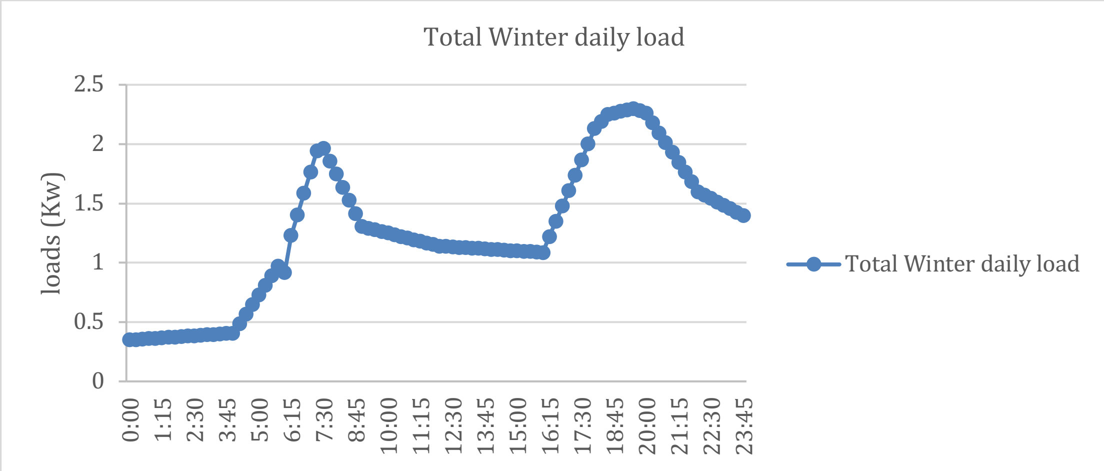
VICTORIA UNIVERSITY OF WELLINGTON
TE HERENGA WAKA
NEW ZEALAND
Archives of Sustainable Energy Systems
https://www.wgtn.ac.nz/sustainable-energy-systems

Reduce stress on local distribution transformers through load, battery control, and photovoltaics: A Wellington case study
Supplementary Material

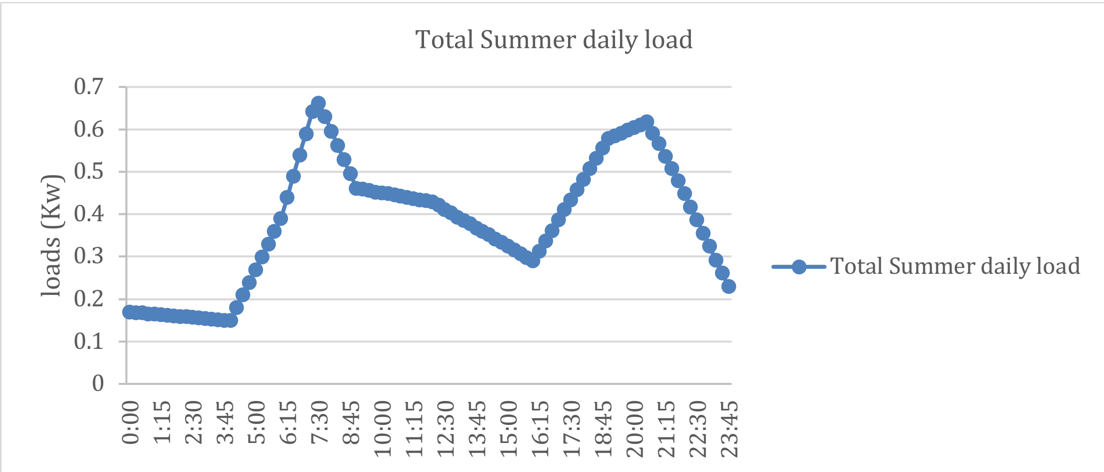
Reference material

Load profile

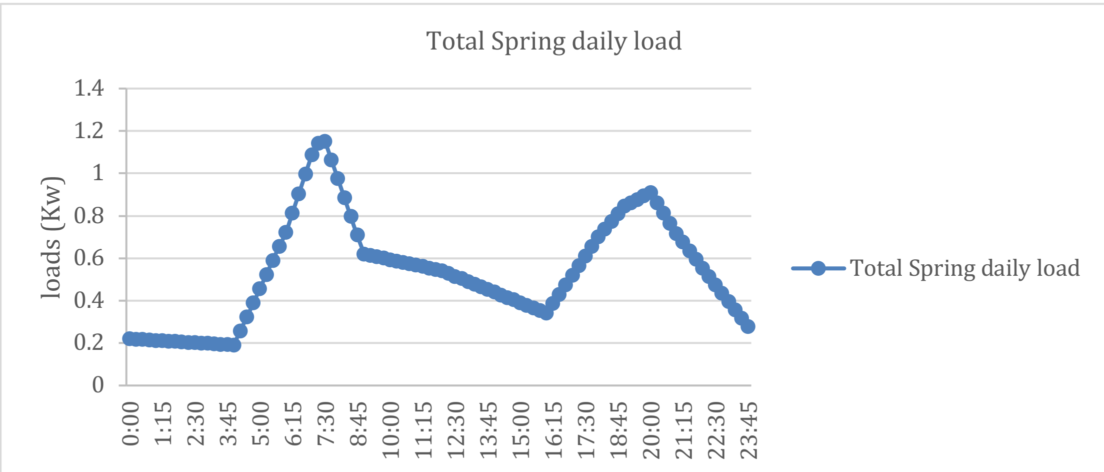
Residential load profile



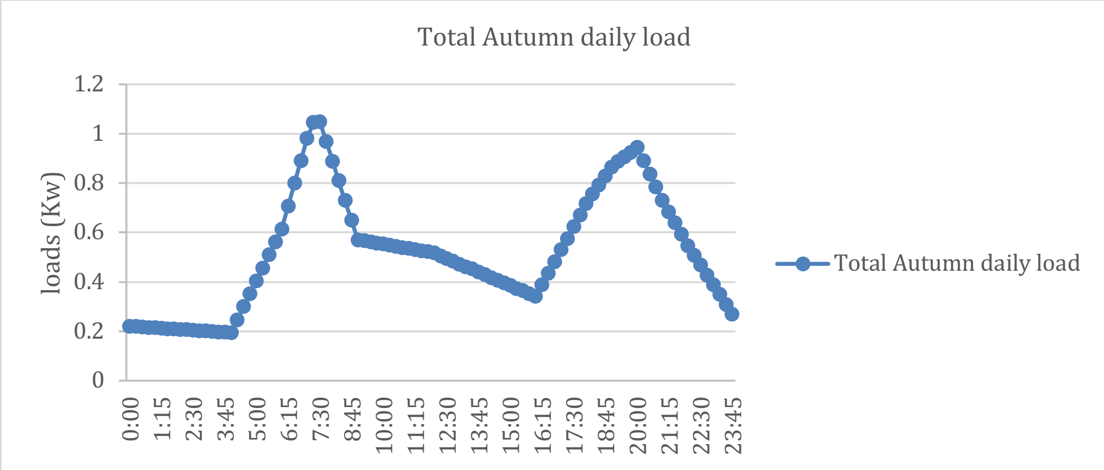
Total Winter daily load



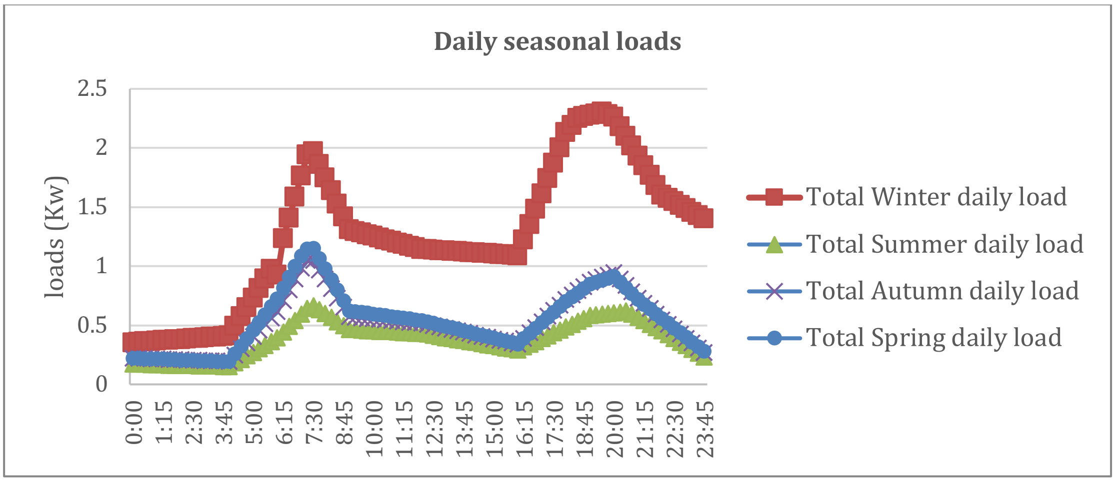
Total Summer daily load



Total Spring daily load

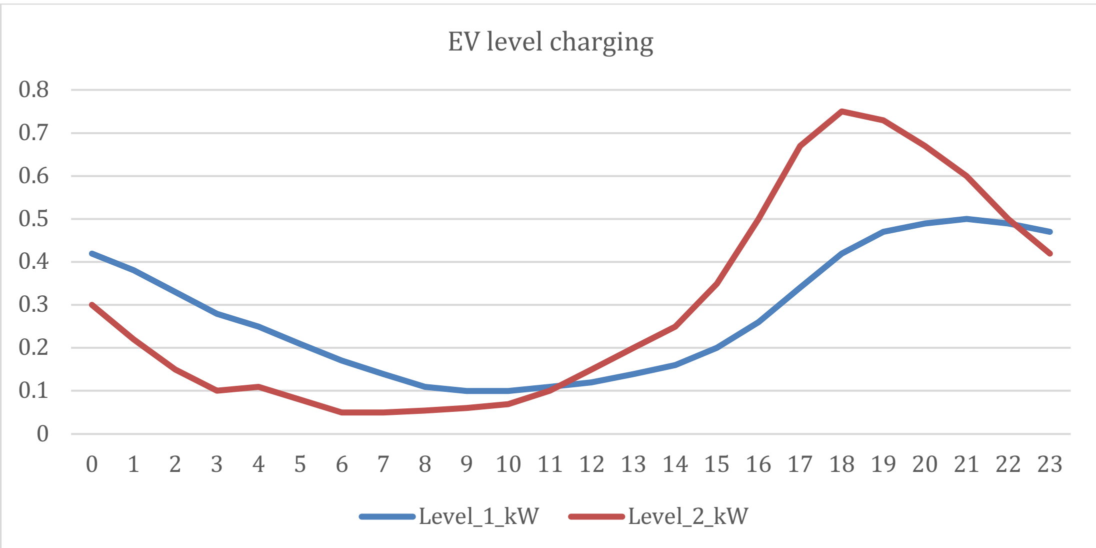


Total Autumn daily load



Total Daily seasonal loads

EV load profile



EV level charging

Hourly count for three hours of timestamp of Car Model Specification Value of 5.69 kwh

Time unit	hour	hour							
		1	2	3	4	5	6	7	8
1	1	5.69	0	0	0	0	0	0	0
	2	5.69	0	0	0	0	0	0	0
	3	5.69	0	0	0	0	0	0	0
2	4	0	5.69	0	0	0	0	0	0
	5	0	5.69	0	0	0	0	0	0
	6	0	5.69	0	0	0	0	0	0
3	7	0	0	5.69	0	0	0	0	0
	8	0	0	5.69	0	0	0	0	0
	9	0	0	5.69	0	0	0	0	0
4	10	0	0	0	5.69	0	0	0	0
	11	0	0	0	5.69	0	0	0	0
	12	0	0	0	5.69	0	0	0	0
5	13	0	0	0	0	5.69	0	0	0
	14	0	0	0	0	5.69	0	0	0
	15	0	0	0	0	5.69	0	0	0
6	16	0	0	0	0	0	5.69	0	0
	17	0	0	0	0	0	5.69	0	0
	18	0	0	0	0	0	5.69	0	0
7	19	0	0	0	0	0	0	5.69	0
	20	0	0	0	0	0	0	5.69	0
	21	0	0	0	0	0	0	5.69	0
8	22	0	0	0	0	0	0	0	5.69
	23	0	0	0	0	0	0	0	5.69
	24	0	0	0	0	0	0	0	5.69

Number of car -370 cars- Using the national graph of level1 charging

time range	time unit	CH-level 1	ratio number	number of ideal car spreading			
				2025	2030	2035	2050
				40	53	99	380
00:00-03:00	1	0.42	0.190045	8	10	19	72
03:00-06:00	2	0.28	0.126697	5	7	13	48
06:00-09:00	3	0.17	0.076923	3	4	8	29
09:00-12:00	4	0.1	0.045249	2	2	4	17
12:00-15:00	5	0.12	0.054299	2	3	5	21
15:00-18:00	6	0.2	0.090498	4	5	9	34
18:00-21:00	7	0.42	0.190045	8	10	19	72
21:00-24:00	8	0.5	0.226244	9	12	22	86
	total of car	2.21	1	41	53	99	379

PV generation profile

PV Active Power Profile for Summer and Winter

Time	Summer in kW	Winter in kW	Summer_p.u.	Winter_p.u.
00:00	0	0	0.000	0.000
00:15	0	0	0.000	0.000
00:30	0	0	0.000	0.000
00:45	0	0	0.000	0.000
01:00	0	0	0.000	0.000
01:15	0	0	0.000	0.000
01:30	0	0	0.000	0.000
01:45	0	0	0.000	0.000
02:00	0	0	0.000	0.000
02:15	0	0	0.000	0.000
02:30	0	0	0.000	0.000
02:45	0	0	0.000	0.000
03:00	0	0	0.000	0.000
03:15	0	0	0.000	0.000
03:30	0	0	0.000	0.000
03:45	0	0	0.000	0.000
04:00	0	0	0.000	0.000
04:15	0	0	0.000	0.000
04:30	0	0	0.000	0.000
04:45	0	0	0.000	0.000
05:00	0	0	0.000	0.000
05:15	0	0	0.000	0.000
05:30	0	0	0.000	0.000
05:45	0	0	0.000	0.000

06:00	0	0	0.000	0.000
06:15	0.056	0	0.011	0.000
06:30	0.169	0	0.034	0.000
06:45	0.322	0	0.064	0.000
07:00	0.507	0	0.101	0.000
07:15	0.719	0.026	0.144	0.009
07:30	0.952	0.09	0.190	0.030
07:45	1.203	0.185	0.241	0.062
08:00	1.467	0.307	0.293	0.102
08:15	1.742	0.452	0.348	0.151
08:30	2.023	0.617	0.405	0.206
08:45	2.307	0.798	0.461	0.266
09:00	2.591	0.992	0.518	0.331
09:15	2.872	1.194	0.574	0.398
09:30	3.145	1.4	0.629	0.467
09:45	3.41	1.608	0.682	0.536
10:00	3.661	1.812	0.732	0.604
10:15	3.897	2.01	0.779	0.670
10:30	4.116	2.198	0.823	0.733
10:45	4.314	2.372	0.863	0.791
11:00	4.49	2.53	0.898	0.843
11:15	4.643	2.668	0.929	0.889
11:30	4.77	2.785	0.954	0.928
11:45	4.87	2.878	0.974	0.959
12:00	4.942	2.945	0.988	0.982
12:15	4.985	2.986	0.997	0.995
12:30	5	3	1.000	1.000
12:45	4.985	2.986	0.997	0.995
13:00	4.942	2.945	0.988	0.982
13:15	4.87	2.878	0.974	0.959
13:30	4.77	2.785	0.954	0.928
13:45	4.643	2.668	0.929	0.889
14:00	4.49	2.53	0.898	0.843
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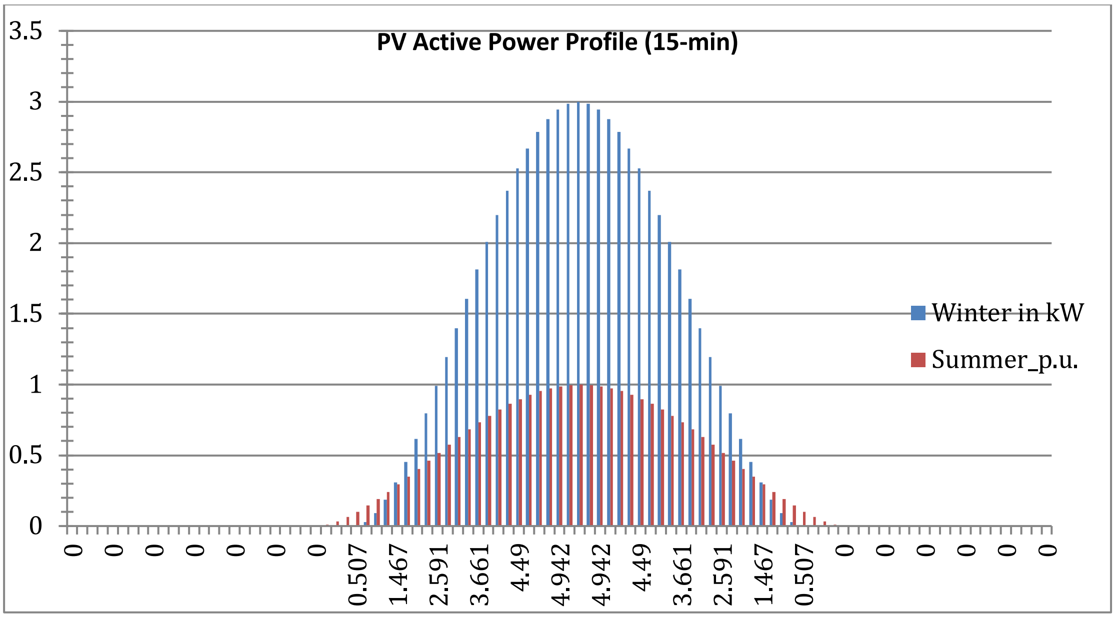
18:30	0.169	0	0.034	0.000
18:45	0.056	0	0.011	0.000
19:00	0	0	0.000	0.000
19:15	0	0	0.000	0.000
19:30	0	0	0.000	0.000
19:45	0	0	0.000	0.000
20:00	0	0	0.000	0.000
20:15	0	0	0.000	0.000
20:30	0	0	0.000	0.000
20:45	0	0	0.000	0.000
21:00	0	0	0.000	0.000
21:15	0	0	0.000	0.000
21:30	0	0	0.000	0.000
21:45	0	0	0.000	0.000
22:00	0	0	0.000	0.000
22:15	0	0	0.000	0.000
22:30	0	0	0.000	0.000
22:45	0	0	0.000	0.000
23:00	0	0	0.000	0.000
23:15	0	0	0.000	0.000
23:30	0	0	0.000	0.000
23:45	0	0	0.000	0.000
24:00	0	0	0.000	0.000

Winter and Summer energy generation

year	Number of Panel	Winter energy generation (KWh)	Summer energy generation (KWh)
2030	33	1024.419	379.203
2035	66	67611.654	25027.398
2050	186	190541.934	70531.758



PV energy generation in Winter and Summer

Transformer size

Transformer Model and Size

Transformer	Model	Size (KVA)
A	TS_703	(1000)KVA
B	S0_512	(500)KVA
C	TS_2036	(500)KVA
D	S0_165	(750)KVA
E	TS_1065	(750)KVA
F	SO_177	(600)KVA
G	S0_049	(500)KVA
H	S0_473	(500)kVA
H2	S0_473	(500)kVA
H3	S0_473	(500)kVA

Battery controlled size value

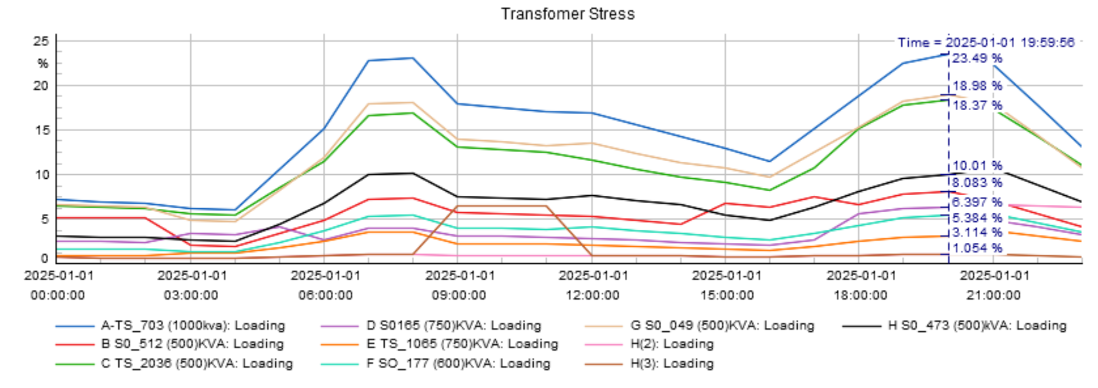
The battery size value for the centralised and decentralised battery.

Quasi dynamic simulation: Quasi dynamic model Balanced and Unbalanced AC load flow Parameter	Centralised battery control charging	Decentralised battery control charging
Eini: Storage Energy Size [MWh]	X	0.02
SOCini: Initial state of charge [%]	80.	80.
SOCmin: Minimal state of charge [%]	20.	20.
SOCmax: Maximal state of charge [%]	90.	90.
Pstore: Nominal storing active power [MW]	0.04	0.004
Qstore: Nominal storing reactive power [Mvar]	0.02	0.002
PFullStore: Power to store at full power [MW]	0.03	0.003
PStartStore: Power to start storing [MW]	0.01	0.001
Pfeed: Nominal feeding active power [MW]	0.05	0.005
Qfeed: Nominal feeding reactive power [Mvar]	0.02	0.002
PStartFeed: Power to start feeding [MW]	0.00001	0.00001
PFullFeed: Power to feed at full power [MW]	0.05	0.005
orientation: 1 = terminal j is closest, otherwise -1	-1.	-1.

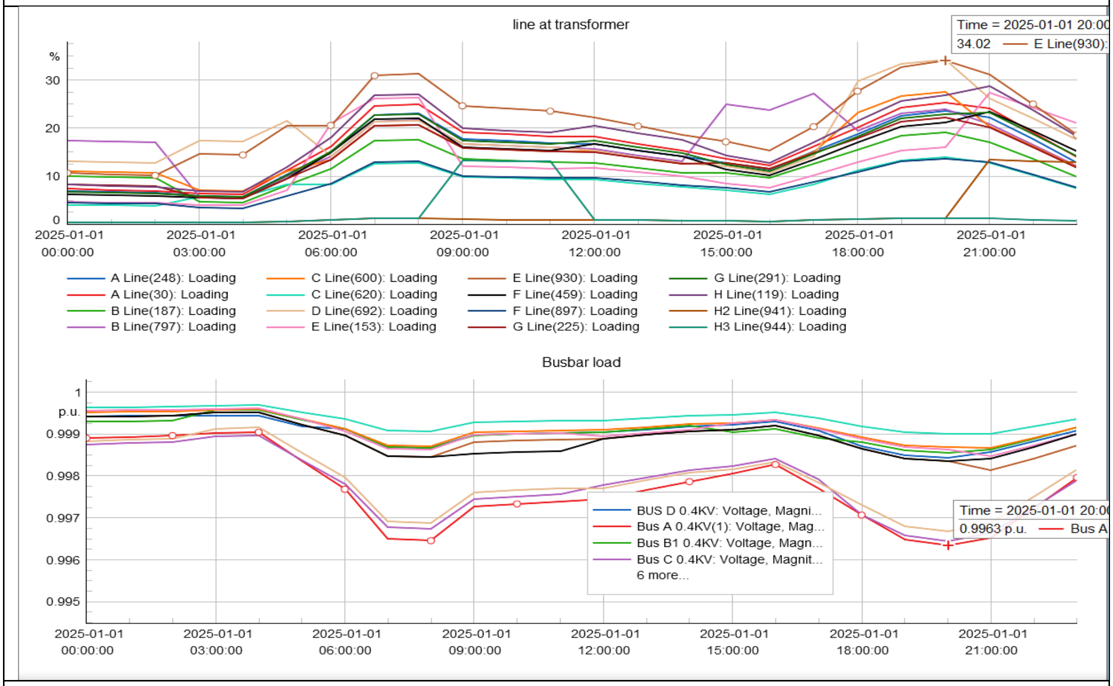
Results

2025

<u>Summer - Base case</u>

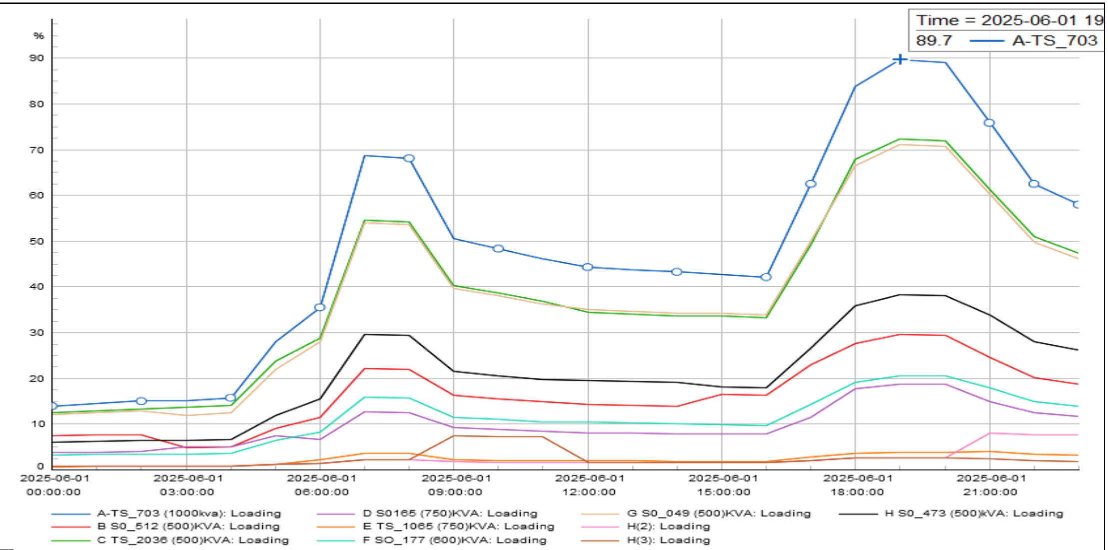


Transformer stress in Summer - Base case 2025

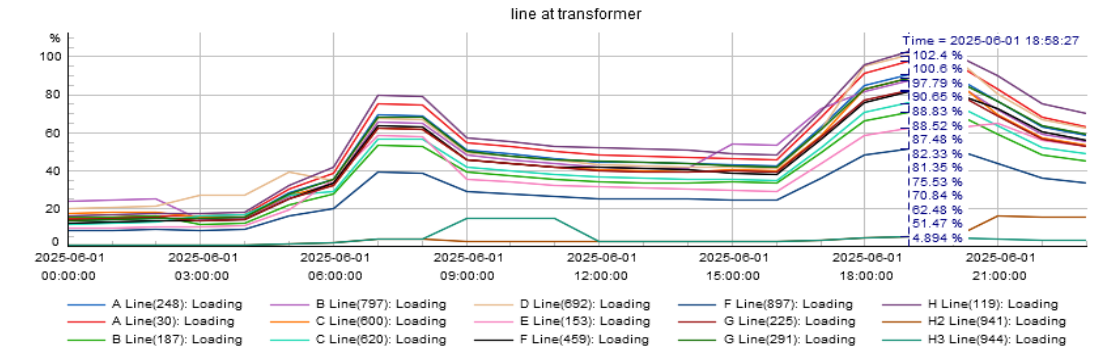


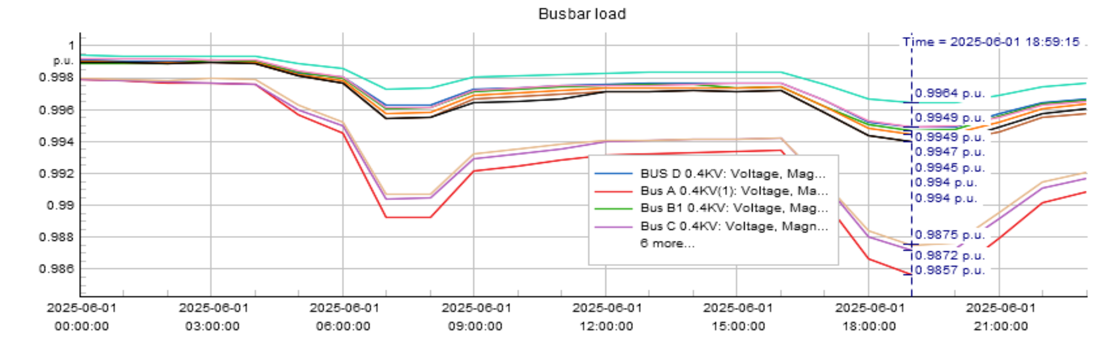
Line and Bus loading in in Summer - Base case 2025

Winter - Base case



Transformer stress in Winter- Base case 2025

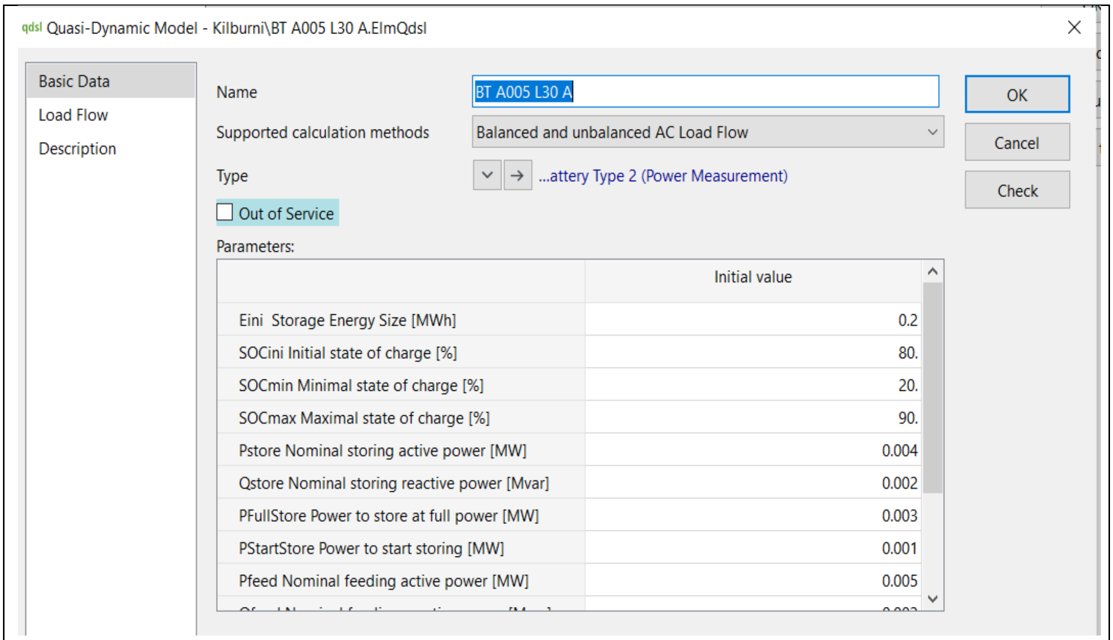




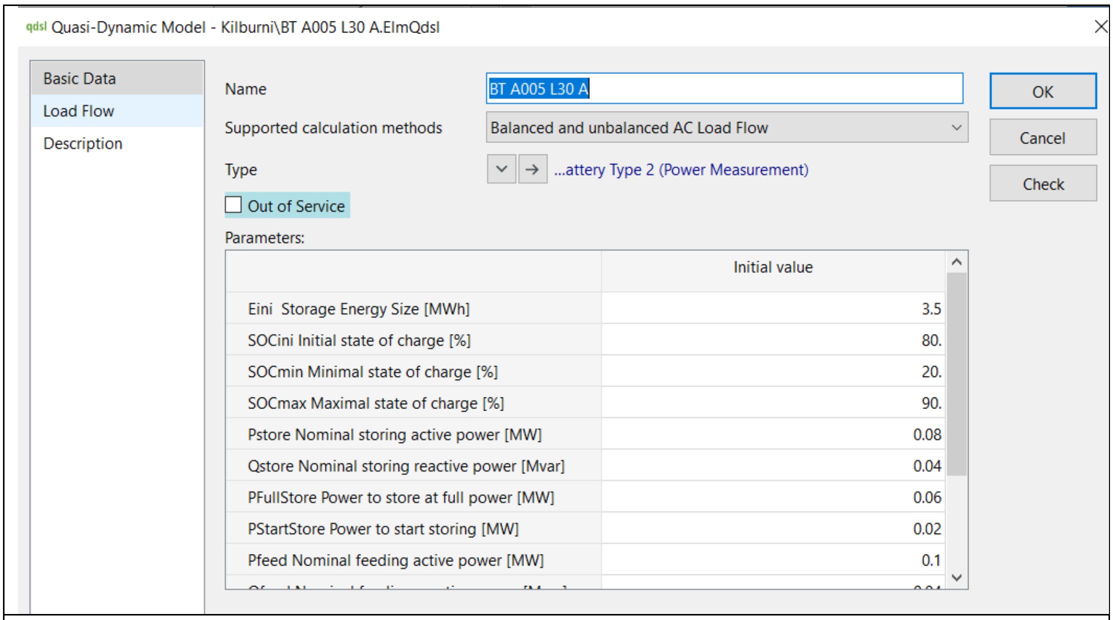
Line and Bus loading in in Winter - Base case 2025

2030

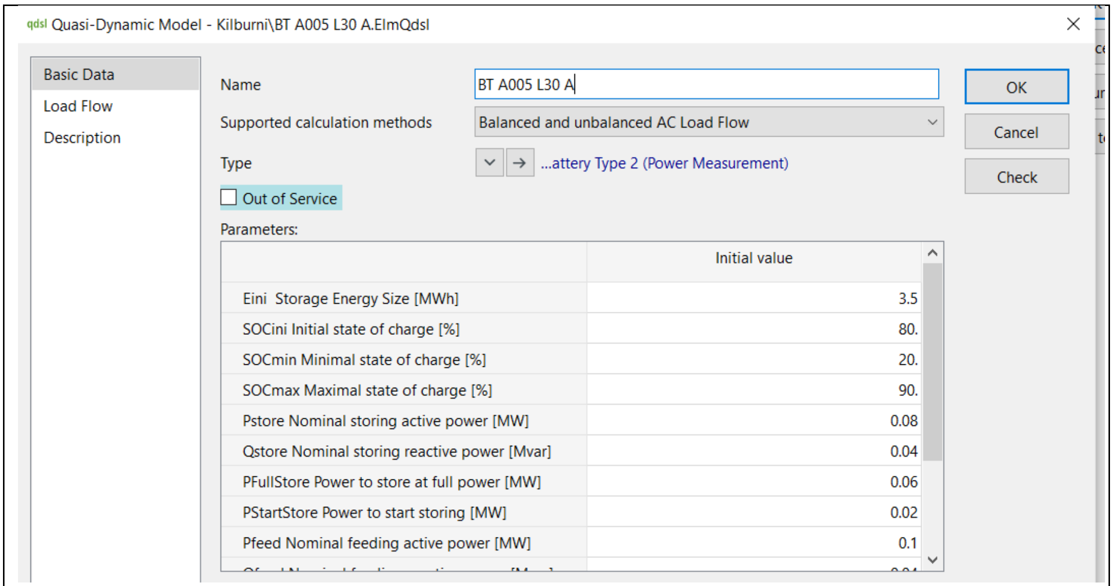
2030 - Summer and Winter- Centralised Battery - Controlled Size value



2030 - Summer – Centralised Small Battery Size

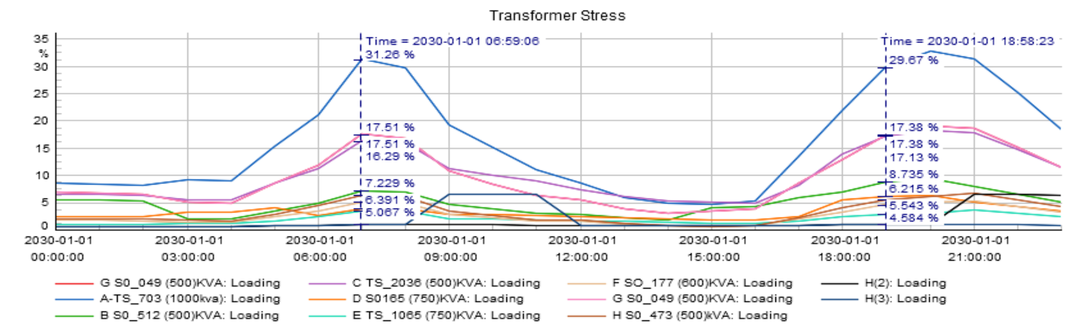


2030 - Summer - Centralised Large Battery Size

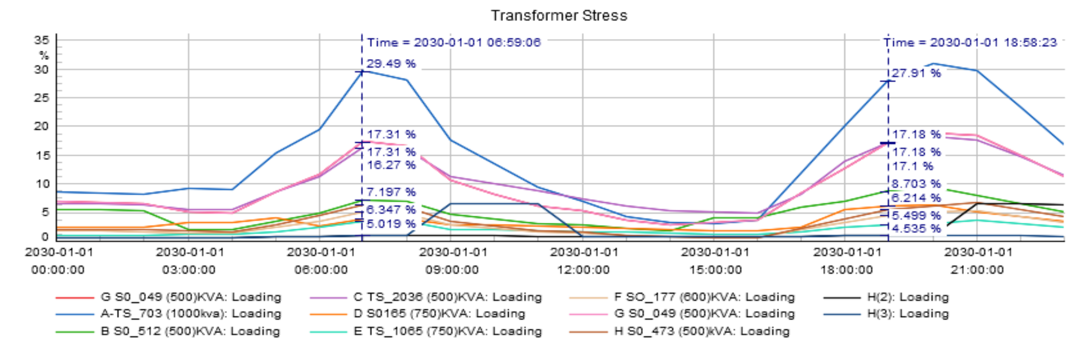


2030 - Winter - Centralised Large Battery Size

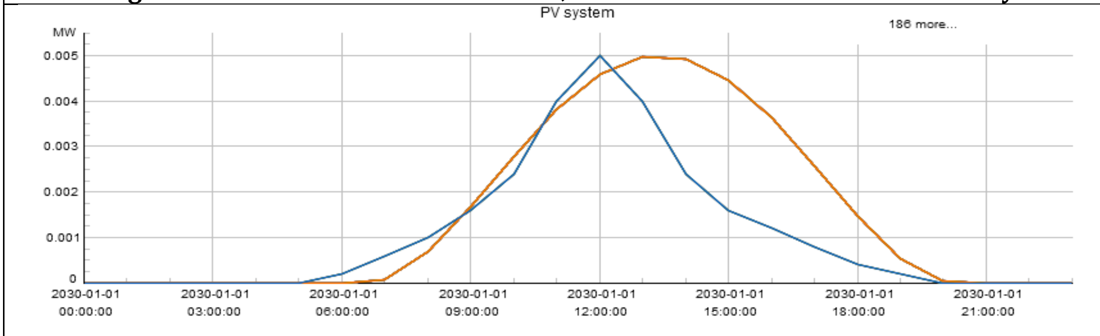
2030 - Summer - Small Centralised Battery



Percentage of transformer stress in Summer, 2030 without Small Centralised Battery

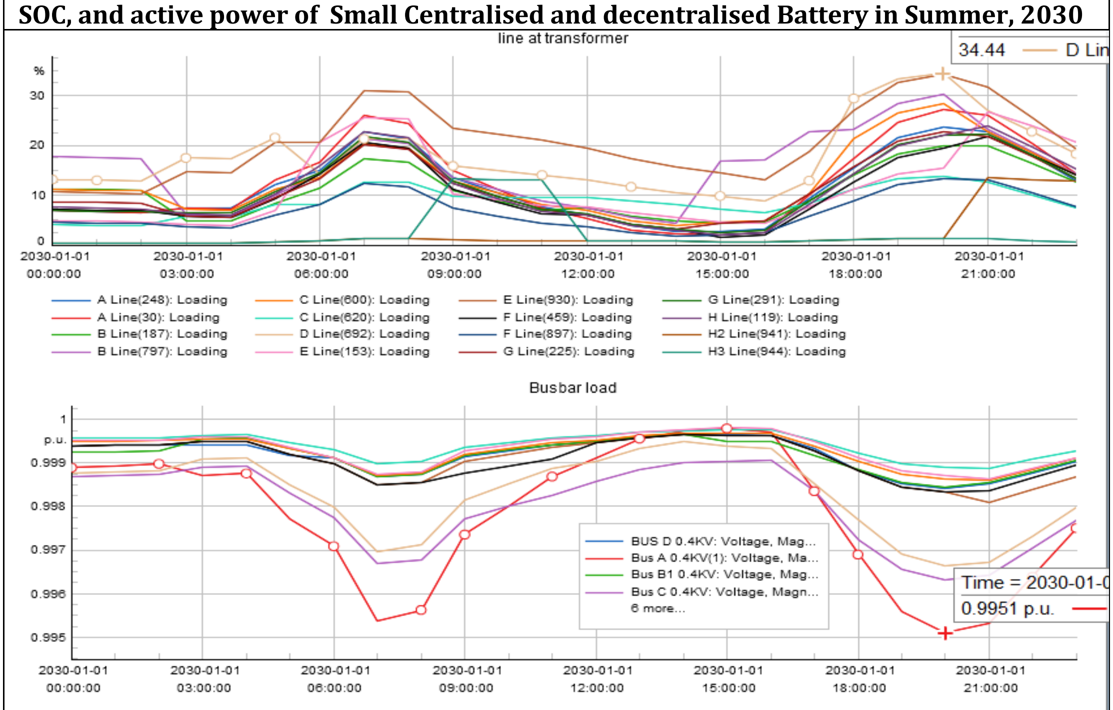


Percentage of transformer stress in Summer, 2030 with Small Centralised Battery



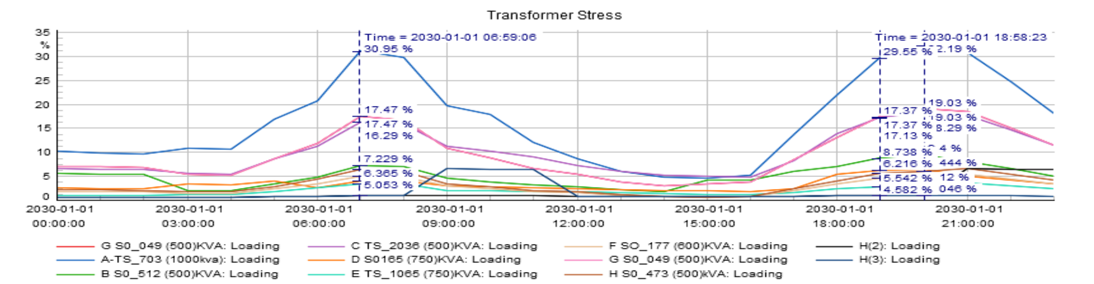
PV generation in Summer, 2030

SOC, and active power of Small Centralised and decentralised Battery in Summer, 2030

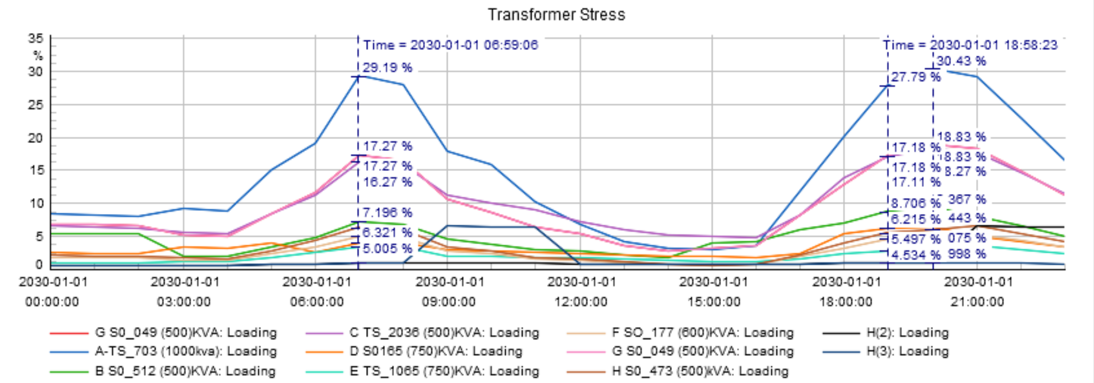


Line and Bus loading in Summer, 2030 with Small Centralised Battery

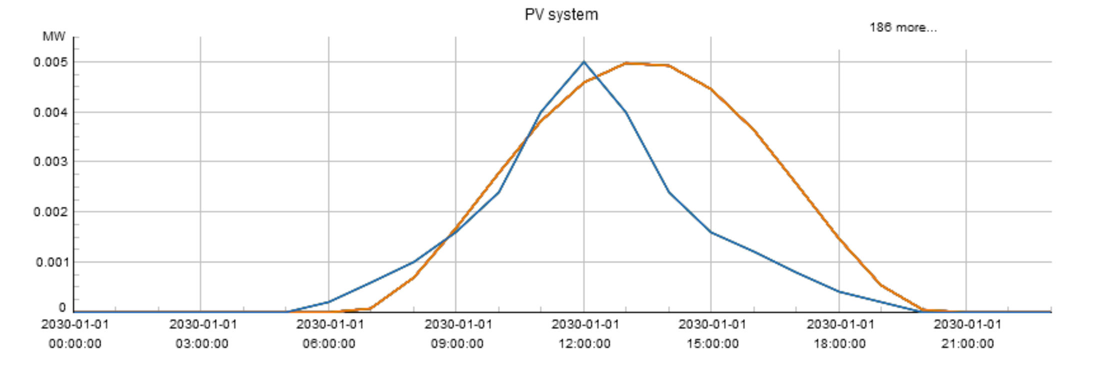
2030 - Summer - Small Centralised and Decentralised battery



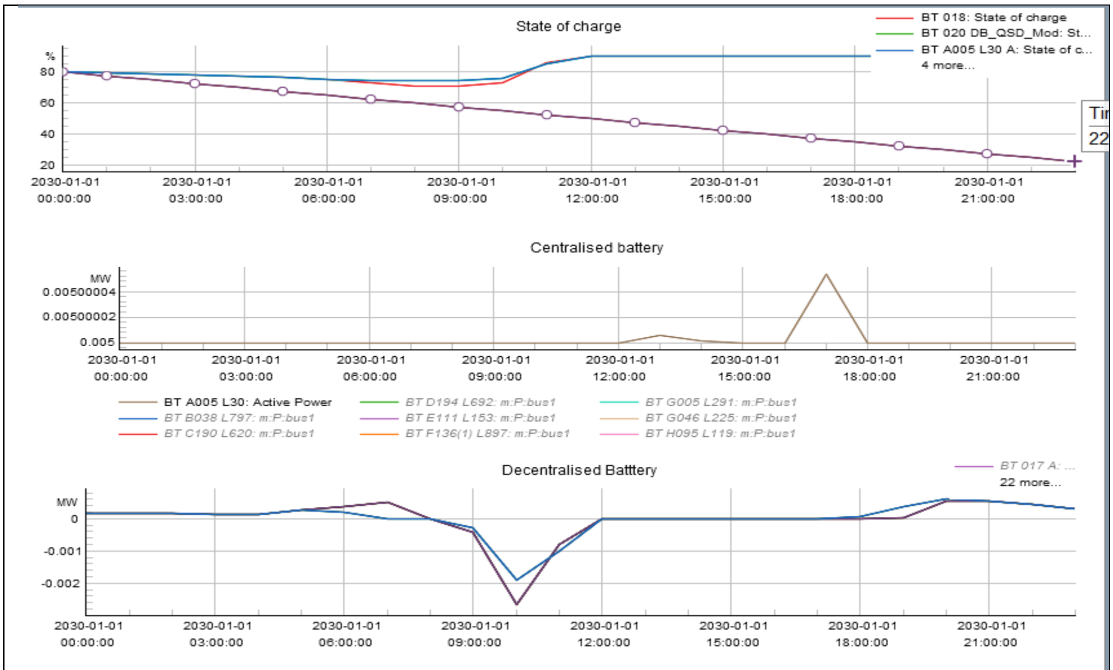
Percentage of transformer stress in Summer, 2030 without Centralised and Decentralised Battery



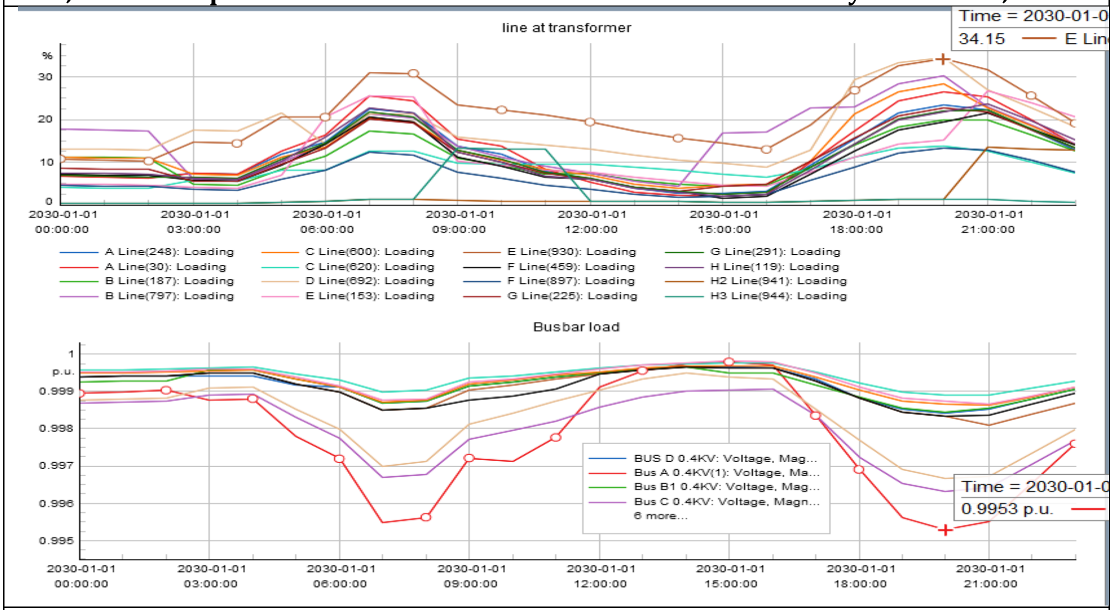
Percentage of transformer stress in Summer, 2030 with Small Centralised and Decentralised Battery



PV generation in Summer, 2030

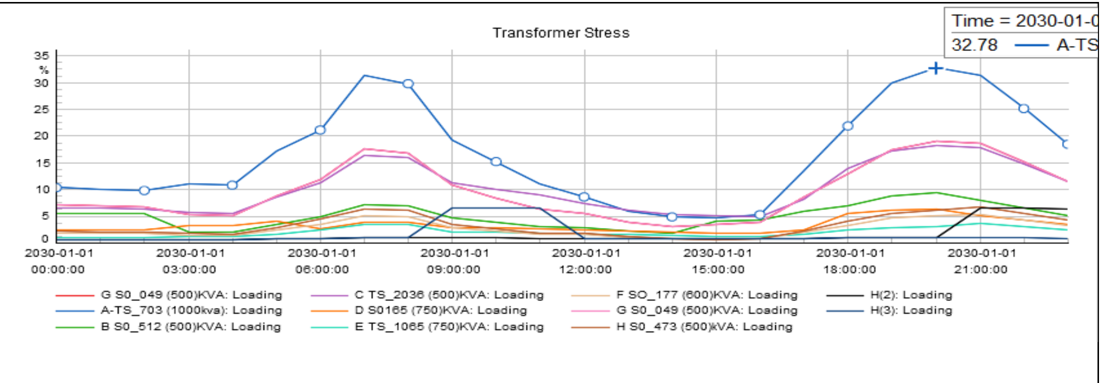


SOC, and active power of Small Centralised and decentralised Battery in Summer, 2030

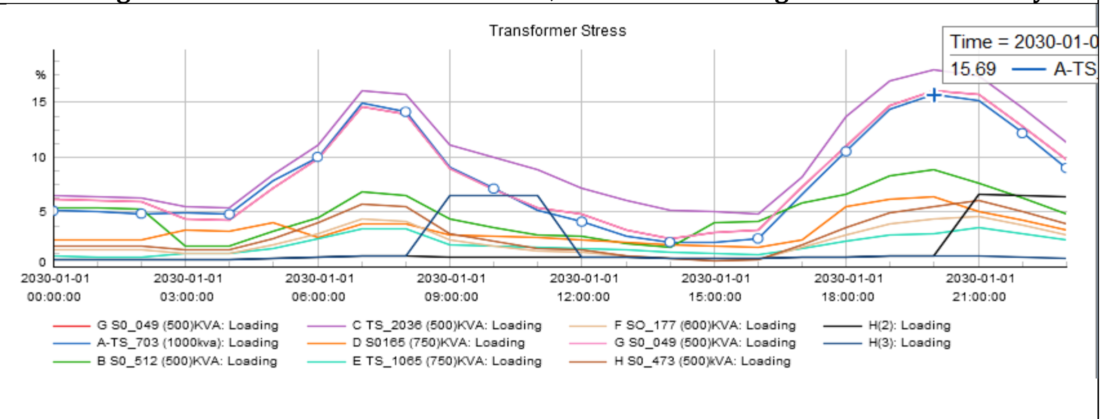


Line and Bus loading in Summer, 2030 with Small Centralised and Decentralised Battery

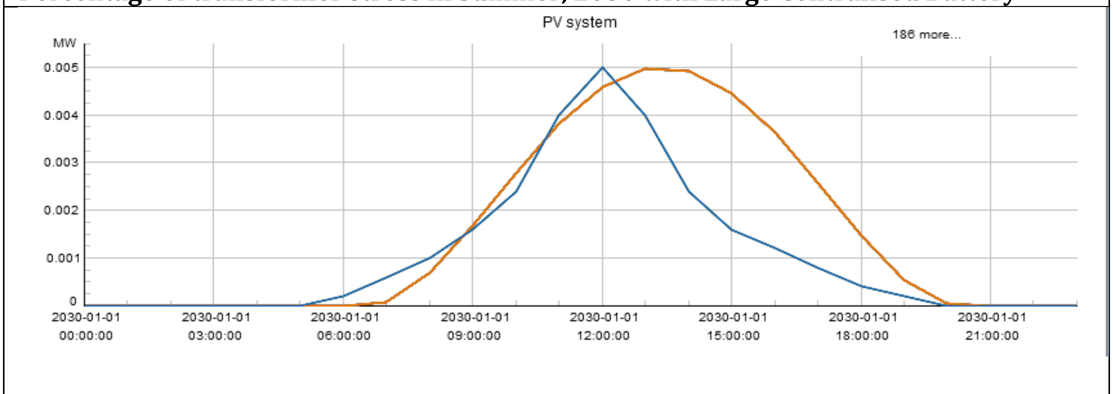
2030 - Summer - Large Centralised battery



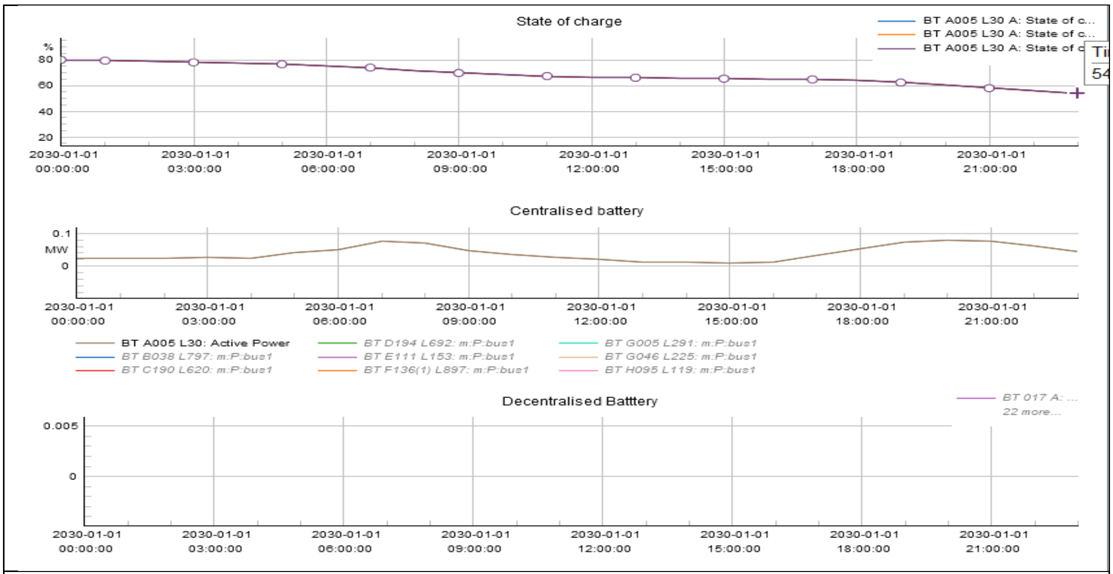
Percentage of transformer stress in Summer, 2030 without Large Centralised Battery



Percentage of transformer stress in Summer, 2030 with Large Centralised Battery

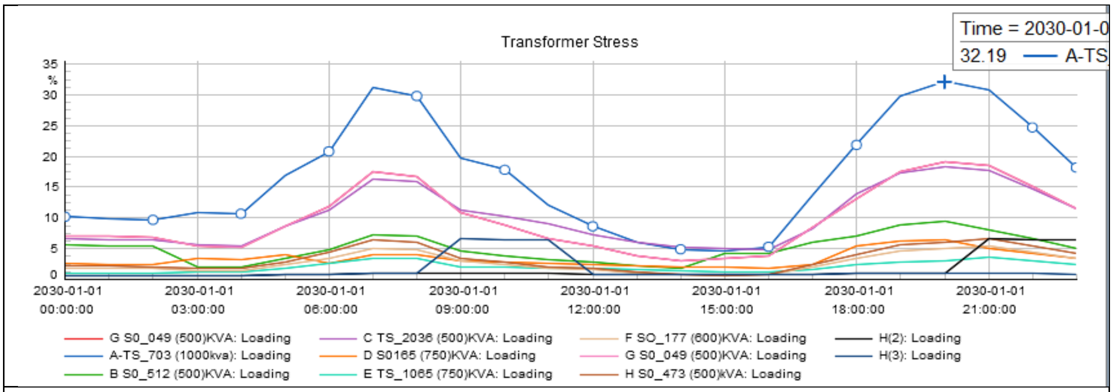


PV generation in Summer, 2030

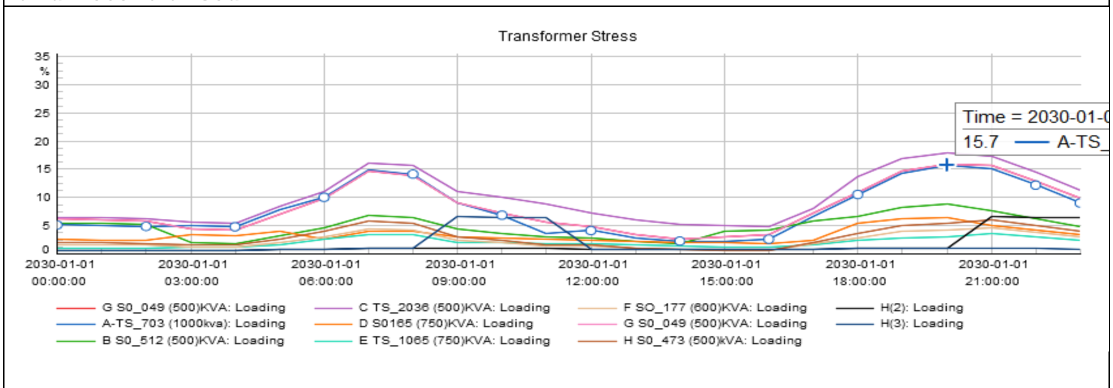


SOC, and active power of Large Centralised and Decentralised Battery in Summer, 2030

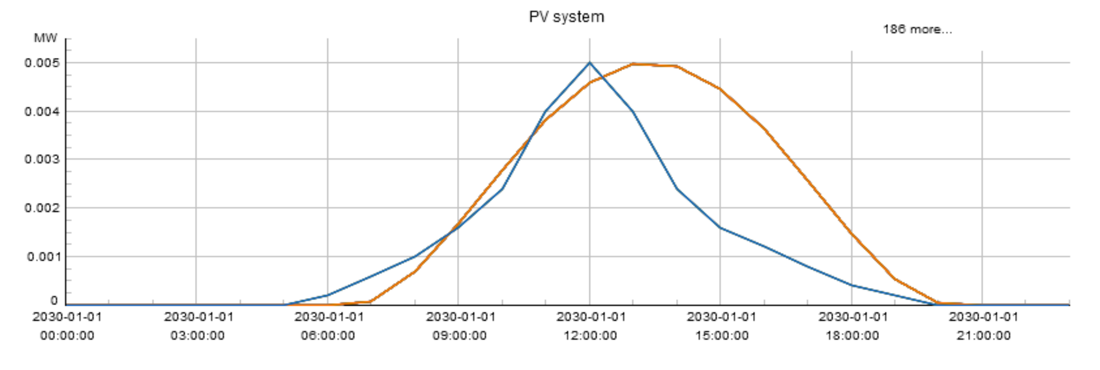
2030 - Summer - Large Centralised and Decentralised battery



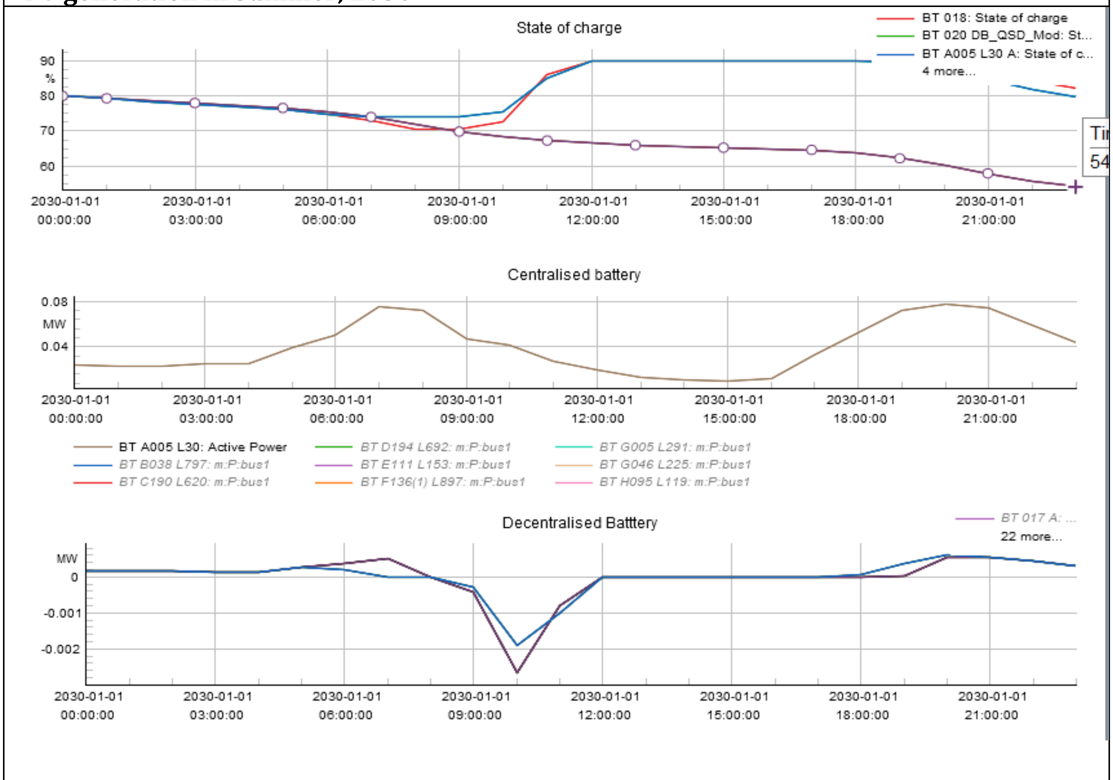
Percentage of transformer stress in Summer, 2030 without Large Centralised Battery and Decentralised



Percentage of transformer stress in Summer, 2030 with Large Centralised and Decentralised Battery

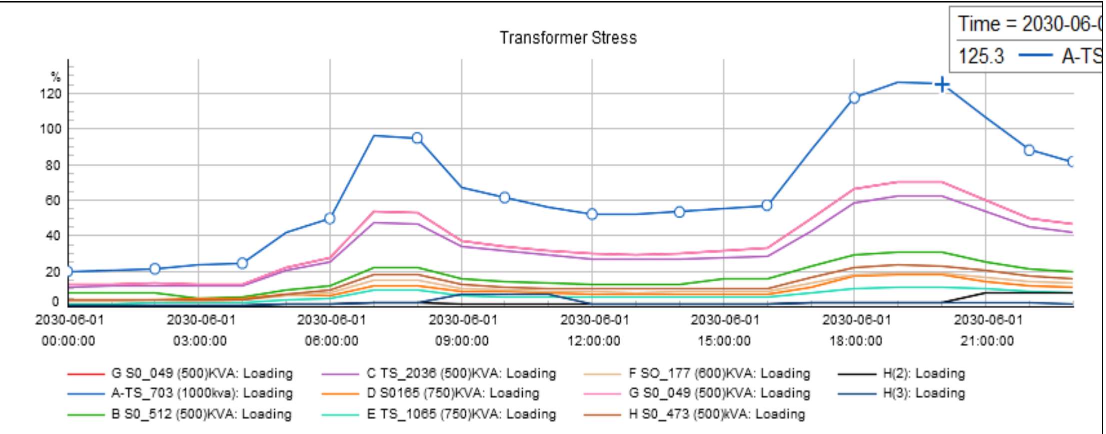


PV generation in Summer, 2030

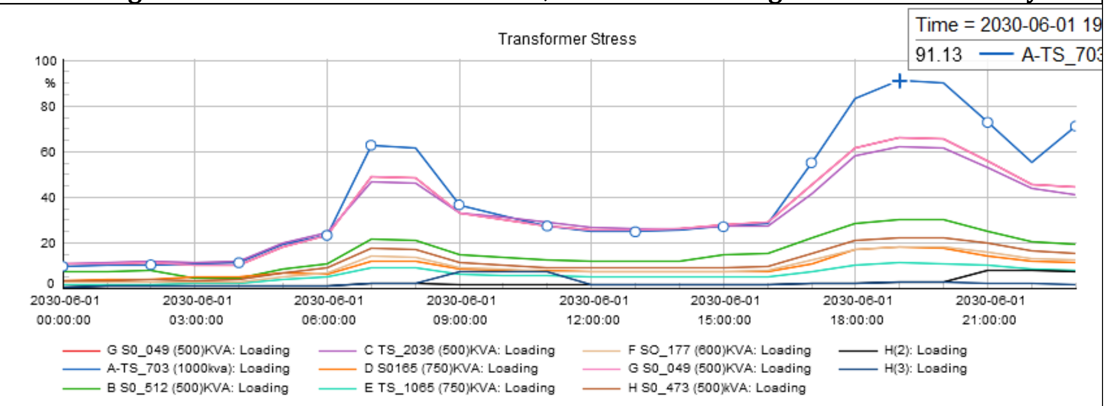


SOC, and active power of Large Centralised and Decentralised Battery in Summer, 2030

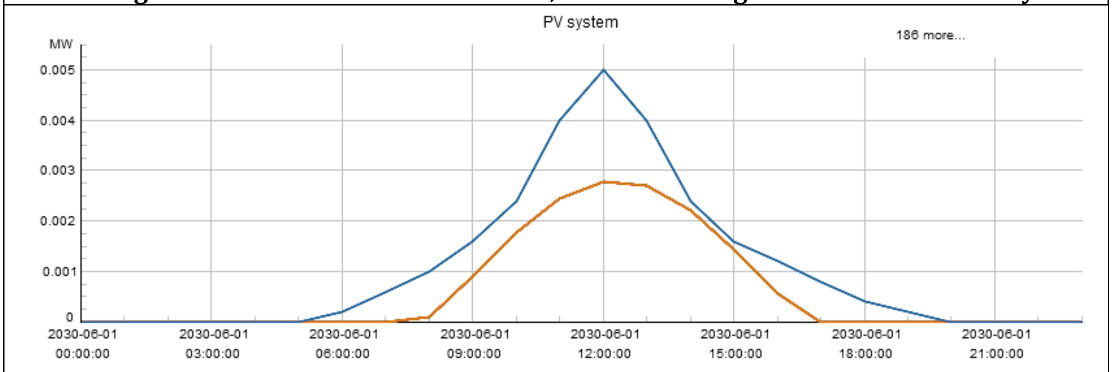
2030 - Winter - Large Centralised battery



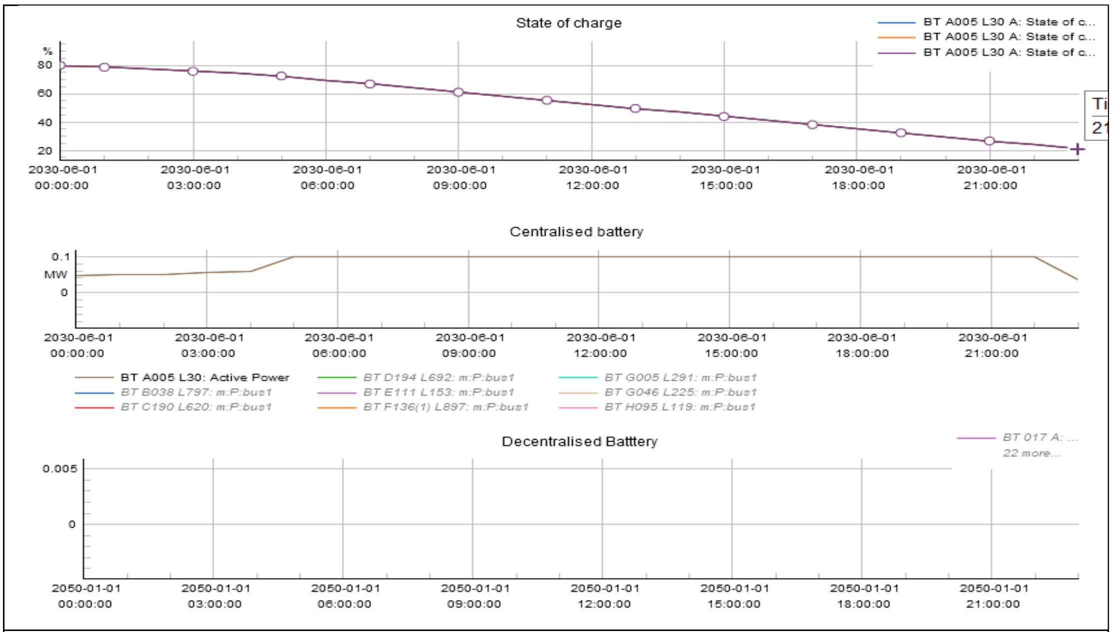
Percentage of transformer stress in Winter, 2030 without Large Centralised Battery



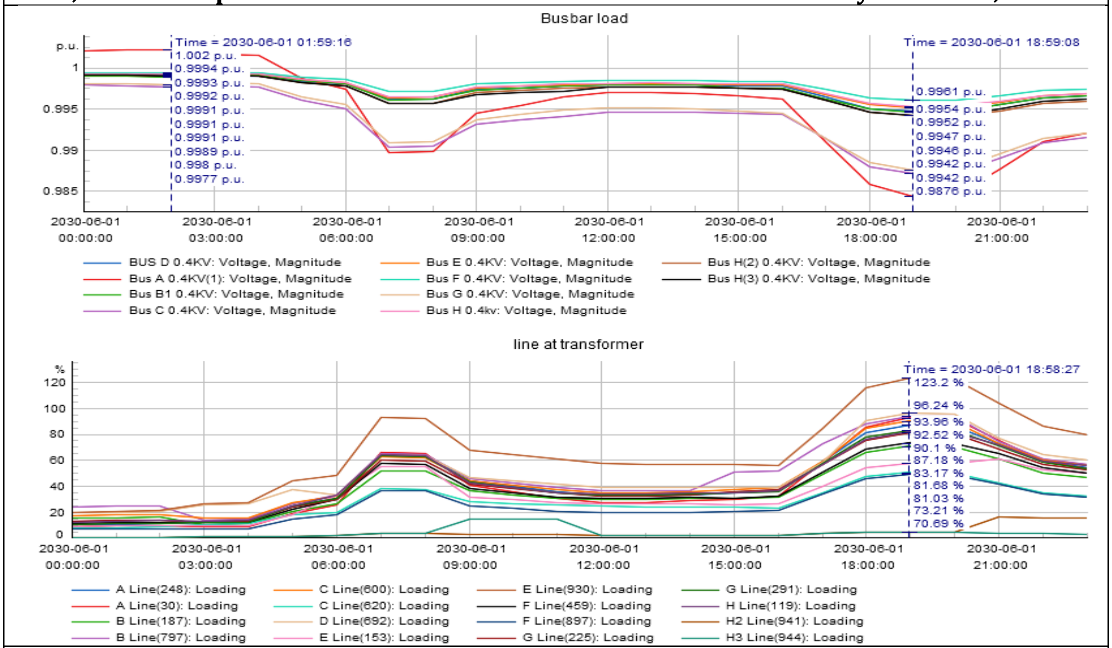
Percentage of transformer stress in Winter, 2030 with Large Decentralised Battery



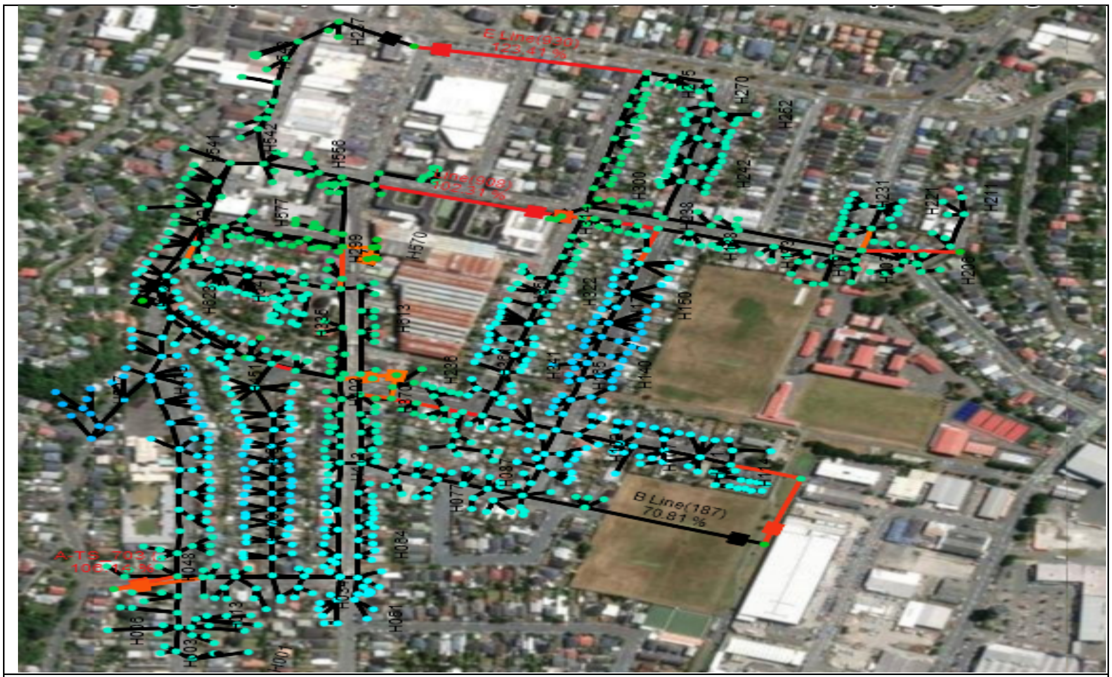
PV generation in Winter, 2030



SOC, and active power of Small Centralised and Decentralised Battery in Winter, 2030

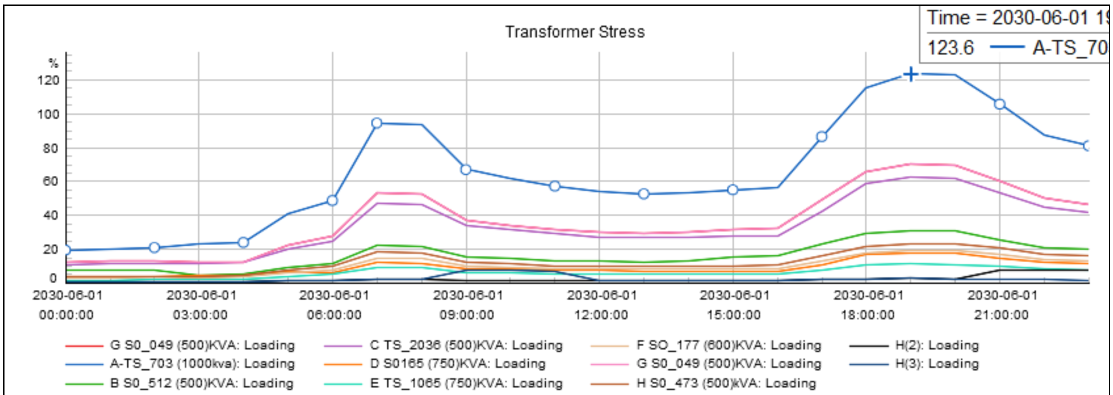


Line and Bus loading in Winter, 2030 with Large Centralised Battery

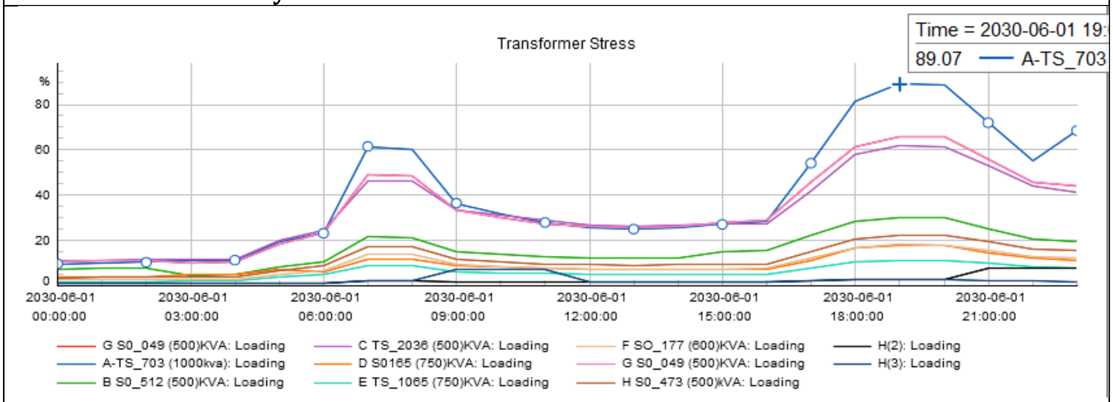


Line and Bus Mapping in Winter, 2030 with Large Centralised Battery

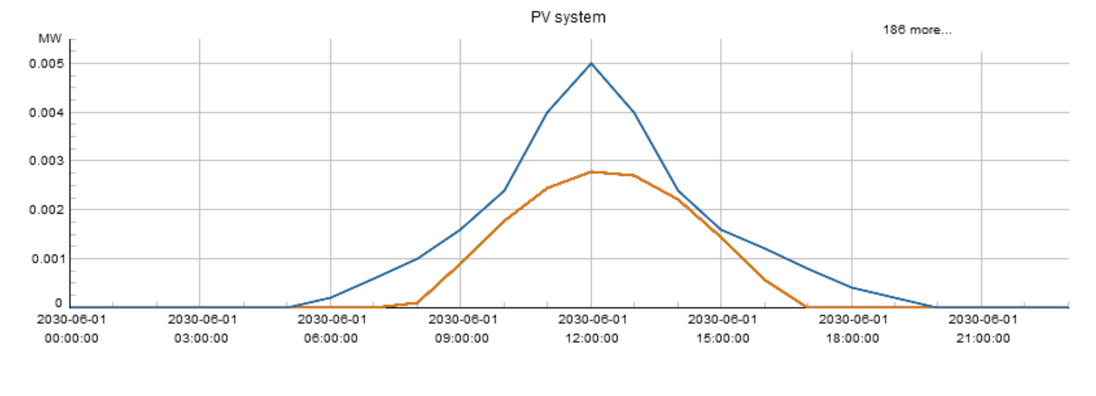
2030 - Winter - Large Centralised and Decentralised battery



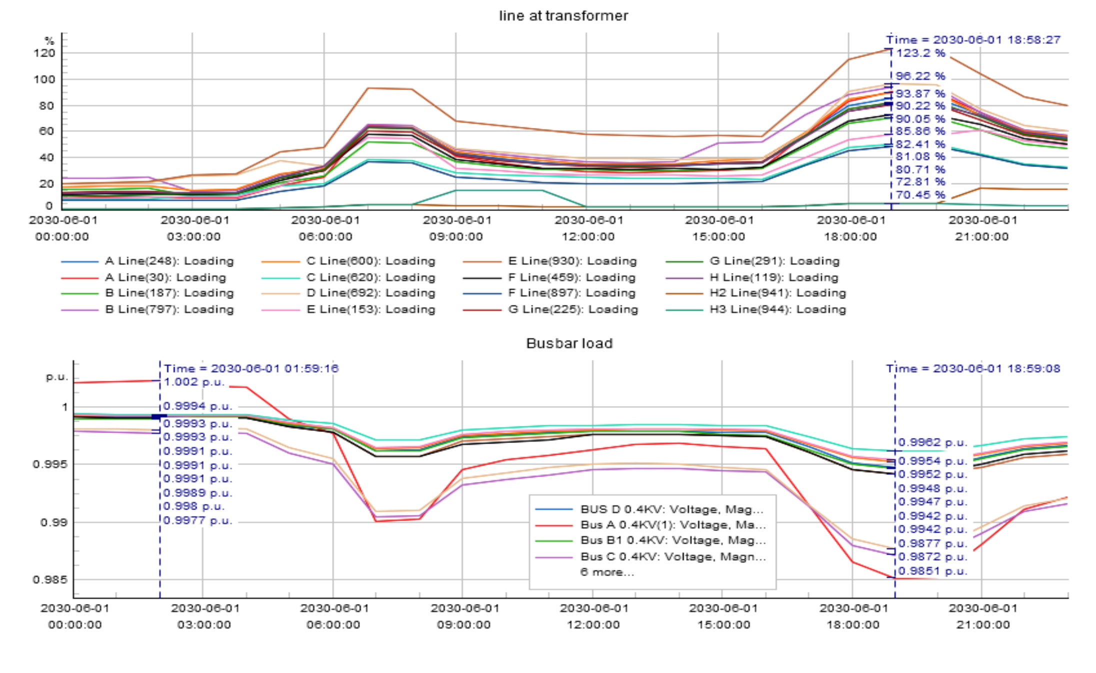
Percentage of transformer stress in Winter, 2030 without Large Centralised and Decentralised Battery



Percentage of transformer stress in Winter, 2030 with Large Centralised and Decentralised Battery



PV generation in Winter, 2030

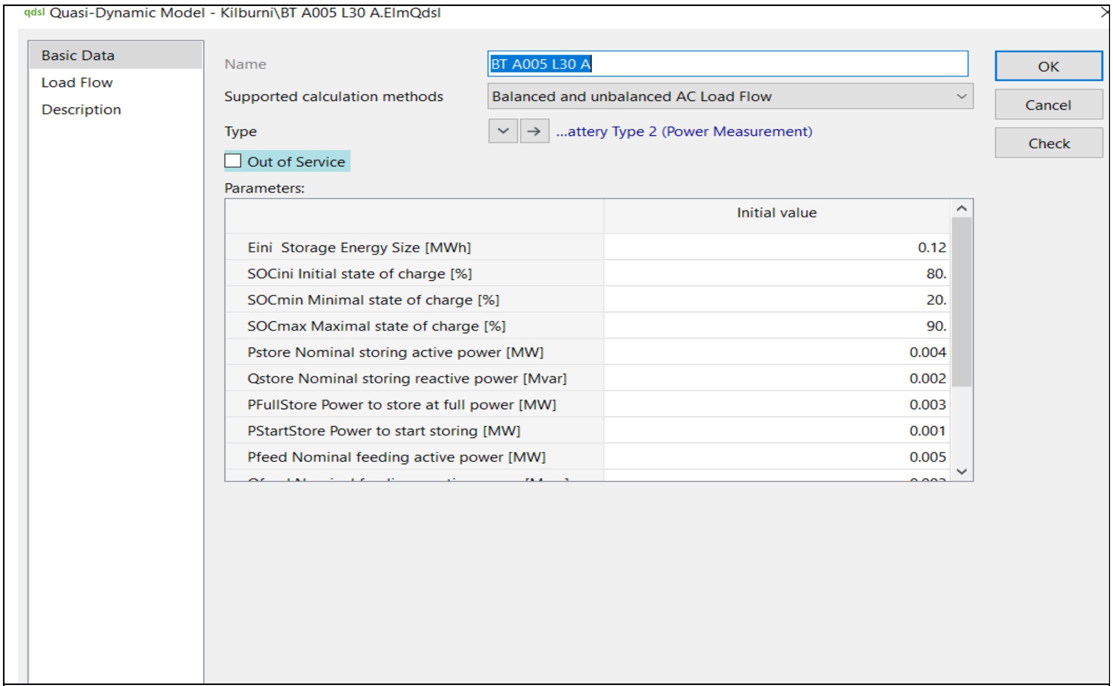


Line and Bus loading in Winter, 2030 with Large Centralised and Decentralised Battery

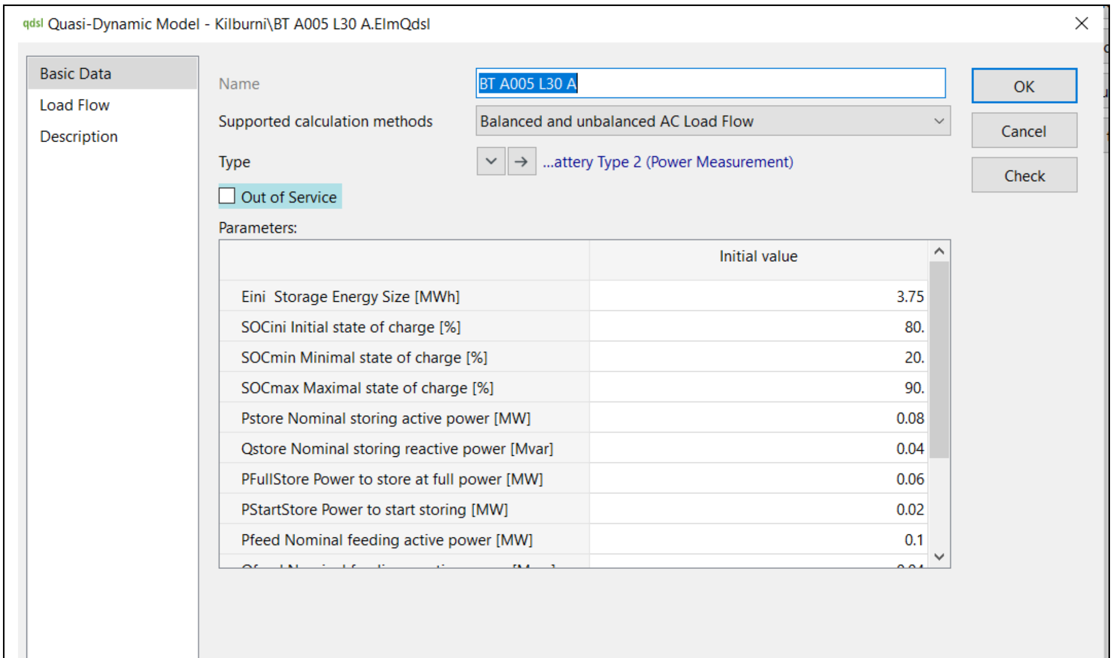
Line and Bus Mapping in Winter, 2030 with Large Decentralised Battery

2035

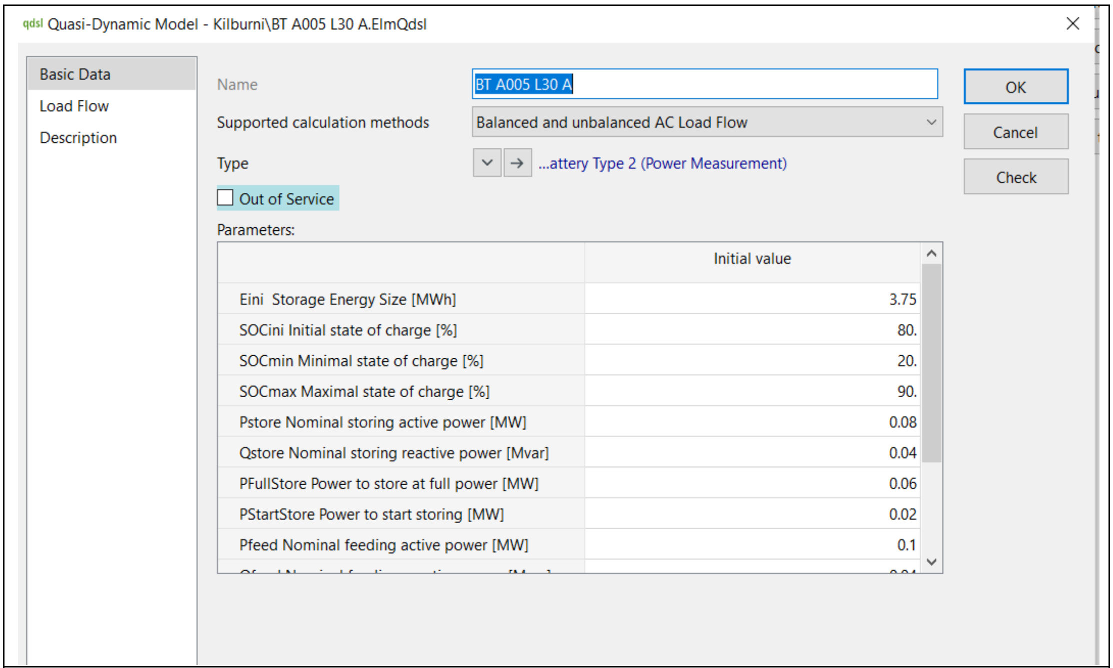
<u>2035 - Summer and Winter- Centralised Battery - Controlled Size value</u>



2035 - Summer – Centralised Small Battery Size

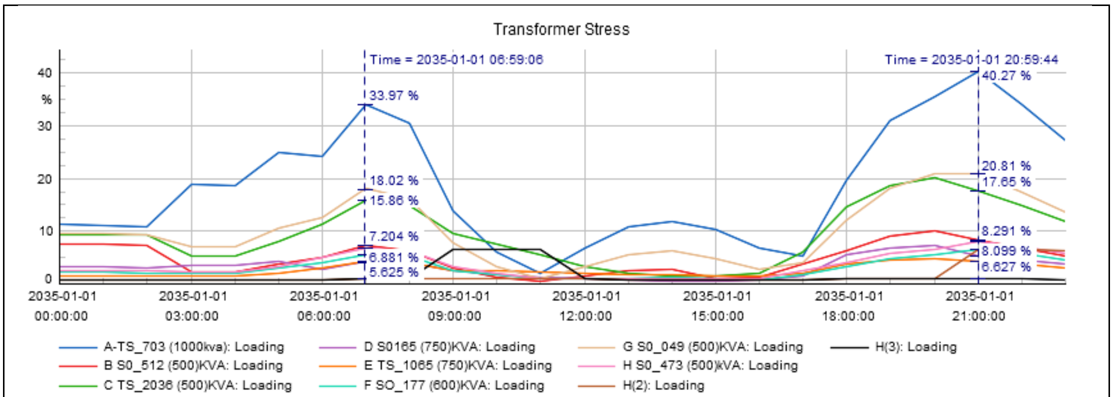


2035 - Summer - Centralised Large Battery Size

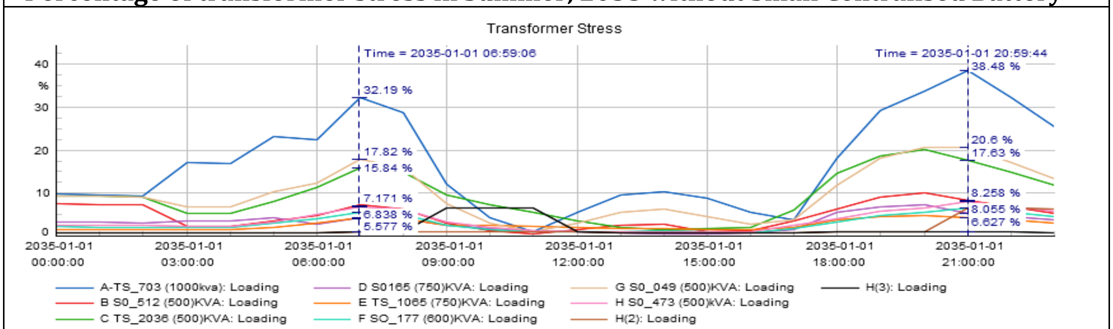


2035 - Winter - Centralised Large Battery Size

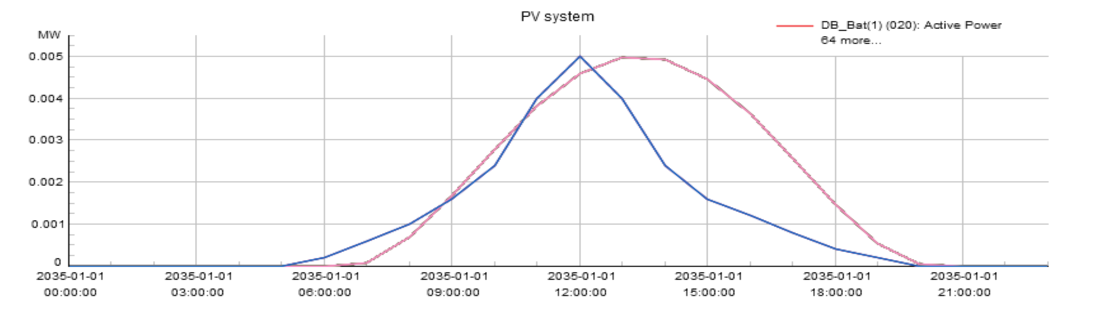
<u>2035 - Summer - Small Centralised Battery</u>



Percentage of transformer stress in Summer, 2035 without Small Centralised Battery

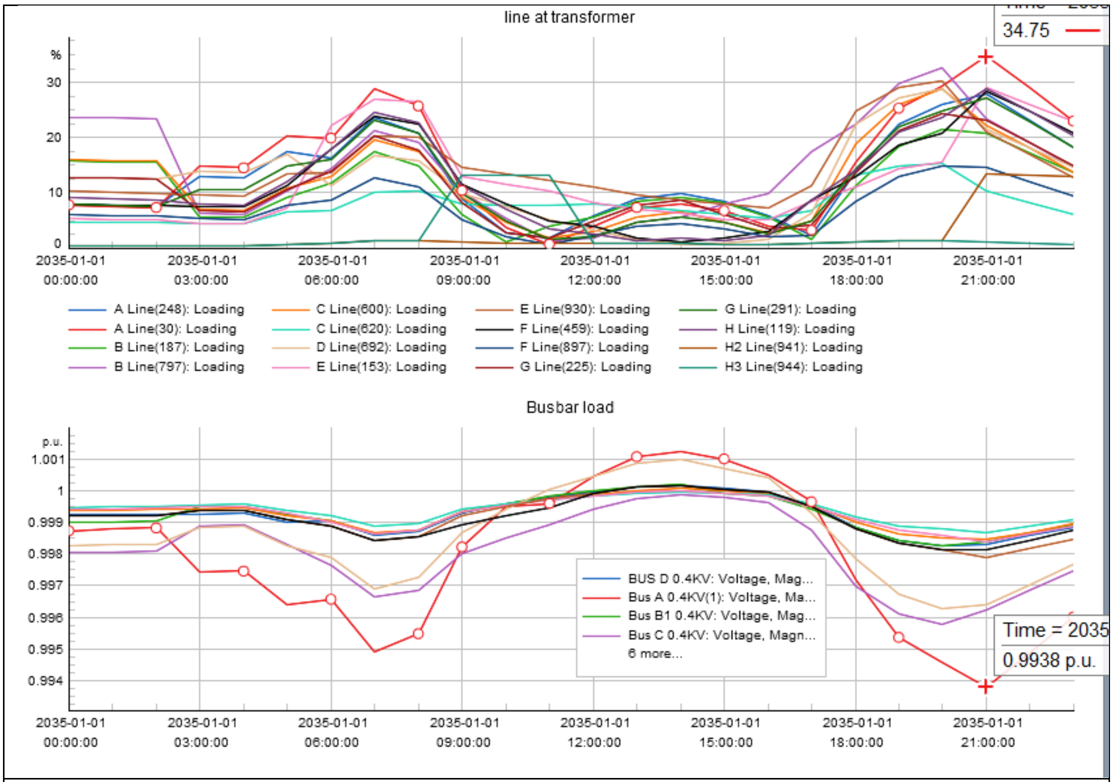


Percentage of transformer stress in Summer, 2035 with Small Centralised Battery



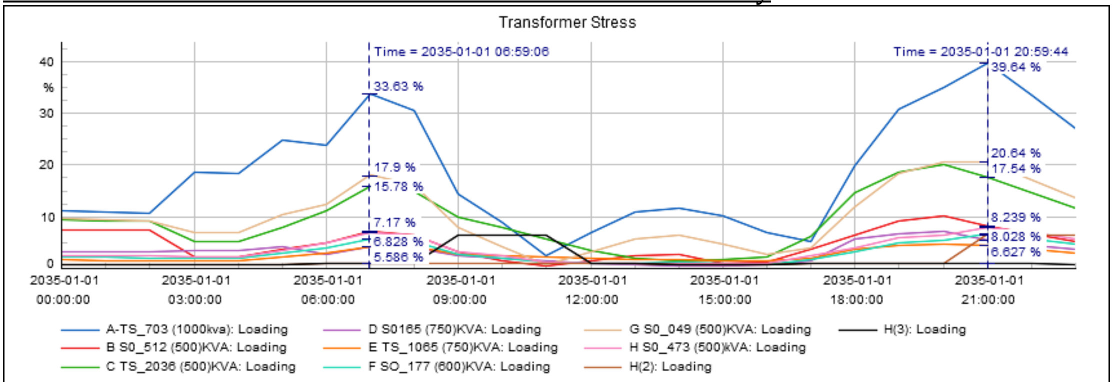
PV generation in Summer, 2035

SOC, and active power of Small Centralised and Decentralised Battery in Summer, 2035

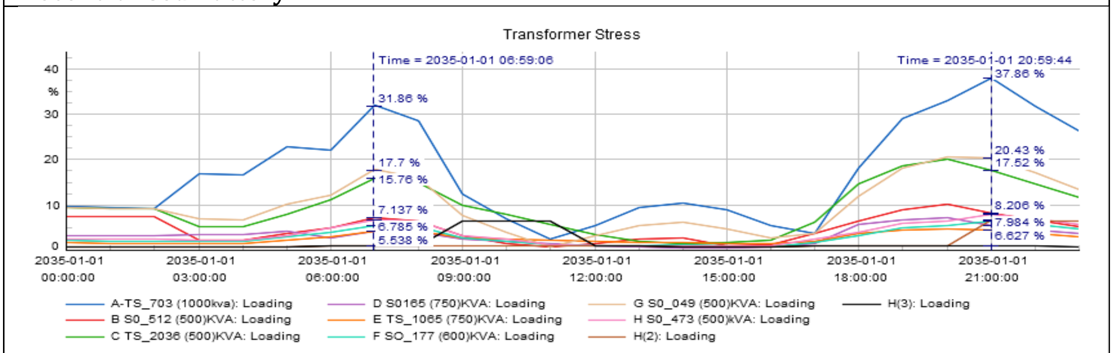


Line and Bus loading in Summer, 2035 with Small Centralised Battery

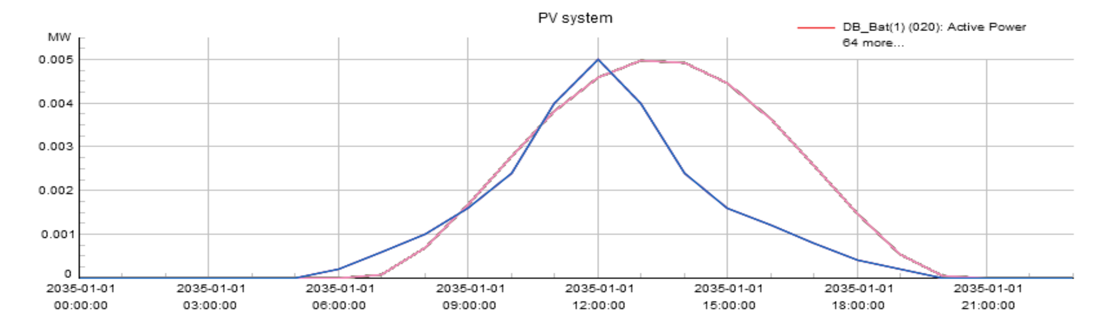
2035 - Summer - Small Centralised and Decentralised Battery



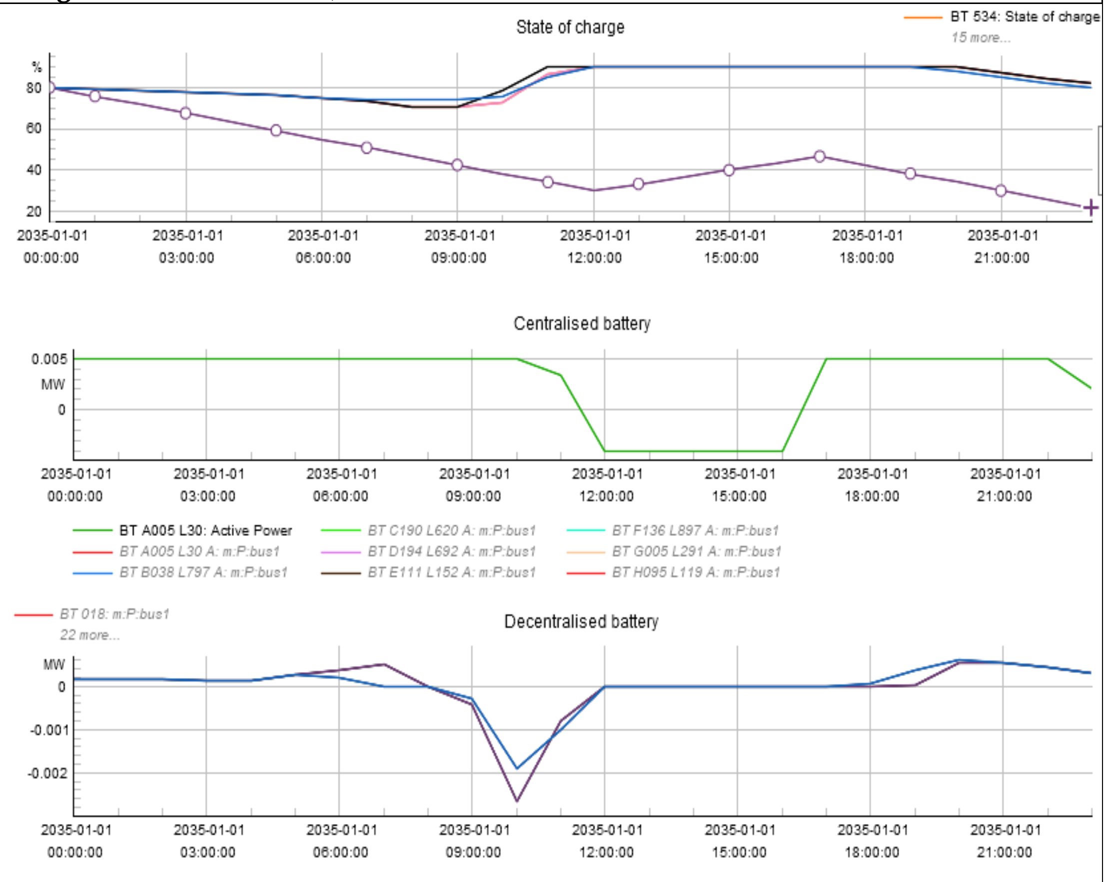
Percentage of transformer stress in Summer, 2035 without Small Centralised and Decentralised Battery



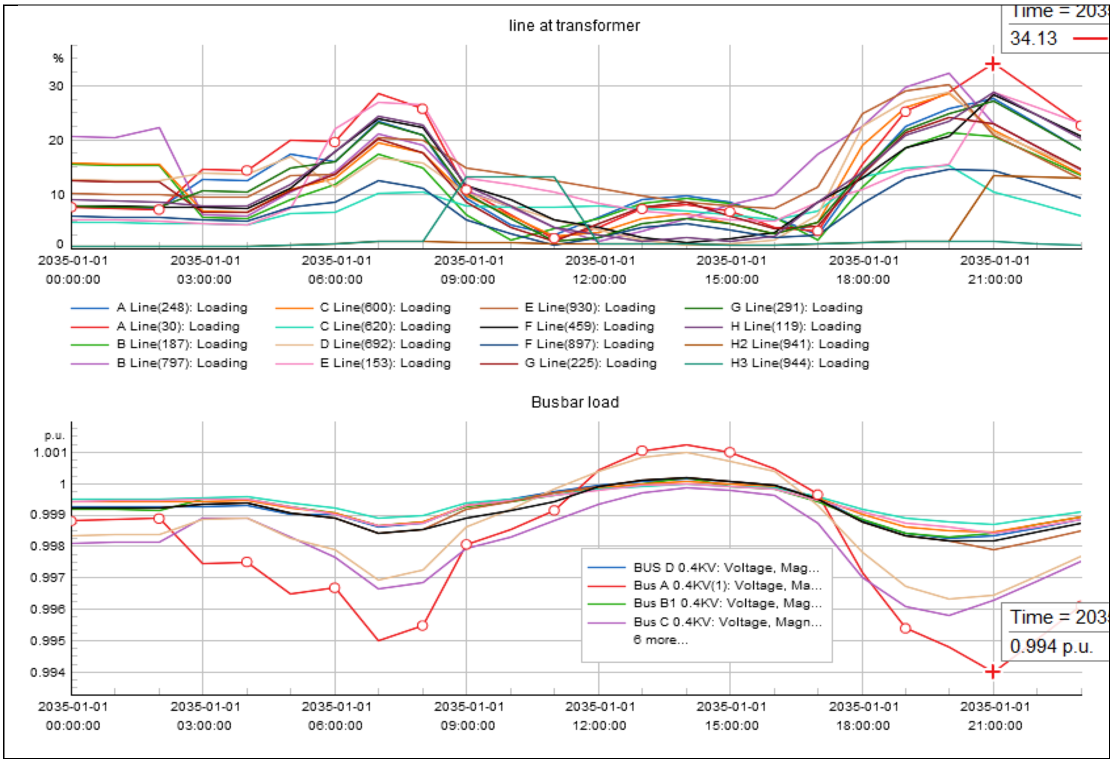
Percentage of transformer stress in Summer, 2035 with Small Centralised and Decentralised Battery



PV generation in Summer, 2035

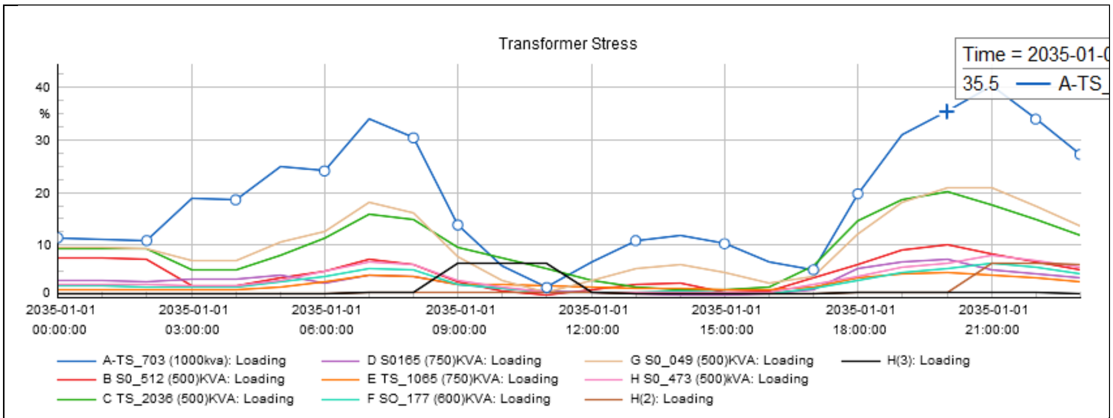


SOC, and active power of Small Centralised and Decentralised Battery in Summer, 2035

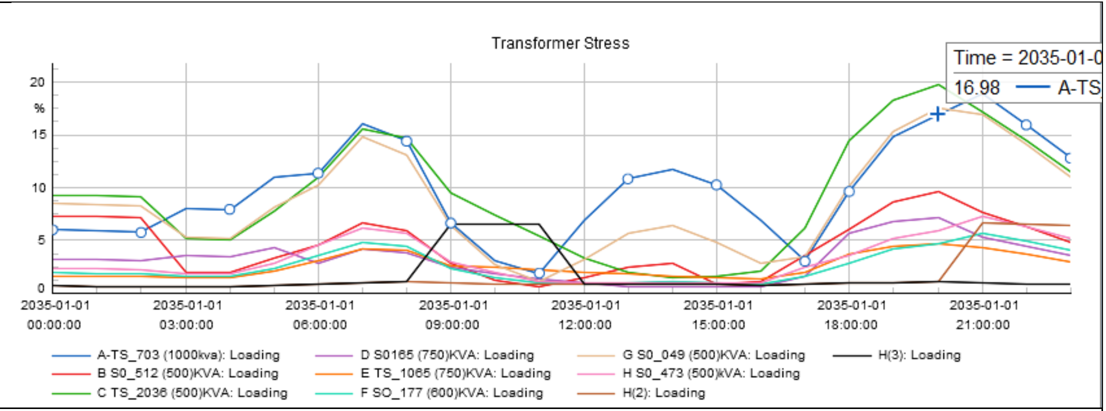


Line and Bus loading in Summer, 2035 with Small Centralised and Decentralised Battery

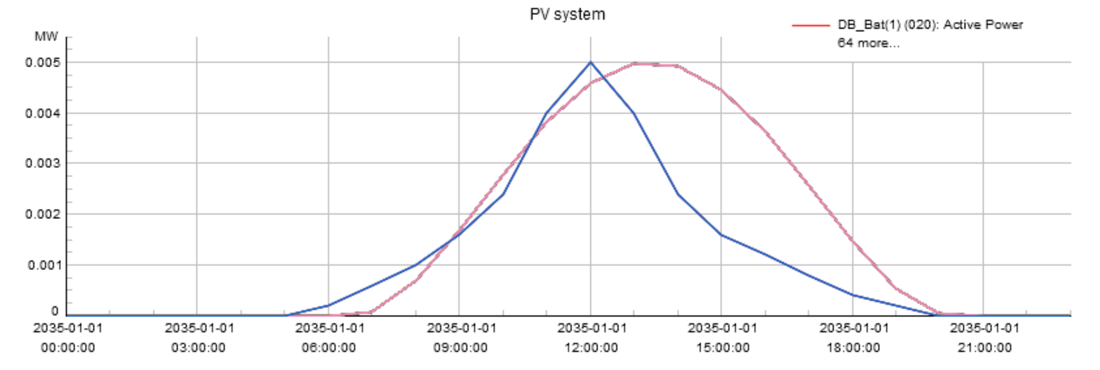
2035 - Summer - Large Centralised Battery



Percentage of transformer stress in Summer, 2035 without Large Centralised Battery



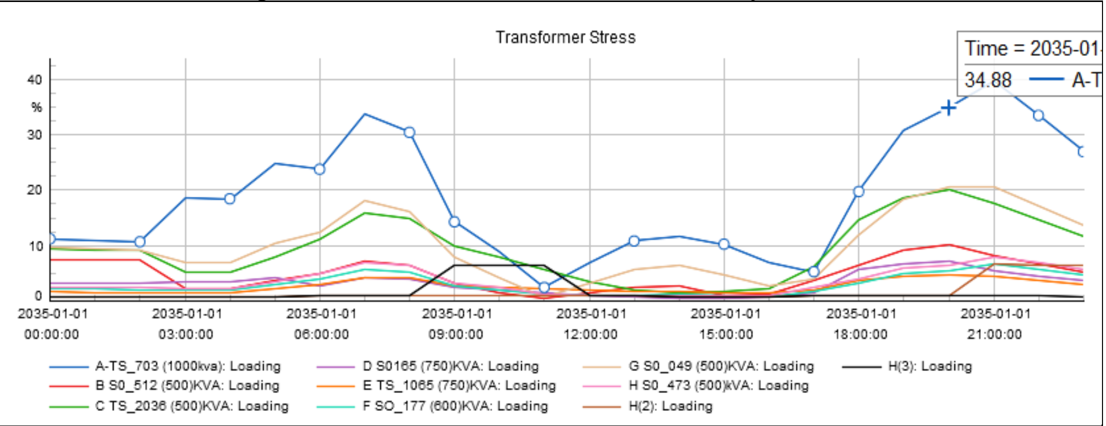
Percentage of transformer stress in Summer, 2035 with Large Centralised Battery



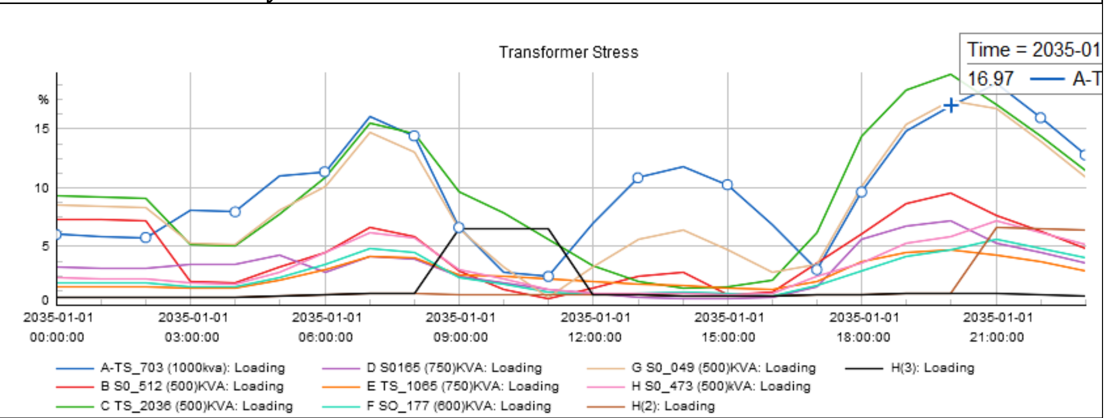
PV generation in Summer, 2035

SOC, and active power of Large Centralised and decentralised Battery in Summer, 2035

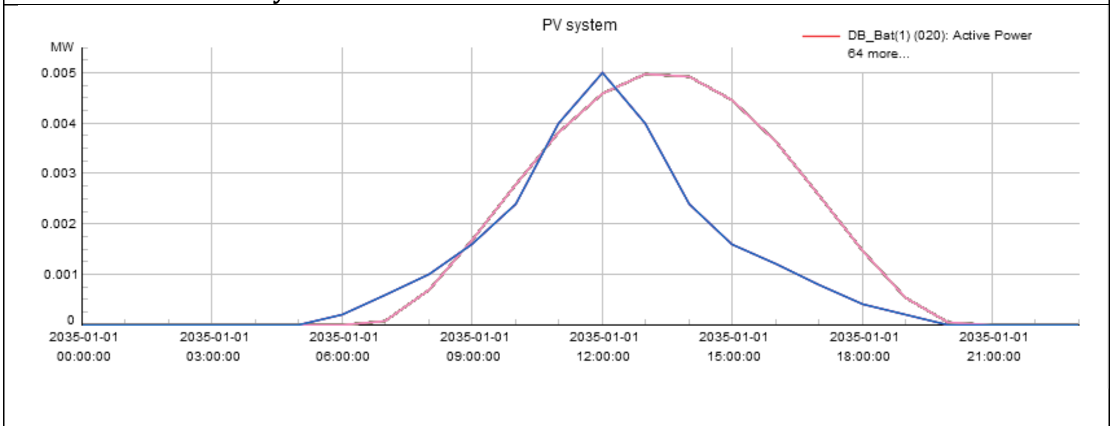
2035 - Summer - Large Centralised and Decentralised Battery



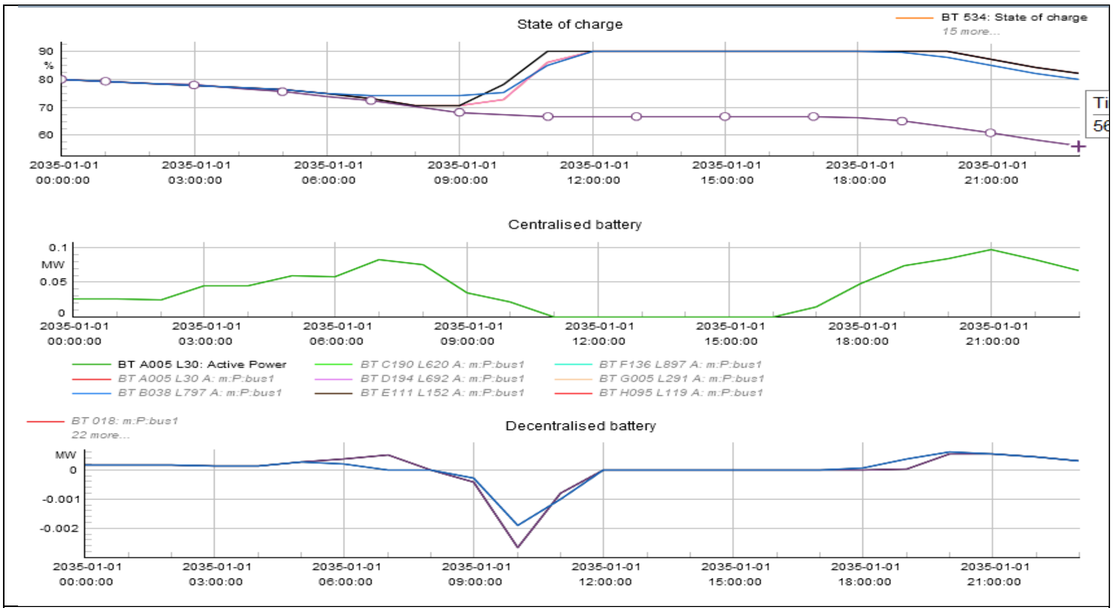
Percentage of transformer stress in Summer, 2035 without Large Centralised and Decentralised Battery



Percentage of transformer stress in Summer, 2035 with Large Centralised and Decentralised Battery

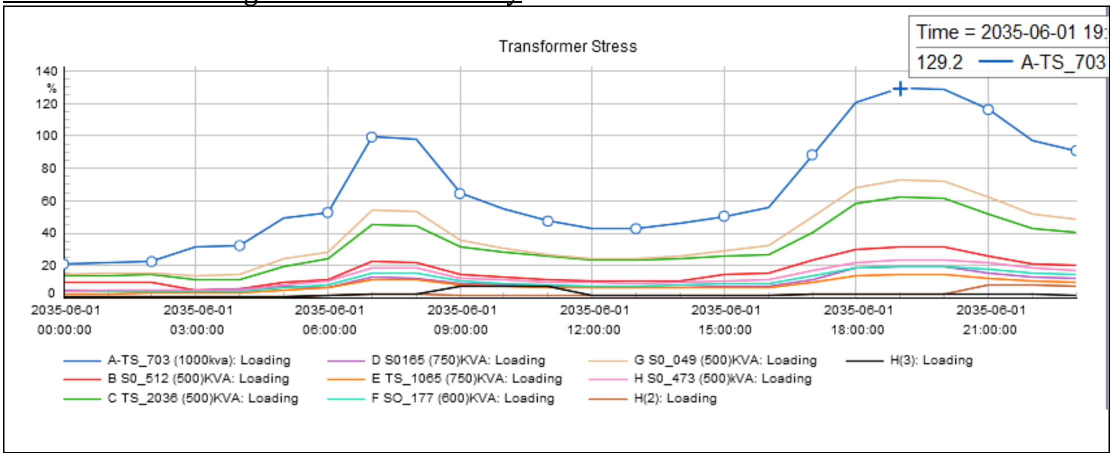


PV generation in Summer, 2035

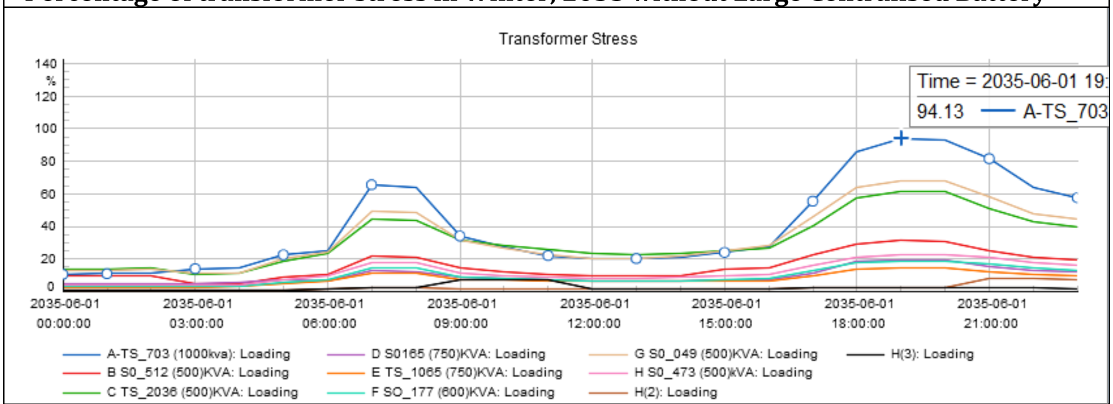


SOC, and active power of Large Centralised and decentralised Battery in Summer, 2035

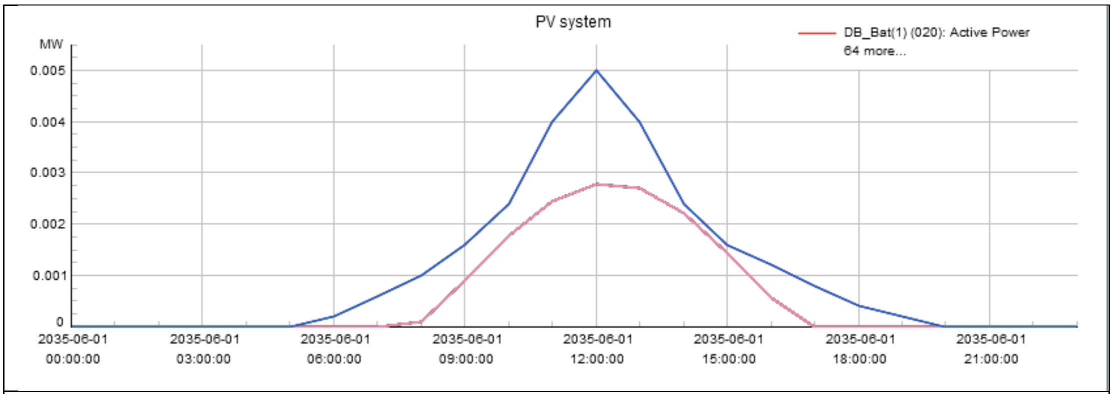
<u>2035 - Winter - Large Centralised Battery</u>



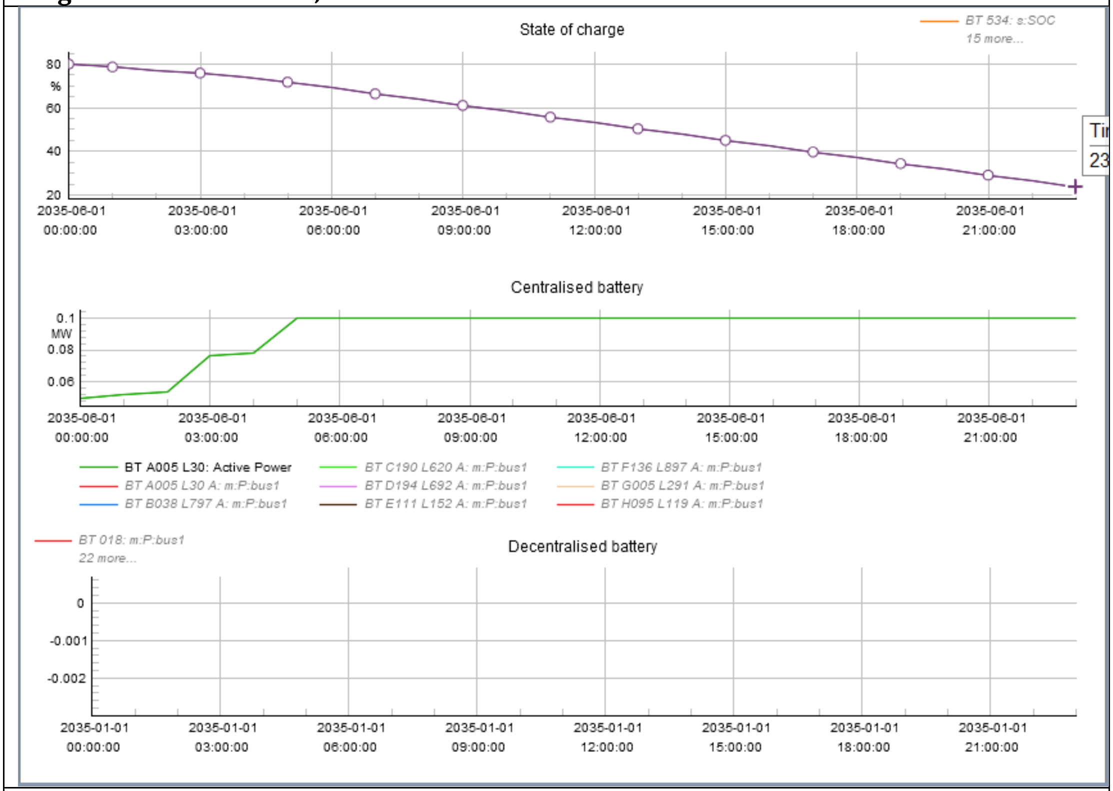
Percentage of transformer stress in Winter, 2035 without Large Centralised Battery



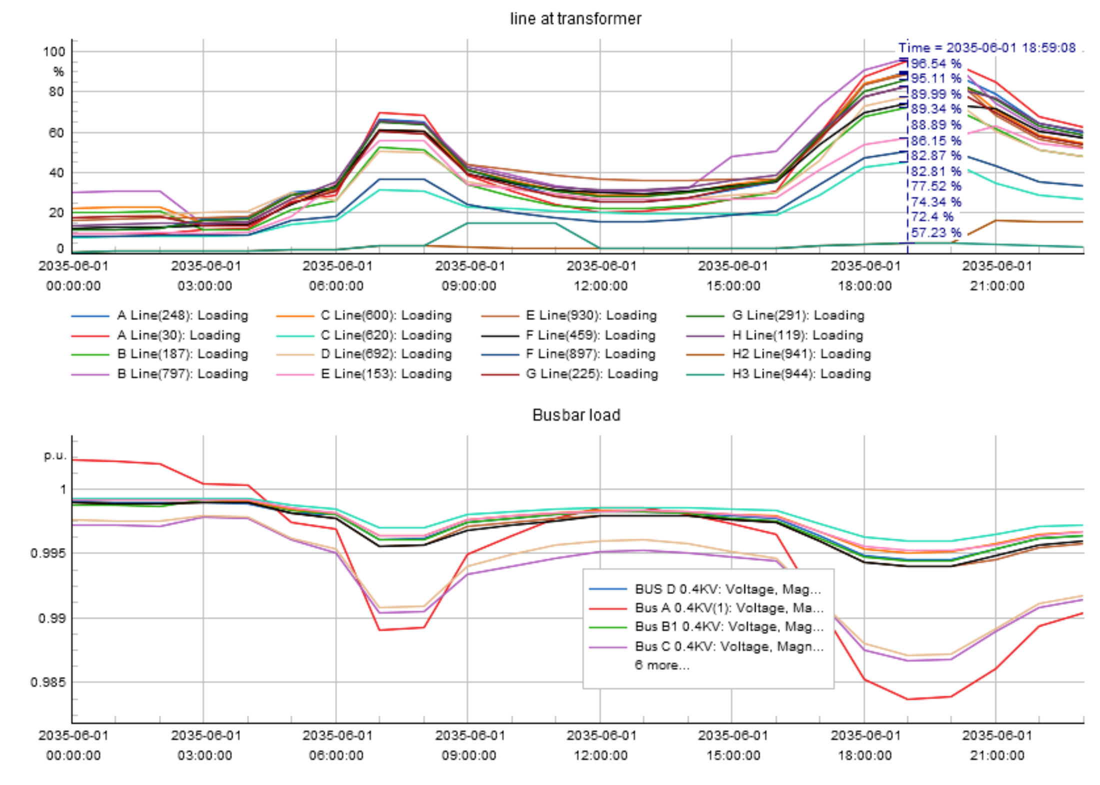
Percentage of transformer stress in Winter, 2035 with Large Centralised Battery



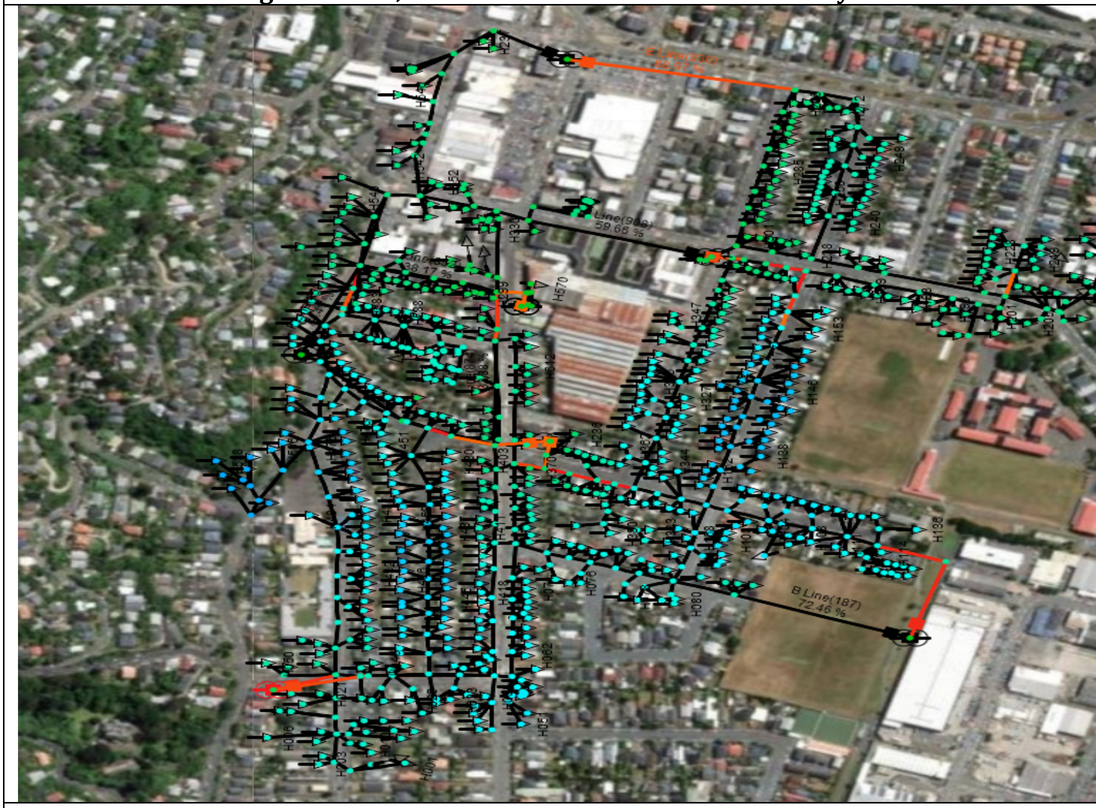
PV generation in Winter, 2035



SOC, and active power of Large Centralised and decentralised Battery in Winter, 2035

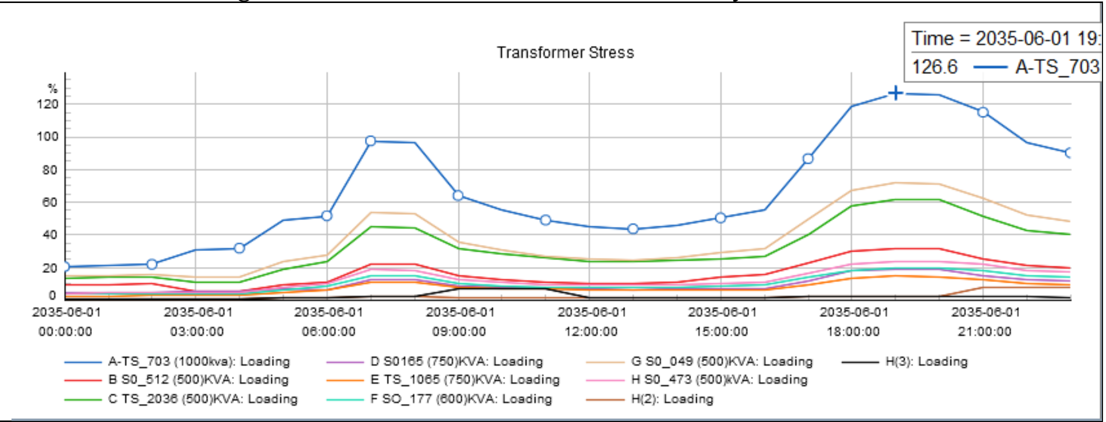


Line and Bus loading in Winter, 2035 with Small Centralised Battery

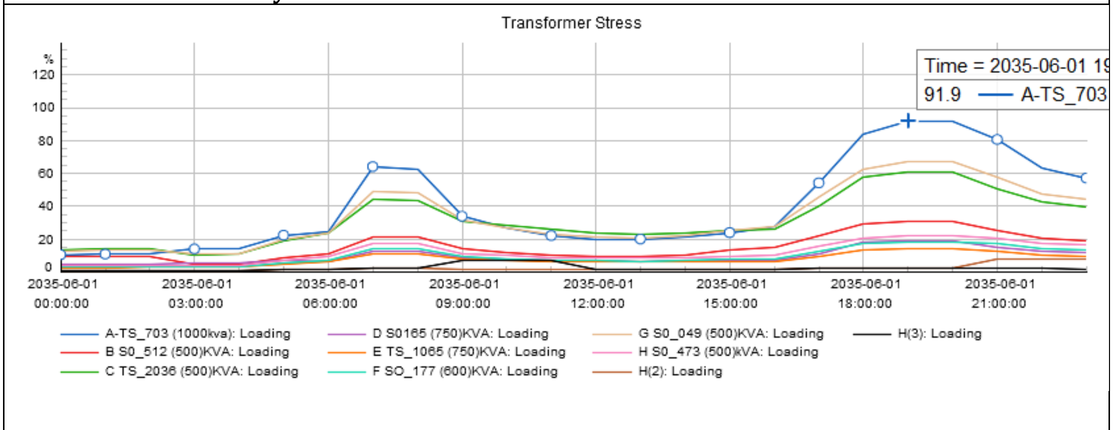


Line and Bus Mapping in Winter, 2035 with Large Centralised Battery

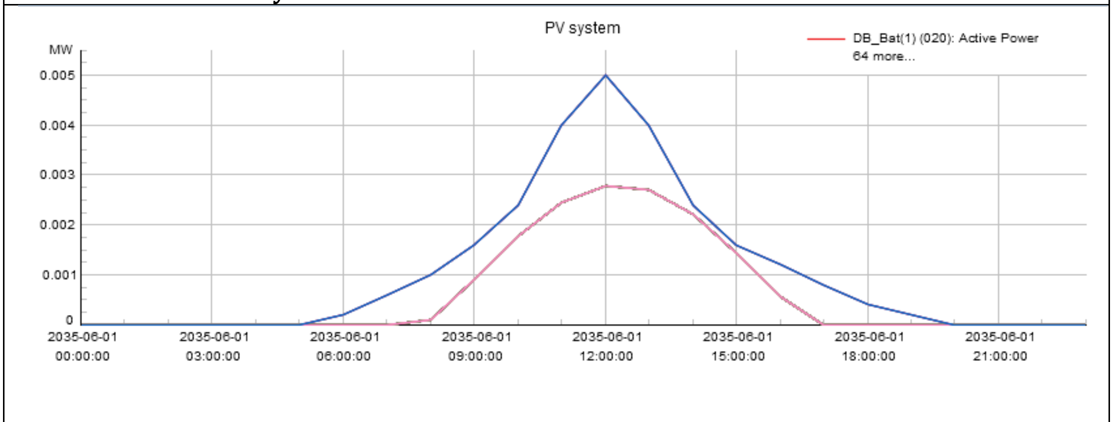
2035 - Winter - Large Centralised and Decentralised Battery



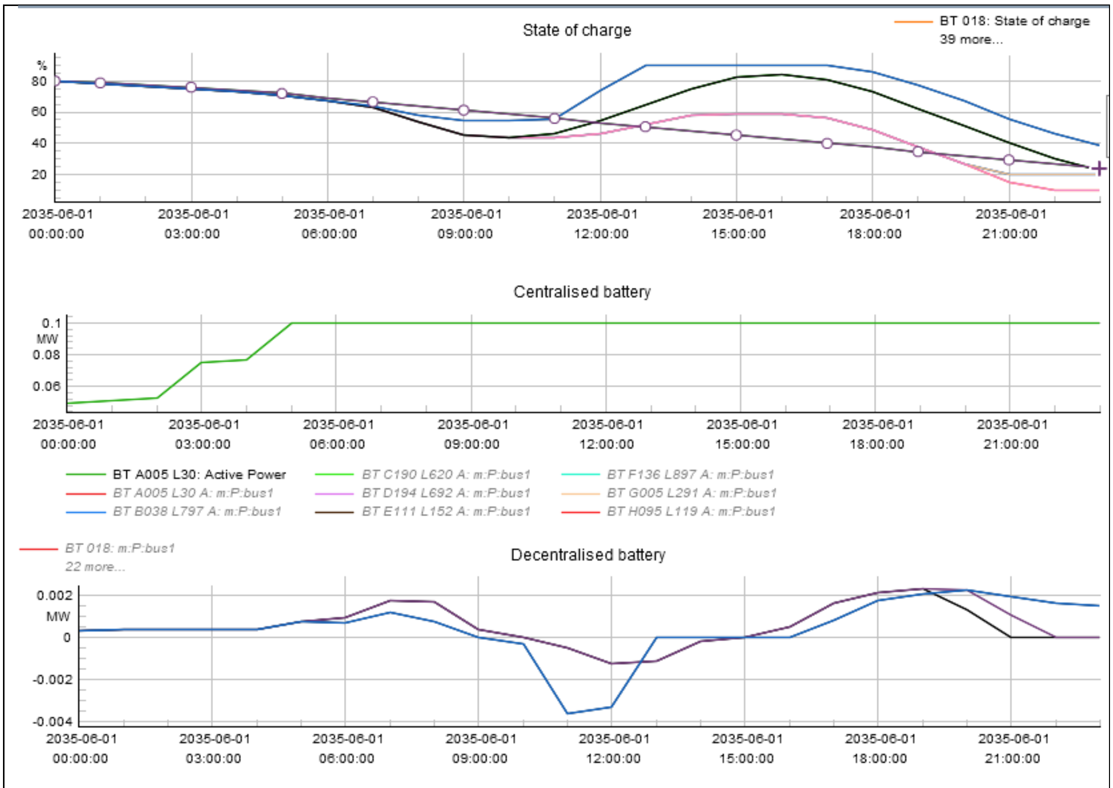
Percentage of transformer stress in Winter, 2035 without Large Centralised and Decentralised Battery



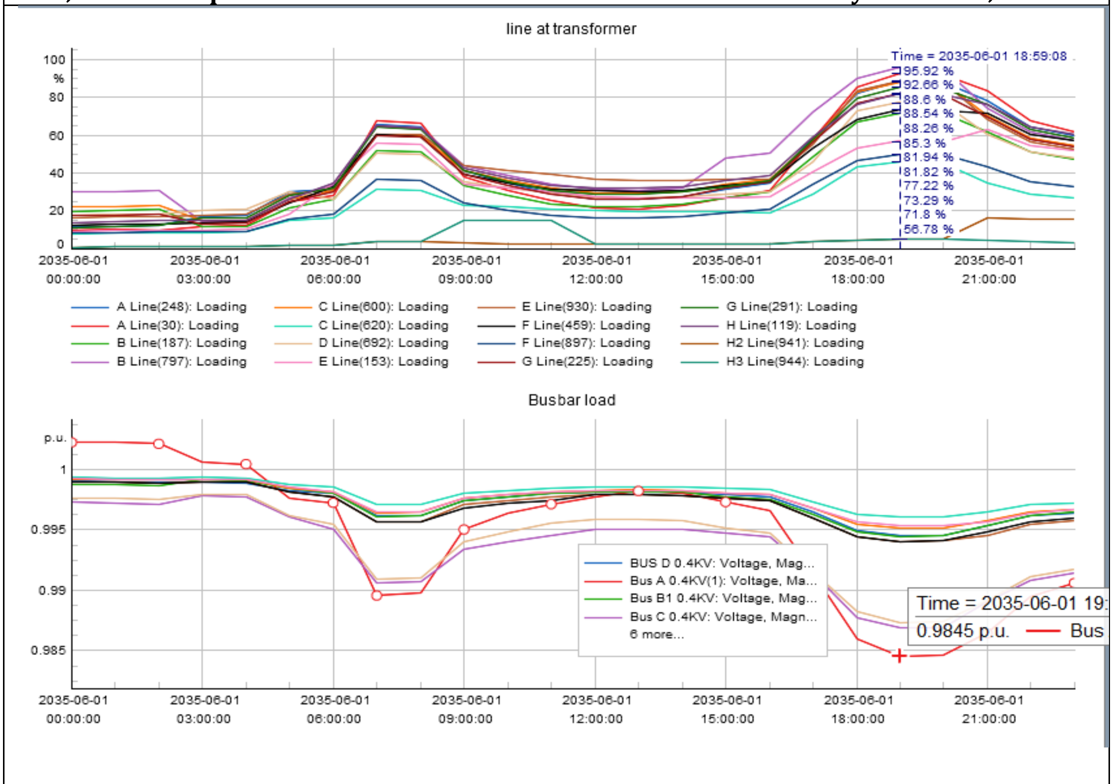
Percentage of transformer stress in Winter, 2035 with Large Centralised and Decentralised Battery



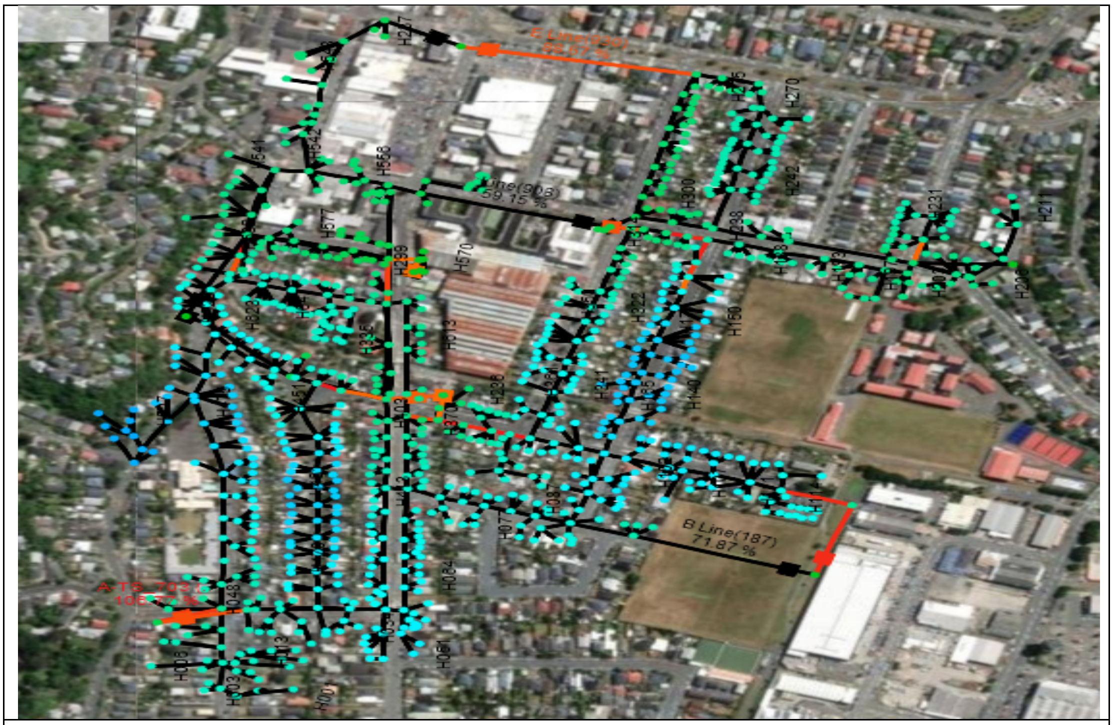
PV generation in Winter, 2035



SOC, and active power of Small Centralised and Decentralised Battery in Winter, 2035



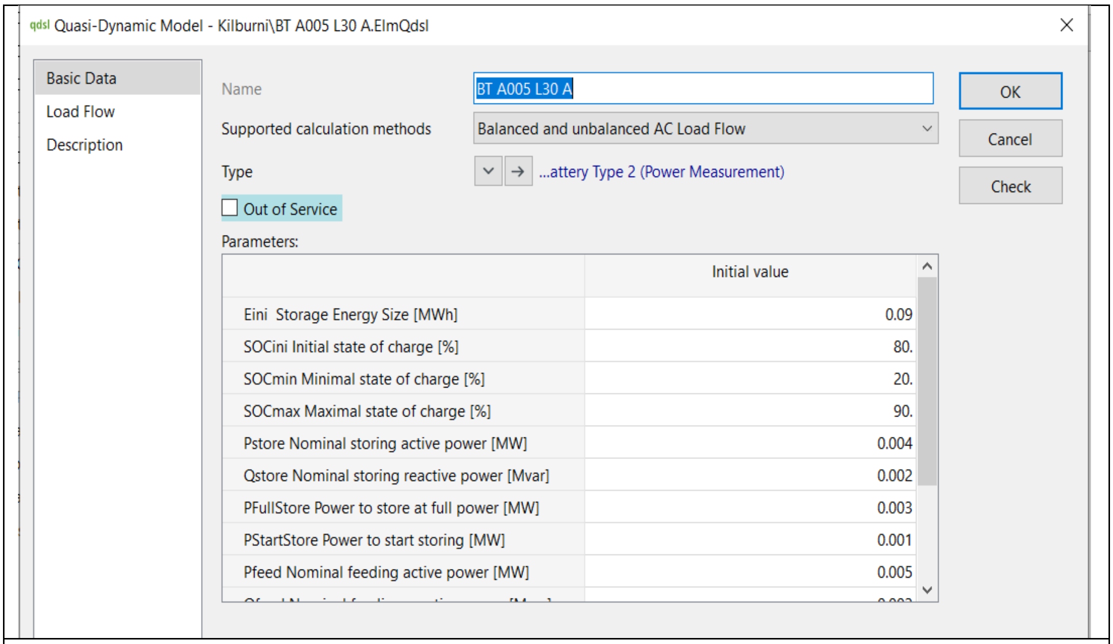
Line and Bus loading in Winter, 2035 with Large Centralised and Decentralised Battery



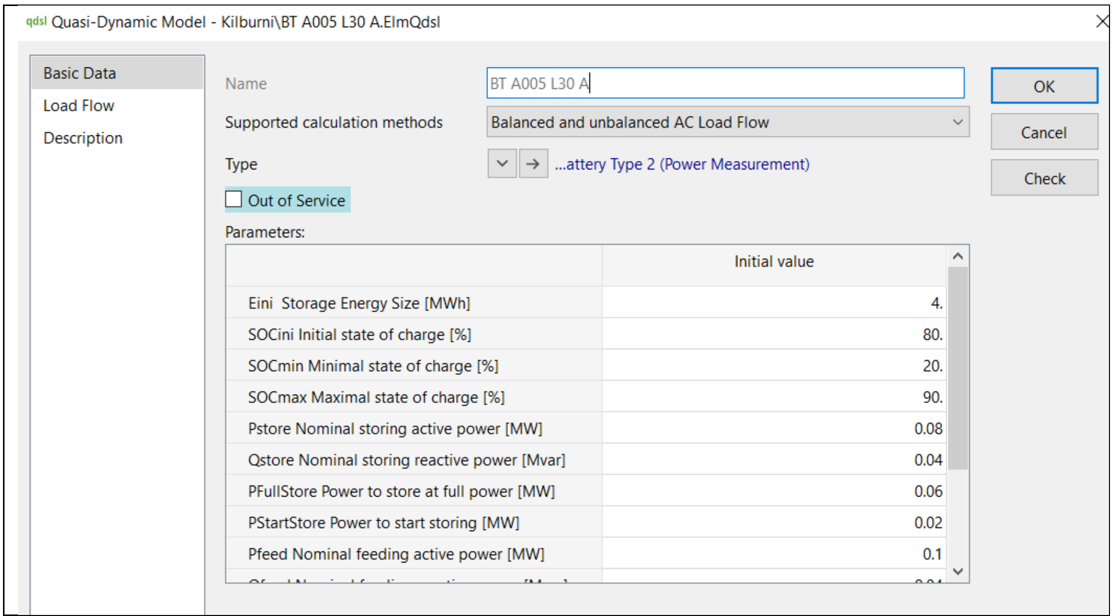
Line and Bus Mapping in Winter, 2035 with Large centralised and Decentralised Battery

2050

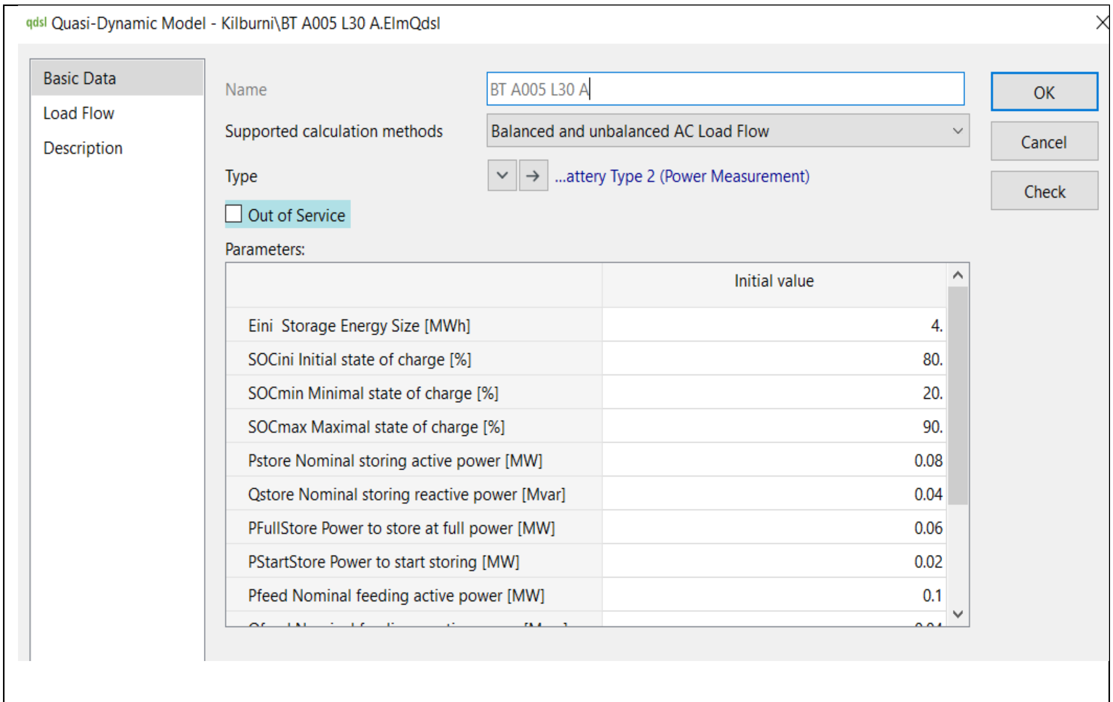
<u>2050 - Summer and Winter- Centralised Battery - Controlled Size value</u>



2050 - Summer - Centralised Small Battery Size

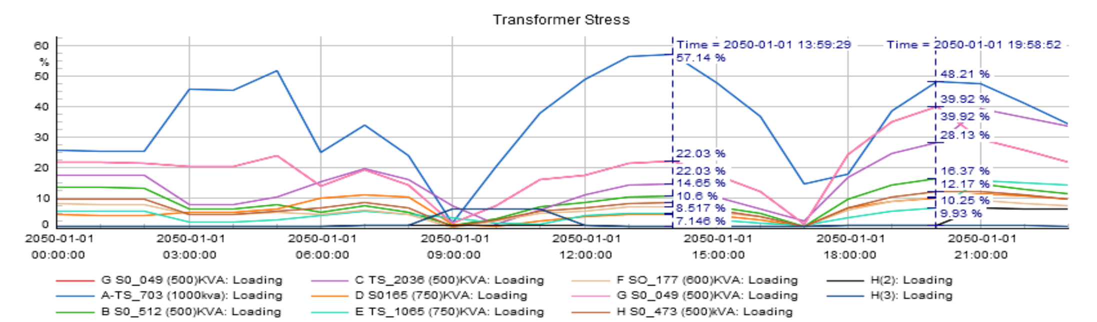


2050 - Summer - Centralised Large Battery Size

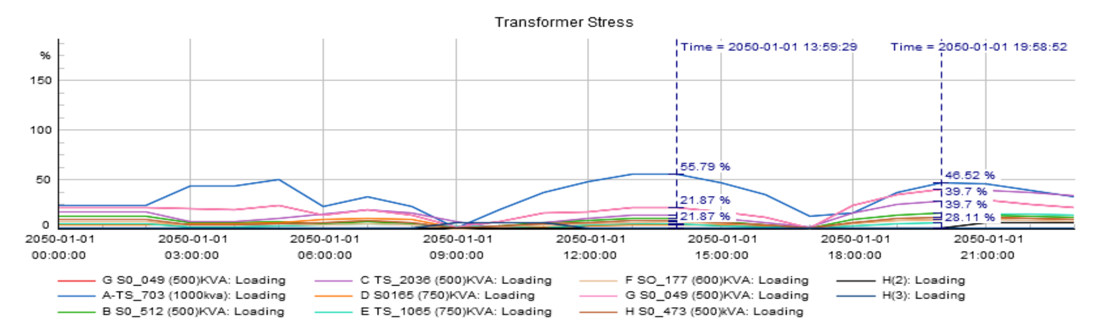


2050 - Winter - Centralised Large Battery Size

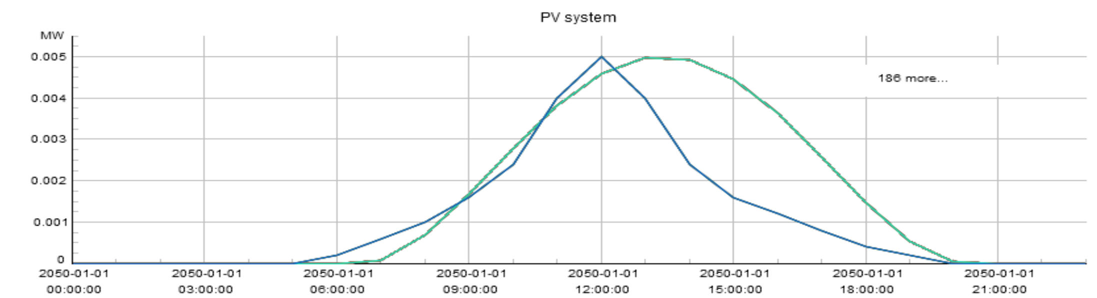
2050 - Summer - Small Centralised Battery



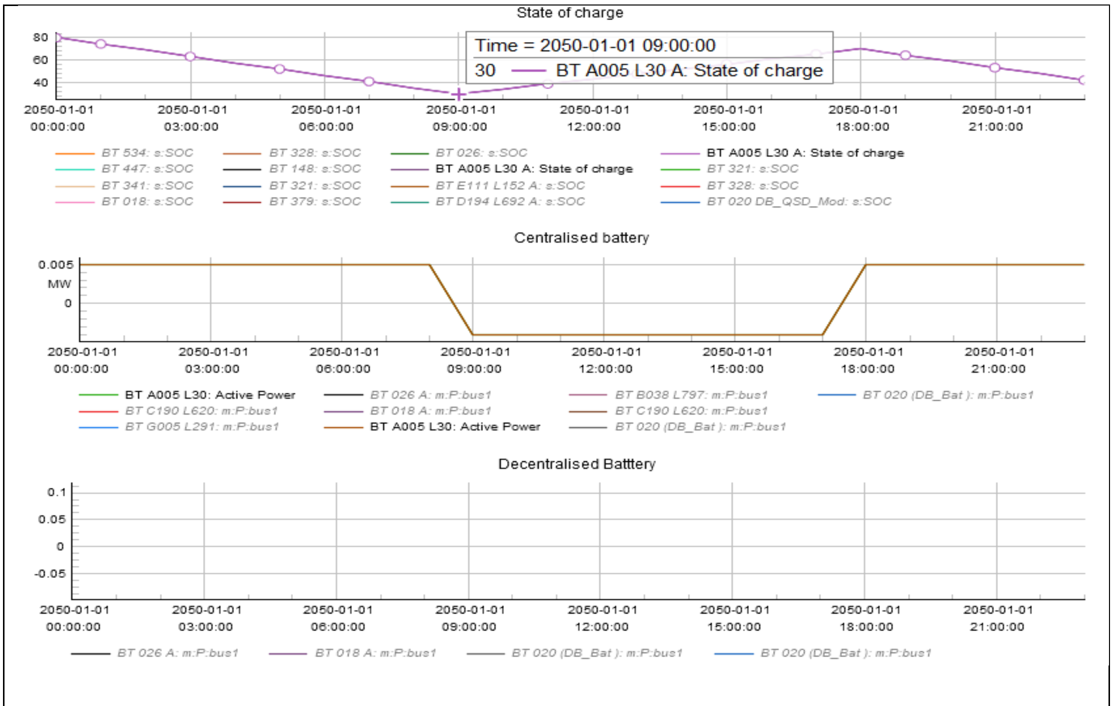
Percentage of transformer stress in Summer, 2050 without Small Centralised Battery



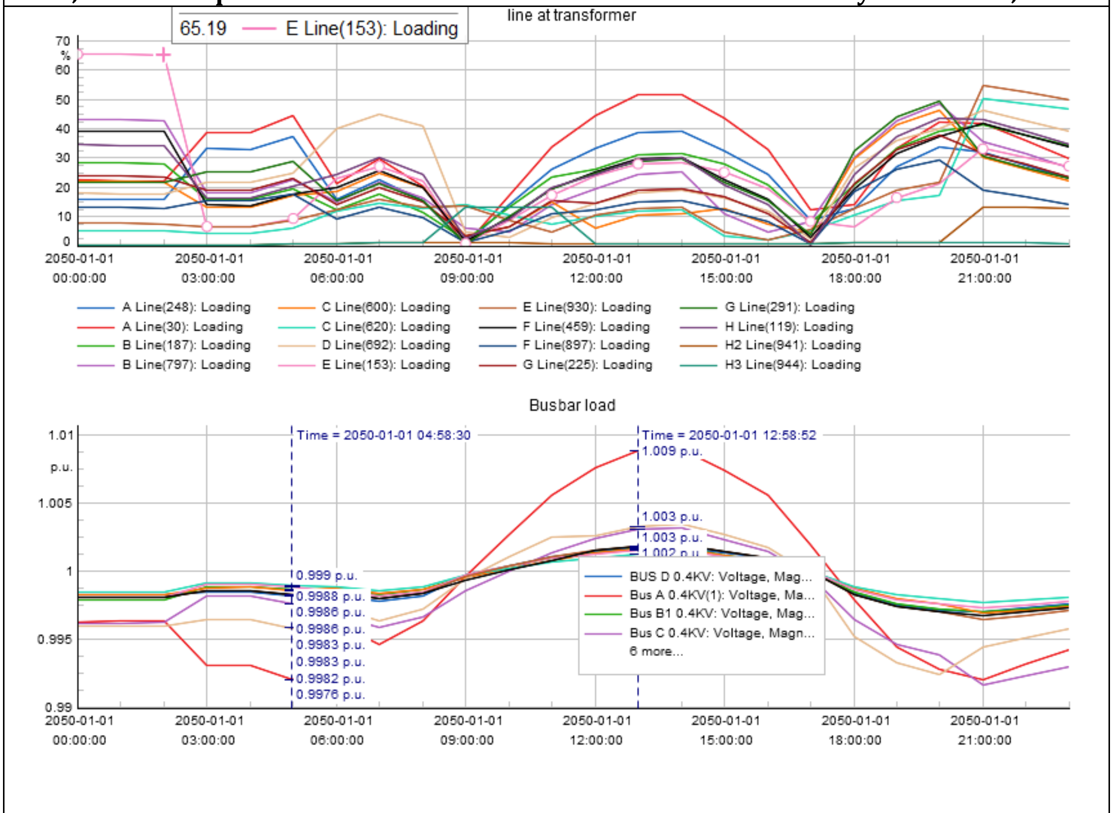
Percentage of transformer stress in Summer, 2050 with Small Centralised Battery



PV generation in Summer, 2050

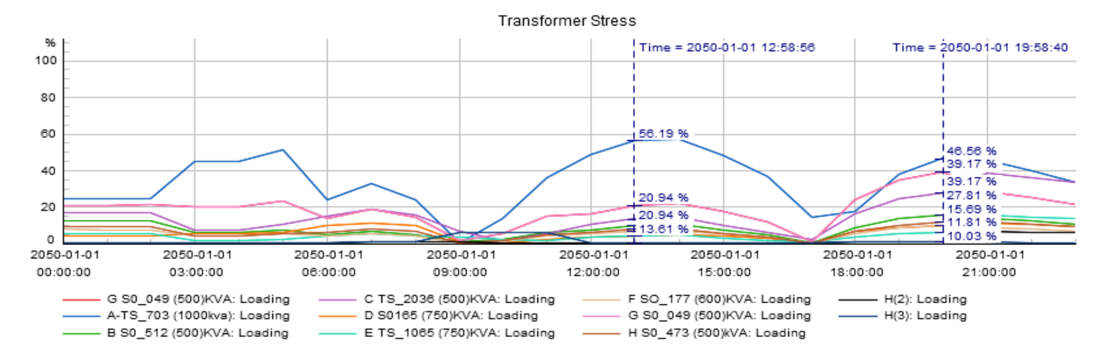


SOC, and active power of Small Centralised and Decentralised Battery in Summer, 2050

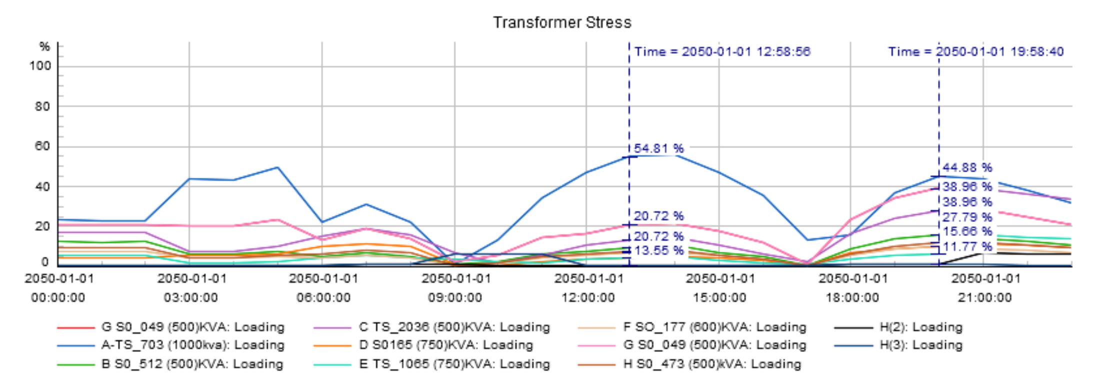


Line and Bus loading in Summer, 2050 with Small Centralised Battery

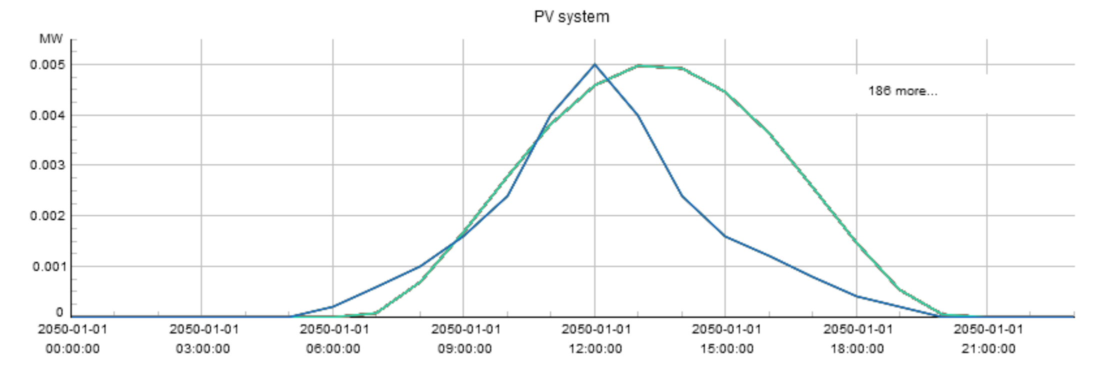
2050 - Summer - Small Centralised and Decentralised Battery



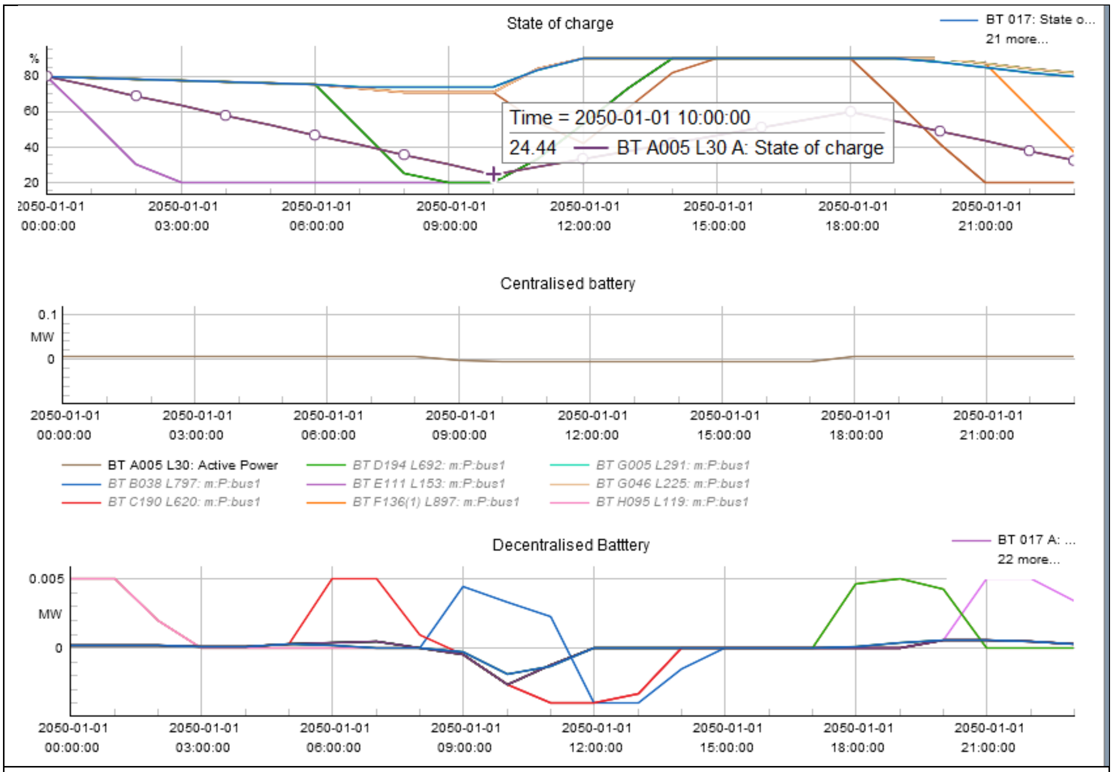
Percentage of transformer stress in Summer, 2050 without Small Centralised and Decentralised Battery



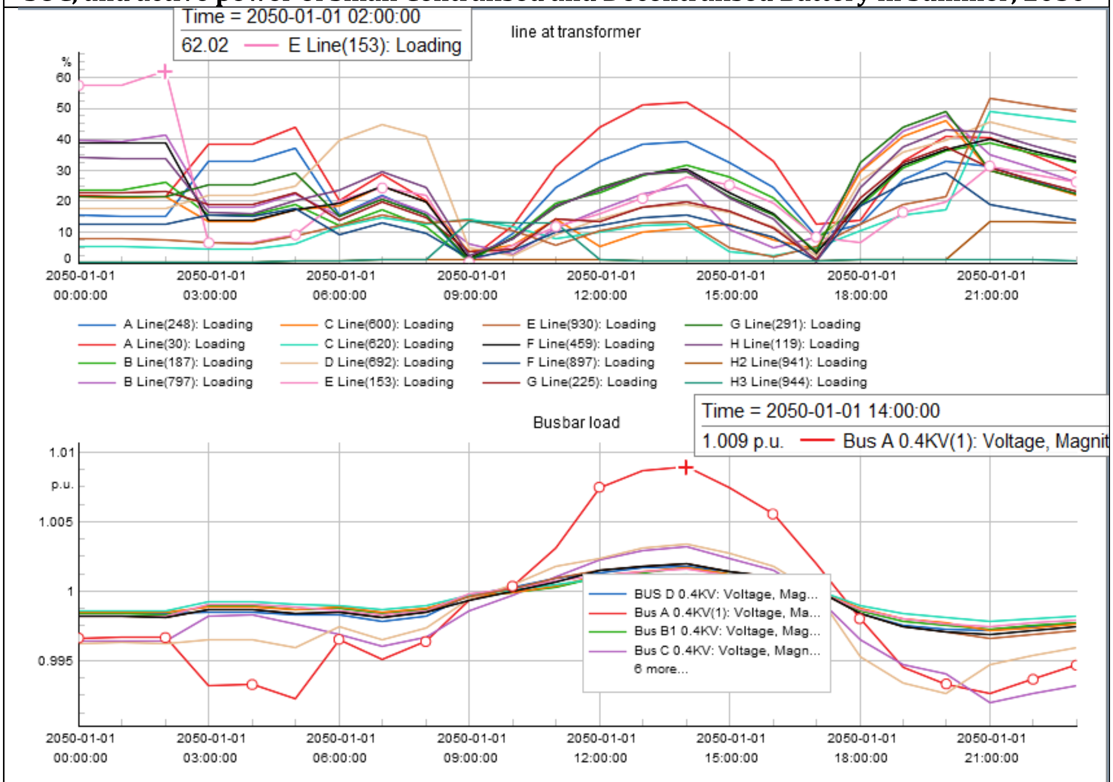
Percentage of transformer stress in Summer, 2050 with Small Centralised and Decentralised Battery



PV generation in Summer, 2050

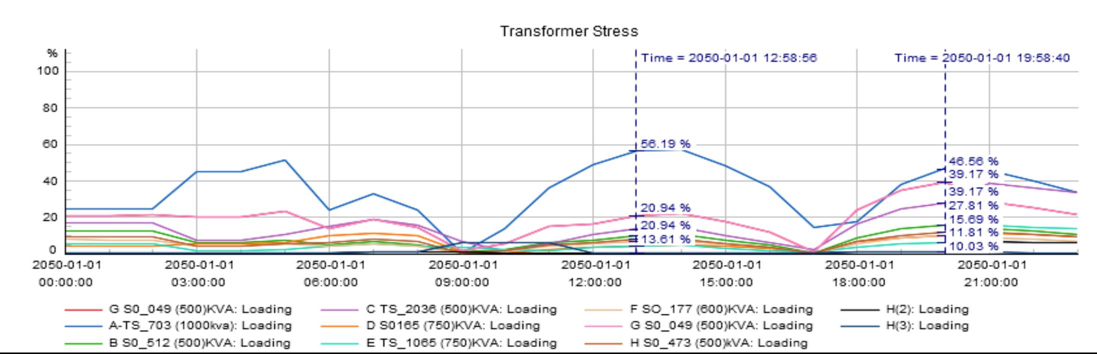


SOC, and active power of Small Centralised and Decentralised Battery in Summer, 2050

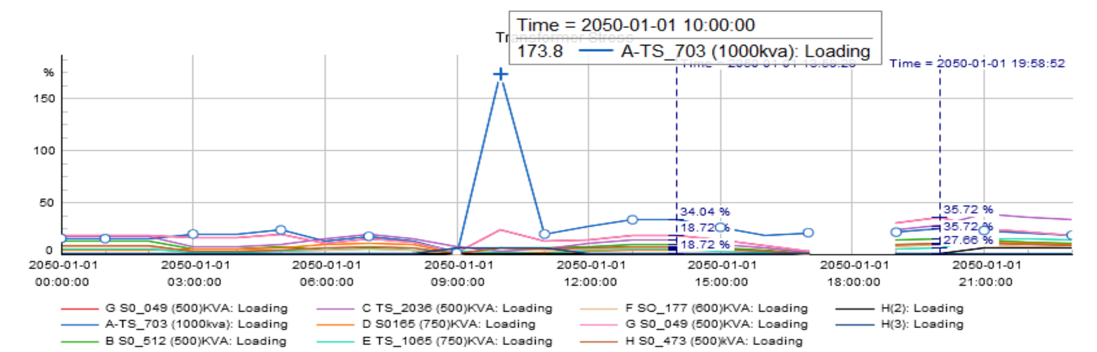


Line and Bus loading in Summer, 2030 with Small Centralised and Decentralised Battery

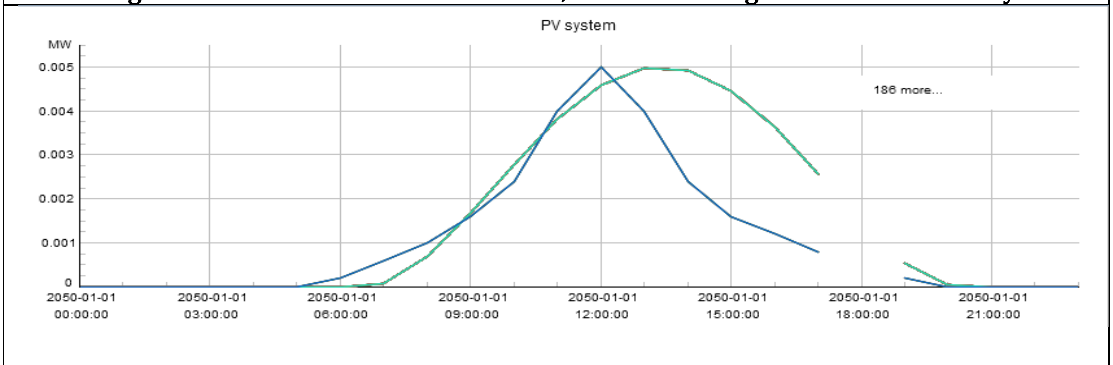
2050 - Summer - Large Centralised Battery



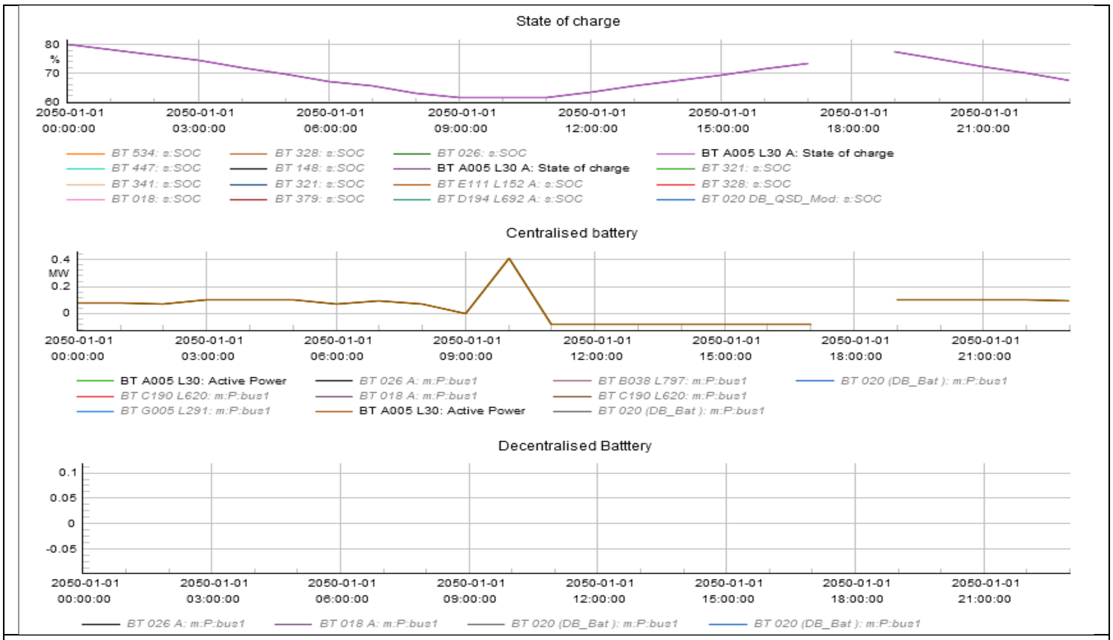
Percentage of transformer stress in Summer, 2050 without Large Centralised Battery



Percentage of transformer stress in Summer, 2050 with Large Centralised Battery

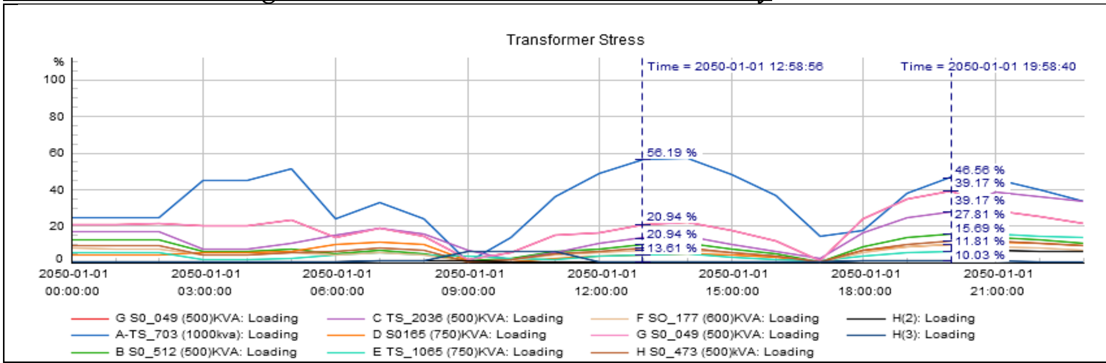


PV generation in Summer, 2030

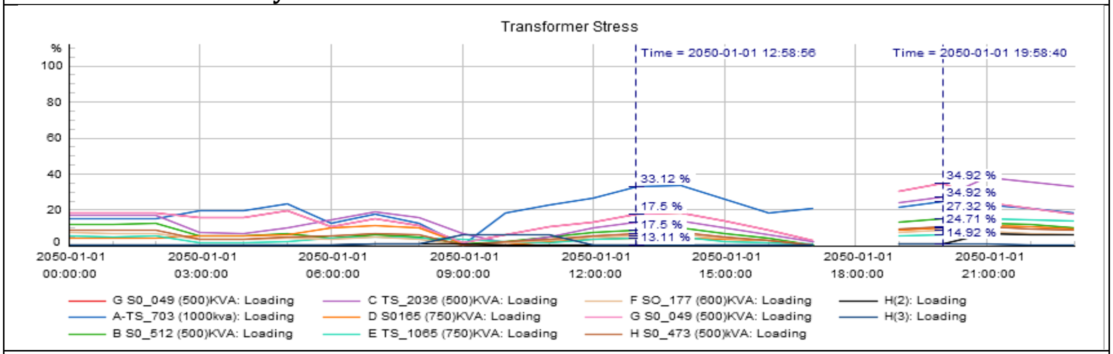


SOC, and active power of Large Centralised and Decentralised Battery in Summer, 2050

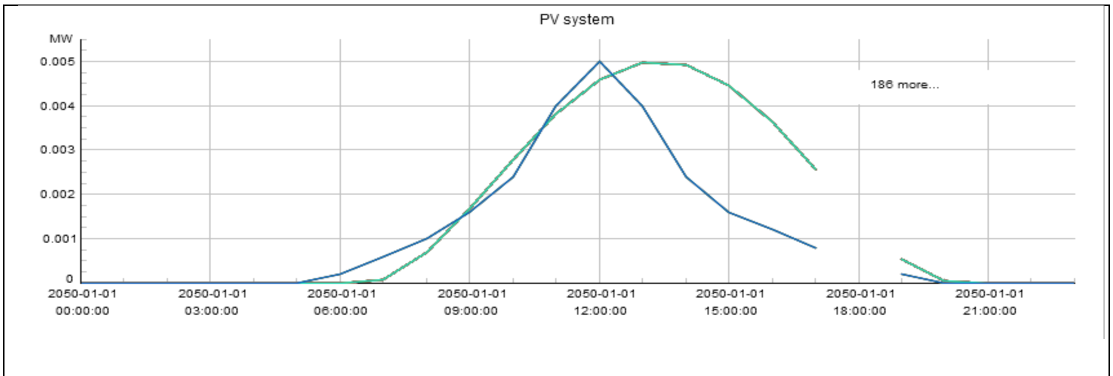
2050 - Summer - Large Centralised and Decentralised Battery



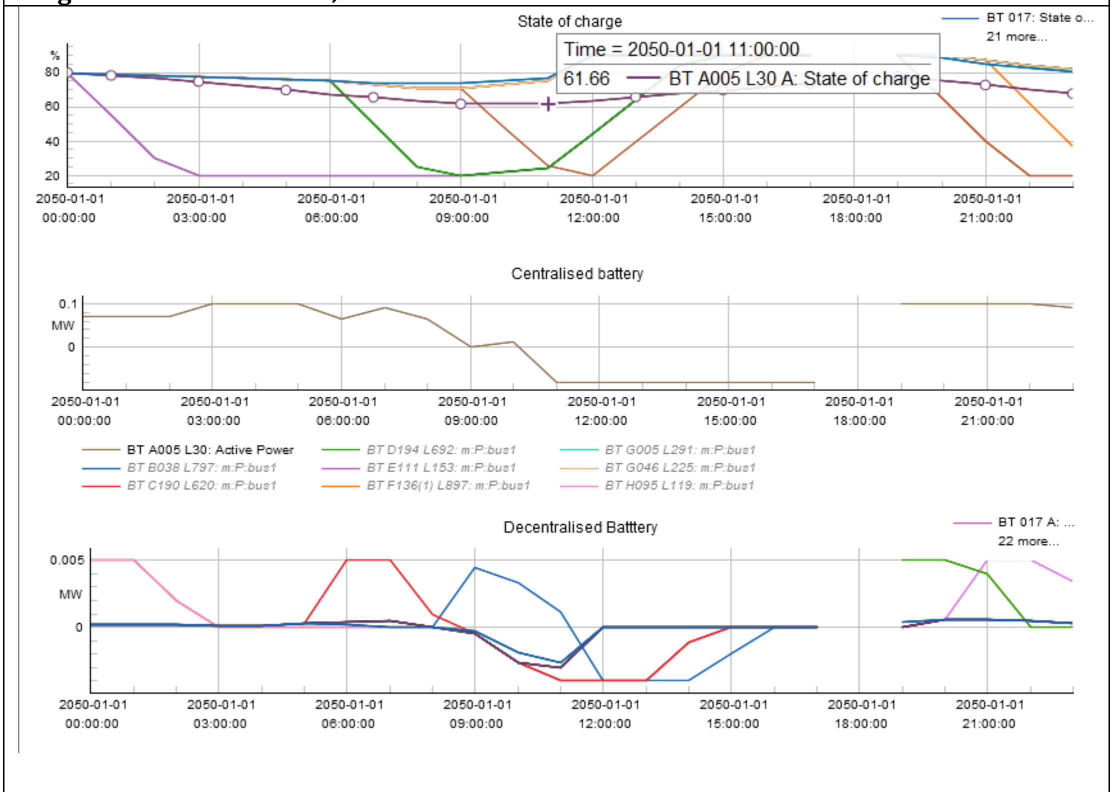
Percentage of transformer stress in Summer, 2050 without Large Centralised and Decentralised Battery



Percentage of transformer stress in Summer, 2050 with Large Centralised and Decentralised Battery

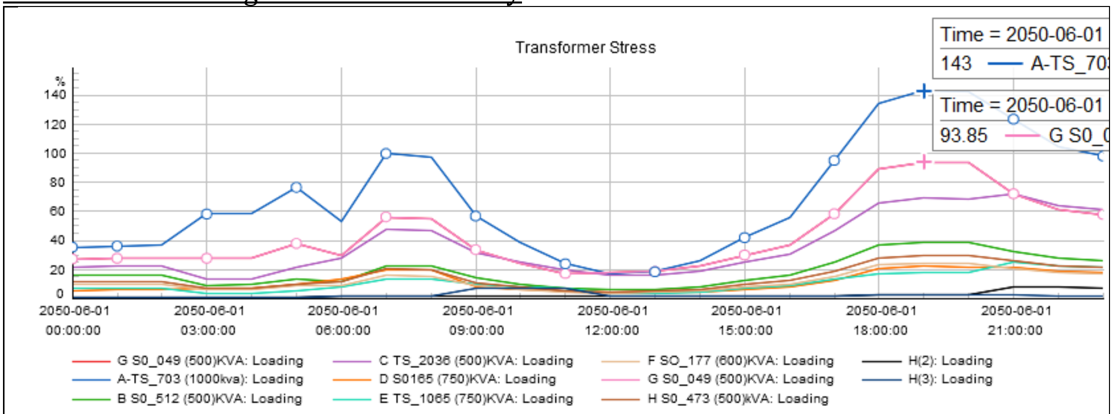


PV generation in Summer, 2050

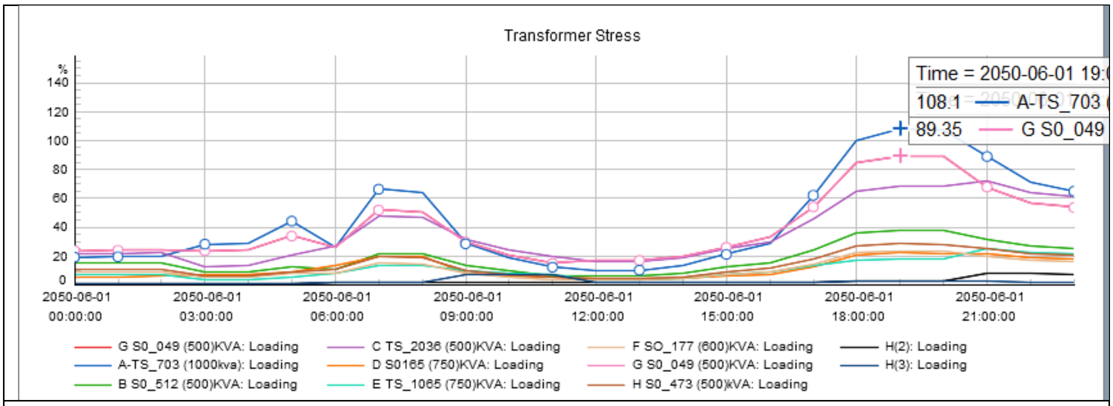


SOC, and active power of Large Centralised and Decentralised Battery in Summer, 2050

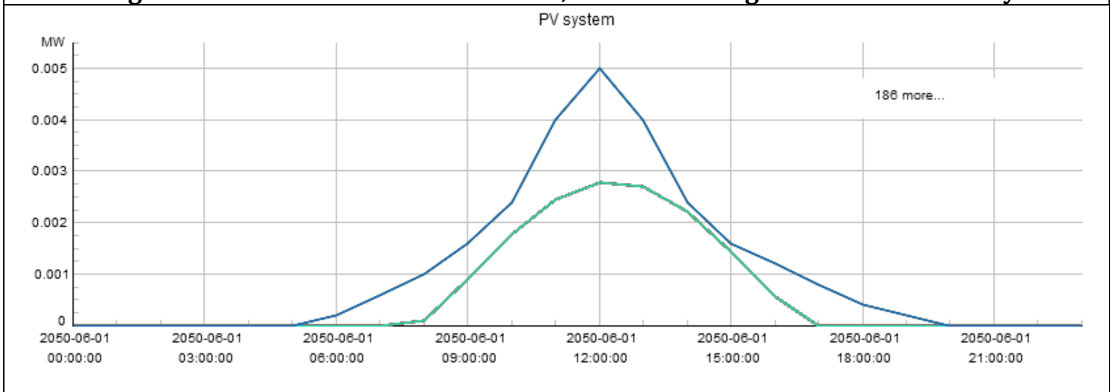
<u>2050 - Winter - Large Centralised Battery</u>



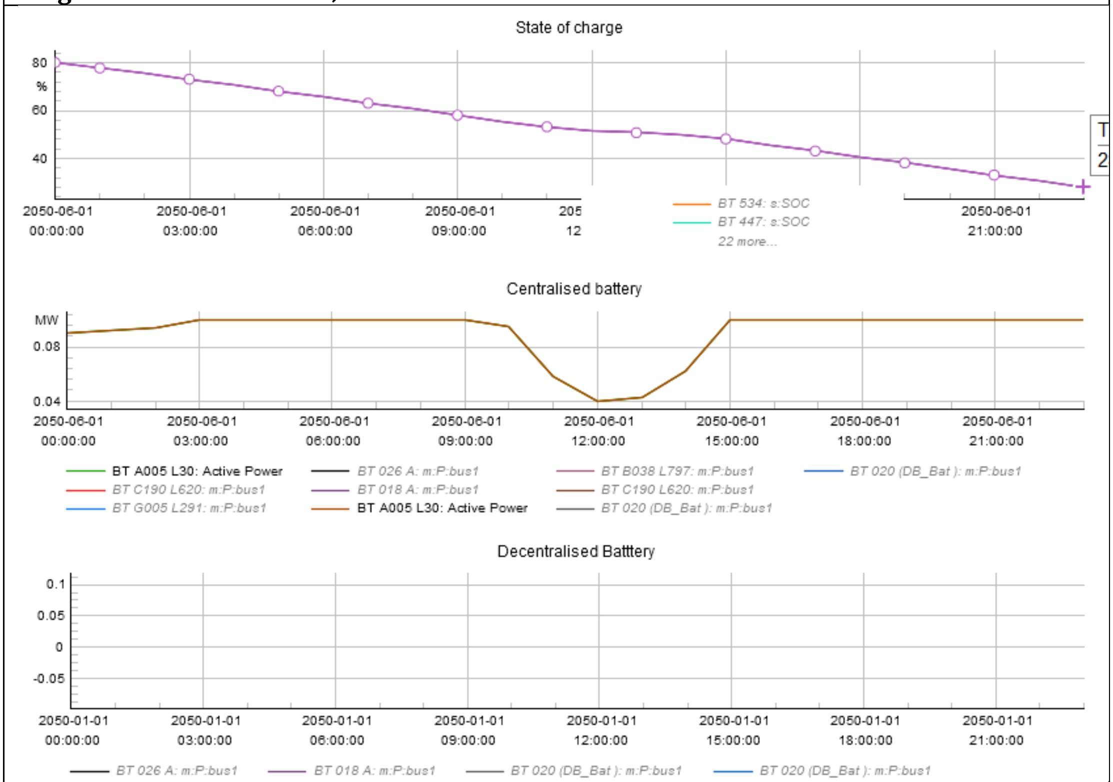
Percentage of transformer stress in Winter, 2050 without Large Centralised Battery



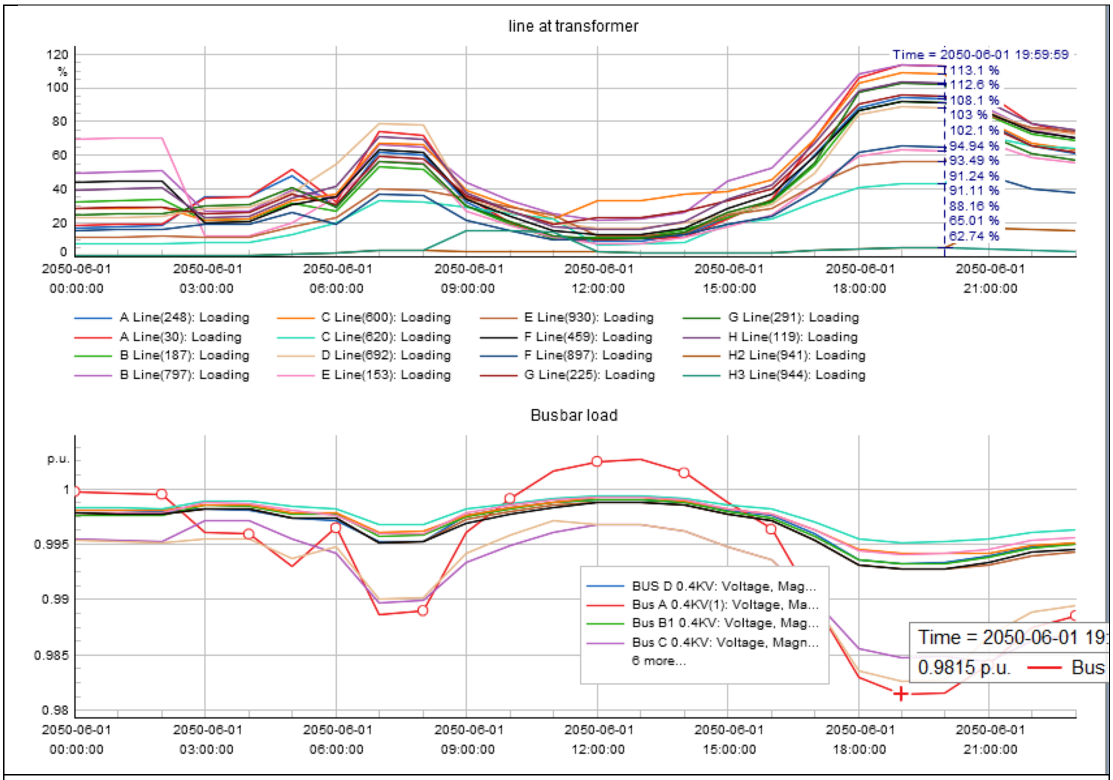
Percentage of transformer stress in Summer, 2050 with Large Centralised Battery



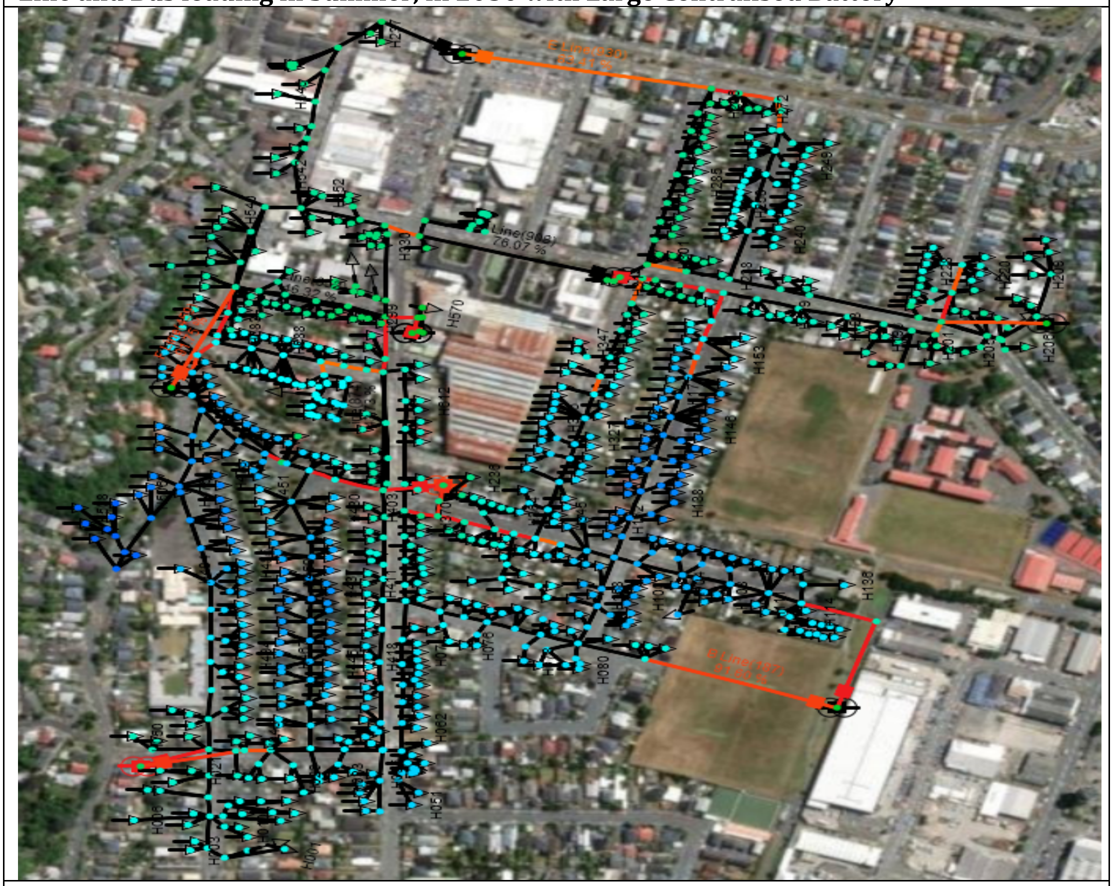
PV generation in Summer, 2050



SOC, and active power of Large Centralised and Decentralised Battery in Winter, 2030

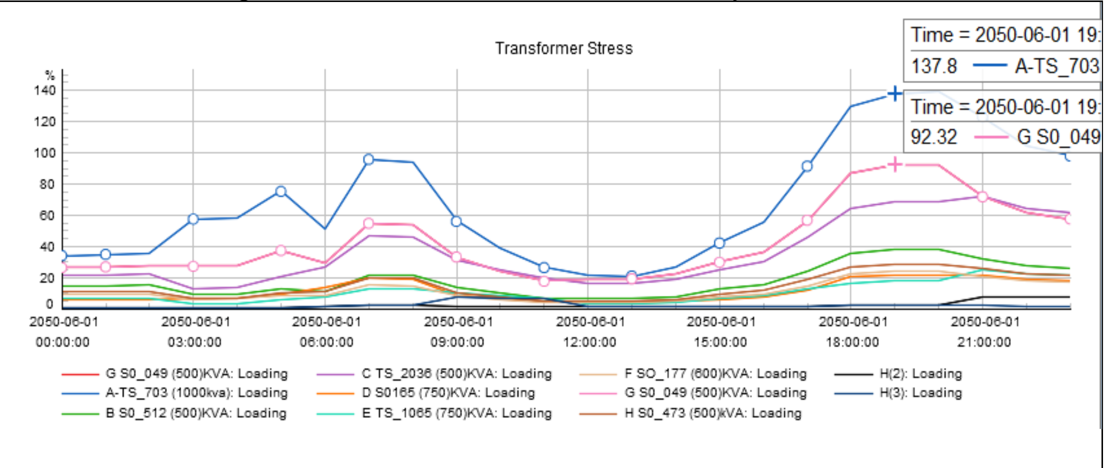


Line and Bus loading in Summer, in 2050 with Large Centralised Battery

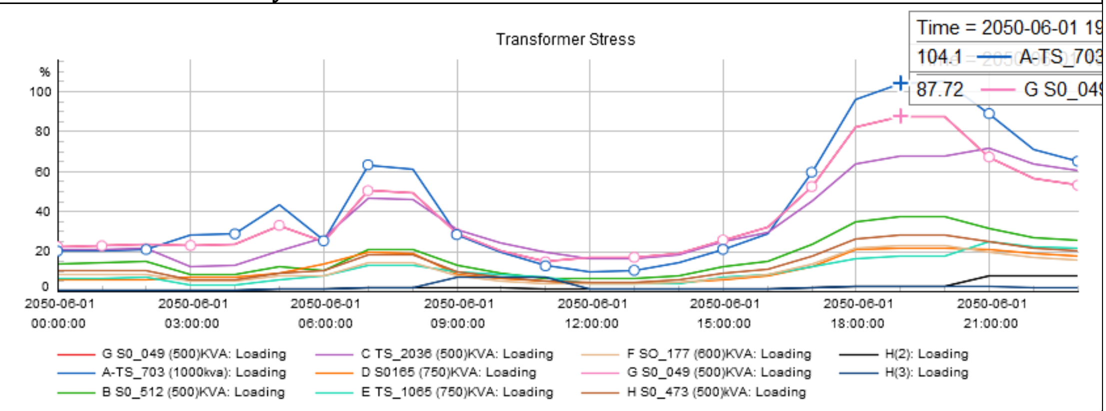


Line and Bus Mapping in Winter, 2050 with Large Centralised Battery

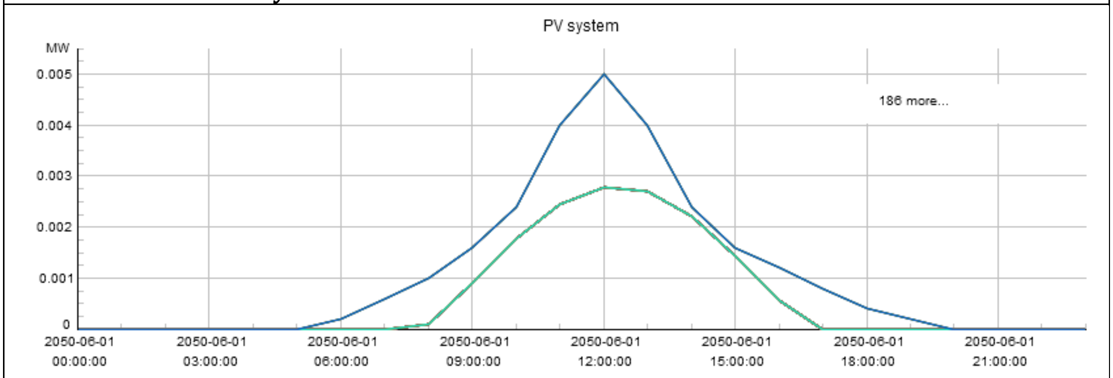
2050 - Winter - Large Centralised and Decentralised Battery



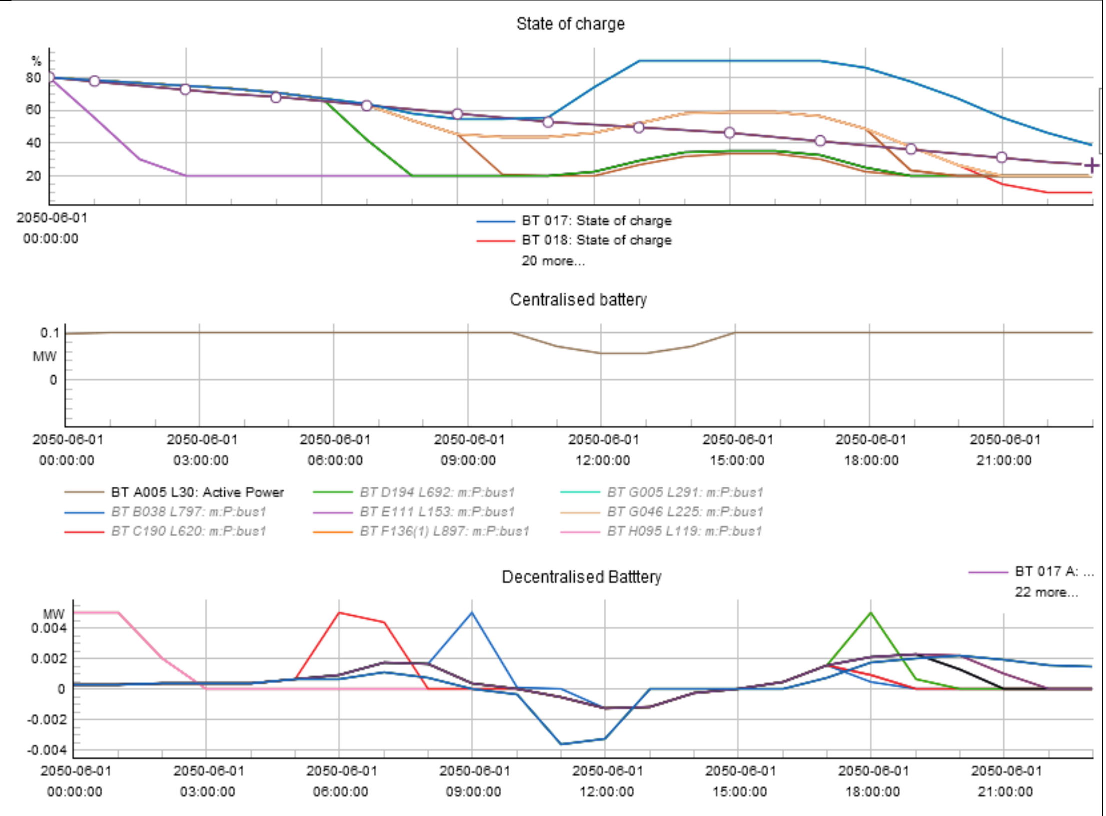
Percentage of transformer stress in Winter, 2050 without Large Centralised and Decentralised Battery



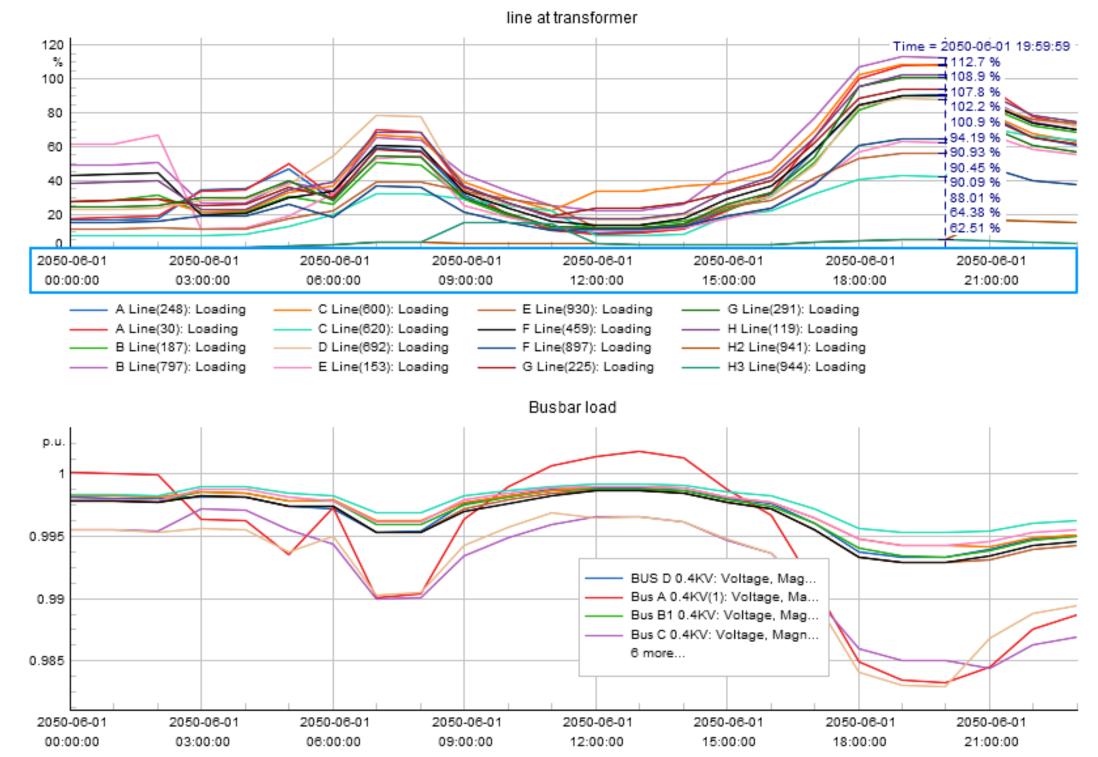
Percentage of transformer stress in Winter, 2050 with Large Centralised and Decentralised Battery



PV generation in Winter, 2050



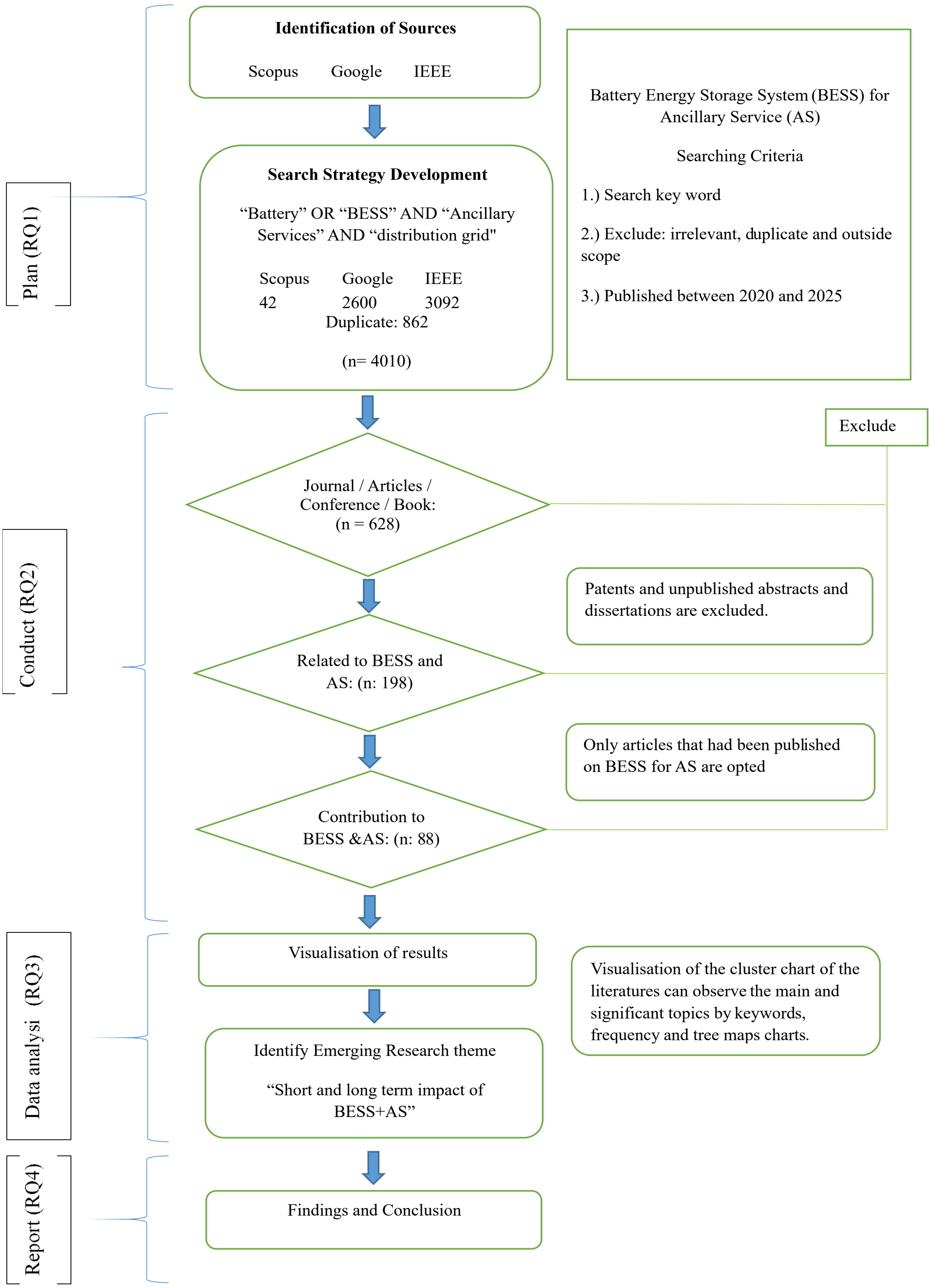
SOC, and active power of Large Centralised and Decentralised Battery in Winter, 2050



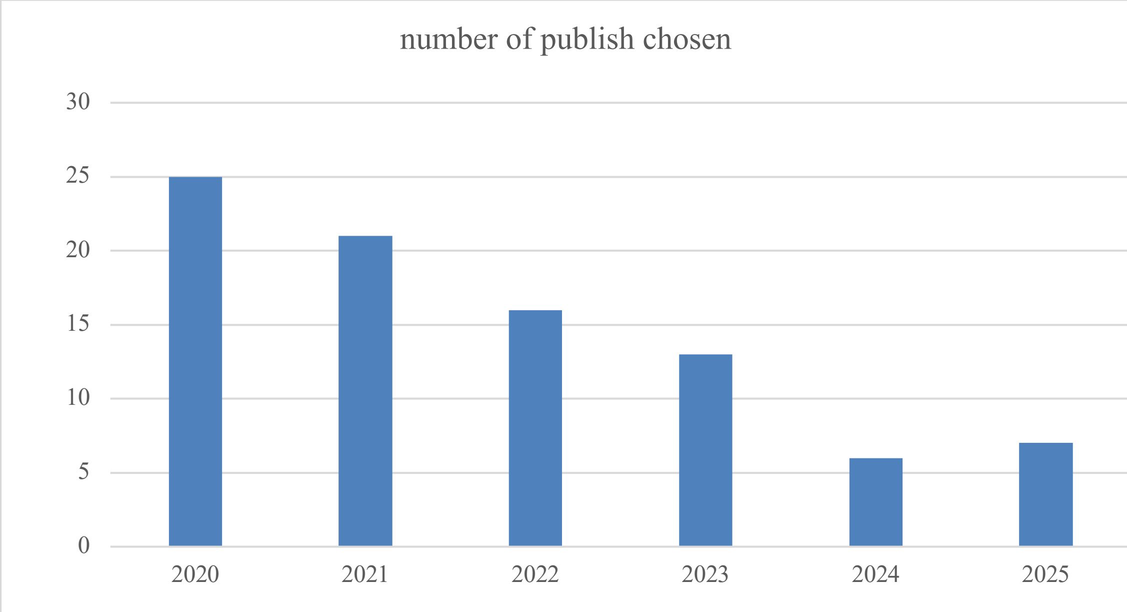
Line and Bus loading in Winter, 2050 with Large Centralised and Decentralised Battery

Line and Bus Mapping in Winter, 2050 with Large Centralised Battery and Decentralised Battery

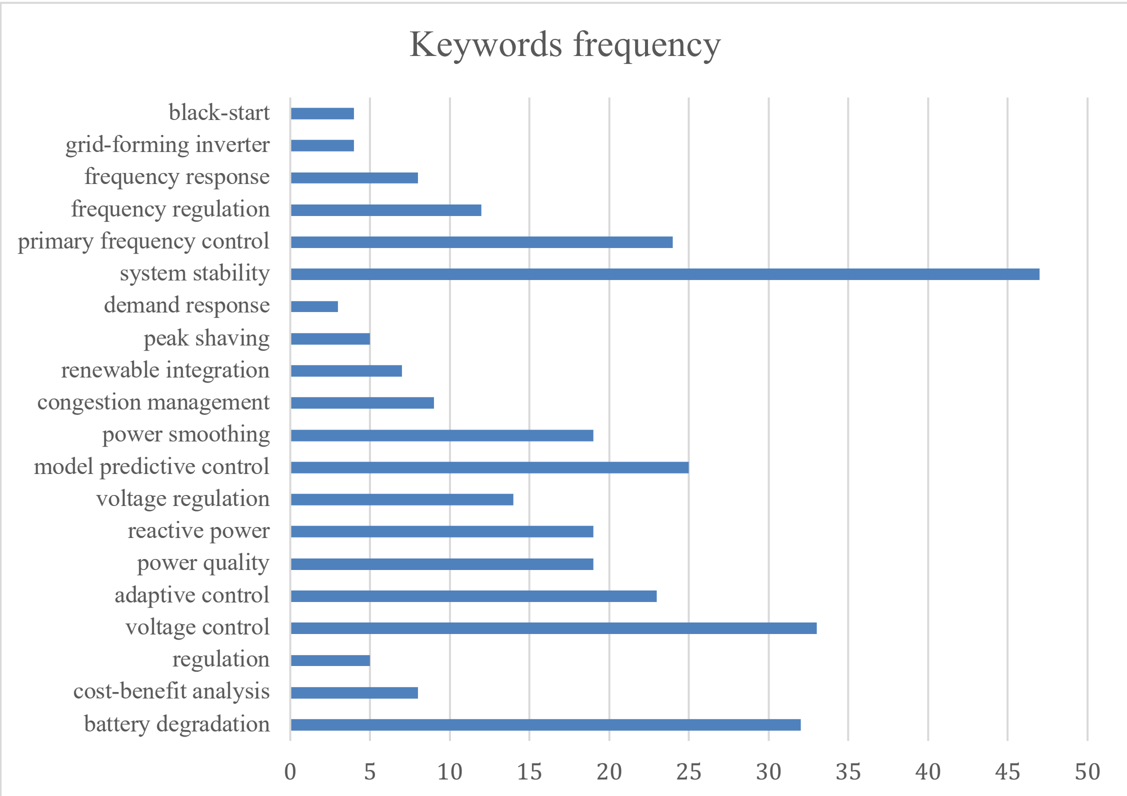
Literature review



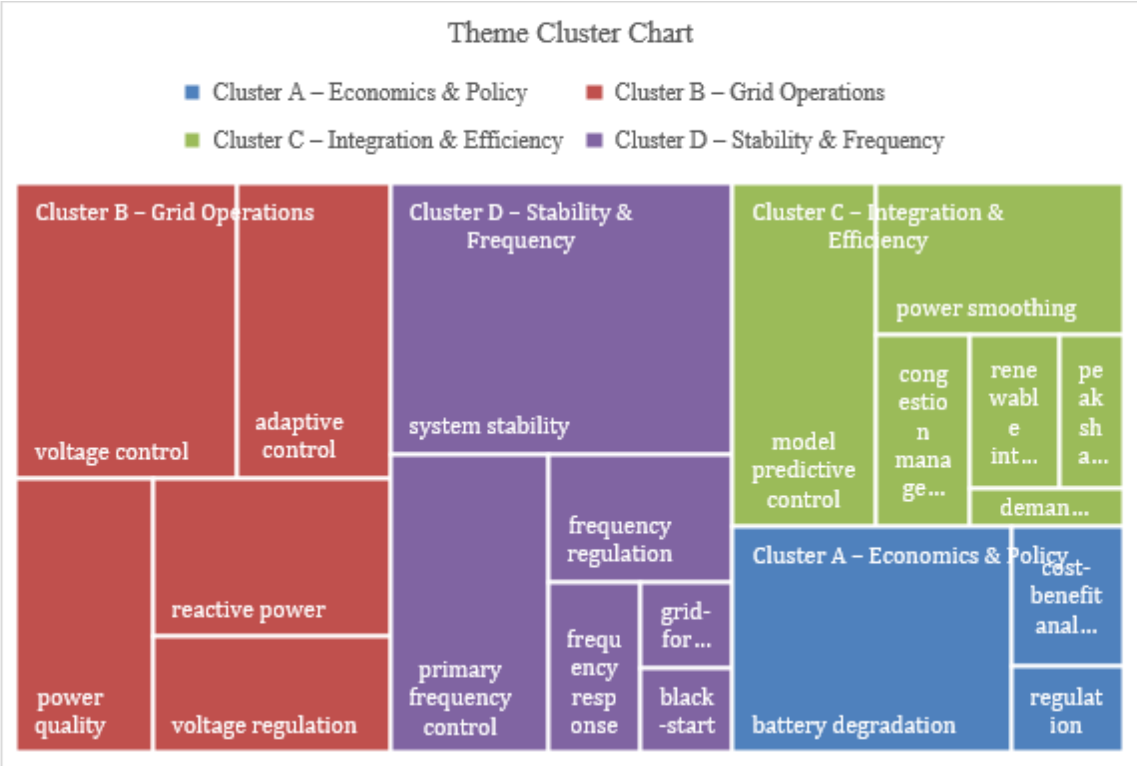
The flow of the PRIMAS diagram of BESS and AS



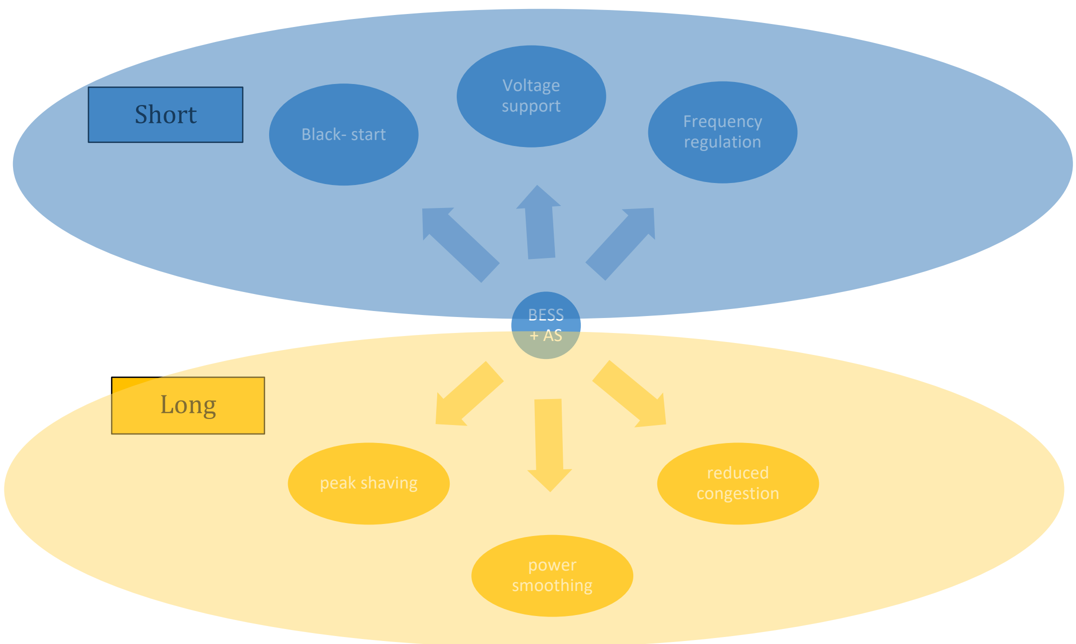
Number of published choices



Keyword frequency



Theme Cluster Chart



Ancillary services types for distribution grids.