# Energy Twin (PSS®DE)
# Feasibility Study Report

# Brandon Garage Electrification Plan
# Winnipeg Transit

**Siemens Canada Limited**

| | |
|---|---|
| Winnipeg Transit contact: | Erin Cooke, P.Eng., PMP<br>Project Manager – Bus Electrification Program |
| Date | 04 March 2022 |
| Siemens contact: | Jordan Hebbert |
| Office address | 1577 North Service Road East,<br>Oakville, Ontario, L6H 0H6 |
| Phone | +1-905-580-2876 |

SIEMENS

# Disclaimer

Please note, that any data or information contained in this study is provided for information purposes only and that any data or information therefore is made available "as is" and no warranties are given or liabilities of any kind are assumed with respect to the quality of any such data or information, including, but not limited, to its fitness for the purpose, non-infringement of third-party rights, or its correctness.

# Executive summary

The economic and environmental aspects of Winnipeg Transit have been evaluated in detail. For all cases, a suggested asset mix of 1.1MW of rooftop solar generation, a BESS with a capacity of 4.5-4.7 MWh for 1-hour duration, as well as a microgrid controller have been suggested. This requires an approximate initial investment of $4 million, reducing demand charges to a maximum of $2.16M CAD over the project.

This result is based on a study using Siemens PSS®DE, a techno-economic simulation tool specifically designed to realistically model hybrid energy generations systems in detail. The simulation included project specific loads, price and renewable energy time series, detailed models with partial load limitations and aging considerations, as well as a realistic optimization and dispatch algorithm consistent with Siemens' proven Microgrid portfolio. All costs and sensitivity scenarios were aligned with the consumer's energy team.

The project was conducted with three different goals guiding how the study was to be analyzed. The first and most important goal of the study was regarding grid stability. With the current plan of onboarding new electric buses each year, the infrastructure in place is not enough to support it. Therefore, three different options were assessed to determine the best way to handle the increased demand.

The second project goal is lowering GHG emissions at the Brandon Garage site. Since the preference was to bring in renewable energy sources to handle the high demand, the site was assessed for the potential of installing distributed energy resources (DERs).

The final goal of the project is to optimize any possible capital expenditures (CAPEX) that will be spent and minimize the operational expenses (OPEX) that are associated with the DERs selected.

Various alternative scenarios were considered, which included the use of photovoltaic, energy storage, natural gas, and diesel generators. The configuration consisting of the rooftop solar and battery energy storage system, in addition to the current grid infrastructure, was the best configuration that met all three project goals. Firstly, it was able to fully meet the load without any load shedding events. Secondly, removing the diesel generator within the source mix fits within Winnipeg Transit's green energy plan. Lastly, the financial KPIs are either equivalent or more advantageous than the reference scenario.

An alternative configuration using the onsite diesel generator, in addition to the rooftop solar and BESS, was also considered. The main purpose of this alternative is to prevent any downtimes within the system if blackouts occur, and slightly reduce overall demand charges. However, this goes against the second goal of lowering CO2 emissions.

Therefore, it is recommended to go forward with the configuration which utilizes the current grid supply, as well as rooftop solar and a BESS, with a microgrid controller operating the daily activities

## Table of Contents

1 Introduction ........................................................................ 6

2 Simulation Inputs .................................................................. 7
  2.1 Loads Overview (KPIs) ........................................................ 7
  2.2 Loads plots ........................................................................ 7
  2.3 Load Heatmaps .................................................................... 8
    2.3.1 Electrical load ................................................................ 9
  2.4 External energy prices ........................................................ 9
    2.4.1 Fuel prices ...................................................................... 9
    2.5 Electrical grid import prices ............................................. 9
  2.6 Renewable resources ......................................................... 10
    2.6.1 Photovoltaic Plots ........................................................... 12
    2.6.2 Photovoltaic Heatmaps ................................................... 13

3 Project setup and dispatch .................................................... 14
  3.1 Electrical Infrastructure Risk .............................................. 14
  3.1.1 When is the grid power supply not sufficient? ...................... 14
  3.1.2 How much per month to discharge to meet demand? ............... 14
  3.2 Solving Infrastructure Problem for Year 5 .............................. 19
  3.2.1 Case 0 – Do Nothing ........................................................ 19
  3.2.2 Case 1 - Solar and Battery without Diesel Generator .............. 20
  3.2.3 Case 2 - Solar and Battery with Diesel Generator .................. 20

4 Sizing Results ...................................................................... 21
  4.1 Rooftop Solar Estimate ....................................................... 21
  4.2 Sizing of Case 1: Solar and Battery ...................................... 23
  4.3 Sizing of Case 2: Solar, Battery and Diesel Generator .............. 25

5 Simulation results - Configuration comparison ........................... 25
  5.1 Financial Comparison ......................................................... 26
    5.1.1 Financial Inputs ............................................................. 26
    5.1.2 Levelized Cost of Energy (LCoE) ....................................... 26
  5.2 Environmental Comparison ................................................... 28
    5.2.1 Annual carbon emissions – comparison of both solutions ........ 28
    5.2.2 Photovoltaic (PV) Energy Share ......................................... 29
  5.3 Cashflow Comparison ......................................................... 30
    5.3.1 CAPEX Comparison ......................................................... 30
    5.3.2 OPEX Comparison ........................................................... 31
    5.3.3 Revenue and Expenses Comparison .................................... 32
  5.4 Generation Comparison ....................................................... 33

6 Simulation results – Configuration analysis .............................. 34
  6.1 Analysis of Case 1: Current Grid + New Rooftop Solar and BESS .... 34
    6.1.1 Photovoltaic Energy Share ................................................ 34
    6.1.2 Energy Flow ................................................................... 34
    6.1.3 Expenses ....................................................................... 36
    6.1.4 Cashflow ....................................................................... 37
    6.1.5 Generation ..................................................................... 38

6.1.6 Importance of the Energy Storage ........ 39
6.2 Analysis of Case 2: Current Grid and Gen + New PV and BESS ........ 40
6.2.1 Photovoltaic Energy Share ........ 40
6.2.2 Energy Flow ........ 41
6.2.3 Expense ........ 42
6.2.4 Cashflow ........ 43
6.2.5 Generation ........ 44
6.3 Configuration Summary ........ 44

7 Outage Response ........ 45
7.1 Case 1: Outage Simulation ........ 46
7.2 Case 2: Outage Simulation ........ 46

8 Project Execution Overview ........ 47
8.1 SICAM Microgrid Controller ........ 47
8.2 Control System Main Components ........ 48
8.2.1 Master control element SICAM A8000 CP-8050 ........ 48
8.2.2 SICAM A8000 Technical Data ........ 49
8.2.3 HMI- SICAM SCC ........ 49
8.3 System Communication Architecture ........ 49
8.4 Protection and Control Solution ........ 51
8.5 Cybersecurity ........ 52

9 Appendix ........ 52
9.1 Sizing optimization ........ 52
9.2 Levelized Cost of Electricity (LCoE) ........ 53
9.3 Sankey Diagrams ........ 54
9.4 List of Abbreviations ........ 55
9.5 References ........ 55

# 1 INTRODUCTION

The intelligent utilization of alternative energy generation concepts to complement conventional generation systems provides the opportunity to reduce generation costs, improve reliability of energy supply, as well as caring for the environment by reducing carbon emissions.

Each consumer has their own specific requirements dependent on their location, and energy usage and needs. A reference model can be created by careful consideration of energy consumption, available resources, fuels and external grid connections, and existing infrastructure. Evolving conditions, including load growth, cost increases, and asset degradation can be modeled over a period of years, providing a realistic baseline of the costs a consumer can expect. A description of the baseline is given in section 2.

Scenarios are developed to systematically explore alternative possibilities for generation, and a detailed system model was created for each scenario. The system model makes an economic optimization for every timestep, replicating the operation of the relevant energy generation scenario over the project lifetime. The model's outputs are economic and technical KPIs, which form the basis for the financial evaluation. Annual escalation rates (e.g., for fuel, operating and maintenance and grid imports/exports) are also considered. The results provide a clear overview of the financial and economic benefits for each scenario.

This study was performed using Siemens PSS®DE, a techno-economic simulation tool specifically designed to model high-fidelity hybrid energy generations systems. Studies evaluate various assets under consideration for the optimal solution under specified economic and technical criteria. The tool serves to assess and optimize against various competing scenarios under test to ensure the best technical solution under laid out economic constraints. The detailed system models can be refined as higher quality input data is available, with a seamless transition to online operation as an Energy Twin (i.e., the digital twin for the energy generation system).

# 2 SIMULATION INPUTS

This section summarizes the input data that was used within PSS® DE to simulate the defined scenarios.

## 2.1 Loads Overview (KPIs)

The simulation included 4 separate loads based on the charging schedule for the buses, including one overnight charging schedule and three midday charging schedules. The load profiles have several factors contributing to their overall estimated load curves.

1. Between the months of October to April, the winter profile is used, and the remaining months use the summer profile.
2. The weekend schedule is considered to be 50% of the weekday schedule.
3. As per the data received from Winnipeg Transit, information regarding the amount of energy realistically estimated to be used by the buses vs. the worst-case peak, is provided. The table below shows the estimate by each month, including yearly profile KPIs.

Finally, there is a staged approach to onboarding the electric buses. Each of the first five years, 15 buses will be introduced. In the 6th year there will be a total of 30 buses added, totaling 105 for the program.

## 2.2 Loads Plots

Combined Summer Profile:

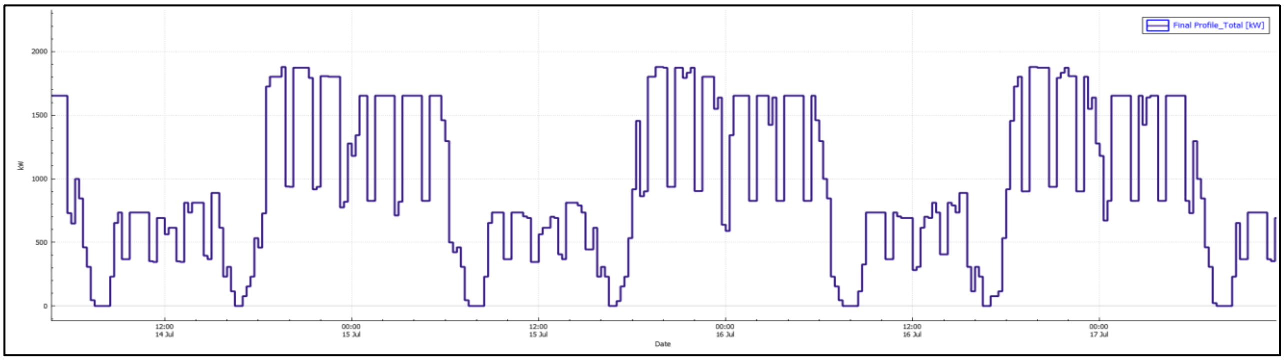


Figure 1: Combined Summer Profile

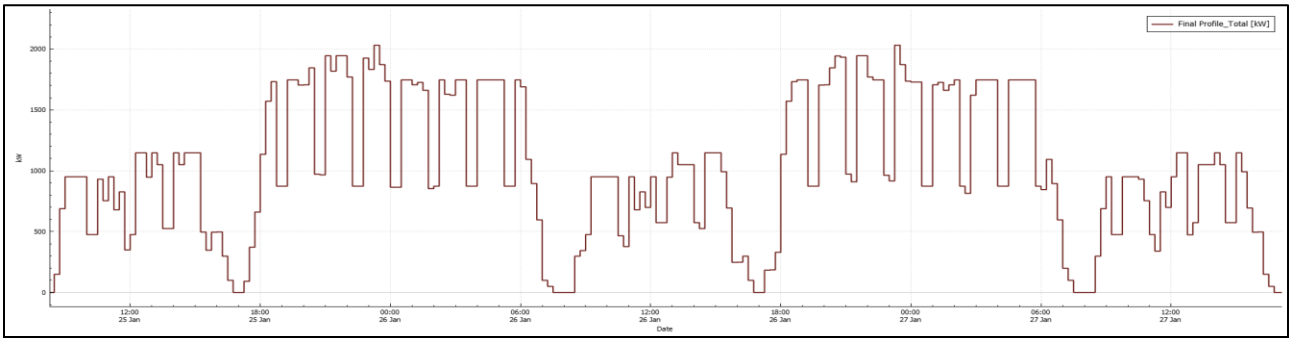


Figure 2: Combined Winter Profile

| Timeseries | Load | Cumulative – 1 year | Min | Max | Average |
|---|---|---|---|---|---|
| **Final Profile_Total** | Trip Total | 8,692,909.4 kW | 0.0 kW | 2,219.5 kW | 992.3 kW |

Table 1: Combined Technical KPIs

| Year | Buses | Profile Percentage |
|---|---|---|
| **1** | 15 | 14.25% |
| **2** | 30 | 28.5% |
| **3** | 45 | 42.75% |
| **4** | 60 | 57% |
| **5** | 75 | 71.25% |
| **6** | 105 | 100% |

Table 2: Load Percentage per Year

| Month | Energy Estimate | Profile |
|---|---|---|
| **January** | 66.26% | Winter |
| **February** | 72.39% | Winter |
| **March** | 71.44% | Winter |
| **April** | 61.71% | Winter |
| **May** | 55.53% | Summer |
| **June** | 47.14% | Summer |
| **July** | 51.23% | Summer |
| **August** | 48.19% | Summer |
| **September** | 47.25% | Summer |
| **October** | 69.89% | Winter |
| **November** | 72.55% | Winter |
| **December** | 69.33% | Winter |

Table 3: Energy Estimates per Month

## 2.3 LOAD HEATMAPS

Below shows a heatmap of the load profile. It shows the 24-hour schedule vertically, while displaying the yearly schedule horizontally. The colour represents the demand for that time.

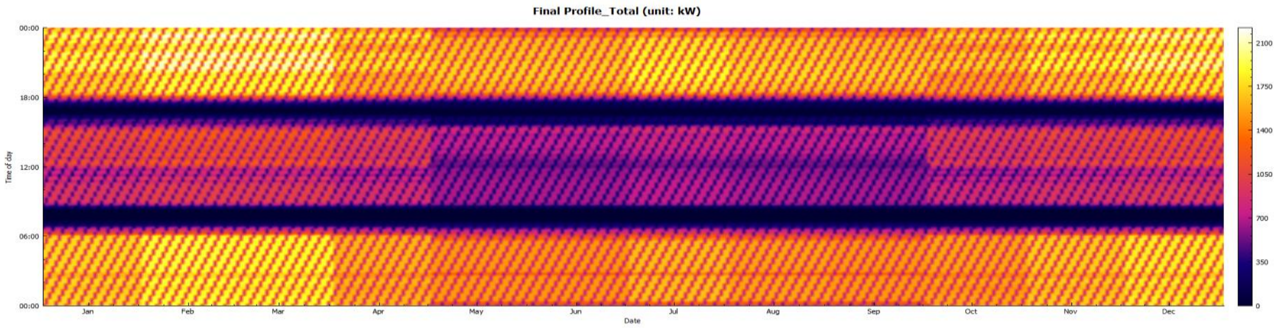


Figure 3: Profile Heat Map

### 2.3.1 Electrical load

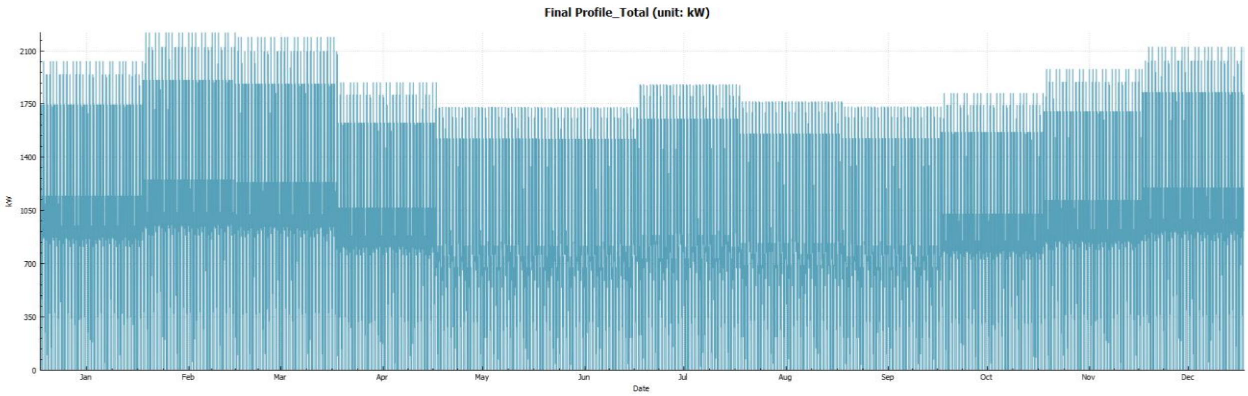


Figure 5: Yearly Load Profile

## 2.4 EXTERNAL ENERGY PRICES

The energy generated within this study was reliant on fuel imports for the currently installed diesel generator and imported energy costs from the grid.

### 2.4.1 Fuel prices

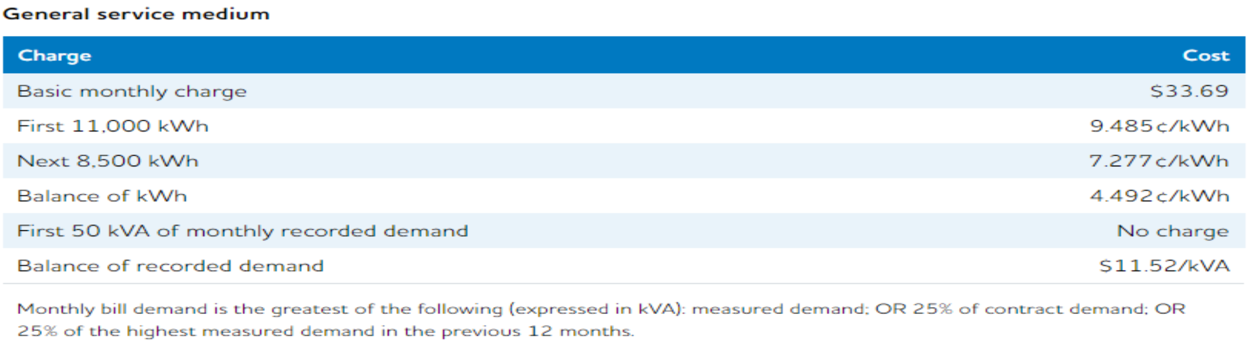
The following list of fuel prices were used.

| Year | Diesel Cost ($/l) |
|---|---|
| **2022** | 1.2320 |
| **2023** | 1.2553 |
| **2024** | 1.2191 |
| **2025** | 1.2918 |
| **2026** | 1.3660 |

Table 4: Diesel Cost

## 2.5 Electrical grid import prices

For the first five years, General Service Medium was used for the financials. After the fifth year, the service changed to General Service Large, based on the planned infrastructure change.

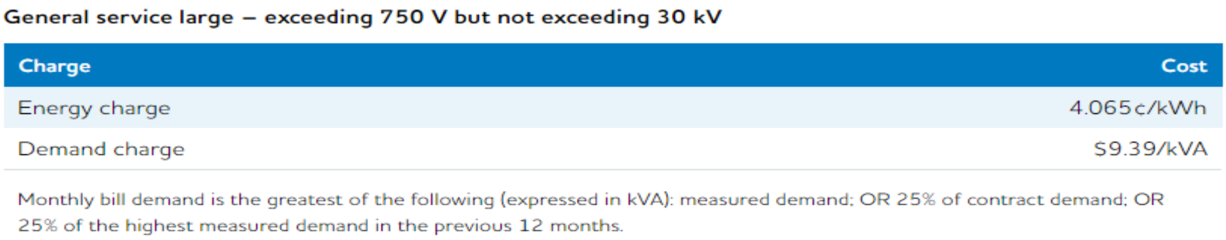


**General service medium**

| Charge | Cost |
|---|---|
| Basic monthly charge | $33.69 |
| First 11,000 kWh | 9.485 c/kWh |
| Next 8,500 kWh | 7.277 c/kWh |
| Balance of kWh | 4.492 c/kWh |
| First 50 kVA of monthly recorded demand | No charge |
| Balance of recorded demand | $11.52/kVA |

Monthly bill demand is the greatest of the following (expressed in kVA): measured demand; OR 25% of contract demand; OR 25% of the highest measured demand in the previous 12 months.

Figure 6: Medium Service Electricity Costs



**General service large – exceeding 750 V but not exceeding 30 kV**

| Charge | Cost |
|---|---|
| Energy charge | 4.065¢/kWh |
| Demand charge | $9.39/kVA |

Monthly bill demand is the greatest of the following (expressed in kVA): measured demand; OR 25% of contract demand; OR 25% of the highest measured demand in the previous 12 months.

Figure 7: Large Service Electricity Costs

## 2.6 RENEWABLE RESOURCES

The renewable resources summarized in the following table (year 1 of reference config) were used. The image below also shows the location where the information is collected from.

| Timeseries | Unit | Used by | Cumulative | Min | Max | Average |
|---|---|---|---|---|---|---|
| **[49.867300 N, 97.138400 W] Direct radiation (hr)** | W/m^2 | PV w Central Inverter | 1,692,471.8 | 0.0 | 985.4 | 193.2 |
| **[49.867300 N, 97.138400 W] Diffuse radiation (hr)** | W/m^2 | PV w Central Inverter | 554,489.8 | 0.0 | 436.2 | 63.3 |
| **[49.867300 N, 97.138400 W] Ambient temperature (hr)** | deg C | PV w Central Inverter | 31,592.6 | -31.5 | 33.8 | 3.6 |

Table 5: PV Data

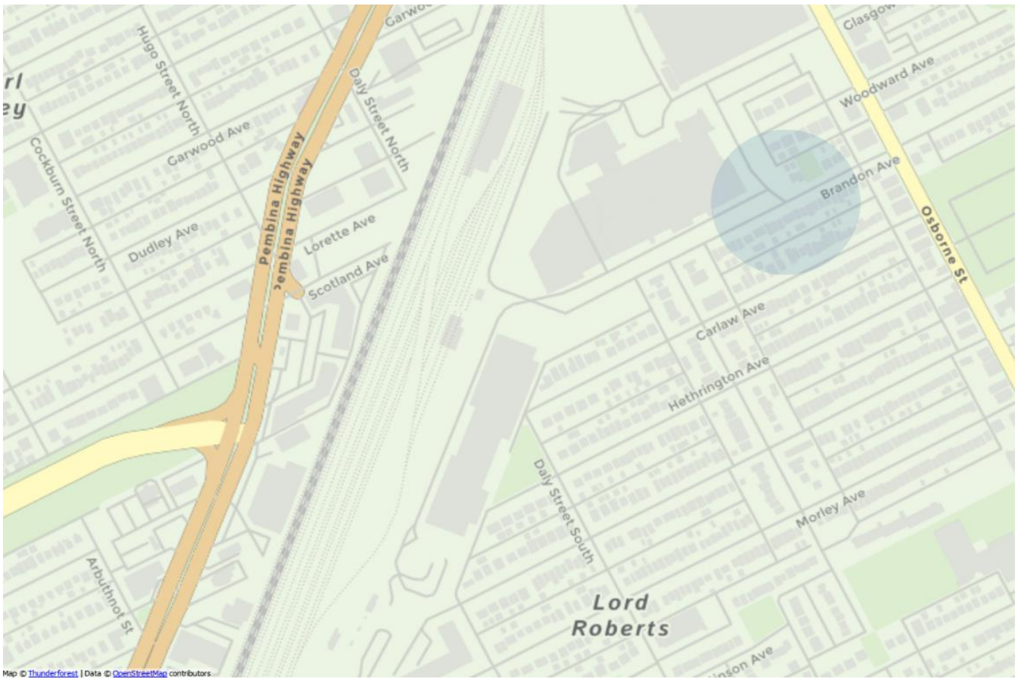


Figure 8: Location of Weather Data

### 2.6.1 Photovoltaic Plots

This timeseries is used for the direct radiation in PV calculations.

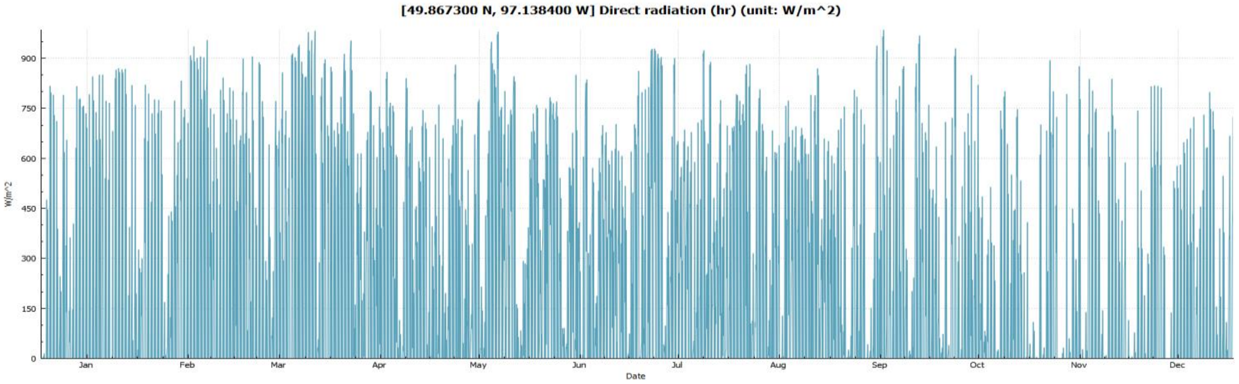


Figure 9: Direct Radiation Profile

This timeseries is used for the diffuse radiation in PV calculations.

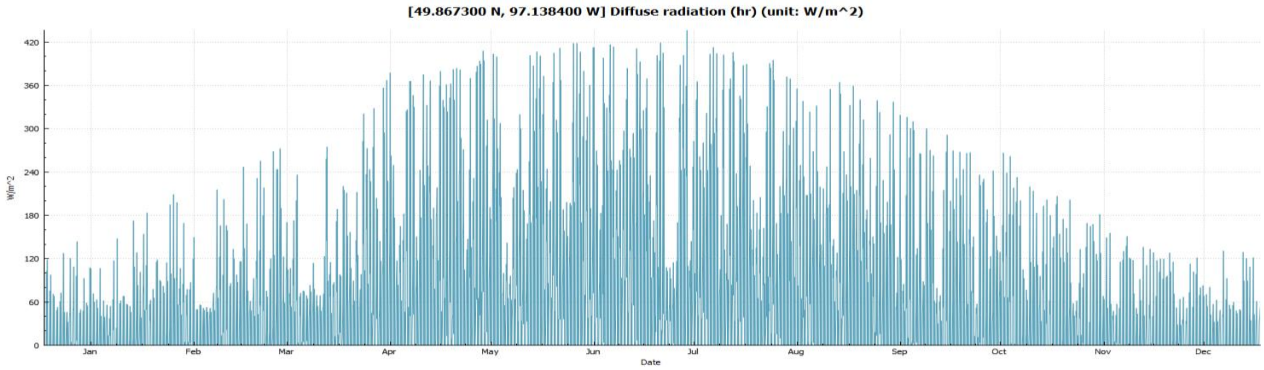


Figure 10: Diffuse Radiation Profile

This timeseries is used for the ambient temperature in PV calculations.

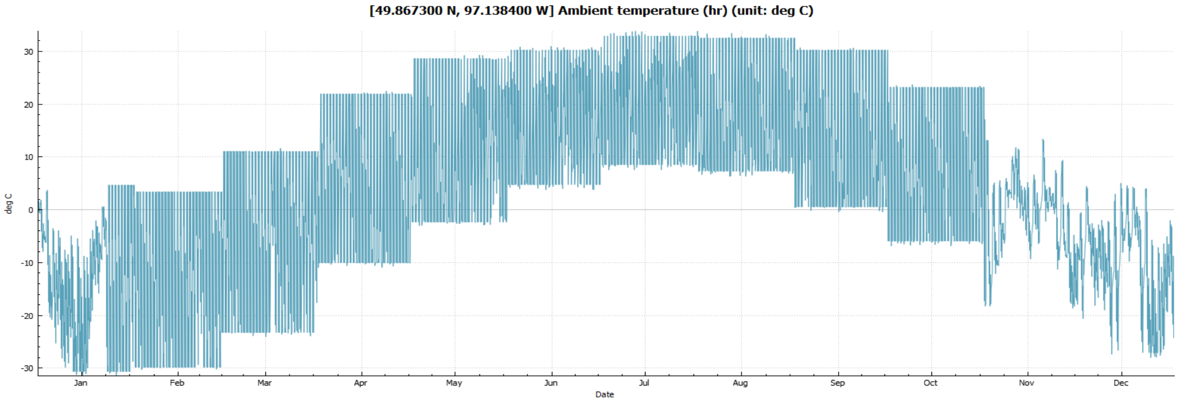


Figure 11: Ambient Temperature Profile

### 2.6.2 Photovoltaic Heatmaps

This heatmap is used for the direct radiation in PV calculations.

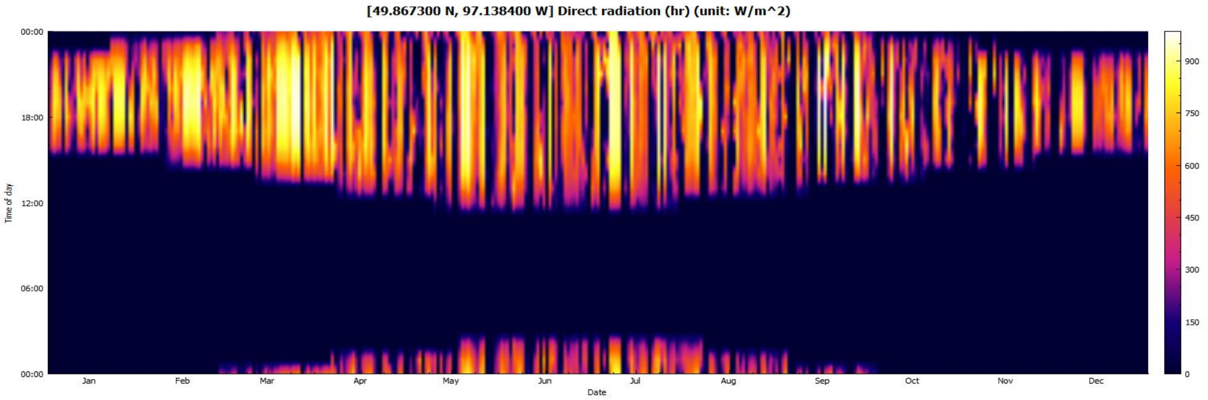


Figure 12: Direct Radiation Heatmap

This heatmap is used for the diffuse radiation in PV calculations.

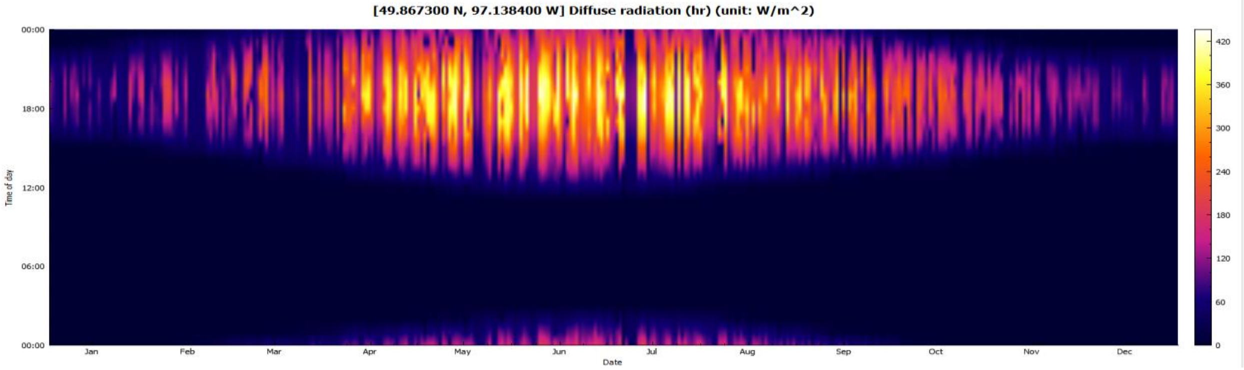


Figure 13: Diffuse Radiation Heatmap

This heatmap is used for the ambient temperature in PV calculations.

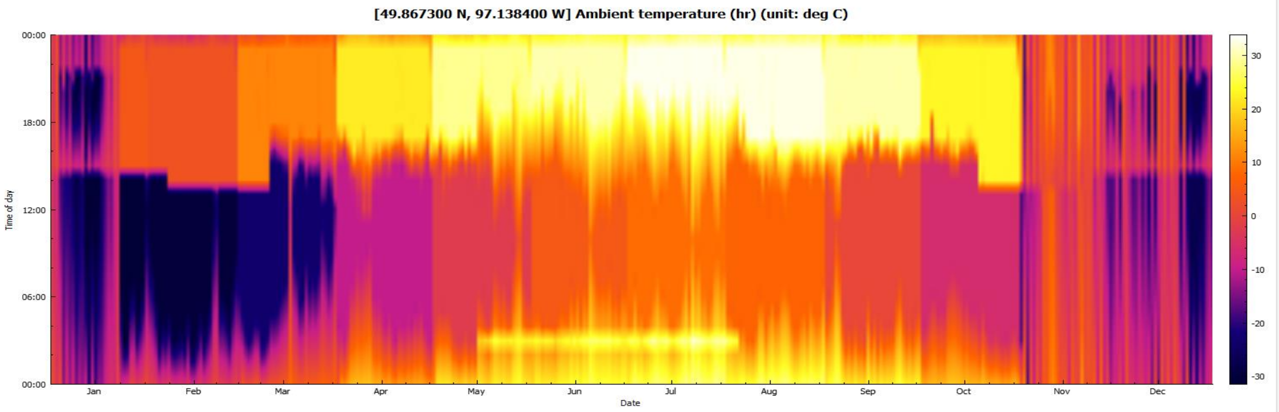


Figure 14: Ambient Temperature Heatmap

# 3 PROJECT SETUP AND DISPATCH

## 3.1 ELECTRICAL INFRASTRUCTURE RISK

The project has one major risk that needs to be addressed, which is how will the infrastructure handle the new demand being brought into the system. The load profiles are adjusted based on the estimated percentage for each month as shown in table 3. For this exercise, the worst case, 100% load, was considered instead of the weighted estimates.

### 3.1.1 WHEN IS THE GRID POWER SUPPLY NOT SUFFICIENT?

In order to understand the problem better, we need to determine when there is a risk that the grid cannot properly supply the demand:

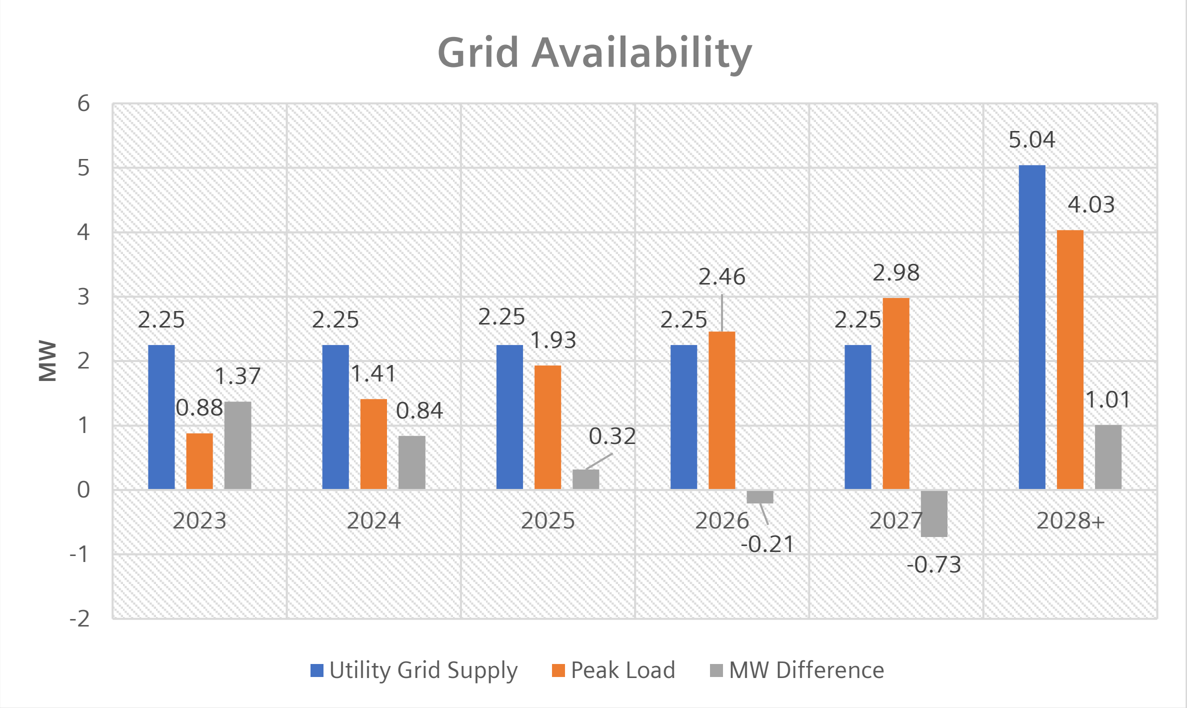


Figure 15: Grid Availability vs System Load

As shown in the graph above, the peak load (charging load plus building demand) is less than the maximum grid capacity until the fourth year, at which time there is a risk of an electrical capacity deficit of 210 kW. In the fifth year, there is a risk of an electrical capacity deficit of 730 kW.

### 3.1.2 HOW MUCH PER MONTH TO DISCHARGE TO MEET DEMAND?

For year four, the grid supply available is only 210 kW lower than the peak demand of the load during the year. Therefore, when there is a risk of an electrical capacity deficit, the 225-kW diesel generator currently onsite could be used to effectively manage these peak loading events.

The other alternative to operating the diesel generator is to reduce the electric buses deployed during the peak months, if necessary. The below graph shows the limit of the grid and load profile for year 4. The table below shows key details highlighting which months the load would need to be lowered:

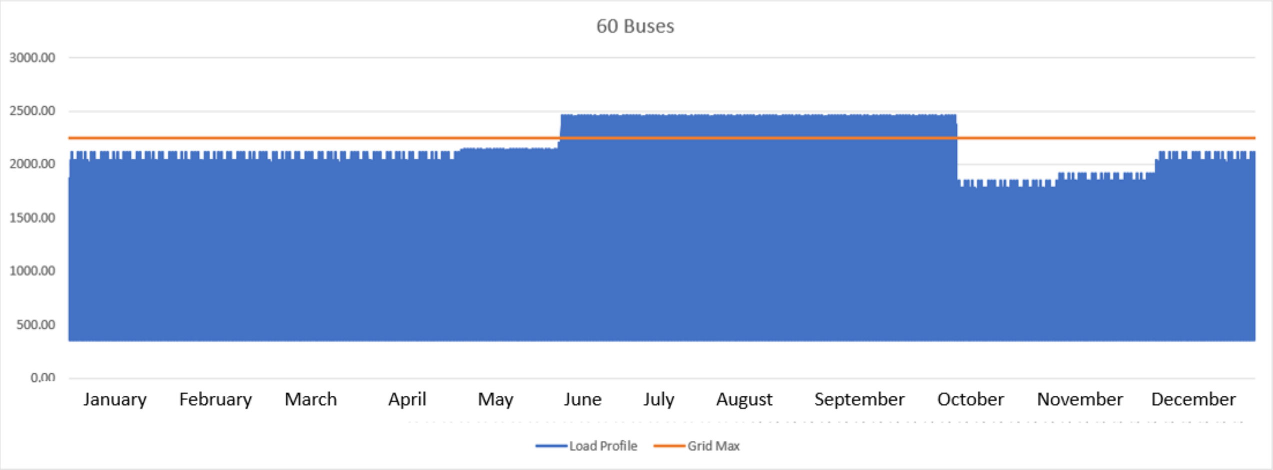
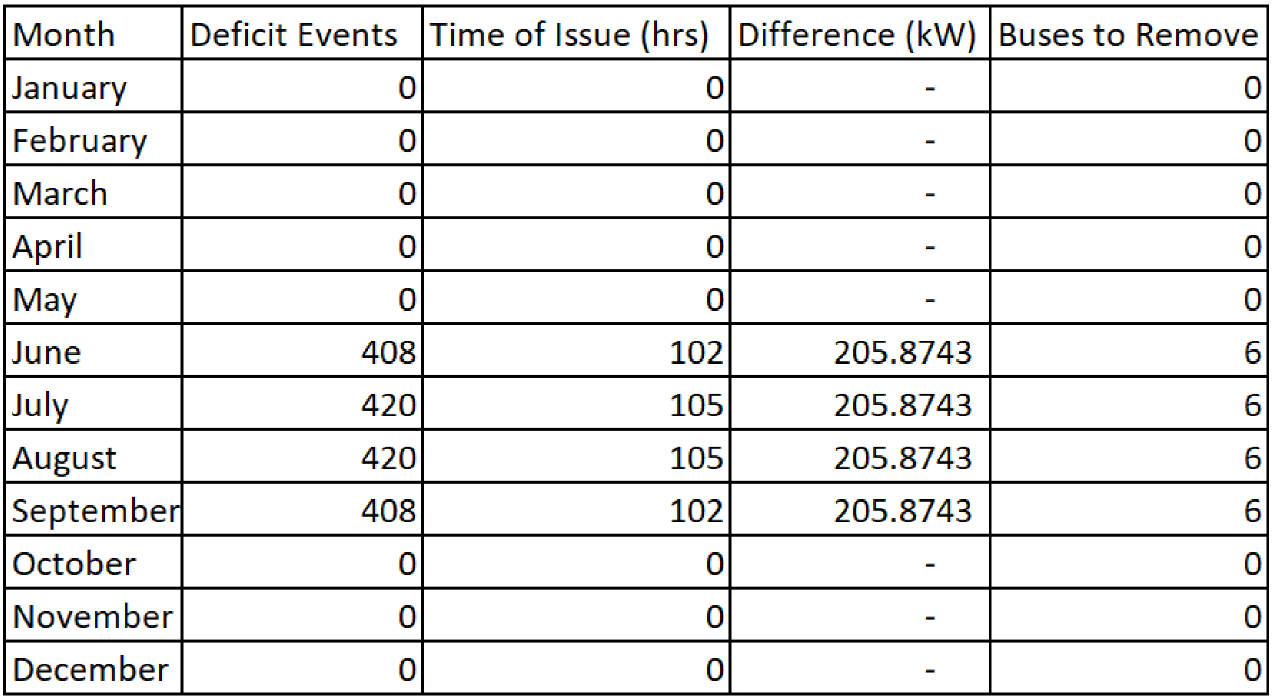


Figure 16: Load profile of 60 Buses plus Building Base Load



| Month | Deficit Events | Time of Issue (hrs) | Difference (kW) | Buses to Remove |
|---|---|---|---|---|
| January | 0 | 0 | - | 0 |
| February | 0 | 0 | - | 0 |
| March | 0 | 0 | - | 0 |
| April | 0 | 0 | - | 0 |
| May | 0 | 0 | - | 0 |
| June | 408 | 102 | 205.8743 | 6 |
| July | 420 | 105 | 205.8743 | 6 |
| August | 420 | 105 | 205.8743 | 6 |
| September | 408 | 102 | 205.8743 | 6 |
| October | 0 | 0 | - | 0 |
| November | 0 | 0 | - | 0 |
| December | 0 | 0 | - | 0 |

Table 6: Monthly Details for 60 buses

For year 5, the demand difference is much greater and running the diesel generator alone would not suffice. To better understand the possible demand requirements for year 5, three different load profiles were addressed. Firstly, if the onboarding schedule for the battery electric buses (BEB) stays on track, 75 BEBs would be in circulation. For the second scenario we are considering 79 BEBs, as Winnipeg Transit has indicated that this could be a potential intermediary phase for the electrification of the fleet. Lastly, we simulated 72 buses, which would reflect 90% availability of 79.

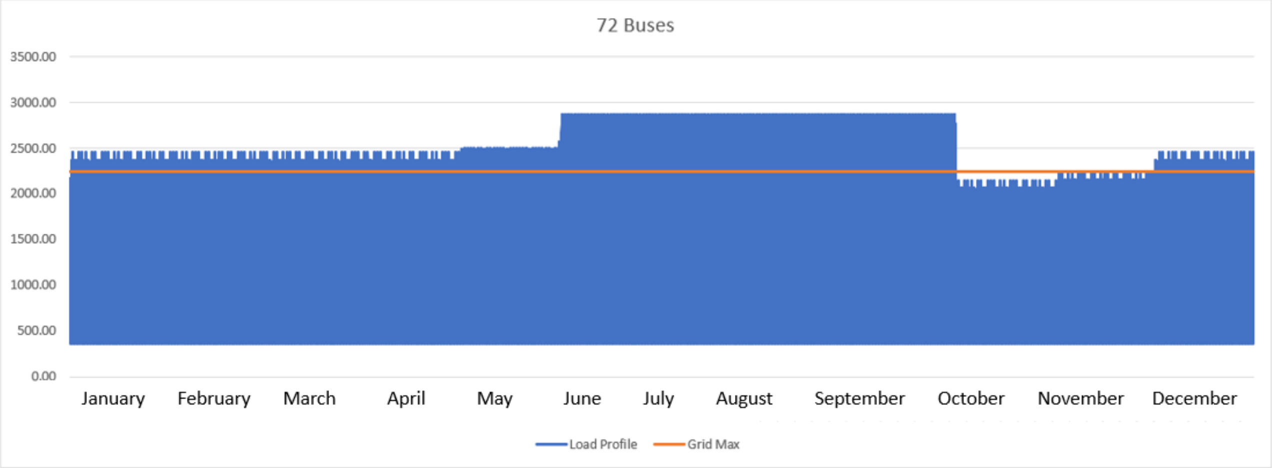


Figure 17: Load profile of 72 Buses plus Building Base Load

| Month | Deficit Events | Time of Issue (hrs) | Difference (kW) | Buses to Remove |
|---|---|---|---|---|
| January | 221 | 55.25 | 212.4000 | 8 |
| February | 200 | 50 | 212.4000 | 8 |
| March | 221 | 55.25 | 212.4000 | 8 |
| April | 215 | 53.7 | 212.4000 | 8 |
| May | 421 | 105.25 | 247.7918 | 10 |
| June | 942 | 235.5 | 625.0491 | 18 |
| July | 975 | 243.75 | 625.0491 | 18 |
| August | 975 | 243.75 | 625.0491 | 18 |
| September | 942 | 235.5 | 625.0491 | 18 |
| October | 0 | 0 | - | 0 |
| November | 0 | 0 | - | 0 |
| December | 221 | 55.25 | 212.4000 | 8 |

Table 7: Monthly Details for 72 buses

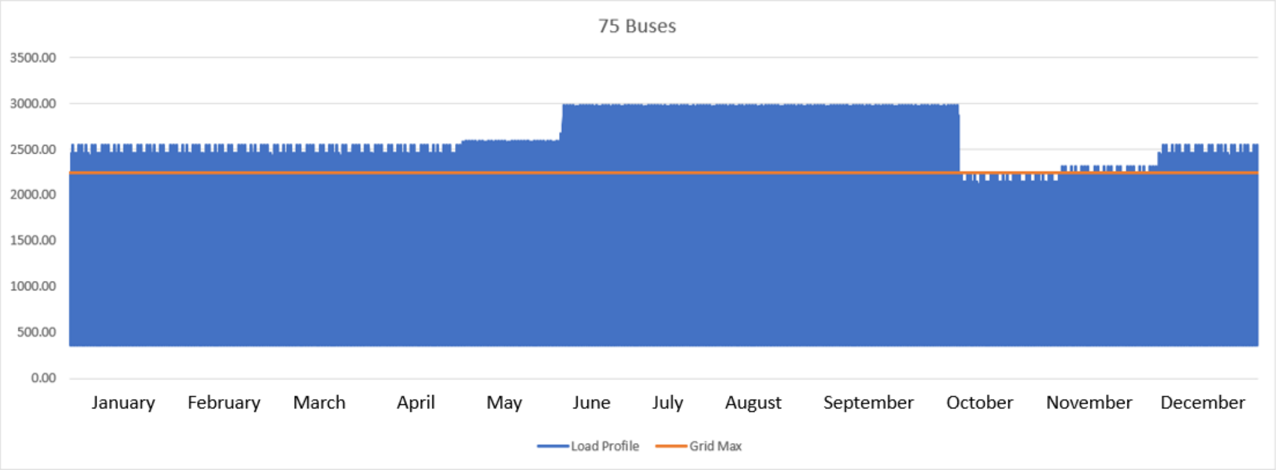
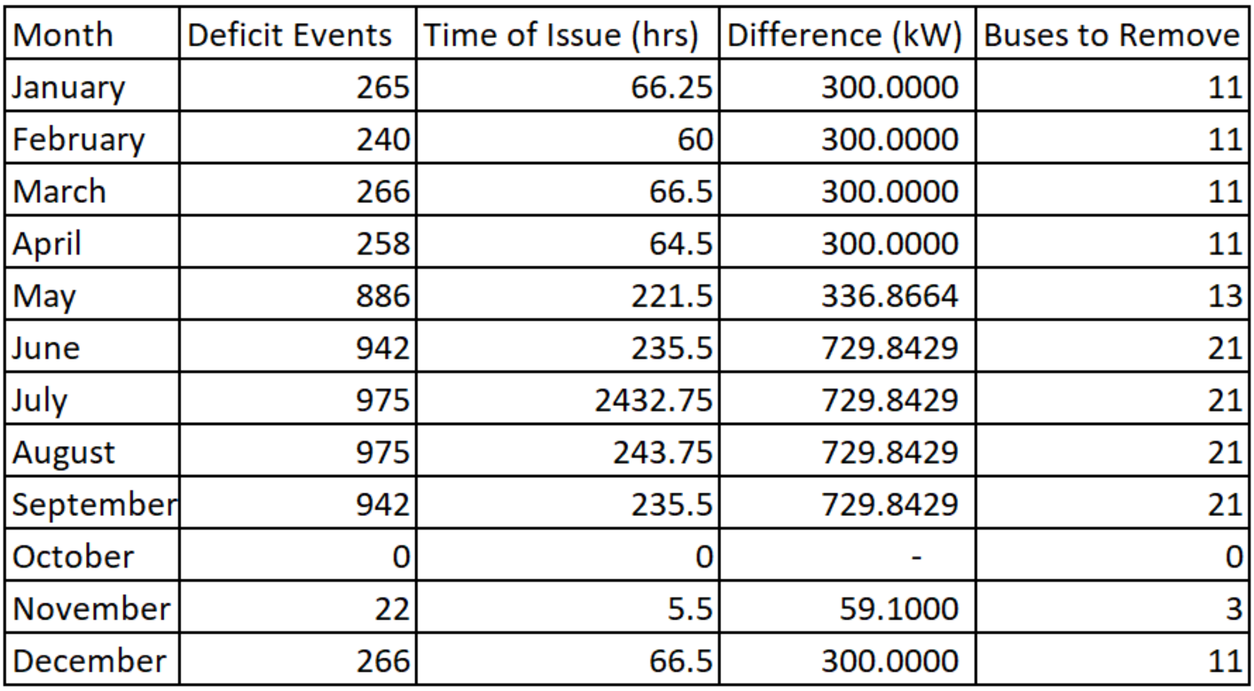


Figure 18: Load profile of 75 Buses plus Building Base Load



| Month | Deficit Events | Time of Issue (hrs) | Difference (kW) | Buses to Remove |
|---|---|---|---|---|
| January | 265 | 66.25 | 300.0000 | 11 |
| February | 240 | 60 | 300.0000 | 11 |
| March | 266 | 66.5 | 300.0000 | 11 |
| April | 258 | 64.5 | 300.0000 | 11 |
| May | 886 | 221.5 | 336.8664 | 13 |
| June | 942 | 235.5 | 729.8429 | 21 |
| July | 975 | 2432.75 | 729.8429 | 21 |
| August | 975 | 243.75 | 729.8429 | 21 |
| September | 942 | 235.5 | 729.8429 | 21 |
| October | 0 | 0 | - | 0 |
| November | 22 | 5.5 | 59.1000 | 3 |
| December | 266 | 66.5 | 300.0000 | 11 |

Table 8: Monthly Details for 75 buses

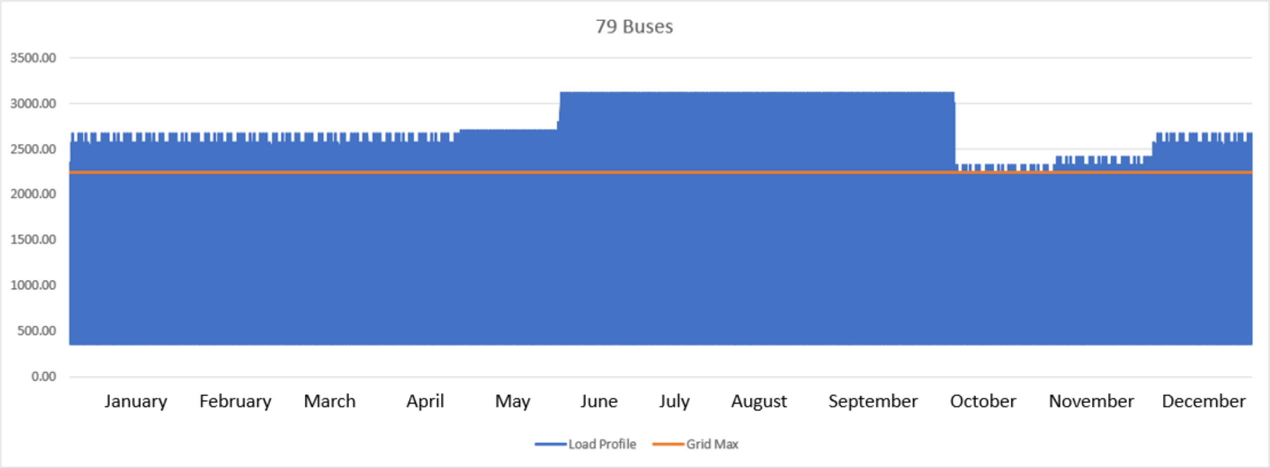
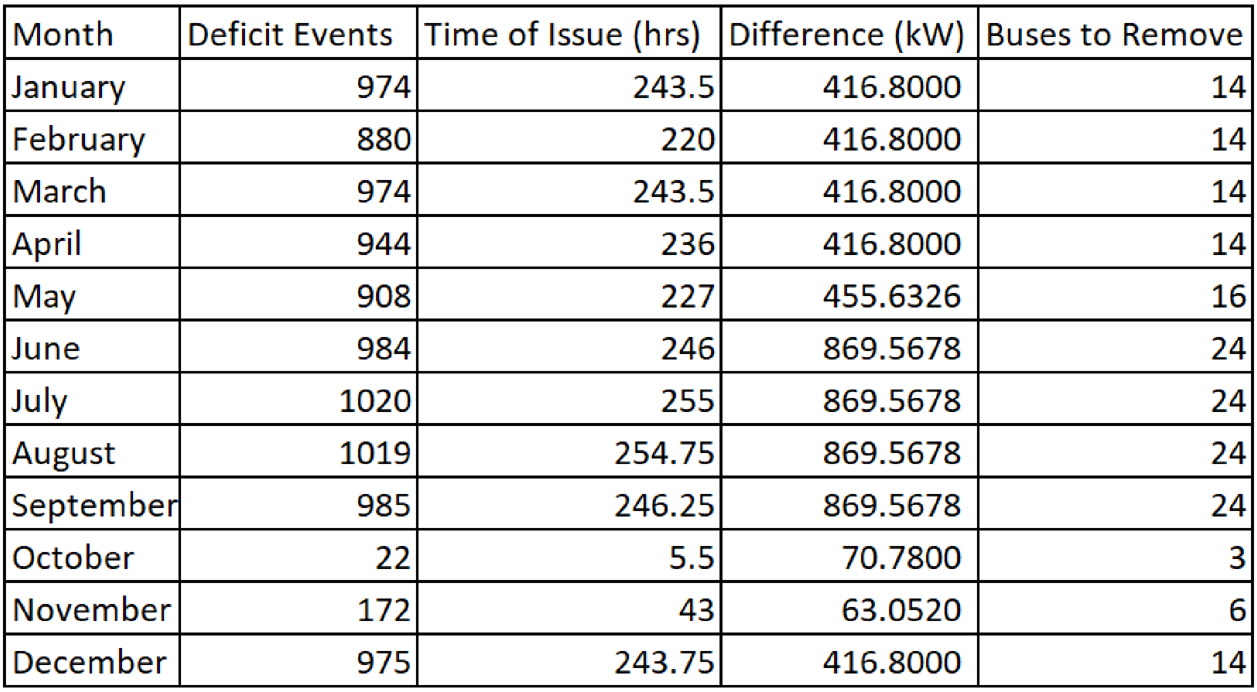


Figure 19: Load profile of 79 Buses plus Building Base Load



| Month | Deficit Events | Time of Issue (hrs) | Difference (kW) | Buses to Remove |
|---|---:|---:|---:|---:|
| January | 974 | 243.5 | 416.8000 | 14 |
| February | 880 | 220 | 416.8000 | 14 |
| March | 974 | 243.5 | 416.8000 | 14 |
| April | 944 | 236 | 416.8000 | 14 |
| May | 908 | 227 | 455.6326 | 16 |
| June | 984 | 246 | 869.5678 | 24 |
| July | 1020 | 255 | 869.5678 | 24 |
| August | 1019 | 254.75 | 869.5678 | 24 |
| September | 985 | 246.25 | 869.5678 | 24 |
| October | 22 | 5.5 | 70.7800 | 3 |
| November | 172 | 43 | 63.0520 | 6 |
| December | 975 | 243.75 | 416.8000 | 14 |

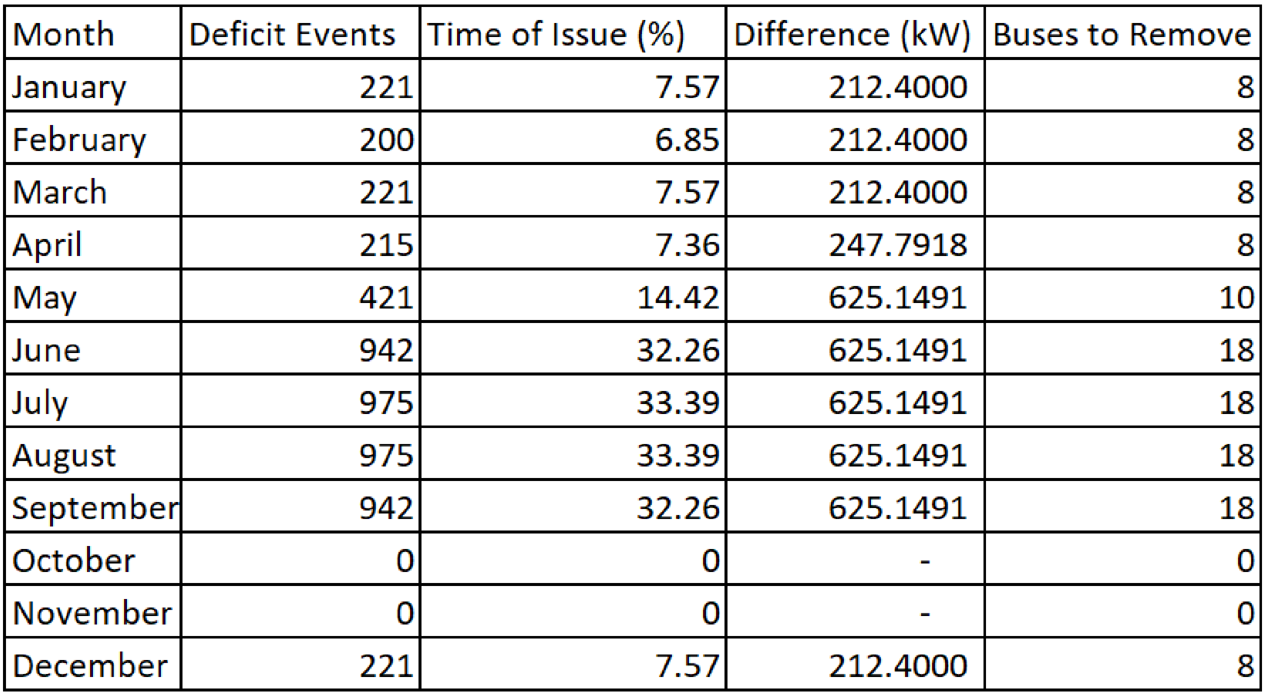
Table 9: Monthly Details for 79 buses

## 3.2 SOLVING INFRASTRUCTURE PROBLEM FOR YEAR 5

Since the diesel generator alone will not be sufficient when operating 72+ buses prior to the grid upgrade, there are three alternatives to analyze: Case 0 – Do nothing and evaluate the likeliness of the worst-case scenario, while accepting the risks of not meeting the electrical charging demand, Case 1 - Implementing a rooftop solar and energy storage without the use of the current onsite generator, and Case 2 - Implementing rooftop solar and energy storage with the use of the current diesel generator.

### 3.2.1 CASE 0 – DO NOTHING

First, let's start by understanding the percentage of the year in each month when a deficit event occurs. Note: a deficient event is a time when the charging requirements of the operational electric buses exceeds the grid's capacity.



| Month | Deficit Events | Time of Issue (%) | Difference (kW) | Buses to Remove |
|---|---:|---:|---:|---:|
| January | 221 | 7.57 | 212.4000 | 8 |
| February | 200 | 6.85 | 212.4000 | 8 |
| March | 221 | 7.57 | 212.4000 | 8 |
| April | 215 | 7.36 | 247.7918 | 8 |
| May | 421 | 14.42 | 625.1491 | 10 |
| June | 942 | 32.26 | 625.1491 | 18 |
| July | 975 | 33.39 | 625.1491 | 18 |
| August | 975 | 33.39 | 625.1491 | 18 |
| September | 942 | 32.26 | 625.1491 | 18 |
| October | 0 | 0 | - | 0 |
| November | 0 | 0 | - | 0 |
| December | 221 | 7.57 | 212.4000 | 8 |

Table 10: Monthly % Peak is missed for 72 Buses Deployed

For most months, the percentage of time when the demand is too high is under 10% of the total month. However, when we reapply the adjusted estimates shown in table 3, the maximum peak of the load profile is always under the threshold. This is also the case when we simulate 79 out of the 105 BEBs, with the adjusted profile. Additional real-world data is needed to validate the magnitude and frequency of these events. A suggested KPI would be to track the real energy consumption data of the BEBs vs. the predicted worst-case consumption, to compare how often and when there is a deviation between the two data points.

### 3.2.2 CASE 1 - SOLAR AND BATTERY WITHOUT DIESEL GENERATOR

The second option is to install a combination of battery storage and solar panels to increase the potential supply for the worst-case load, while using a microgrid system as the main controller for all operations. As the high peak is throughout the evening, the battery is necessary to limit the curtailed energy from the PV. The battery will store the excess PV energy and discharge it throughout the evening.

The topology view shows the superset of all components used in the project.

Current Grid Infrastructure with new rooftop solar and battery energy storage system

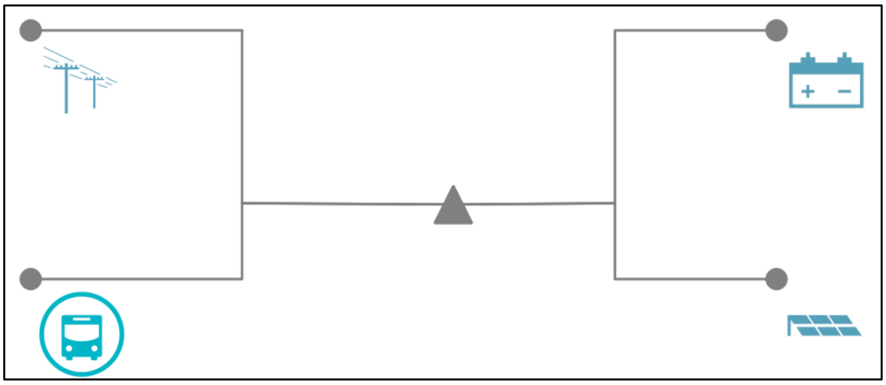


Figure 20: High Level SLD of PV and BESS

### 3.2.3 CASE 2 - SOLAR AND BATTERY WITH DIESEL GENERATOR

The next option is to utilize the battery, rooftop solar and onsite diesel generator, again using a microgrid system to control all operations. The generator is used as an additional resiliency measure in case the mix of solar and battery isn't sufficient to supply the load.

Current Grid Infrastructure and diesel generator, with new rooftop solar and battery storage system

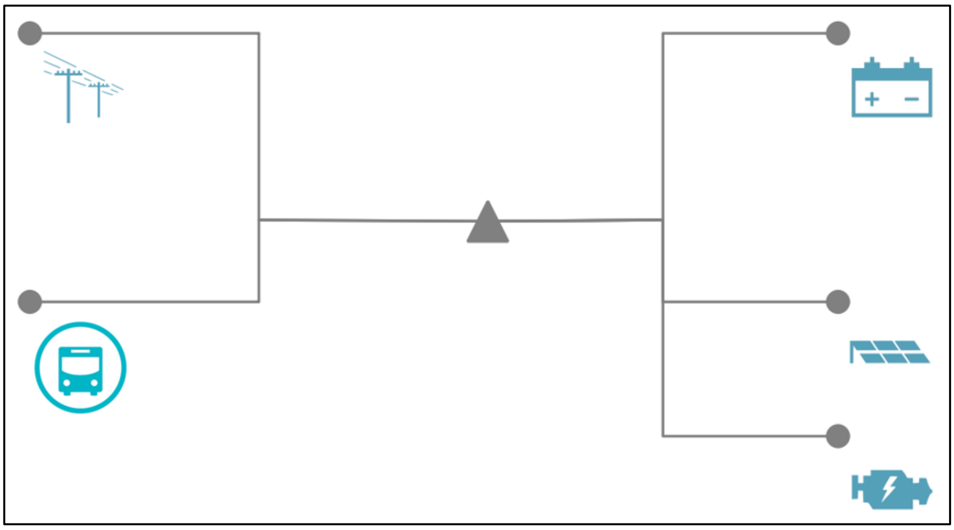


Figure 21: High Level SLD of PV, BESS, and Diesel Generator

# 4 SIZING RESULTS

Note: an explanation of the Sizing Optimization process which Siemens uses is described in the report's Appendix, under Section 8.1.

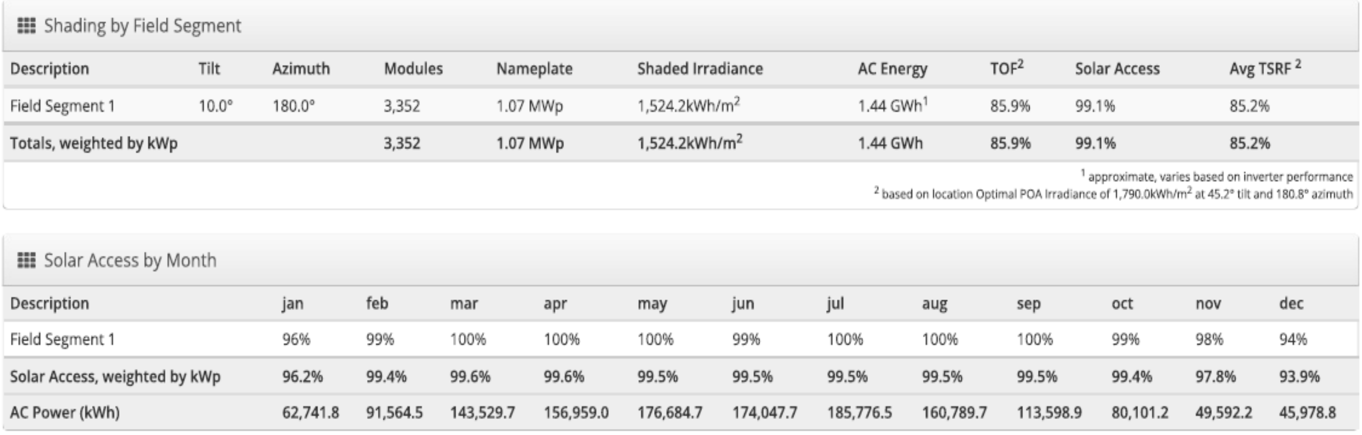
The following section shows results derived from the simulation of various sizing analysis, to determine the optimal size of the battery based on the rooftop top solar. The first is to determine the potential size of the rooftop solar. A separate report had been conducted previously for Winnipeg Transit. This value was cross referenced to ensure the estimate calculated was in line with their estimate. Once the rooftop solar size was finalized, sizing of the battery was completed.

## 4.1 ROOFTOP SOLAR ESTIMATE

The first image shows the estimated layout of the solar panel array from a topside view:

Figure 22: Potential Rooftop Solar Layout

Below you will find a table showing technical values of the simulation. These values are based on the information shown in section 2.6 and run in the PV estimation software. All outputs show the adjusted outputs after all losses are considered (i.e., Inverter losses, inverter efficiency etc.):



Shading by Field Segment

| Description | Tilt | Azimuth | Modules | Nameplate | Shaded Irradiance | AC Energy | TOF[2] | Solar Access | Avg TSRF [2] |
|---|---|---|---|---|---|---|---|---|---|
| Field Segment 1 | 10.0° | 180.0° | 3,352 | 1.07 MWp | 1,524.2kWh/m$^2$ | 1.44 GWh[1] | 85.9% | 99.1% | 85.2% |
| **Totals, weighted by kWp** | | | **3,352** | **1.07 MWp** | **1,524.2kWh/m$^2$** | **1.44 GWh** | **85.9%** | **99.1%** | **85.2%** |

[1] approximate, varies based on inverter performance

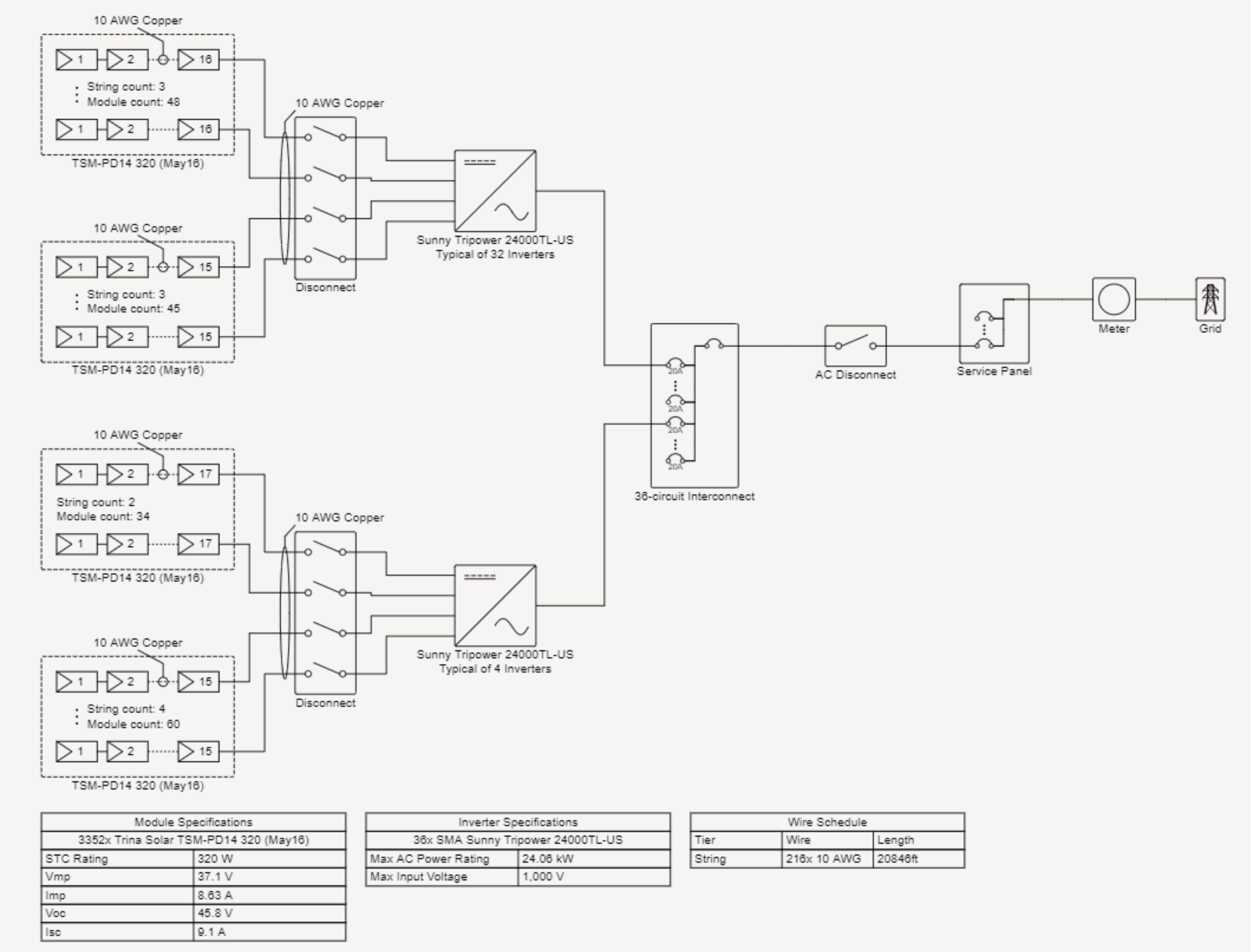
[2] based on location Optimal POA Irradiance of 1,790.0kWh/m$^2$ at 45.2° tilt and 180.8° azimuth

Solar Access by Month

| Description | jan | feb | mar | apr | may | jun | jul | aug | sep | oct | nov | dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field Segment 1 | 96% | 99% | 100% | 100% | 100% | 99% | 100% | 100% | 100% | 99% | 98% | 94% |
| **Solar Access, weighted by kWp** | **96.2%** | **99.4%** | **99.6%** | **99.6%** | **99.5%** | **99.5%** | **99.5%** | **99.5%** | **99.5%** | **99.4%** | **97.8%** | **93.9%** |
| **AC Power (kWh)** | **62,741.8** | **91,564.5** | **143,529.7** | **156,959.0** | **176,684.7** | **174,047.7** | **185,776.5** | **160,789.7** | **113,598.9** | **80,101.2** | **49,592.2** | **45,978.8** |

Figure 23: Project Rooftop Solar Values

The final image is the potential single line diagram of the solar panel array:



| Module Specifications | |
|---|---|
| 3352x Trina Solar TSM-PD14 320 (May16) | |
| STC Rating | 320 W |
| Vmp | 37.1 V |
| Imp | 8.63 A |
| Voc | 45.8 V |
| Isc | 9.1 A |

| Inverter Specifications | |
|---|---|
| 36x SMA Sunny Tripower 24000TL-US | |
| Max AC Power Rating | 24.06 kW |
| Max Input Voltage | 1,000 V |

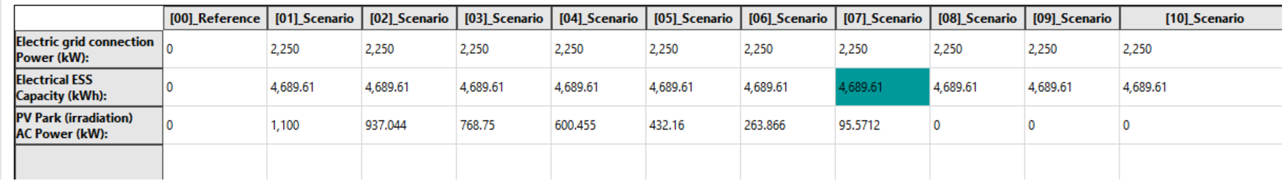
| Wire Schedule | | |
|---|---|---|
| Tier | Wire | Length |
| String | 216x 10 AWG | 20846ft |

Figure 24: Rooftop Solar High Level SLD

## 4.2 SIZING OF CASE 1: SOLAR AND BATTERY

The final step for case 1 is to determine the battery size needed to maximize the PV output. This was done using the sizing tool within the software. First, the software takes in the current setup of the site as a base line. Then capacity and financial limits are set for any new assets being simulated. For this sizing exercise, a maximum of 6,000 kWh was set for the BESS and 1,100kW for the rooftop solar. As the aim was to maximize rooftop solar penetration, the BESS size was chosen based on that value. The load profile used in sizing was the worst case in year five, having 79 out of the 105 buses online and running.

As shown in the image below, the suggested BESS size was 4.689 MWh for all scenarios. This is the value that will be used in the dispatch analysis.



| | [00]_Reference | [01]_Scenario | [02]_Scenario | [03]_Scenario | [04]_Scenario | [05]_Scenario | [06]_Scenario | [07]_Scenario | [08]_Scenario | [09]_Scenario | [10]_Scenario |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Electric grid connection Power (kW):** | 0 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 |
| **Electrical ESS Capacity (kWh):** | 0 | 4,689.61 | 4,689.61 | 4,689.61 | 4,689.61 | 4,689.61 | 4,689.61 | 4,689.61 | 4,689.61 | 4,689.61 | 4,689.61 |
| **PV Park (irradiation) AC Power (kW):** | 0 | 1,100 | 937.044 | 768.75 | 600.455 | 432.16 | 263.866 | 95.5712 | 0 | 0 | 0 |
| | | | | | | | | | | | |

Figure 25: BESS Sizing Configurations

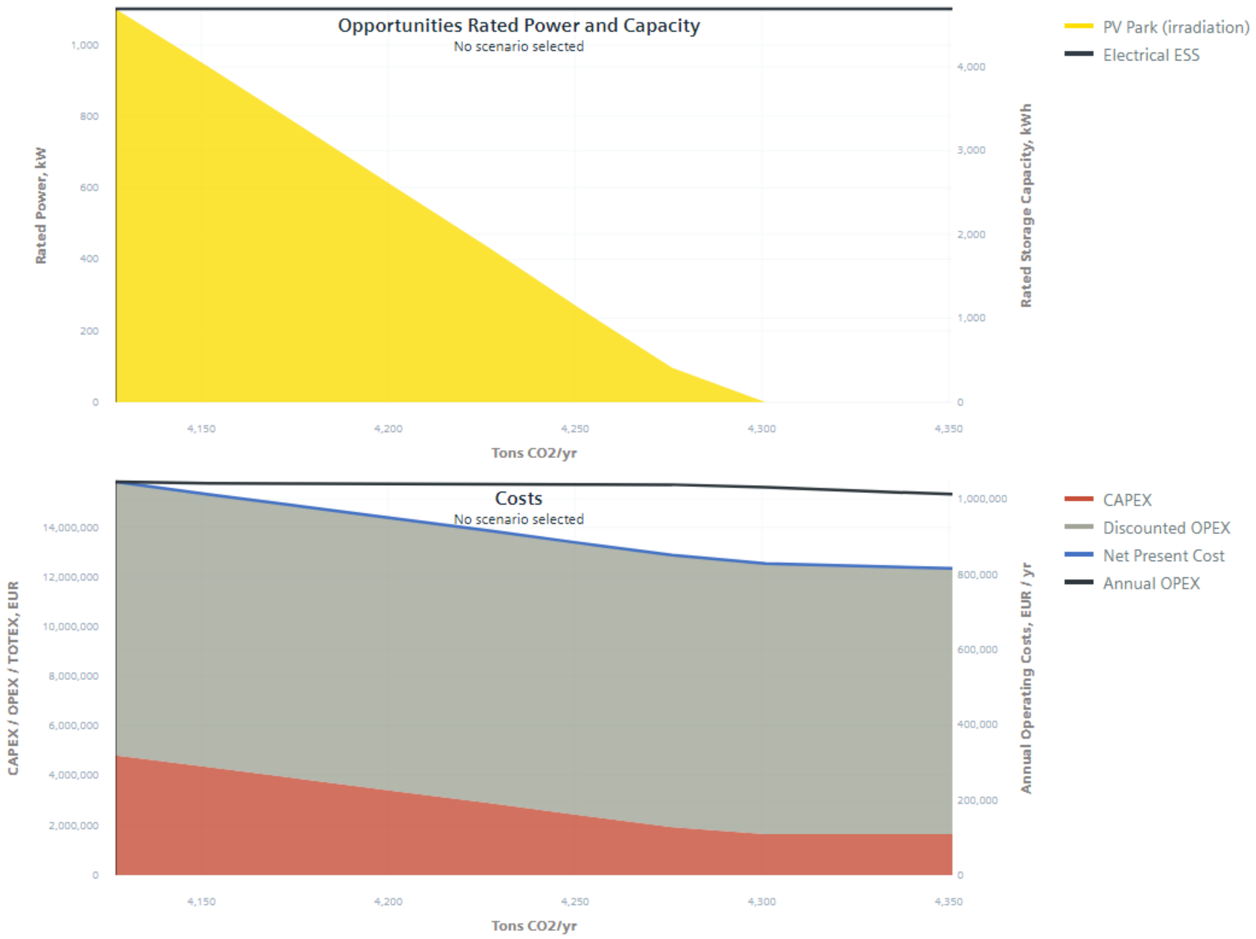
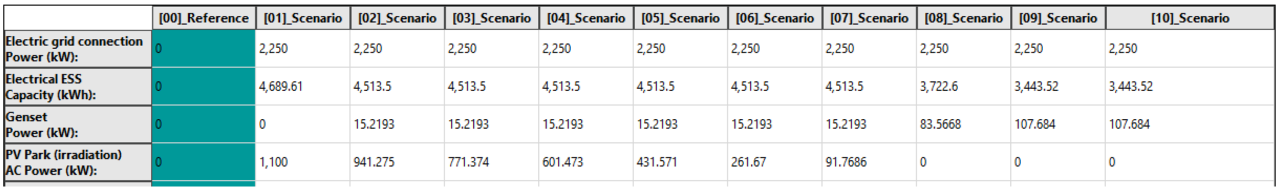


Figure 26: Opportunity Curve

There are two main graphs as outputs of the sizing optimization. The top graph represents the technical size of the asset. The lower graph identifies the CAPEX and OPEX of the assets. On the horizontal axis from left to right are 10 separate scenarios. The farther left the scenario is on the X axis, the higher priority the algorithm placed on GHG emissions reductions. The farther right the scenario was, the higher priority was given towards cost reduction. As shown on the top graph, the farther left the scenario was, the higher the suggested PV was, as it reduces overall CO2 output. However, the corresponding costs for that scenario was the highest.

## 4.3 SIZING OF CASE 2: SOLAR, BATTERY AND DIESEL GENERATOR

We repeat the final step, but add the opportunity of the diesel generator, to a maximum of 225 kW. The resulting size optimization was 4,513 kWh for the battery and 15 kW for the diesel generator, as shown below. This battery size will be used for this scenario during the dispatch analysis. The only case where the diesel generator needed to provide more than 15 kW was when zero PV was utilized:



| | [00]_Reference | [01]_Scenario | [02]_Scenario | [03]_Scenario | [04]_Scenario | [05]_Scenario | [06]_Scenario | [07]_Scenario | [08]_Scenario | [09]_Scenario | [10]_Scenario |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric grid connection Power (kW): | 0 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 | 2,250 |
| Electrical ESS Capacity (kWh): | 0 | 4,689.61 | 4,513.5 | 4,513.5 | 4,513.5 | 4,513.5 | 4,513.5 | 4,513.5 | 3,722.6 | 3,443.52 | 3,443.52 |
| Genset Power (kW): | 0 | 0 | 15.2193 | 15.2193 | 15.2193 | 15.2193 | 15.2193 | 15.2193 | 83.5668 | 107.684 | 107.684 |
| PV Park (irradiation) AC Power (kW): | 0 | 1,100 | 941.275 | 771.374 | 601.473 | 431.571 | 261.67 | 91.7686 | 0 | 0 | 0 |

Figure 27: BESS Sizing Configurations

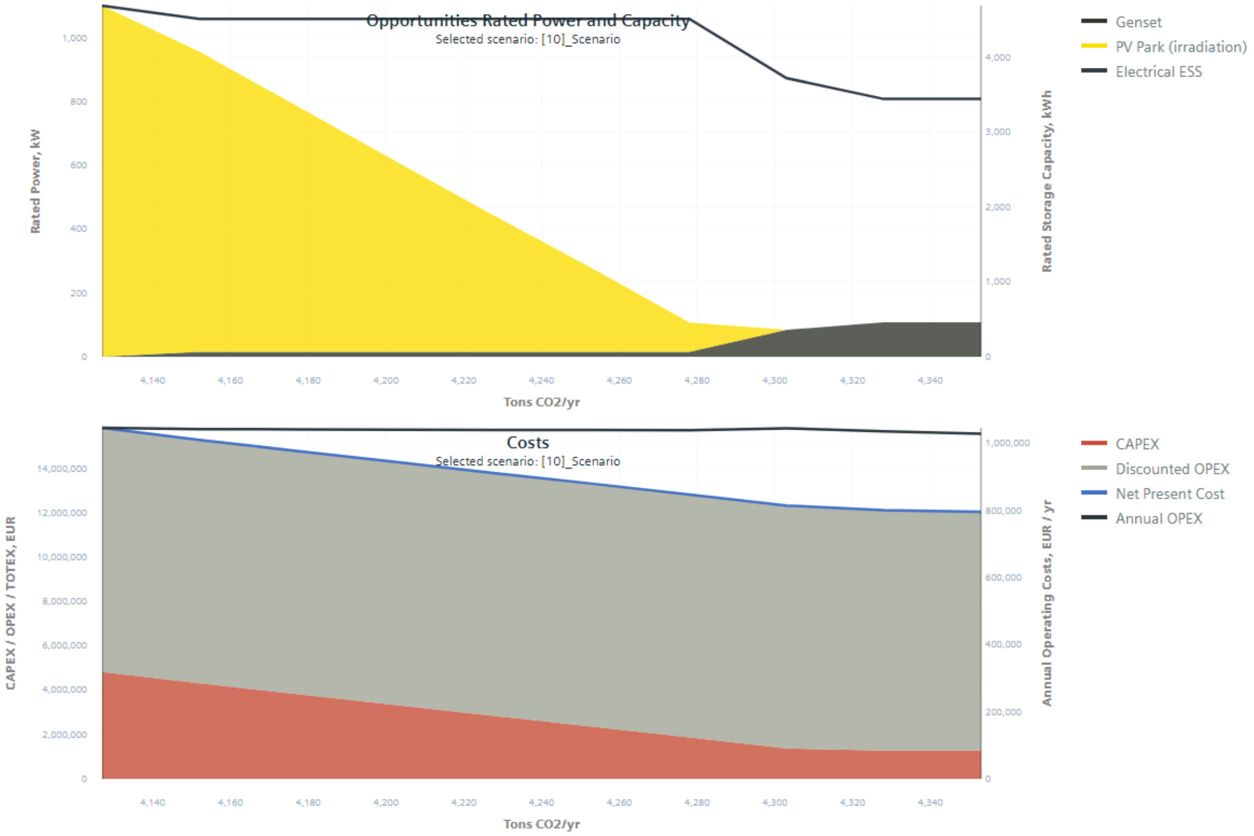


Figure 28: Opportunity Curve

# 5 SIMULATION RESULTS - CONFIGURATION COMPARISON

The following section shows results derived from the simulation of the configurations, comparing key results for each configuration. Two scenarios were simulated, each are shown and described on the x-axis of all Figures, with the results shown on the y-axis. Both scenarios used the same microgrid controller.

## 5.1 FINANCIAL COMPARISON

The following financial comparisons show Case 2 on the left, and Case 1 on the right.

### 5.1.1 Financial Inputs

The following financial inputs are used to calculate several KPIs in the report.

| Financial KPI | Value |
|---|---|
| Corporate Tax | 30% |
| Equity Share | 30% |
| Credit Share | 70% |
| Credit Buffer | 5% |
| Interest Rate of Debt | 6% |
| Repayment Period | 14 Years |
| Grace Period | 2 Years |
| Fuel Escalation Year over Year | 2% |
| O&M Escalation Year over Year | 2% |
| Grid Import Escalation Year over Year | 2% |

### 5.1.2 Levelized Cost of Energy (LCoE)

The Levelized Cost of Energy (LCoE) is given for electricity and is shown in the following figure. It is the discounted relative cost of production of energy for the stakeholder. An additional explanation regarding the LCoE methodology can be found in the report’s Appendix, under section 8.2.

Costs for each stakeholder are the sum of what is incurred including CAPEX, OPEX, fuel, replacement, and financing.

Generated energy for a stakeholder includes all produced plus imported Electricity (from both external networks and/or other stakeholders). It is irrelevant how this Electricity is used (i.e., it makes no difference if this is exported, used to supply loads and/or is converted to another energy type).

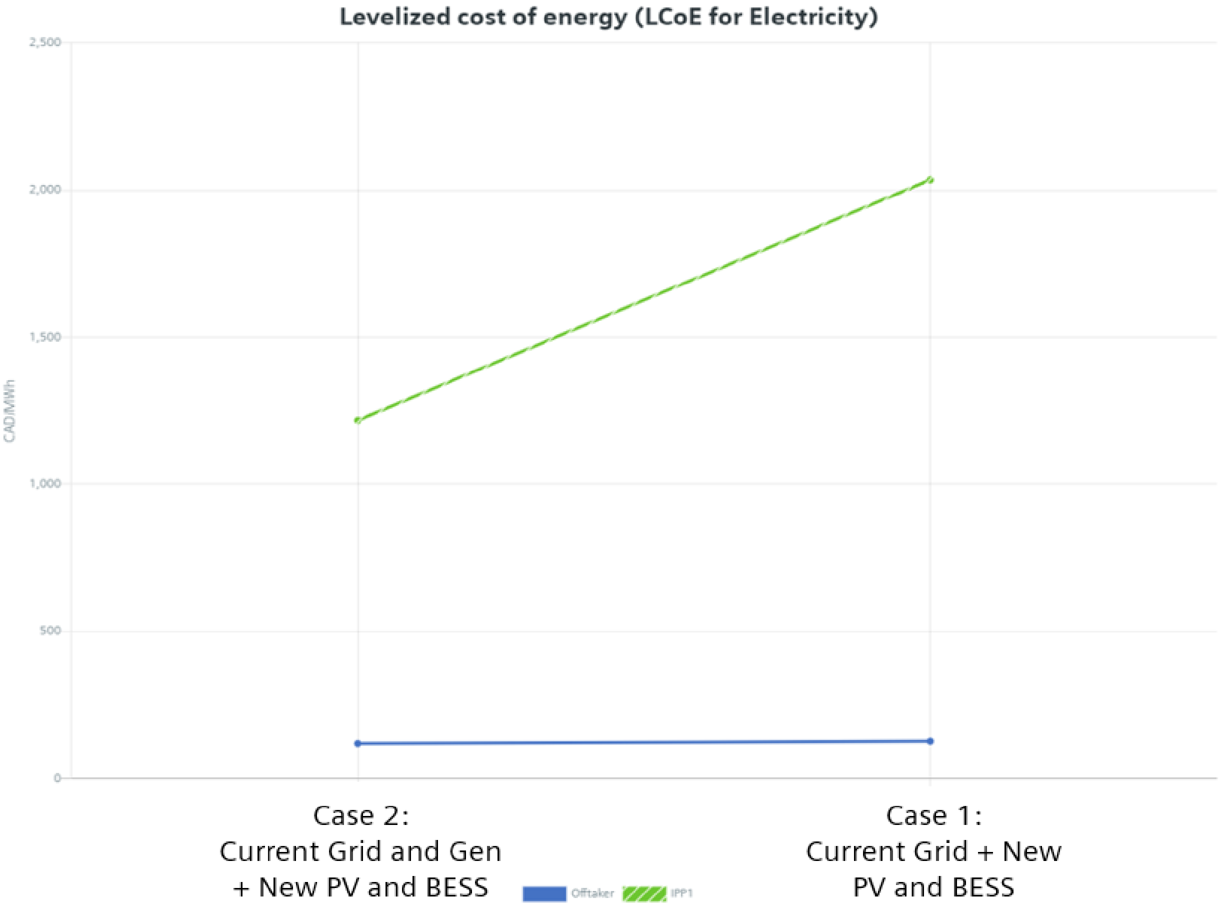


Figure 31: LCoE in Year 1

The levelized cost of energy in the first year is lower for Case 2 vs Case 1 since the additional generator is primarily used to lower demand charges. This is because the requested load is still under the capacity limit of the grid.

## 5.2 ENVIRONMENTAL COMPARISON

### 5.2.1 Annual carbon emissions – comparison of both solutions

The annual carbon emissions for the first year are shown in the following figure.

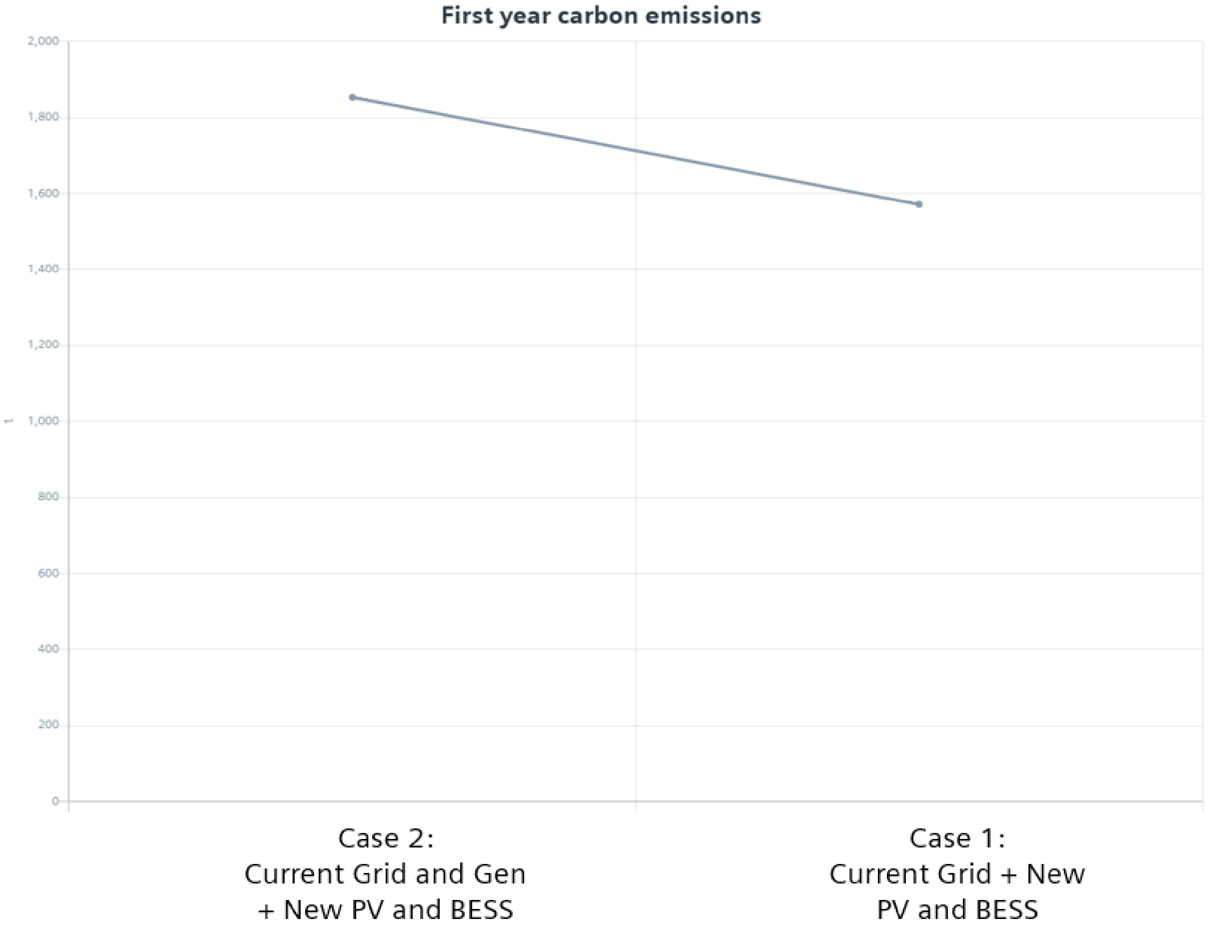


Figure 32: First Year Carbon Emissions

Case 1 compared to Case 2 has a lower output of $CO_2$ emissions, as there is no use of the diesel generator.

The total carbon emissions for the project lifetime are shown below for each Case:

| Case Number | Project Carbon Emissions Estimate |
|---|---|
| **Case 1: Current Grid + New PV and BESS** | 92,445.41 Tons |
| **Case 2: Current Grid and Gen + New PV and BESS** | 95,536.79 Tons |

Table 11: Total Project Carbon Emissions

### 5.2.2 Photovoltaic (PV) Energy Share

The PV energy share for the fourth year at 60 out of 105 buses is shown in the following table. For this table, fourth year values are used as it is the planned installation year for both PV and BESS. This table still reflects some unused energy due to curtailment. The curtailment of energy occurs since the controller must ensure the BESS is charged enough during the day to handle the demand overnight. If the BESS is discharged enough to ensure no curtailment occurs, there is a risk the demand may not be fully met.

| Case Number | PV Energy Share Year 4 | PV Energy Share Overall |
|---|---|---|
| **Case 1: Current Grid + New PV and BESS** | 3.77 % | 2.23 % |
| **Case 2: Current Grid and Gen + New PV and BESS** | 3.76 % | 2.23 % |

Table 12: Renewable Energy Share

| Case Number | Curtailed PV Energy Year 4 | Curtailed PV Energy Overall |
|---|---|---|
| **Case 1: Current Grid + New PV and BESS** | 2.35 MWh | 10.15 MWh |
| **Case 2: Current Grid and Gen + New PV and BESS** | 3.38 MWh | 16.55 MWh |

Table 13: Curtailed Energy

## 5.3 CASHFLOW COMPARISON

### 5.3.1 CAPEX Comparison

The CAPEX is shown in the following figure. It is the total expenditure invested in new assets over the project lifetime. This does not include expenditure for the replacement assets, the electric bus chargers, or the microgrid system.

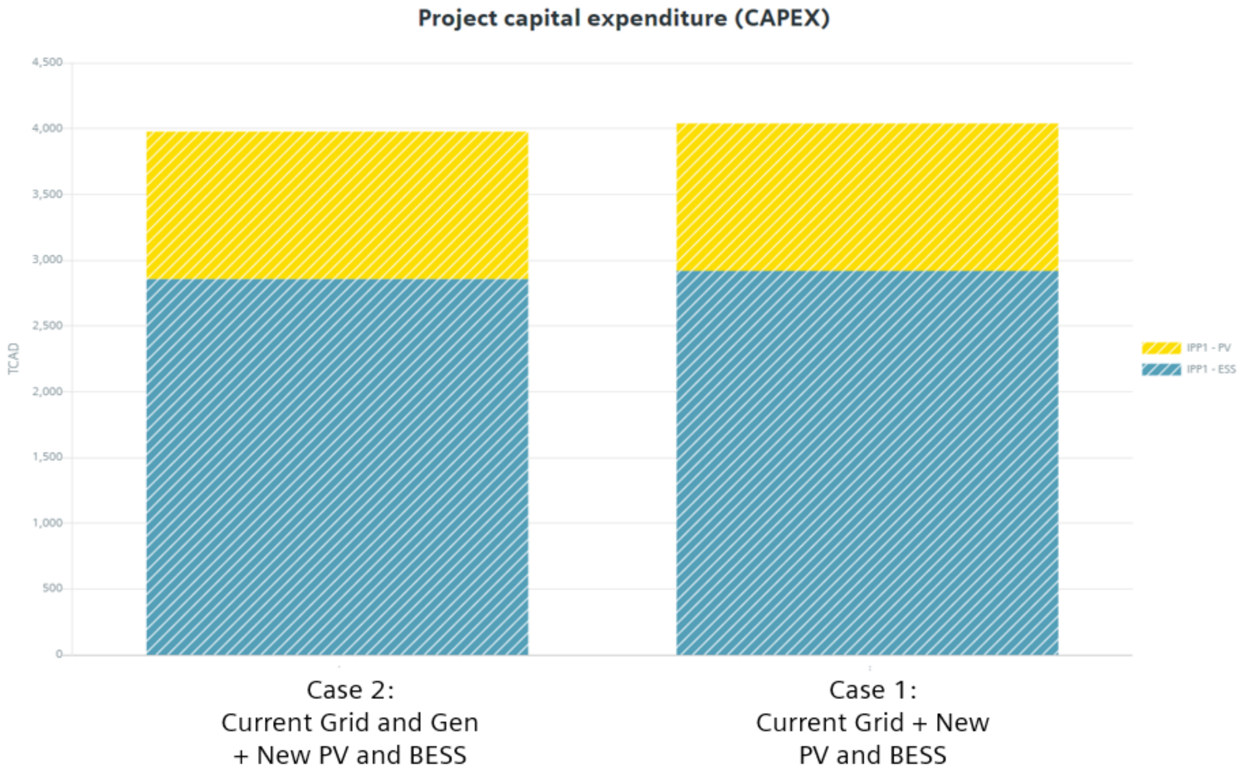


Figure 34: CAPEX

The only difference between the two cases regarding CAPEX is with the size of the battery suggested, as shown in Section 4. Case 1 uses a 4.689 MWh BESS and Case 2 uses a 4.513 MWh BESS. Since the onsite generator is already running, it does not count towards Case 2’s CAPEX calculation.

### 5.3.2 OPEX Comparison

OPEX is shown in the following figure. It is the total expenditure invested in operating costs over the project lifetime. It includes all ongoing costs including operation and maintenance, fuel, imports and exports, replacements, and other ongoing costs. Comparing Case 2 to Case 1, it is shown in the image below that Case 2's OPEX is slightly higher. The main reason is because the high costs of diesel fuel do not offset the additional savings from the demand charge reduction. Case 1 does not have any diesel generator in the simulation.

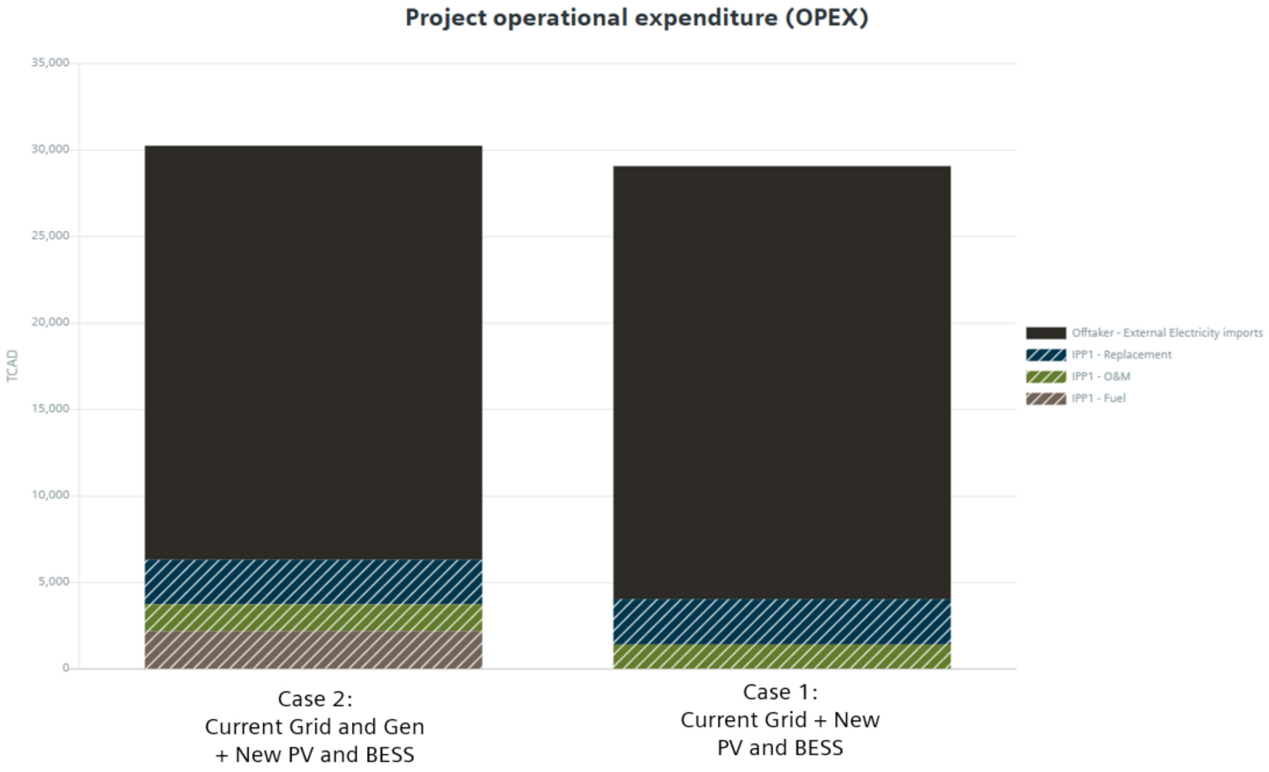


Figure 35: OPEX over the project

The added asset in Case 2 incurs higher demand charge savings when compared to Case 1. The table below shows the project and year 4 demand charges. Once again, Year 4 is shown as it is the install year for the new assets. Even with these additional savings, Case 1 still has a lower overall OPEX.

| Case Number | Demand Charge Year 4 | Demand Charge Overall |
|---|---|---|
| **Reference: Grid Only** | $296,743 CAD | $8,42M CAD |
| **Case 1: Current Grid + New PV and BESS** | $232,668 CAD | $6.84M CAD |
| **Case 2: Current Grid and Gen + New PV and BESS** | $196,705 CAD | $6.12M CAD |

Table 14: Demand Charge Savings

### 5.3.3 Revenue and Expenses Comparison

The summary of both revenue and expenses are shown in the following figure. Revenue includes any salvage value from selling the older assets; while expenses include grid costs, replacement, O&M, Diesel Fuel and CAPEX.

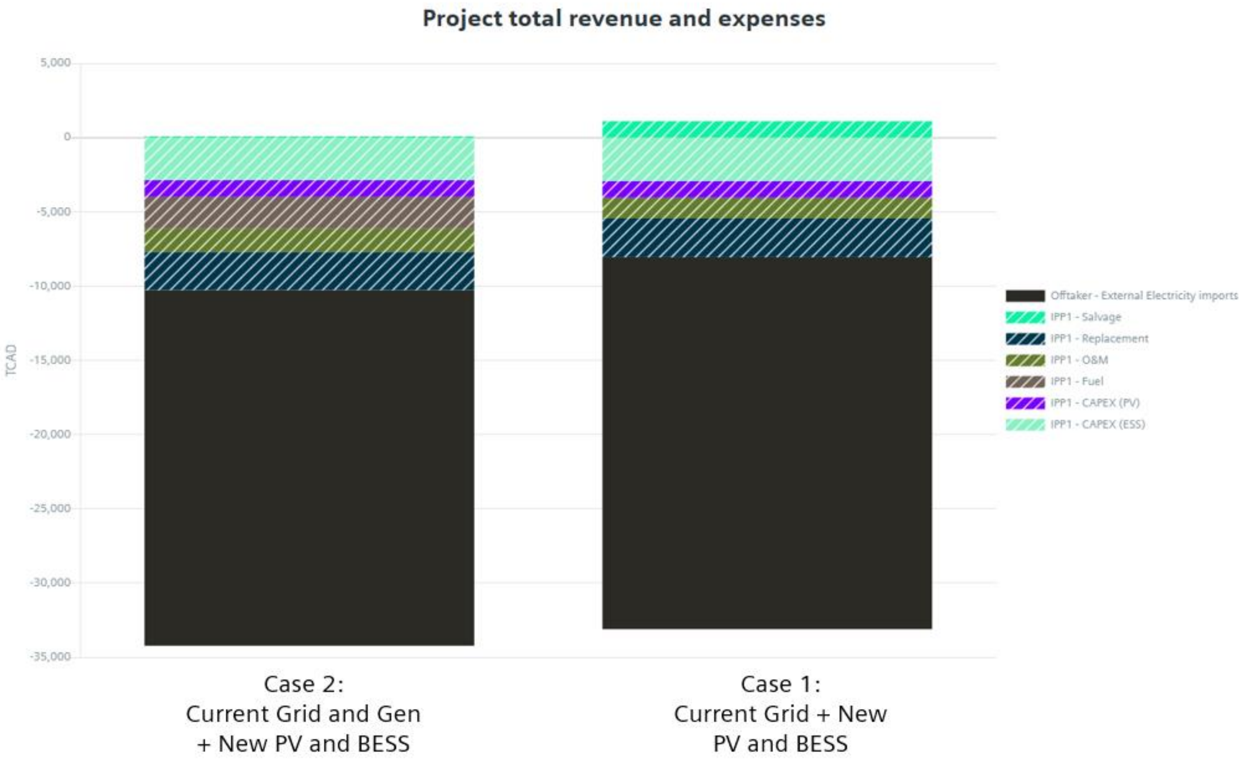


Figure 33: Revenue and Expenses

## 5.4 GENERATION COMPARISON

A generation comparison for the first year is shown in the following figures. The removal of any unnecessary diesel and maximized PV energy use is the main factor distinguishing the two cases.

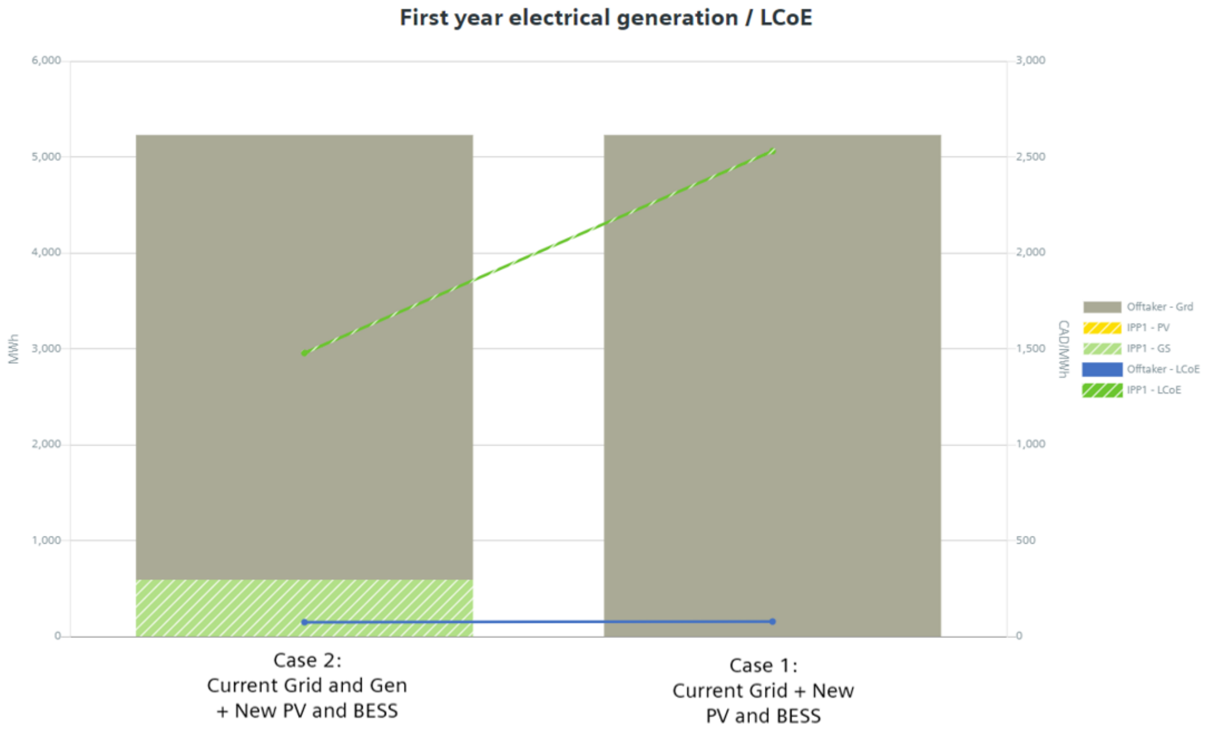


Figure 36: Generation and LCoE for Year 1

| Case Number | Fuel Consumption (kL) Overall | Fuel Consumption (MWh) Overall |
|---|---|---|
| **Case 1: Current Grid + New PV and BESS** | N/A | N/A |
| **Case 2: Current Grid and Gen + New PV and BESS** | 1,429 | 5,196 |

Table 15: Fuel Consumption

# 6 SIMULATION RESULTS – CONFIGURATION ANALYSIS

The following section provides an in-depth analysis of the configurations of interest identified.

## 6.1 ANALYSIS OF CASE 1: CURRENT GRID + NEW ROOFTOP SOLAR AND BESS

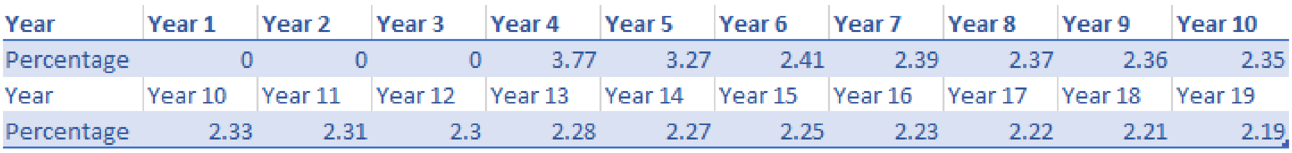
The first case simulated adding new rooftop solar (1.1MW) and battery storage (4.689MWh). Please see some of the main financial KPIs listed from above:

| CAPEX | Total Cost | Total Net Present Cost |
|---|---|---|
| $4.04M CAD | $24.218M CAD | $13.94M CAD |

Table 16: Key Financial KPIs

### 6.1.1 Photovoltaic Energy Share

The potential Photovoltaic Energy Share for this solution is shown in the following table for each year of the project:



| Year | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Percentage | 0 | 0 | 0 | 3.77 | 3.27 | 2.41 | 2.39 | 2.37 | 2.36 | 2.35 |
| Year | Year 10 | Year 11 | Year 12 | Year 13 | Year 14 | Year 15 | Year 16 | Year 17 | Year 18 | Year 19 |
| Percentage | 2.33 | 2.31 | 2.3 | 2.28 | 2.27 | 2.25 | 2.23 | 2.22 | 2.21 | 2.19 |

Figure 37: Renewable Energy Share

### 6.1.2 Energy Flow

Below shows the Sankey diagram for the fourth year. On the left-hand side, it shows the sources of energy, that being solar and grid. On the far right, you will see the loads that are accepting the energy. Finally, the middle shows the bus that connects the source to load. Load 1 is the charging load from the buses and Load 2 is the building load.

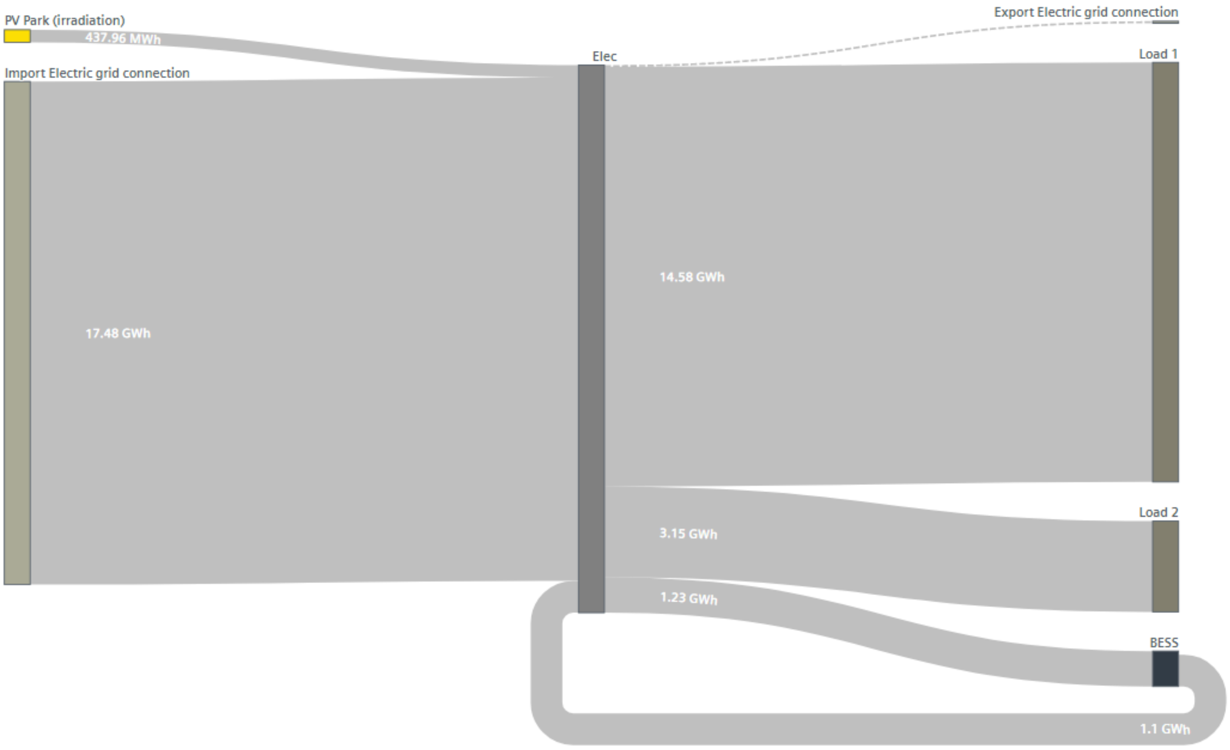


Figure 38: Renewable Energy Share

An additional explanation regarding Sankey diagrams can be found in the report’s Appendix, under section 8.3.

### 6.1.3 Expenses

The expenses for case 1 are shown in the following figure.

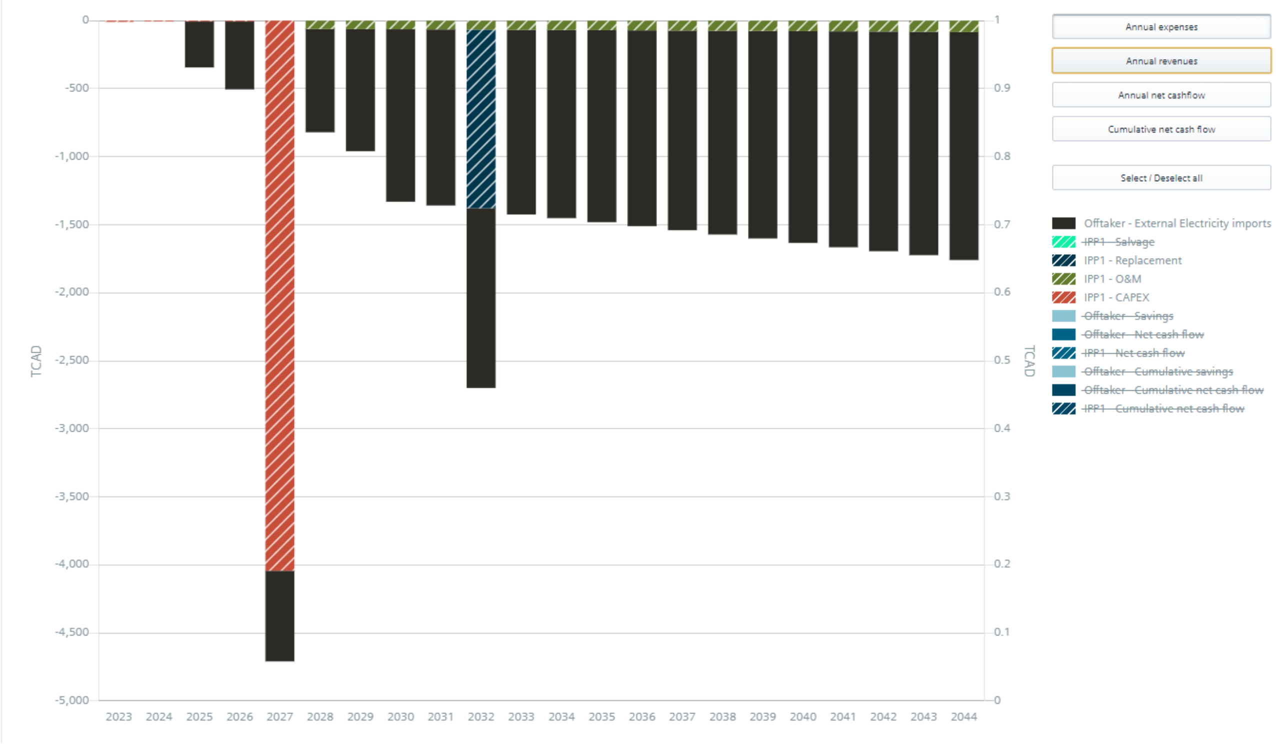


Figure 39: Revenue and Expenses for Case 1

### 6.1.4 Cashflow

The cashflow is shown in the following figure.

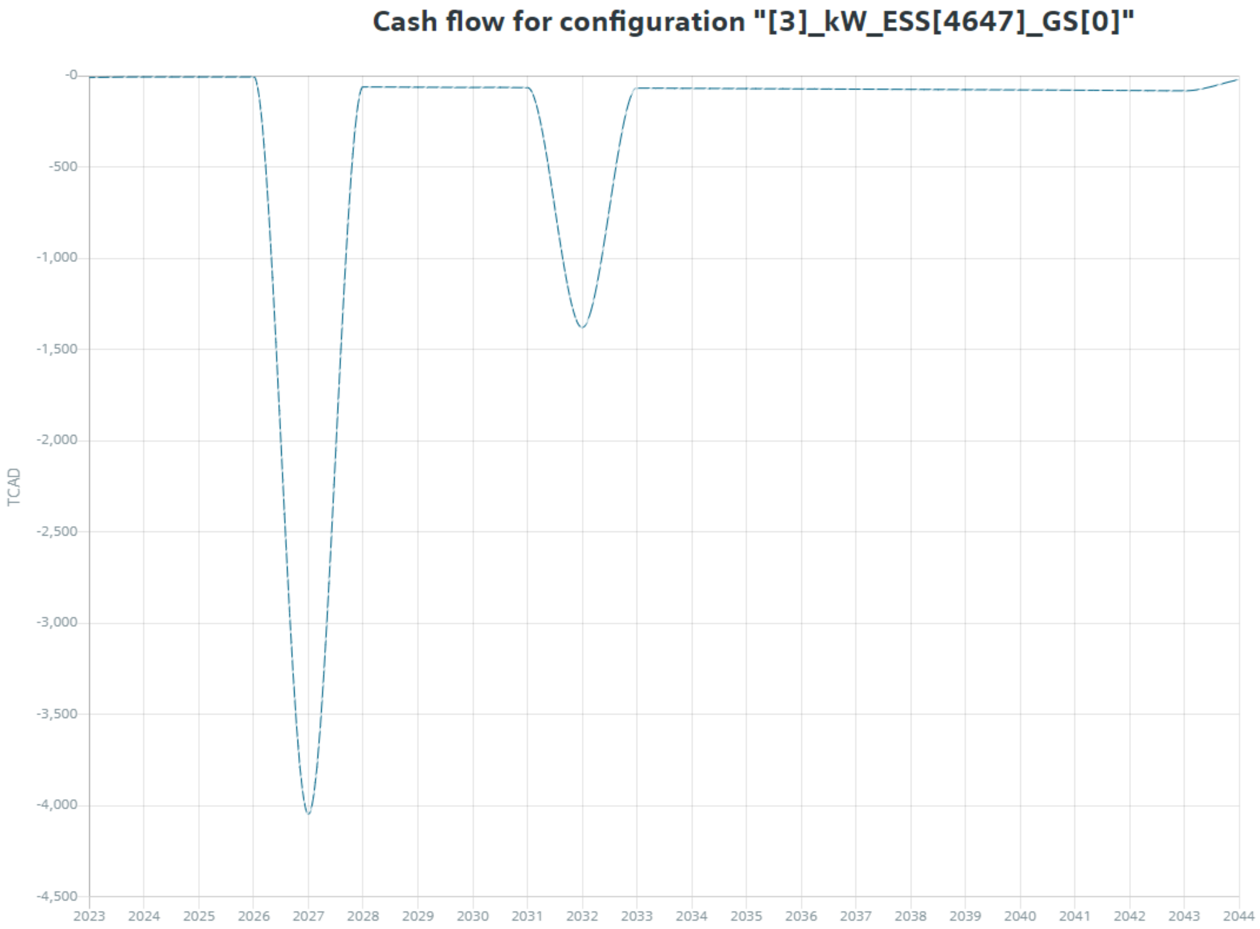


Figure 40: Cash Flow for Case 1

### 6.1.5 Generation

The generation breakdown for Case 1 is shown in the following figures. Majority of energy is from grid.

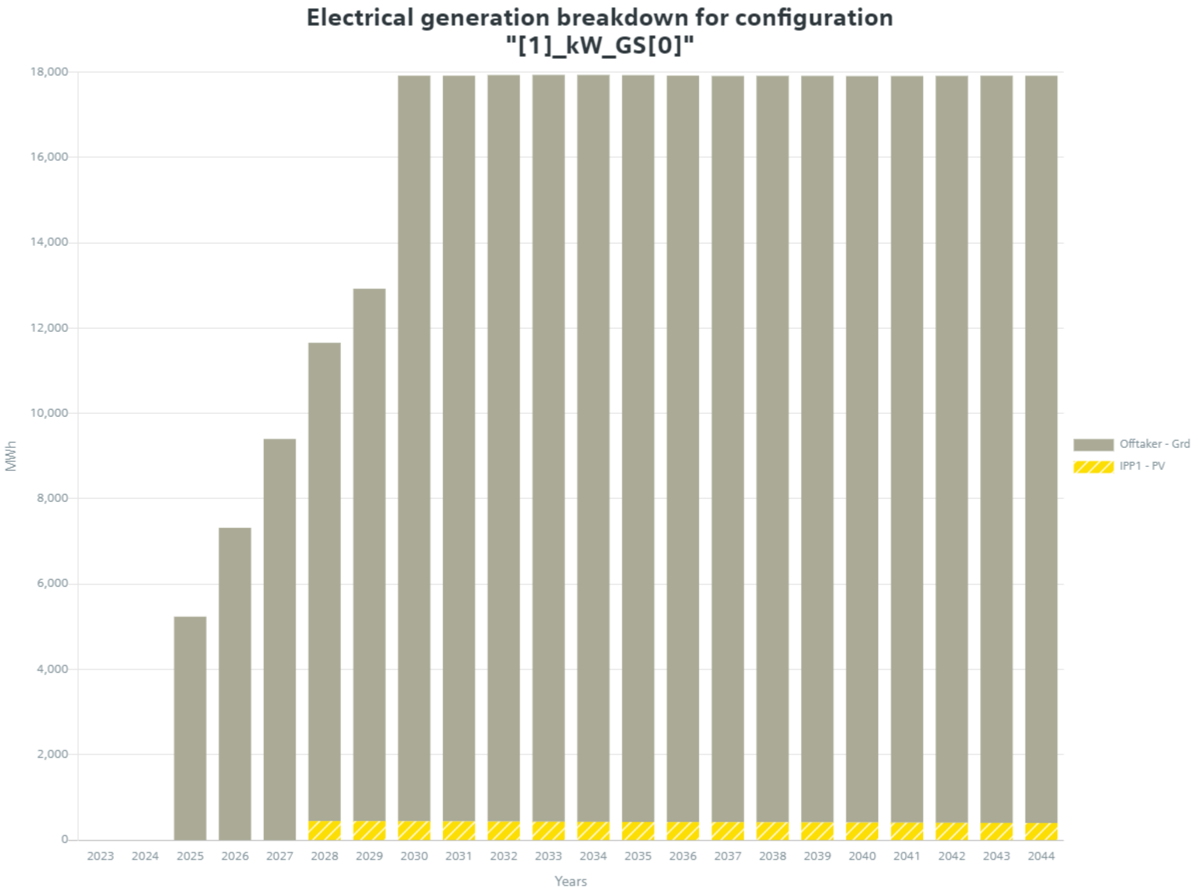


Figure 41: Generation Breakdown

### 6.1.6 Importance of the Energy Storage

The battery plays a pivotal role in maximizing the PV energy as most of the demand is overnight, and the PV energy is created throughout the day. The below graph shows the curtailed energy on the top chart and the utilized energy on the bottom when no battery is implemented.

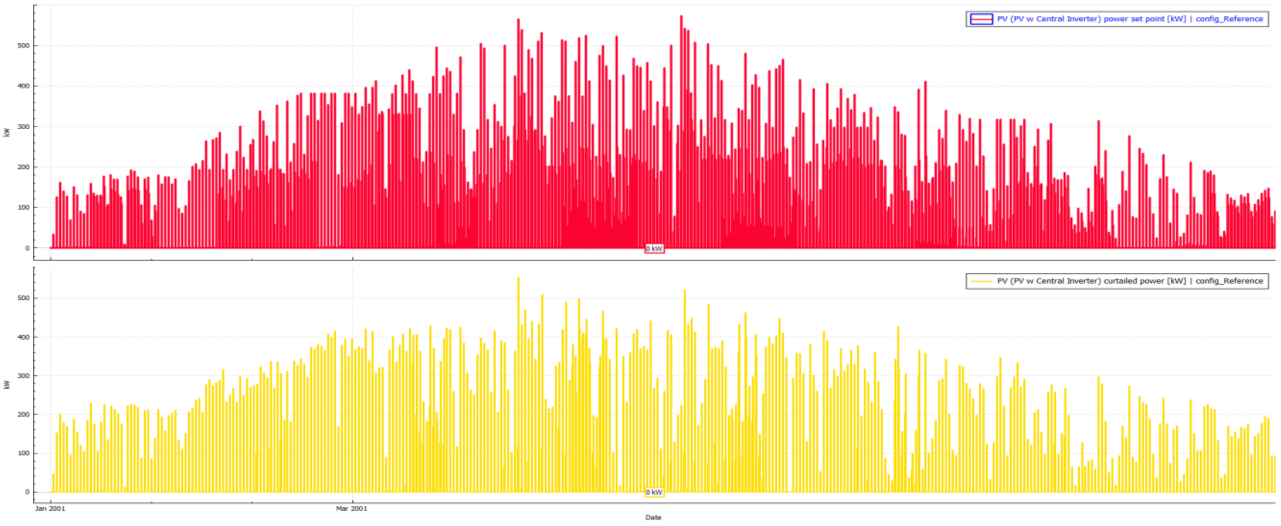


Figure 42: Curtailment over the year

The next figure shows the daily interaction of the energy. The top profile is the available PV energy, the second is what was used to supply the load, the third is the curtailed energy, and the fourth is the demanded load.

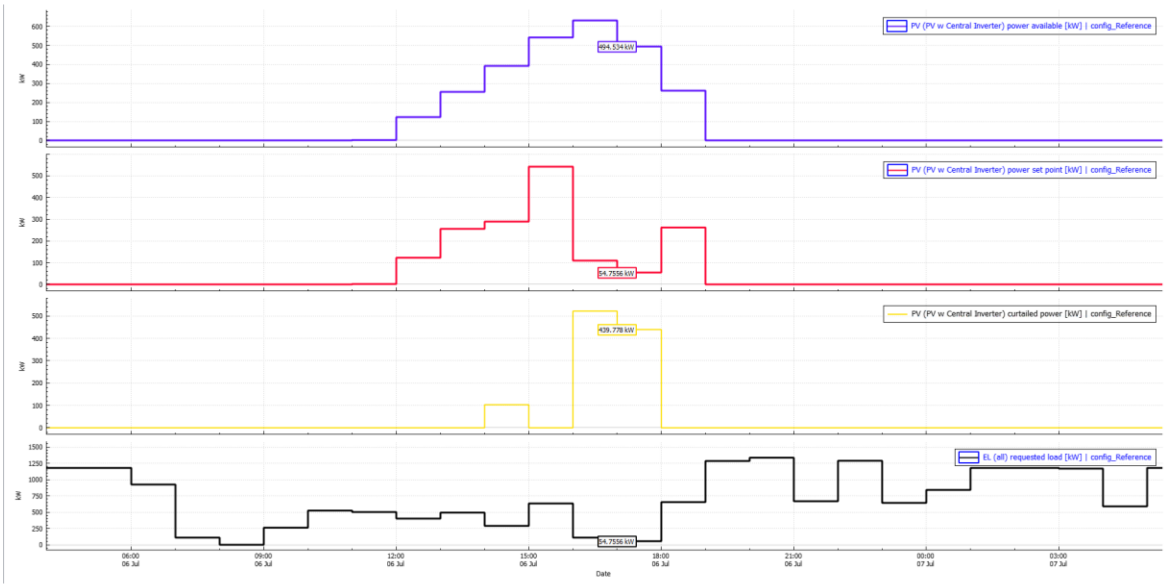


Figure 43: Curtailment Example

## 6.2 Analysis of Case 2: Current Grid and Gen + New PV and BESS

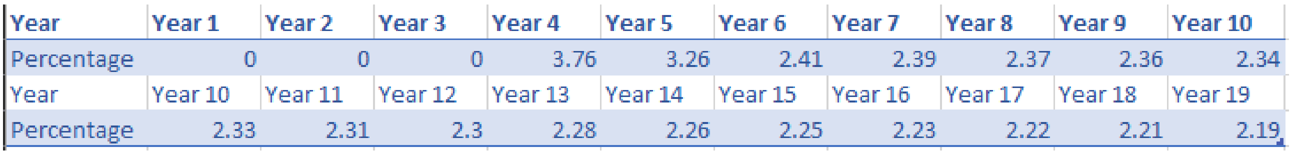
The second case simulated adding new rooftop solar (1.1MW) and a BESS (4.513MWh), in addition to the onsite generator. Please see some of the main financial KPIs listed from above:

| CAPEX | Total Cost | Total Net Present Cost |
|---|---|---|
| $3.97M CAD | $25.2M CAD | $14.8M CAD |

Table 17: Key Financial KPIs

### 6.2.1 Photovoltaic Energy Share

The potential Renewable Energy Share for this solution is shown in the following table for each year of the project:



| Year | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Percentage | 0 | 0 | 0 | 3.76 | 3.26 | 2.41 | 2.39 | 2.37 | 2.36 | 2.34 |
| Year | Year 10 | Year 11 | Year 12 | Year 13 | Year 14 | Year 15 | Year 16 | Year 17 | Year 18 | Year 19 |
| Percentage | 2.33 | 2.31 | 2.3 | 2.28 | 2.26 | 2.25 | 2.23 | 2.22 | 2.21 | 2.19 |

Figure 44: Photovoltaic Energy Share

## 6.2.2 Energy Flow

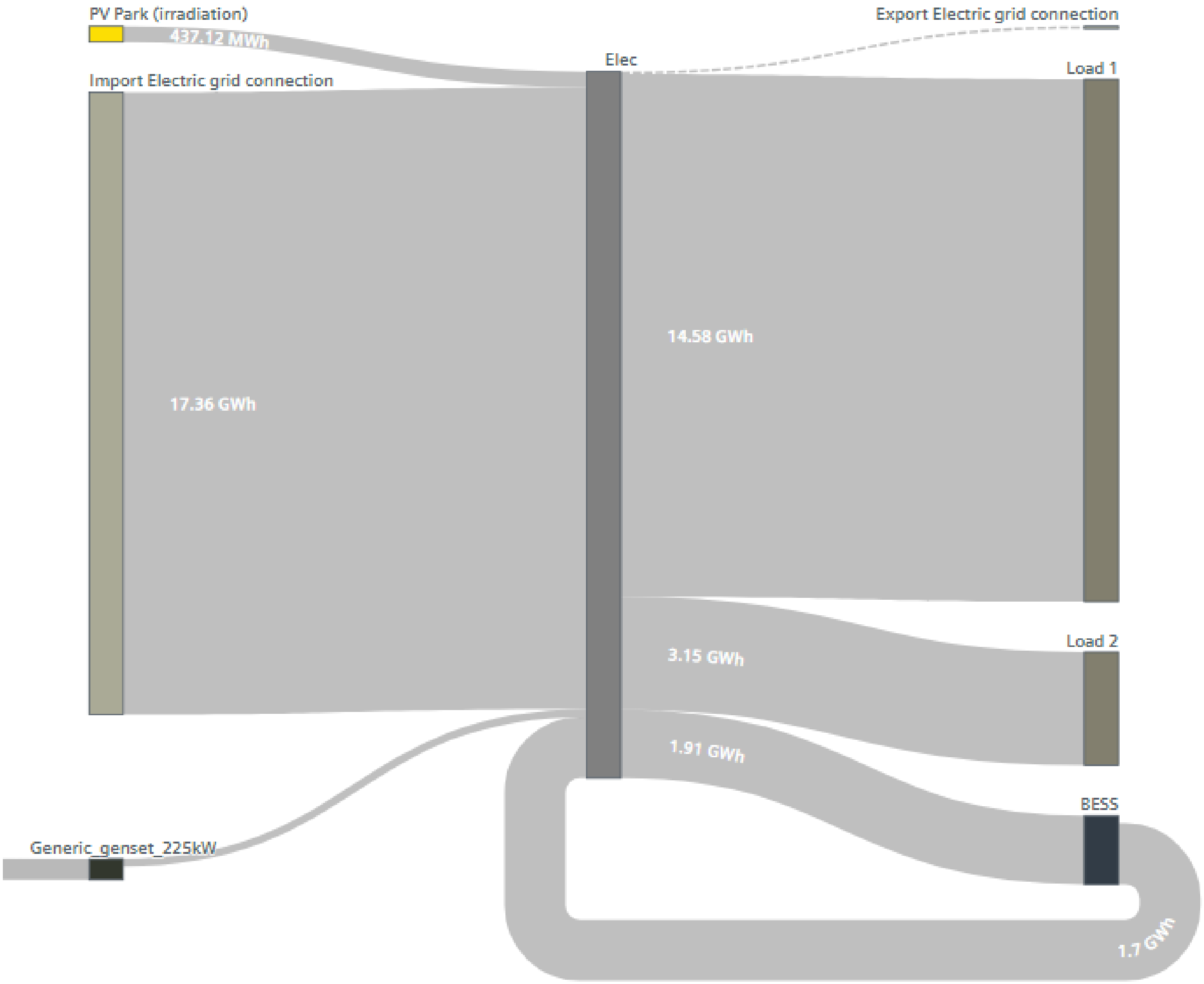


Figure 45: Revenue and Expenses for Case 2

### 6.2.3 Expense

The expenses for Case 2 are shown in the following figure.

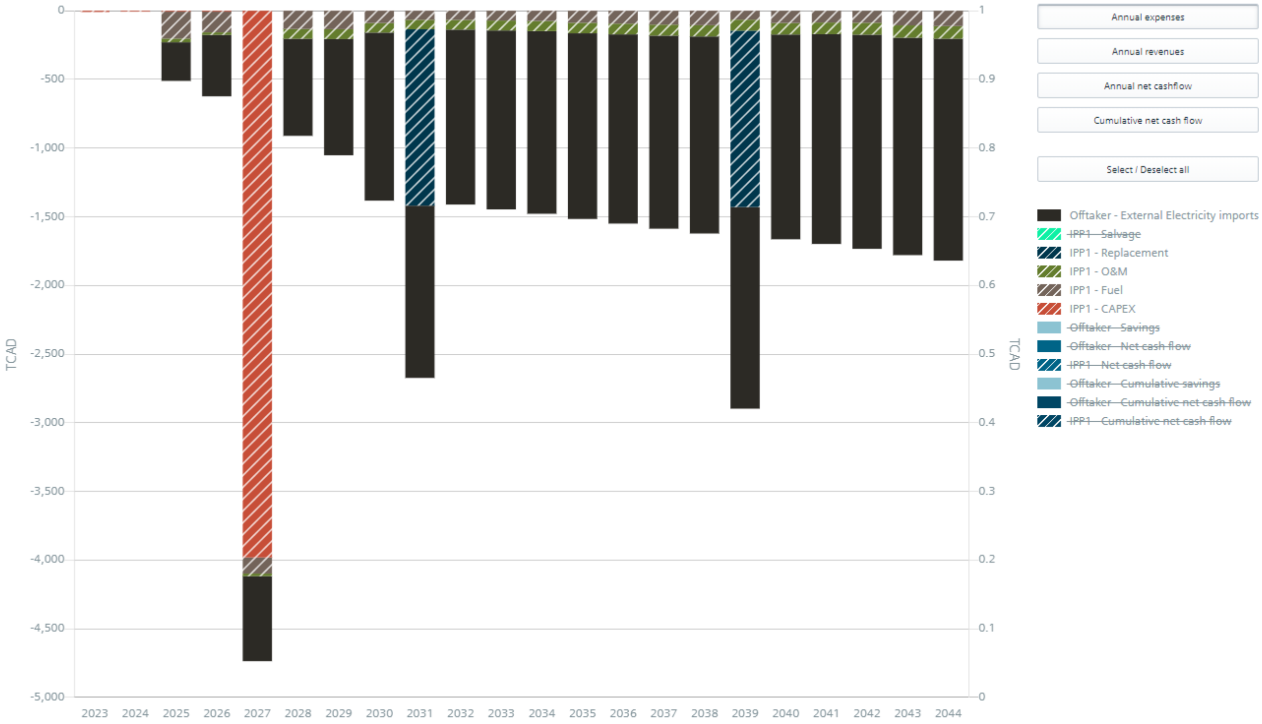


Figure 46: Revenue and Expenses for Case 2

### 6.2.4 Cashflow

The cashflow for Case 2 is shown in the following figure. The major dips that are seen in the graph is the initial investment of the assets in year 4, and their replacement costs throughout the project lifetime.

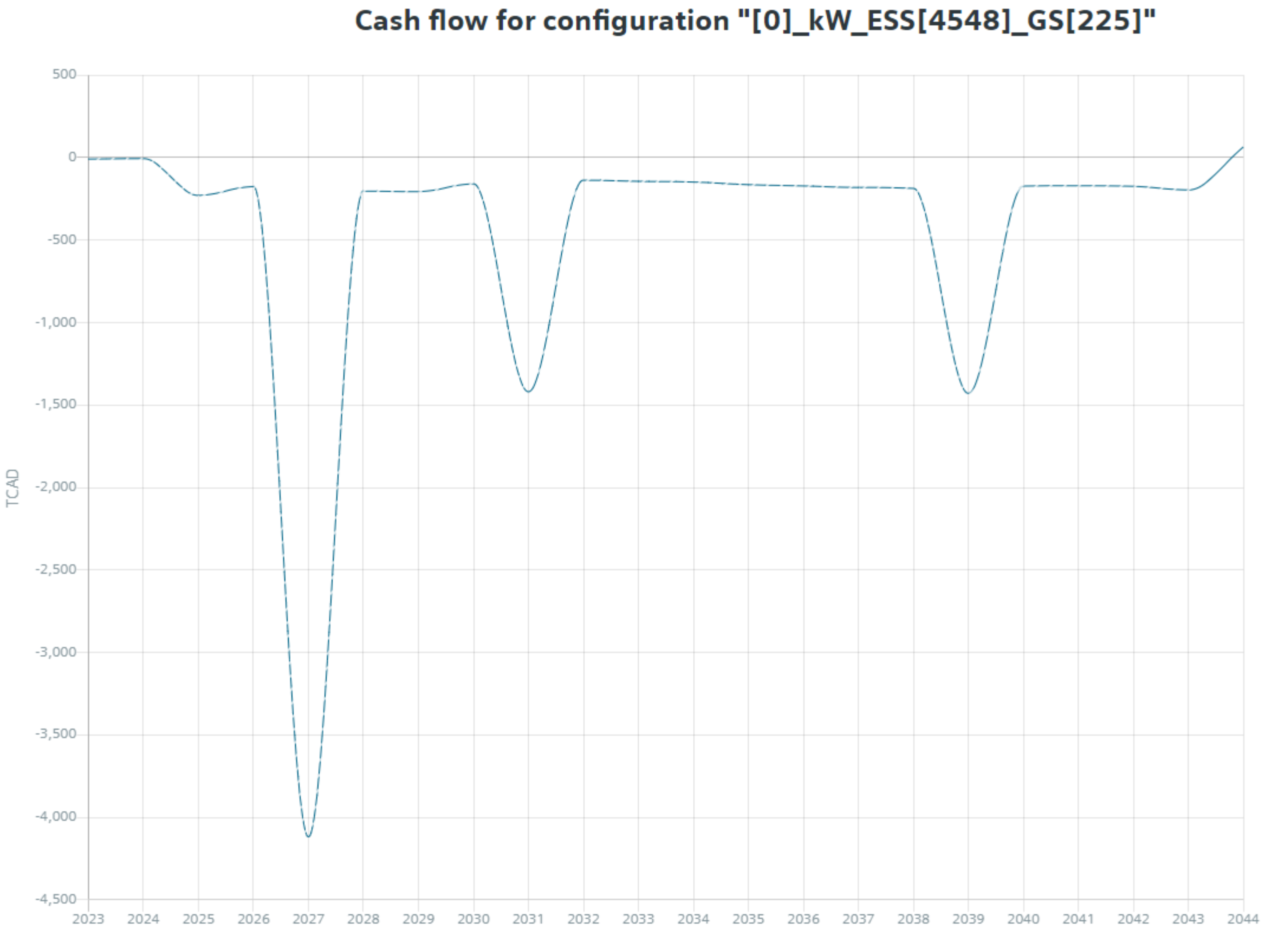


Figure 47: Cash flow for Case 2

### 6.2.5 Generation

The generation breakdown for Case 2 is shown in the following figures.

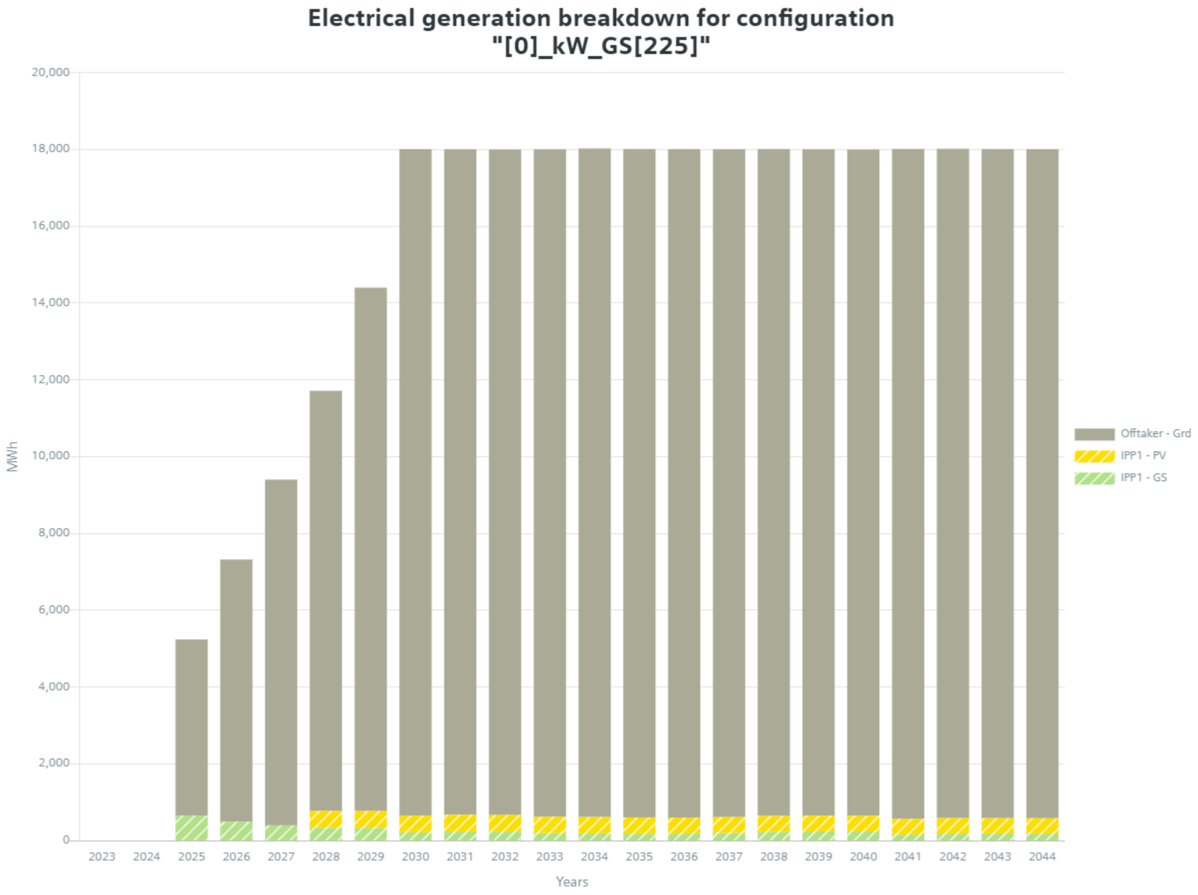


Figure 48: Generation Breakdown for Case 2

## 6.3 Configuration Summary

Overall, both configurations met all three project goals. The first goal was to ensure grid stability, which these solutions achieved, as there were no power outages or load shedding events during the 20-year project period. The second goal was to reduce GHG emissions, which was also achieved by limiting the use of the onsite diesel generator. The final goal was to optimize CAPEX and reduce OPEX, which was achieved by using the sizing optimization to identify the best asset mix to handle the new demand.

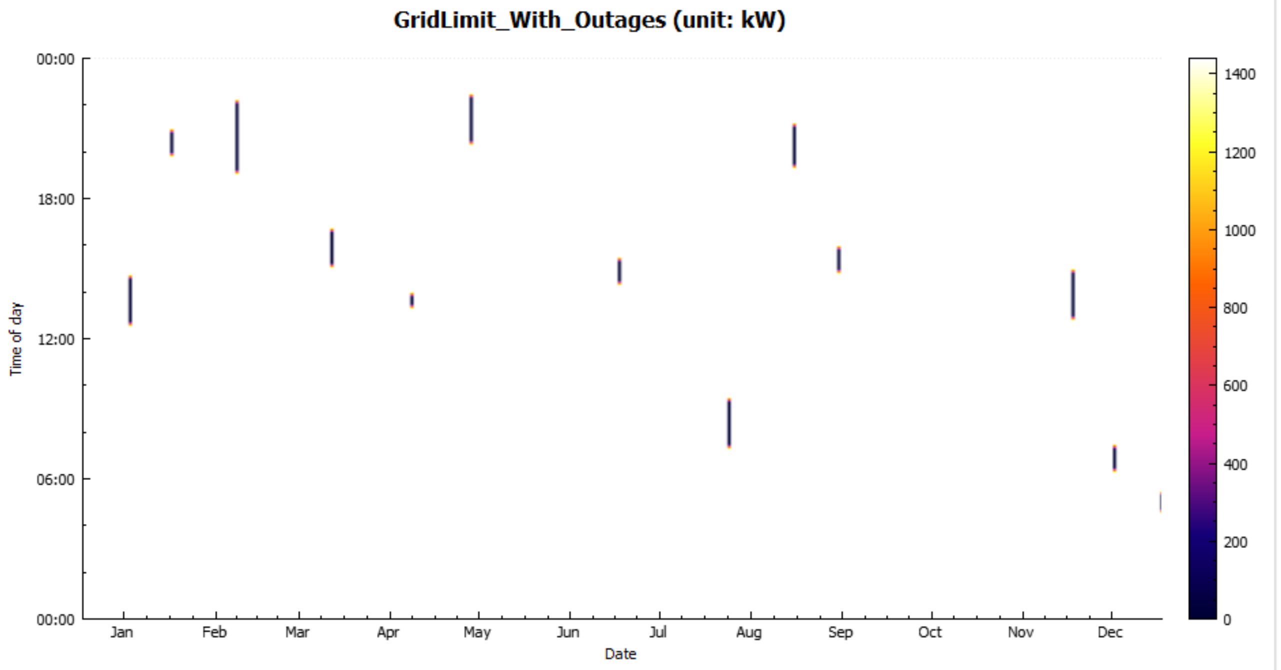
# 7 OUTAGE RESPONSE

Although the main risk may be handled for possible deficits between peak load demand and the grid supply, there is still a risk of outages. The following analysis highlights the number of outages simulated per year, and how the system was able to handle them.

For each year, 14 outages were simulated, ranging from 30 minutes in length, to up to 3 hours. The table below indicates how many of each length were simulated. For the outages, we simulated both full and half load to understand how the system would handle it.

| Outage Length (hours) | Frequency Simulated (#) |
|---|---|
| 0.5 | 1 |
| 1.0 | 4 |
| 1.5 | 3 |
| 2.0 | 4 |
| 2.5 | 1 |
| 3.0 | 1 |

The following figure shows when and how long the planned outages will occur:



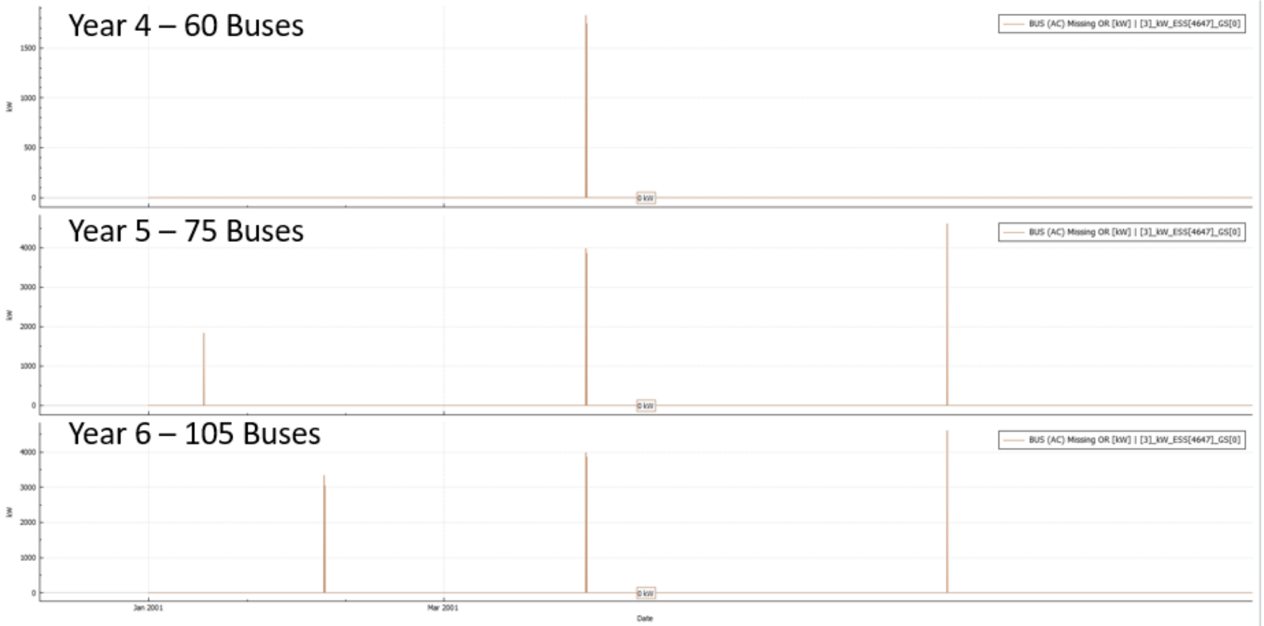
For each year up to year 6, the table below indicates the buses in circulation, the outage events met and not met, as well as what DER assets were available for Case 1 and Case 2. Finally, Year 6 and above were grouped together, as there will be 105 buses for the remainder of the project.

## 7.1 Case 1: Outage Simulation

| Year | Outages Met at Full Load (Events) | Outages Met at Half Load (Events) | DER |
|---|---|---|---|
| 1 (15 Buses) | 0 | 0 | Grid |
| 2 (30 Buses) | 0 | 0 | Grid |
| 3 (45 Buses) | 0 | 0 | Grid |
| 4 (60 Buses) | 13 (92%) | 14 (100%) | Grid, BESS + PV |
| 5 (75 Buses) | 11 (78.6%) | 14 (100%) | Grid, BESS + PV |
| 6+ (105 Buses) | 11 (78.6%) | 14 (100%) | Grid, BESS + PV |

The first three years, the only available source is the connected grid. Therefore, when a grid outage occurs, it is not possible for the load to be supplied by another means. For years 4 and onwards, the new assets have been installed. For the 'full load' simulation, the system was able to handle 35 out of 42 events in three years and was able to handle all 42 when 'half-load' was simulated.

Below shows when the outages were missed in the full load simulation, during years 4 to 6:

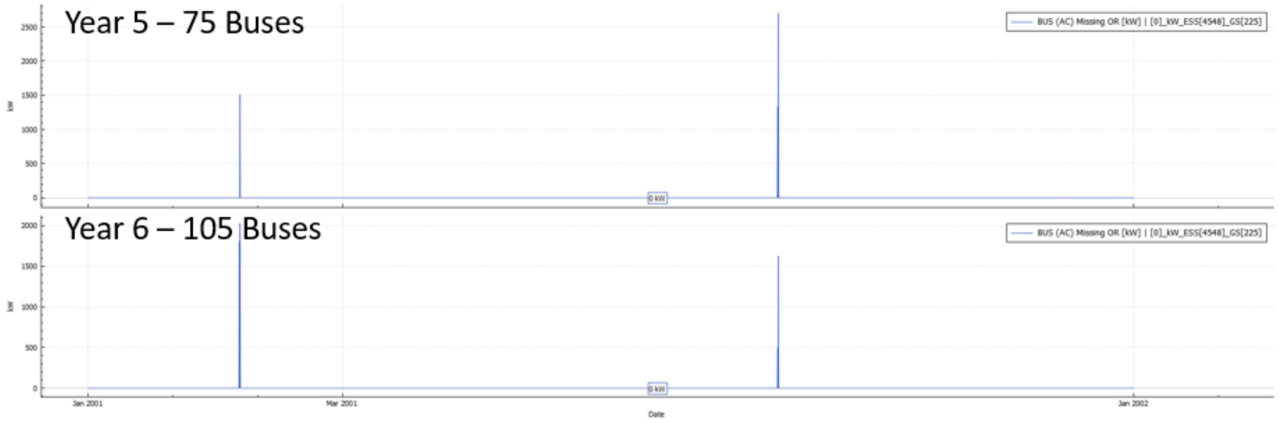


## 7.2 Case 2: Outage Simulation

| Year | Outages Met at Full Load (Events) | Outages Met at Half Load (Events) | DER |
|---|---|---|---|
| 1 (15 Buses) | 0 | 0 | Grid + Gen |
| 2 (30 Buses) | 0 | 0 | Grid + Gen |
| 3 (45 Buses) | 0 | 0 | Grid + Gen |

| | | | |
|---|---|---|---|
| 4 (60 Buses) | 14 (100%) | 14 (100%) | Grid, Gen, BESS + PV |
| 5 (75 Buses) | 12 (85.7%) | 14 (100%) | Grid, Gen, BESS + PV |
| 6+ (105 Buses) | 12 (85.7%) | 14 (100%) | Grid, Gen, BESS + PV |

The main difference between Case 1 to Case 2 is the additional onsite generator running all year. With the base building load of 400kVA, the generator was too small to handle any outage in the first three years. However, during years 4 to 6, 38 out of 42 outages were handled for the 'Full Load' situation, and all for the 'Half Load' simulation.



In conclusion, using the DER mix for both cases, assuming a 50% load profile during the outages, all outages will successfully be met with no interruption to the charging schedule.

# 8 PROJECT EXECUTION OVERVIEW

In this section, the project execution approach for the microgrid controller is broken down from a high-level perspective. It explains the various components necessary to support a Distributed Energy Resource (DER) installation, and their interconnections with each other. These components include the SICAM microgrid controller, the human machine interface (HMI), and the protective equipment. The microgrid controller at its core accomplishes two main functions: 1) enable communication pathways between assets previously unable to communicate and 2) command these devices to operate based on specific functions that have been created.

## 8.1 SICAM Microgrid Controller

The SICAM Microgrid Controller is a state-of-the-art rule-based controller that has been developed locally within Canada for the North American Market. With local competencies in Microgrid Controller development, Winnipeg Transit will benefit from customization possibilities starting with pre-defined modules and algorithms.

The controller solution is a SCADA system based on a substation automation platform that serves as a data concentrator and protocol converter. The hardware utilized is the Siemens SICAM A8000. The HMI visualization software is SICAM SCC. It has a multitude of features as well as a data historian for archiving, trending and alarming functionality.

Figure 49: SICAM A8000

The communication architecture drawing details the connectivity from the SICAM MGC to other equipment.

Below is the proposed configuration of these systems, with the final specification and list of equipment to be approved after design meetings with the customer.

## 8.2 Control System Main Components

### 8.2.1 Master control element SICAM A8000 CP-8050

- The Master control element, the SICAM A8000 CP-8050 is the brain of MGC system
- Up to fourteen communications interfaces: 2x RJ45 (Eth), 1x RS232 (RJ45), 1x RS485, 10x RJ45 (Eth) with CI-modules
- Interfacing of up to 16 I/O lines via extension modules
- Function diagram design according to IEC 61131-3 with CAExplus for open-loop and closed-loop control functions
- Configurable telecontrol functions with and without time tagging
- Time synchronization with an accuracy of +/- 3.5 ppm (-40°C to +80°C), +/- 2 ppm (0°C to +40°C) via NTP, SNTP, automatic adjustment to daylight saving time Parameter setting, diagnostics, and testing by SICAM TOOLBOX II, both locally and from remote location
- Storing of parameters, algorithms, and firmware on SD memory card

To provide a flexible and adaptable possibility to connect assets to Microgrid Control, extension modules are available in several configurations to realize the communication.

- Extension modules consist of power supply modules, communication interface extension modules and up to eight I/O modules
- All modules are mounted by means of bus connector and locking hook on a DIN rail
- Acquisition, processing and output of process data
- Note: the above description reflects the full capability of the device and order code selection will determine the included modules and capabilities

### 8.2.2 SICAM A8000 Technical Data

Technical data of SICAM A8000 and peripheral elements:

- Protocols: IEC 61850, Modbus RTU/TCP and DNP 3.0
- Memory for online test and real time archive: 512 kB
- Number of variables for application: 200000 binary or analog data types, thereof 5000 non-volatile
- Maximum number of data points: 400 000 (sum of process images over all 8 interfaces)
- EMC: IEC 60870-2, IEC 60255, IEC 61000, EN 50082, ...
- Supply voltage: 24 – 60 VDC or 110 – 220 VDC
- Temperature range: Master control element: – 40°C to + 70°C (depending on equipment), Extension module: – 40°C to + 70°C
- Dimensions (H x W x D): Master module: 132 x 30 x 124 mm, Extension module: 132 x 30 x 124 mm
- Supported number of primary assets: 8 generators, 3 wind turbines, 3 photovoltaic plants, 3 battery storage devices, 10 controllable loads and feeders

### 8.2.3 HMI- SICAM SCC

The operator station is installed with Industrial PC and enhances the functional coverage of Microgrid Control and provides User Interface and expands communication capability of the MGC:

- Robust industry equipment
- User Interface
- Integrated User Management
- Message system
- Local Archiving system: 500 GB storage capacity
- Reporting and Logging System
- Control technology functions (Basic Process Control)
- Wizards and libraries
- Multilingual applications
- Client-Server solutions
- Central Archive Server Solutions
- Web-Client Solutions
- Scripting

## 8.3 System Communication Architecture

Connectivity to the Siemens SIPROTEC 5 relays and the SICAM P855 power quality (PQ) meters will be over IEC61850 - advanced substation automation protocol.

Where appropriate, the architecture considers IEC61850 GOOSE communication which allows for peer-to-peer inter-IED communication over fiber optic medium thus reducing the requirement of additional I/O within the relays as well as additional copper cabling to realize interlocking requirements and selective blocking solutions.

Upstream communication from the IED (SIPROTEC 5 relays, SICAM P855 PQ meters) to the SICAM MGC will also be carried out over IEC61850 protocol.

The devices assets considered to be integrated into the solution and have remote connectivity and controllability from the SICAM MGC are:

- BESS (Modbus TCP assumed)
- Protection System — SIPROTEC 5 Relays (IEC61850 fixed) smart meters — SICAM P855 PQ Meters (IEC61850 fixed)

This plan considers all supply of cables (RJ45 and FO Cables) and wiring works to be out of scope and supplied by others except for cabling form the MGC Panel to a junction box, both of which would be in the E-House. Siemens will assist Winnipeg Transit in the selection of the cables required to be procured.

The communication architecture is highlighted in the image below. It is shown in full detail in the appendix.

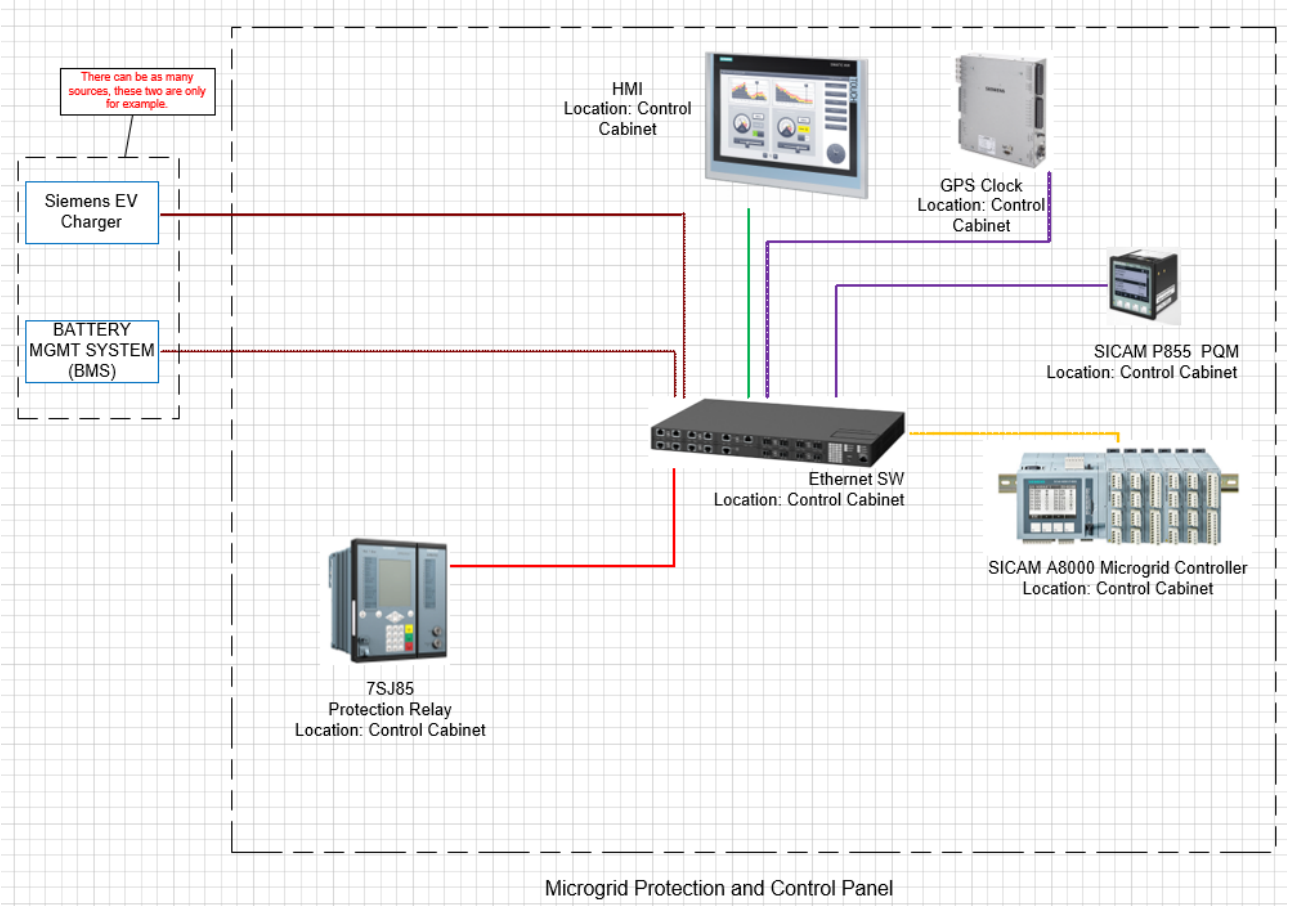


Figure 50: High Level Communication Architecture

## 8.4 Protection and Control Solution

The protection system being put in place will ensure that all components are protected adequately from possible fault scenarios and safety of all working personnel within the environment is covered. Protection and control requirements to be confirmed and documented with the customer through design discussions.

The Siemens solution from the protection perspective includes the following:

- Siemens SIPROTEC 5 7SJ85 Overcurrent Relay (DER Controller) Identification: 7SJ85

The above-mentioned relay is state-of-the-art Siemens SIPROTEC 5 series relay that are modular and expandable in terms of number of inputs and outputs and are capable of handling multi-feeder arrangements and have multi-protection functions.

Protection functions considered to be configured:

- 50/51 - Overcurrent protection
- 25 - Synchrocheck function
- 32 - Reverse power protection
- 27 - Undervoltage protection
- 59 - Overvoltage protection
- 67 - Directional overcurrent protection
- 81 U/O - Under/over frequency protection
- 86 - Lockout function
- Measured values, standard
- Continuous Function Chart (CFC) Automation functionality for logic programming (standard)
- Circuit breaker control
- Inputs and outputs (I/O) have been considered for the BESS and other controllable breakers/shunt trips

Figure 51: SIPROTEC Relay

From a control perspective, in order to allow for increased automation with minimal manual intervention, Siemens recommends field level equipment connect to a contactor-based solution that will allow for either manual or remote automated control of all CB from the SICAM MGC via the relay.

Details of the operational sequences of the DER assets will be input for full scope assessment of the interlocking requirements to maintain a safe system. Siemens has considered interlocking configuration of the assets, but these will need to be confirmed through design discussions.

Metered and measured data is essential for the monitoring of various measured and meter calculated criteria (I, V, P, Q, harmonics, energy, etc.) to monitor generation production of DER, demand requirements on the load side as well as power quality related information at various points on the power system. This real-time information collection will be aggregated at the SICAM MGC and used to assess inflow and outflow of power (plus other criteria) to take necessary automated action of increased production of DER. Field side equipment (CT and PT) selection and classification (for measurement) are assumed to be correct for integration of these smart meters.

- The selected Power Quality meter is the SICAM P855 (non-revenue grade meter) that will allow for measurement and metering information, configurable limit value threshold alarms as well as PQ recording and reporting functionality. Selection of this meter will allow for both real-time (short-term) as well as long term (archived) assessment possibilities of the overall power system network.
- The SICAM P855 is proposed as a solution for AC smart meters only.

An MGC Panel has been proposed to enclose the MGC and related protection and control equipment. Based on the relays and number of meters, this panel enclosure will be sized accordingly and options for these sizes can be discussed in detail during the design discussions with Winnipeg Transit.

### 8.5 Cybersecurity

All equipment and software being provided are compliant with Siemens’ cybersecurity standards. All activities in the system shall be logged and the owner can limit the access based on the authority of the user. The complete guideline and access right settings will be provided as part of O&M manual and during the onsite training. In general, there are three user types that can have access to the system which are View Only, Operator and System Engineer and all their authorities can be set based on their roles. Also, the system is flexible to set additional role-based access and it can be freely customized.

## 9 APPENDIX

### 9.1 Sizing optimization

Sizing optimization helps determine an unbiased technology type and size suggestion for customer projects. This sizing algorithm uses “perfect foresight” (i.e., the entire year) to simultaneously optimize the design and dispatch of an energy system, with respect to a weighting in cost and CO2 emissions. It is possible to solve for a specific weighting, or to automatically run multiple scenarios for differing CO2 emissions. Sizing optimization is intended for preliminary design, as simplifications are made in both the algorithm and technology models.

The reference configuration is configured to reflect either the existing energy generation system for brown- or green- field projects, or the "standard" generation system alternative for greenfield projects. Relevant loads (electrical, steam, hot or cold water and hydrogen) are also defined. More complex systems can be modeled by adding additional energy types (buses) and configuring how technologies are connected. Components can be copied multiple times as necessary.

Opportunities for optimizing cost and/or CO2 emissions are simulated in alternative scenarios. Technologies of interest can be activated with an associated range of size. The Environmental Compassion Factor defines the weighting for the optimization of a scenario between cost or CO2. This can be considered as a spectrum that is unique for every project. As shown in the diagram below, cost and CO2 reduction are normally conflicting goals, as lower costs will typically cause higher CO2 emissions, and lower CO2 emissions will typically require higher costs. The Environmental Trade-off Analysis (ETA) automatically creates a range of scenarios with staggered CO2 emissions, providing an overview of this relationship.

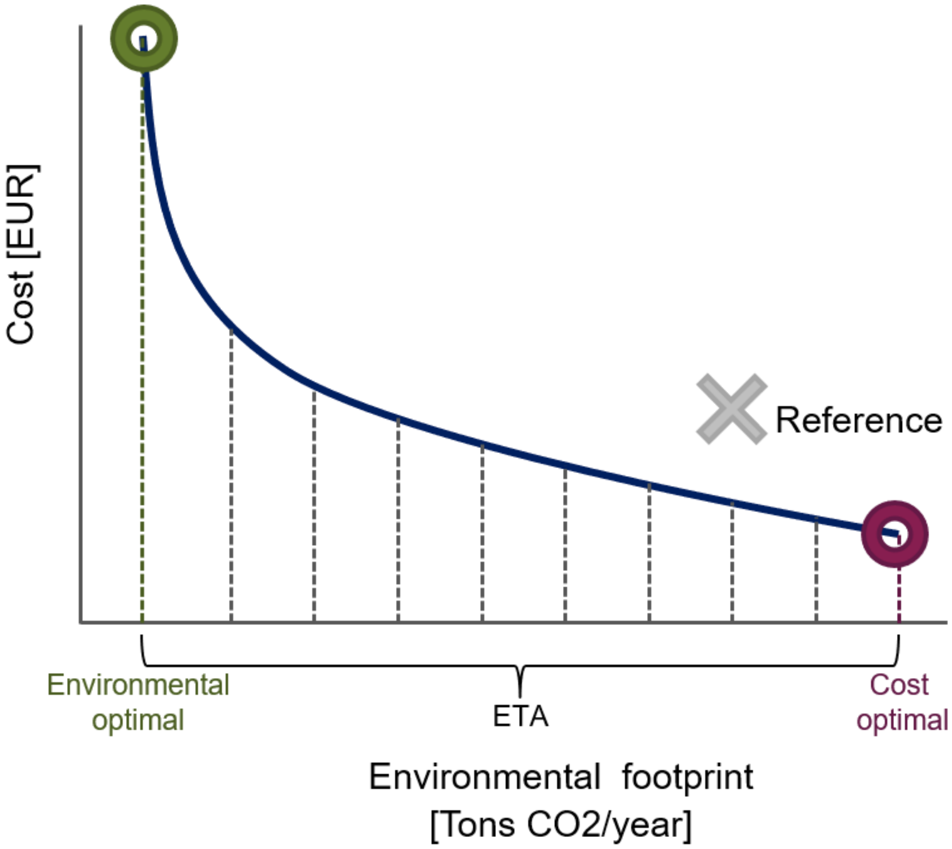


Figure 52: Environmental Trade-off Analysis

## 9.2 Levelized Cost of Electricity (LCoE)

LCoE (Levelized Cost of Electricity) is the measured cost over the project lifetime, divided by the energy production. A simplified calculation for this is shown in the following image below:

$$\frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

$I_t$ = Investment expenditures in year t (including financing)
$M_t$ = Operations and maintenance expenditures in year t
$F_t$ = Fuel expenditures in year t
$E_t$ = Electricity generation in year t
$r$ = Discount rate
$n$ = Life of the system

This is a key index used to evaluate the overall impact of adding in new assets within the system. For example, if the operating costs and initial investment is extremely high, it will have a greater LCoE compared to an asset with a lower up-front cost.[1]

## 9.3 Sankey Diagrams

A Sankey diagram is a graphic illustration of flows - like energy, material, or money - where they can be combined, split, and traced through a series of events or stages. The width of each stream represents the amount of material or energy in the flow. Sankey diagrams, which are typically used to visualize energy transfers between processes, are named after the Irishman Matthew H. P. R. Sankey, who used this type of diagram in a publication on energy efficiency of a steam engine, in 1898.[2]

## 9.4 List of Abbreviations

| Abbreviation | Definition / Meaning |
|---|---|
| AVG TSRF | Average Total Solar Resource Fraction |
| BESS | Battery Energy Storage System |
| CAPEX | Capital Expenditure |
| CB | Circuit Breaker |
| CT | Current Transformer |
| DER | Distributed Energy Resources |
| GHG | Green House Gases |
| IED | Intelligent Electronic Devices |
| KPI | Key Performance Indicators |
| LCoE | Levelized Cost of Energy |
| MGC | Microgrid Controller |
| O&M | Operations and Maintenance |
| OPEX | Operational Expenses |
| PQ | Power Quality |
| PSS DE | Power Systems Simulator – Distributed Energy |
| PT | Power Transformer |
| PV | Photovoltaic |
| SCADA | Supervisory Control and Data Acquisition |
| SLD | Single Line Diagram |
| TOF | Tilt-Orientation Factor |

## 9.5 References

1. https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf
2. https://ec.europa.eu/eurostat/statistics-explained/index.php/Sankey_diagrams_for_energy_balance#:~:text=Methodology%20notes-,Introduction,or%20energy%20in%20the%20flow