Rise Carr Battery Energy Storage System – Half Hourly Losses Impact Assessment

1 Purpose

This report analyses the impact of Rise Carr Battery Energy Storage System (BESS) on network losses, and uses this analysis to estimate the wider impact of BESS on network losses.

Variable losses are calculated for the 33 kV Darlington North - Rise Carr double circuit and the two 33/6.4 kV transformers at Rise Carr for the scenarios of i) no BESS, and ii) BESS. Losses are also calculated for the Rise Carr BESS based on the difference between energy in and energy out of the BESS, and the network losses impact of BESS operation under Firm Frequency Response (FFR) and Triad regimes are reviewed. All analysis is undertaken using half hourly data and some generalised assumptions, on the basis that this will be sufficient to determine the materiality of the losses impact.

2 Assumptions

Key assumptions are listed below and are explained in more detail in subsequent sections.

1. Use half hourly demand data only. A sensitivity could be carried out at a later date to account for the second-by-second operation of the BESS.
2. No analysis of the impact on the High Voltage (HV) nor Low Voltage (LV) network. Given that the BESS connects directly onto the Rise Carr primary bar, there is negligible impact on the network beneath the primary.
3. No analysis of the impact on the EHV/132/transmission network above Darlington North BSP 33 kV bar, nor the other 33 kV feeders connecting other primaries to Darlington North.
4. Generally, the underlying demand profile at Rise Carr will be aligned to the demand profile of the wider network (i.e. following a similar load curve). Subsequently, the impact from the BESS on network losses at Darlington North 33 kV and upstream, be it an increase or decrease, would also apply, but would be an order of magnitude smaller. The analysis is simplified by excluding the wider network, and the impact is shown to be relatively small as follows; the I^2 comparison at 132 kV as a percentage of that at 33 kV is 6% ($(33/132)^2$).
5. Assume lossless (i.e. zero resistance) series reactors on secondary side of Rise Carr primary transformers in absence of suitable data – IPSA and AMP2VIEW only report reactance value. This will underestimate losses.
6. Resistances for the overhead lines are taken from IPSA.
7. Resistances for transformers are calculated backwards from test certificate losses information. This is due to the power system model transformer information being in per unit, and therefore the primary and secondary winding resistances being lost. In absence of a test certificate which articulates the winding resistances, this is the best approach.
8. PI half hourly data input data are as follows:
    a. Rise Carr Primary Net (MVA) demand (i.e. metered power flow) – due to data issues, the T1 and T2 current analogues are used.
    b. Rise Carr BESS export/import (which can then be deducted from the above for analysis) – real power (MW) data is used.
9. Remove periods for which the BESS is not operational or when there is bad data.
10. Undertake two scenarios for variable losses calculation:
    a. Without BESS
    b. With BESS
11. Review losses in relation to:
    a. General operation.
    b. Triad periods
    c. BESS charge and discharge cycles.
12. Compare the delta, and use generic energy cost and carbon cost values to quantify the impact.

3 Rise Carr – Substation Overview

Rise Carr is a primary near Darlington, connected to Darlington North BSP via two 33 kV overhead line circuits. Darlington North BSP connects to Norton GSP. Rise Carr site is operated at 6.3 kV, and has a maximum demand of c12 MVA. Refer to appendices 1 and 2 for NMS diagrams and IPSA diagrams respectively.

4 Rise Carr - Battery Energy Storage System Overview

Rise Carr BESS was installed in 2013 as part of the Customer Led Network Revolution (CLNR) innovation project. The battery is a +/-2.5 MW, 5 MWh facility. The battery is currently owned by Northern Powergrid, but operated on behalf of NPg by Kiwi Power. The operating regime of the battery is associated primarily with Firm Frequency Response (FFR) and also with Triad avoidance (roughly 20 events per year). These are explained in more detail below.

4.1 Firm Frequency Response

National Grid Electricity System Operator (NGESO) has a statutory obligation to maintain system frequency at 50 Hz ± 1% (49.5 Hz – 50.5 Hz), and typically manages the frequency to a tighter limit of 49.8 Hz – 50.2 Hz. System frequency is determined by the balance of generation and demand. If generation is greater than demand, frequency rises, and vice versa. NGESO manages system frequency via contracts with providers of frequency response; either demand or generation – or in the case of Rise Carr BESS, the facility can act as both demand and generation. Rise Carr's main revenue stream is from FFR contracts with NGESO, and subsequently, the majority of the BESS operation is related to FFR. FFR requires that the BESS responds second by second to system frequency. To provide more context around FFR and the impact on power flows, a 3 hour system frequency graph is provided below (which shows the typical fluctuations).

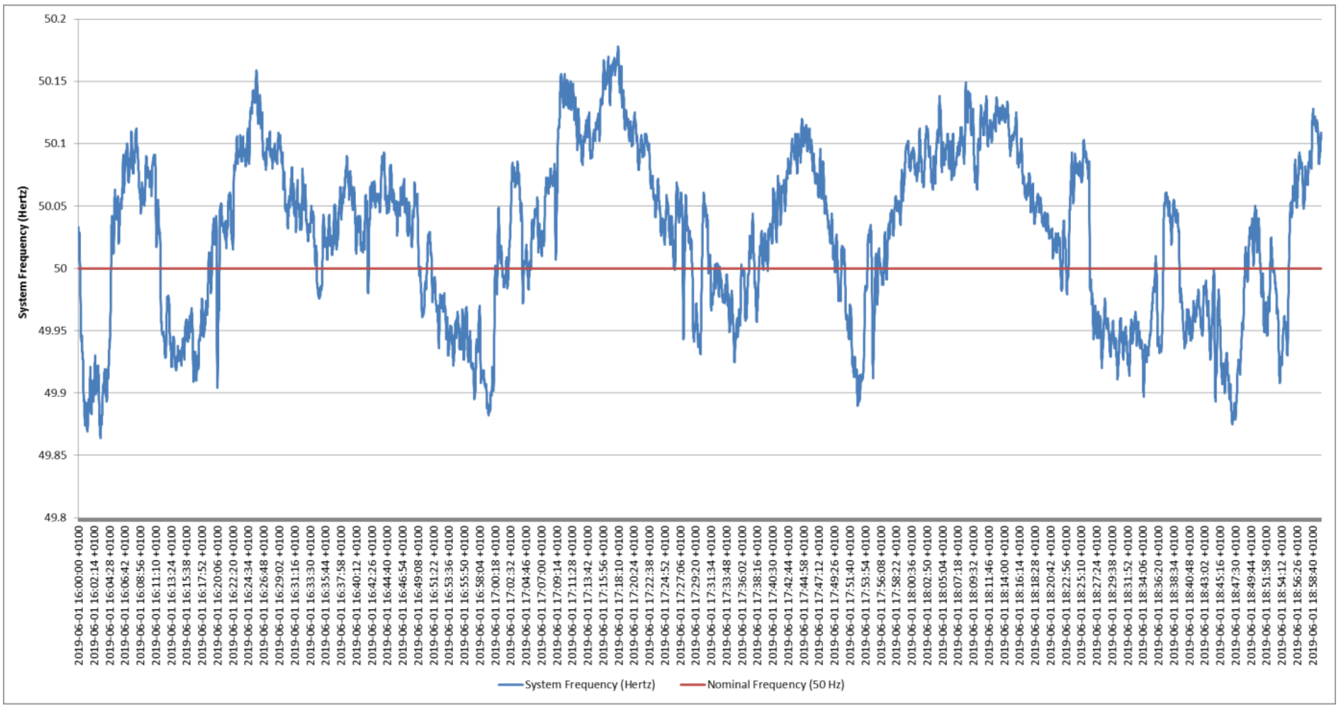


Figure 1: System frequency trace for 1st Jun 2019 16:00 – 19:00. It is typical that frequency is kept within the 49.8 Hz – 50.2 Hz band, with multiple 50Hz intersections as the frequency passes from low to high or high to low. A key detail is that there are often periods of 5-10 minutes where the frequency trace does not intersect 50 Hz, and therefore the majority of BESS power flows (and the losses impact) will be defined by these 5-10 minute periods.

Despite the importance of second by second analyses, this report only analysis the half hourly impact as the second by second data was not available at the time of producing the report. Subsequently, the large fluctuations that will occur within a half hour; and therefore the losses impact detailed in this report will be an underestimate. For example, a half hour in which the BESS fluctuates between full import and full export, but has a net of zero power flow over this half hour (e.g. in a given half hour, 15 minutes of 250 kWh export and 15 minutes of 250 kWh import would be a net of zero); would result in a losses impact of zero for half hourly analysis. In reality, however, a random (assumed to be the case for FFR) import/export operation, would simply increase the variability (fluctuations) of the power flow, and therefore would increase the losses. Appendix 6 gives further information on higher time resolution for Rise Carr BESS, and shows that for a given half hour with a net of -30 kW, there is a significant fluctuation when reviewed on a minute-by-minute basis.

There are three FFR slots throughout the day (23:00 – 07:00, 07:00 – 15:00, 15:00 – 23:00). Typically, the battery would not operate for all slots in order to manage state of charge. The operating regime is not reviewed in more detail, with the exception of noting that following FFR slots, the BESS would often charge/discharge at full capacity, which is shown to have a detrimental impact on the network (c.f. Figure 6).

Kiwi Power has confirmed that the BESS FFR operation is set against the 5 different bands defined in the table below for both low and high frequency response. Rather than the BESS responding in increments/steps, a droop setting is applied instead. This means that there is a linear relationship between frequency and import/export, so that for every 0.001 Hz, the BESS adjusts import/export by 5 kW (i.e. 0.5 Hz = 2500 kW, thus 0.001 Hz = 5 kW).

Table 1: Rise Carr BESS FFR bands (source: Kishan Rawal, Kiwi Power; 2nd December 2019). Note that primary response requires service delivery within 10 seconds and sustained for up to 20 seconds, whilst secondary response requires service delivery within 30 seconds and sustained for up to 30 minutes. BESS is able to provide both services, and enters both markets simultaneously.

Low Frequency Response (50Hz or Less)		
Frequency Deviation (Hz)	**Primary Response: Applicable Factor (%)**	**Secondary Response: Applicable Factor (%)**
-0.1	0.2 (20%)	0.2 (20%)
-0.2	0.4 (40%)	0.4 (40%)
-0.3	0.6 (60%)	0.6 (60%)
-0.4	0.8 (80%)	0.8 (80%)
-0.5	1.0 (100%)	1.0 (100%)
High Frequency Response (50Hz or More)		
Frequency Deviation (Hz)	**Primary Response: Applicable Factor (%)**	**Secondary Response: Applicable Factor (%)**
0.1	0.2 (20%)	0.2 (20%)
0.2	0.4 (40%)	0.4 (40%)
0.3	0.6 (60%)	0.6 (60%)
0.4	0.8 (80%)	0.8 (80%)
0.5	1.0 (100%)	1.0 (100%)

Because of the FFR role, the battery responds on a second by second basis to network frequency, and therefore even during periods of high demand at Rise Carr primary, the battery could start importing power if the frequency is too high; exacerbating any peak demand issues. **Half hourly data is not suitable for accurately determining the impact of BESS FFR. Minute resolution should be suitable.**

4.2 Triads

"Triads are the three half-hour settlement periods of highest demand on the GB electricity transmission system between November and February (inclusive) each year, separated by at least ten clear days. National Grid uses the Triads to determine TNUoS demand charges for customers with half hourly meters." [Source: https://www.nationalgrideso.com/sites/eso/files/documents/Guidance%20What%20are%20Triads.pdf]

For Rise Carr BESS, KIWI Power confirmed they forecast potential Triad settlement periods, and they operate the battery up to 20 days per year in order to reduce TNUoS charges – that is, they guess when Triads, may occur, and despatch the BESS accordingly. In short, the battery exports power at time of forecast system peak, and this means that during the same day (usually), the battery must import in order to replace the energy required for the Triad export. Because Triads are defined by the half-hourly settlement periods, **half hourly data is suitable for accurately determining the impact of BESS Triad avoidance.**

5 Rise Carr Demand Data

5.1 Rise Carr BESS

Real and reactive power data was available from PI. Uncertainty around the validity of the reactive power data resulted in the kVA value simply being equated to the kW value (i.e. reactive power information omitted). The reactive demand was generally negative (capacitive), and if this was indeed the case, this would offset the (inductive) reactive demand of Rise Carr overall, and would reduce losses. This is not discussed further.

5.2 Rise Carr T1 and T2

Real and reactive power data was often missing or of poor quality (e.g. repeated values), and therefore the current analogues were used instead, and converted to MVA by simply multiplying by √(3)V. It was assumed the site ran at 6.3 kV when determining the MVA demand.

5.3 Data cleansing

It is important that only suitable time periods are analysed, given that the battery has been out of service on numerous occasions. The trace below shows the last 6 years of historical PQ data for Rise Carr BESS, and is split into windows which are then reviewed in more detail to determine their suitability for analysis. Starting with the 19,364 half hours covered by windows E,F1,F2, and G; 3,711 half hours were removed from the data-set due to data quality issues, leaving 15,653 half hours – roughly 326 days of data (not all covering the full 48 settlement periods for each day).

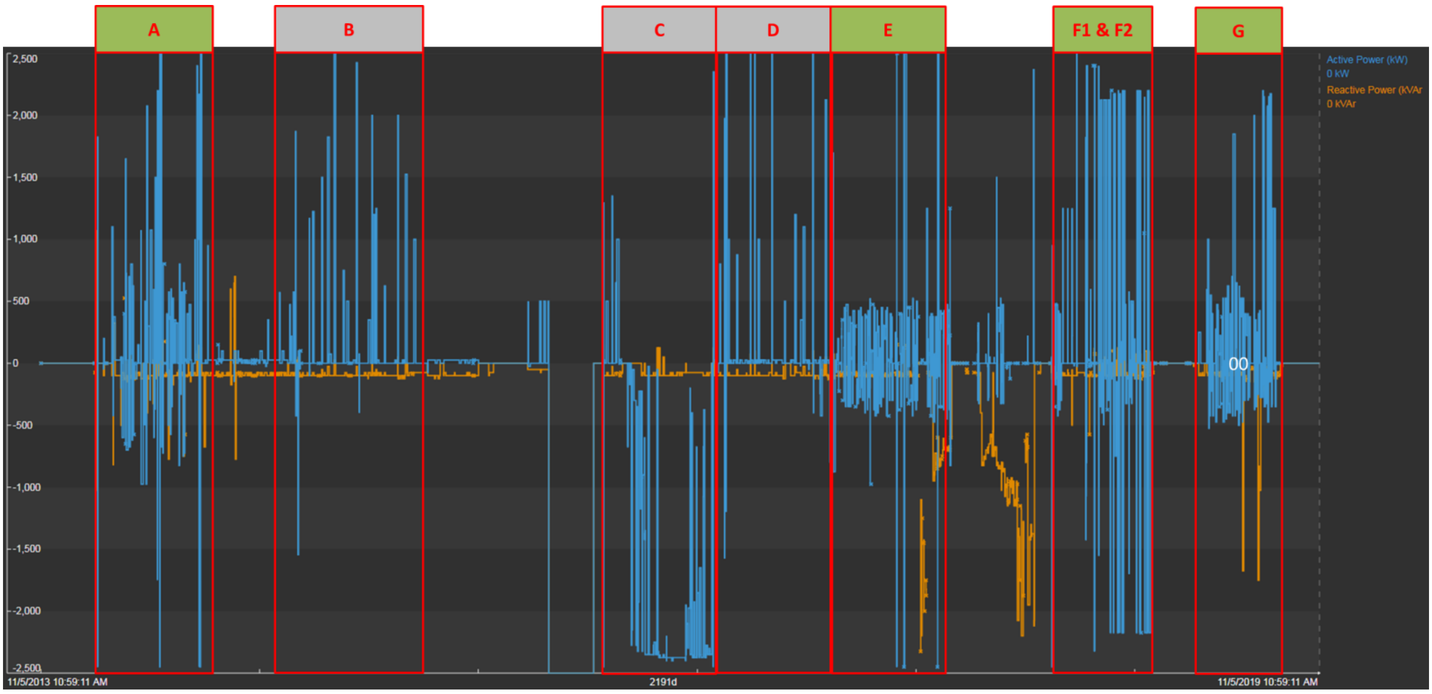


Figure 2: Last six years of real and reactive power data for Rise Carr BESS (Transformer 3 at Rise Carr), split into windows for which the losses impact may be analysed. Note that due to difficulties obtaining data for window A, this has been omitted.

Table 2: Rise Carr BESS windows with start and end dates along with comment on suitability for analysis.

Window	Start	End	Comment
A	01-Apr-14	07-Oct-14	Data looks suitable for analysis – however data could not be sourced, therefore not included.
B	16-Feb-15	17-Sep-15	do not use - very limited operation and appears skewed to export.
C	30-Jul-16	23-Jan-17	do not use - potential data issues
D	24-Jan-17	05-Aug-17	do not use - potential data issues
E	29-Aug-17	27-Feb-18	Data looks suitable for analysis
F1	14-Aug-18	31-Aug-18	Data looks suitable for analysis
F2	01-Nov-18	25-Jan-19	Data looks suitable for analysis
G	01-May-19	24-Aug-19	Data looks suitable for analysis

Note: Appendix 4 provides import/export traces for each window.

The table below shows the windows shown in a year-month matrix, and is presented to give confidence that with the exception of monthly overlap between windows E and F2, and the lack over coverage on March and April, the windows selected broadly represent the whole year, and therefore the results presented will be done so on this basis.

Table 3: Rise Carr BESS windows shown by calendar month

	January	February	March	April	May	June	July	August	September	October	November	December
2017								E	E E E	E E E	E E E	E E E
2018	E E E	E E E						F1 F1			F2 F2 F2	F2 F2 F2
2019	F2 F2 F2				G G G	G G G	G G G	G G G				

6 Methodology

Losses are calculated for each half hour using Microsoft Excel. The calculation is derived below along with the determination of the resistance values for the network components. Rise Carr (primary) is connected to Darlington North (BSP) via two (virtually) identical circuits and transformers and the resistance values are as follows:

6.1 Overhead Line Resistance

Table 4: 33 kV overhead line data converted into ohms, and a calculation for variable losses at 15 MVA[Note 1] circuit loading.

IPSA circuit data	
OHL Circuit 1 resistance (pu)	0.00872
OHL Circuit 2 resistance (pu)	0.00863
OHL Circuit Average (pu) – *average to be used for simplicity*	0.008675
Converting from pu to ohmic	
Base Power (MVA)	100
Base Voltage (kV)	33
Base Impedance (Ohm/phase)	10.89
OHL Circuit average resistance (Ohms/phase)	**0.0945**
Calculating losses at 15 MVA per circuit	
Current for 15 MVA/cct (Amps/phase)	262.4
Ohmic Losses for 15 MVA/cct (kW)	19.5
Ohmic losses for 30 MVA across both OHL circuits (kW)	**39.0**

Note 1: 15 MVA chosen as this is name-plate rating of the transformers.

Note 2: Base impedance is calculated using $Z = V_{base}^2/S_{base}$.

6.2 Transformer Resistance

With reference to Appendix 3, the effective resistance (from the perspective of 33 kV) is calculated below, based on the tested losses of 95kW. Note that transformer 2 tested at 95.9 kW but for simplicity 95 kW is used for each. The I^2R losses are therefore equated to 95 kW, to calculate 'R'.

Table 5: 33 kV/11.5/6.4 kV transformer losses information and associated resistance.

Transformer - Effective resistance at 33 kV taking into account the known load losses	
Transformer (single unit) losses at 15 MVA and 75°C (kW)	95
Transformer (single unit) losses at 15 MVA and 75°C (kW/phase)	31.67
Current at 33 kV for 15 MVA (Amps/phase)	262.43
Effective Resistance (Ohms/phase)	0.4598

Note: The resistance is taken to be constant based on 75 °C operation. Temperature coefficient of resistance for copper is 0.4% per °C, therefore the resistance at 75 °C operation is 25% higher than that at 15 °C. This is not taken into account for the analysis, thus the analysis overestimates the losses, by potentially up to 25%.

6.3 Single Circuit Resistance - 33 kV circuit & 33/6.4 kV Transformer

The line and transformer resistance values in series for a single circuit sum at 0.55 ohms. 83% of this value is associated with the transformer (noting again this is a simplification assuming a constant voltage and turns ratio on the transformer, for the purpose of calculating losses). Note the total losses below for each circuit loaded at 15 MVA is 229 kW (or 0.76%).

Table 6: Calculation of total circuit resistance and associated losses at 15 MVA circuit loading.

Total single circuit (OHL+Tx) resistance, losses and double circuit losses	
Total equivalent single circuit resistance (Ohms/phase) (Single cct OHL + single Tx)	0.55427075
Circuit losses at 15 MVA single circuit loading (kW) *(i.e. losses on single cct OHL + single Tx)*	114.5
Double circuit losses at 15 MVA* single circuit loading (kW) *(i.e. losses on double cct OHL + both Tx)* **30 MVA across both ccts*	229.0

Note: This is as expected given that the two Tx losses of 2x95 kW and the line losses of 39 kW as determined in Table 4.

6.4 Defining the relationship between Demand and Losses

It's important that the PI data for a given Rise Carr net demand can simply by fed into a formula that calculates the losses; which can be applied for every half hour of the two scenarios of i) no BESS and ii) BESS. The generic formula is derived below:

Current in single circuit 'x' for an identical double circuit (circuit x and circuit y), feeding a total demand S_{Total}, where only half of the total demand is transmitted by circuit 'x':

$$I_x = \frac{S_{Total}}{2\sqrt{3}V}$$

Where I_x is current in amps, S_{Total} is total apparent power in kVA, V is line to line RMS voltage in kV.

Losses per single circuit 'x' in W:

$$Circuit\ x\ losses = 3{I_x}^2R_x$$

Where R_x is the total single circuit resistance in ohms (which will include the total effective transformer resistance calculated for 33 kV).

Inserting the term for current gives:

$$3{I_x}^2R_x = 3\left(\frac{{S_{Total}}^2}{12V^2}\right)R_x$$

$$Circuit\ x\ losses = \frac{{S_{Total}}^2R_x}{4V^2}$$

Finally, for the total losses in kW for both x and y, which are identical circuits:

$$\boldsymbol{Double\ circuit\ (OHL + Tx) losses\ (kW) = \frac{{S_{Total}}^2R_x}{2000 * V^2}}$$

For the Rise Carr analysis, kWh losses are calculated using PI half hourly power data and dividing the above equation by 2. For Rise Carr analysis; Rx = 0.55 ohms/cct, V = 33 kV.

Plotting this shows the square relationship, and the losses value of 229 kW matches that determined above for a net demand of 30 MVA.

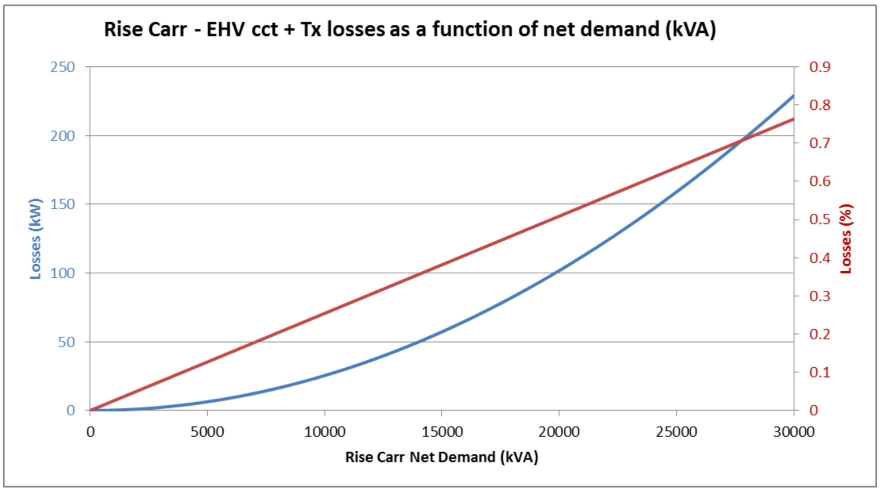


Figure 3: Variable losses for the Darlington North 33 kV – Rise Carr 33 kV and the Rise Carr T1 and T2 primary transformers as a function of Rise Carr net demand (kVA) – up to ONAN nameplate rating of transformers. The blue line shows the losses in kW (left vertical axis), and the red line shows the losses as a percentage of demand (right vertical axis).

Restricting the scale to 12 MVA (the maximum metered demand at Rise Carr recorded – *when the BESS was importing at time of high demand, c.f. Figure 11*) shows the max losses could reach ~35kW on this double circuit. For a demand of 5 MVA, this would equate to 6.36 kW (0.13%); 3.2 kWh per half hour.

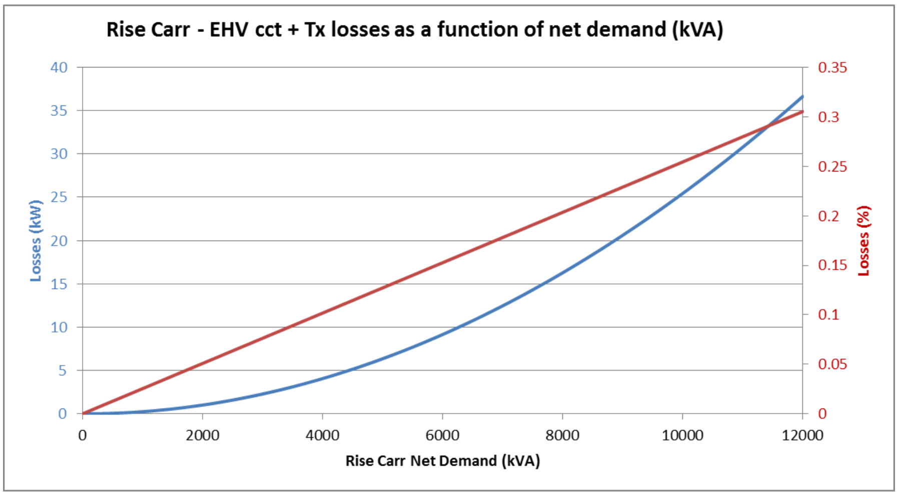


Figure 4: Variable losses (kW) for the Darlington North 33 kV – Rise Carr 33 kV and the Rise Carr T1 and T2 primary transformers as a function of Rise Carr net demand (kVA) – limited to maximum demand at Rise Carr of 12 MVA. The blue line shows the losses in kW (left vertical axis), and the red line shows the losses as a percentage of demand (right vertical axis).

7 Results

Results provided below for the half hourly analysis for windows E, F1, F2 and G. Unless stated otherwise, the losses refer to losses on the Darlington North 33 kV – Rise Carr 33 kV circuits and the two 33/6.4 kV Rise Carr transformers.

Note: All raw data and tables are contained the excel file and folder path:
File Rise Carr Analysis - 12 Nov 19
Folder \\ad03.local\shares\Smart Grid Implementation Unit\08 Losses\LDR\Tranche 3\LDR Tranche 3 draft\Understanding of losses 25pc\Rise Carr.

7.1 Network Losses Overall

Table 7: Losses analysis on the Darlington North – Rise Carr double circuit (inc. T1 and T2) for the 326 days of BESS operation. The losses increase by 677 kWh, which is an increase in losses on this section of the network in real terms of 0.0014 percentage points; which equates to a 0.8% increase in losses when compared to the losses scenario 'without BESS'.

	Without BESS	With BESS	BESS Impact
Rise Carr EHV Losses (kWh)	82,753	83,430	677
As % of Rise Carr consumption* without battery	0.1745	0.1759	0.0014
As % of circuit losses without battery	100.00	100.82	0.82

* Total consumption of Rise Carr (without BESS) over duration of analysis is 47.4 GWh.

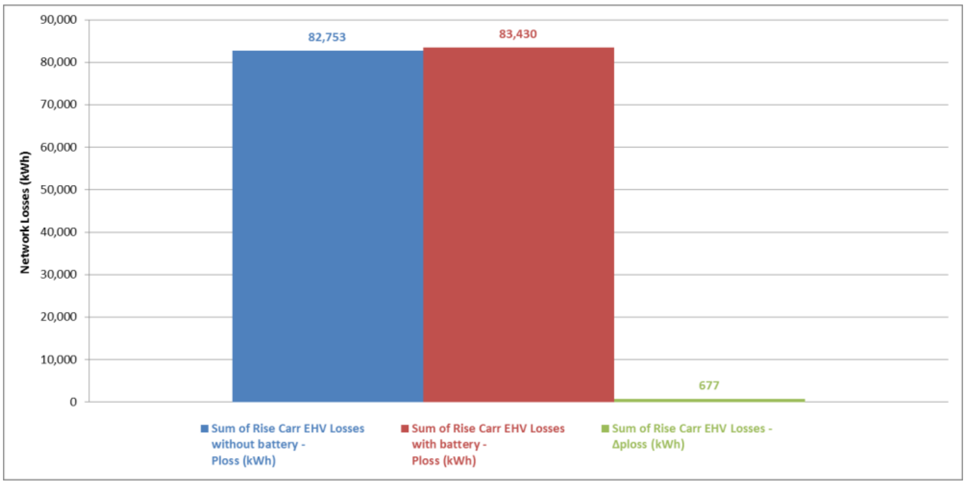


Figure 5: Darlington North – Rise Carr losses for the 326 days of battery operation analysed total 677 kWh; a 0.8% increase in the losses on this section of the network.

For further context, a full graph showing the Rise Carr demand, BESS operation and cumulative increase in network losses is provided below. The most important thing to note is that there is an underlying trend of increasing losses for operation of BESS, averaging 677 kWh over 326 days – i.e. 2.1 kWh per day. On the graph below, the daily impact of BESS on losses is slightly higher in Nov-Dec 2018. For example, for the 1213 half hours in November 2018, the total impact on losses is 133.7 kWh; or 5.3 kWh per day (133.7*1213/48). This is due to a daily pattern of the BESS importing 2 MVA for the half hour starting 07:30, which results in losses for this half hour of ~4 kWh. It is not known why the BESS operated in this manner.

Triad operation will be reviewed in more detail, but given that FFR operation forms the majority of the behaviour, this will not be reviewed in more detail. The impact of FFR operation is approximated to the overall BESS operation; 2.1 kWh increase in Rise Carr losses per day. As stated previously, it would be worth reviewing this when minute-by-minute data is available, as 2.1 kWh will be an underestimate of the losses.

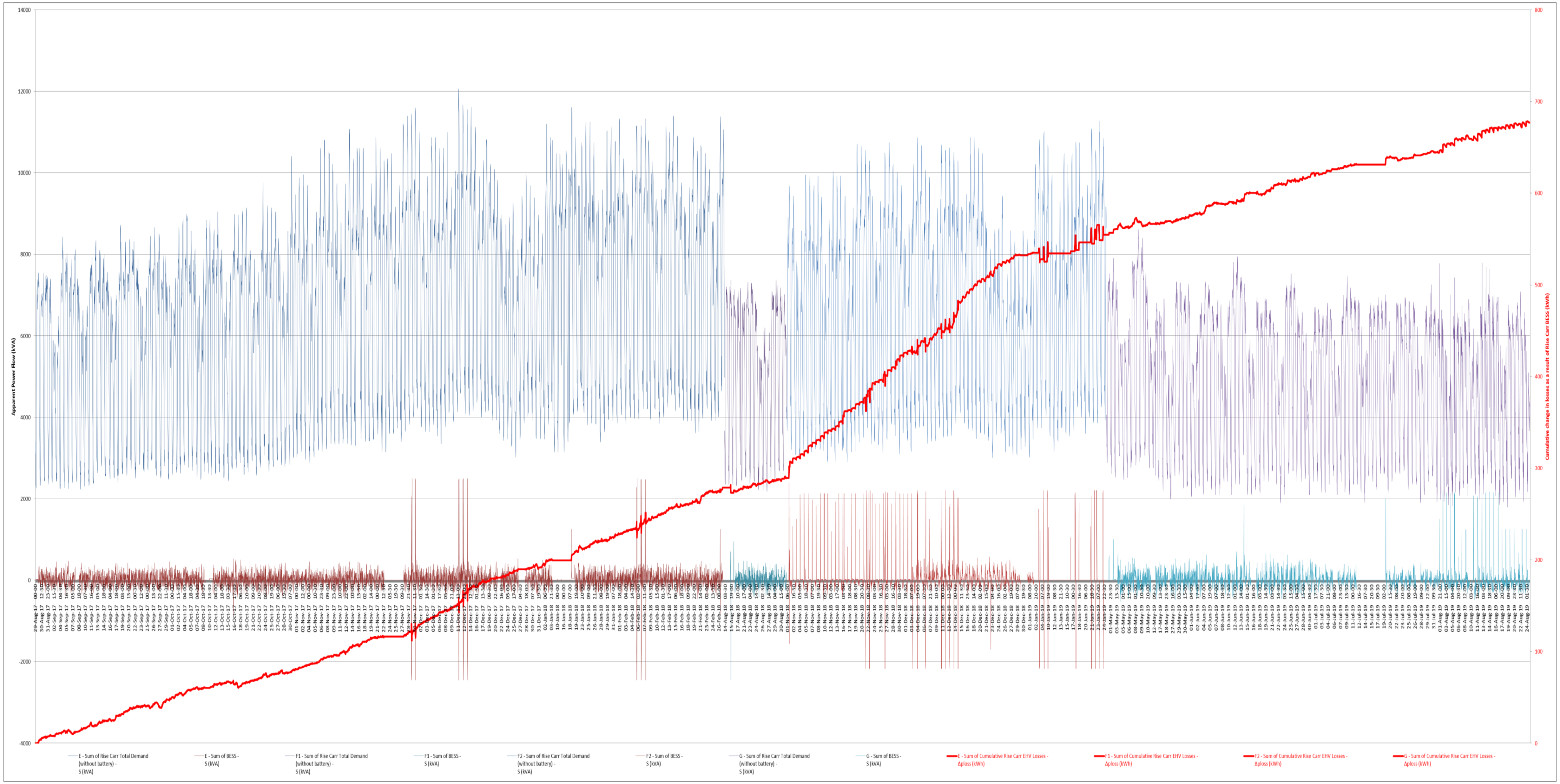


Figure 6: Graph showing for each window, E, F1, F2, G, the half hourly data for; i) Rise Carr total demand without BESS (shown by the trace against the left vertical axis with values between 2 MVA and 12 MVA), ii) Rise Carr BESS import/export (shown by the trace against the left vertical axis with values between -2.5 MVA and + 2.5 MVA), iii) cumulative losses impact of BESS operation (shown by the trace against the right vertical axis, with the losses steadily increasing from 0 kWh to 677 kWh). Although not explored further in this report, the average daily losses impact is highest from Nov '18 – Jan 19 as a result of the battery charging at nearly full import at 07:00 – 08:00 following completion of an overnight FFR slot.

7.2 BESS Site Losses

Over the period 29 Aug 17 – 24 Aug 19, the losses for the BESS Rise Carr system (i.e. not the distribution network) can be assessed based on the total energy in and the total energy out (measured on the HV side of Transformer 3). Noting that the demand data is cleansed by removal of settlement periods with bad data; therefore there will be some errors in the energy flows. On average, however, across the 326 days' worth of half hours (15,635 hh), this error should reduce to zero. For the windows E, F1, F2 and G, for the BESS site (including the transformer and inverter/rectifier):

1) Total Energy In = 1134 MWh
2) Total Energy Out = 824 MWh
3) Efficiency = 100*(In – Out)/In = 100*(1134-824)/1134 = 72.7% *(i.e. 27.3% losses)*
4) **BESS Losses = 27.3% * Total Energy In = In-Out = 309 MWh**

This calculation highlights that the network losses are small in magnitude compared to the losses at the battery site; 2.1 kWh per day vs. 947.9 kWh per day (a ratio of 1:451). The figure below provides more context around the validity of this calculation and the round trip efficiency of c73%.

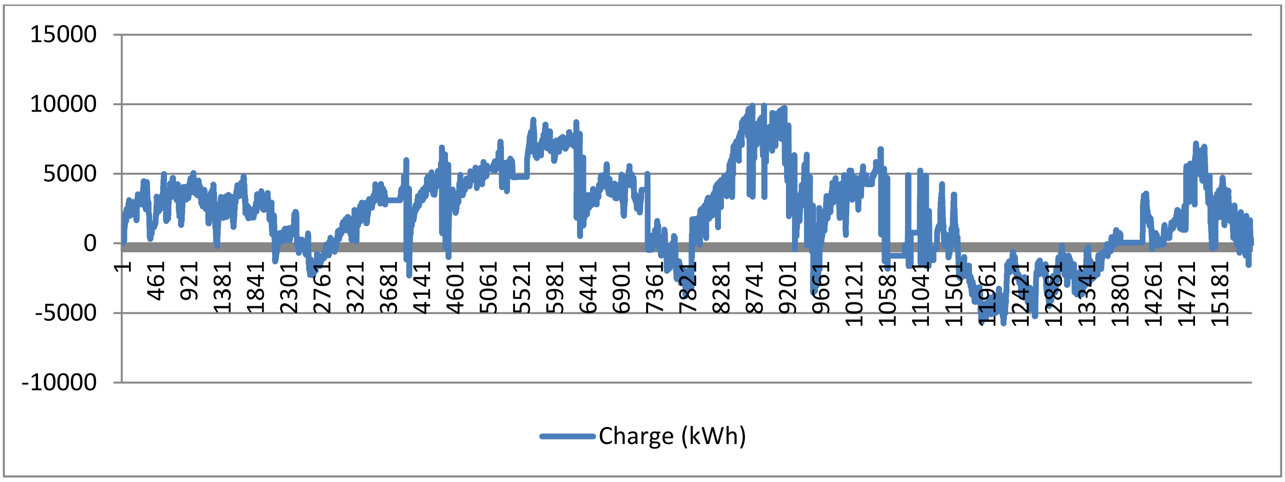


Figure 7: Calculated BESS Charge status (kWh) based on cleansed data assuming round trip efficiency of 72.7%. Purpose of this figure is to show that within the expectation of charge status between 0 kWh and 5,000 kWh, the calculated value (ranges from -6,000 kWh to +10,000 kWh) is broadly aligned to the expectation, and gives confidence in the round trip efficiency value of c73%%. The error itself is associated with removal of bad data, and the assumption that the efficiency is a constant – which of course, will vary as a function of temperature and charge/discharge rate.

7.3 Impact of BESS Efficiency on Network Losses

A sensitivity undertaken with the BESS operating at 100% efficiency instead of 73% efficiency would reduce the losses, as it would result in a lower overall demand at Rise Carr. Instead of 677 kWh losses impact on the network across the 326 days of BESS operation, the losses impact would reduce to 108 kWh.

7.4 Triad Losses Impact

The BESS data below shows the data for the operation associated with Triad avoidance (called Triad event in this document), and is presented on the basis that every kWh of export requires at least one kWh of import to balance (but does not account for round trip efficiency, which would require an additional 0.37 kWh import per kWh import). It's evident from the graph below that during Triad periods, the BESS operates at high export (typically -2175 kW), but unfortunately operates at high import either just prior, and/or just after the Triad time. The result of which is that the benefit of Triad avoidance to system losses (which decreases losses at time of system peak) are lost – with an overall increase in losses (typically 1.8 kWh). This is explored further below.

First, the power flows are summarised for the Triad events at Rise Carr BESS.

Figure 8: Power flows for 24 Triad events, for i) Rise Carr without BESS, ii) Rise Carr with BESS, iii) BESS. The bottom axis denotes each event. Each Triad event includes the demand either side of the Triad period, and it is noted that the import required to facilitate Triad export occurs close to time of system peak.

Second, the losses impact of BESS Triad avoidance events is quantified.

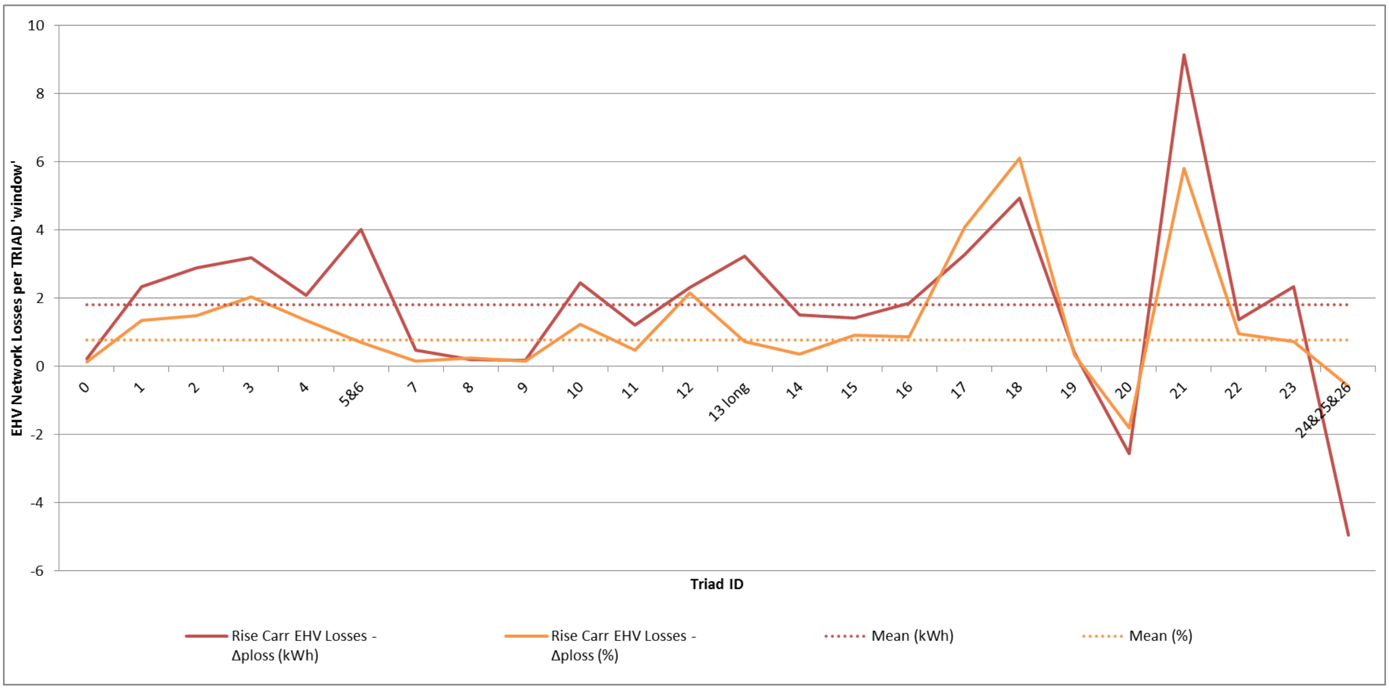


Figure 9: The Impact of BESS Triad event operation on losses (kWh) and as a percentage of total EHV power flow (%). The total impact across all Triad events is an increase in losses from 5,830 kWh to 5,867 kWh; a net increase of 43 kWh (mean of 1.8 kWh), or 0.77%. Note: Triad event 20 is outlier as it was not possible to define the event duration to give a net zero BESS consumption; instead, the net position was -675 kWh (i.e. net export position, which would reduce losses).

Third, the losses impact for a typical Triad period is reviewed.

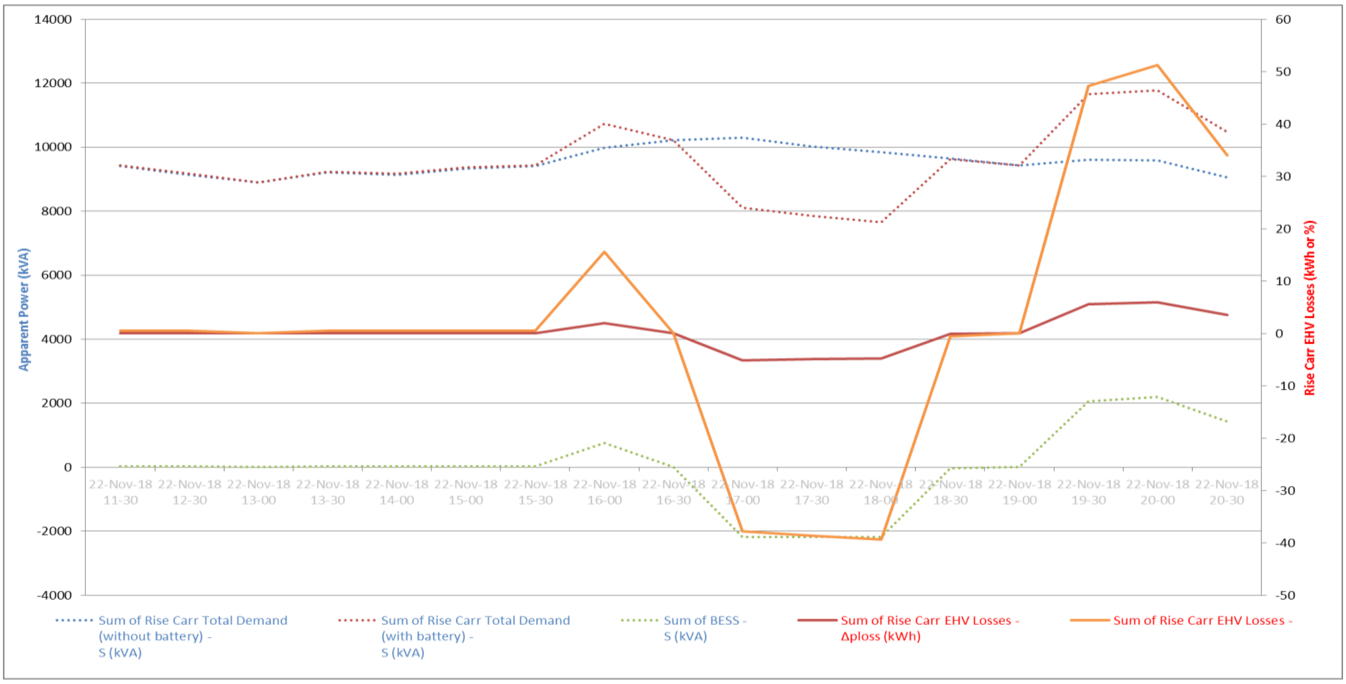


Figure 10: Triad event 10 (22 Nov 18) half hourly power flow (left axis) and analysis of change in losses (right axis). Total network losses increases from 197.3 kWh to 199.8 kWh, an increase of 2.5 kWh or 1.2%. Note that this is an underestimation of the losses given the half hourly data, and the analysis based on net zero sum of inputs and outputs – i.e. excluding impact on network of BESS round trip efficiency of 73%. Losses are reduced for the Triad settlement periods (given that the BESS exports and thus reduces net demand at Rise Carr), however the behaviour of importing immediately before and afterwards results in a net losses increase.

Losses are reduced for the Triad settlement periods (given that the BESS exports and thus reduces net demand at Rise Carr), however the behaviour of importing immediately before and afterwards increases the losses more for these settlement periods by a greater magnitude than losses were reduced during the Triad, thus a net increase of losses results. As a simple explanation, starting with 10 MVA demand over two periods (losses proportional to10^2 + 10^2 i.e. 200), and then an alternate whereby a BESS shifts 2 MVA of demand from one period to the other; 8 MVA and 12 MVA demand (losses proportional to 8^2 + 12^2 i.e. 208); it can be understood how the above behaviour increases losses.

Fourth (finally), the losses impact for the full day, showing an optimised BESS Triad operation.

It is apparent that the behaviour of the BESS increases losses in relation to Triad events as the BESS imports immediately prior to and post BESS export. In order to explain the optimal behaviour, a full daily load curve is used, on the basis that the optimised BESS would import power overnight when demand is lowest. Note that the day selected has the BESS at full import at 07:30 which increases losses; however this is not deemed to be related to the Triad and is not adjusted for this analysis. The approach taken to optimise the BESS operation simply shifts the imports between 15:00 and 21:00 and is distributed overnight to flatten the load curve between 00:00 and 06:00.

It is not clear why the BESS imports during settlement periods with high wholesale prices, and not overnight when they are typically lowest. The result of this behaviour is that overall losses are increased rather than decreased; the example below showing an increase of 2.8 kWh and potential decrease of 7.0 kWh if the behaviour was adjusted to import overnight.

Table 8: Triad event 10 (22 Nov 18) analysis of losses without BESS, with BESS (increase of 7 kWh), and with Triad optimised BESS (decrease of 2.8 kWh). Triad avoidance could be used to minimise losses if the import is properly aligned with minimum demand.

	Without BESS	BESS	Triad Optimised BESS
Rise Carr EHV Losses (kWh)	343	350	340
Impact of BESS (kWh)	N/A	7.0	-2.8
Impact of BESS (%)	N/A	2.0	-0.8

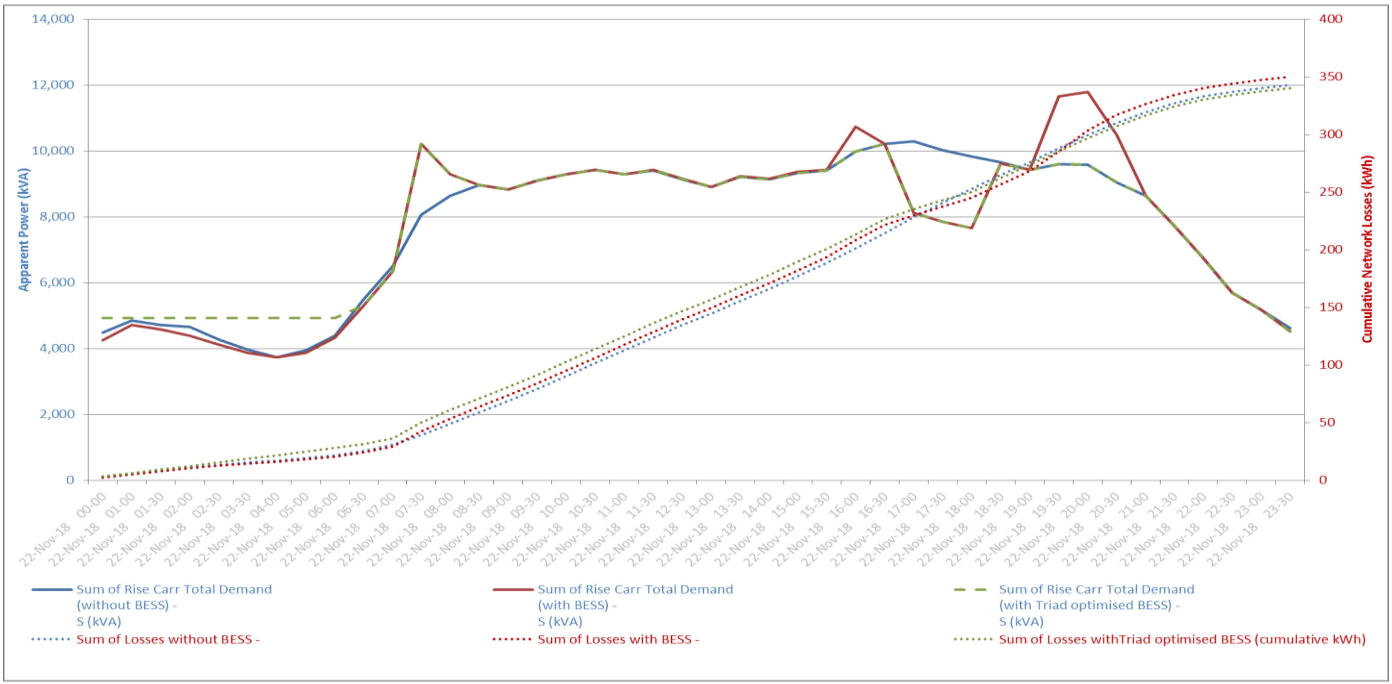


Figure 11: Triad event 10 (22 Nov 18) full day analysis or power flow and cumulative losses for i) Rise Carr without BESS, ii) Rise Carr with BESS, iii) Rise Carr with BESS optimised to reduce losses associated with the Triad event.

7.5 Extrapolating for all BESS

In isolation, it is hard to understand the materiality of BESS and its losses impact. As a simple extrapolation, assuming that on average for a typical BESS, the network losses impact and BESS losses are the same as for Rise Carr BESS, the total losses can be estimated across the Northern Powergrid network, for all connected and accepted BESS projects. For context, the total annual losses for both Northern Powergrid licence areas, totals 1.9 TWh, equating to £95m in energy costs (assuming £50/MWh). With reference to the table below, it can be seen that the estimation of £7k annual network losses impact is negligible compared to total network losses of £95m. The total BESS losses of £3m is, significant, however these losses are not network losses, but customer losses that are paid for by BESS owner/operators. The efficiency of BESS is similar to pumped storage, and offers significant benefits to the network – in particular in its role as an FFR provider and storage capability to facilitate the move towards more renewable generation.

Table 9: Extrapolation of Rise Carr network and BESS losses to estimate the total network and BESS losses for all accepted and connected BESS customers to the NPgY and NPgN networks. £50/MWh is used for energy costs, and 300 gCO_2/kWh is used for carbon emissions impact.

Connection Status	Export Capacity (MW)	Annual Network Losses				Annual BESS Losses			
		MWh/MW	MWh	£k	tonnes CO_2	MWh/MW	MWh	£k	tonnes CO_2
Accepted	339	0.32	109	5	1,628	138.4	46,941	2,347	14,082,257
Connected	129	0.32	41	2	619	138.4	17,853	893	5,355,825
Total	**468**	**0.32**	**150**	**7**	**2,247**	**138.4**	**64,794**	**3,240**	**19,438,082**

8 Conclusion

Rise Carr BESS half hourly analysis shows that the average daily impact on network losses is 2.1 kWh, which over the course of a year would be 0.8 MWh of additional network losses. Using an average wholesale energy cost of £50/MWh, this amounts to £38/annum in additional network losses. Using an average carbon intensity of 300gCO_2/kWh and social cost of carbon of £50/tCO_2, this amounts to 0.2 tCO_2 and £12 cost of carbon. It is important to note that despite the detrimental impact on network losses, BESS provides essential services which results in a net benefit to the energy system, and that on balance, the losses impact is not significant.

Firm Frequency Response forms the majority of the import and export behaviour of the BESS, and therefore the impact of this on losses is approximately 2.1 kWh per day. Given that system frequency fluctuates within each half-hour period, it is evident that the calculated losses impact is an underestimate. It is recommended that once higher resolution information is available, the impact of BESS FFR operation on losses is reviewed.

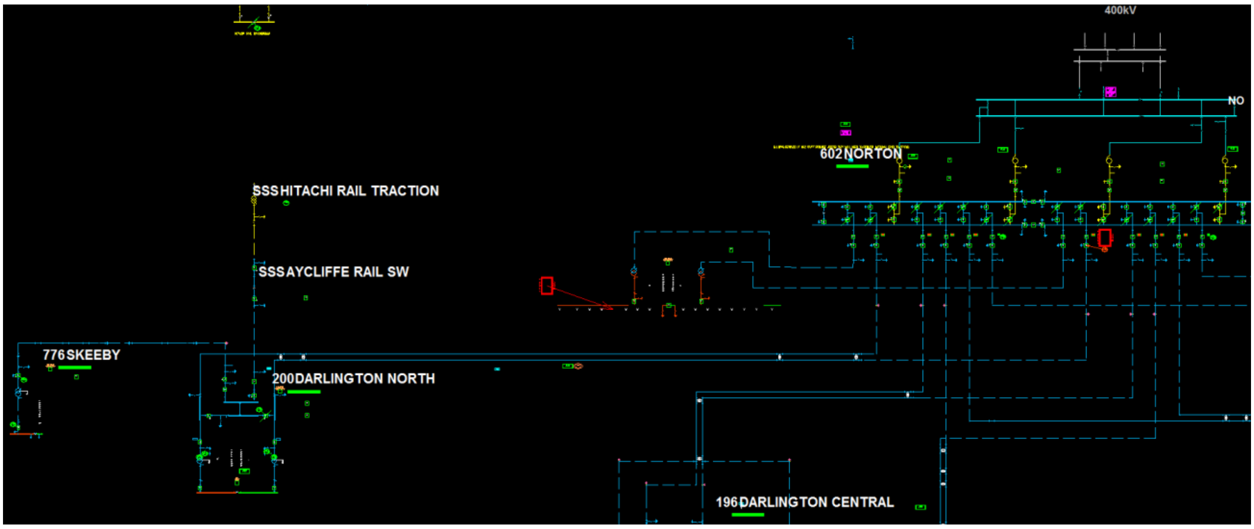
Triad avoidance operation is carried out by the battery, based on Kiwi Power's forecast of potential Triad events. Whilst there is a losses benefit of Triad avoidance (several kWh) per half hour, the existing operation of the BESS results in an increase in net Rise Carr demand at the time periods either side of system peak, and therefore overall, there is an average increase in losses associated with Triad avoidance of 1.8 kWh. If the BESS was optimised to import energy overnight when net demand was lowest, there could be a decrease in losses associated with Triad avoidance of several kWh.

Rise Carr BESS round trip efficiency is roughly 73%, and therefore the associated losses with BESS efficiency far outweigh network losses. The average daily BESS losses are 948 kWh, which over the course of a year would be 346 MWh of losses. Using an average wholesale energy cost of £50/MWh, this amounts to £17,298/annum. Using an average carbon intensity of 300gCO_2/kWh and social cost of carbon of £50/tCO_2, this amounts to 103.8 tCO_2 and £5,189 cost of carbon.

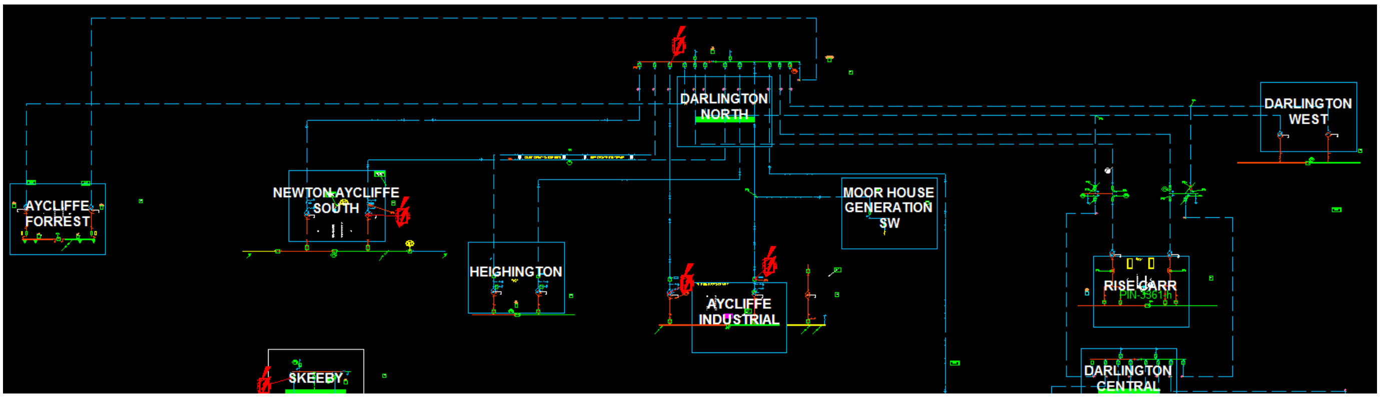
Extrapolation of Rise Carr losses impact (both network and BESS losses) to cover 468 MW of connected and accepted BESS projects, provides an order of magnitude estimate that provides further clarity to the losses assessment. Total annual network losses impact of £7k compared to total annual cost of losses across the NPg networks of £95m highlights that BESS losses are not material to an extent that would warrant further action. Total BESS (round trip efficiency) losses of £3m is significant, however, recognising that i) the efficiency of BESS is similar to pumped storage, ii) these losses are paid for by BESS owners/operators, and iii) the important benefits provided by BESS in facilitating the shift to a low carbon future; it is concluded that losses do not require any action from Northern Powergrid over and above those already taken as part of our Losses Strategy and Code of Practice for the Methodology of Assessing Losses.

Appendix 1: NMS Information

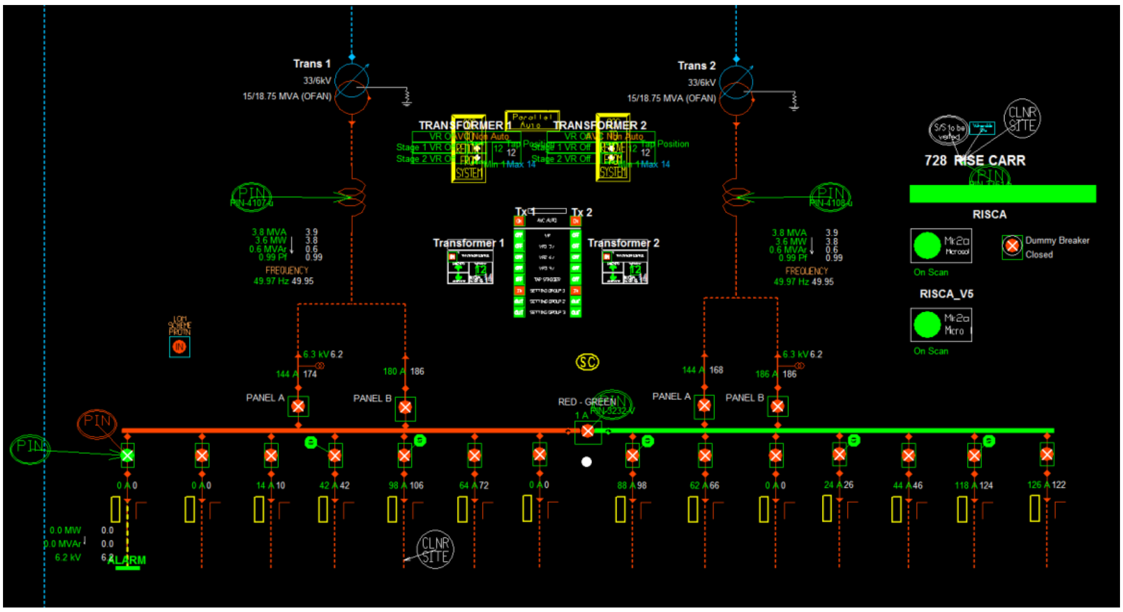
NMS view of Rise Carr network – 132 kV diagram (snapshot taken 4 Nov 19 @ 12.56).



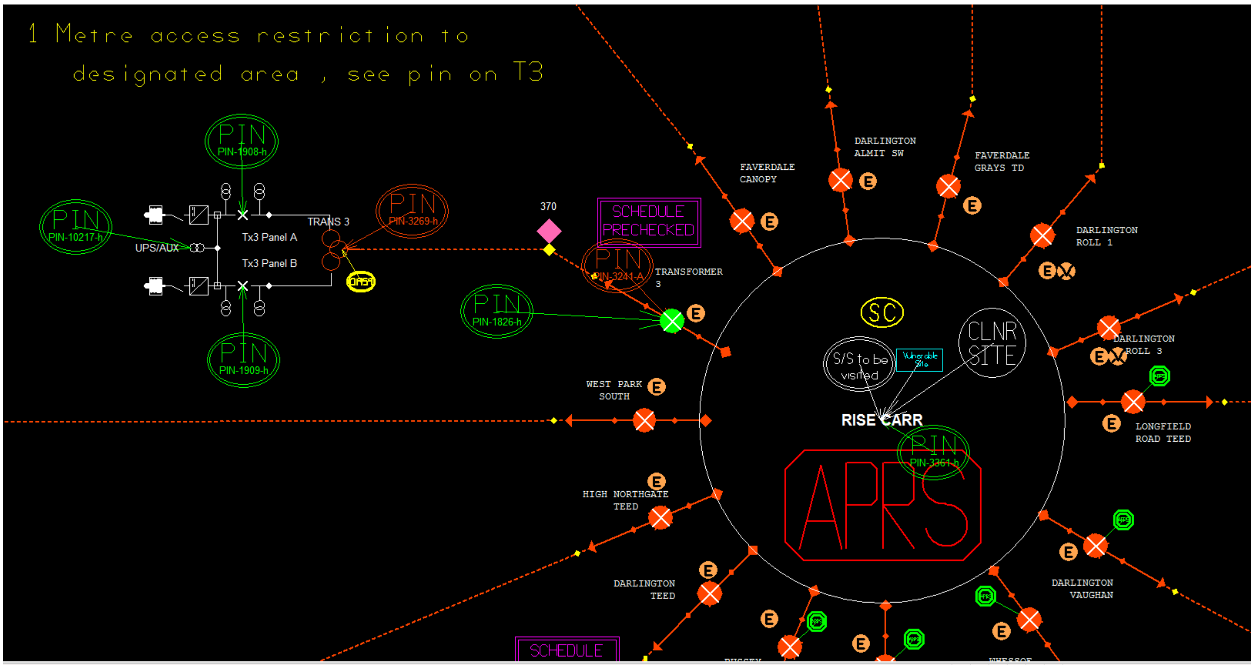
NMS view of Rise Carr EHV network – EHV diagram (snapshot taken 4 Nov 19 @ 12.56). Note that Rise Carr is fed directly via a double circuit, which normally runs to only feed Rise Carr.



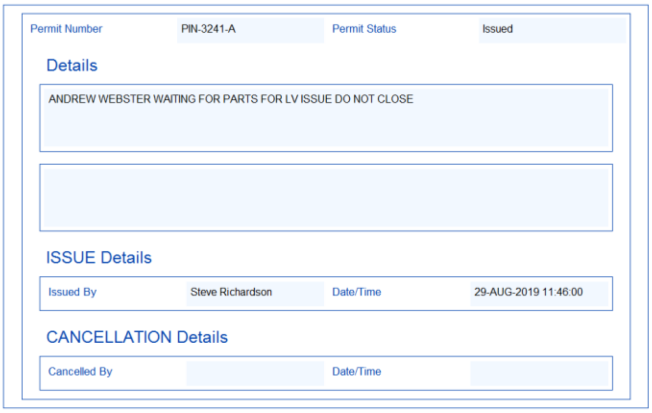
NMS view of Rise Carr network – EHV (snapshot taken 4 Nov 19 @ 12.56). The pin labelled "CLNR SITE", simply notes that the CLNR site was 'opened' on 27 Feb 2013.



NMS view of Rise Carr network – HV diagram (snapshot taken 4 Nov 19 @ 12.56). Note that Rise Carr BESS is fed via the Transformer 3 feeder (10 o'clock).



NMS view of PIN relating to BESS being out of service since Aug 2019.



Permit Number	PIN-3241-A	Permit Status	Issued

Details

ANDREW WEBSTER WAITING FOR PARTS FOR LV ISSUE DO NOT CLOSE

ISSUE Details

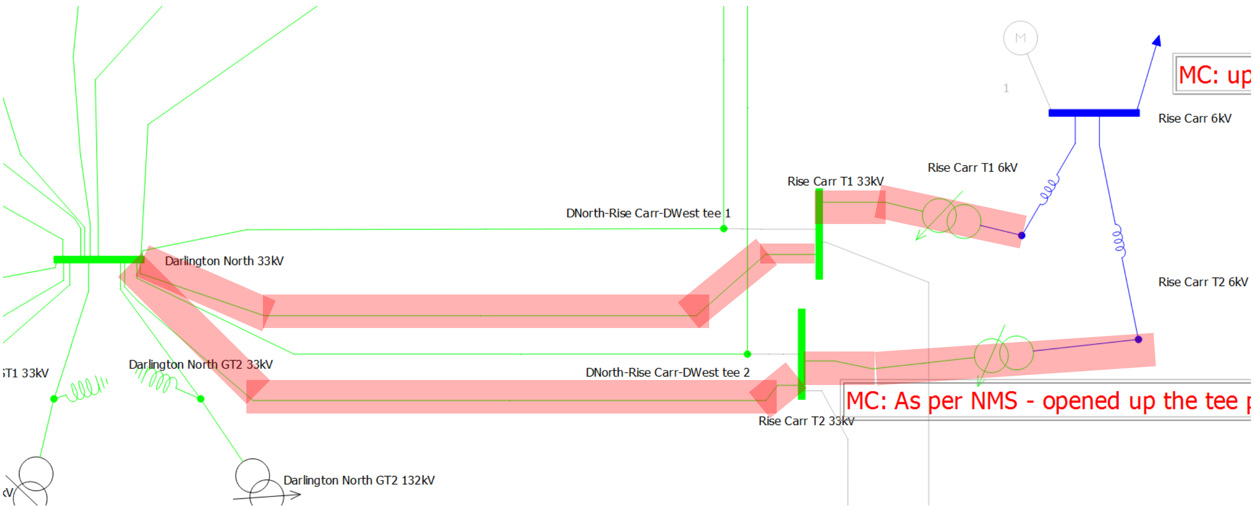
Issued By	Steve Richardson	Date/Time	29-AUG-2019 11:46:00

CANCELLATION Details

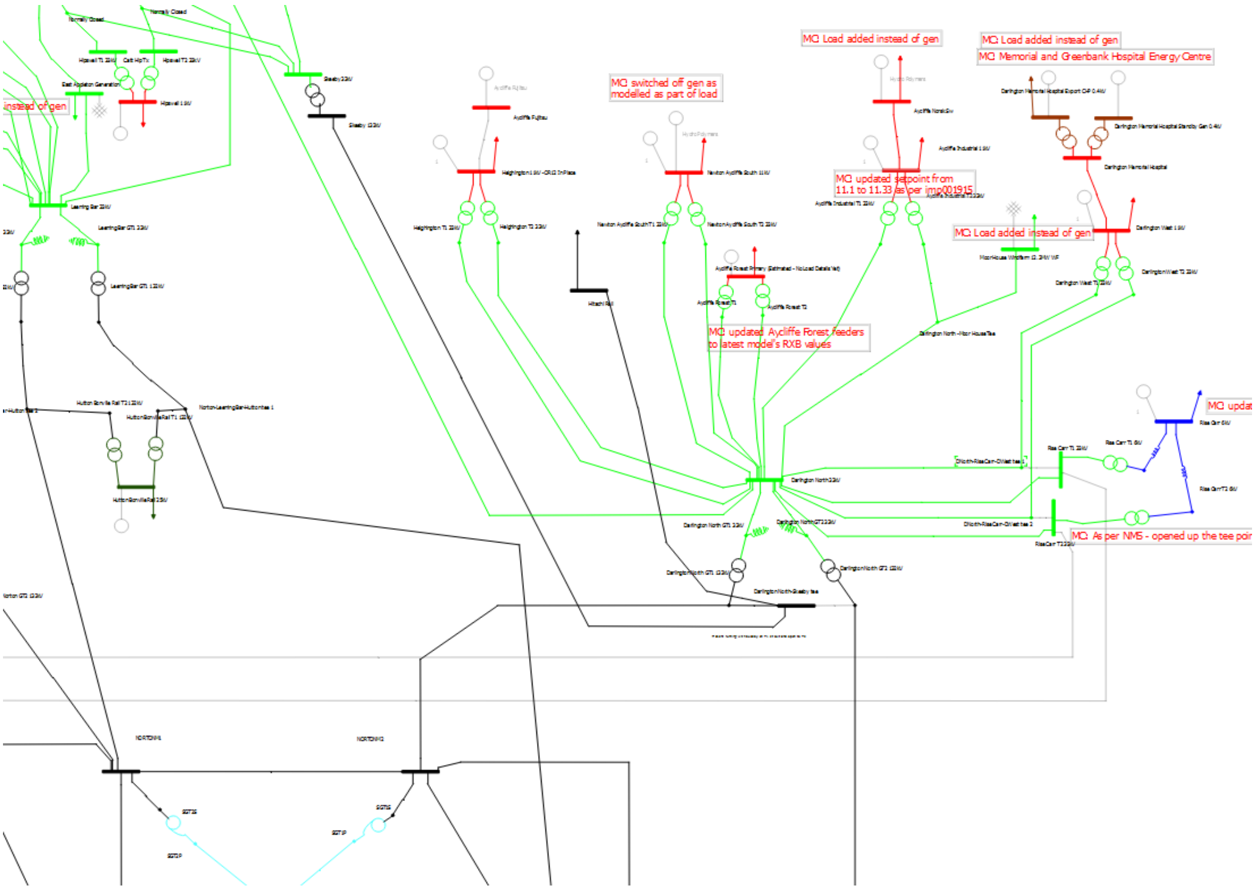
Cancelled By		Date/Time	

Appendix 2: IPSA Information

IPSA screen-grab of Darlington North – Rise Carr network section. Note both Rise Carr Tx are dual tap type, tapped to 6.4 kV, and a target voltage of 6.3 kV. Analysed EHV assets shaded in pink.



IPSA screen-grab of Darlington North EHV network, showing Skeeby interconnection – i.e. the EHV connectivity. This has not been analysed, and analysis is limited to the Darlington North – Rise Carr EHV circuits and 33/6.4 kV Rise Carr transformers. Note that Rise Carr is in the middle right of the diagram.



Appendix 3: Transformer Information.

Note that these transformers are dual rated (i.e. secondary voltage of either 11.5 kV or 6.4 kV can be connected).

It will be assumed that the 15 MVA rating c95kW copper losses are applicable based on the information below found in the losses folder, in absence of test certificates *(none located in folder: \\ad03.local\shares\PUBLICPLA\Information Systems\DINIS\NEDL Transformer Test Sheets).*

Date source information.

Filename: Northeast transformer losses data
Folder: T:\Asset_Info\LOSSES\Transformer Losses Data

ID	315	316
LOCATION	RISE CARR	RISE CARR
DESCRIPTION	TRANSFORMER 1	TRANSFORMER 2
MANUFACTURER	CROMPTON PARKINSON	CROMPTON PARKINSON
VOLTAGE	33/11.5/6.4KV	33/11.5/6.4KV
RATING	15MVA	15MVA
SPECIFICATION	BS171	BS171
DATE OF MANUFACTURE	1964	1964
SERIAL NO	H480/2	H480/1
VECTOR GROUP	Yy6	Yy6
IMPEDANCE		
TAPCHANGER MANUFACTURER	FERRANTI	FERRANTI
TAPCHANGER TYPE	DC3	DC3
TAPPING RANGE		
TAPCHANGER SER NO	1048	1047
TRANSPORTATION WEIGHT		
TOTAL OIL VOLUME	13181L	13181L
IRON LOSS	11.71KW	12.40KW
COPPER LOSS	95KW	95.9KW
HV TERMINATIONS	CABLE BOX	CABLE BOX
LV TERMINATIONS	CABLE BOX	CABLE BOX
FFA LEVEL		
PCB LEVEL		
RADIATOR CONDITION	3.5	3
RADIATORS CHANGED	FALSE	FALSE
YEAR RADIATORS CHANGED		
IS THE TRANSFORMER BUNDED?	TRUE	TRUE
DATE BUND COMPLETED	27/01/1998	27/01/1998
IS A NOISE ENCLOSURE FITTED?	FALSE	FALSE
HAVE THE RADIATORS BEEN CHANGED?	FALSE	FALSE

Appendix 4: Amp2View transformer information – no useful information for this report but included for completeness.

(http://amp2view/applications/Amp2View/Site/Site-Assets.asp?AreaID=9825)

POWER TRANSFORMER Type Components: Index

67891	POWER TRANSFORMER	TRANSFORMER 1	GM - INDOOR	33000	1964	CROMPTON PARKINSON	33/11/6KV GM	H480/2	NEDL	DARLINGTON - MAJOR PROJECTS	COMMISSIONED	03/06/1965
67892	POWER TRANSFORMER	TRANSFORMER 2	GM - INDOOR	33000	1964	CROMPTON PARKINSON	33/11/6KV GM	H480/1	NEDL	DARLINGTON - MAJOR PROJECTS	COMMISSIONED	03/06/1965
7602172	POWER TRANSFORMER	TRANSFORMER NO.3	GM - INDOOR	6600		DYNAPOWER	6.6KV 2500KVA GM	88733-001	NEDL	DARLINGTON - MAJOR PROJECTS	COMMISSIONED	09/11/2013
64875	POWER TRANSFORMER	TRANSFORMER 3	GM - INDOOR	6000	1964	YET	6KV 100KVA GM	Y13860	NEDL	DARLINGTON - MAJOR PROJECTS	SCRAPPED	15/04/2013

POWER TRANSFORMER ON TRANSFORMER 1 CIRCUIT @ RISE CARR - Details

Asset Location Details:

Site Name: RISE CARR
Site Type: PRIMARY SITE
Site Class: BUILDING - WITHOUT COMPOUND
Site Inspected By: NEDL
Site Maintained By: DARLINGTON - MAJOR PROJECTS
Site Asset ID: 9825
OS Grid Reference: NZ2861416869

Asset Base Details:

Asset Type: POWER TRANSFORMER
Circuit Name: TRANSFORMER 1
Make: CROMPTON PARKINSON
List items of the same type recorded in the system
Owned By: NEDL
Asset Status: COMMISSIONED
Installed By:
Date at Status: 03-JUN-1965
Model: 33/11/6KV GM
Serial Number: H480/2
Asset_ID: 67891
External Identifier:
Year of Manufacture: 1964
Situation: GM - INDOOR
Maintained By: DARLINGTON - MAJOR PROJECTS

Additional Details:

Transformer No: T01
Vector Group: YY0
Primary Terminal Type: CAB BOX FOR 1 SINGLE CORE/PHASE
Tap Changer Type: ON LOAD AUTOMATIC
Insulation Type: OIL
Breather / Oil Seal Type: SILICA-GEL BREATHER
Transformer Specification: BS 171
Phasing Indication: RED - YELLOW - BLUE
Secondary Terminal Type: CABLE BOX FOR 2SINGLE CORE/PHASE+CABLE BOX FOR2X1CORE/PHASE
Tap Changer Scheme: MASTER/FOLLOWER
Buchholz Relay Fitted: Yes

Asset Characteristics:

Characteristic	Value	Unit of Measure
IMPEDANCE	13.18	%
MAXIMUM TAP	104.5	%
MINIMUM TAP	85	%
NUMBER OF CUSTOMERS	0/4	
NUMBER OF PHASES	3	
OFAN RATING	18750	kVA
ONAN RATING	15000	kVA
QUANTITY OF OIL	9701	litres
TOTAL MASS	35	Tonnes
VOLTAGE - DUAL RATIO	11500/6400	volts
VOLTAGE - PRIMARY	33000	volts
VOLTAGE - SECONDARY	6400	volts

Additional File Information:

No additional file information files exist for this asset — Manage Additional File Information

POWER TRANSFORMER ON TRANSFORMER 2 CIRCUIT @ RISE CARR - Details

Asset Location Details:

Site Name: RISE CARR
Site Type: PRIMARY SITE
Site Class: BUILDING - WITHOUT COMPOUND
Site Inspected By: NEDL
Site Maintained By: DARLINGTON - MAJOR PROJECTS
Site Asset ID: 9825
OS Grid Reference: NZ2861416869

Asset Base Details:

Asset Type: POWER TRANSFORMER
Circuit Name: TRANSFORMER 2
Make: CROMPTON PARKINSON
List items of the same type recorded in the system
Owned By: NEDL
Asset Status: COMMISSIONED
Installed By:
Date at Status: 03-JUN-1965
Model: 33/11/6KV GM
Serial Number: H480/1
Asset_ID: 67892
External Identifier:
Year of Manufacture: 1964
Situation: GM - INDOOR
Maintained By: DARLINGTON - MAJOR PROJECTS

Additional Details:

Transformer No: T02
Vector Group: YY0
Primary Terminal Type: CAB BOX FOR 1 SINGLE CORE/PHASE
Tap Changer Type: ON LOAD AUTOMATIC
Insulation Type: OIL
Breather / Oil Seal Type: SILICA-GEL BREATHER
Transformer Specification: BS 171
Phasing Indication: RED - YELLOW - BLUE
Secondary Terminal Type: CABLE BOX FOR 2SINGLE CORE/PHASE+CABLE BOX FOR2X1CORE/PHASE
Tap Changer Scheme: MASTER/FOLLOWER
Buchholz Relay Fitted: Yes

Asset Characteristics:

Characteristic	Value	Unit of Measure
IMPEDANCE	13.2	%
MAXIMUM TAP	104.5	%
MINIMUM TAP	85	%
NUMBER OF CUSTOMERS	0/4	
NUMBER OF PHASES	3	
OFAN RATING	18750	kVA
ONAN RATING	15000	kVA
QUANTITY OF OIL	9701	litres
TOTAL MASS	35	Tonnes
VOLTAGE - DUAL RATIO	11500/6400	volts
VOLTAGE - PRIMARY	33000	volts
VOLTAGE - SECONDARY	6400	volts

Additional File Information:

No additional file information files exist for this asset — Manage Additional File Information

POWER TRANSFORMER ON TRANSFORMER NO.3 CIRCUIT @ RISE CARR - Details

Asset Location Details:

Site Name: RISE CARR
Site Type: PRIMARY SITE
Site Class: BUILDING - WITHOUT COMPOUND
Site Inspected By: NEDL
Site Maintained By: DARLINGTON - MAJOR PROJECTS
Site Asset ID: 9825
OS Grid Reference: NZ2861416869

Asset Base Details:

Asset Type: POWER TRANSFORMER
Circuit Name: TRANSFORMER NO.3
Make: DYNAPOWER
List items of the same type recorded in the system
Owned By: NEDL
Asset Status: COMMISSIONED
Installed By:
Date at Status: 09-NOV-2013
Model: 6.6KV 2500KVA GM
Serial Number: 88733-001
Asset_ID: 7602172
External Identifier:
Year of Manufacture:
Situation: GM - INDOOR
Maintained By: DARLINGTON - MAJOR PROJECTS

Additional Details:

Transformer No:
Vector Group: DY11
Primary Terminal Type: BUSHINGS - INDOOR
Tap Changer Type: OFF CIRCUIT TAPCHANGER
Insulation Type: AIR - INDOOR
Breather / Oil Seal Type:
Transformer Specification:
Phasing Indication: RED - YELLOW - BLUE
Secondary Terminal Type: BUSHINGS - INDOOR
Tap Changer Scheme: NOT APPLICABLE
Buchholz Relay Fitted: -

Asset Characteristics:

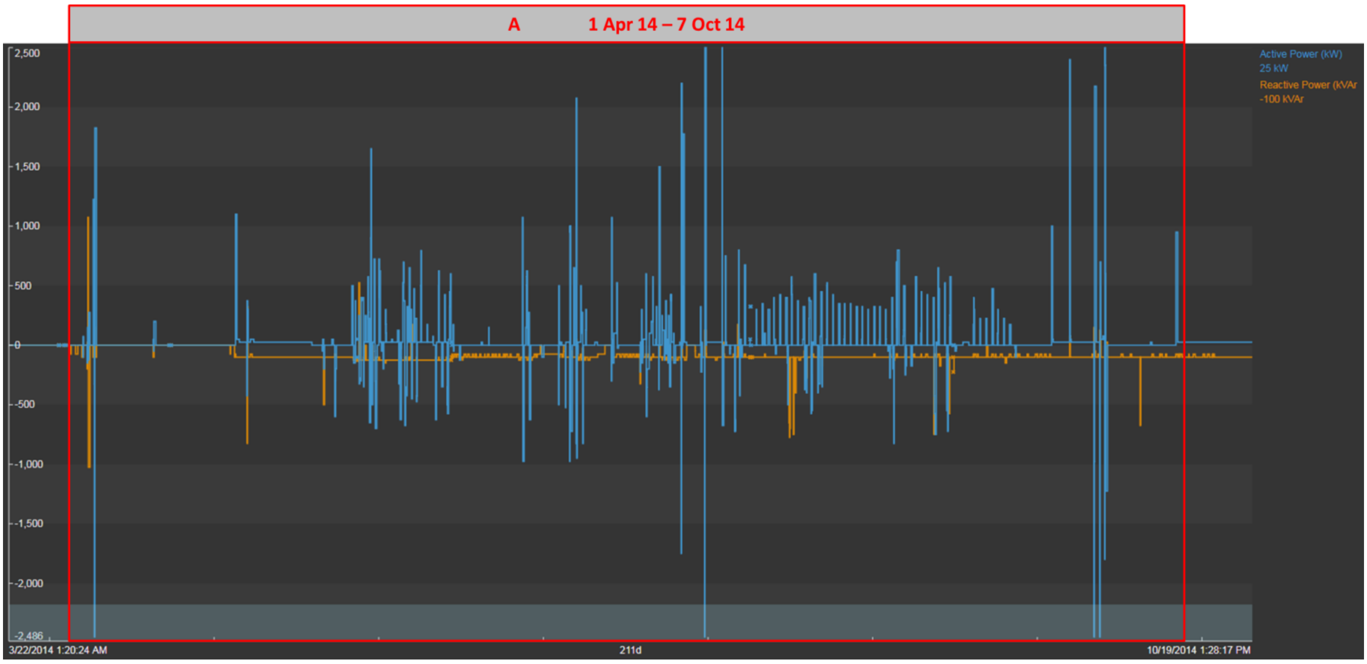
Characteristic	Value	Unit of Measure
JOB NUMBER (WHEN COMMISSIONED)	CLNR003	
MAXIMUM TAP	105	%
MINIMUM TAP	95	%
NUMBER OF CUSTOMERS	0/4	
ONAN RATING	2500	kVA
TAP CONNECTED	95	%
VOLTAGE - PRIMARY	6600	volts
VOLTAGE - SECONDARY	480	volts

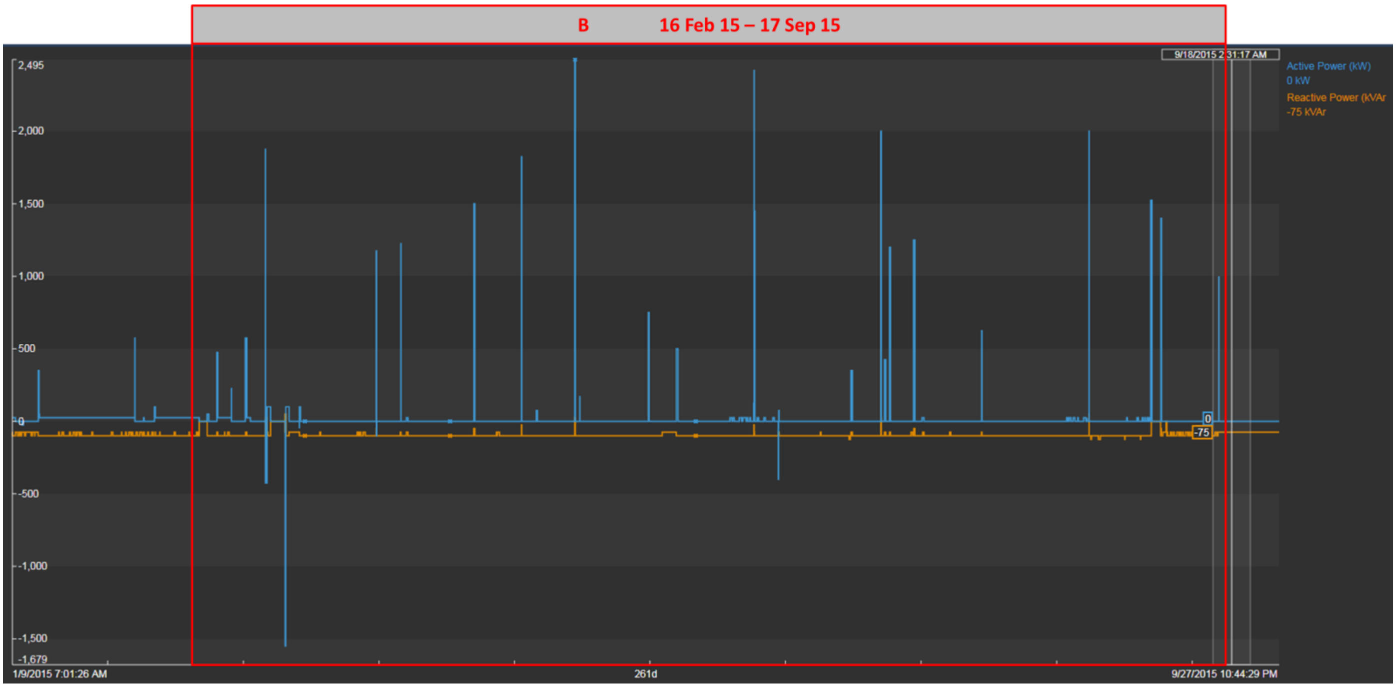
Additional File Information:

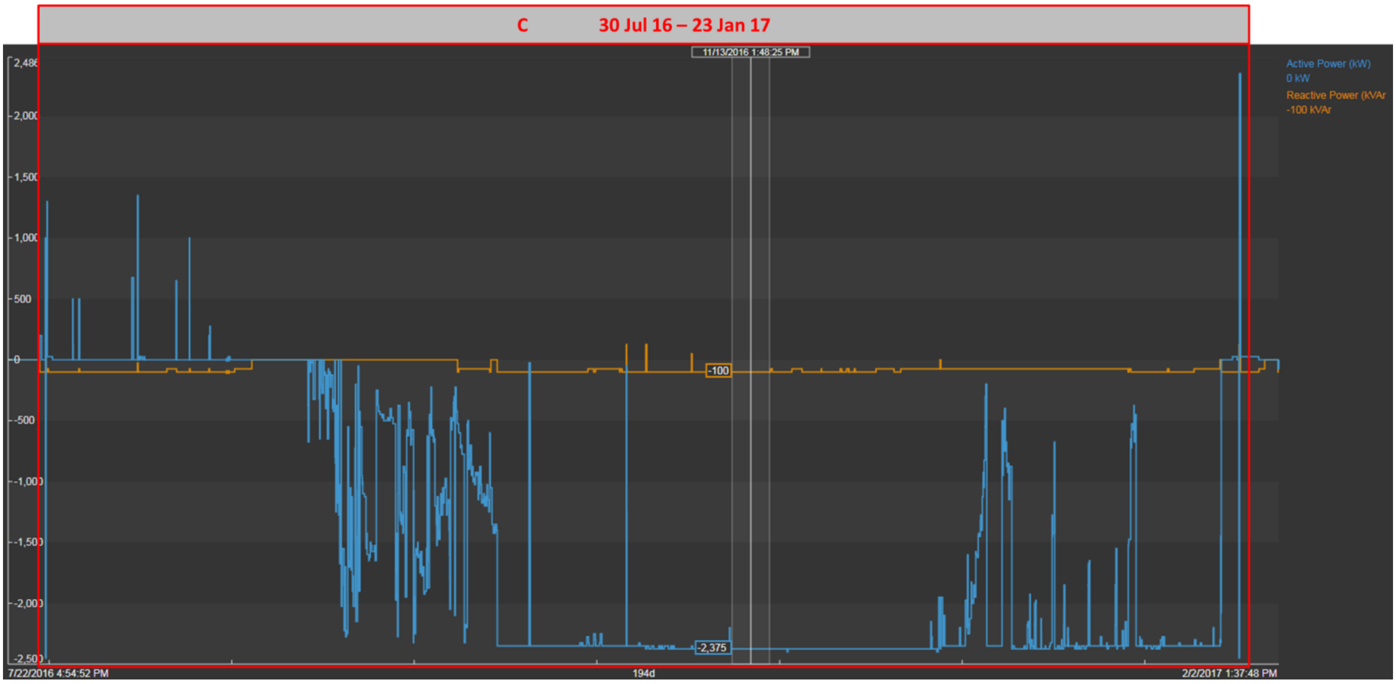
No additional file information files exist for this asset — Manage Additional File Information

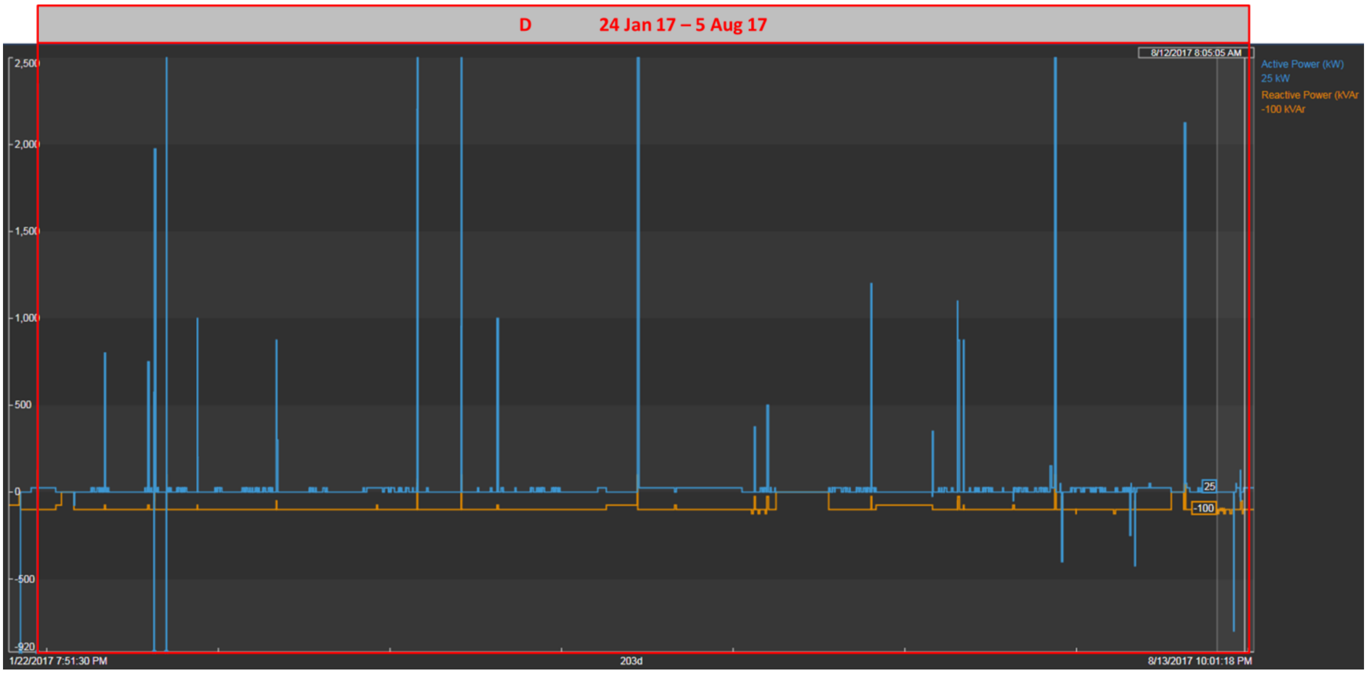
Appendix 5: PI Data for Rise Carr BESS – Windows A, B, C, D, E, F1, F2, G.

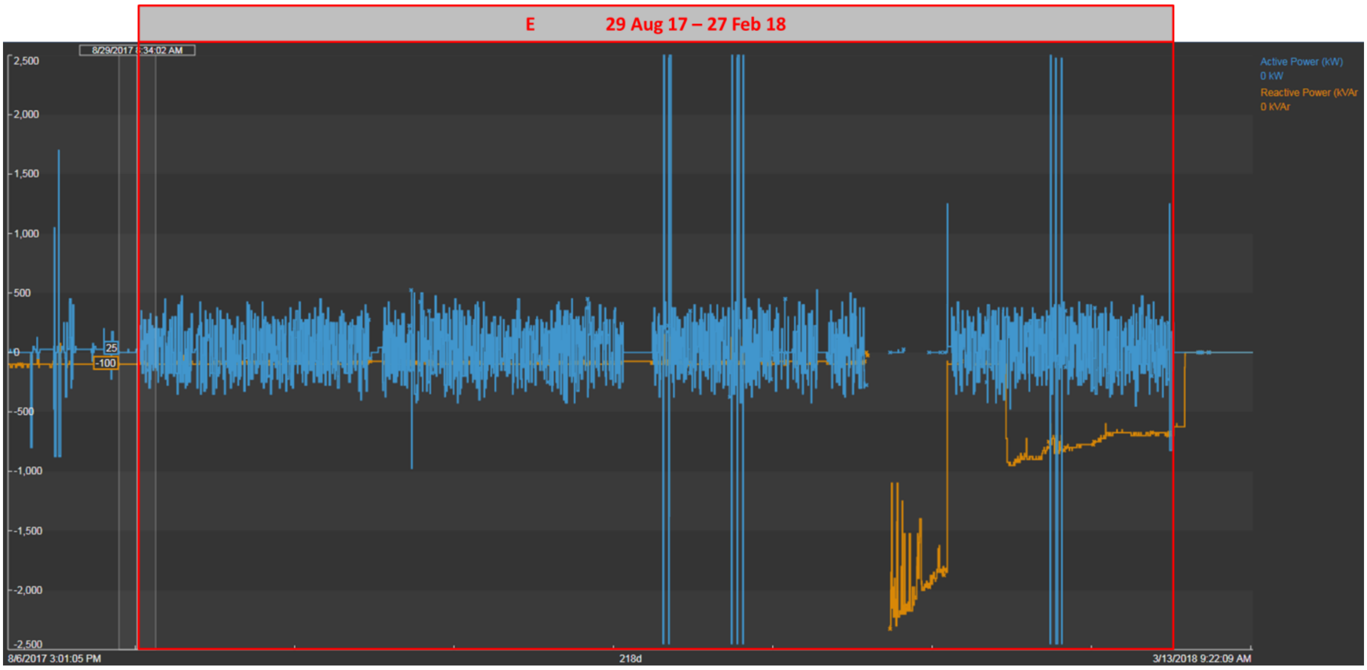
Shortcut to saved template: http://sv300049/PIVision/#/Displays/216/Rise-Carr---6-Years

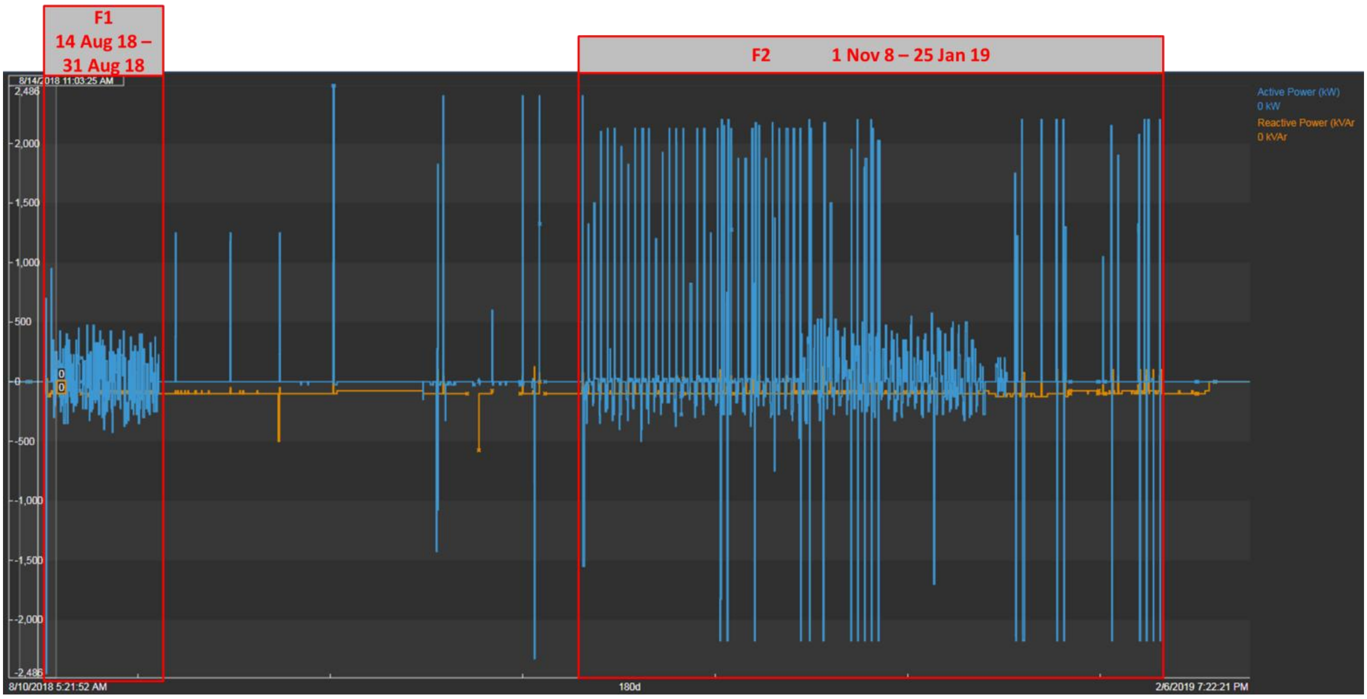


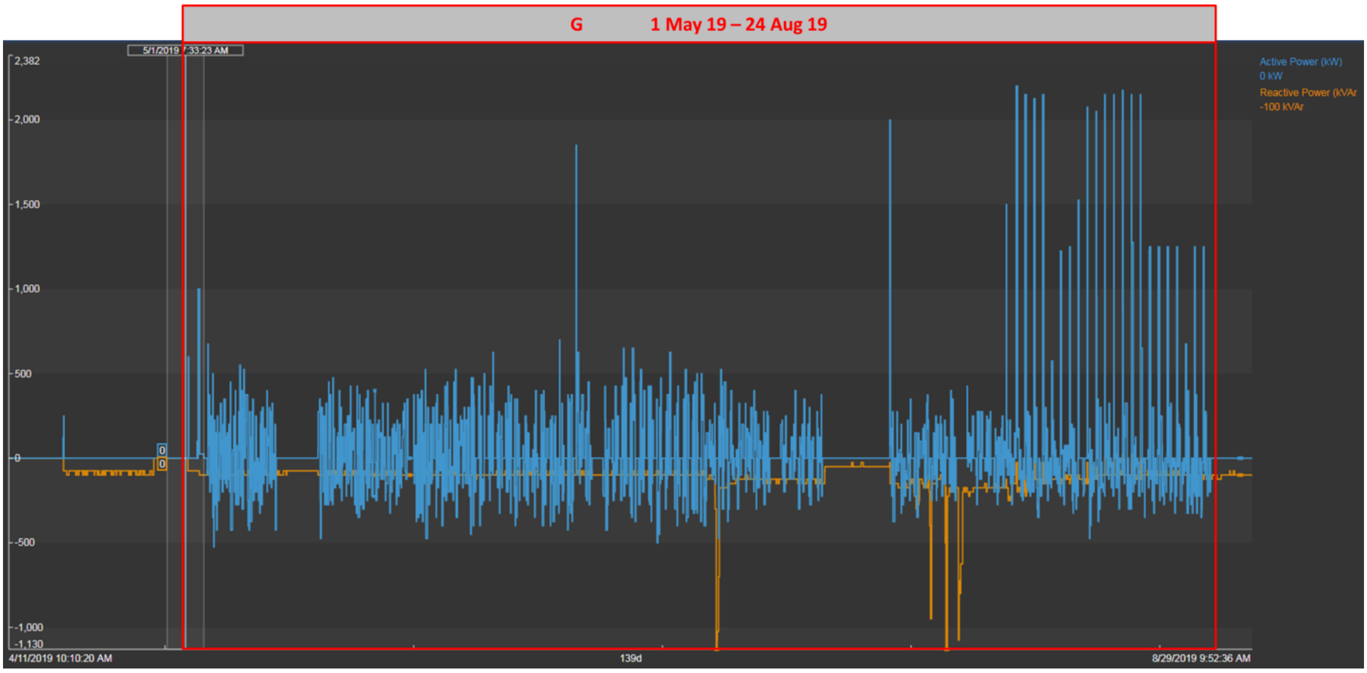



C
30 Jul 16 – 23 Jan 17
11/13/2016 1:48:25 PM
Active Power (kW)
0 kW
Reactive Power (kVAr
-100 kVAr
2,486
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-2,000
-2,500
-100
-2,375
7/22/2016 4:54:52 PM
194d
2/2/2017 1:37:48 PM


D
24 Jan 17 – 5 Aug 17
8/12/2017 8:05:05 AM
Active Power (kW)
25 kW
Reactive Power (kVAr
-100 kVAr
2,500
2,000
1,500
1,000
500
0
-500
-920
25
-100
1/22/2017 7:51:30 PM
203d
8/13/2017 10:01:18 PM

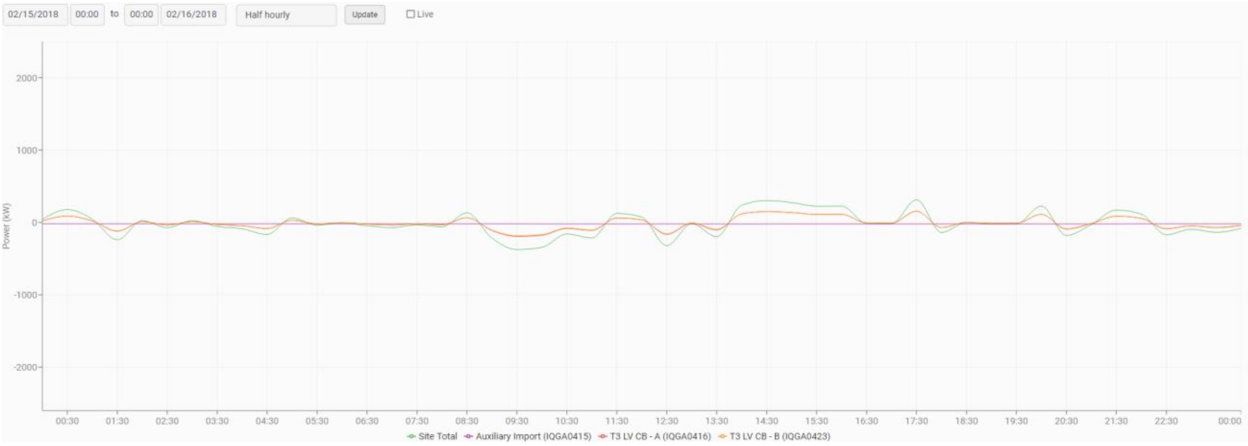

E
29 Aug 17 – 27 Feb 18
8/29/2017 6:34:02 AM
Active Power (kW)
0 kW
Reactive Power (kVAr
0 kVAr
8/6/2017 3:01:05 PM
218d
3/13/2018 9:22:09 AM


F1
14 Aug 18 –
31 Aug 18
F2
1 Nov 8 – 25 Jan 19
8/14/2018 11:03:25 AM
Active Power (kW)
0 kW
Reactive Power (kVAr
0 kVAr
8/10/2018 5:21:52 AM
180d
2/6/2019 7:22:21 PM


G
1 May 19 – 24 Aug 19
5/1/2019 7:33:23 AM
2,382
2,000
1,500
1,000
500
0
-500
-1,000
-1,130
4/11/2019 10:10:20 AM
139d
8/29/2019 9:52:36 AM
Active Power (kW)
0 kW
Reactive Power (kVAr
-100 kVAr

Appendix 6: Rise Carr BESS data from Kiwi Power's data historian (KOMP)

15 Feb 2018 - 00:00 – 23:59 – half hourly resolution:



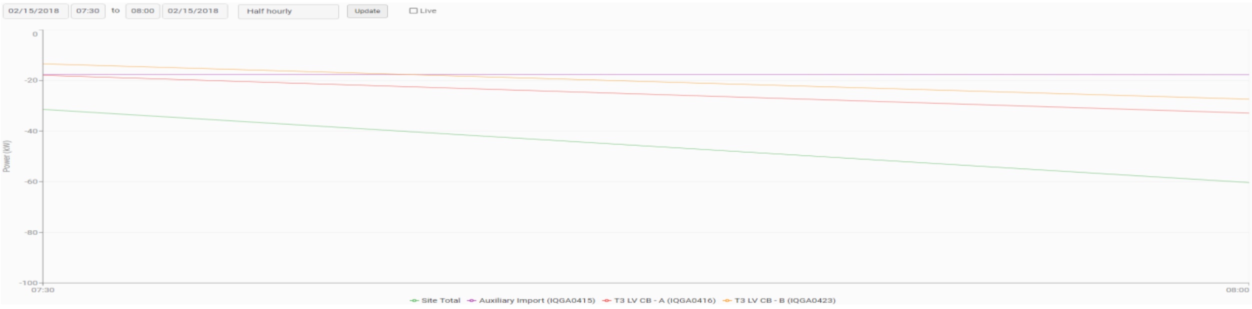
15 Feb 2018 - 00:00 – 23:59 – minute resolution:

15 Feb 2018 - 00:00 – 23:59 – thirty second resolution:

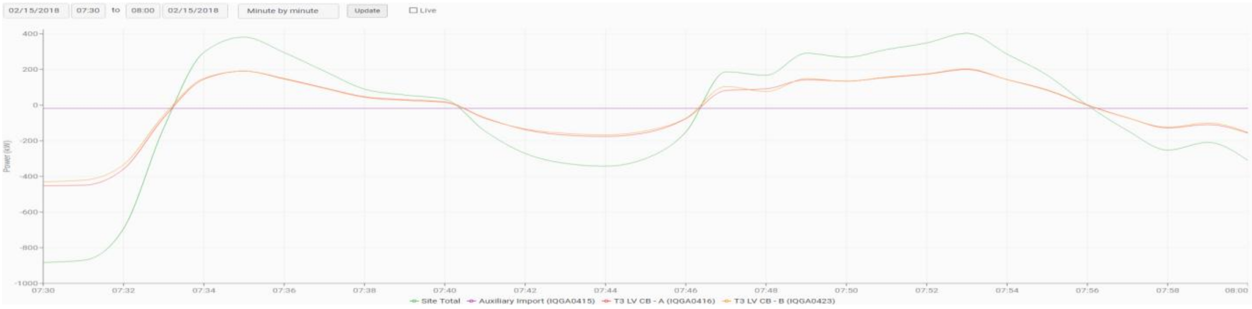
15 Feb 2018 - 00:00 – 23:59 – second-by-second resolution:

It was not possible to produce a trace for second by second resolution (crashed the system), therefore the traces below are produced for a single half hour period – which is at -30kW at 07:30, with subsequent resolutions showing the large variation in excess of 30kW.

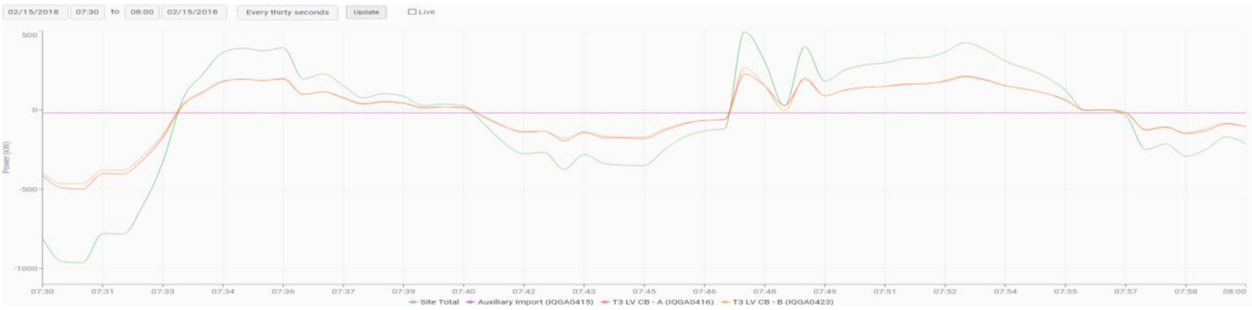
15 Feb 2018 - 07:30 – 08:00 – half hourly resolution:



15 Feb 2018 - 07:30 – 08:00 – minute resolution:



15 Feb 2018 - 07:30 – 08:00 – thirty second resolution:



15 Feb 2018 - 07:30 – 08:00 – ten second resolution:

15 Feb 2018 - 07:30 – 08:00 – second-by-second resolution: