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Kluane ń-ts'i (wind) energy project: power system impact study

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PROJECT TEAM

Lead Authors

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FOREWORD

This report details the power system impact study for the Kluane Ń-Ts'i (Wind) Project. The objective is to model a wide range of power system studies to determine the potential impact of the proposed renewables on the isolated power system in Burwash Landing and Destruction Bay.

DISCLAIMER

Results from this study are based on power system models and may not inherently capture all phenomena. The modelling is performed with every effort to use real equipment data; where real equipment data were not available, reasonable assumptions have been used and described. The scope of this study is focused on technical aspects of this research, while system planning, parameters, and control are not meant to be addressed nor designed by the Northern Energy Innovation team. This is intended to ensure unbiased and transparent results that are pertinent and valuable to all parties involved.

ACKNOWLEDGMENTS

The project team sends our thanks to all participants and contributors for their commitment and hard work throughout this project.

Financial support and guidance are provided by the Kluane First Nation, and we are grateful for our ongoing partnership. Other funding is provided by from the Natural Sciences and Engineering Research Council through the Industrial Research Chair for Colleges program. The Northern Energy Consortium, comprised of ATCO Electric Yukon, Northwest Territories Power Corporation, and Yukon Energy Corporation provided continued financial support, access to data, and their invaluable expertise.

We would like to especially note the open communication, support and ongoing availability of Norm Curzon at ATCO Electric Yukon throughout the project, as well as the team at Hatch and the Natural Resources Canada's CERRC Team. The Northern Energy Innovation Team is grateful for everyone's support and input throughout the project.

EXECUTIVE SUMMARY

Kluane First Nation, together with project partners has proposed a 900kVA wind turbine generator project. The potential impacts of the renewable generation have been investigated. A detailed electric power system model was developed in MATLAB/Simulink for the power system studies. An energy system (Quasi-Static Time Series analysis, or QSTS) study has been completed. This analysis divides up an entire year into 1 minute timesteps and allows us to examine system adequacy over the course of a year. Two model scenarios were explored:

- A reference model of the system as it currently is, using a load profile from 2019
- The reference model with a wind turbine generator, battery, microgrid controller, a new school, and an anticipated load profile for 2042

To analyze the impacts on the 300kVA step up transformer, the following additional scenarios were modelled.

- The reference model in 2019, 2023, 2028, 2033, 2042, assuming 1.75% load growth per year
- The full model with wind turbine, battery, microgrid controller, and new school, in the years 2023, 2028, 2033, 2042, assuming the same 1.75% load growth.

These additional scenarios allowed us to investigate the impact of load growth and the proposed wind project on the 300kVA step up transformer the power system as a whole, and other equipment in the system.

The quasi-static time series simulations found the following key results:

- If a wind turbine and battery energy storage system are implemented the current system will experience some under and over voltage issues
- The 300kVA step-up transformer exceeded its rated capacity in all scenarios that include the wind project and new school.
- If the system remains unchanged (no wind turbine / BESS), the modelling indicates that the transformer will exceed its rated capacity during peak load events by 2028.
- No issues related to spinning reserves were found.
- The BESS State of Charge stayed within the 10% - 90% limits set by the microgrid controller

The microgrid controller was found to sufficiently curtail the wind power to maintain power balance throughout the year.

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1 INTRODUCTION

The communities of Burwash Landing and Destruction Bay are located within the traditional territory of Kluane First Nation in the Kluane Region of Yukon, Canada, at miles 1093 and 1083 along the Alaska Highway, on the western shore of Kluane Lake. The proximity of the communities, and their interconnection to the same remote power system results in these two communities being grouped together as the Kluane electric power system for the purpose of this report. Combined, the communities have a population of approximately 150, according to 2016 census data. Burwash Landing acts as the administrative centre of the Kluane First Nation, while Destruction Bay hosts the thermal generation plant and several Yukon Government buildings.

The Kluane electric power system is supplied by three diesel electric generators of various sizes. In 2019, the maximum load of the community was 415kW, while the minimum load was 103kW, however, a new school, with a rated maximum load of 75kW is a planned addition to the Burwash Landing community in the next few years.

Kluane First Nation, along with ATCO Electric Yukon and other project partners have commissioned this study to investigate potential impacts of integrating a proposed renewable energy project into the Kluane electric power system.

This report includes detailed information regarding the Kluane power system model and a Quasi-Static Time Series (QSTS) analysis (steady-state) study.

The QSTS analysis allows us to identify the following key power system adequacy risks:

- Lack of spinning reserve during periods of high renewable generation and low diesel generation
- Maximum and minimum voltages observed at each node in the power system
- Ability to supply the required total electric power and energy, without exceeding system component ratings or system operating limits
- Battery Energy Storage System State of Charge is kept within tolerance
- Whether the microgrid controller can successfully curtail renewable generation when required to do so

2 POWER SYSTEM MODEL

The Destruction Bay and Burwash Landing (Kluane) power system is a radially configured overhead distribution system with a primary system voltage of 2.4kV line-line for the 3-wire delta configured Destruction Bay portion and 14.4kV line-line for the 3wire delta configured Burwash Landing portion. Service to consumers is provided mainly as single-phase 120/240V through secondary distribution from pole-mounted secondary service transformers, with some three-phase loads. Power is generated directly at the primary voltage of 2.4kV line-line by three diesel-electric generators in the thermal generation plant in Destruction Bay. Figure 1 shows an overview of the Kluane power system. Figure 2, Figure 3, and Figure 4 provide the single line diagram of the Kluane power system.

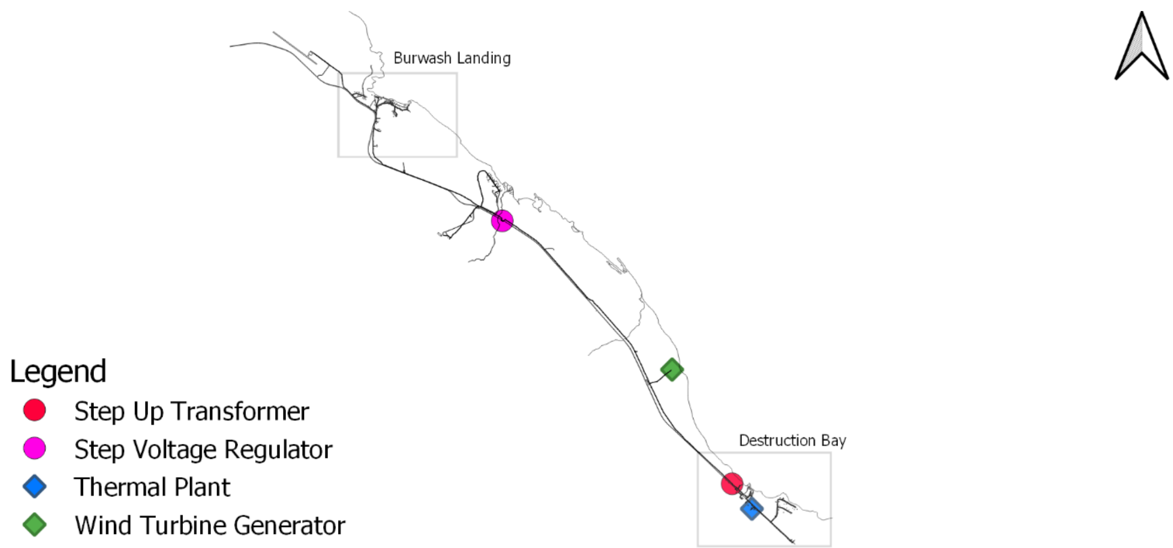

Figure 1: Kluane power system overview

MATLAB/Simulink has been used for 1) its ability to perform both quasi-static time series analysis using phasor simulations, 2) its ability to integrate controls models into the simulations, and 3) its ability to perform discrete electromagnetic transient simulations.

OpenDSS has been used for 1) its ability to solve imbalanced distribution systems, 2) its open source nature, and 3) for model validation purposes. For discussion on models, solvers, etc., the reader is referred to the OpenDSS reference manual and the EPRI Smart Grid Resource Centre [1,2].

The following subsections provide an overview of the system configurations studied, system characteristics and assumptions, and model information. A site review of the system was performed by the NEI team in September 27-28 and October 4-5, 2021. Phasing of lines, transformers, loads, etc.

is as observed during the site review. Note that some information was not able to be confirmed during the site review, and assumptions have been made as necessary and approved by all stakeholders.

2.1 SYSTEM CONFIGURATIONS

The system configuration for the study has been selected based on the required changes to the system to accommodate the proposed wind turbine generator. The proposed wind turbine generator is situated between Burwash Landing and Destruction Bay. The energy storage system has been assumed to be located adjacent to the thermal generation plant.

Within this report, the terminology “node” is used; however, it is interchangeable with “bus” and “pole”. With only a few exceptions (namely plant buses or convenient points such as terminals of a switch), all nodes in the model represent actual distribution poles.

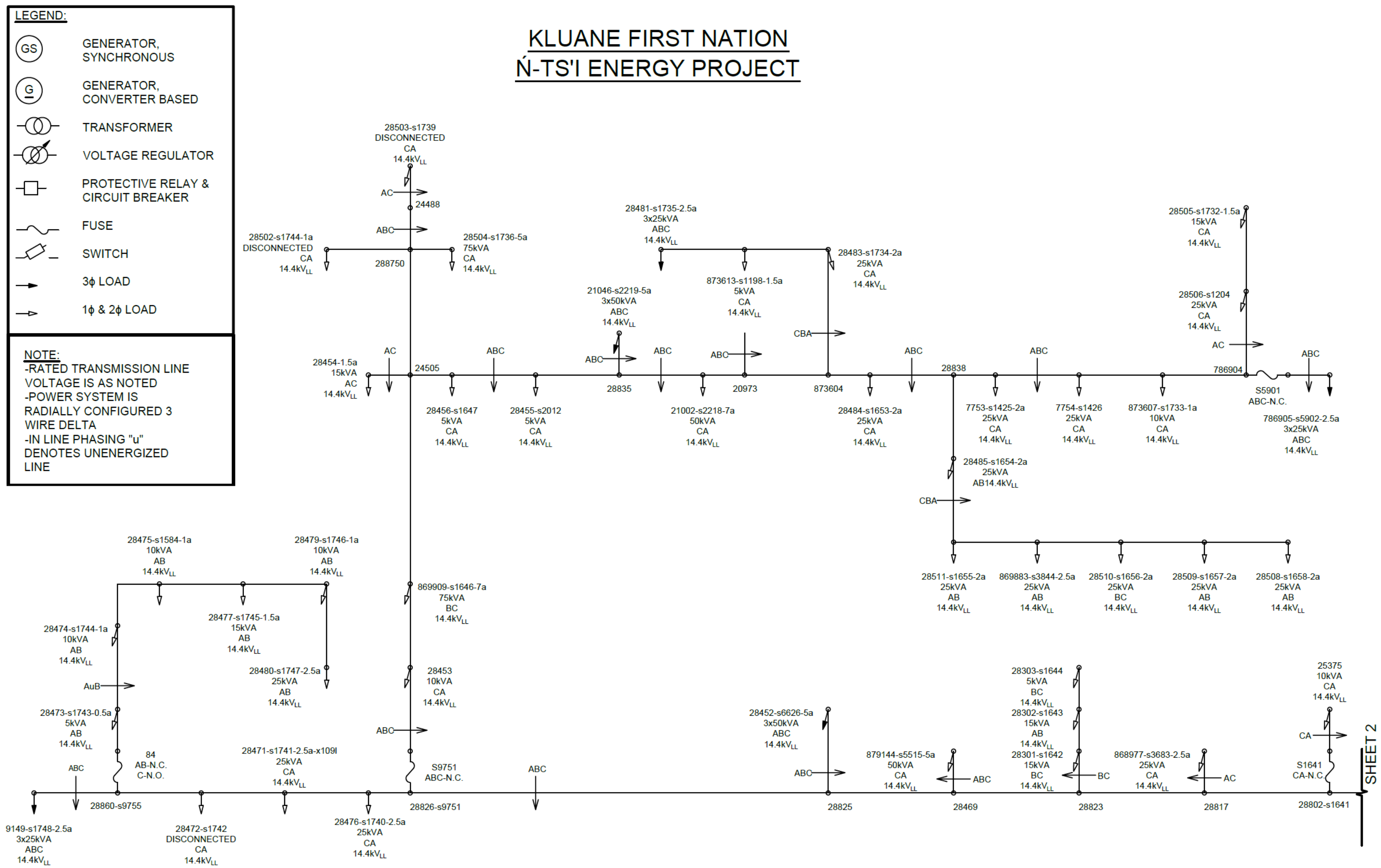

Figure 2: Kluane Power grid Single Line Diagram, p1, Burwash Landing

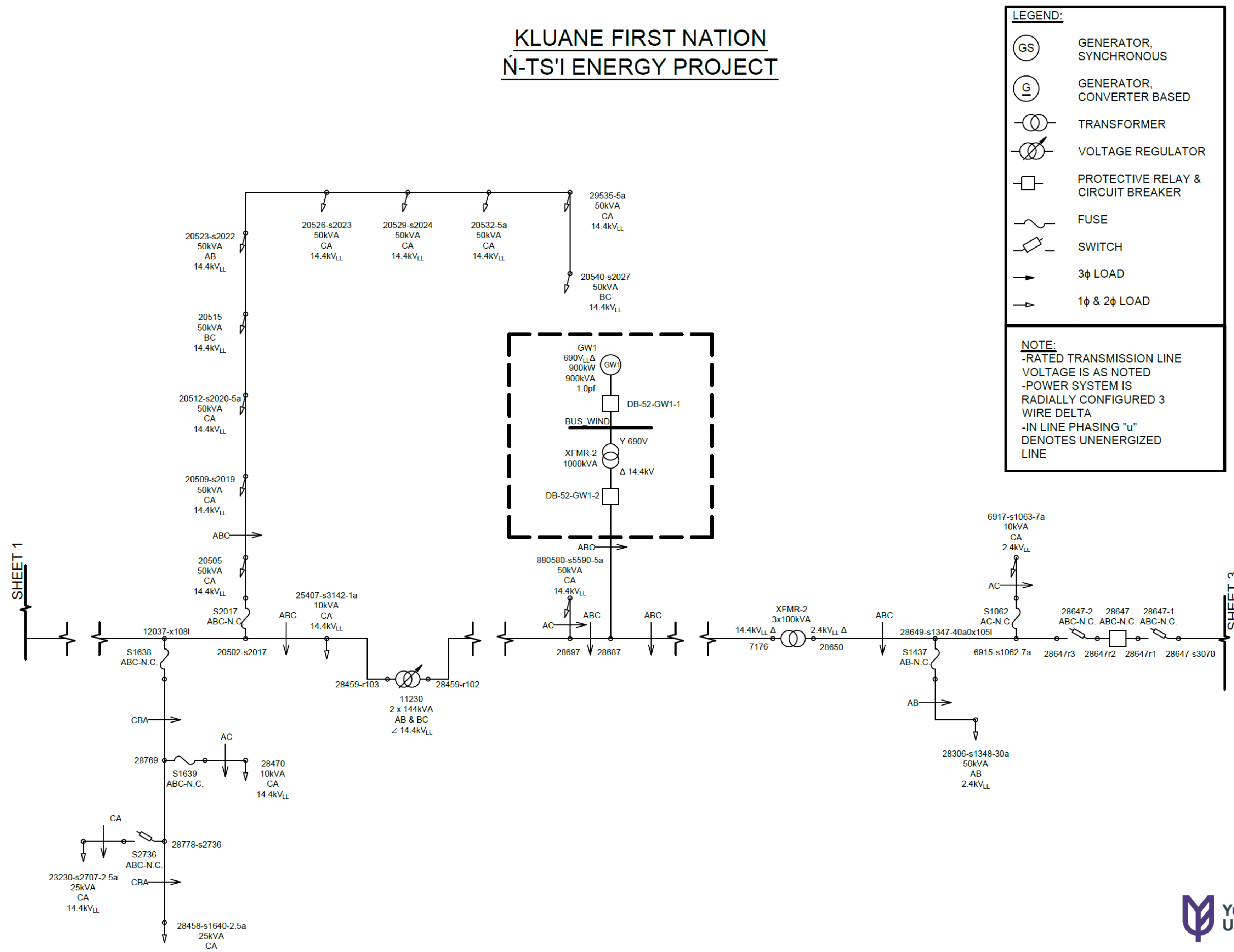

Figure 3: Kluane Power grid Single Line Diagram, p2

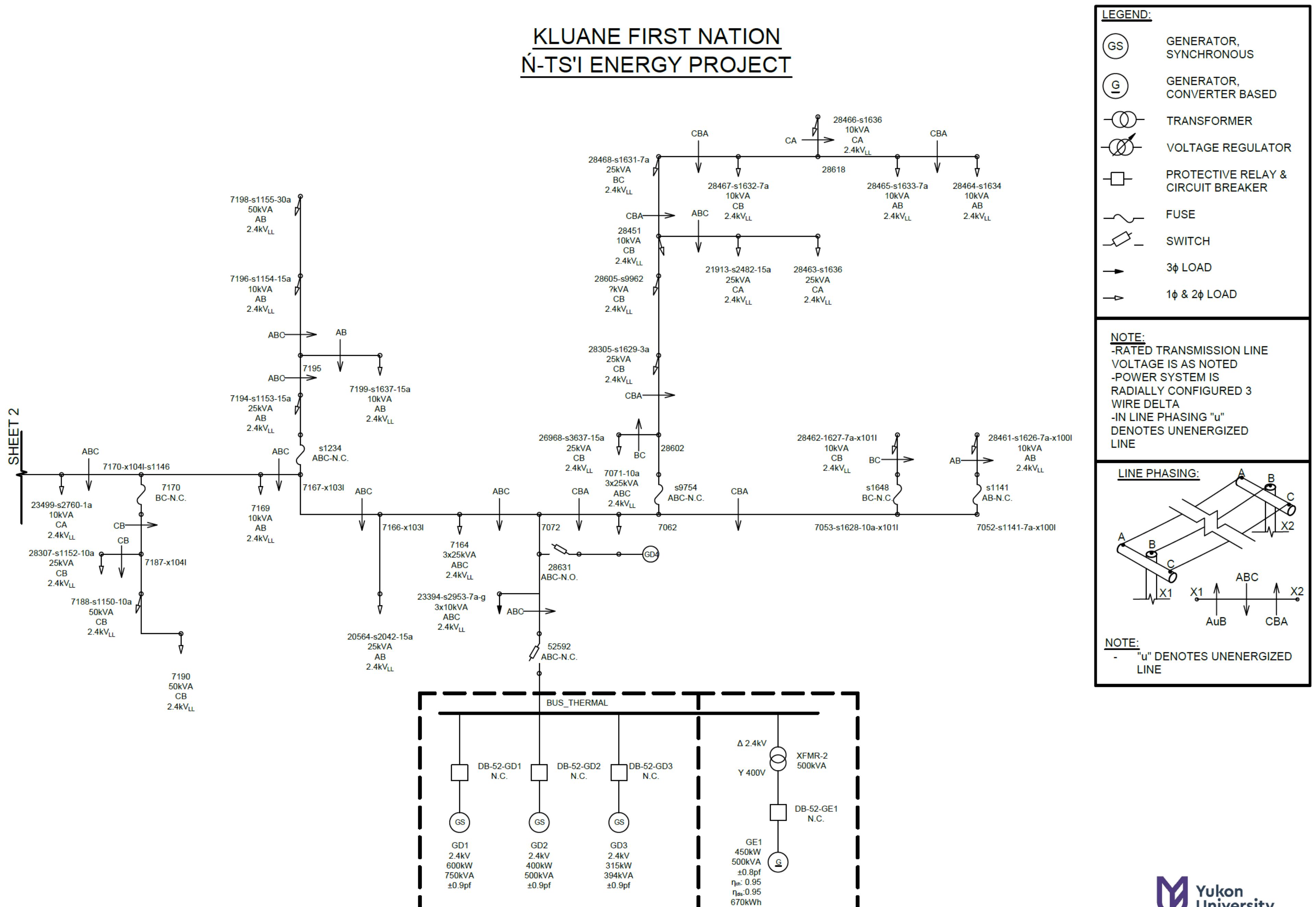

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Figure 4: Kluane Power grid Single Line Diagram, p3, Destruction Bay

2.2 SYSTEM GENERATION MODELS

2.2.1 Synchronous Generator

Within the simulation domain the diesel generator plant is represented by a three-phase voltage source (i.e., swing bus) operating at 2400V. The bus will provide sufficient energy to the system to ensure stability of the simulation is provided. This simplistic model of the generator plant reduces computational expense and does not require models for generator control or dispatch without loss of accuracy in the results.

2.2.2 Renewable Generation

Renewable generators (i.e., wind) are assumed to be electronically coupled and are modeled as a constant active/reactive (PQ) controlled generator in Simulink (type 1 generator in OpenDSS). Note that PQ values are constant for each timestep but vary between timesteps according to the generation profiles and microgrid control.

The proposed wind generation has a rated active power of 900kW and is located between the two communities. It is currently assumed to have a unity power factor.

2.2.3 Energy Storage System

The battery energy storage system (BESS) model for the energy balance study takes instruction from the microgrid controller provided by Hatch. The BESS model operates in two control schemes that operate in conjunction. The BESS model operates in active/reactive power (PQ) control mode when the microgrid controller has the thermal generator(s) on, with the possibility of charging or discharging based on the battery power requested by the microgrid controller. The BESS operates in voltage/frequency (Vf) control when the microgrid controller has the thermal generators off and is set as a swing bus to manage voltage and frequency. In the simulation, this is modelled by switching from the battery model (PQ mode) to a 3-phase source model (Vf control mode).

The BESS model integrates power with respect to time to monitor the state of charge of the BESS. The efficiencies of the charge and discharge portions of the BESS are applied here. The state of charge is output as a decimal from 0 to 1 and as a percentage from 0 to 100%. It should be noted that if the BESS is in Vf control mode, it will not limit the state of charge of the battery, thus enabling the battery to reach a state of charge of 100% and still take in power. This could potentially be an issue if the microgrid controller was unable change state (i.e., switch to diesel-on) and/or to curtail enough renewable generation to maintain power balance (issues are flagged and recorded in the simulation). This is assessed and evaluated in the post-processing of the results.

2.2.4 Microgrid Controller

The microgrid controller (MGC) logic was provided by Hatch and is implemented in a Stateflow Simulink block for the purposes of our QSTS simulations. This microgrid controller can curtail the wind turbine's output based on the load of the system and the current wind turbine output. Furthermore, the MGC can decide whether to disconnect the diesel generators based on the amount of wind, the BESS state of charge, and the current system load. For more information about the MGC control, please contact Hatch.

2.3 SYSTEM DEMAND MODELS

The 2019 system demand profile can be seen in Figure 5, with a maximum demand of 415kW and an average demand of 270kW. The system demand of the Kluane system for 2023, shown as a probability density function (PDF), is shown in Figure 6. A load growth of 1.75% per year has been assumed, and years 2019, 2023 and 2042 have been fully simulated as well as the critical portions of 2028 and 2033.

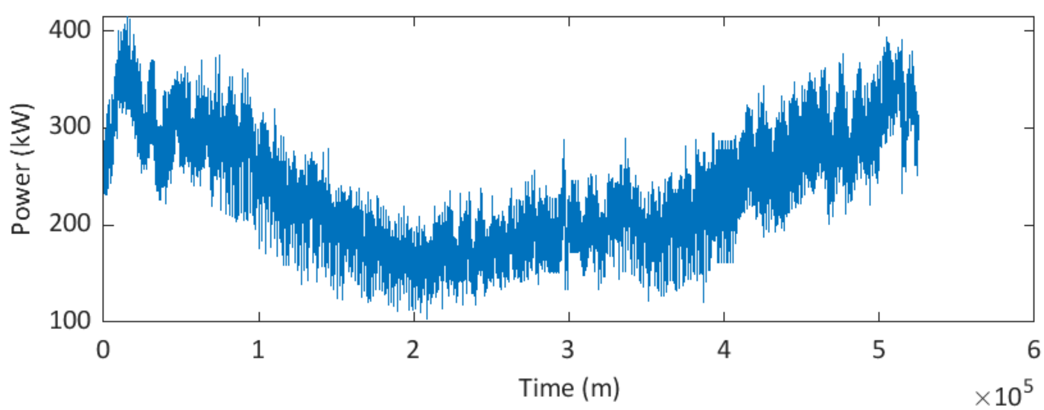

Figure 5: Kluane System Demand Profile (2019)

For the 2042 simulation case it has been assumed that a school load that is connected through three single-phase transformers (3 x 25kVA = 75kVA total) has been added to the system – the maximum predicted load in 2042 will therefore be 694kW. A system demand PDF for year 2042 with the added school is shown in Figure 7.

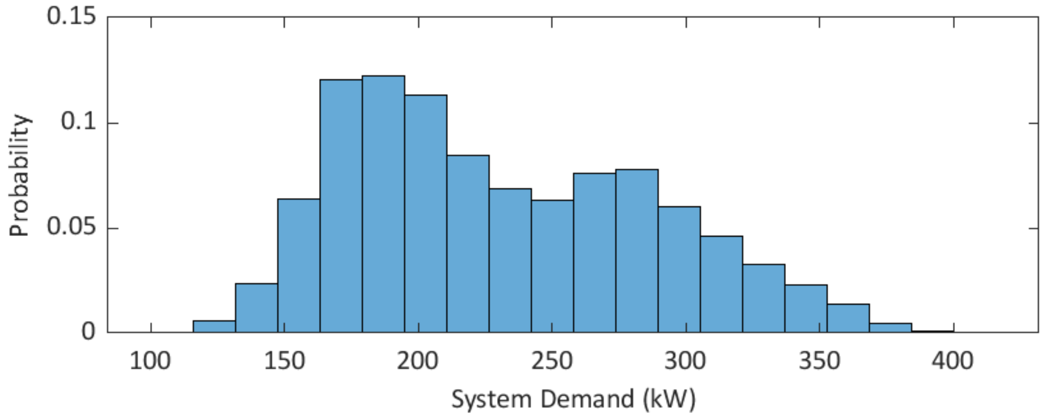

Figure 6: Estimated Kluane System Demand Probability Density Function (PDF) for 2023

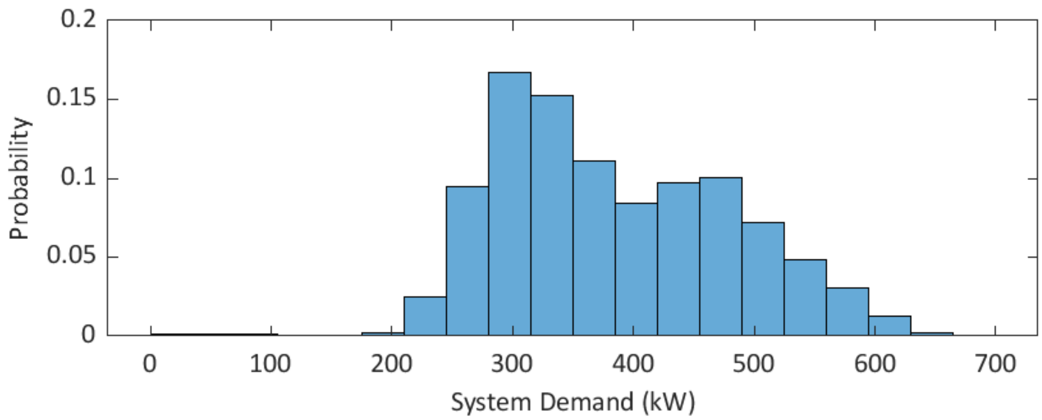

Figure 7: Expected System Demand in 2042 for Kluane

2.3.1 Load Models

Loads are modeled as a constant PQ generator in Simulink (type 1 generator in OpenDSS). Note that PQ values are constant for each timestep but are varied between timesteps according to the generation profiles and microgrid control.

However, our model assumed that the single-phase loads were connected Line to Neutral. As such, an iterative process was used to calibrate the single-phase load multipliers to match the expected load with the system load. A total decrease of 43% was therefore implemented to the single-phase loads in order to match the system load to the expected load.

2.4 DISTRIBUTION LINES

Overhead distribution line parameters have been calculated for the provided overhead line constructions and conductors used by ATCO with the methodology detailed by Kersting and CIGRE technical brochure 575 [1,2-6].

Phase conductors are assumed as ACSR #4, ACSR #6, ACSR 1/0 for overhead lines and #1 AWG for underground cables [1, 7]. Neutral conductors for overhead lines are assumed to be the same as the phase conductors. Poles are assumed to be approximately 10 meters above grade.

Line sag has been neglected, given the negligible effect on the line parameters as determined through calculation of line parameters. This is as expected, given the series resistance is dependant on the length of the conductors, the series inductance is dependant on the spacing between conductors, and shunt capacitance is dependant on distance to ground. Line sag causes a negligible increase in length over the span and no change in spacing between conductors. Furthermore, capacitance is negligible for typical overhead distribution lines, so the negligible variations due to line sag can be expected to have a negligible effect on the results [4].

2.5 TRANSFORMERS

To simplify the model, all secondary service transformers and loading on the secondary service are assumed as loads on the primary distribution system. The exception to this assumption is where renewables are connected to secondary service through the secondary service transformers.

Single-phase pole mounted distribution transformers and banks of single-phase pole mounted distribution transformers (i.e. three-phase pole mounted distribution transformers) of 225kVA capacity or less are assumed to have an impedance of 0.02pu with both a resistance and reactance of 0.014pu based on the data available in *Electric Power Distribution Engineering* by T. Gönen [10, Table 3.3-3.4, pp.104-107].

Three-phase transformers of greater than 225kVA rating are assumed to have an impedance of 0.06pu, based on similar transformers in other remote communities and confirmed with ATCO [1]. Note, the transformer model allows impedances on both the primary and secondary side; however, the impedance is assumed on the secondary side to conform to the standard practice for transformer models. The X/R (reactance/resistance) ratio of the transformers is assumed as X/R=10, based on IEEE Std. 141 [37], which gives X = 0.0597pu and R = 0.00597pu. The calculation of these results is shown below.

$$Z = R + jX = \frac{X}{10} + jX \quad \textbf{(11)}$$

Where Z = impedance

$$|Z| = 0.06\,pu \quad \textbf{(22)}$$

Solving for the magnitude of the impedance

$$0.6 = \sqrt{X^2 + 100X^2}$$

$$X^2 + 100X^2 = 0.36 \rightarrow X = \pm 0.0597022$$

$$X = 0.0597022, R = 0.00597022\ pu$$

2.6 STEP VOLTAGE REGULATOR

The Kluane system has a Step Voltage Regulator (SVR) placed after the transmission line from Destruction Bay to Burwash Landing. This SVR is configured as an open delta system and regulates the line-to-line voltages of phase AB and BC. Phase CA is regulated through these two phase-to-phase voltage changes.

The SVR is set up using two single phase regulators connected in an open delta configuration, both having a rated apparent power of 144kVA and 32 different tap settings (16 above the nominal voltage and 16 below). Each tap change modifies the voltage by 0.00625pu of the rated voltage of 14400V (±90V). The SVR has a tap changing time delay of 30s – due to the 1 minute time resolution of the QSTS simulation, it was rounded up to a time delay of 1 minute for the purposes of our simulation.

Table 1: Step Voltage Regulator Model Parameters

Parameter	Value
NominalParameters [Pnom (kVA) Fnom(Hz)]	[288, 60]
Winding1 [V1(kVrms ph ph) R1(pu) X1(pu)]	[14.4 0.005 0.007]
Winding2 [V2(kVrms ph ph) R2(pu) X2(pu)]	[14.4 0.005 0.007]
RXpuTaps [Rt(pu) Xt(pu)]: Tapped Regulation Winding	[0.005 0.007]
RXmag [Rm(pu) Lm(pu)]: Magnetization branch	[5 5]
DeltaU (pu): Voltage step per tap	0.00625
Regulator [Vref(kV) Deadband(V) timeDelay(minute)]: Voltage Regulator Params	[14.4 480 1]

3 QUASI-STATIC TIME SERIES ANALYSIS STUDY

3.1 METHODOLOGY

Power system adequacy is assessed using Quasi-Static Time Series (QSTS) analysis which examines steady-state power flow throughout the system at each time step (1 minute) over the course of an entire year. QSTS is an important analysis method because it allows investigation of path dependent control interactions such as generator dispatching, microgrid controls, and tap changers. Voltage profiles are created from the system data to provide a visual representation of system behavior.

A series of additional load profiles were also created for the subsequent years of this project. These load profiles assume a 1.75% load growth per year. Furthermore, since there are plans to add a new school in the community of Burwash Landing, a 75kW maximum load was added to these load profiles through the following equation:

$$New\ Load\ Profile = Old\ Load\ Profile * \frac{\max(Old\ Load\ Profile) + 75kW}{\max\ (Old\ Load\ Profile)} \quad \textbf{(3)}$$

As such, the new load profiles will have a peak increase of 75kW but less so at lower load values. This shows the worst-case scenario for the load increase.

The power generation profile of the wind turbine was calculated by Hatch and ranges from 0kW to 900kW, assuming no power is used for blade heating. These data were calculated using a resolution of 10 minutes. The resolution was increased to one minute by linearly interpolating between data points.

The wind resource is modelled as a PQ controllable source operated at unity power factor. It has the functionality to have its output limited by a microgrid controller through a curtailment scheme.

The battery model used in this study can take over voltage and frequency control from the diesel generator plant when indicated by the microgrid controller. This is modelled by the BESS functioning as a PQ controllable load when the microgrid controller has the generators turned on and as a three-phase source (i.e., swing bus) if the generators are turned off.

The diesel generator plant is modelled as a grounded wye three-phase source (i.e., swing bus) capable of disconnecting from the system when a command is provided by the microgrid controller.

To maintain simulation stability a parasitic load on the order of 1W is connected in parallel to the three-phase sources representing the diesel generator plant and the BESS.

It should be noted that, due to the transmission line between the two communities, voltage deviations from nominal are expected throughout the system. A step-up transformer is placed before the transmission line connecting Destruction Bay and Burwash Landing with the tap setting set at 1.05pu.

A step voltage regulator is also placed near Burwash Landing to further regulate the phase-to-phase voltages after this transmission line.

The tap setting on the step-up transformer was confirmed by ATCO field staff on February 24th, 2022.

3.2 SIMULATION SCENARIOS

The baseline case with the 2019 Kluane load profile was first simulated to understand the current situation of the Kluane electric grid. A second simulation was performed to simulate the year 2042 which includes the proposed new school, wind turbine, BESS and microgrid controller, and 20 years of load growth at 1.75% growth per year. These results, along with their respective voltage profiles, are given in the next section. Additionally, the maximum and average going through the step-up transformer was calculated in five-year increments without considering the wind turbine or BESS / microgrid controller for the various years (see Figure 26).

The maximum and average apparent power going through the step-up transformer were also calculated for the worst case (winter) period while adding the wind turbine / BESS and are presented in Figure 27.

3.3 RESULTS

3.3.1 Baseline Case – 2019 Load Profile

The baseline case has a maximum line to line voltage of 1.031pu and a minimum line to line voltage of 0.937pu. These voltage values are within the CSA preferred AC voltage range or 0.92pu to 1.08pu.

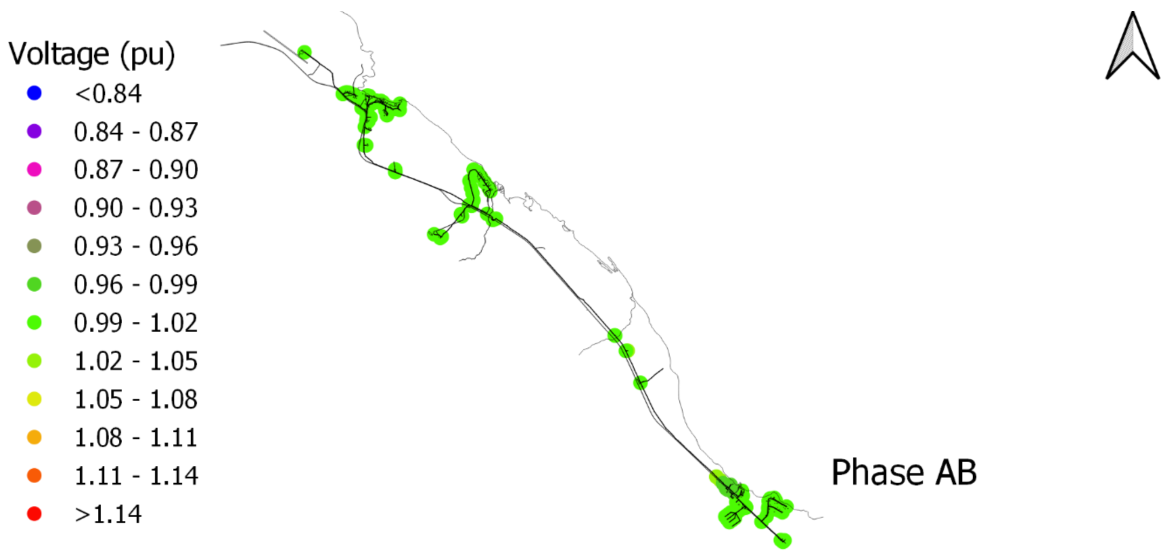

Figure 8: Maximum Voltage on nodes for phases AB, 2019

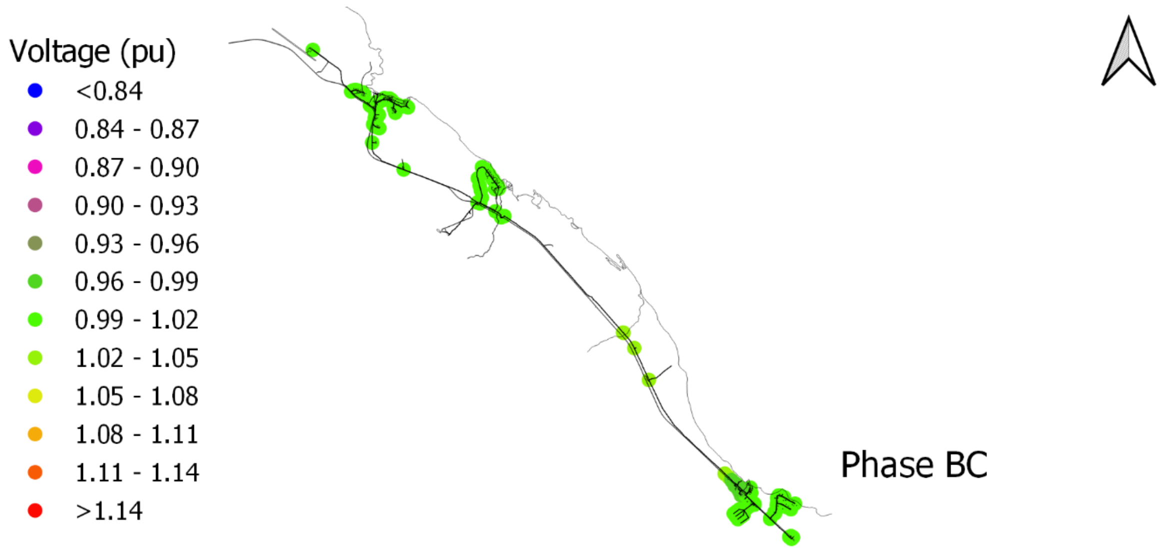

Figure 9 - Maximum Voltage on nodes for phases BC, 2019

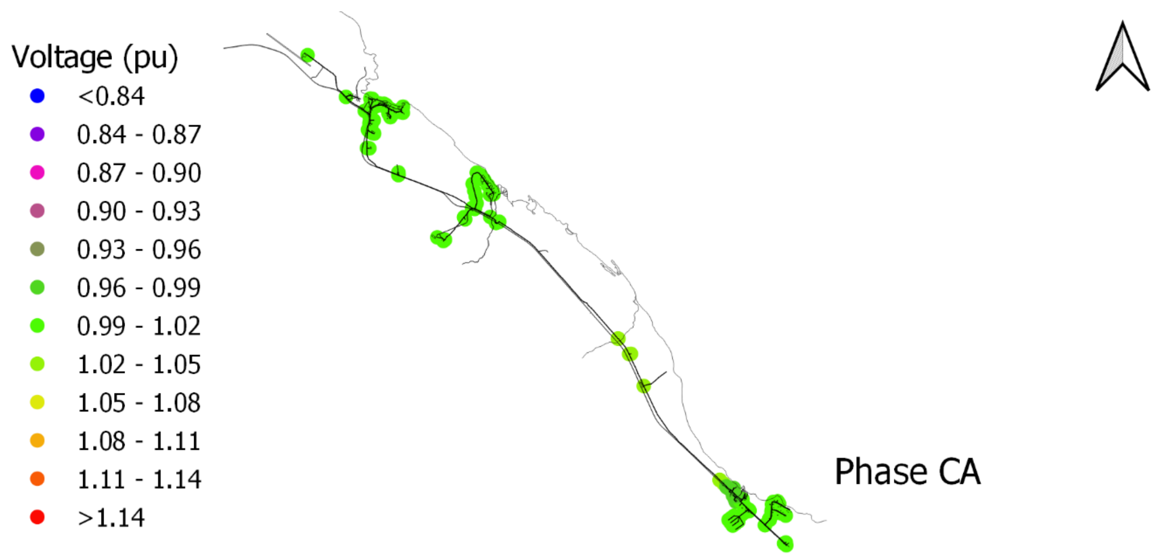

Figure 10 - Maximum Voltage on nodes for phases CA, 2019

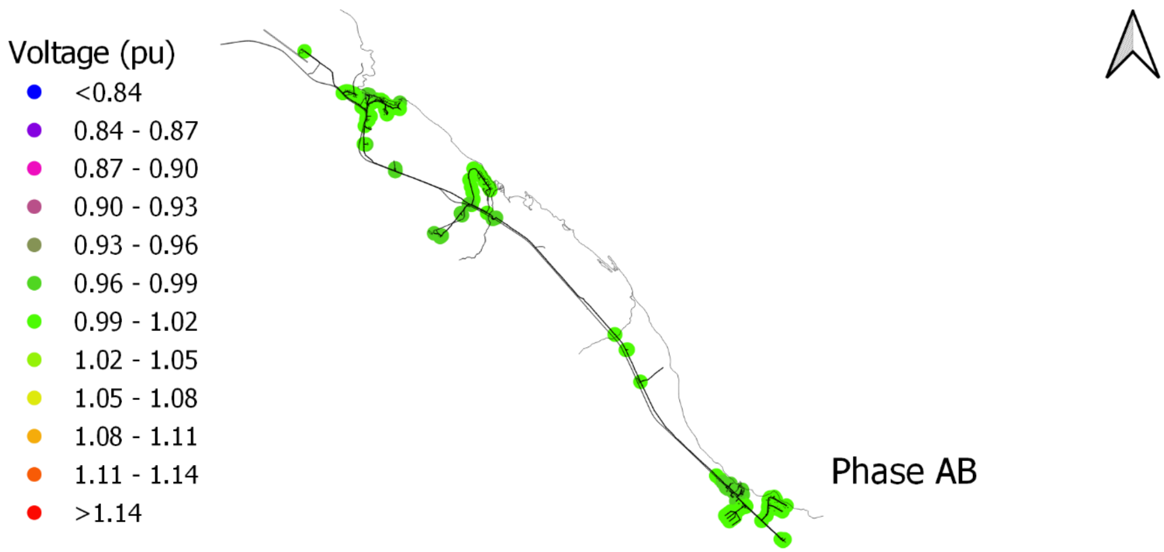

Figure 11: Minimum Voltage on nodes for phases AB, 2019

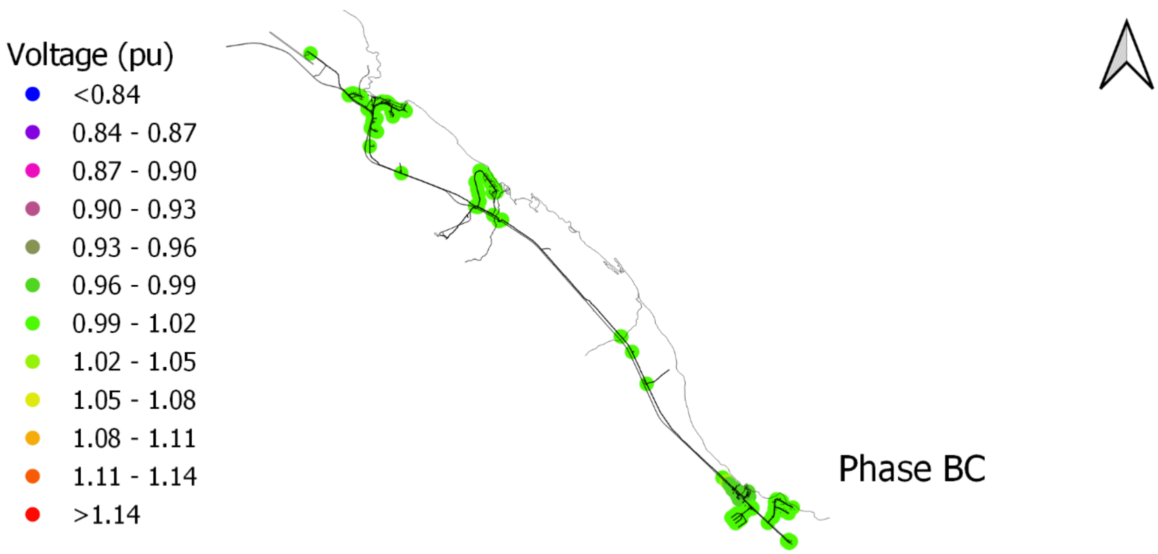

Figure 12 - Minimum Voltage on nodes for phases BC, 2019

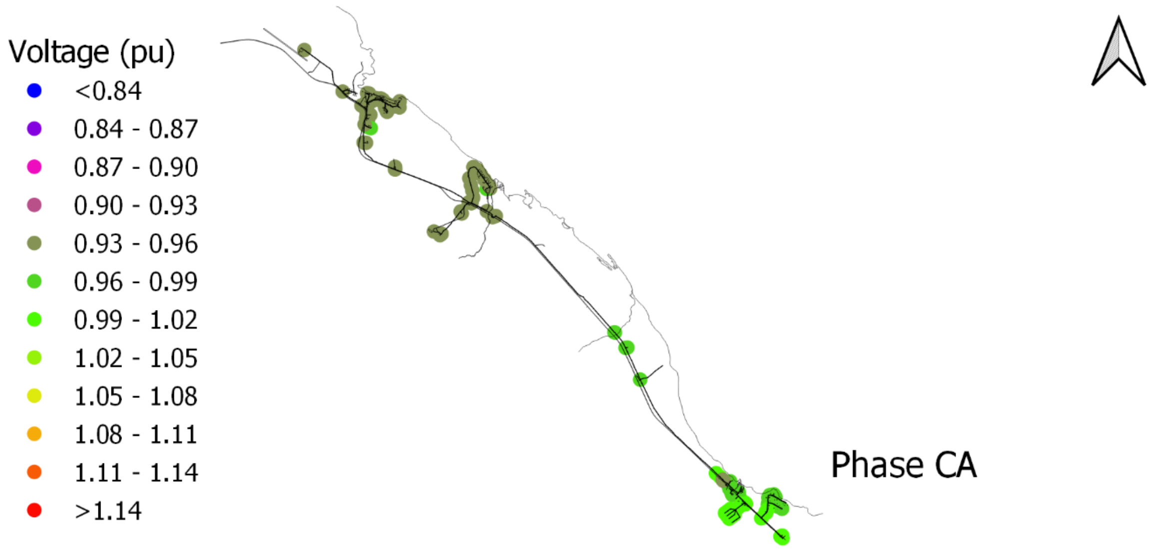

Figure 13 - Minimum Voltage on nodes for phases CA, 2019

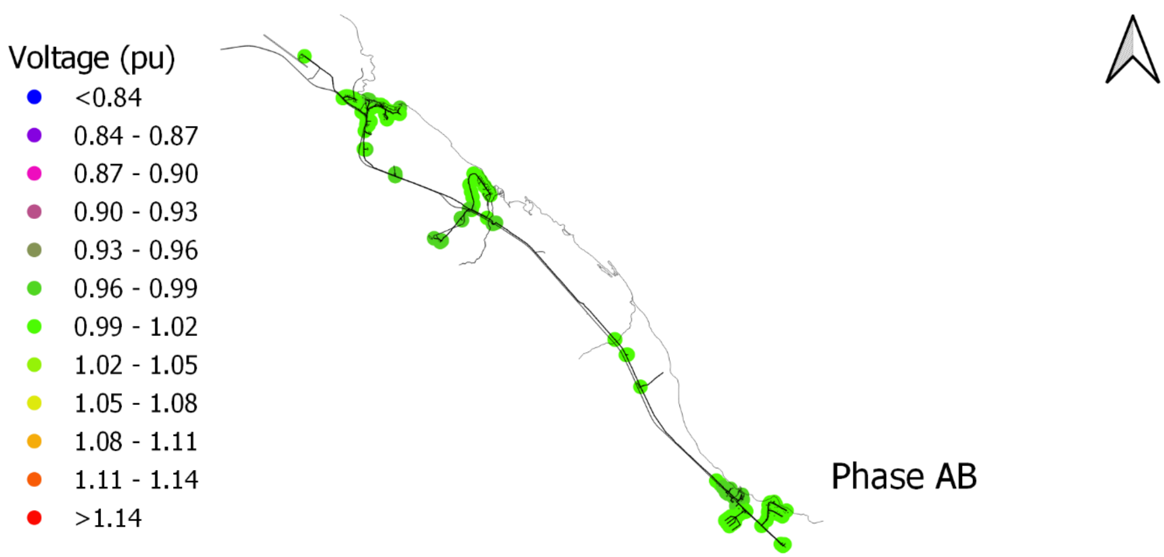

Figure 14: Average Voltage on nodes for phases AB, 2019

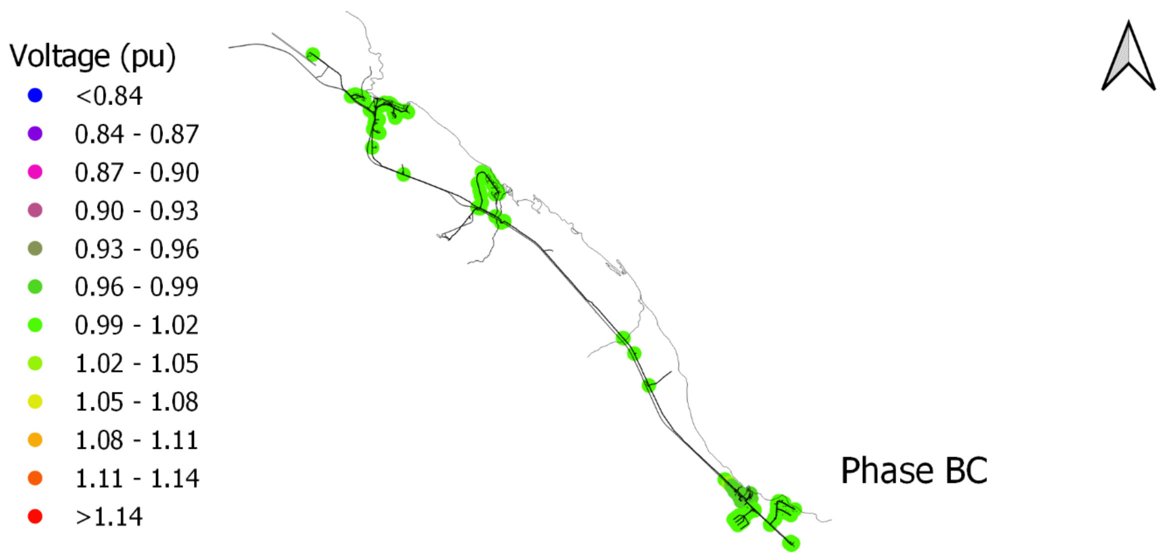

Figure 15: Average Voltage on nodes for phases BC, 2019

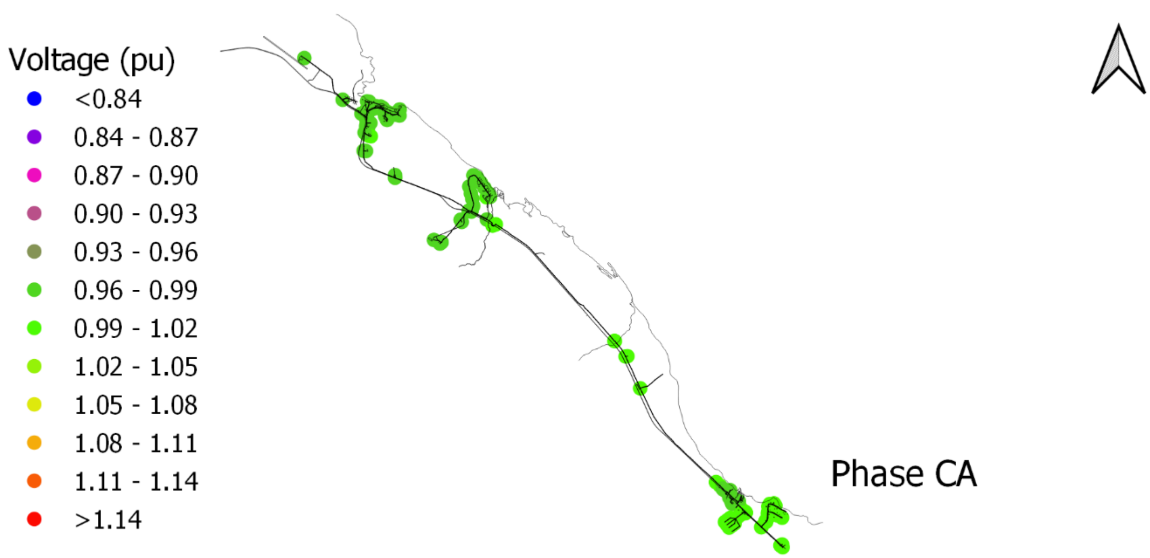

Figure 16: Average Voltage on nodes for phases CA, 2019

3.3.2 2042, added school

The following voltage profiles are the result of the 2042 simulation including the new school, wind turbine, BESS, and 20 years of load growth.

The 2042 plus school case has a maximum line to line voltage of 1.084pu and a minimum line to line voltage of 0.846pu. These voltage values are outside of the mandated voltage limits of 8% above and below nominal values.

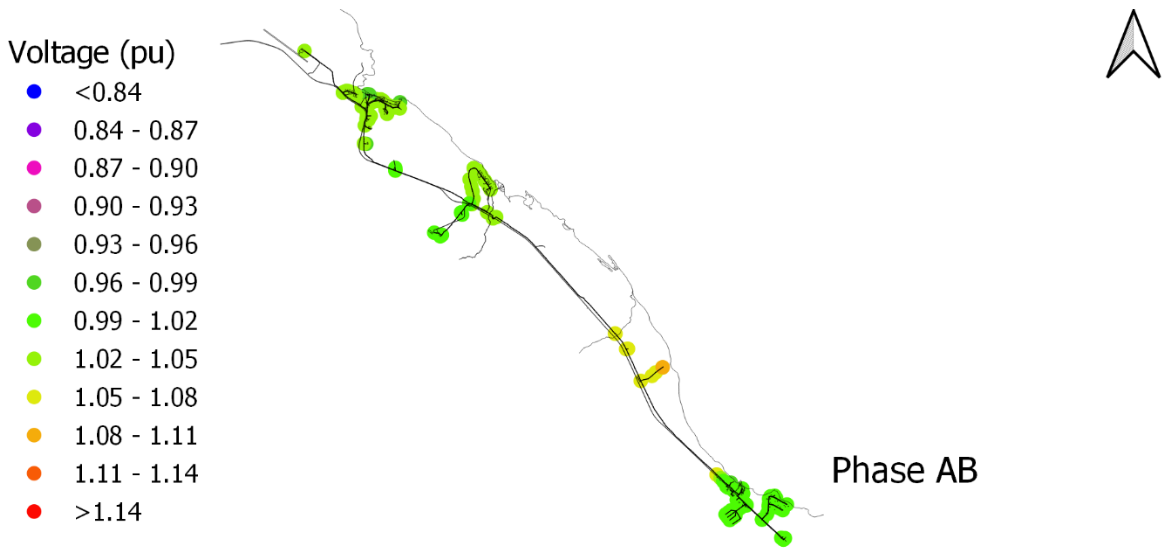

Figure 17: Maximum voltage on nodes for phases AB, 2042

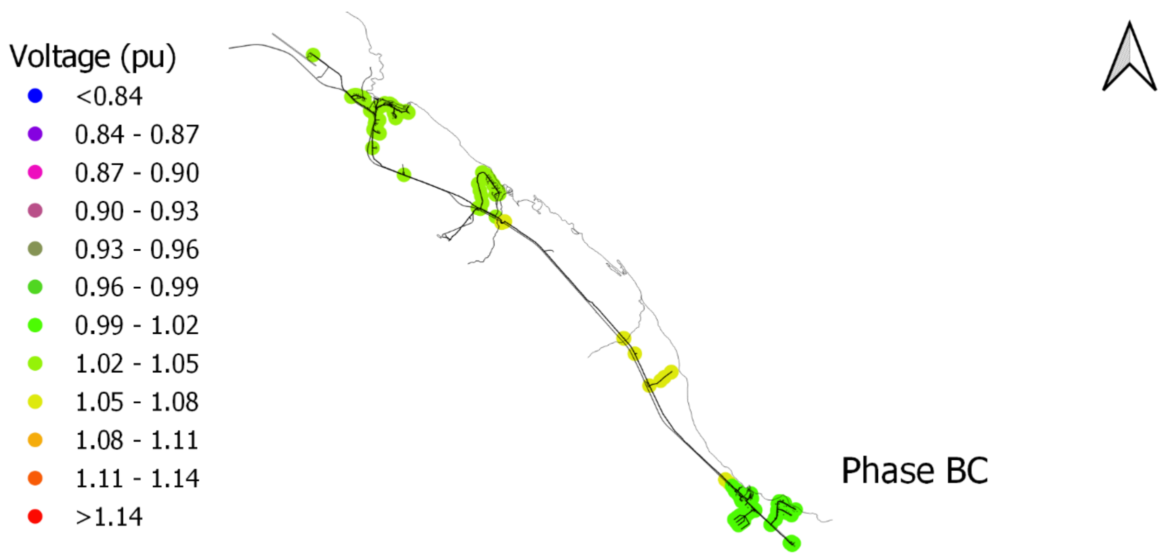

Figure 18: Maximum voltage on nodes for phases BC, 2042

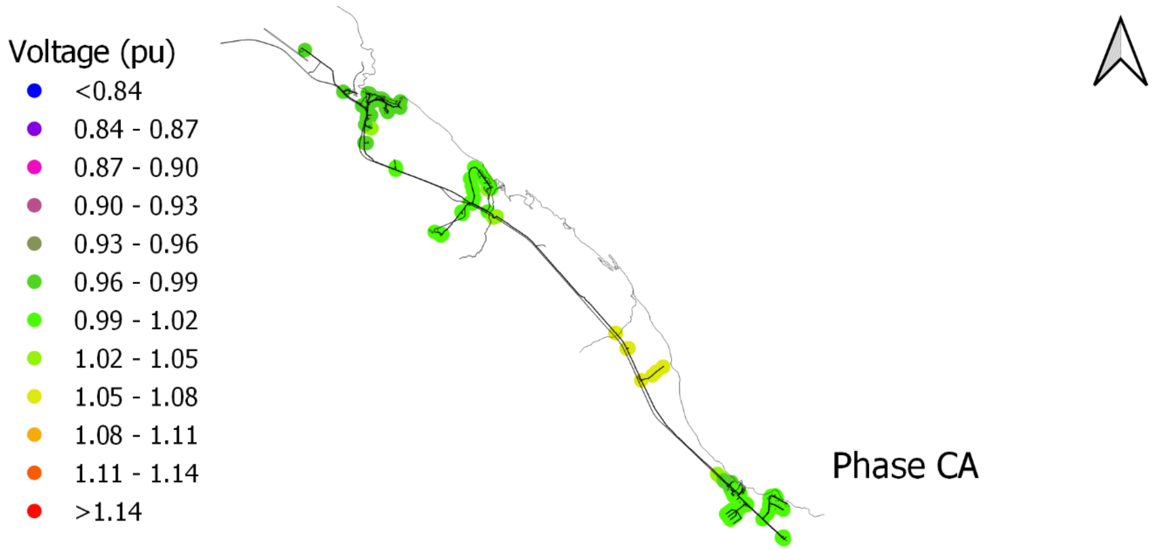

Figure 19: Maximum voltage on nodes for phases CA, 2042

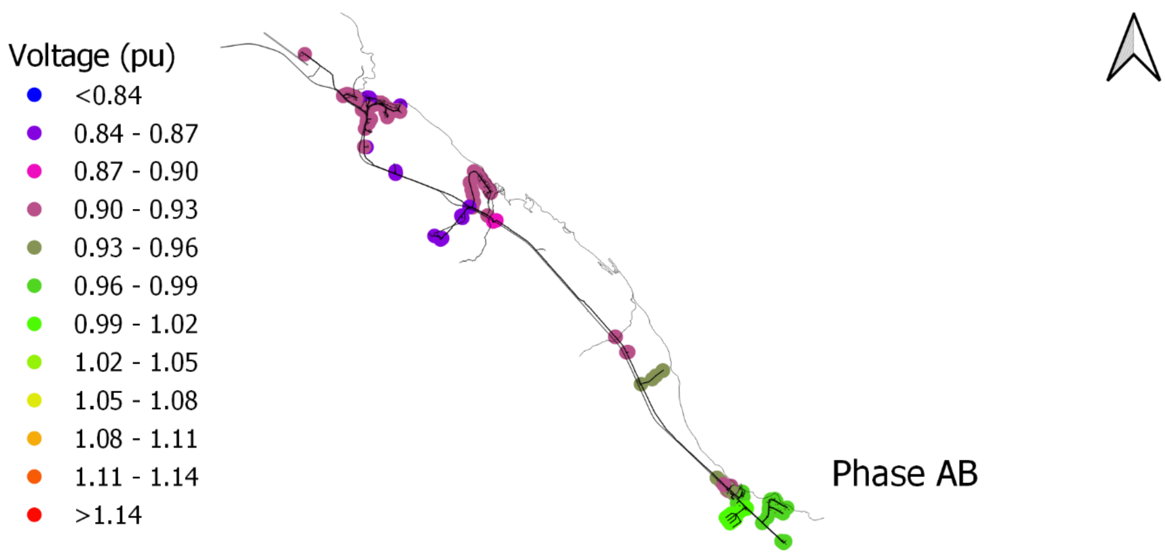

Figure 20: Minimum voltage seen on nodes for phases AB, 2042

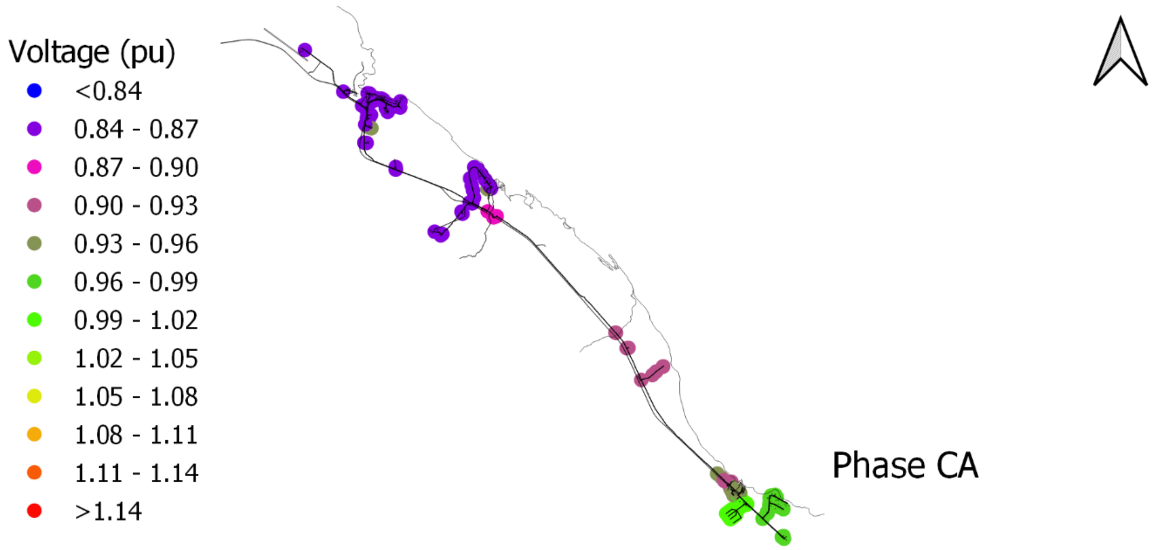

Figure 21: Minimum voltage seen on nodes for phases BC, 2042

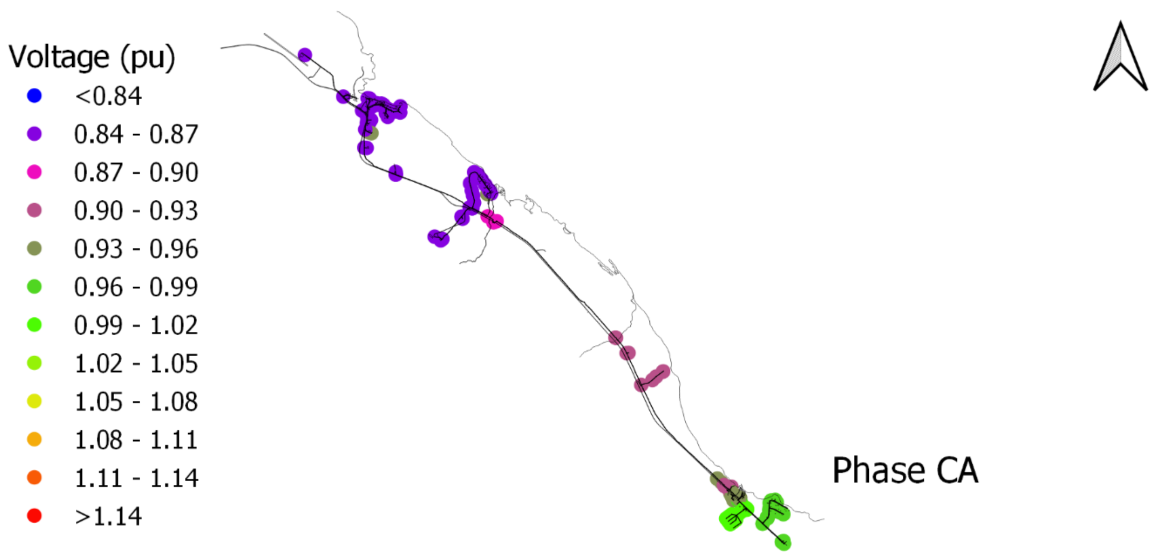

Figure 22: Minimum voltage seen on nodes for phases CA, 2042

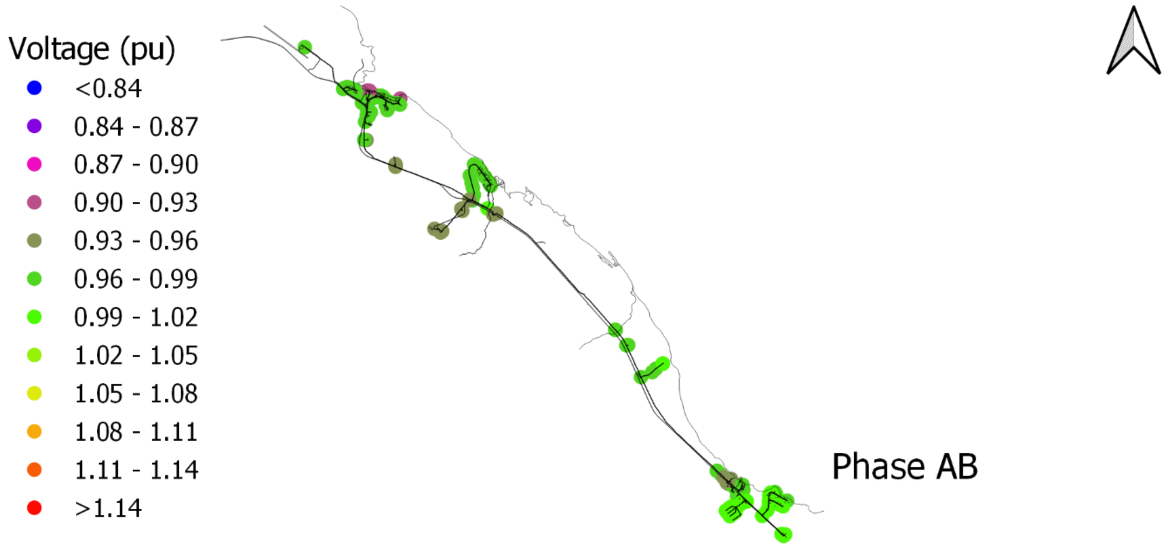

Figure 23: Average voltage seen on nodes for phases AB, 2042

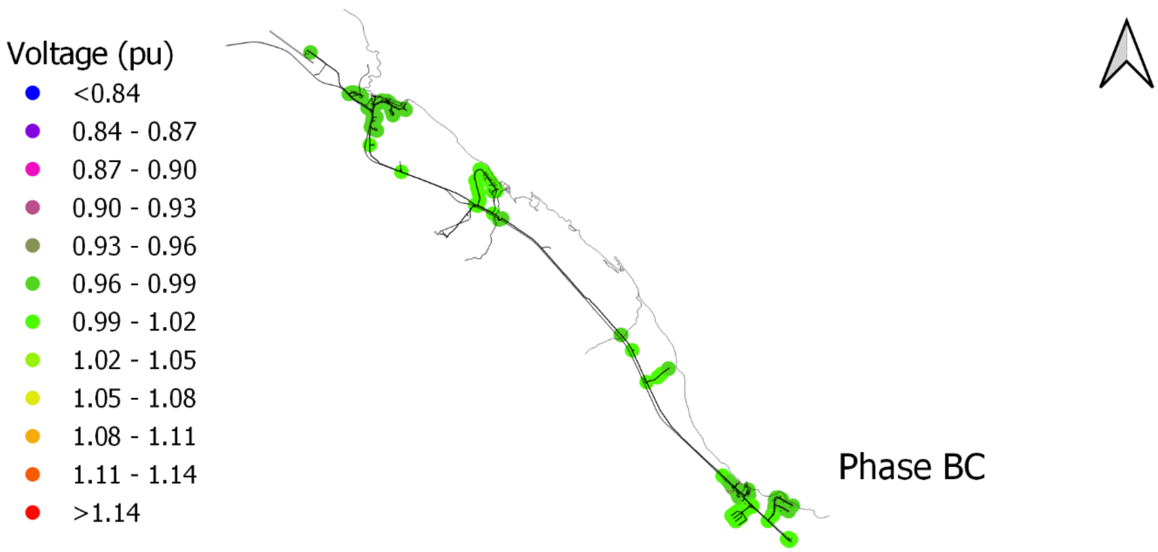

Figure 24: Average voltage seen on nodes for phases BC, 2042

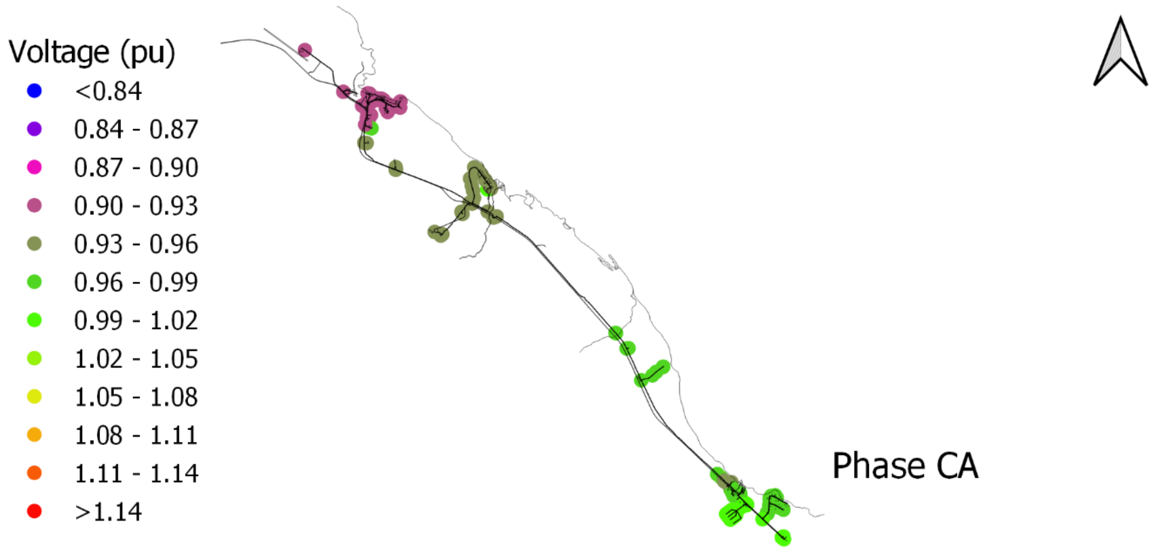

Figure 25: Average voltage seen on nodes for phases CA, 2042

3.3.3 Step-Up Transformer Power Flow

The step-up transformer placed down stream of the community of Destruction Bay is rated to 300kVA. The 2019 simulation showed a peak power flowing through this transformer of 270kVA, while the average power through was 172.5kVA. As per ATCO and Hatch's request, the power through the transformer for the years 2023, 2028, 2033 and 2042 were also simulated with and without adding a wind turbine, BESS / MGC and the planned school. It should be noted that the maximum power though the transformer occurs for at most 1 minute since this is the timestep resolution of our model.

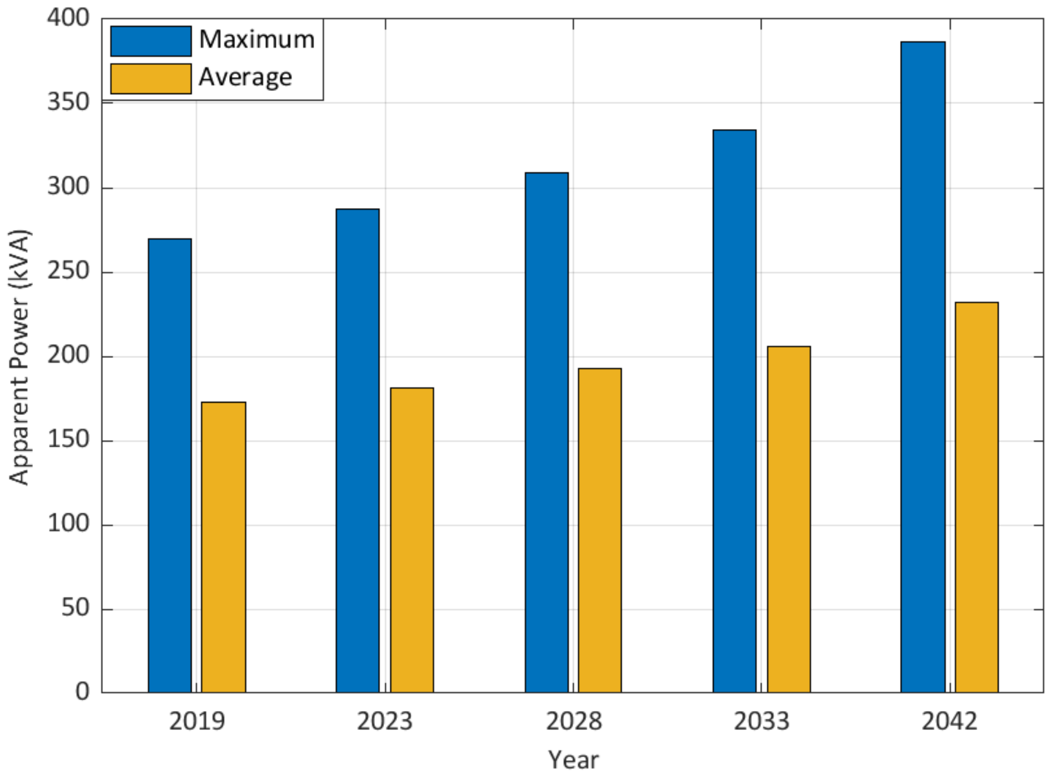

Figure 26: Power through the 300kVA step-up transformer without wind project or new school

These simulations were also run using the models with a wind turbine and school, for years 2023, 2028, 2033 and 2042, as seen in Figure 27. An 80kVA increase was seen for year 2023's maximum power through the transformer when comparing Figure 26 and Figure 27, going up to 350kVA when adding a wind turbine, school, and BESS.

The same simulation was done without a Wind Turbine or BESS in Figure 28. In this scenario 75kW was added to the maximum load of each year, and the powerflow snapshot taken. The maximum powerflow through the transformer exceeds the rated capacity of the transformer at the year 2023 by 29kW and increases further in subsequent years.

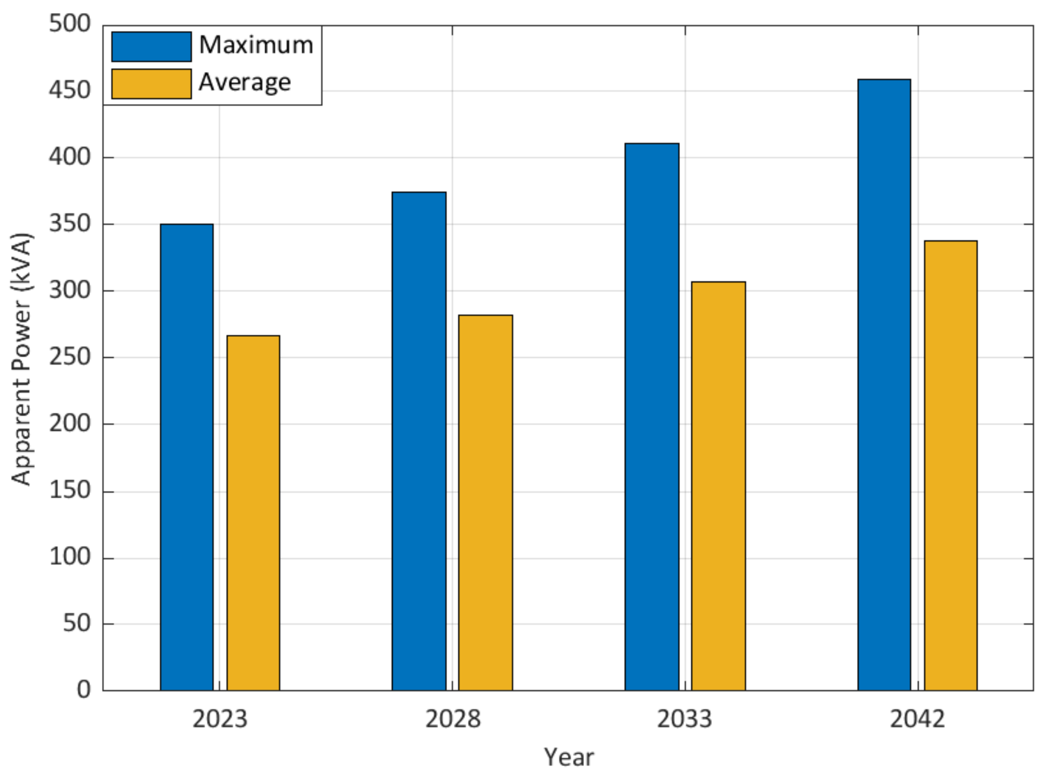

Figure 27: Power through step-up transformer, with Wind Turbine / BESS and Planned School

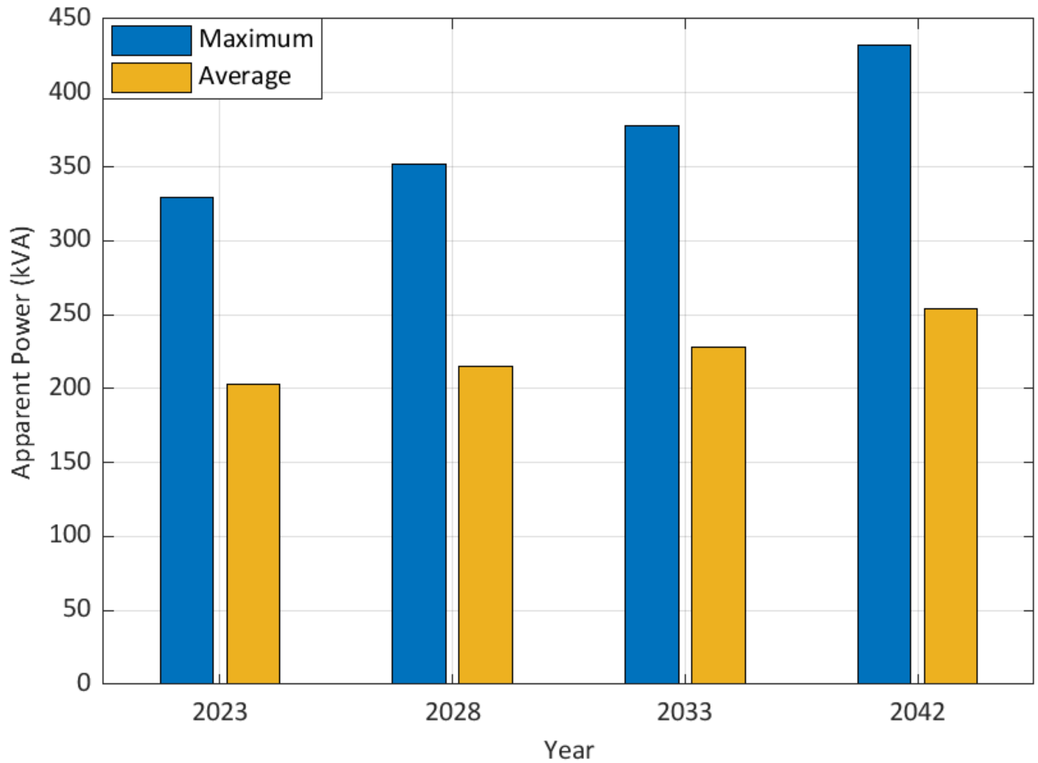

Figure 28: Power through step-up transformer, with Planned School but no Wind Turbine / BESS

4 DISCUSSION

Changes to the step-up transformer tap settings or to the reactive power draw of the wind turbine will have to be implemented to keep the voltages within mandated voltage limits. There are several different changes that could be made to address this:

- As the worst impacts for minimum voltages occur in phase CA in Burwash Landing, this could be addressed in part by adding another single phase step voltage regulator to the SVR and reconfiguring it as closed delta, which would then allow direct phase regulation of phase CA. Currently, only phase AB and BC are regulated directly.
- Utilization of the wind turbine for voltage regulation, which can be done as fixed power factor, volt-var control, etc.

The step-up transformer is rated to 300kVA. However, due to the microgrid controller allowing the wind turbine to charge the battery at its rated capacity of 450kVA, the step-up transformer will have to be upgraded unless additional curtailment can be implemented.

4.1 ADDITIONAL RESULTS – WIND SALES

Table 2: Estimated Wind Sales for Various Years

Year	YukonU Model (MWh)	Hatch Model (MWh)
2023	1120.2	1,065.9
2023, with School	1252.0	
2028	1172.4	1,106.9
2028, with School	1308.4	
2033	1232.2	1,145.4
2033, with School	1352.8	
2042	1323.5	1,215.1
2042, with School	1448.5	

The addition of a school in the community, with an assumed maximum load of 75kW during the peak community load, increases the wind sales by approximately 125MWh each of the simulated years.

5 CONCLUSION

Power system adequacy is assessed using quasi-static time series simulations which examined the power flow throughout the system across one year. Two different models, one with no wind turbine / BESS with the 2019 load and the other with the predicted 2042 load, a new school, a wind turbine / BESS and microgrid control system, were simulated. It was assumed that the community load grew at a rate of 1.75% per year.

Under and Over Voltage Conditions

It was seen that the system will experience some under- and over-voltage issues if the system remains unchanged and a wind turbine / BESS are implemented, with values of at most 0.848pu and 1.084pu in the worst case (in year 2042). However, some solutions are available to mitigate this such as changing the step-up transformer tap setting or adding/removing some reactive power of the wind turbine output.

Spinning Reserve

No issues related to insufficient spinning reserves were found when operating in diesel on mode. Furthermore, the addition of the BESS would reduce any potential spinning reserves even more if the MGC is set up to be able to add to this spinning reserve when the generators are operating.

System Component Operating Limits

It was seen that the step-up transformer will exceed its rated capacity of 300kVA if the microgrid controller allows for the 450kVA battery to charge at maximum capacity using the wind turbine. However, curtailing the 900kVA wind turbine to stay within the current transformer's capacity will decrease wind sales. The load growth and added school will exceed the rated capacity in the year 2023 by approximately 29kVA, while adding a wind turbine and BESS will exceed the rated capacity in 2023 by 50kVA.

Battery Energy Storage System State of Charge

The BESS State of Charge stayed within the 10% and 90% limits set by the microgrid controller. As such, no issues were seen in our simulation with respect the BESS State of Charge using the MGC logic provided by Hatch.

Microgrid controller Effectiveness

The MGC was found to sufficiently curtail the wind turbine power to maintain power balance throughout the year.

6 REFERENCES

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