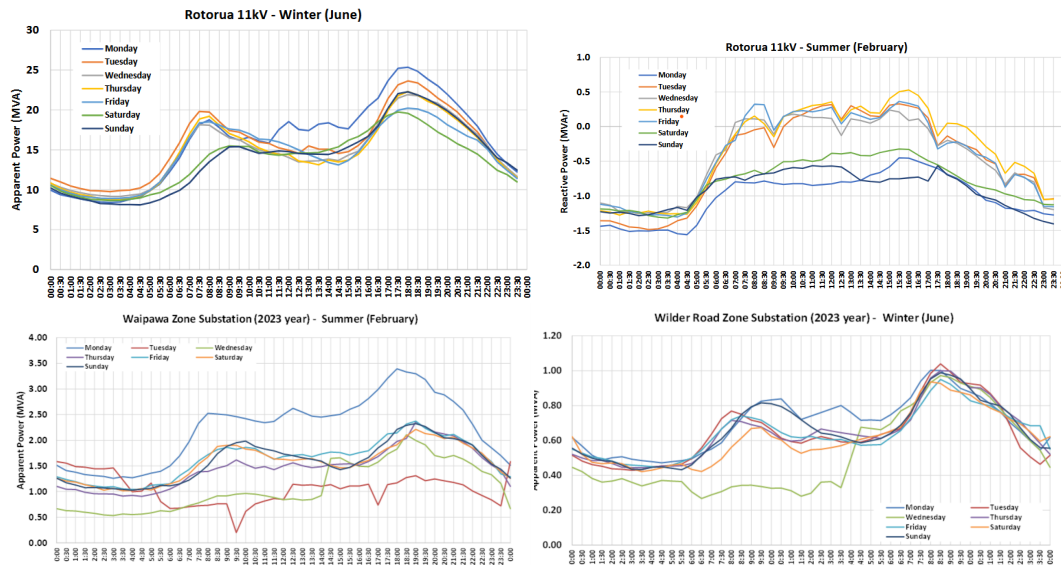




Technical evaluation of retrofitting solid-state transformers and battery energy storage systems for peak shaving within the footprint of ageing line-frequency distribution transformers in Aotearoa New Zealand

Supplementary Material

Data collection samples for demand curves



Sample of curves used to estimate demand curves



Simulated demand curves (swapping options original, Full Reverse (2-11)Block Swap (2-6 ↔ 7-11))

Storage(kWh): Storage gained , **P_Shav(kW):** limited loading of transformer, **P_En(kW)l:** maximum loading of transformer at which BESS is allowed to charge, **P_Chg(kW):** maximum allowed charging power allowed, **P_Dis(kW)** maximum power allowed from BESS



Transformer (Tx)

Scenario 1

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_001752

SST: LC-Avg (0.5375 kVA/L)

Storage: LD-Low (0.0200 kWh/L)

Actual Trans. Loading : 1.08

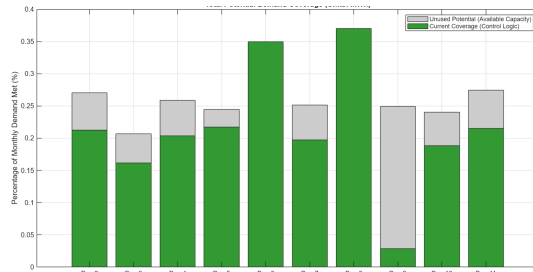
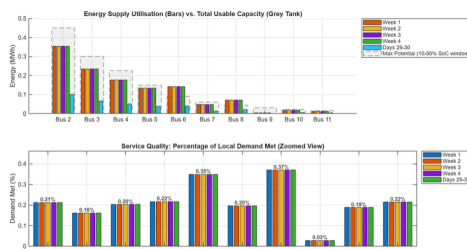
Load limiting of Tx as % of Its Capacity (shaving): 95.00

Load of Tx as % and below allows for ESS charging: 85.00

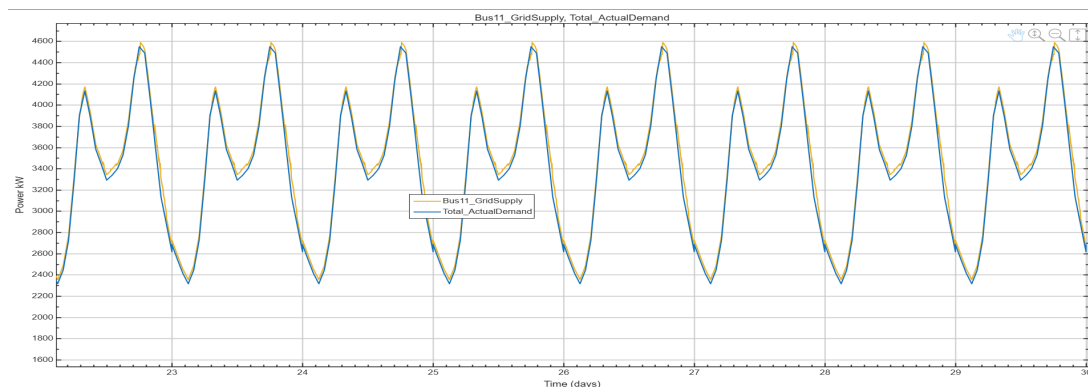
% of Tx max used for charging ESS: 10.00

BUS ALLOCATION

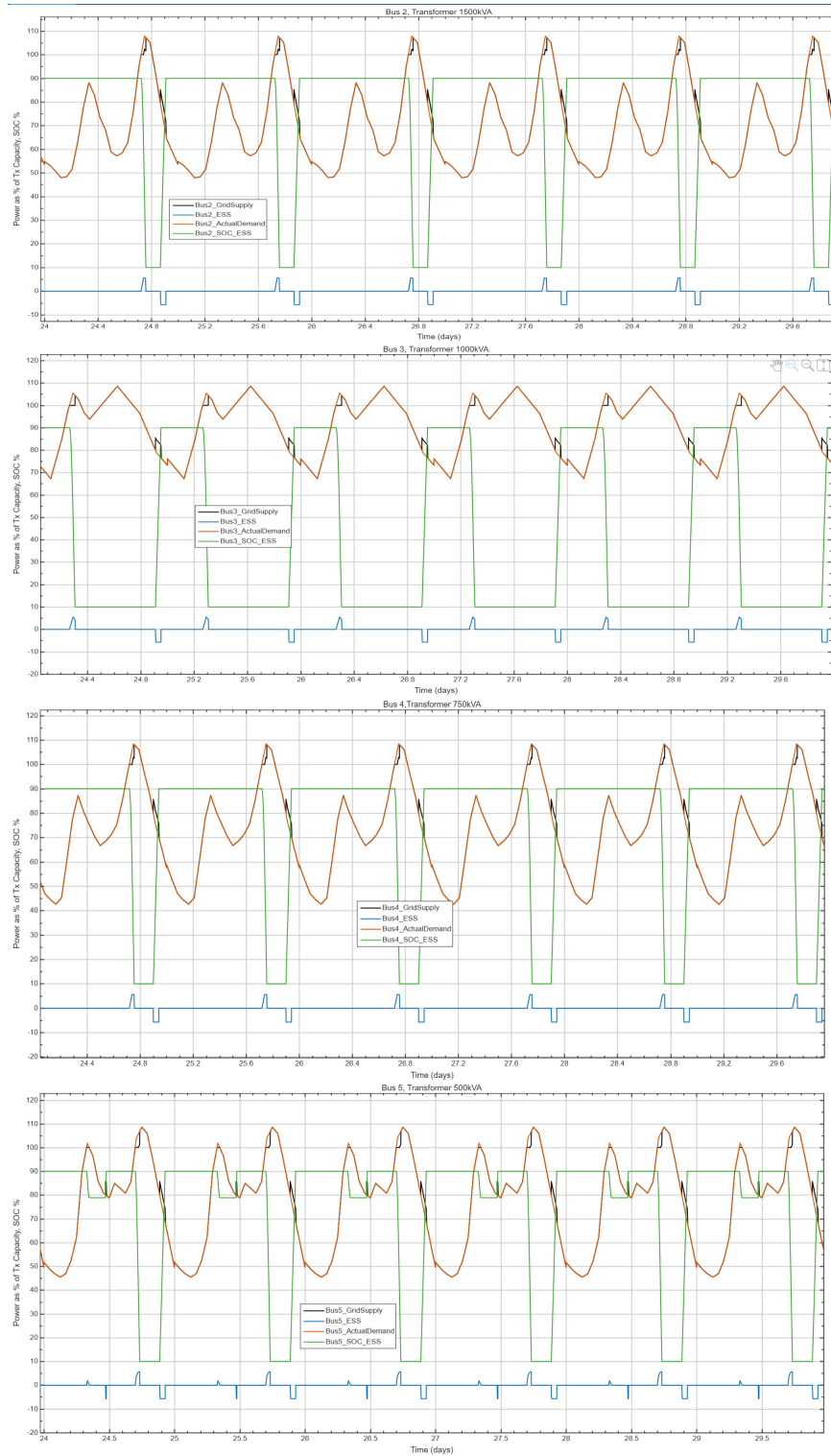
Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	80.5497	150.0000	80.5497
Bus3	53.6998	100.0000	53.6998
Bus4	40.2748	75.0000	40.2748
Bus5	26.8499	50.0000	26.8499
Bus6	16.1099	30.0000	16.1099
Bus7	10.7400	20.0000	10.7400
Bus8	8.0550	15.0000	8.0550
Bus9	5.3700	10.0000	5.3700
Bus10	4.0275	7.5000	4.0275
Bus11	2.6850	5.0000	2.6850
TOTAL STORAGE: 248.3615 kWh			

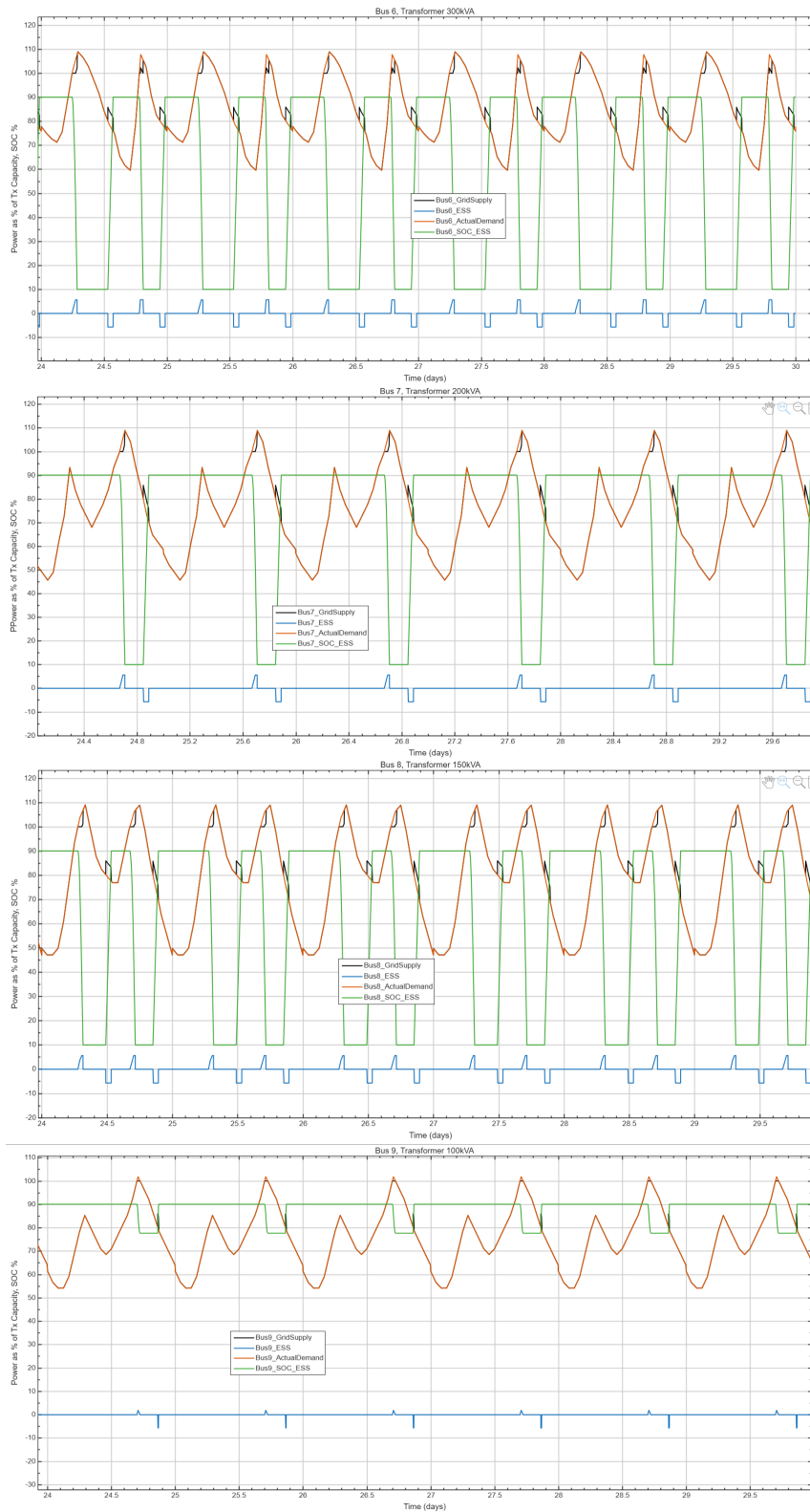


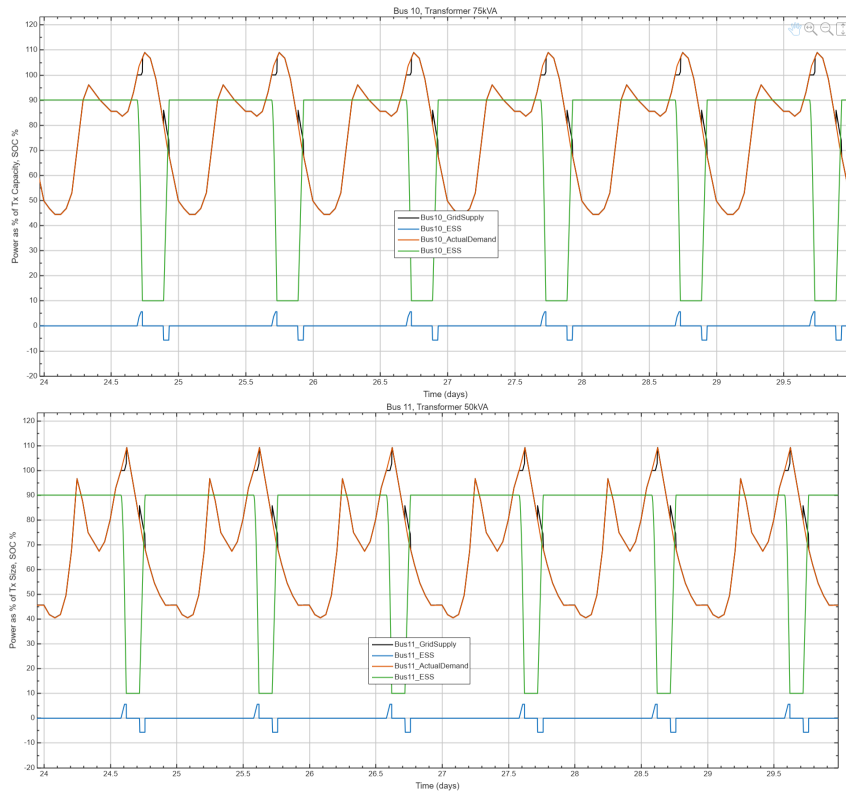
Gives the statistics on the limitations for the given storage technology and constraint charging



Feeder 11 kV for scenario 1 results







Results for the 10 transformer locations for scenario 1

Scenario 2

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_122109

SST: MC (1.5600 kVA/L)

Storage: LD-Low (0.0200 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 95.00

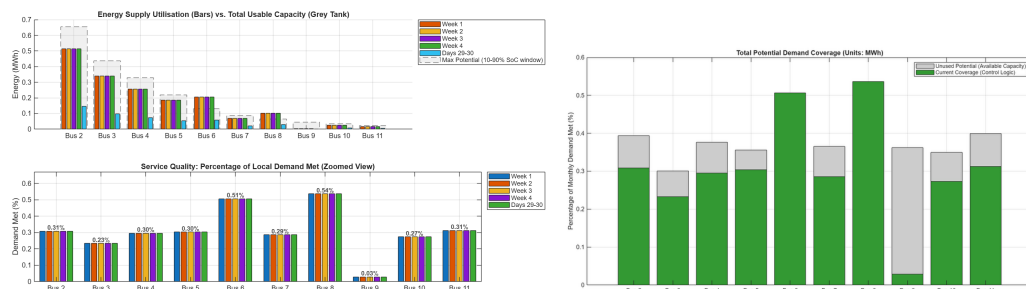
Load of Tx as % and below allows for ESS charging: 85.00

% of Tx max used for charging ESS: 10.00

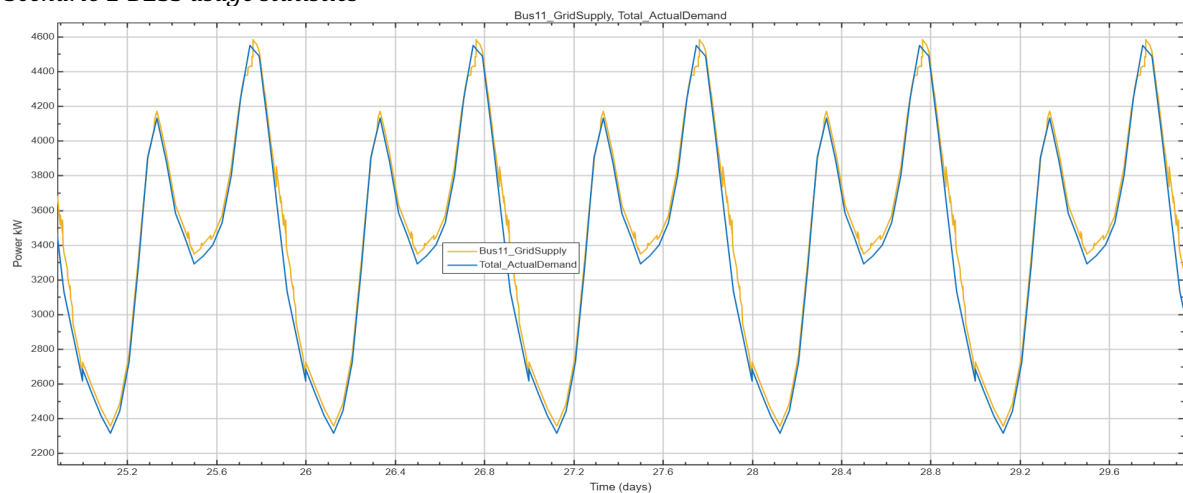
BUS ALLOCATION

Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	117.1329	150.0000	117.1329
Bus3	78.0886	100.0000	78.0886
Bus4	58.5664	75.0000	58.5664
Bus5	39.0443	50.0000	39.0443
Bus6	23.4266	30.0000	23.4266
Bus7	15.6177	20.0000	15.6177
Bus8	11.7133	15.0000	11.7133
Bus9	7.8089	10.0000	7.8089
Bus10	5.8566	7.5000	5.8566
Bus11	3.9044	5.0000	3.9044

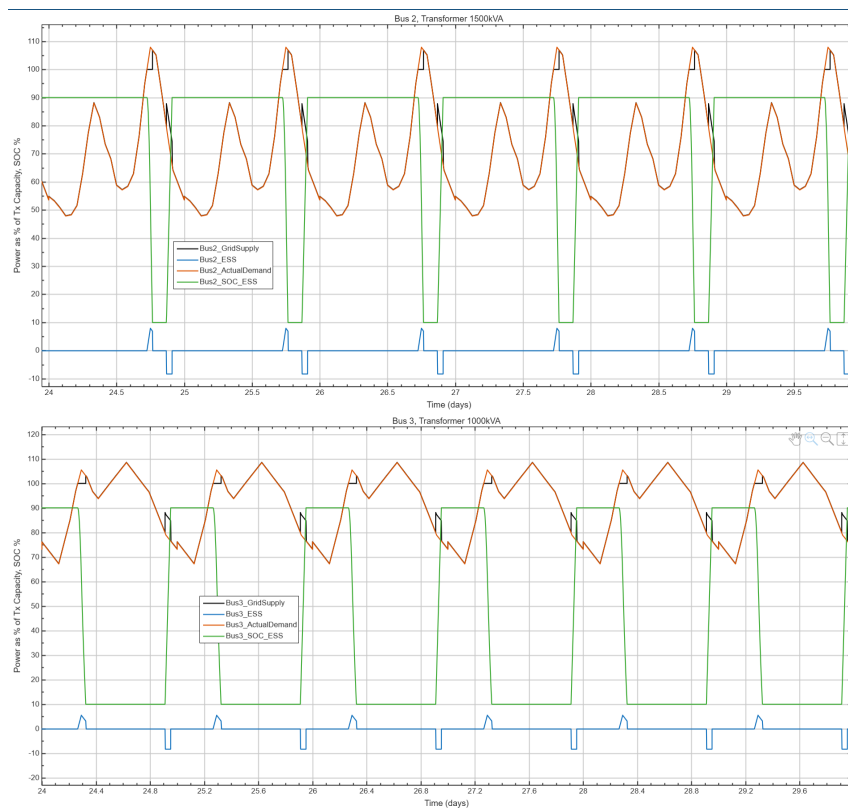
TOTAL STORAGE: 361.1597 kWh

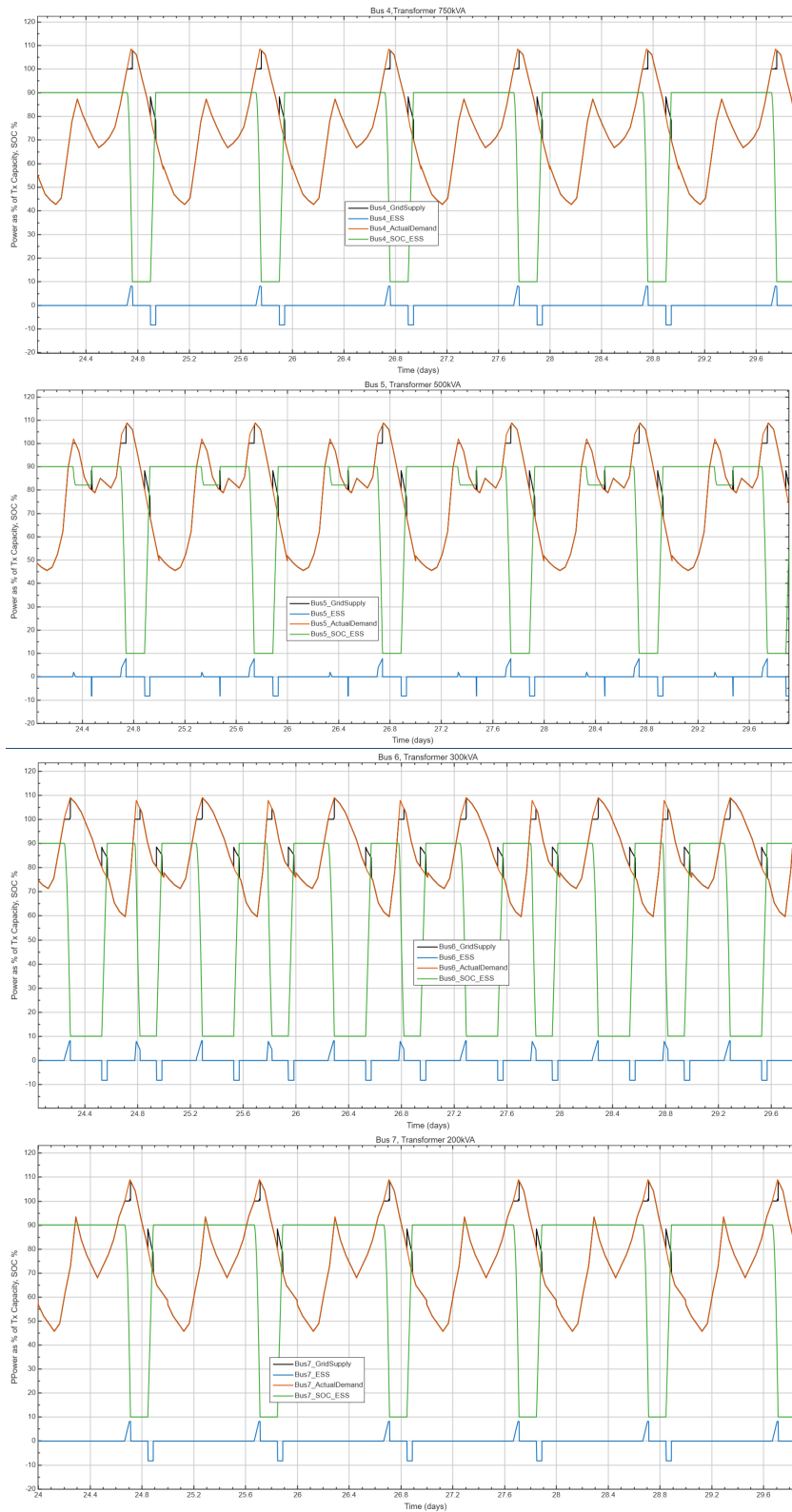


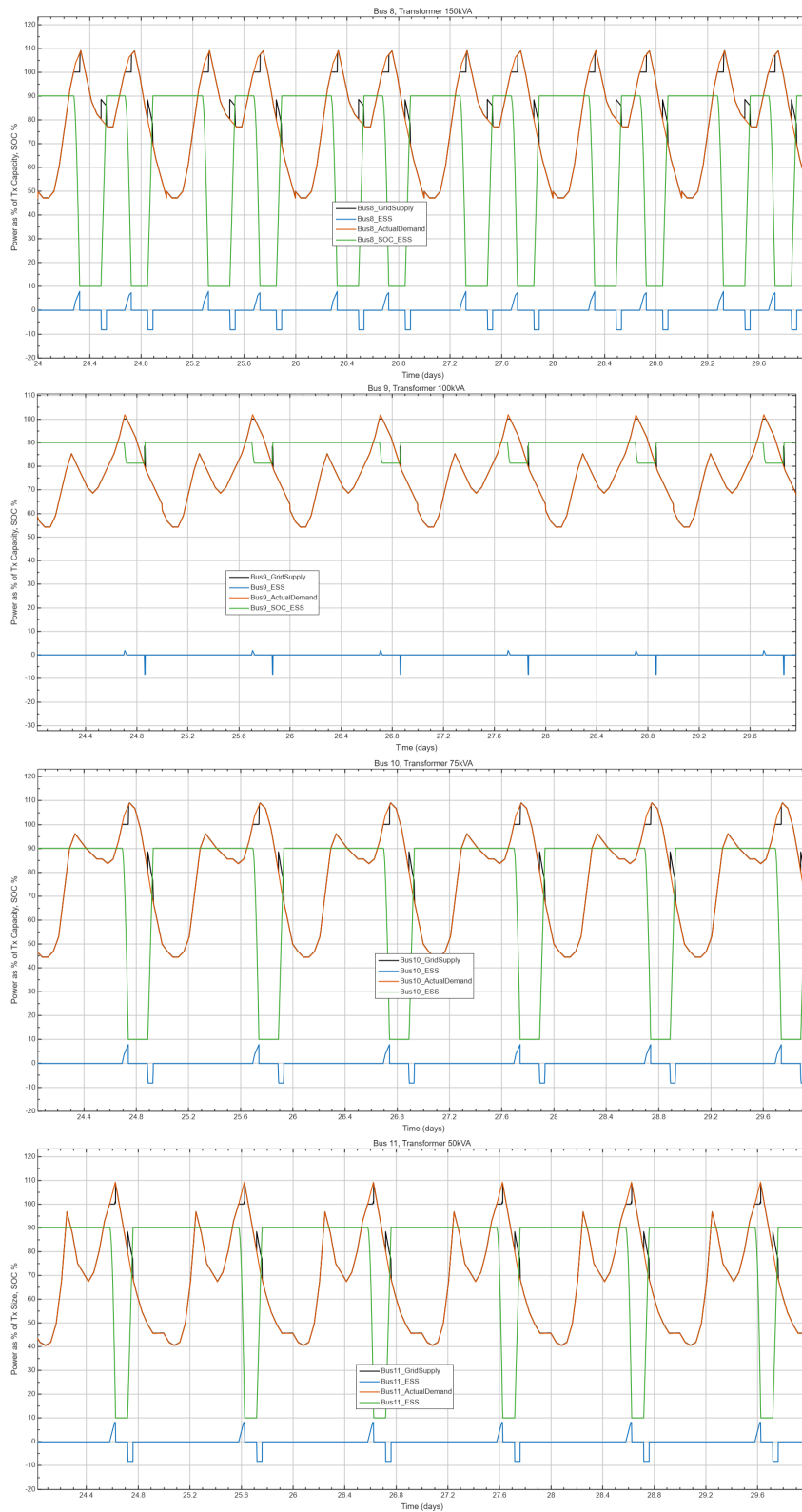
Scenario 2 BESS usage statistics



Scenario 2 11 kV feeder







Scenario 2 transformer points results



Scenario 3

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_134549

SST: MC (1.5600 kVA/L)

Storage: LD-High (0.0800 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 95.00

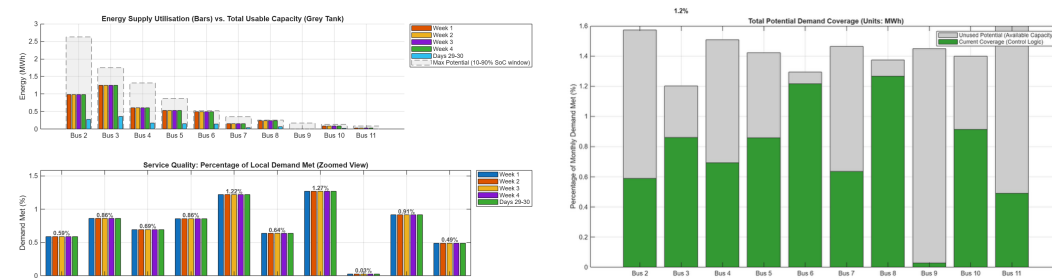
Load of Tx as % and below allows for ESS charging: 85.00

% of Tx max used for charging ESS: 10.00

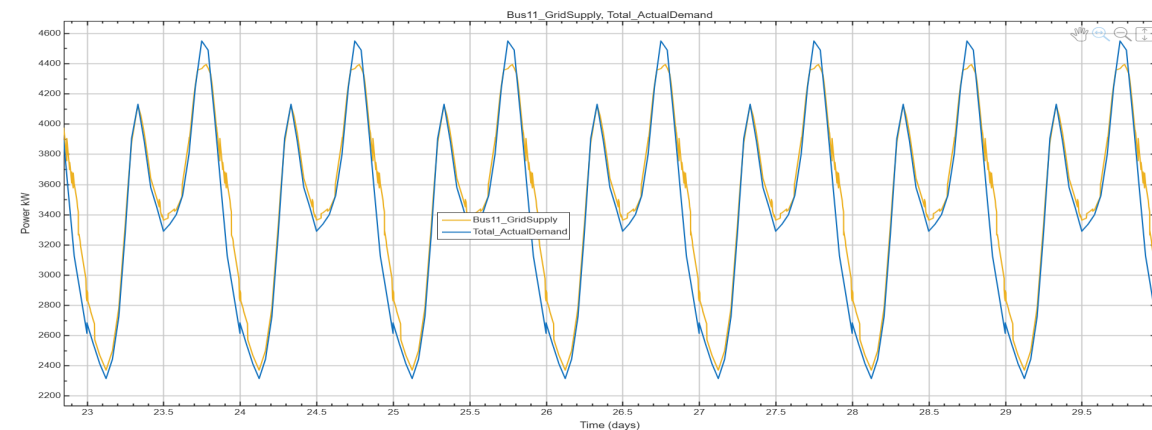
BUS ALLOCATION

Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	468.5315	150.0000	468.5315
Bus3	312.3543	100.0000	312.3543
Bus4	234.2657	75.0000	234.2657
Bus5	156.1772	50.0000	156.1772
Bus6	93.7063	30.0000	93.7063
Bus7	62.4709	20.0000	62.4709
Bus8	46.8531	15.0000	46.8531
Bus9	31.2354	10.0000	31.2354
Bus10	23.4266	7.5000	23.4266
Bus11	15.6177	5.0000	15.6177

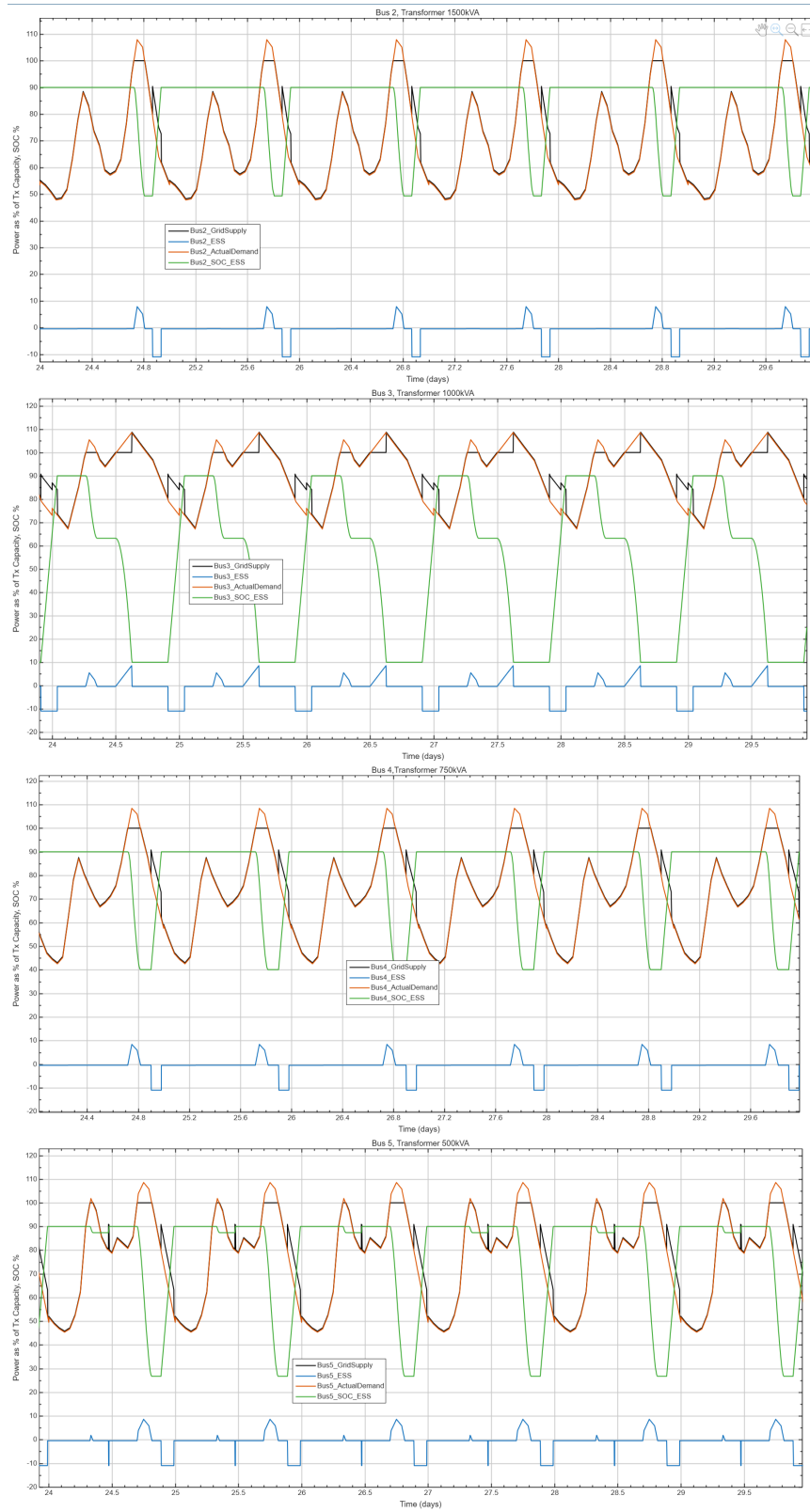
TOTAL STORAGE: 1444.6387 kWh

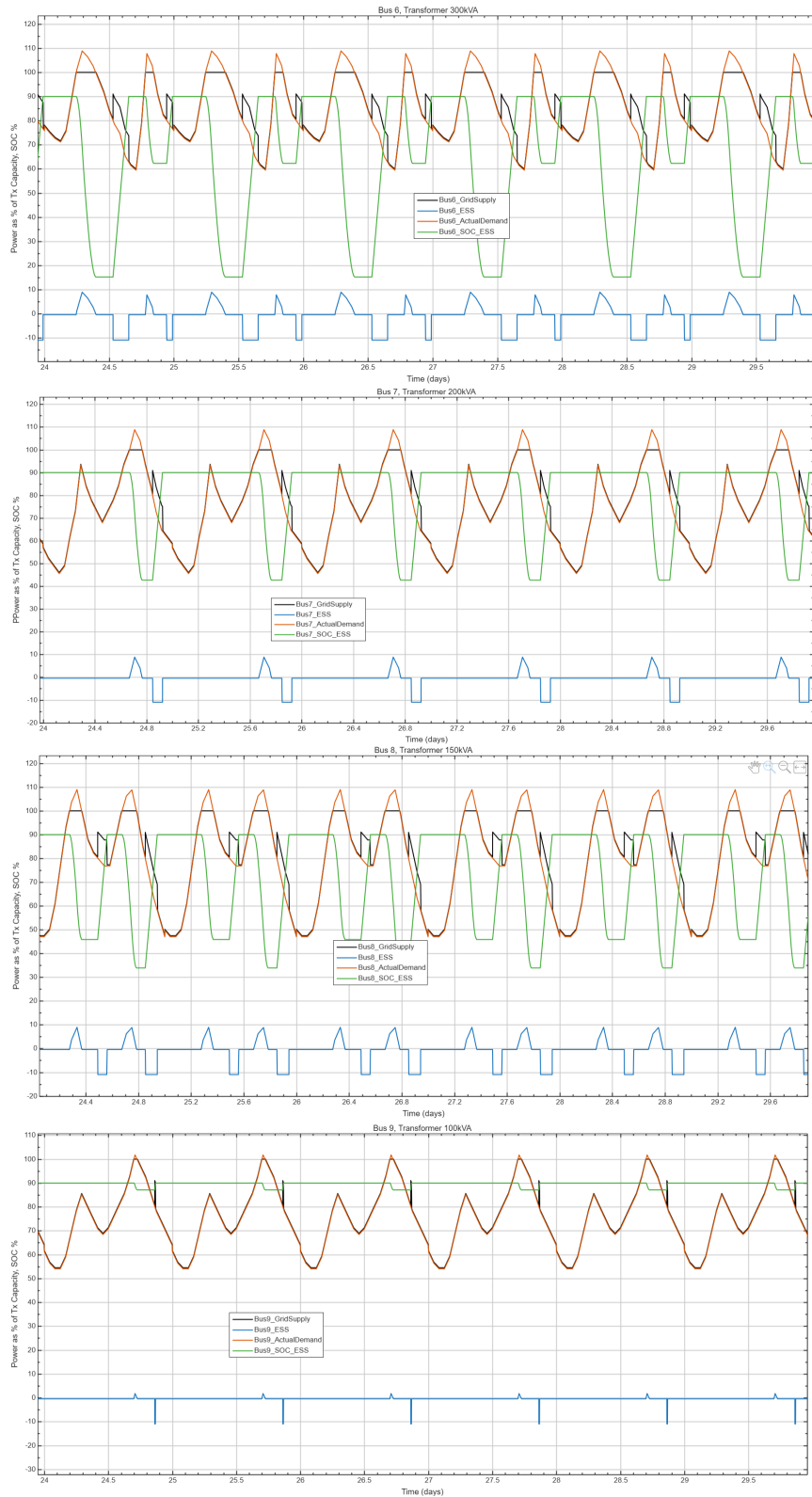


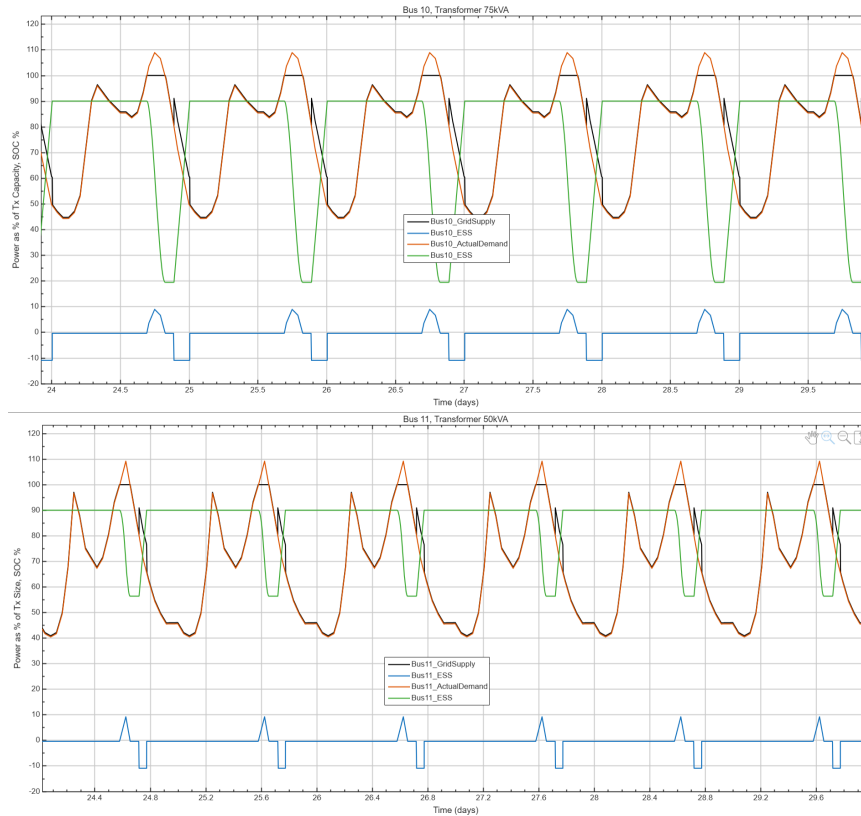
Statistics on storage usage scenario 3



Main feeder scenario 3 results







Scenario 3 results

Scenario 4

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_144927

SST: MC (1.5600 kVA/L)

Storage: MD-Low (0.1500 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 95.00

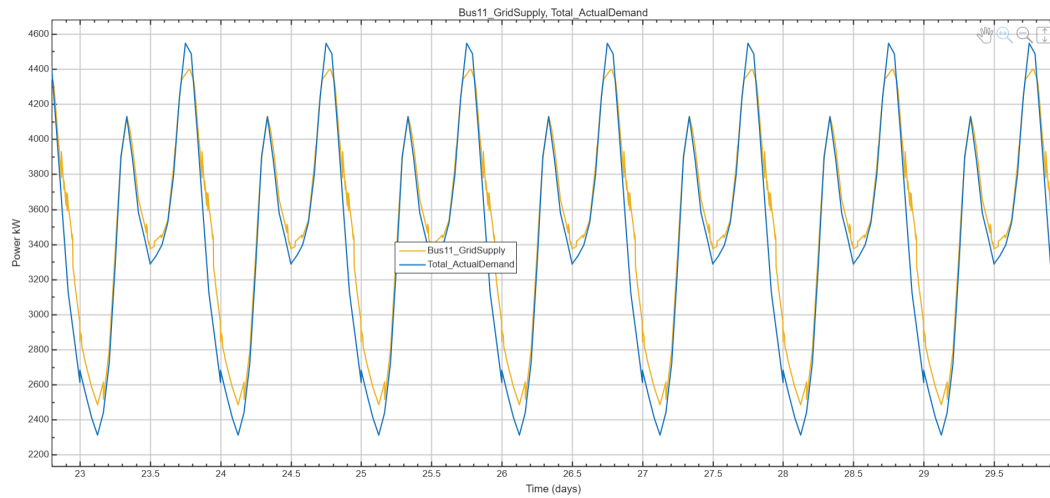
Load of Tx as % and below allows for ESS charging: 85.00

% of Tx max used for charging ESS: 10.00

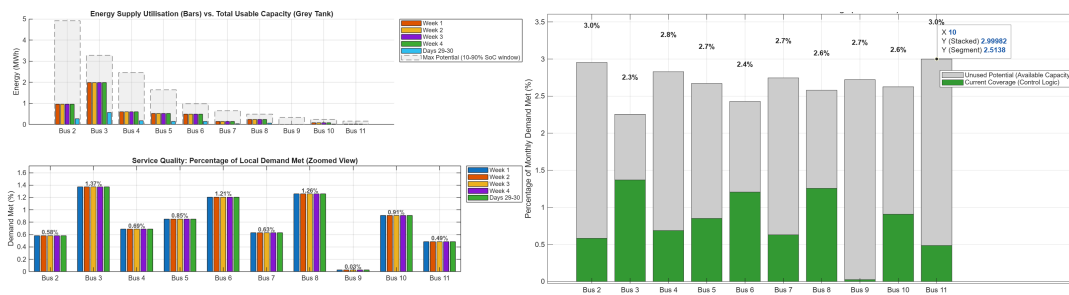
BUS ALLOCATION

Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	878.4965	150.0000	878.4965
Bus3	585.6643	100.0000	585.6643
Bus4	439.2483	75.0000	439.2483
Bus5	292.8322	50.0000	292.8322
Bus6	175.6993	30.0000	175.6993
Bus7	117.1329	20.0000	117.1329
Bus8	87.8497	15.0000	87.8497
Bus9	58.5664	10.0000	58.5664
Bus10	43.9248	7.5000	43.9248
Bus11	29.2832	5.0000	29.2832

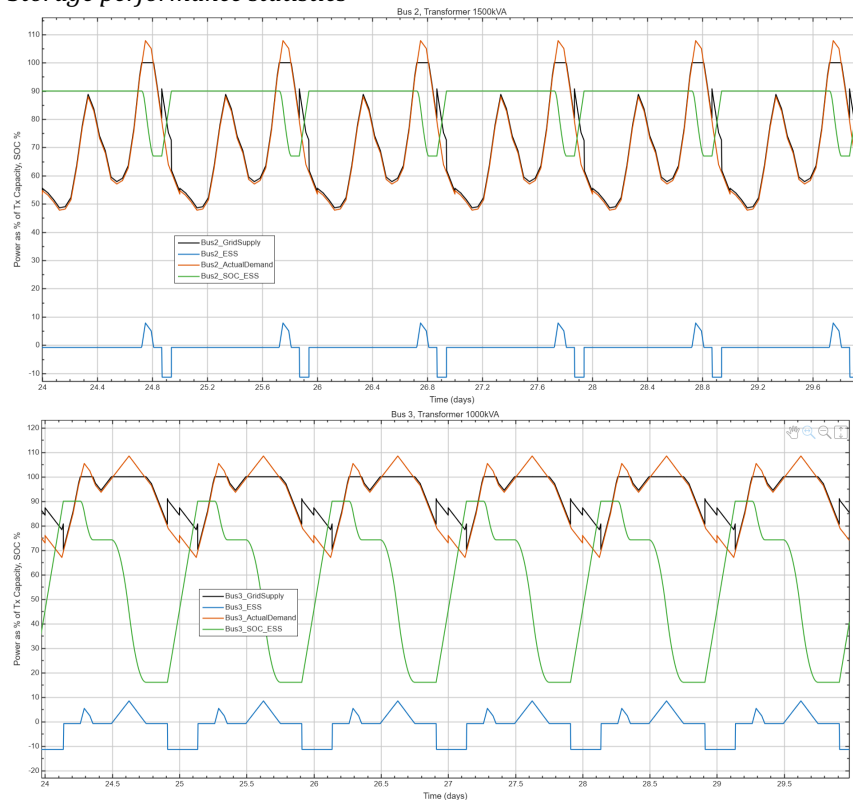
TOTAL STORAGE: 2708.6976 kWh

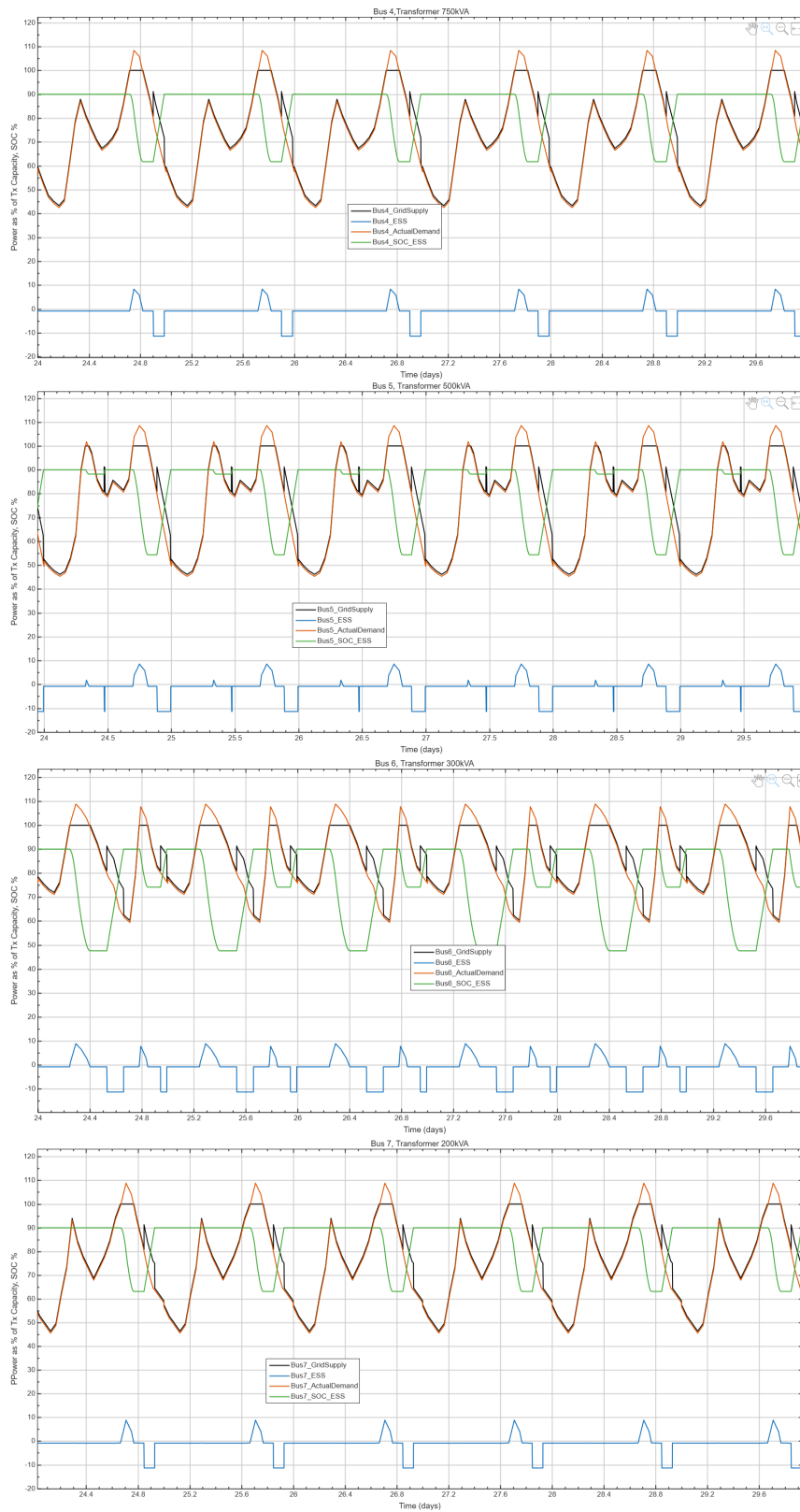


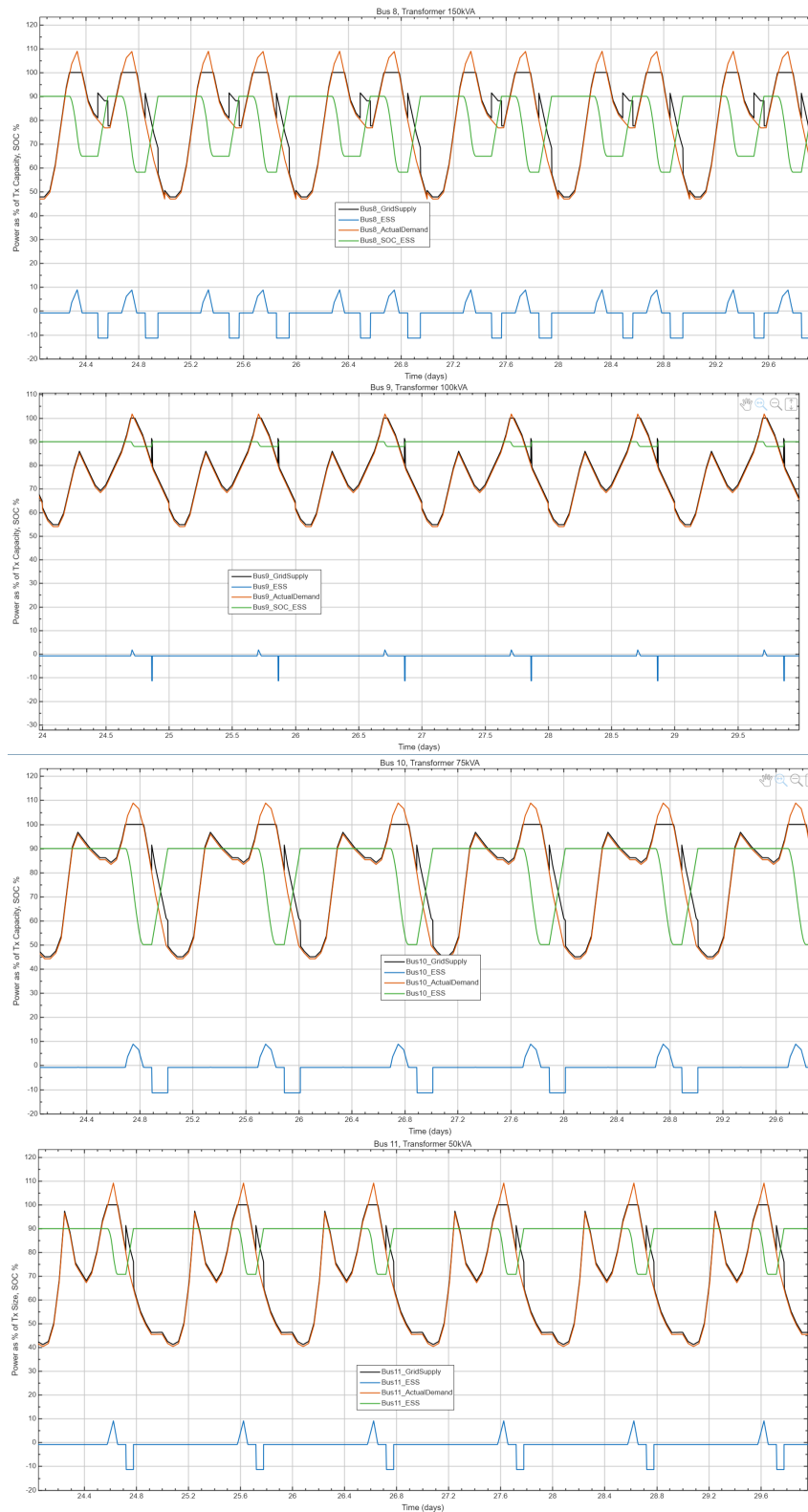
11 kV feeder results



Storage performance statistics







Scenario 4 results



Scenario 5

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_144927

SST: MC (1.5600 kVA/L)

Storage: MD-Low (0.1500 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 90.00

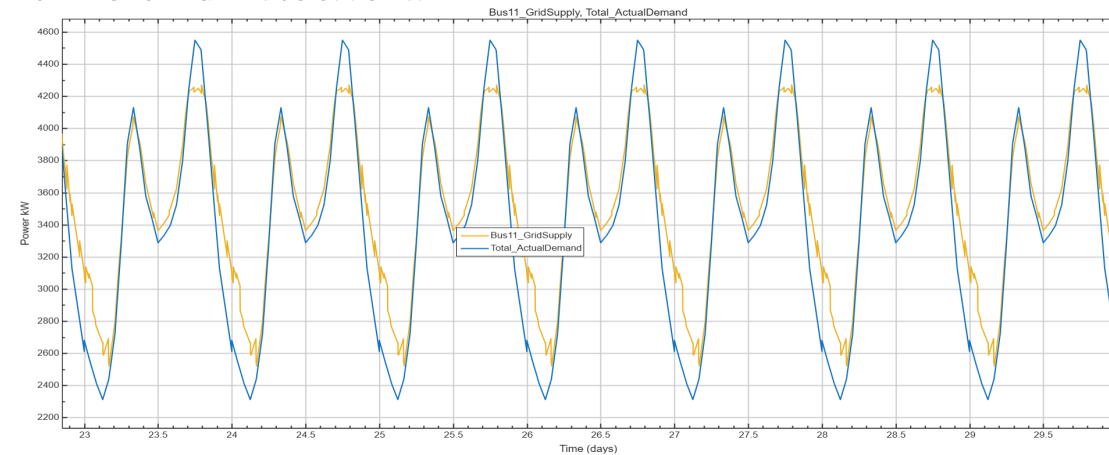
Load of Tx as % and below allows for ESS charging: 80.00

% of Tx max used for charging ESS: 10.00

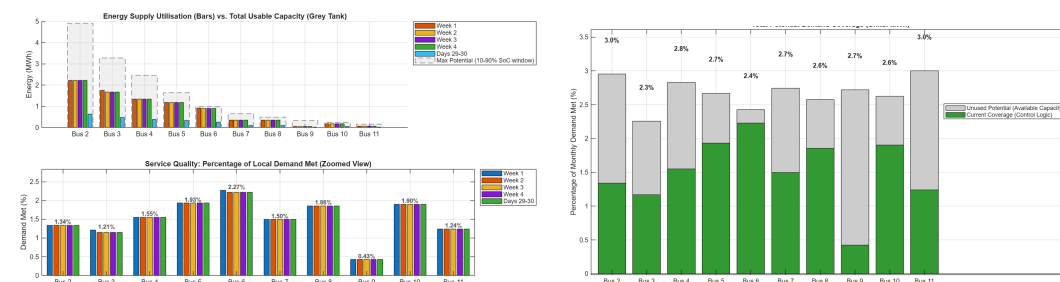
BUS ALLOCATION

Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	878.4965	150.0000	878.4965
Bus3	585.6643	100.0000	585.6643
Bus4	439.2483	75.0000	439.2483
Bus5	292.8322	50.0000	292.8322
Bus6	175.6993	30.0000	175.6993
Bus7	117.1329	20.0000	117.1329
Bus8	87.8497	15.0000	87.8497
Bus9	58.5664	10.0000	58.5664
Bus10	43.9248	7.5000	43.9248
Bus11	29.2832	5.0000	29.2832

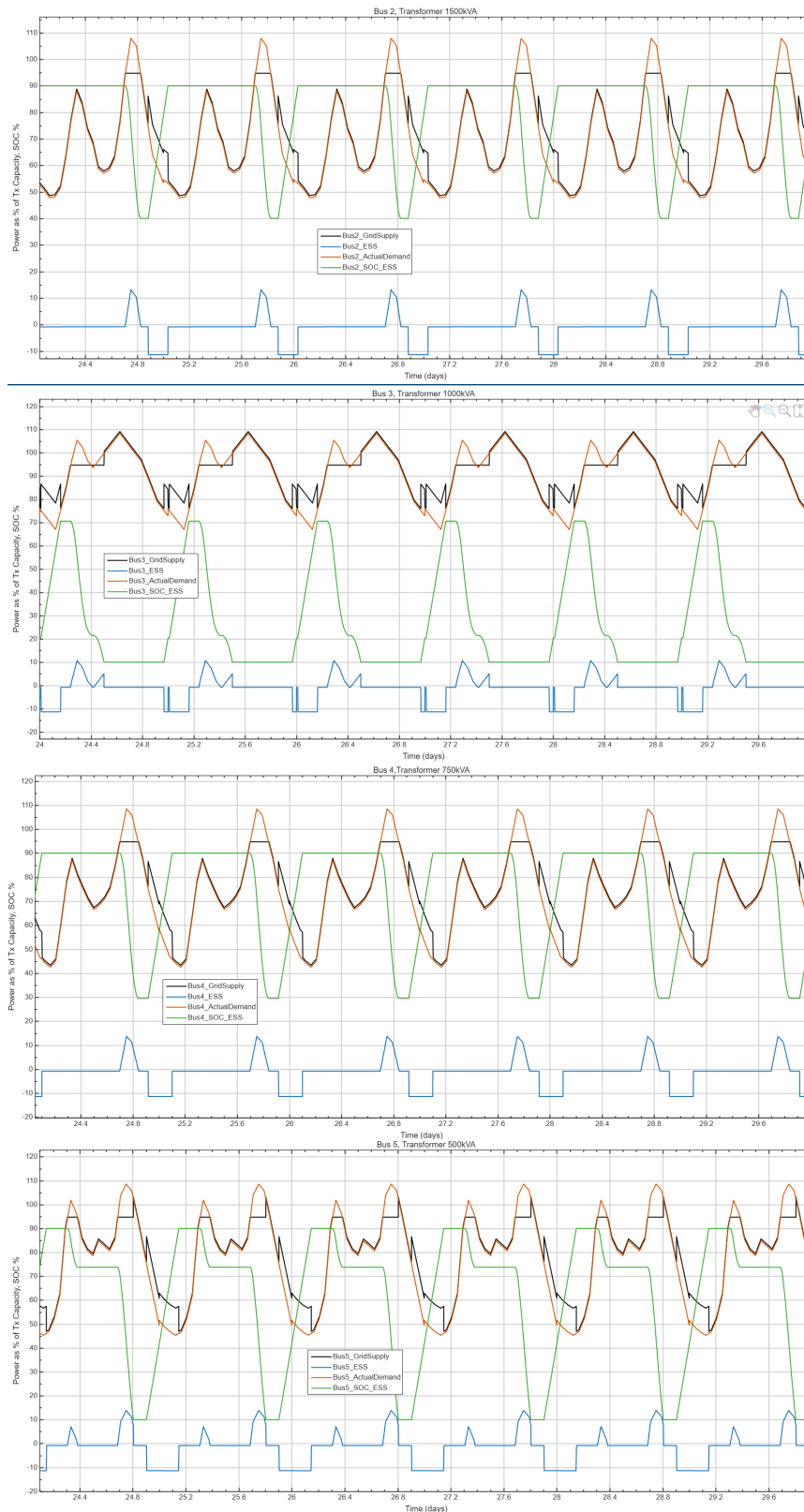
TOTAL STORAGE: 2708.6976 kWh

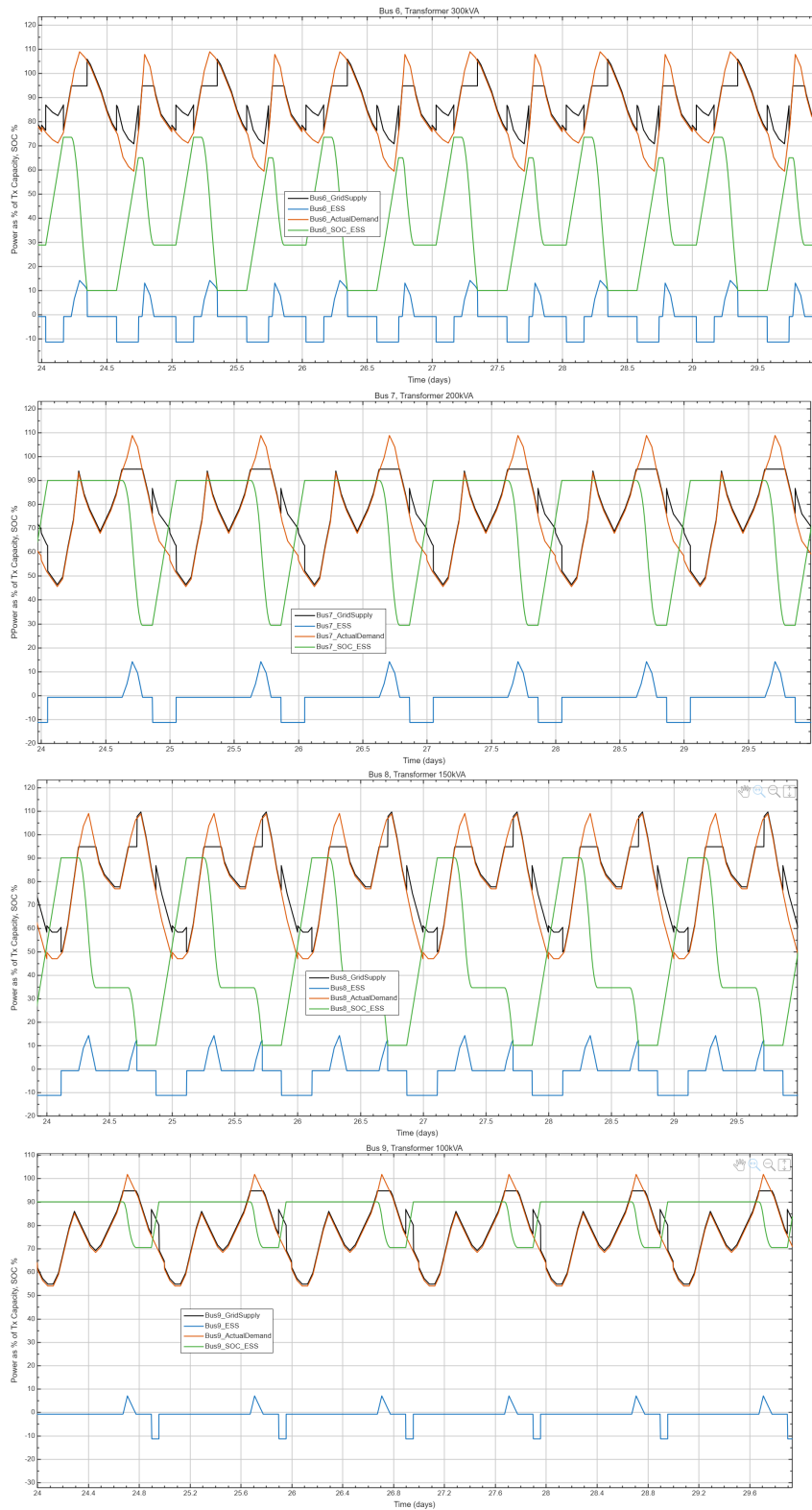


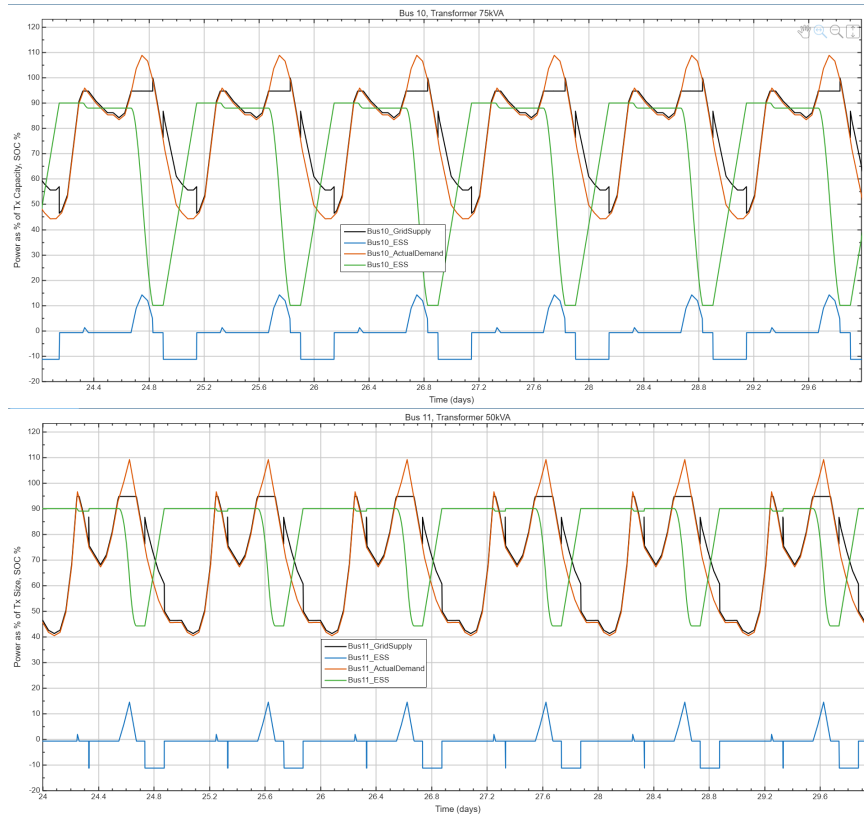
11 kV feeder results



Statistics on storage for scenario 5







Scenario 4 results

Scenario 5

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_154557

SST: MC (1.5600 kVA/L)

Storage: MD-High (0.3500 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 90.00

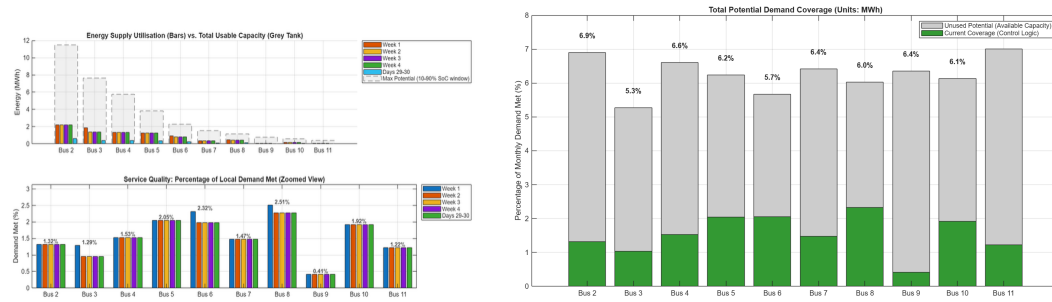
Load of Tx as % and below allows for ESS charging: 80.00

% of Tx max used for charging ESS: 10.00

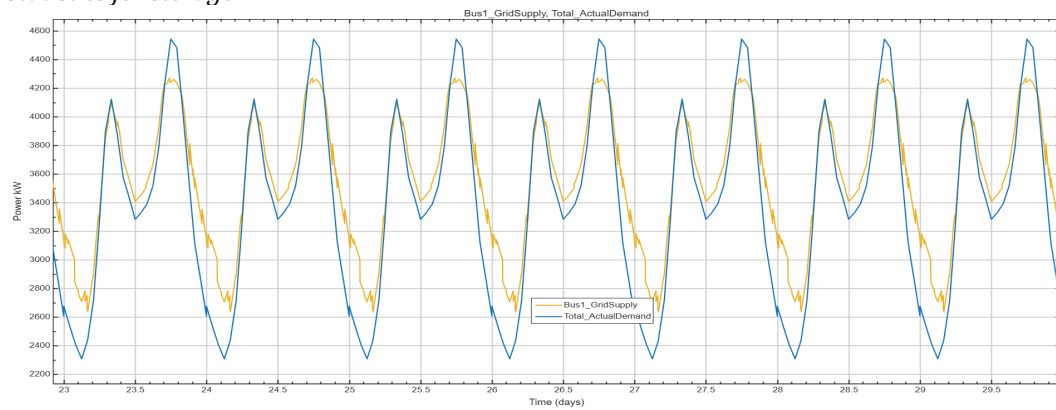
BUS ALLOCATION

Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	2049.8252	150.0000	2049.8252
Bus3	1366.5501	100.0000	1366.5501
Bus4	1024.9126	75.0000	1024.9126
Bus5	683.2751	50.0000	683.2751
Bus6	409.9650	30.0000	409.9650
Bus7	273.3100	20.0000	273.3100
Bus8	204.9825	15.0000	204.9825
Bus9	136.6550	10.0000	136.6550
Bus10	102.4913	7.5000	102.4913
Bus11	68.3275	5.0000	68.3275

TOTAL STORAGE: 6320.2943 kWh

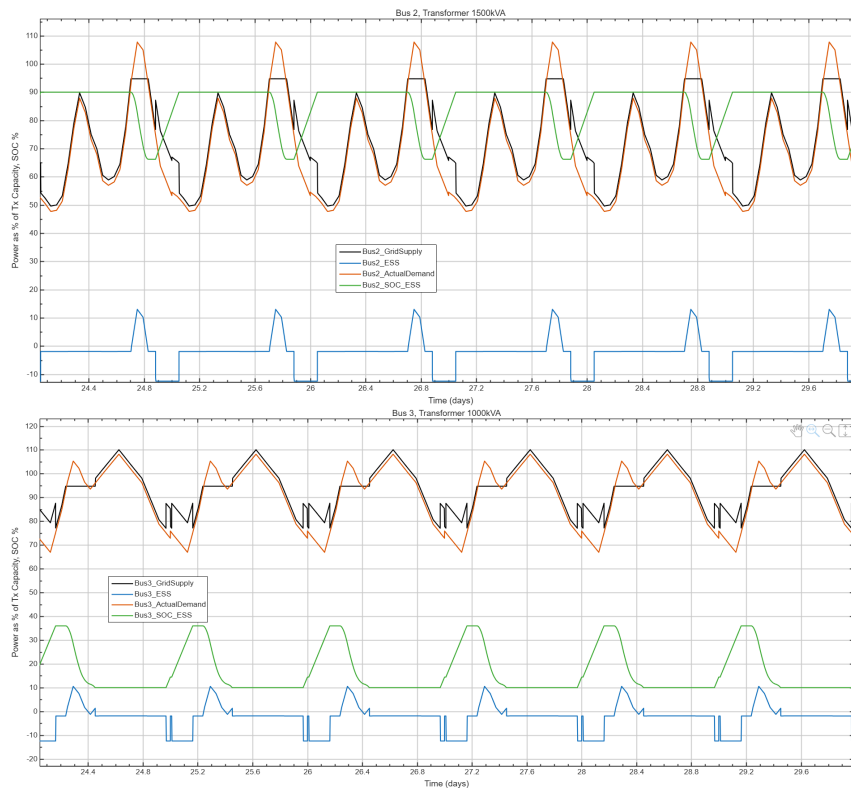


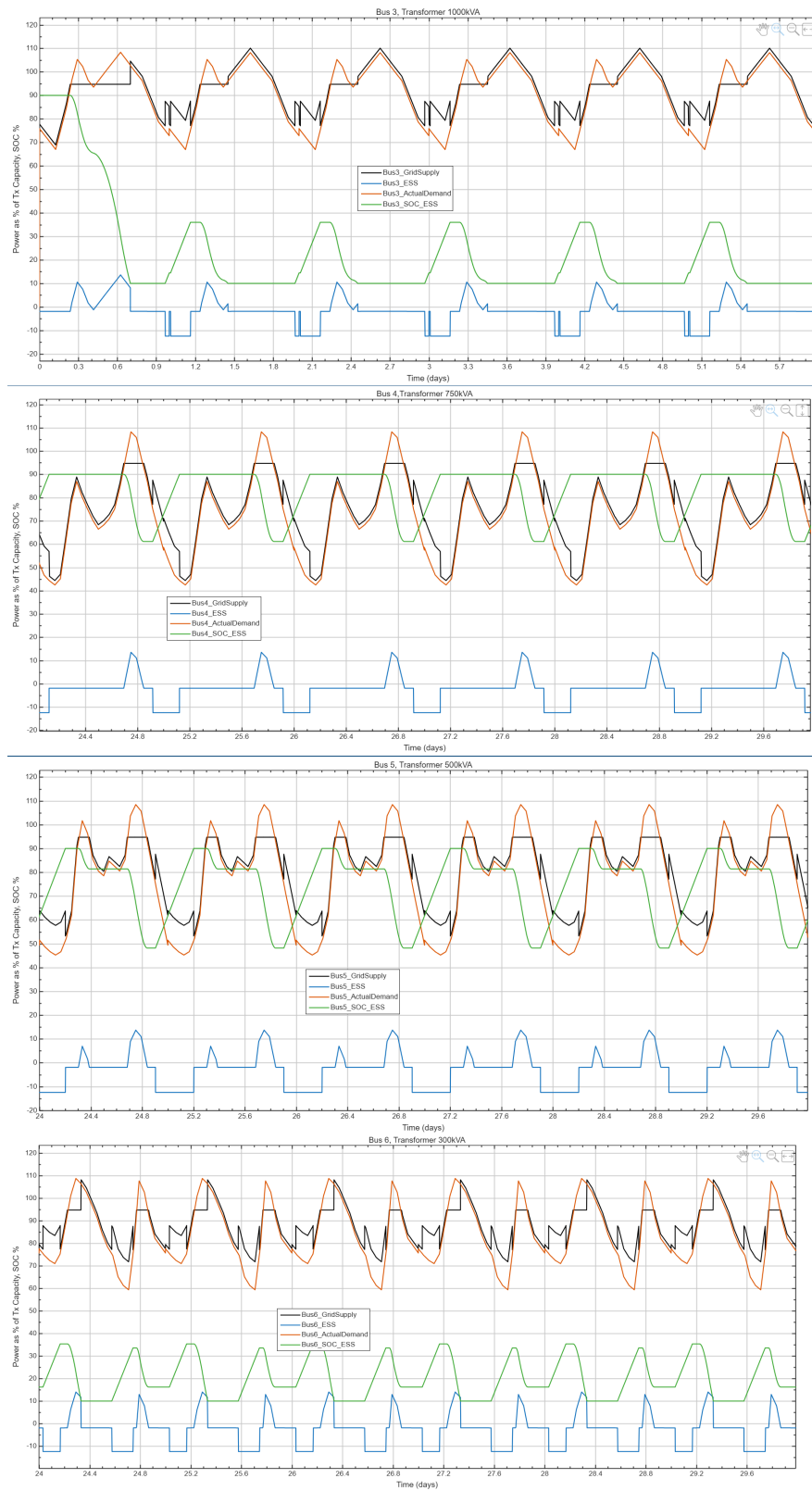
Statistics for storage

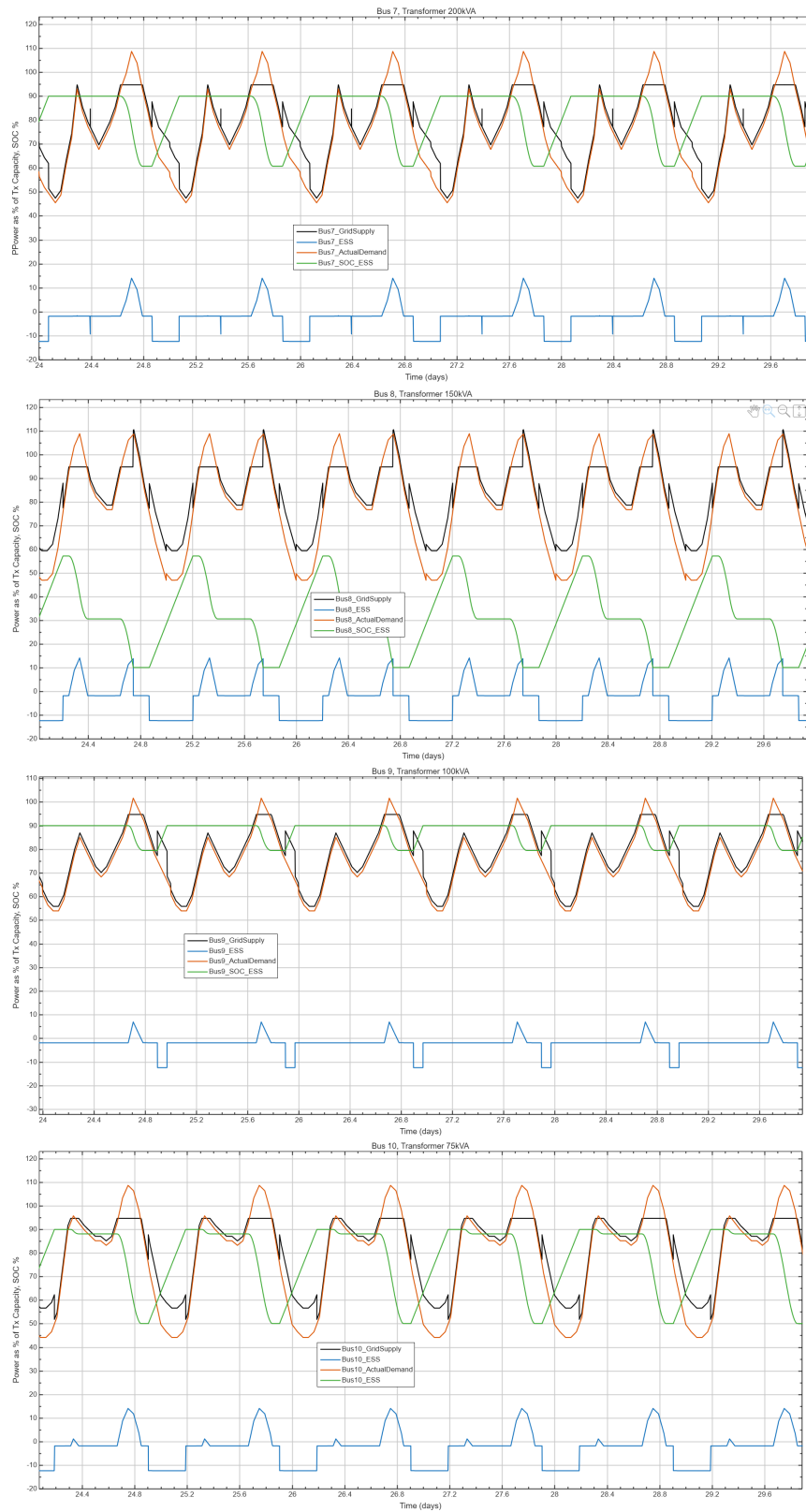


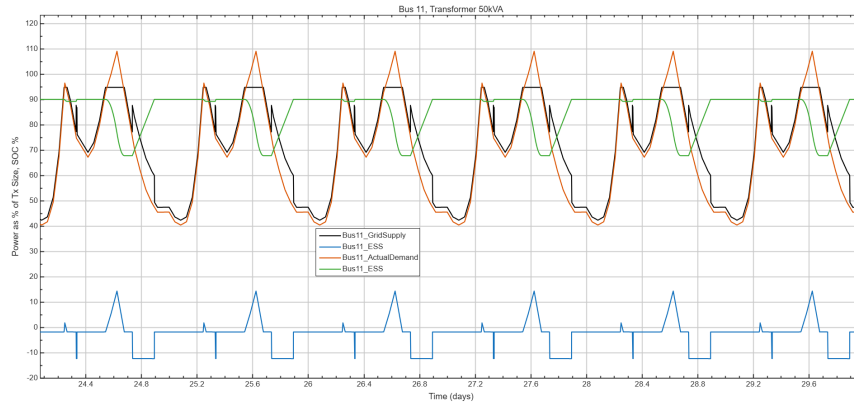
11

kV feeder results









Scenario 5 results

Scenario 6

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_160616

SST: HC-Avg (2.3000 kVA/L)

Storage: MD-High (0.3500 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 90.00

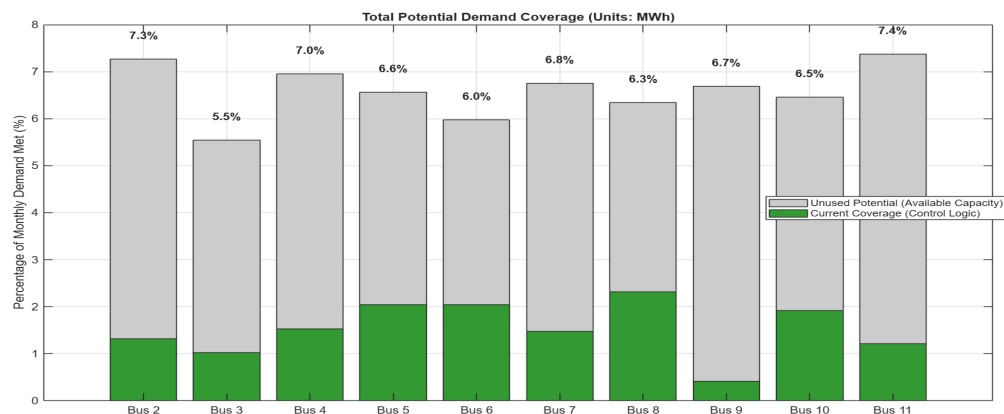
Load of Tx as % and below allows for ESS charging: 80.00

% of Tx max used for charging ESS: 10.00

BUS ALLOCATION

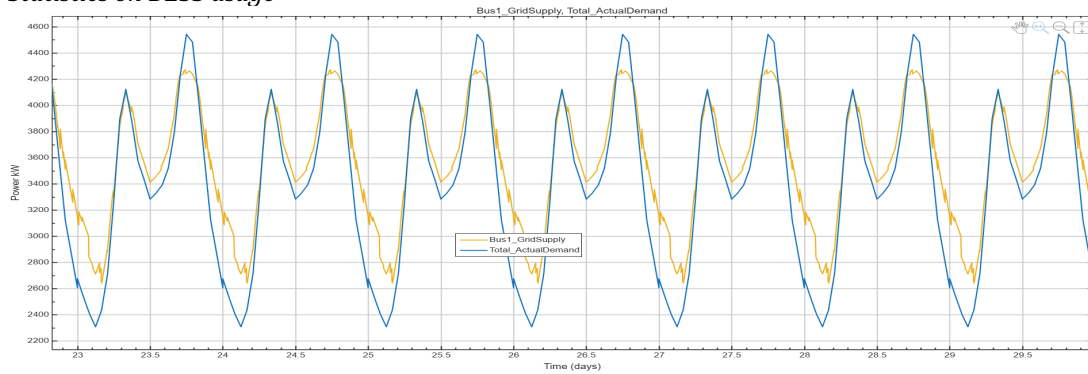
Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	2158.1028	150.0000	2158.1028
Bus3	1438.7352	100.0000	1438.7352
Bus4	1079.0514	75.0000	1079.0514
Bus5	719.3676	50.0000	719.3676
Bus6	431.6206	30.0000	431.6206
Bus7	287.7470	20.0000	287.7470
Bus8	215.8103	15.0000	215.8103
Bus9	143.8735	10.0000	143.8735
Bus10	107.9051	7.5000	107.9051
Bus11	71.9368	5.0000	71.9368

TOTAL STORAGE: 6654.1502 kWh

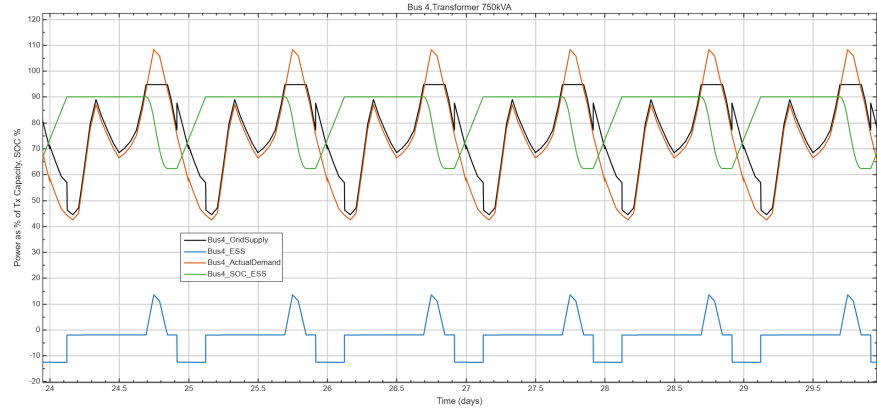
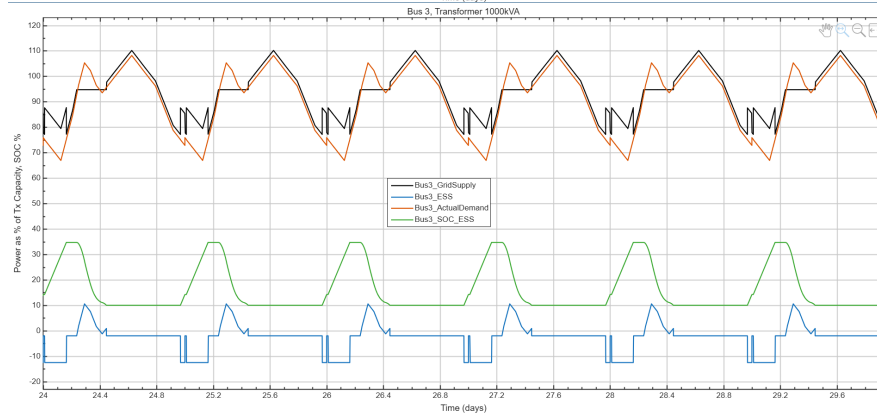
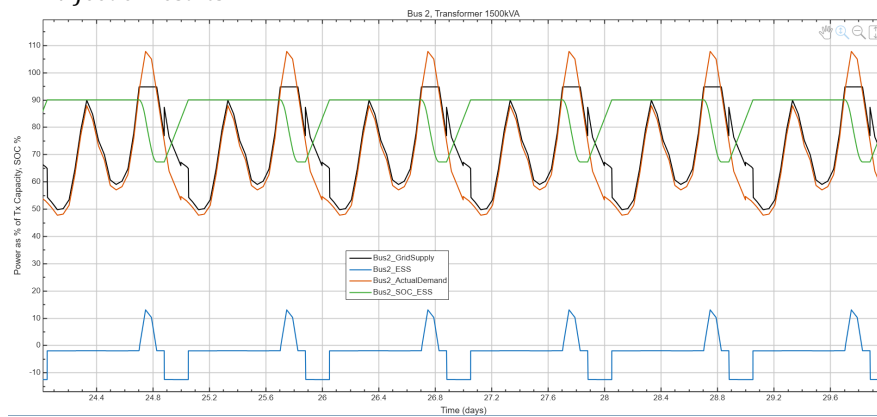


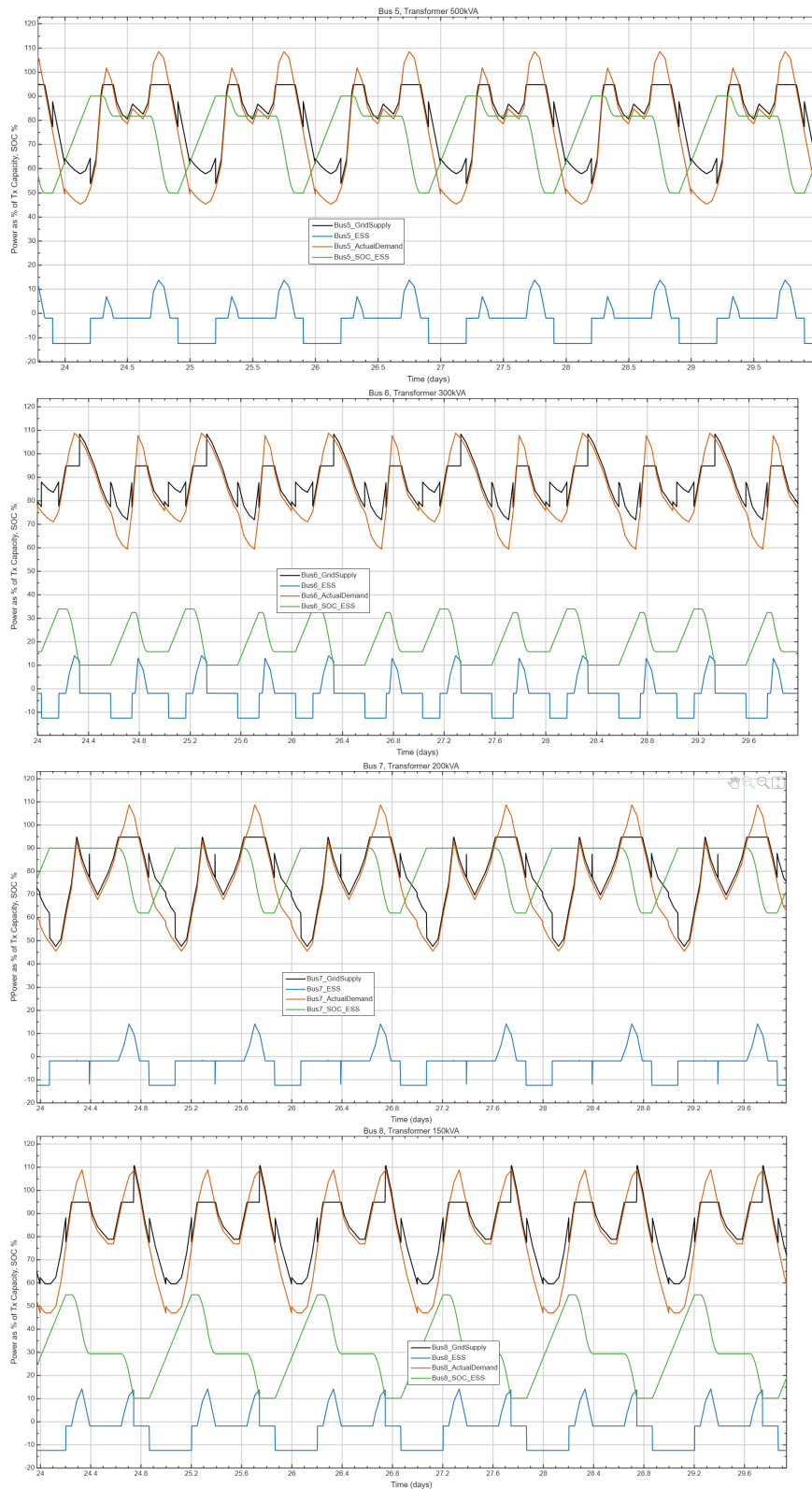


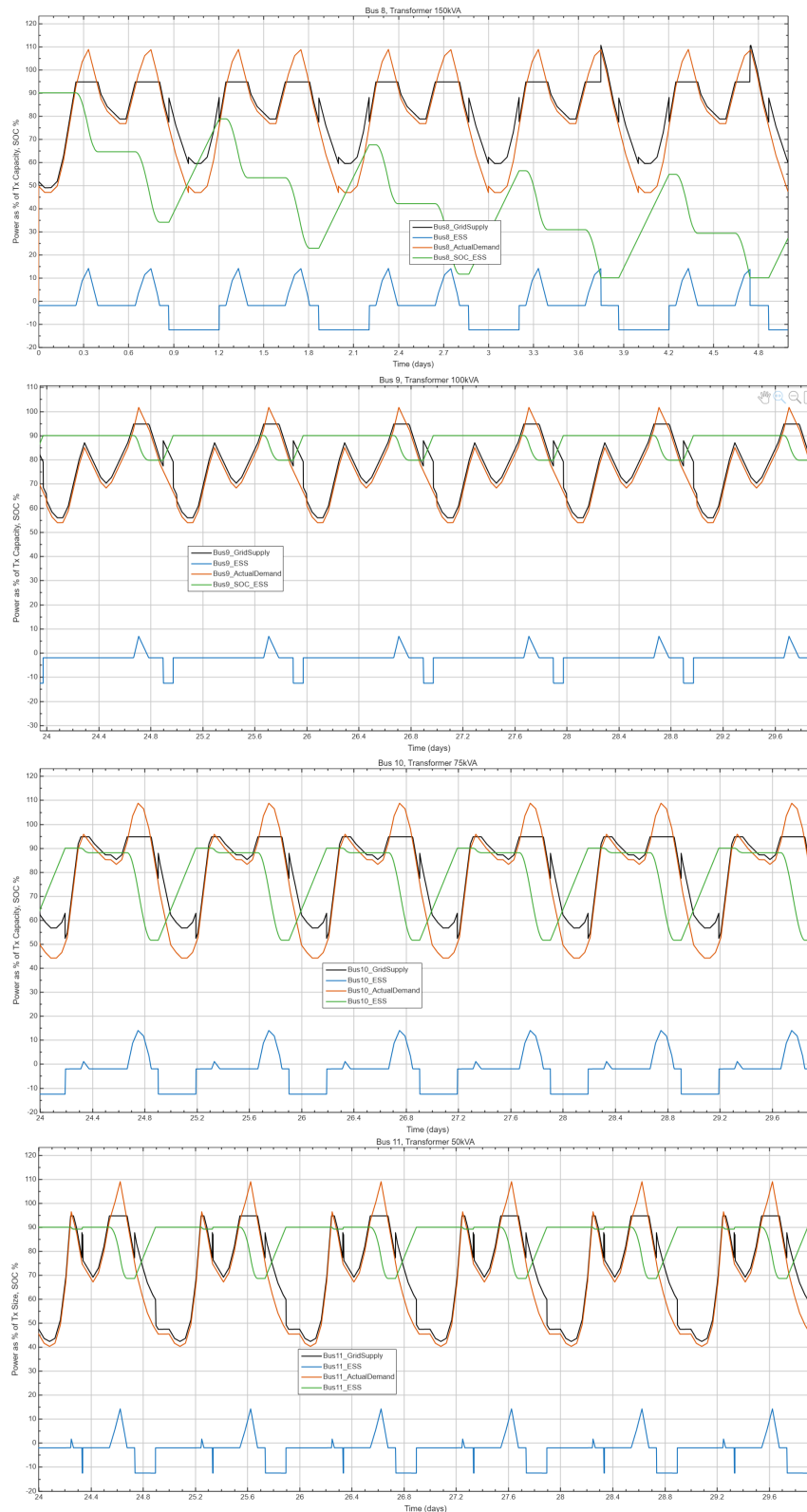
Statistics on BESS usage



11 kV feeder results







Scenario 6 results



Scenario 7

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_192607

SST: HC-Avg (2.3000 kVA/L)

Storage: HD-High (0.7000 kWh/L)

Actual Trans. Loading: 1.08

Load limiting of Tx as % of Its Capacity (shaving): 90.00

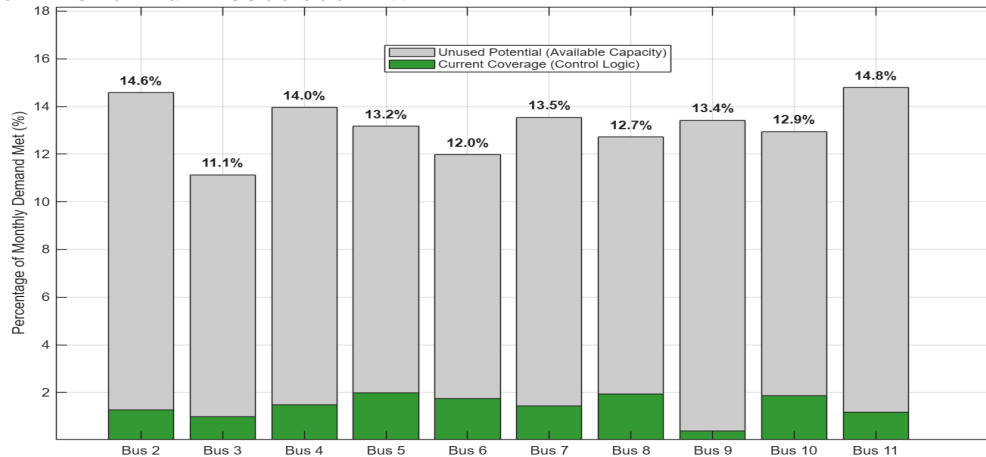
Load of Tx as % and below allows for ESS charging: 80.00

% of Tx max used for charging ESS: 10.00

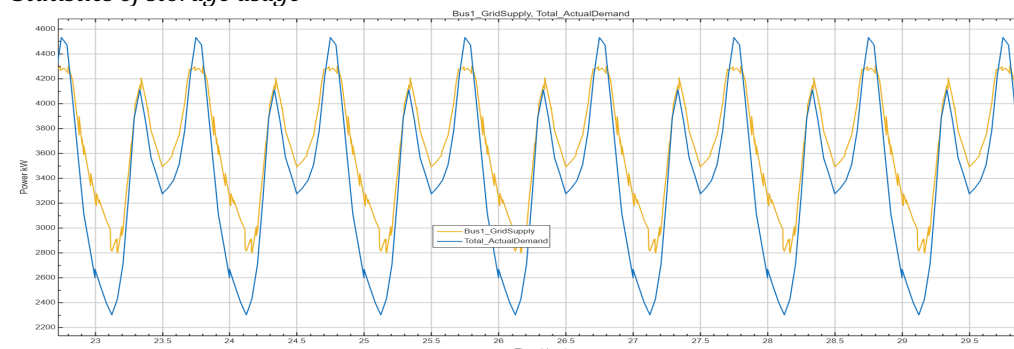
BUS ALLOCATION

Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	4316.2055	150.0000	4316.2055
Bus3	2877.4704	100.0000	2877.4704
Bus4	2158.1028	75.0000	2158.1028
Bus5	1438.7352	50.0000	1438.7352
Bus6	863.2411	30.0000	863.2411
Bus7	575.4941	20.0000	575.4941
Bus8	431.6206	15.0000	431.6206
Bus9	287.7470	10.0000	287.7470
Bus10	215.8103	7.5000	215.8103
Bus11	143.8735	5.0000	143.8735

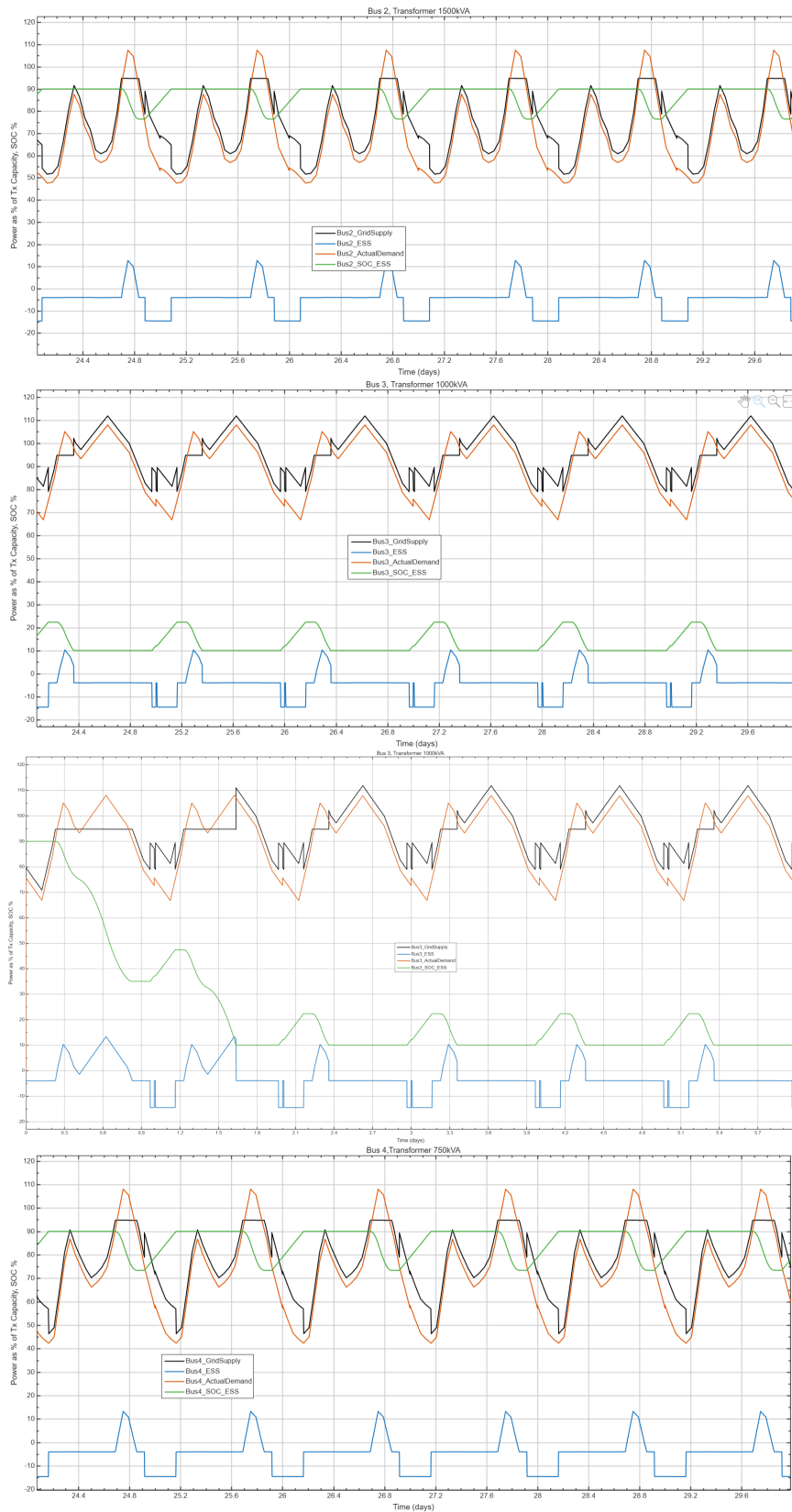
TOTAL STORAGE: 13308.3004 kWh

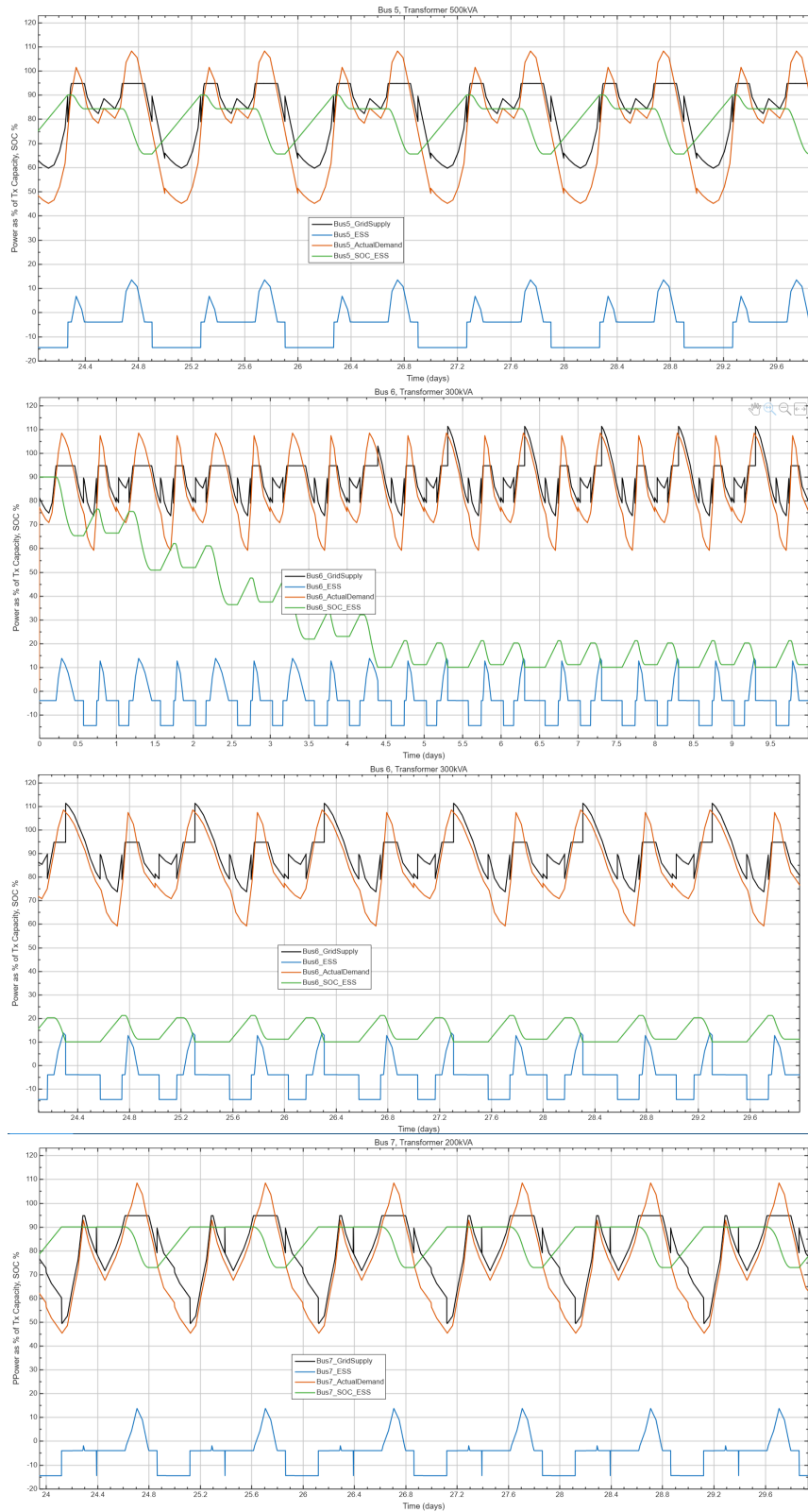


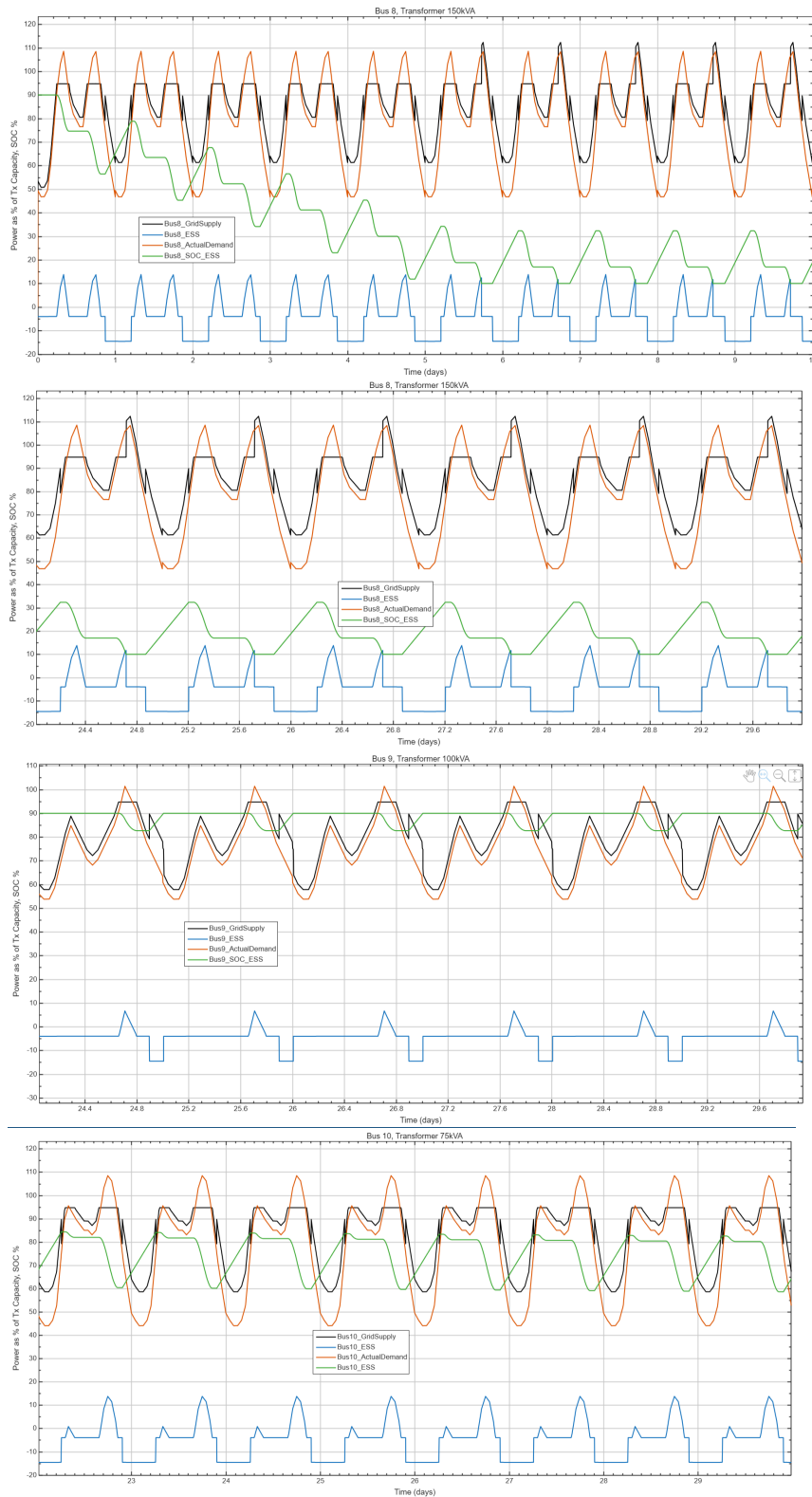
Statistics of storage usage



11 kV feeder results







Scenario 7 results



Scenario 8

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_195237

SST: MC (1.5600 kVA/L)

Storage: HD-Avg (0.5500 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 85.00

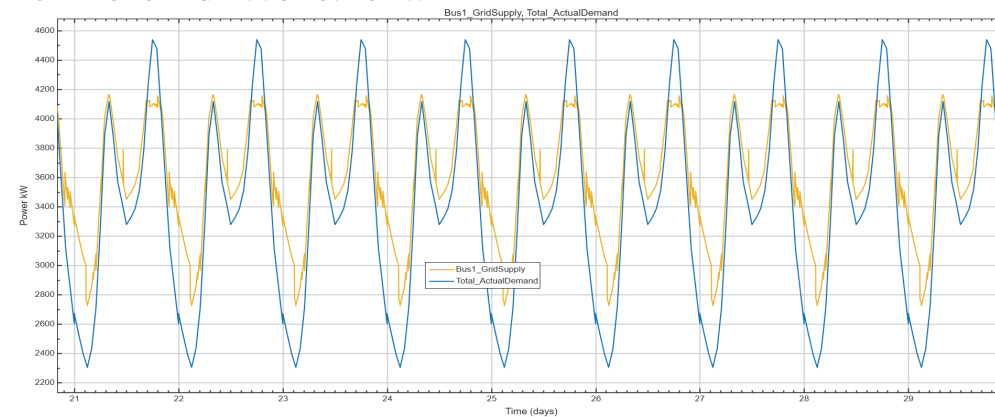
Load of Tx as % and below allows for ESS charging: 70.00

% of Tx max used for charging ESS: 15.00

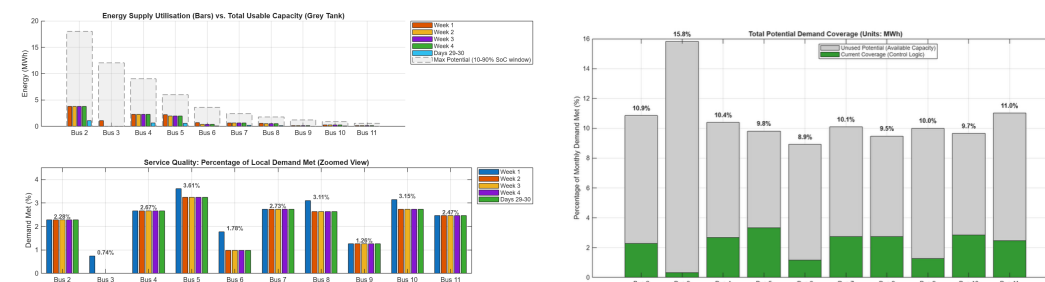
BUS ALLOCATION

Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	3221.1538	225.0000	3221.1538
Bus3	2147.4359	150.0000	2147.4359
Bus4	1610.5769	112.5000	1610.5769
Bus5	1073.7179	75.0000	1073.7179
Bus6	644.2308	45.0000	644.2308
Bus7	429.4872	30.0000	429.4872
Bus8	322.1154	22.5000	322.1154
Bus9	214.7436	15.0000	214.7436
Bus10	161.0577	11.2500	161.0577
Bus11	107.3718	7.5000	107.3718

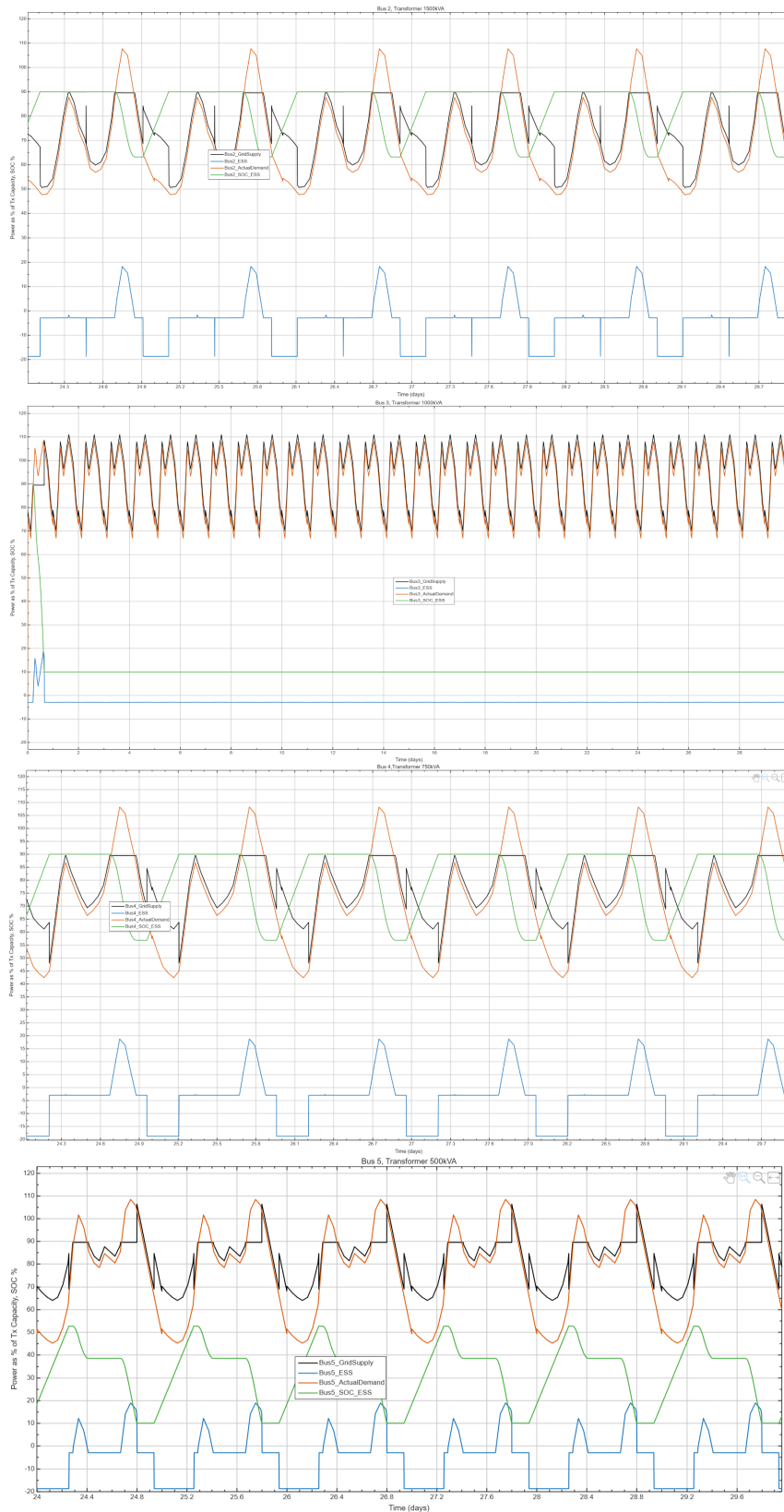
TOTAL STORAGE: 9931.8910 kWh

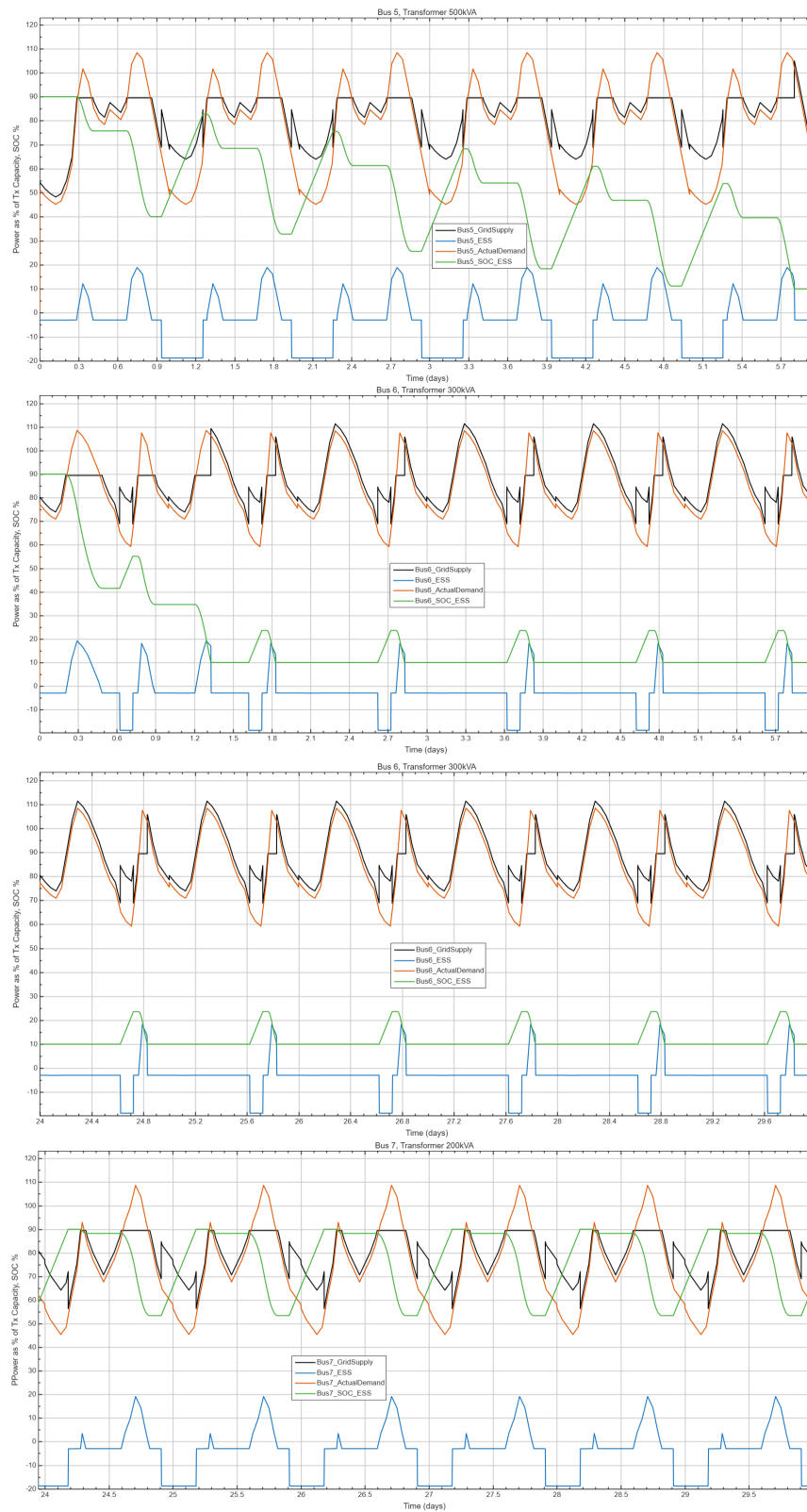


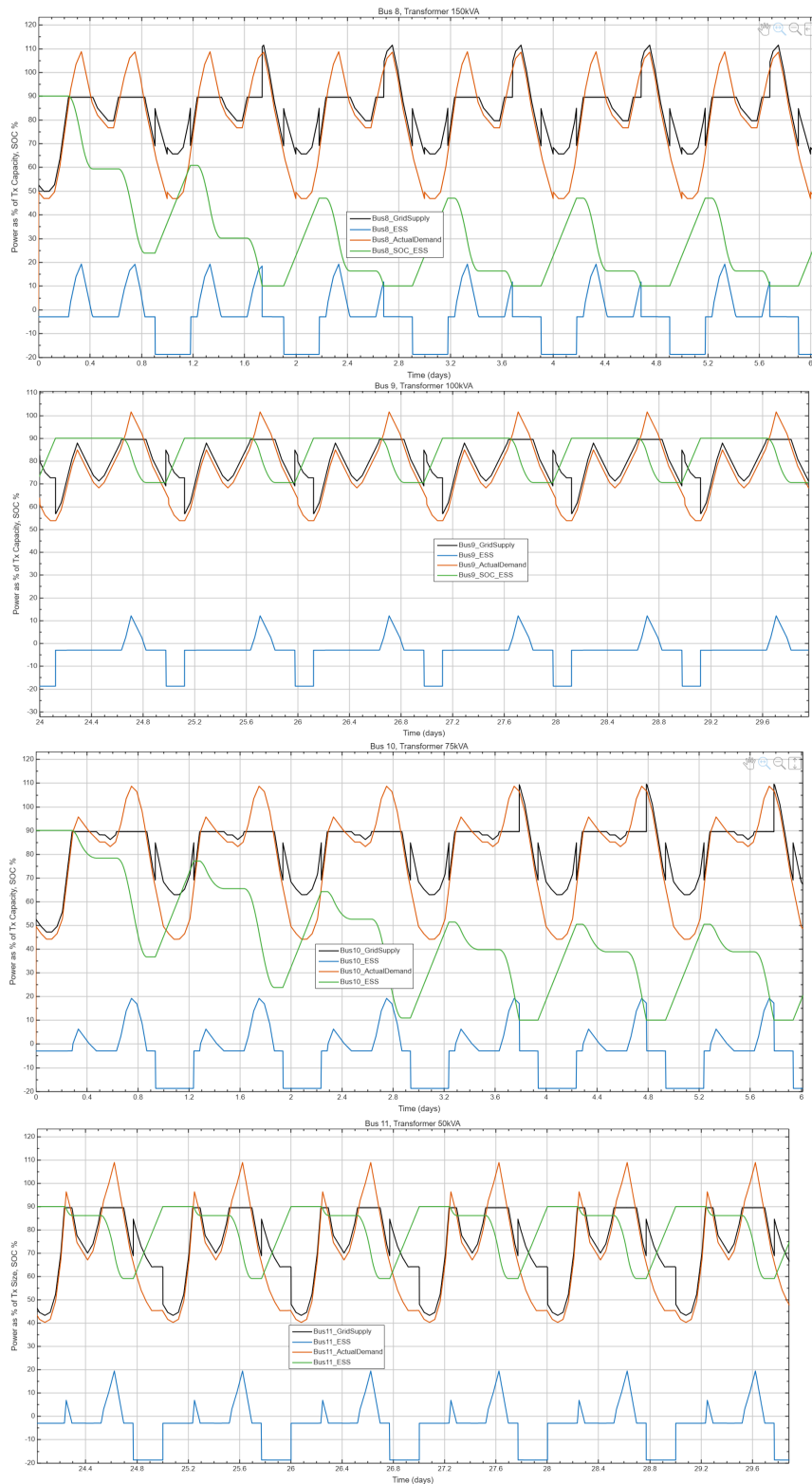
11 kV feeder results



Statistics on storage usage







Scenario 8 results



Simulation 9

Sensitivity Test simulation to see the impact of swapping the per unit demand curves and scaling to the bus size. And the impact of the dual peak morning and evening.

SIMULATION PARAMETERS

=====

Timestamp: 2026_04_15_203510

SST: MC (1.5600 kVA/L)

Storage: HD-Low (0.4000 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 90.00

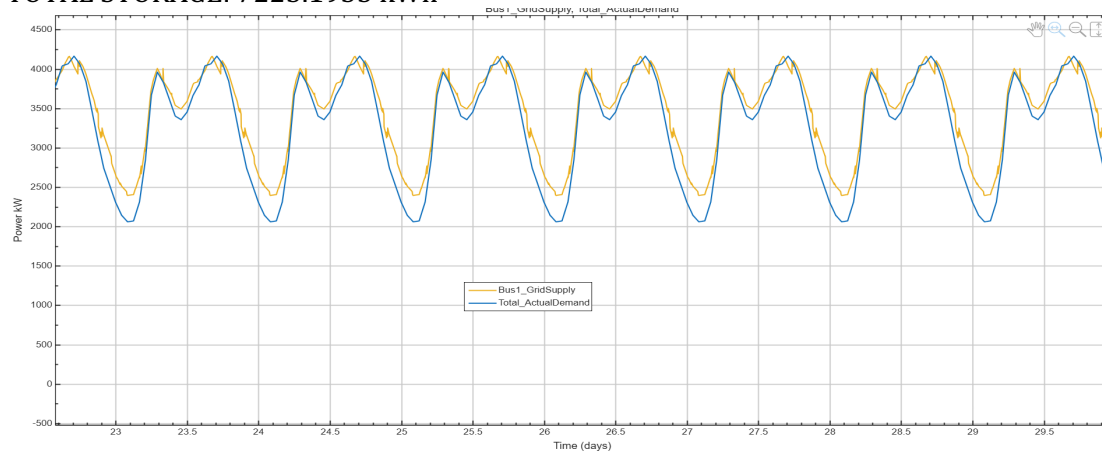
Load of Tx as % and below allows for ESS charging: 80.00

% of Tx max used for charging ESS: 10.00

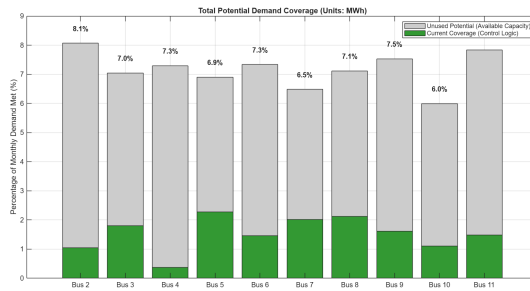
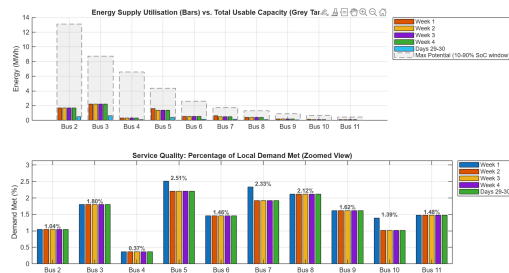
BUS ALLOCATION

Bus	Storage(kWh)	P_Chg(kW)	P_Dchg(kW)
Bus2	2342.6573	150.0000	2342.6573
Bus3	1561.7716	100.0000	1561.7716
Bus4	1171.3287	75.0000	1171.3287
Bus5	780.8858	50.0000	780.8858
Bus6	468.5315	30.0000	468.5315
Bus7	312.3543	20.0000	312.3543
Bus8	234.2657	15.0000	234.2657
Bus9	156.1772	10.0000	156.1772
Bus10	117.1329	7.5000	117.1329
Bus11	78.0886	5.0000	78.0886

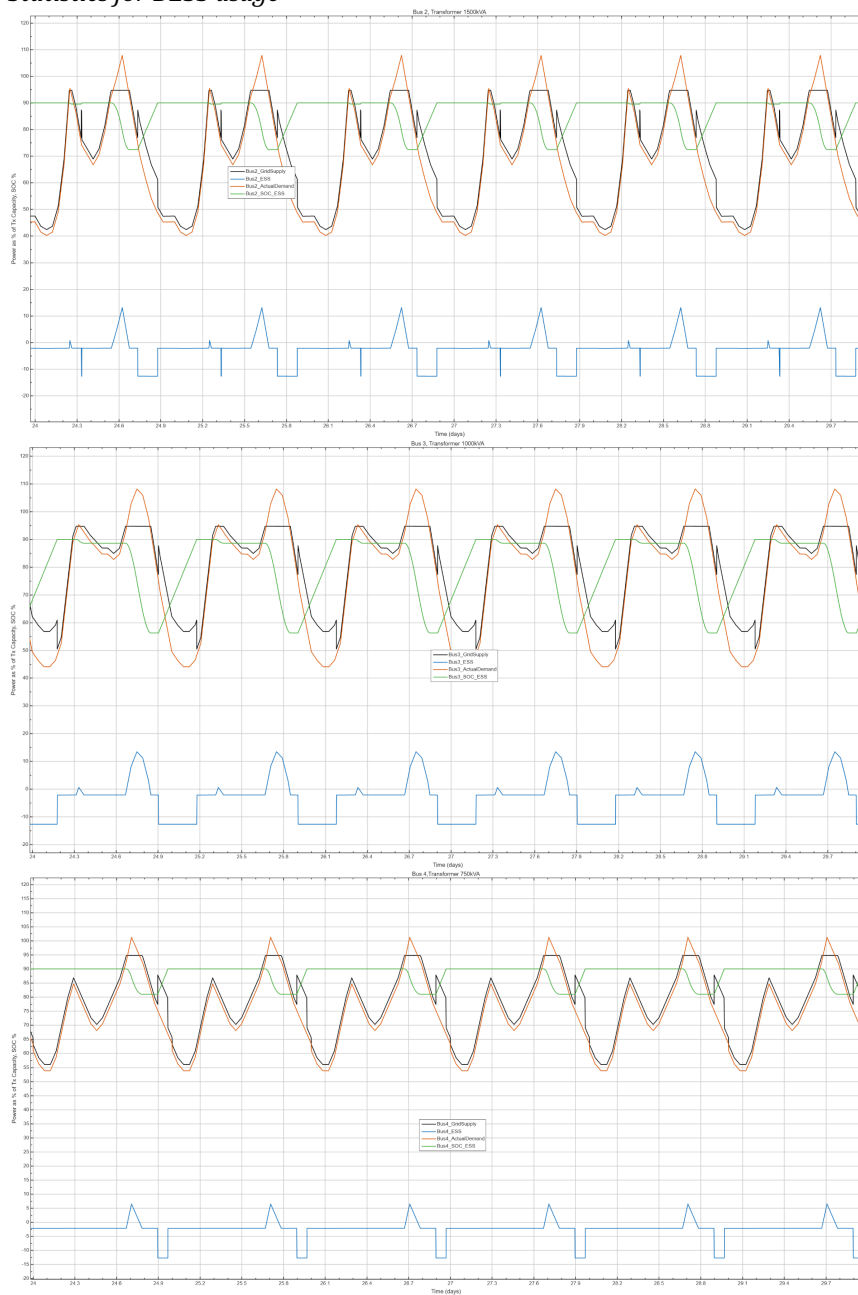
TOTAL STORAGE: 7223.1935 kWh

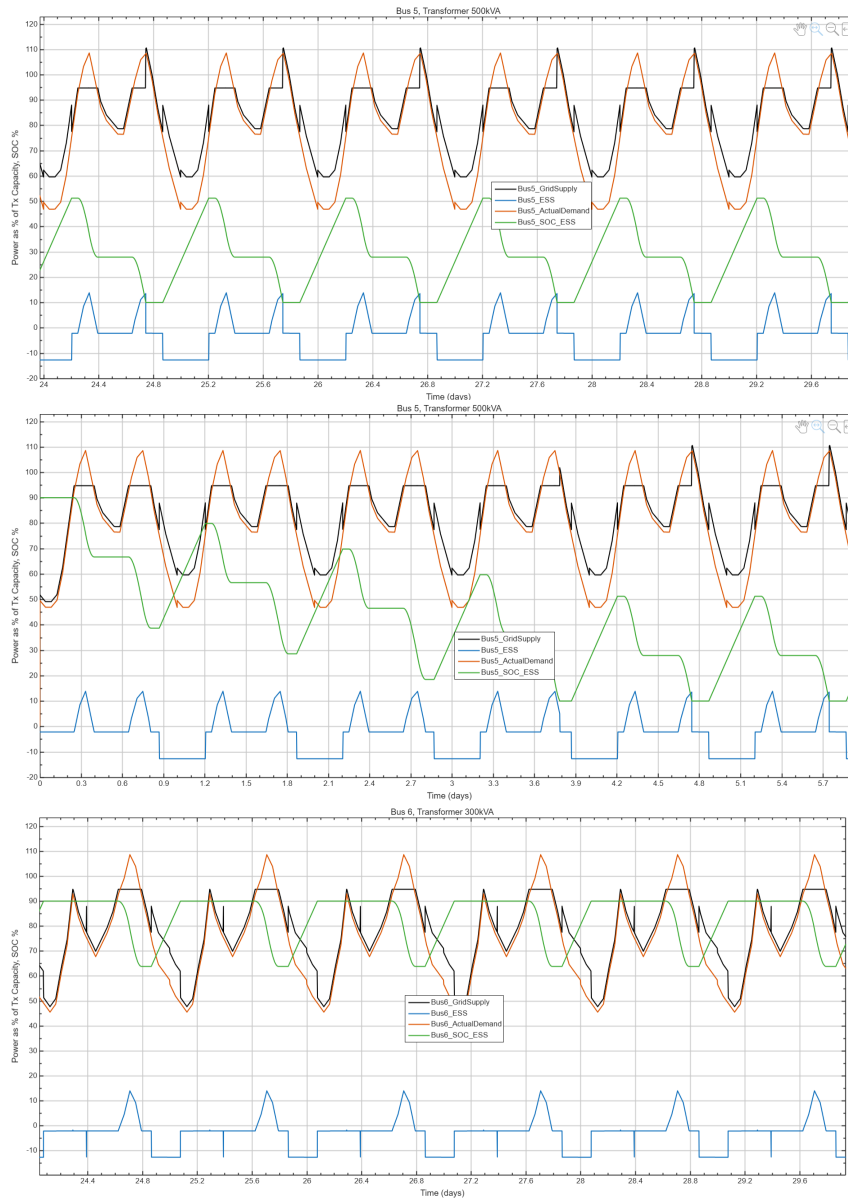


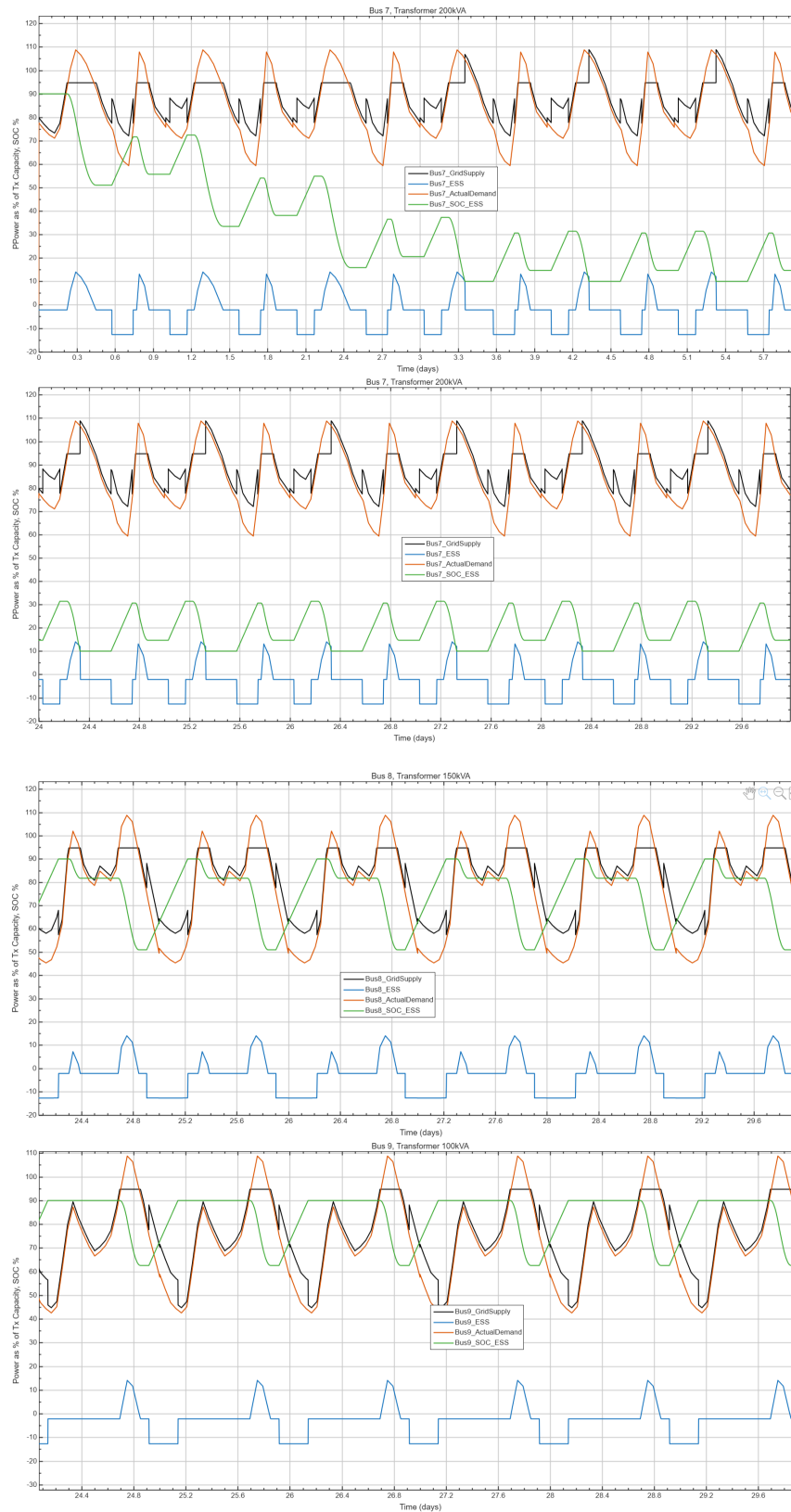
11 kV feeder results

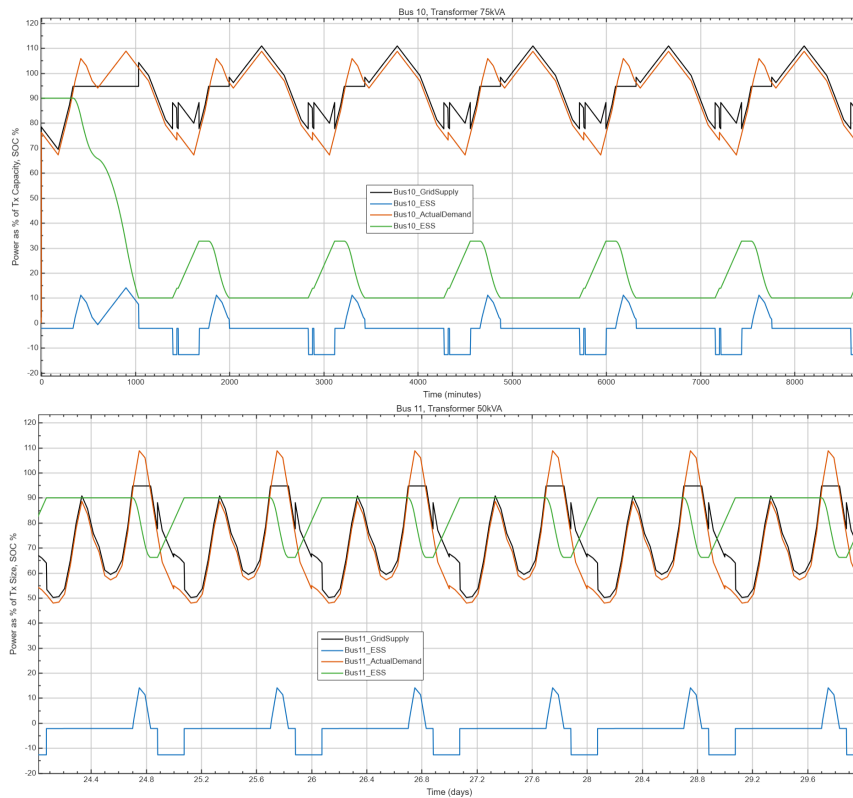


Statistics for BESS usage









Scenario 9 results

Scenario 10

SIMULATION PARAMETERS

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Timestamp : 2026_04_16_081227

SST : MC (1.5600 kVA/L)

Storage : MD-Low (0.1500 kWh/L)

Actual Trans. Loading : 1.08

Load limiting of Tx as % of Its Capacity (shaving): 90.00

Load of Tx as % and below allows for ESS charging: 80.00

% of Tx max used for charging ESS: 10.00

C-rate (h) : 1.00

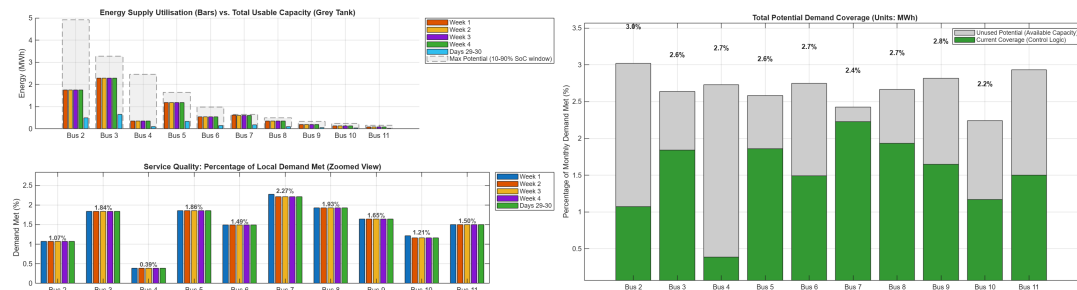
BUS ALLOCATION & POWER LIMITS

=====

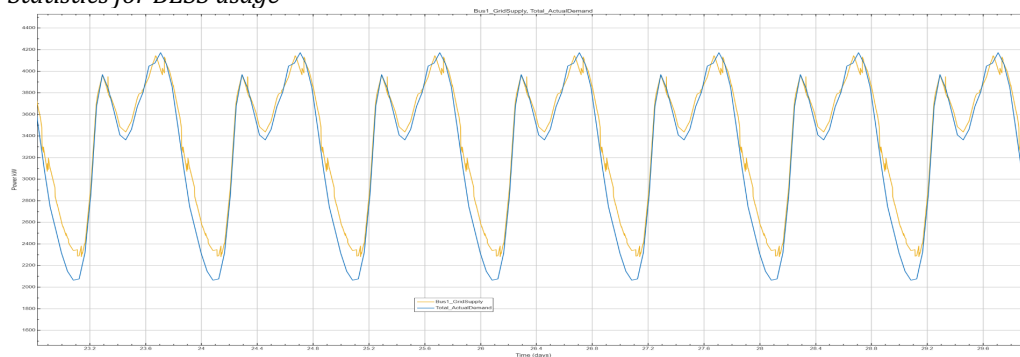
Bus	Storage(kWh)	P_Shav(kW)	P_En(kW)	P_Chg(kW)	P_Dis(kW)
Bus2	878.4965	1350.0000	1200.0000	150.0000	878.4965
Bus3	585.6643	900.0000	800.0000	100.0000	585.6643
Bus4	439.2483	675.0000	600.0000	75.0000	439.2483
Bus5	292.8322	450.0000	400.0000	50.0000	292.8322
Bus6	175.6993	270.0000	240.0000	30.0000	175.6993
Bus7	117.1329	180.0000	160.0000	20.0000	117.1329
Bus8	87.8497	135.0000	120.0000	15.0000	87.8497
Bus9	58.5664	90.0000	80.0000	10.0000	58.5664
Bus10	43.9248	67.5000	60.0000	7.5000	43.9248
Bus11	29.2832	45.0000	40.0000	5.0000	29.2832

TOTALS SUMMARY

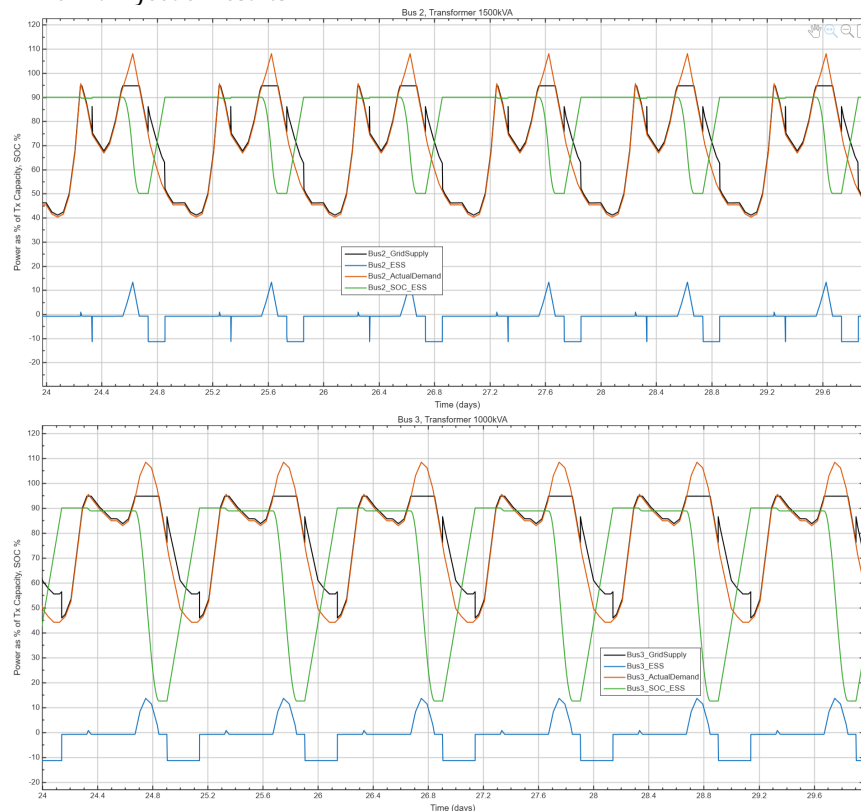
=====
Total Storage Capacity : 2708.6976 kWh

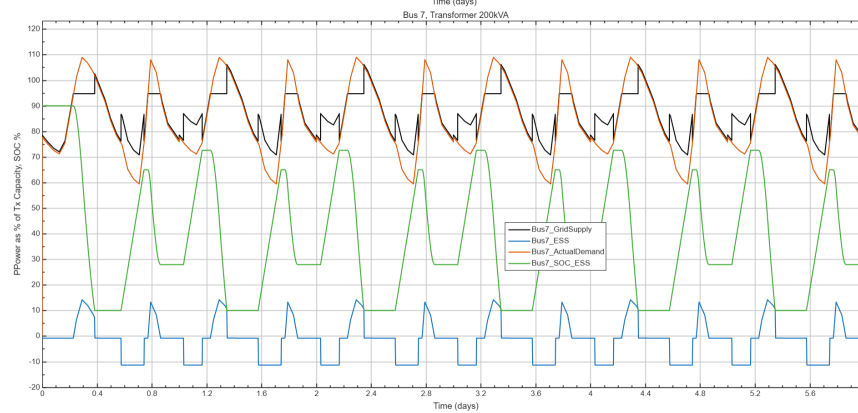
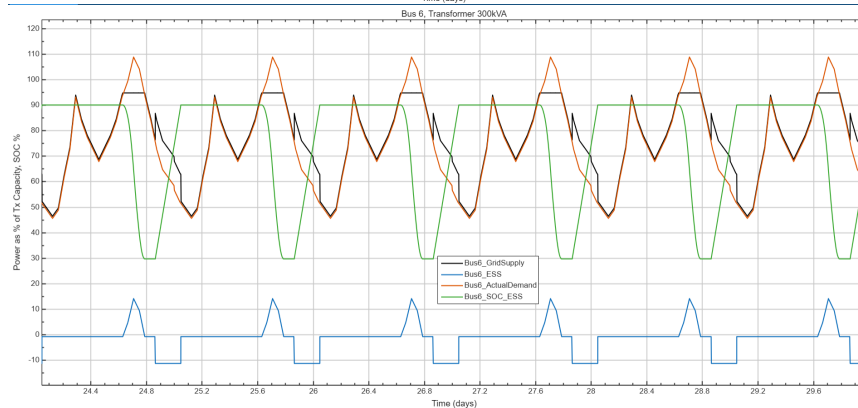
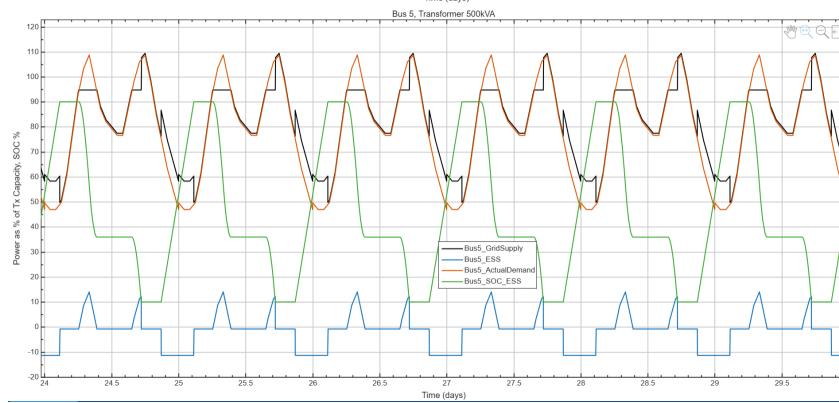
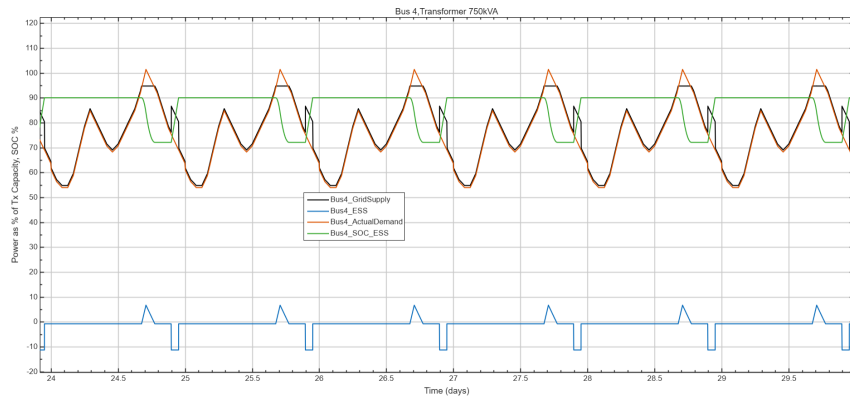


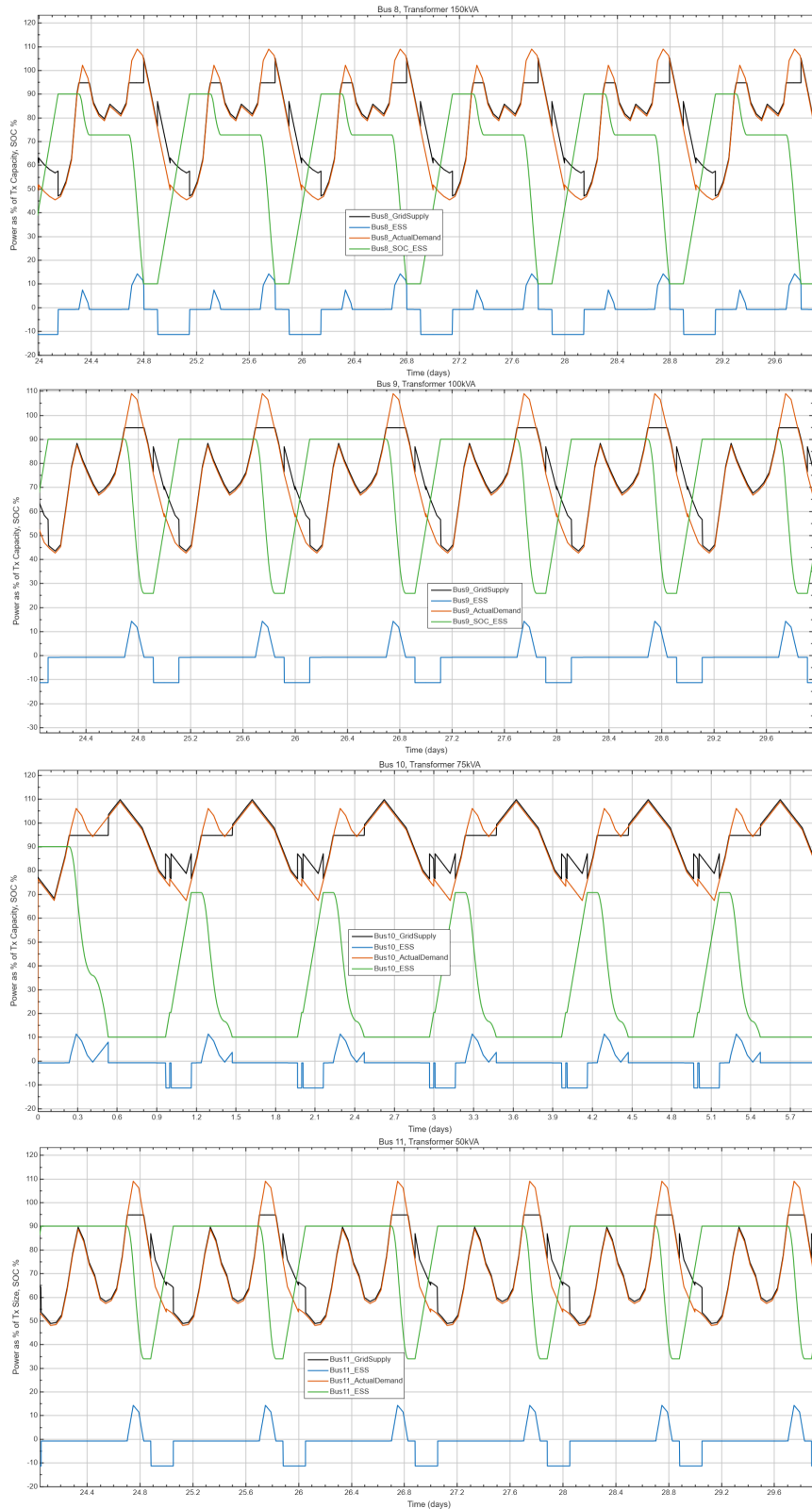
Statistics for BESS usage



11 kV main feeder results







Scenario 10 results