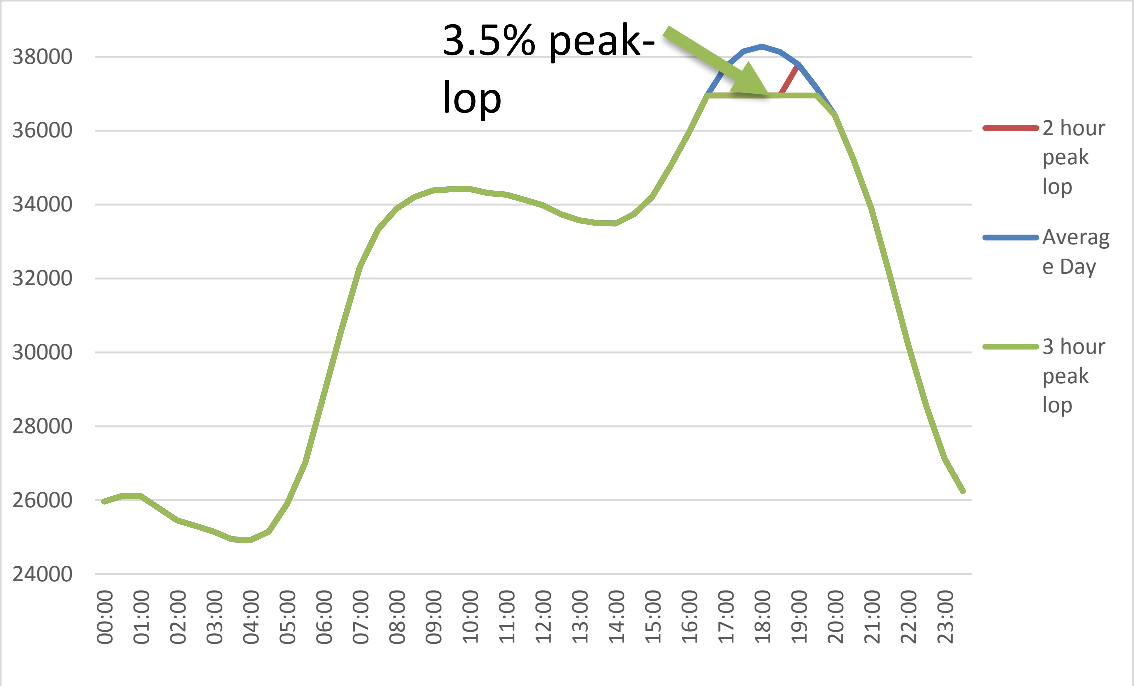
- Arbitrage at 2016 prices only reached 13% of FFR revenue
- At 2018 prices it reaches >33%
- Price variability is expected to increase, increasing this revenue stream
- Behind the meter batteries/batteries added to generation assets are at the mercy of existing grid agreements.
- Good capture of this revenue requires dedicated energy trading teams.
- The lack of geographic sensitivity and the lack of requirement to successfully bid on a contract to access this revenue makes it the expected future default case

Any Questions?

Network Demand Peak Lopping

Goals:

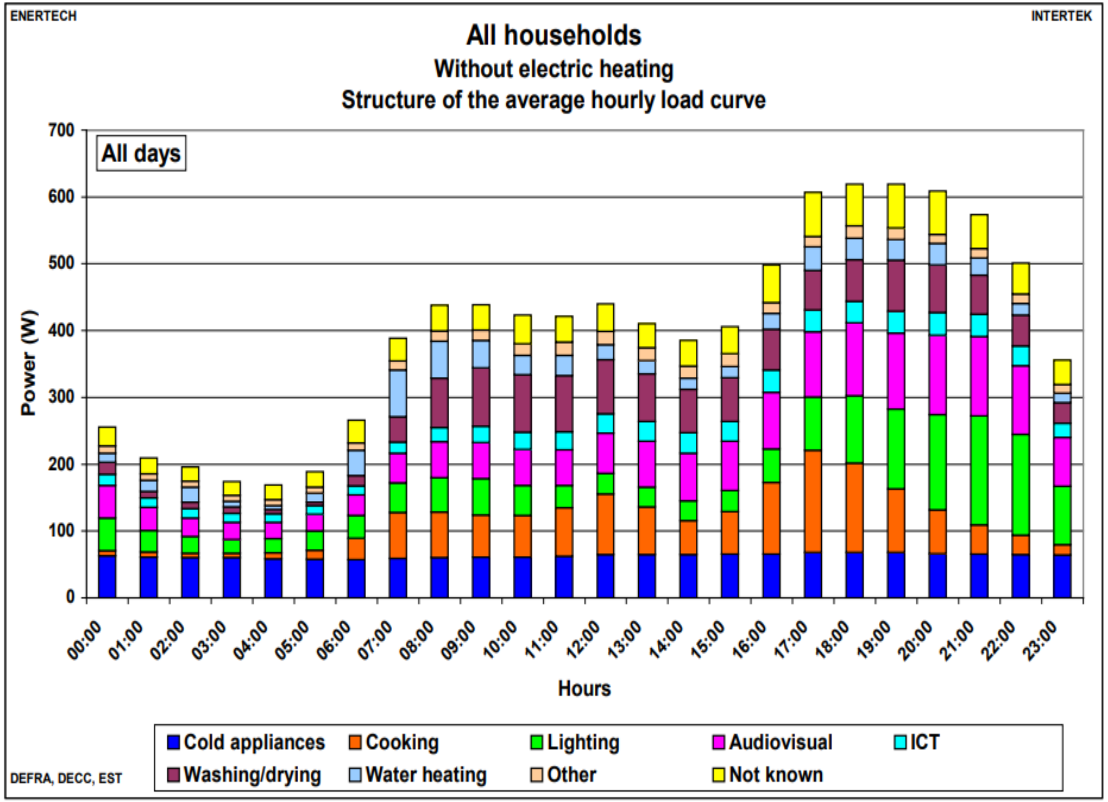
- Compliance with network planning standards e.g. P2/6
- Increase asset life
- Defer expensive upgrades
- Allow flexibility in selecting upgrade windows
- Reduce costs for consumers



Average UK-wide energy consumption

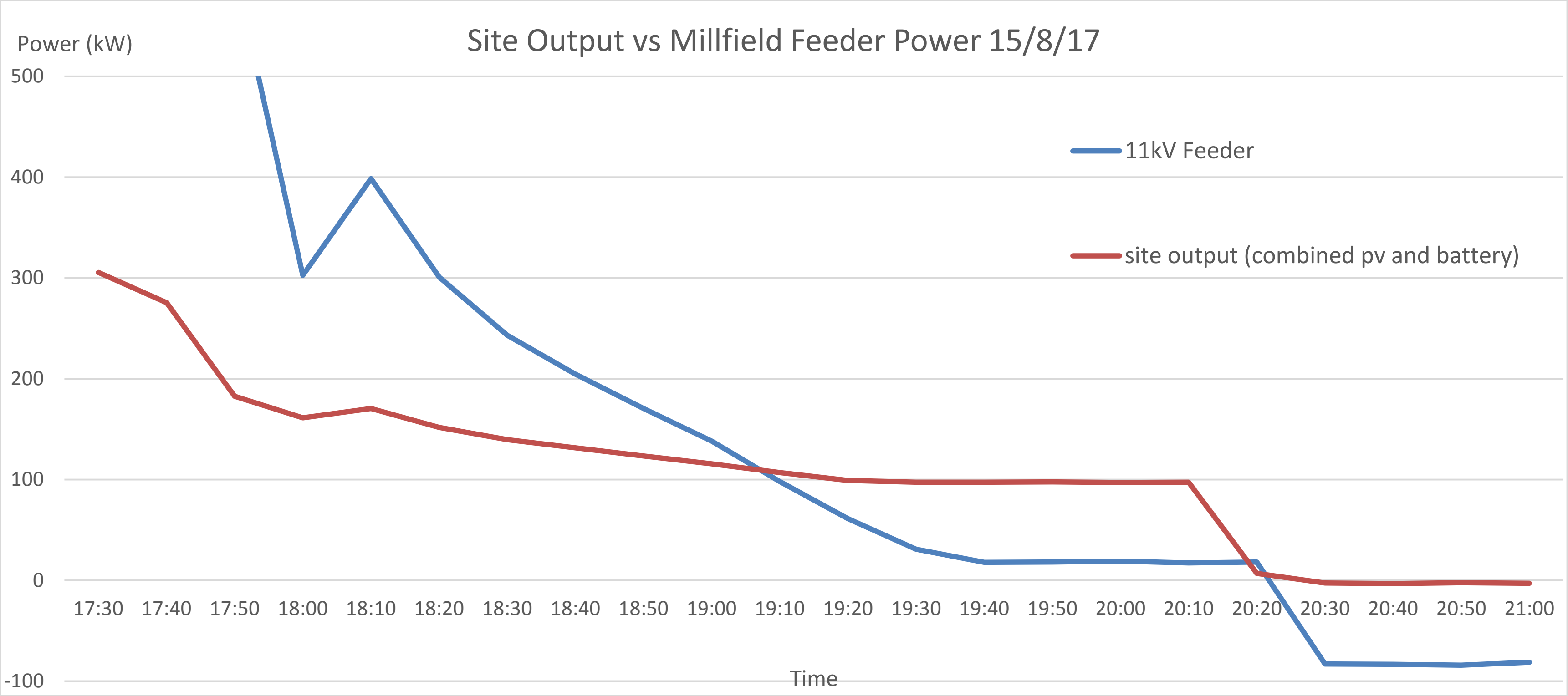
Class of Supply	Group Demand Range	Minimum Demand to be Met After	
		First Circuit Outage (n-1)	Second Circuit Outage (n-2)
A	Up to 1MW	In repair time: Group Demand	Nil
B	Over 1MW and up to 12MW	(a) Within 3 hours: Group Demand minus 1MW (b) In repair time: Group Demand	Nil
C	Over 12MW and up to 60MW	(a) Within 15 minutes: Smaller of Group Demand minus 12MW and 2/3 Group Demand (b) Within 3 hours: Group Demand	Nil
D	Over 60MW and up to 300MW	(a) Within 60 seconds: Group Demand minus 20MW (automatically disconnected) (b) Within 3 hours: Group Demand	(c) Within 3 hours (for Group Demand greater than 100MW): Smaller of Group Demand minus 100MW and 1/3 Group Demand (d) Within time to restore arranged outage: Group Demand
E	Over 300MW and up to 1500MW	(a) Within 60 seconds: Group Demand	(b) Within 60 seconds: All customers at 2/3 Group Demand (c) Within time to restore arranged outage: Group Demand
F	Over 1500MW	In accordance with the relevant transmission company licence security standard	

Network Demand Peak Lopping – Domestic Load



- Ability to peak lop highly dependent on primary load characteristic
- Predominantly domestic substations are likely to have predictable peak times
- Predictable peaks mean predictable contracts, reducing the time energy storage has to dedicated to this service and thereby reducing costs.
- Unlikely to be a long term revenue stream unless load growth rate is very slow, or with very predictable peaks
- Use case already being considered by DNOS, in SSE's CMZ (constraint management zone) tender

Network Demand Peak Lopping – Reducing Feeder Load

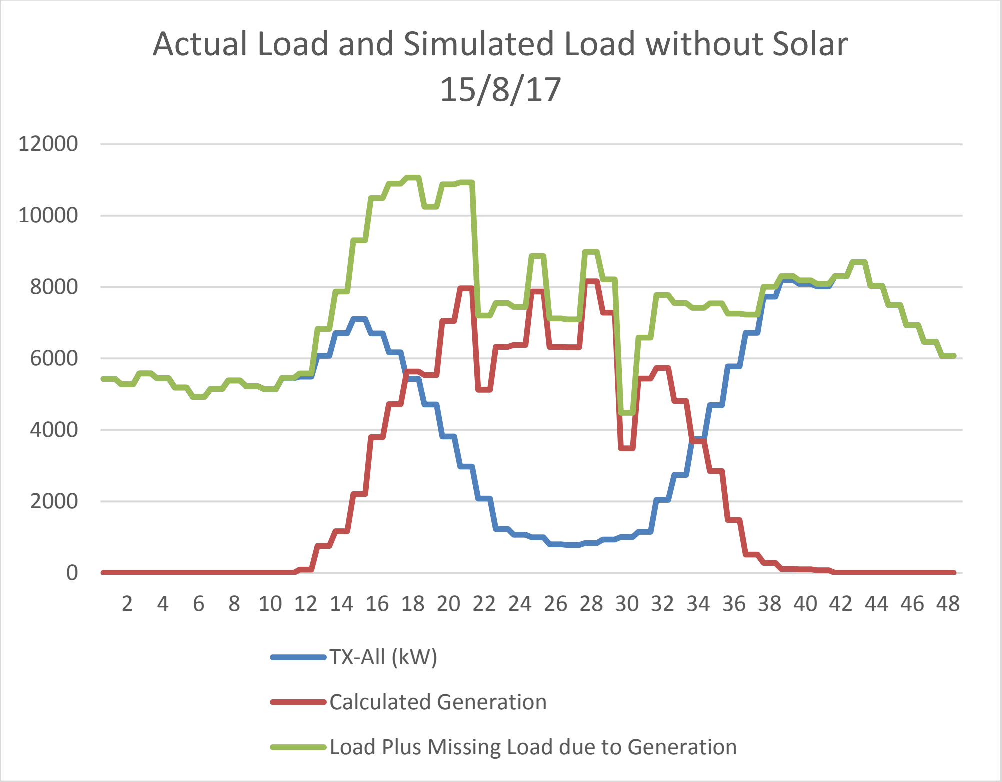


Network Demand Peak Lopping – Analysing Millfield Primary's Load Profile

Millfield Primary has a mixed load. It also has a total of three solar parks connected to the 11kV side, meaning that during the summer the WPD analogues see a large drop in load.

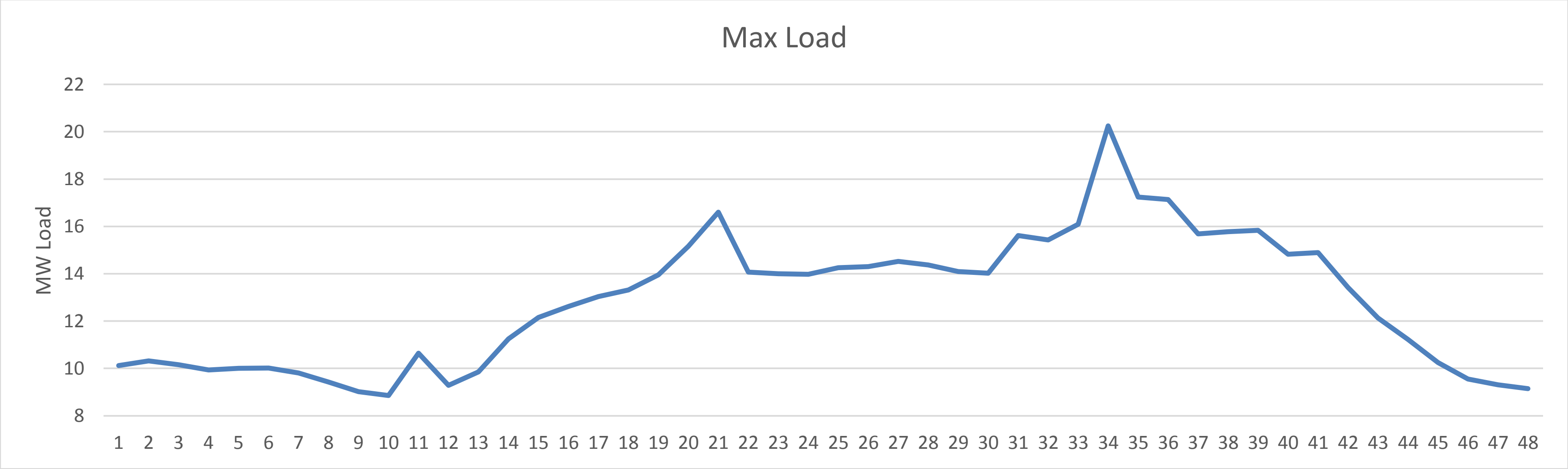
This load needs to be added back to the analogues to show a true picture of the Millfield consumption. As can be seen, this creates a very large morning peak, far in excess of the evening peak (likely due to Millfield School).

The distributed generation, the exact properties of which are hidden from the DNOs, makes sizing network assets more complex and hides changes in consumption.



Network Demand Peak Lopping – Max Loads at Millfield

- Obvious large peak during red charging period.
- Unexpected secondary peak at 10:30 am. (biggest challenge, not covered by expectations)
- Contracts run for 3 months at certain hours of the day, reducing costs
- Depending on capacity of the battery, potentially only part of the power would be required
- Accessing multiple markets at once drives costs down even further



Network Demand Peak Lopping – Results

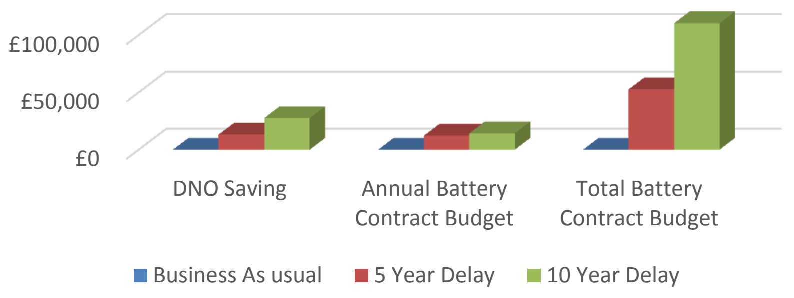
- Estimated cost of 33kV transformer replacement: £300-500k
- Substation requires replacement in pairs, for firm capacity
- Deferring investment saves money due to the time value of money
- Battery contracts have to be cheaper than this saving, to take into account reliability
- At the £2.79 hourly rate for a 310kW battery, the saving would be sufficient to contract a 700kW battery
- Longer contract length means potential for lower prices to be accepted

Large capital costs mean smaller battery payments more favourable

DNO will need to allow for some of the savings to cover admin costs

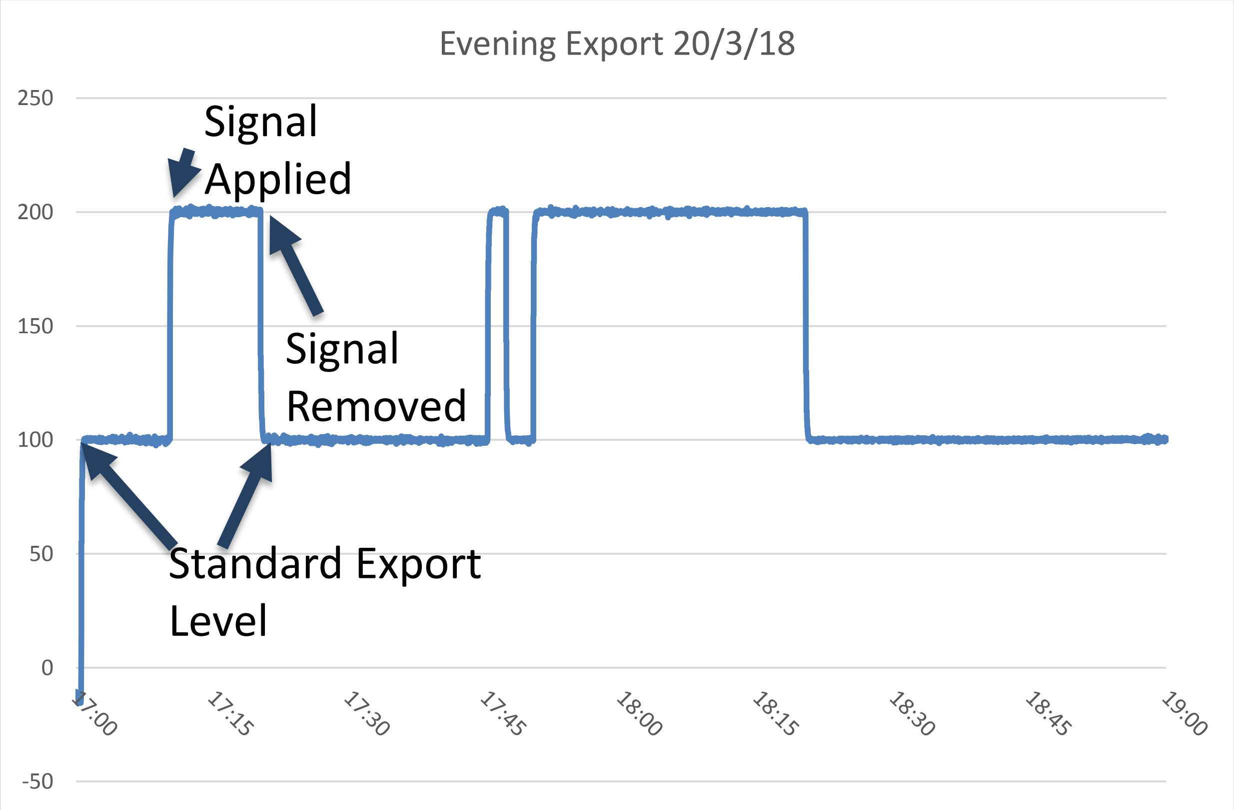
Geographically sensitive

Values of Delaying upgrades for 5/10 years, 2% inflation 5% discount rate



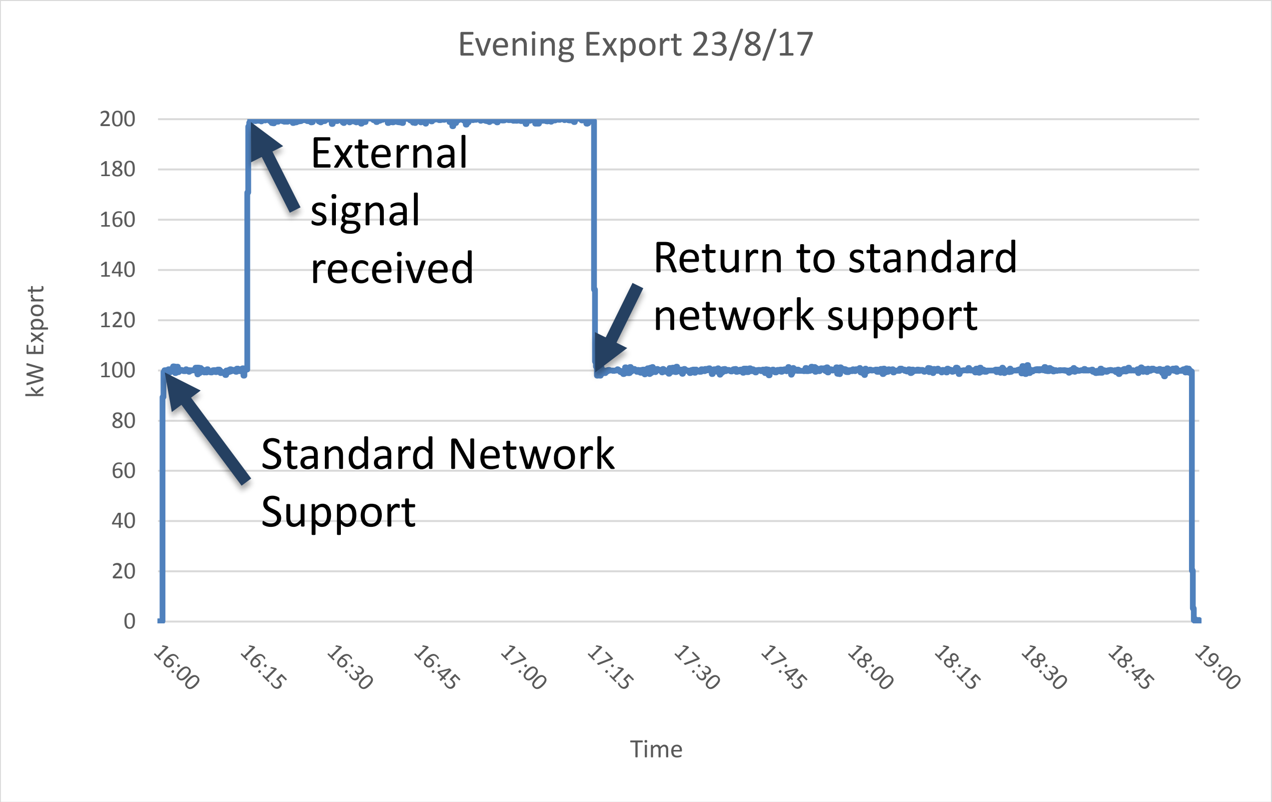
	Business As usual	5 Year Delay	10 Year Delay
DNO Saving	£0.00	£13,137.65	£27,555.92
Annual Battery Contract Budget	£0.00	£12,137.86	£14,274.47
Battery Contract Budget	£0.00	£52,550.58	£110,223.68

Local Demand Peak Lopping



- Shares similarities with network peak lopping
- Reliant on specific network constraints and a single high-power customer
- Demonstrates response from external signal
- Reliable response to the trigger, even with multiple signals in the same schedule.
- Originally meant to be emulating a soft-intertrip ANM signal, but demonstrates wider interoperability between systems.

Combining Local Demand Peak Lopping with Network Peak Lopping

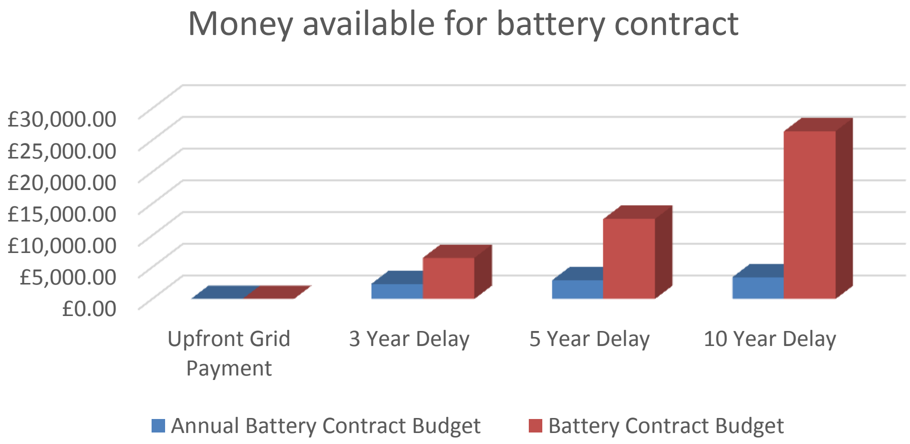


- De-rating of capacity for main use case to allow response to external signal
- This is a simplistic example: would also work with other use cases such as FFR or arbitrage.
- Would only require the ‘net effect’ of the signal to be responded to (i.e. could reduce the batteries import rather than increase the export).
- This use case requires specific network conditions to be viable. However the principle can be used on other use cases
- First combination of multiple use cases during the tests

Local Peak Lopping – Results

- Partial capacity use means opportunity cost is very low (£436 per 100kW, for 2 hours support for 3 months)
- Only a useful service in constrained sections of the network, where large customers are looking to increase their demand.
- Can be used to delay large capital cost of upgrades, or avoid them entirely if contracts are extended
- Not suitable for network sections with unexpected/unpredictable peak loads.
- 10 year delay of £115,000 CAF payment would equate to a contract of 750kW of power for 2 hours over 3 months

	Upfront Grid Payment	3 Year Delay	5 Year Delay	10 Year Delay
Saving Annual Battery Contract Budget	£0.00	£2,378.61	£2,908.03	£3,419.93
Battery Contract Budget	£0.00	£6,477.55	£12,590.24	£26,407.76



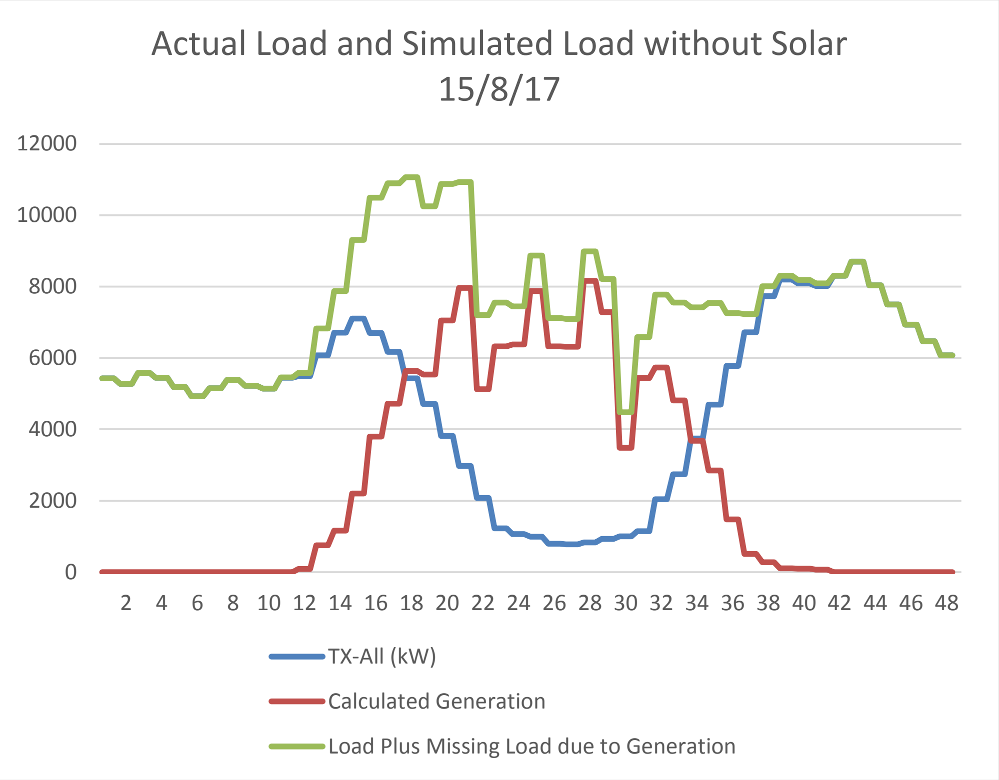
The Wider Market

SSE procuring capacity in CMZ (constraint management zones) to ensure redundancy compliance at 132kV.

Batteries couldn't cover the 5 hour requirements for this service by themselves: if a single asset is required then a gas peaking plant would be the most suitable.

Discussions with DNO's suggest they expect to use services from a variety of assets to get the desired effect at a location.

WPD ran the Project ENTIRE Trial, and Flexible Power is now being rolled out, beginning to stimulate the flexibility market



Any Questions?

Raise Minimum Demand (Reduce Voltage Rise)

Goals:

- Reduce voltage rise on lightly loaded lines
- Avoid restrictions on new connections due to voltages
- Avoid Costs of installing other solutions
- Allow synergy between expected profile of arbitrage and a network requirement.

Argand monitoring equipment

This was an extremely simple use case to program: timed overnight import at a steady power rate.

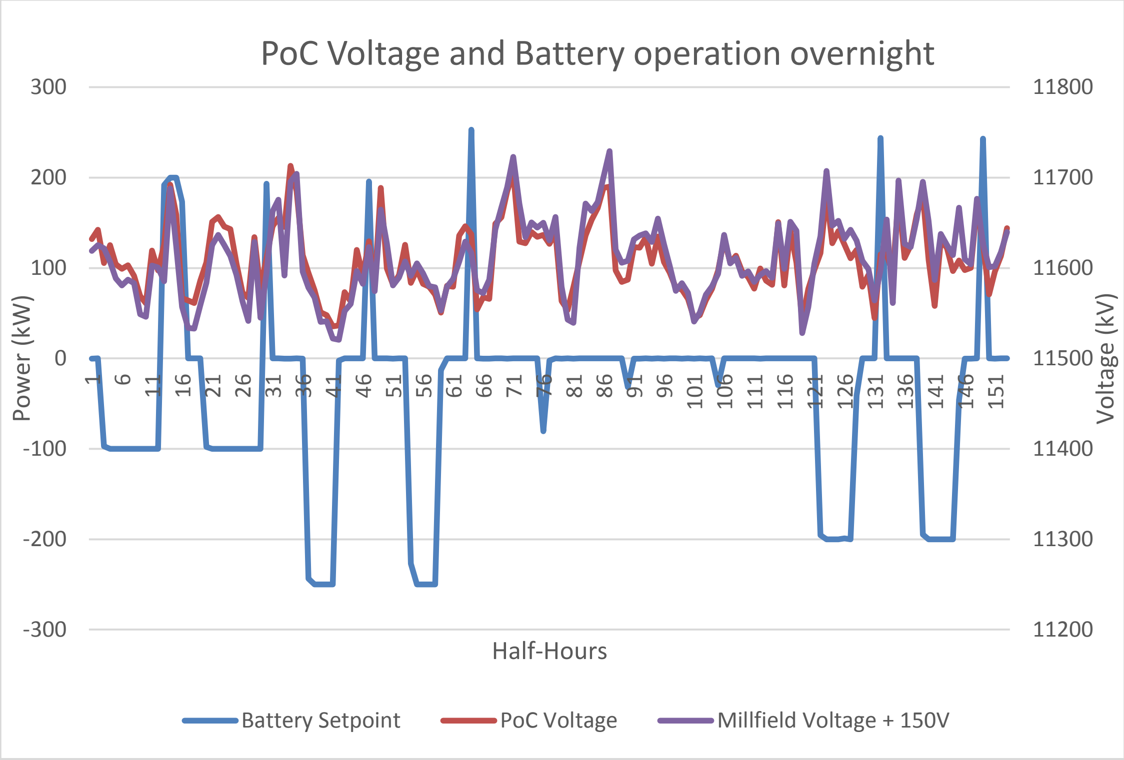
The Argand data monitoring at the Millfield Primary was installed and used to monitor the voltages, which gave an averaged reading every ten minutes.

This could be compared with the PoC voltage monitored by the SCADA system.

Any obvious decline in voltage at the specified times was expected to be attributable to the battery.

PQM voltage readings were inaccurate, appearing to suffer from a zero error, but the magnitude of voltage change was able to be compared, allowing results to be analysed.

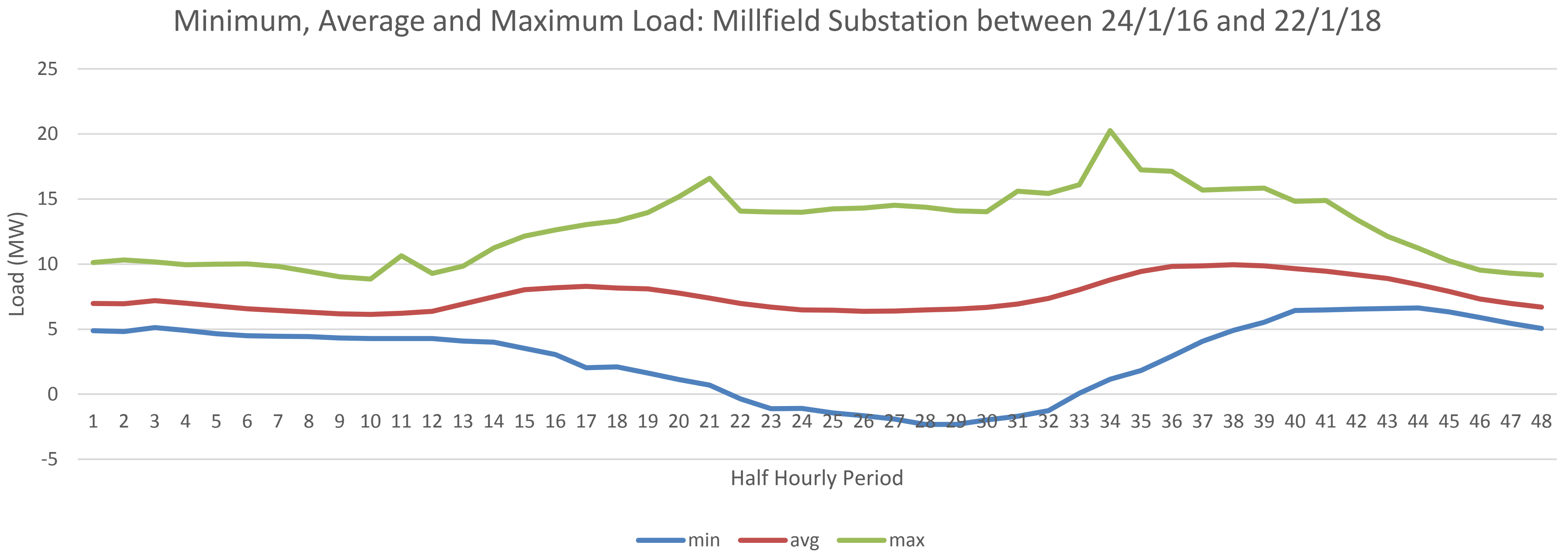
Raise Minimum Demand (Reduce Voltage Rise) - Conclusions



- Graph shows the import tests of the battery, but no corresponding changes on the voltage of the network
- Should be noted that the PoC voltage is less variable than the Millfield voltage: the changing voltage at the PoC is driven by the substation overnight.
- Active capacity of the battery too low to have an effect
- Much larger load required.
- Expected synergy with arbitrage didn't occur: initially assumed there would be arbitrage opportunities every day using low overnight prices.

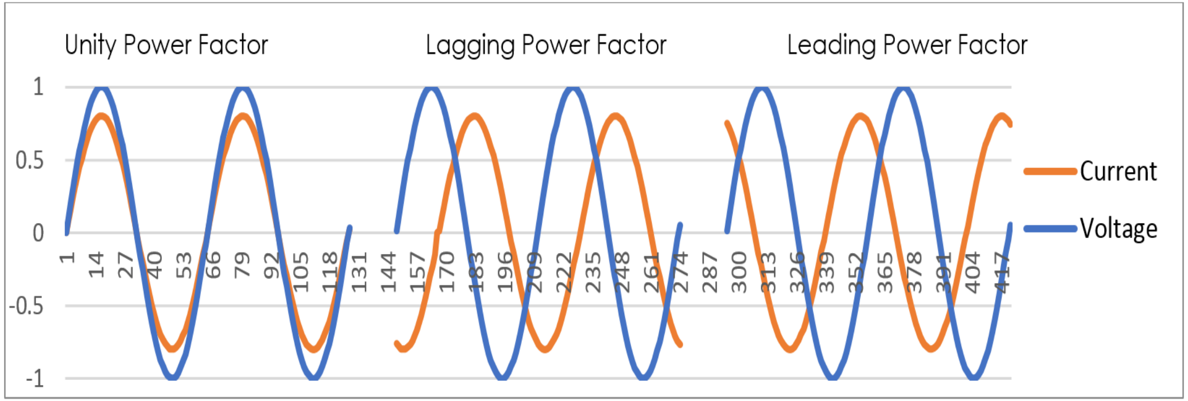
Raise Minimum Demand (Reduce Voltage Rise) - Conclusions

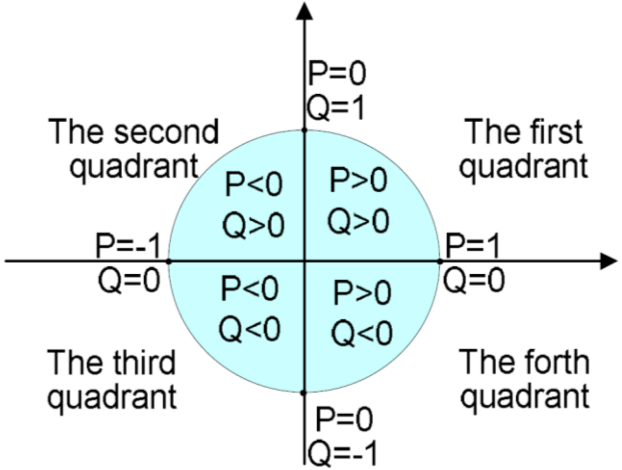
The overnight load on Millfield Primary barely dips below 5MW throughout the year. This means the maximum increase in load the battery can deliver is 6.2% (310/5000). This helps explain why there were no observable effects from operating the battery in this way overnight.



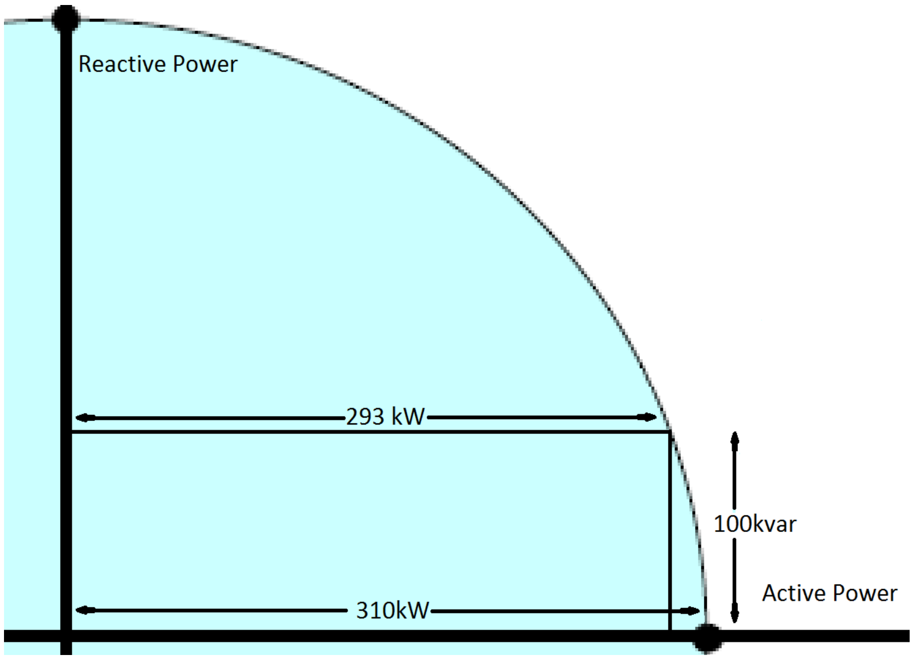
Reactive power is always a component of power flow on the grid, and is required for any load that is not purely resistive. This includes transformers and motors, which require reactive power and thus affect the power factor. Reactive power influences voltage, so by generating or absorbing it the voltage can be controlled.

- Capacitive loads are modelled as 'consumers' of reactive power, causing a lagging power factor.
- Inductive loads are 'generators' of reactive power, creating a lagging power factor.
- Running at excessively low power factor is inefficient, causing high currents to run through the network.
- The BYD battery inverters can operate over a wide range of leading and lagging power factors.



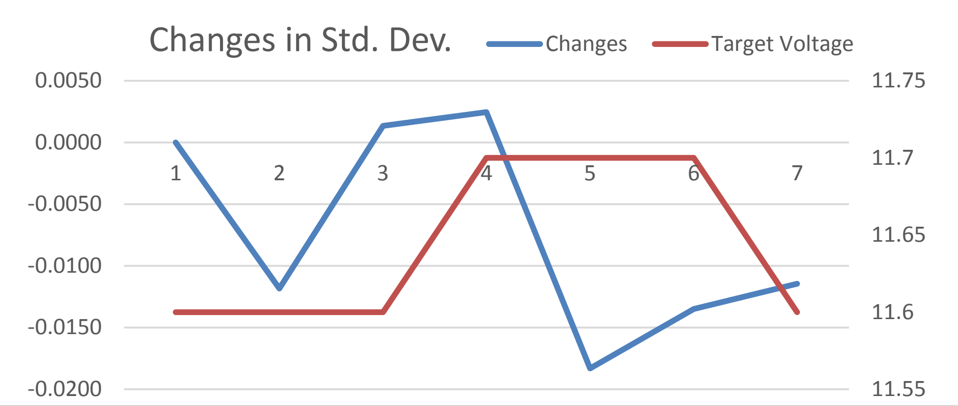


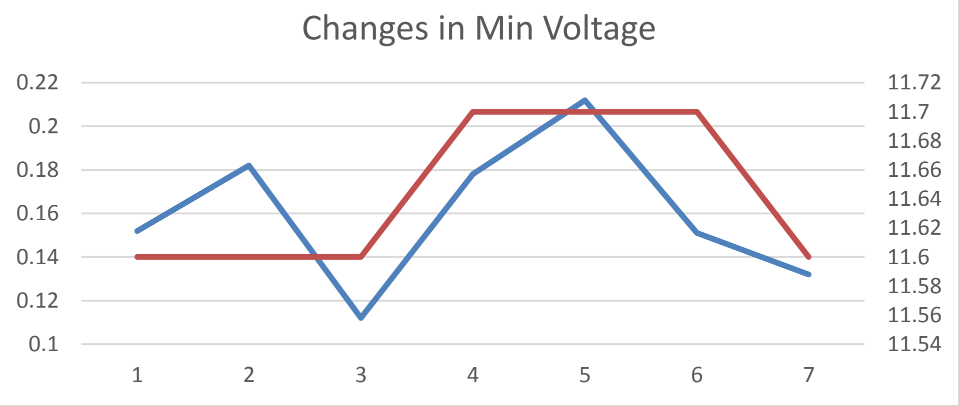
Reactive Power Voltage Control - Testing

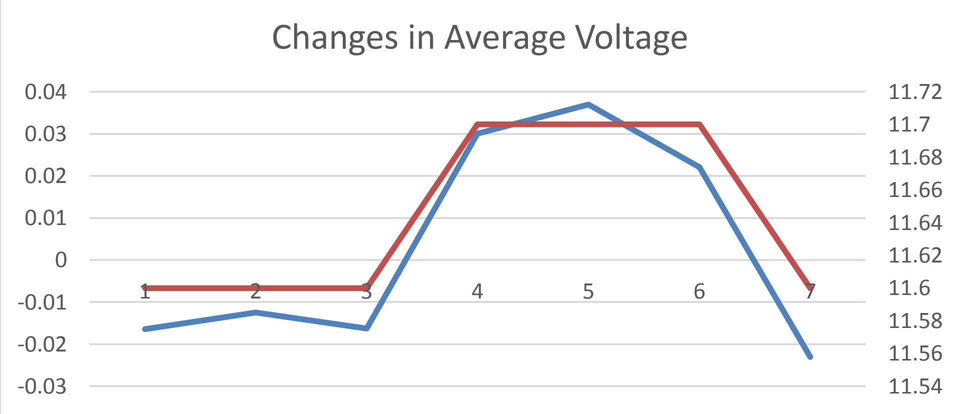


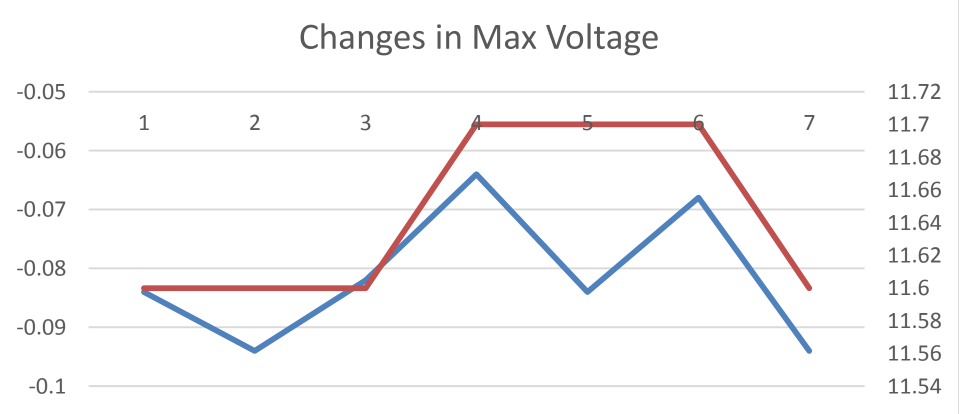
- RESolve has a voltage control mode, taking a target voltage and voltage slope percentage.
- The PQM suffered from a zero error, and the RESolve system uses the highest reading from the three phases as its set point, so the target voltage had to be set artificially high to get the desired effect.
- Unlike any other use case, **there is a non-linear trade-off of capacity.**
- This demonstrates a greater opportunity for commercially successful combination methods
- The maximum reactive capacity of the inverters is 310kVAr
- Despite deliberately setting some targets that meant the battery would work at full capacity, impact on network was low

Reactive Power Voltage Control - Results









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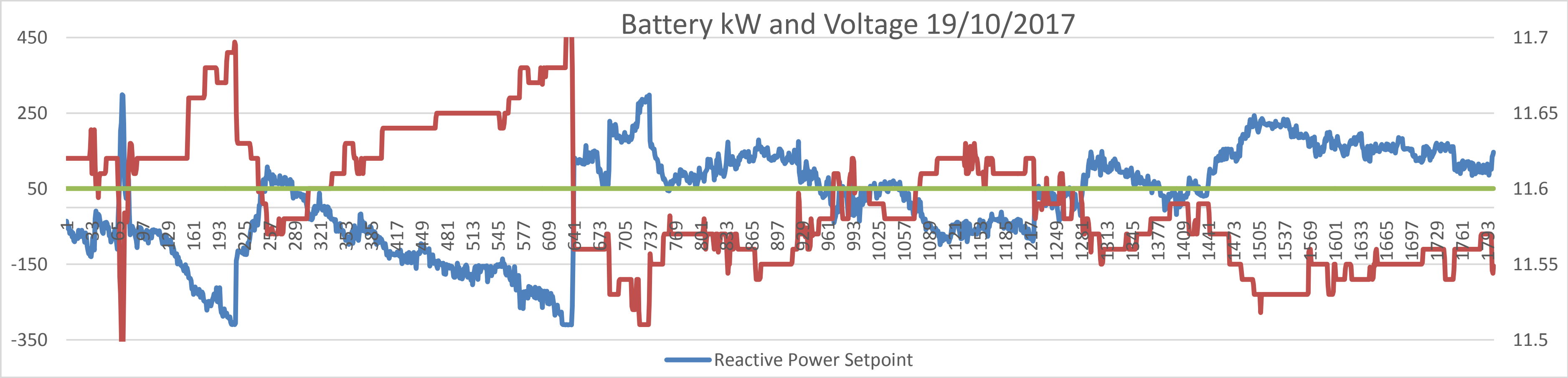
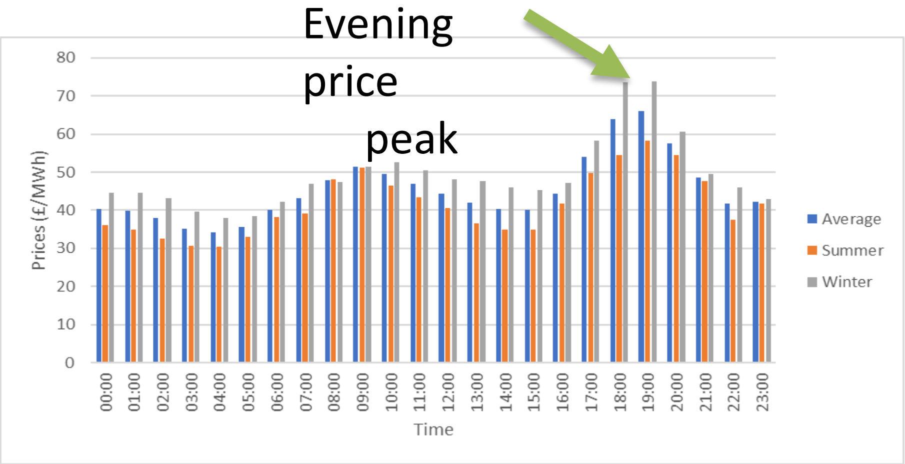
Reactive Power Voltage Control – Conclusions

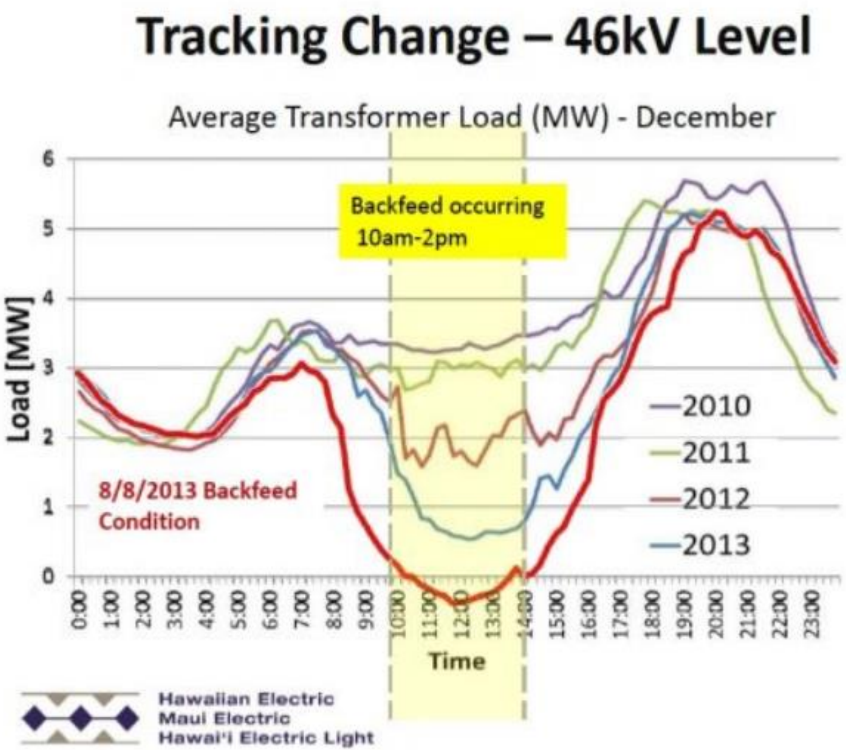
- The lack of obvious effectiveness from the battery is not necessarily surprising. WPD have carried out other tests in the time since this projects inception and conclusion, and found that even a 400kVAr STATCOM is too small to have an impact at 11kV.
- The control algorithm has been proven to function by these tests
- Reactive power control is exciting thanks to low opportunity costs. (6% active power reduction allows use of up to 32% reactive power)
- Power Potential with UKPN beginning to trial this in more detail.
- Flexible import and export means that voltage control can be maintained even over several years, in response to changing network conditions.
- Expected to be a small revenue stream, spread across many assets including non-energy storage assets



Any Questions?

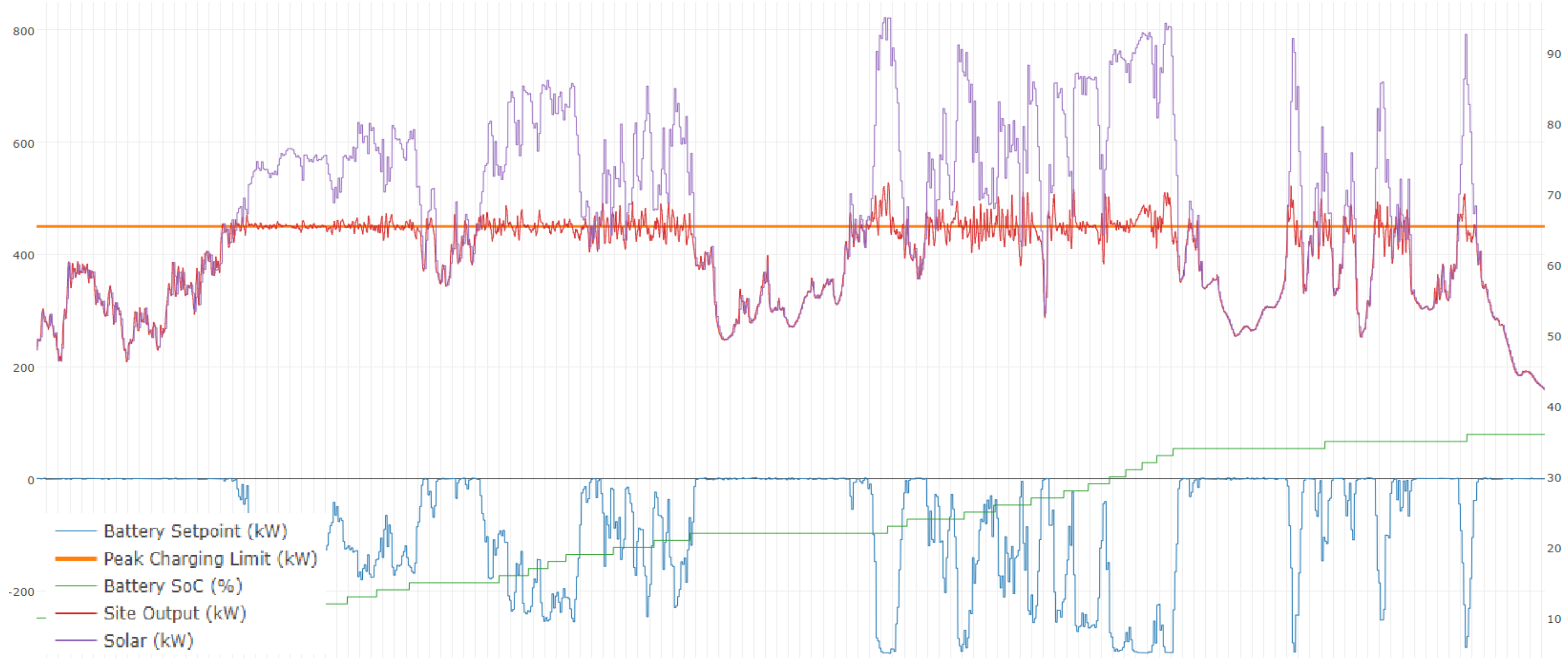
- Two types of solar peak lopping: voluntary and involuntary
- Voluntary uses power that would be exported and time shifts it to the evening price peak
- Involuntary uses power that would otherwise have been wasted or constrained.
- All tests are 'voluntary' in this research as the solar park has no constraints





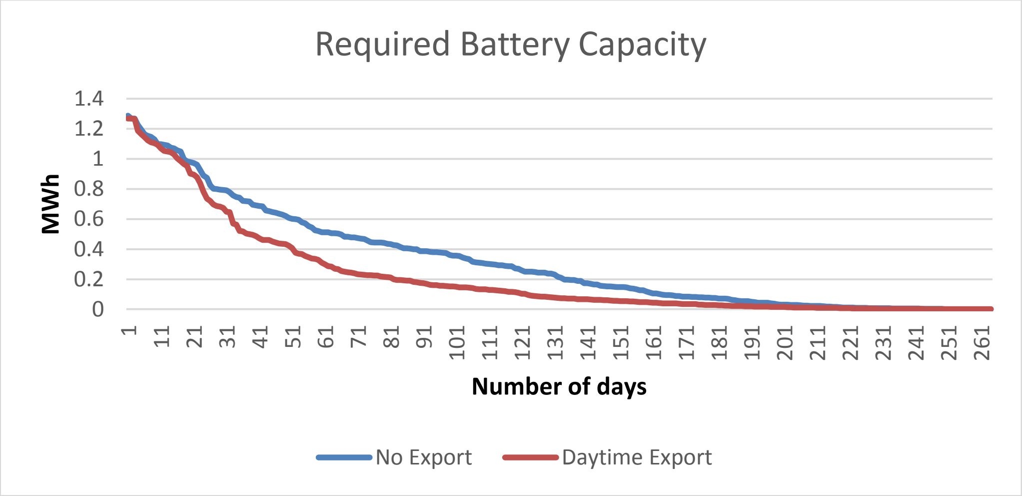
Ref: Greentechmedia Article, Hawaii Nessie Curve

Solar Peak Lopping & Glass Ceiling



Solar Peak Lopping & Glass Ceiling

- Speed of response not yet matching G100 or DNO export limiting requirements.
- However algorithm reliable at a variety of power levels



- Python-based simulation for 2017 at 800kW, showing storage requirement.
- Cost of peak lopped power is nil as it would have been constrained.
- 620kWh battery able to capture 83.6% of all the energy generated over 800kW through the year
- This generated revenue of £3,750
- Opportunity cost is extremely high as the battery must always be ready to peak lop during the day

Solar Peak Lopping & Glass Ceiling

Time Scheduled solar peak lopping:

- Average price increase from 14:00-16:00 to 18:00-20:00 is £17/MWh.
- Set to import as much power as possible between 14:00-16:00 and export each day at 18:00-20:00.
- Pulls no power from the grid.
- Would have generated revenues of £2750
- Base case opportunity cost is £6100, due to the battery being unavailable for 6 hours a day.

Advanced solar peak lopping:

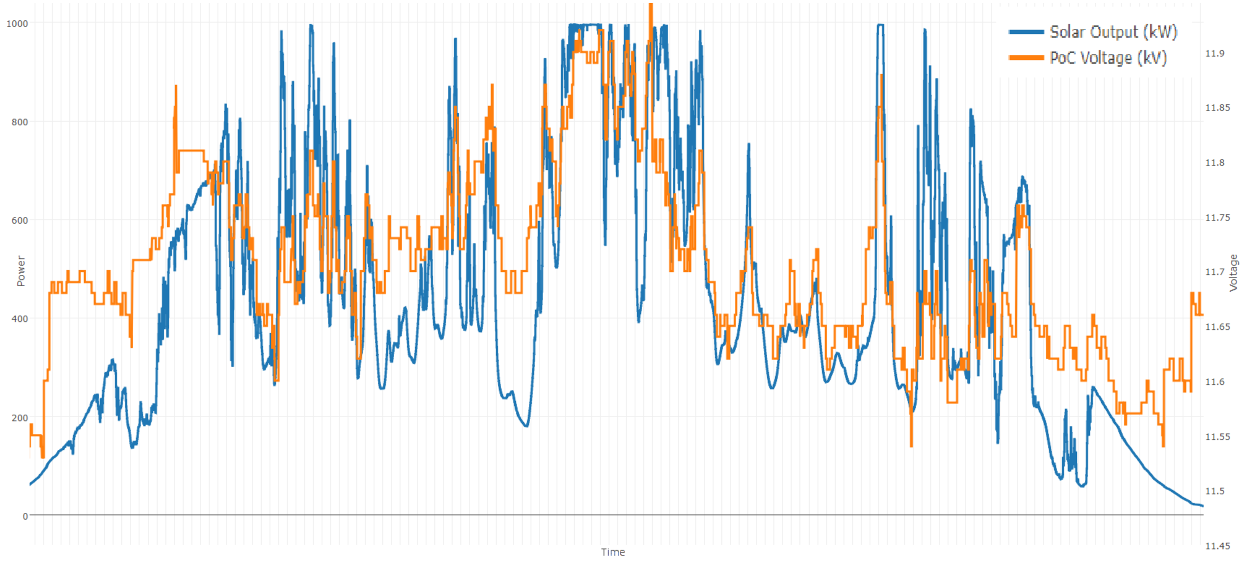
- Average price throughout the day is lower than the evening peak
- Set to import as much power as possible between 14:00-16:00 and, if not enough solar available, rerun the day with an extended import window and export each day at 18:00-20:00.
- Pulls no power from the grid.
- Would generate revenues of £3800
- 55% increase in cycles for 38% increase in income
- Opportunity cost high as peak lopping is extended on poor generation days

Output Smoothing (Ramp Rate Control)

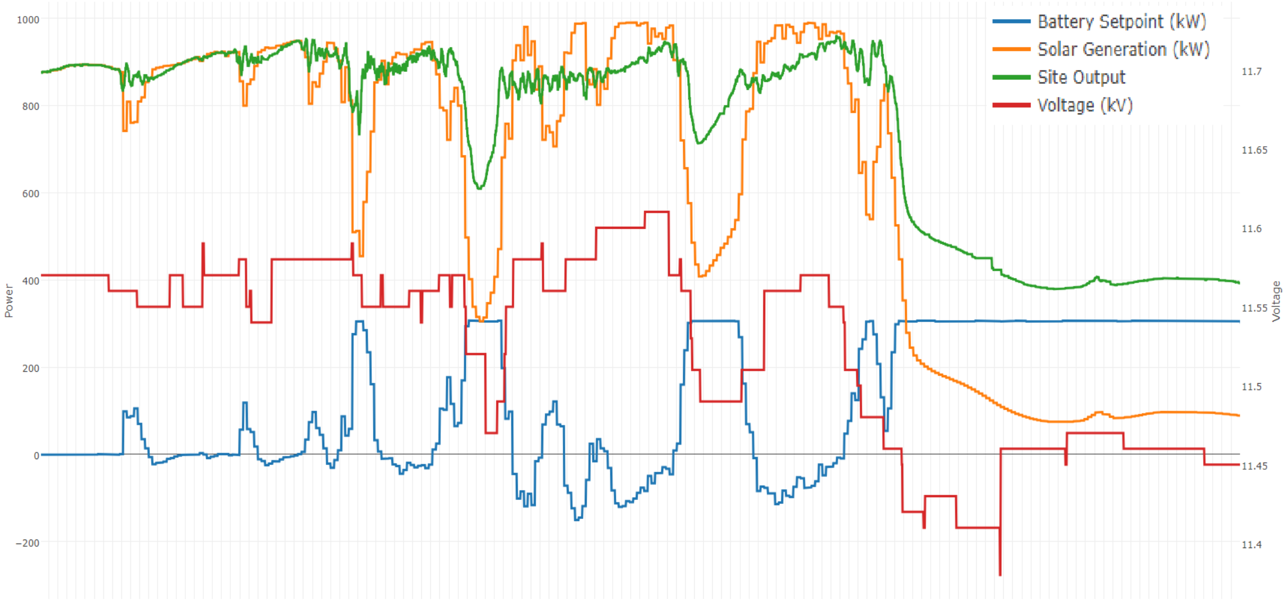
Goals:

- Check link between voltage and solar production
- Improve network power quality by reducing voltage fluctuations
- Reduce Tap Changer operations by reducing voltage fluctuations

- The PoC voltage is noticeably driven by the amount of PV generation
- PV output from adjacent park likely to be similar/identical
- Should be possible to control the extreme drops and rises in voltage by adjusting the output of the site

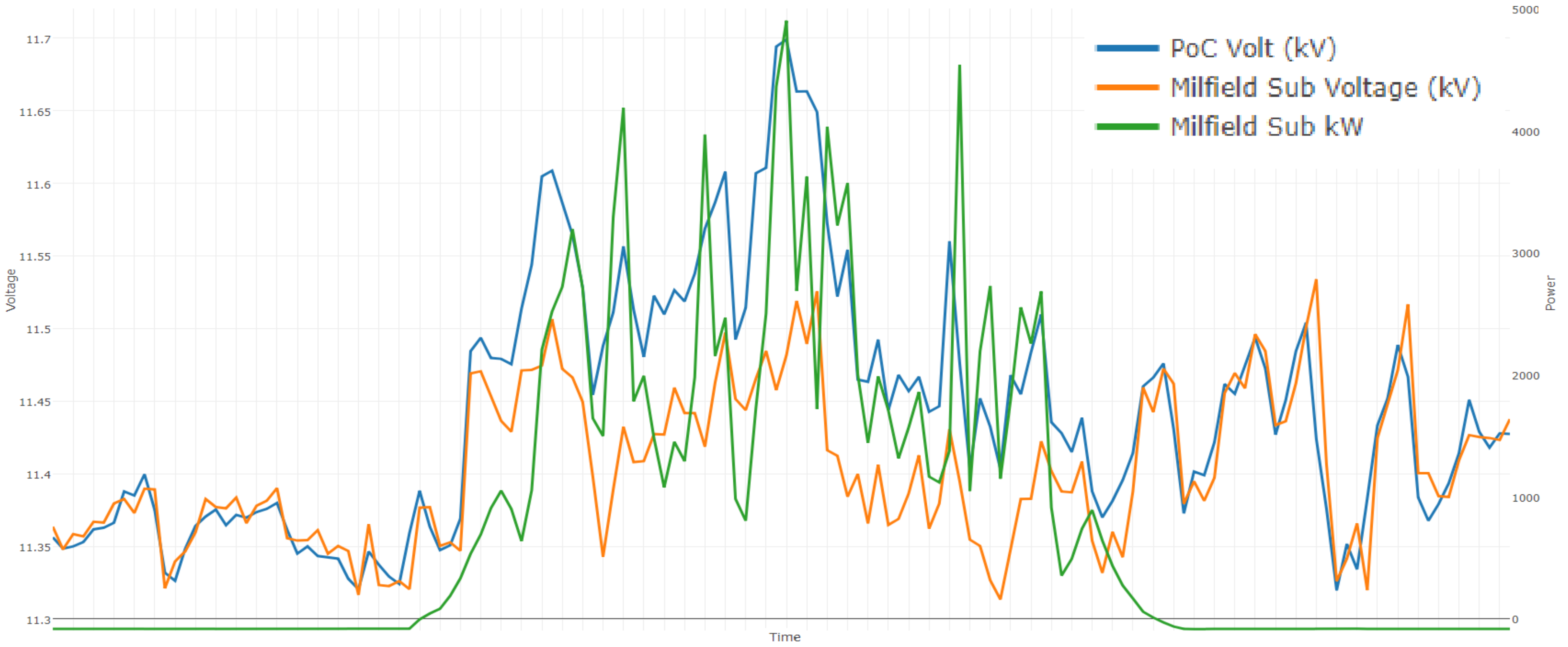


Output Smoothing (Ramp Rate Control)



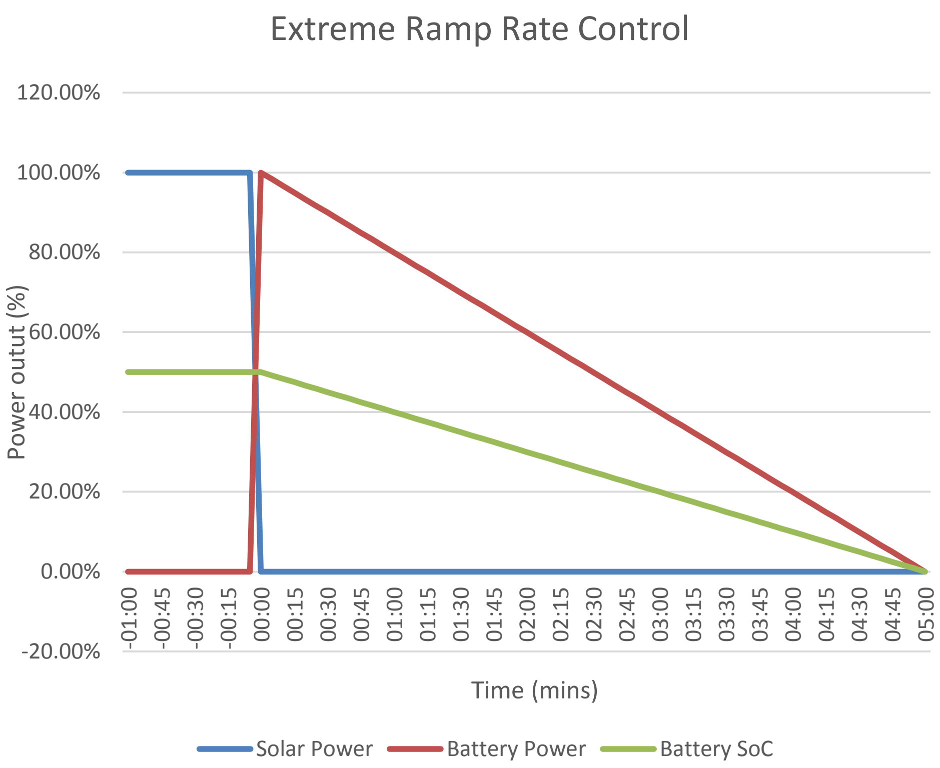
- Control method shows battery responding appropriately.
- Large reduction in output variability from Copley Wood
- However voltage continuing to fluctuate, in line with solar production rather than site output
- Battery output only equates to 31% of Copley Wood output
- Copley Wood is <20% of solar power connected on this feeder, meaning battery is <6.2% of total power (too small to notice)

Output Smoothing (Ramp Rate Control)



Output Smoothing (Ramp Rate Control)

- Potential for very short duration battery to offer this specific service (supercapacitors?).
- Power of energy storage needs to be 80-100% of park rating.
- Could be linked into DC strings to reduce costs.
- 5 minute ramp rate could be provided by only 5 minutes of energy storage (12C battery)
- 5 minutes is significantly longer than the auto tap-changers take to respond, meaning tighter control can be maintained.
- Connecting directly to a Primary could allow aggregation of multiple generators and loads ramping effects.



Any Questions?

Combining Use Cases

- Requires significantly more complexity in control systems
- Many limitations of the combination method were encountered during the tests (can’t combine two instances of the same schedule type, issues with ramp rate vs peak lopping)
- Research suggests that batteries will always have a dominant ‘base case’ revenue stream, and that combinations will provide additionality rather than receiving equal weighting
- Network support and arbitrage are good candidates for the combination method
- Splitting battery capacity is usually worse: why divide capacity rather than stay in the most lucrative market?
- Risk-spreading is better served by splitting revenues across assets, rather than splitting each battery. This involves less complex control systems meaning cheaper installation and maintenance, with less downtime for patches/changes.
- The exception to the above is the reactive power voltage control mode: potential for low opportunity cost network support that benefits both parties (as demonstrated by UKPN Power Potential).

Conclusions – Storage Roll Out

- DNOs now beginning to embrace grid services (WPD Flexible Power, SSE CMZ tender, UKPN Power Potential).
- Energy storage remains the 'highest tier' asset to connect to the grid, with a huge range of flexibility and adaptability.
- Over 3GW of planning-consented energy storage projects in the pipeline across the UK.
- Continuous regulatory changes have reduced investor confidence in the sector.
- Project has run through a turbulent time for energy storage, with the research now being very relevant.
- EFR and FFR triggered a large-scale rush into energy storage, then declining FFR rates halted this.
- DNO's hoped to take advantage of existing projects for grid support services, but under previous FFR prices, the cost for DNO's would have been too high.

Conclusions – Storage Roll Out

- Network Peak Lopping could provide savings by deferring reinforcement, for DNOs, energy storage developers and end-consumers.
- FFR prices now so low there may be less batteries to contract with, however developers now open to more flexible business models with asset-specific contracts.
- DNO’s longer term support contracts could provide incentive for build-out, with many sites practically shovel-ready.
- Project showing learning from variety of use cases expected to be used in transition to smart grid.
- Large report being published showing learning and analysis so far.
- Datasets available for others to analyse and investigate.
- The most recent development in this sector is that all six DNOs have jointly committed to investigating smart flexibility services and compare them to traditional investment (announced on the 13th December 2018).

Any Questions?

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