# Modelling of Remote Diesel-Based Power Systems in the Canadian Territories

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**Photo Credit:** Michael Ross

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The scenario simulations are then analyzed through a form of Monte Carlo filtering (MCF), in which the outcomes of a power system simulation are inherently behavioural or non-behavioural. Non-behaviour is the exceedance of a system variable threshold within a defined period during the simulation. The results of filtering, where multiple measures of the same type throughout the system are taken, are aggregated into a fraction of non-behaviour for each measurement type.

Some system variables or measurements are inherently described as either behavioural or non-behavioural. For example, resource curtailment is not usually desirable, and can be seen as a non-behavioural outcome for a given simulation. A useful context is the amount of curtailment for an increasing renewable resource capacity interconnected to an existing system.

QSTS simulation methods can also be used with the MATLAB/Simulink Parallel Computing toolbox to allow parallelization of simulations, thereby increasing performance and the number of simulation test cases that one may perform. This is useful when performing studies for a large sample space. It also extends to the use of supercomputers for analysis.

The main strengths of the simulation software within MATLAB/Simulink are as follows:

- Versatility in performing both QSTS and EMT analyses.
- Versatility in allowing further analyses to be conducted external to the tool on data obtained from simulations within the tool.
- Capability to expand the type of simulations and integrate between simulation domains. For example, should one wish to model a district heat system in conjunction with the existing power system, MATLAB also contains toolboxes such as Simscape Fluids, which allows the simulation of thermal fluid systems.
- Ease of implementation of user-defined models. The block diagram nature of Simulink makes implementation of user-defined models simple as compared to models implemented in a programming language (as is required for some software).
- Ability to develop open source programs and model libraries within the MATLAB software environment.
- Relatively open nature, thoroughness of documentation, and wide-spread use within academia.

The main limits of the simulation software in MATLAB/Simulink are as follows:

- Black-boxed nature of some solvers and code within the Simscape Electrical Specialized Power Systems toolbox. Note that present development work is aiming to address the main limitations associated with this, in addition to further enhancing the simulation tool.
- The use of the phasor solver in the Simscape SPS toolbox requires the differentiation of equations, which necessitates unit and/or memory delays to prevent algebraic loops in the solution.

Within the context of the EMI framework, the models developed in this tool represent the actual operation and physical dynamics of the equipment that are found in isolated diesel-powered communities in all three Canadian territories. Furthermore, their integrated operation in the power system models represent the realistic responses to the power system, and so the parametric QSTS and EMT studies when evaluating the adequacy and security of the system with renewable generation ensure the system can be appropriately assessed before potentially catastrophic events are witnessed first hand. A power outage in an accessible community is an inconvenience, but a power outage in an isolated community in the Canadian territories can be critical. These results can help support policy in making informed decisions on long-term renewable generation and diesel-reduction goals that also comply with standard power system operating requirements of stability and reliability.

## 2.3 COMPARISON WITH OTHER MODELS WITH SIMILAR OBJECTIVES

Power systems are modelled through digital simulation, as is the case here. Power system studies are also performed as digital simulation with hardware in the loop, or hardware tests; these simulation types are not explored here [7]. Each form of modelling has advantages and disadvantages. Digital simulation provides flexibility in performing many simulations, parameter sweeps, and control of the test environment. The accuracy of the results is highly dependent on the modelling accuracy, environment simplifications, assumptions, and solvers. Hardware-in-the-loop provides the flexibility of including real equipment in the simulation, and it can be used to validate the operation of specific equipment. Hardware tests are expensive, difficult to create specific test case scenarios, or perform multiple tests; however, they provide the most accurate result if identical or comparable equipment are used.

There are many simulation software platforms, each of which has a specific role in power system analyses. Given the focus of this report is on energy modeling, this report will not go into detail regarding dynamic simulation and EMT. For the study of energy and power flow, it is not necessary to use hardware in the loop or hardware tests; however, there is value in using real equipment for EMT studies. Yukon College has developed our own tool to perform power system studies, however other systems exist for the same purpose.

Programs such as RETScreen, HOMER, or GAMS can be used for modelling the energy balance of the power system. RETScreen and HOMER are typically used for feasibility studies, while GAMS is typically used for the solution of optimization problems. An optimization study in remote diesel-based communities in the Canadian territories is given by [8] using GAMS. It is important to understand the distinction between software used for energy studies and software used for power system studies, as using only models for a single time scale range will not provide the whole picture of all electric power system phenomena. The software identified earlier in this paragraph can only represent time scales on the order of minutes to hours, and thus cannot provide a complete model of the power system. As an example, one may find that it is both economic and desirable to install a group of wind turbines at the end of a feeder due to resource availability in an energy study. However, upon studying the power system further, it may become apparent that it would cause voltage regulation issues and require significant capital investment in system upgrades to resolve, thus skewing the original picture painted by the software.

For the study of power flow in distribution systems, software such as CYME/CYMDIST, WindMil, or OpenDSS can be used. Most power system software includes the capability to be controlled programmatically through scripting (e.g., CYME allows scripting using Python, OpenDSS allows scripting using MATLAB and/or Python). Few power system software platforms are open source; OpenDSS for example, is the only open source software of the three software platforms mentioned for power flow studies of distribution systems. While all of the software platforms accomplish many of the same tasks, they do not necessarily all use the same underlying methodology, though the intended results should all be comparable. In comparison with MATLAB/Simulink/SPS, all of these programs provide, at their core, the same overarching functionality. However, as some models and solvers are black-boxed within other platforms, the models and tool developed at the YRC is intended to be openly documented and shared for better understanding of equipment parameters and operation, as well as to easily identify means to improve upon the models.

## 2.4 PLACE IN ENERGY LANDSCAPE / MODELLING ECOSYSTEM

Power system models have an important role in the energy modeling ecosystem. Policy, when made without consideration of the technical limitations and realities of the power systems, can lead to a wide range of issues. In remote diesel-based power systems where reliability is key, lack of detailed studies may lead to more conservative policies. If the goal is to achieve a high penetration of renewables, it is necessary to study the system in detail due to the requisite complexity and consequences if safety and reliability are compromised. Each and every system is unique, and one must be able to study and to understand the implications of both the power system and its controls.

The results of the studies can be used to inform policy on the technical limitations and opportunities of integrating renewable generation on isolated diesel-based electric power systems.

## 2.5 STATE OF DEVELOPMENT & EVOLUTION ROADMAP

The tool is, at present, functional but requires strong knowledge of the structure and methodology used within. While capable of performing QSTS and EMT studies, it requires scripting to use. At present the tool has remained exclusively focused on the electric power system; however, the following development is planned or under progress:

- A power flow solver, external to the black-boxed pre-existing solver in the Simscape Electrical toolbox, is under development. This solver is being developed with a key focus on an open source nature and the capability to handle user-defined models. It will also allow the initialization of user defined models, which is a limitation of Simscape Electrical at present.
- A short circuit solver is planned for development. At present, there is no pre-existing short circuit solver in the Simscape Electrical toolbox; however, it is possible to provide short circuit analyses through EMT simulations. The disadvantage of using EMT simulations to perform short circuit studies is the substantial computational burden, which is acceptable when studying a limited number of cases. A short circuit solver will allow traditional protection coordination studies to be performed. As with the power flow solver, a key focus is on an open source nature and the capability to handle user-defined models.
- Expansion to include thermal fluid systems, such as district heating and electric thermal storage (either distributed or centralized). Given the potential for integrating thermal systems with the electric power system, this will provide a significant improvement in the capacity of the tool to

study practical systems. District heating and thermal energy storage are both means by which a higher penetration of renewables can be achieved. There are many examples of thermal energy storage in use in remote communities in Alaska, USA [9]. There are also examples of thermal energy use in the territories in Canada [10,11,12].

- Expansion to include additional power system models, as required in future studies. Examples of such models could include controls for voltage regulators such as on-load tap changers and step-voltage regulators (note that while there are models of transformers and on-load tap changing transformers, there are no distinct models of voltage regulators with controls available in Simscape Electrical Specialized Power Systems).
- Expansion to include additional data visualization taking advantage of geographical information system (GIS) data.
- Dissemination of the results in a comprehensive fashion that is understandable by policy makers and the general public, without compromising technical rigour nor accuracy by using proper technical terms where necessary. The added benefit of this approach is to enable technical personnel and policy makers to speak the same language when speaking about technical considerations.

# 3 MODEL RESULTS

The model results, as described briefly in the previous section for QSTS analysis, include a range of information from the power flow of the system as well as controls. While one might assess the results of a single simulation, the major advantage of this tool is in the performance of Monte Carlo simulations. The results are intended for use by electrical engineers at utilities, with standard formulation and terminology. The results are also intended to be accessible to community members, policy makers, and the general public. The intent is for the results to be appropriately interpreted and used for successful renewable energy projects by all parties involved.

## 3.1 PRESENTATION AND INTERPRETATION

Given the nature of Monte Carlo simulations, it is necessary to assess the outcomes of each simulation quantitatively in relation to one or more parameters within the sample space. For energy modelling using QSTS, this translates readily to the 'behaviour' or 'non-behaviour' of a variable of interest.

The data output and how it is analyzed within the tool is, at present, defined by fixed code; however, the data output from the simulations can be analyzed independently from this code. Further, user-defined models can be built in such a way as to output the required data. This allows differing outputs from user-defined models to be analyzed as desired by the individual performing the study.

In the majority of cases, data visualization provides the most accessible means of interpreting the results. Common means of data visualization for QSTS analysis in the tool are shown in Figure 1 through **Error! Reference source not found.**Figure 7. Specific numerical results are provided in Section 4.1 for a number of case studies. These figures are intended to provide a visual graphic for interpretation of trends so that engineers and policy makers can easily understand intuitively whether operating thresholds are exceeded, or non-behaviour conditions occur.

Figure 1 shows an example of a voltages throughout a system with respect to thresholds. This figure was produced within QGIS using data exported from MATLAB. QGIS is a free, open source geographic information system software program that allows scripting in Python [13,14]. The figure can be used to identify problematic areas within the system; however, it lacks full detail as to what may be causing the issue. Similarly, a figure showing the magnitude of line currents throughout the system with respect to line ampacity can also be used to visualize problematic areas. This figure, and similar figures, are divided into separate phases to show the effect on individual phases in order to explicitly pinpoint problematic operating conditions and the realities of large phase imbalance on isolated power systems.

Figure 2 shows an example of the voltage profile of a single feeder with respect to distance. It provides a more detailed snapshot of the voltage, showing the average, minimum, and maximum voltages. Figure 1 and Figure 2 each can be produced for partial data of the simulation, allowing one to assess the impact of specific time periods, such as a day, a month, or a season. Seasonal snapshots are useful in that they provide relevant data without an overwhelming number of graphics.

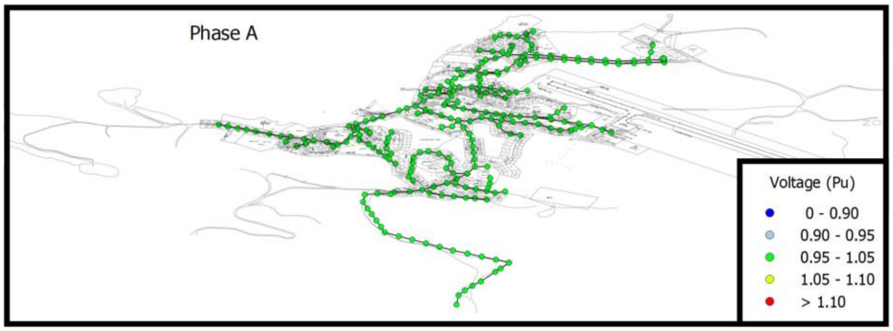


**Figure 1: Maximum measured voltage on phase A in per unit at each node in the Cape Dorset distribution system.**

**Note: A typical figure would also include Phase B and C as well but have been omitted here.**

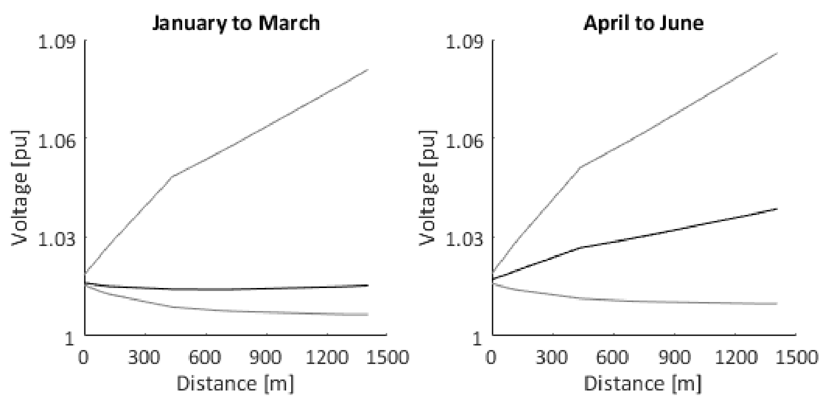


**Figure 2: Voltage profile of Feeder 1 phase A in per unit with respect to distance in the Old Crow distribution system.**

Figure 3 shows an example of the voltage of at two specific nodes in the system model with respect to time. This can be useful when greater detail is needed to examine an issue in the system. For example, the nodes upstream and downstream of a voltage regulator could be investigated.

Figure 4 shows an example of a histogram for a given range of parameters. This is useful when interpreting the result of a single simulation, or in comparing a select number of simulations. In this example, the distribution of diesel off durations is provided, which shows the likelihood of an energy storage system in the community to operate for specific lengths of time. In the case of the below figure it is observed that the battery most likely to operate for greater than 24 hours at a time. The data collected from the model can easily be integrated into a probability distribution function. These results can inform a community or a project proponent that wishes to have diesel-off operation on the trade-offs between energy storage system size and the expected number of hours the diesel generator will be off throughout one year.

Figure 5 shows the cumulative value of occurrences for the total hours of diesel-off operation for a diesel-solar-battery system. It shows the relation between the installed solar capacity and total diesel-off time.

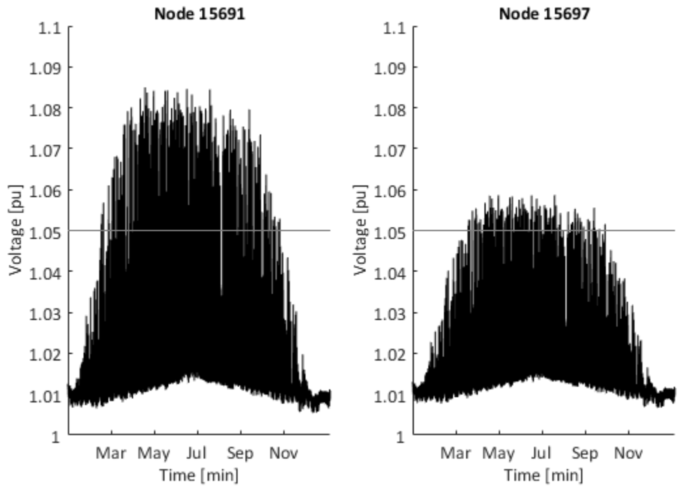


**Figure 3: Voltage profile of Node 15691 and Node 15697 phase A in per unit with respect to time in the Cape Dorset distribution system.**

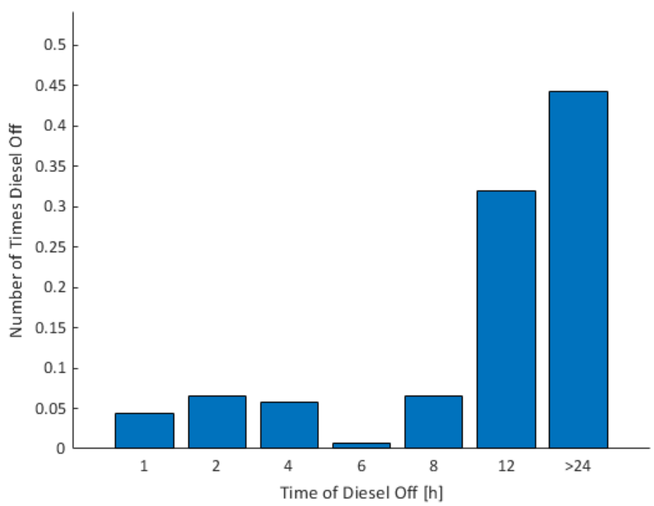


**Figure 4: Normalized histogram of hours diesel on for a diesel-solar-battery hybrid system in Beaver Creek**

Interpretation of model results depends to some degree on the simulation sample space and the study being performed. It may also influence the parameters investigated. For example, a voltage issue could be interpreted as the result of a renewable resource, a voltage regulator, or both.

As an example, curtailment of generation may be under investigation in set of simulations, and so the fraction of curtailed generation with respect to installed resource capacity may be plotted, as shown in Figure 6.

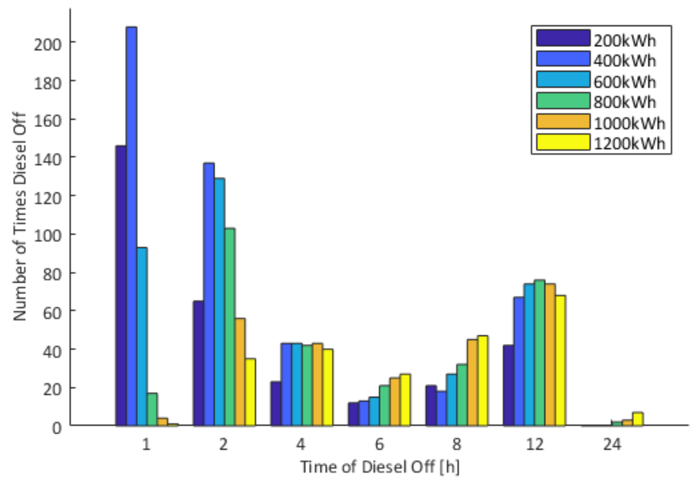


**Figure 5: Histogram function of hours diesel off for a diesel-solar-battery system in Old Crow**

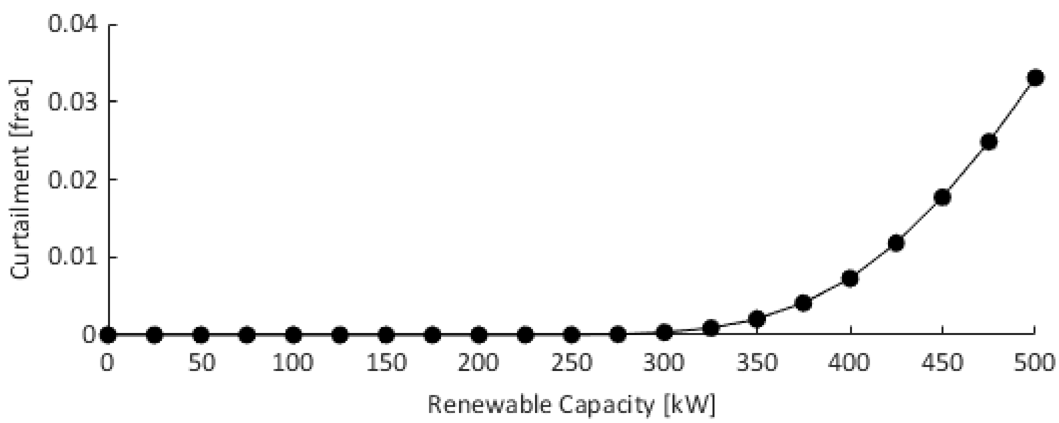


**Figure 6: Fraction of curtailed energy with respect to installed renewable capacity in Cape Dorset.**

This figure can be replotted with respect to energy storage system energy capacity, as shown in Figure 7, or with respect to energy storage system apparent power capacity, or with respect to energy storage system energy capacity. respectively. These figures are the subplots of a scatter plot matrix for the sample space of the simulations. The interpretation of these results is ultimately dependent on the person performing the study and the intended audience. For example, the utility engineer might interpret that certain system upgrades are necessary to support the renewable generation project; however, the community might interpret it as a limiting technical factor that may prevent a larger project. For these specific figures, there are many interpretations that can be made such as, how much renewable capacity can be integrated before curtailment is required, does battery power or battery energy storage play a more important role, etc. Regardless, the results are meant for all audiences so that they can extract from them in an equal manner what is most relevant to them.

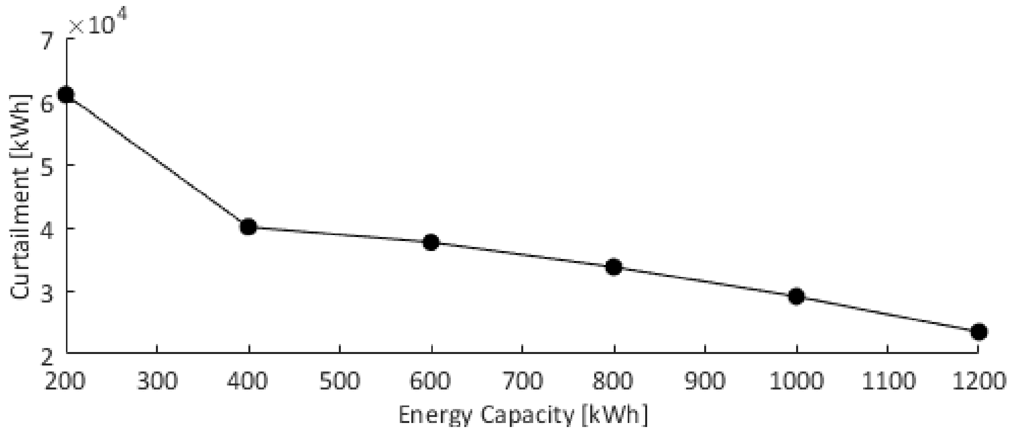


**Figure 7: The total curtailed energy with respect to the energy capacity of an installed ESS on the Old Crow system.**

As a further example, state of charge of a battery energy storage system may be under investigation in a simulation, and so the number of times in which state of charge thresholds are exceeded (i.e., non-behaviour) may be plotted with respect to the energy or power capacity of the energy storage system. It can even be extended to investigate the length of time of charge/discharge. When coupled with the information in the previous example, an energy storage system size could be identified from the results that demonstrates which size of storage, when coupled with renewable generation, yields the best technical vs. economic benefits for the community.

# 4 PLACE IN THE MODELING ECOSYSTEM

## 4.1 USAGE

There are several past studies in which this tool has been used to help further renewable energy projects. The following subsection discuss studies performed in Old Crow, Yukon; Beaver Creek, Yukon; and Cape Dorset, Nunavut. One of the key aspects of the studies is in the unbiased, technical point of view that facilitates decisions making regarding the projects by all involved parties. In remote communities it is not uncommon for both the utility and the local indigenous, communities, and/or municipal or hamlet governments to be involved in a renewable energy project.

While the intent of the results is not meant to explicitly direct policy, the transparent and technically rigorous results have been used by utilities, project owners, and communities to advance their respective renewable energy project. These results, along with other case studies that can be performed by the models, form the basis upon which policy can be responsibly made. To remain unbiased and technical in nature for a wide audience, the results from the tool are meant to inform technical and non-technical audiences alike. Examples of this could be assessing the impact of specific net metering policies on distribution systems, unit sizing metrics for the replacement of diesel generators in remote communities with pre-existing or future renewables, or jurisdictional limitations on integrating renewable generation in electric power systems.

The subsequent sections give specific examples of how the modelling results have informed and advanced renewable generation projects in diesel-powered isolated communities in the Canadian territories.

### 4.1.1 Old Crow Solar Project Power System Impact Study

The Old Crow Solar Project consists of a solar photovoltaic array, a battery energy storage system, and a microgrid controller. The results presented in this section are selected results from the full study [15].

The study first examined the Old Crow system with a parameter sweep of solar array capacity ranging from 20 to 260 kW and no energy storage system. The solar array is curtailed to prevent underloading the smallest generator while maintaining energy balance. The fraction of curtailed energy to the energy produced and curtailed is calculated. The results show that no curtailment is required for solar capacities less than 100 kW, Figure 8. Further increasing the capacity of the PV plant increases the amount of curtailed energy. What this implies is that there is a maximum solar array capacity without energy storage or alternative. The maximum could be due to the requirement for communications and controls, or economic limitations due to curtailment of the resource.

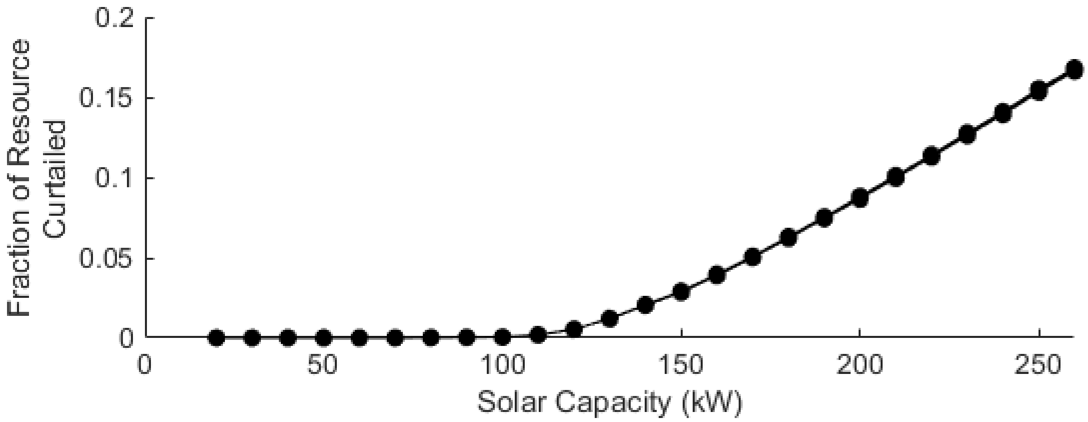


**Figure 8: Fraction of Curtailed Resource to Total Renewable Energy Produced Relative to the Solar Photovoltaic Plant Size [15].**

The models were then used to study the system voltages for the proposed solar array capacity and energy storage system. Over- and under-voltages are observed during the simulations. Injection of power into the system from the solar array results in a voltage rise between the diesel plant and the solar array, which is both expected and observed. Conversely, the under-voltage condition occurs on the other feeder, and is due to the a sufficiently large demand on the feeder to result in the low voltage condition toward the end of the feeder. Both of these conditions needed to be addressed.

Voltage rise from the diesel generation plant to the point of interconnection of the solar array is expected and observed in the simulations. Power factor control, wherein the solar array consumes reactive power in relation to the real power produced and the power factor, is used to mitigate the voltage rise at the point of interconnection. The study examines power factors from unity to 0.9 in steps of 0.025. The simulations show that altering the power factor to consume reactive power decreases the maximum voltage rise for a 450kW solar array, from as high as 1.1 pu to 1.06 pu for the second quarter of the year, Figure 9. A similar decrease in maximum voltage is observed in all quarters. For clarity in the figure, power factors of 0.925 and 0.975 are not shown. What this result shows is that, through a simple control scheme, the voltage rise can be mitigated. It also implies that one must also consider the reactive power limitations of the diesel plant and battery energy storage system when determining an acceptable power factor for the solar array.

The study then investigated the impact of battery capacity. Simulations show that a battery capacity of 400 kWh or greater provides an estimated life span of the battery of greater than 20 years. A battery capacity of 600kWh or greater does not experience discharge cycles of less than 1 hour. Finally, a battery with a capacity of greater than 800 kWh is capable of discharging for over 24 hours. This shows that increasing the battery capacity can increase the life span, can ensure the diesel generators can remain off for over 1 hour, and can allow diesel-off operation for over 24 hours. Increasing the energy capacity of the battery was not shown to decrease the total number of hours diesel-off, which is related in part to the battery energy storage system but also largely to the solar array capacity.

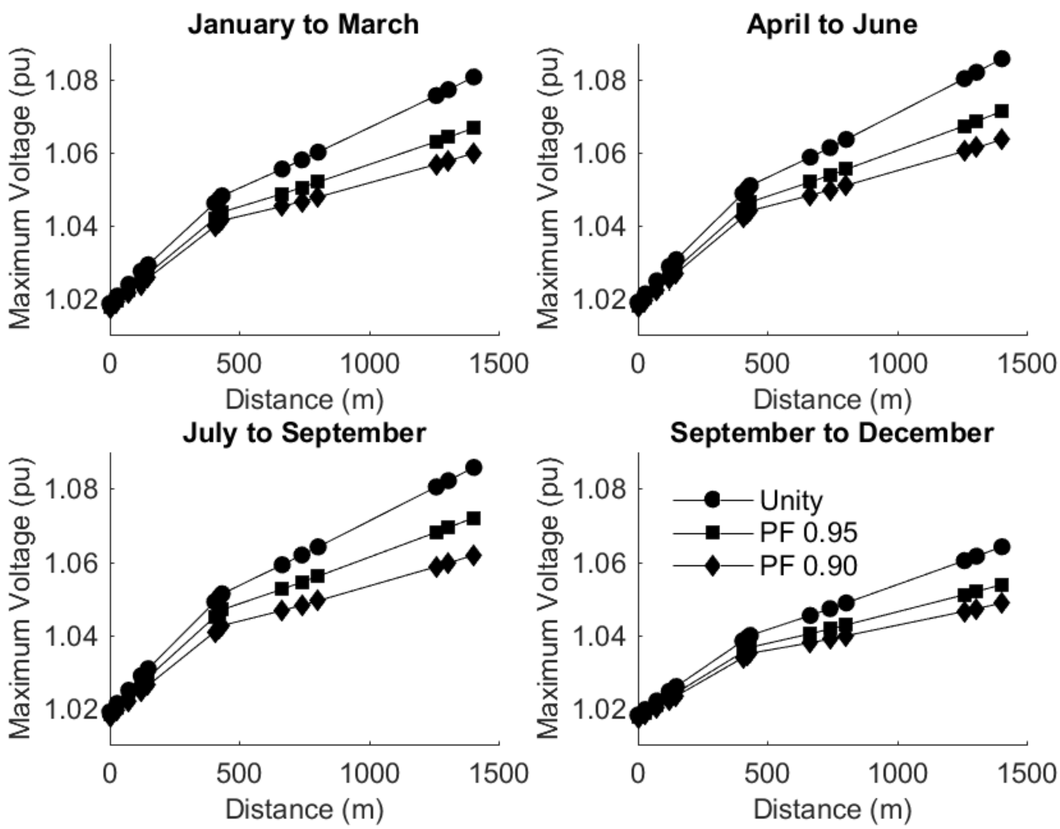


**Figure 9: Maximum Voltage Rise from Generation Plant to Solar Plant Shown for Each Quarter of the Year and for Unity, 0.95, and 0.90 Leading Power Factor [15].**

It is important to note that these results are unique to the control scheme used, wherein the solar generation is used exclusively to charge the battery until the battery has sufficient state of charge for the system to switch to diesel off operation. At this point, any solar generation in excess of the system demand is used charge the battery. The total diesel-off time was found to be between 95 to 105 non-consecutive days.

The presented results have been chosen to highlight how the models and simulation tool can be used to identify technical barriers required to ensure system adequacy and inform policy for a successful project. The impact on solar plant capacity relative to curtailment is shown because it highlights the importance of system adequacy. Beyond some value of installed capacity curtailment is required to ensure adequacy. This can be addressed by installing communications between the diesel plant and the solar plant and then curtailing the solar plant as required. This study was performed in partnership with ATCO Electric Yukon and Vuntut Gwitchin Government, and the results have helped to inform the project's development.

The final project, as is being installed, is a $480kW_{AC}/900kW_{DC}$ east-west facing solar array, a 500kVA/612kWh or 500kVA/822kWh battery energy storage system, and a microgrid controller. The project is expected to offset 200,000 L of diesel consumption (~27% of diesel consumption for electricity generation) and 536 tonnes of $CO_2$ emissions annually. The solar array has been installed and is owned and operated by the Vuntut Gwitchin Government (VGG) as an independent power producer under an energy purchase agreement. The battery energy storage system and microgrid controller will be owned and operated by ATCO Electric Yukon in order to ensure adequacy and security of the system, while supporting the solar generation and allowing the system to operate diesel-off. The solar array is located at the end of one of two feeders in the system, while the battery energy storage system is located at the diesel plant.

### 4.1.2 Beaver Creek Solar Project Power System Impact Study

The Beaver Creek Solar Project consists of a solar photovoltaic array, a battery energy storage system, and a microgrid controller. The solar array will be owned and operated by White River First Nation (WRFN) as an independent power producer. As with Old Crow, ATCO Electric Yukon will own and operate the battery energy storage system and microgrid controller. The solar array and battery energy storage system will be located directly adjacent to the existing diesel plant. The study examines curtailment of the solar generation, renewable penetration, battery cycling, and diesel generator off time. As with the case study for Old Crow, the results presented are selected results from the full study [16].

Due to the location of the solar array and battery energy storage system, no voltage regulation issues were expected nor observed in the simulations as a result of the project.

The study found the solar array generated 893MWh and required 131MWh of generation to be curtailed. The curtailed generation amounts to 15% of the total energy that could be generated by the solar array. Together, the solar array and battery are found to have a maximum instantaneous active power penetration of 547% and an average energy penetration of 53% of the system demand. This amounts to a reduction of 4,443.2 non-consecutive hours of run time on the diesel generators, a reduction of 357,000 liters of diesel, and a 1,000 tonne reduction of $CO_2$ emissions annually in comparison with the status quo. Of course, this is dependent on the utility's diesel generator dispatch logic and the microgrid control logic used in the simulations. Under the microgrid control logic, the battery energy system performs 125 full charge/discharge cycles. In comparison with an assumed 10,000 cycle lifespan, it is found that the battery will not reach its end of life before the end of the project.

The number of hours a generator operates at a specific loading is plotted as a distribution for each respective generator, and for generators G1 and G3 (G13) when operated together. The status quo, with no solar generation or battery, shown in Figure 10, indicates that generators G1 and G2 operate with the greatest frequency, while G3 and G13 operate infrequently. Figure 11 shows the operating hours with the solar array and battery, while Figure 12 shows the difference between the two cases. With the solar array and battery, there is a decrease in hours of operation on G1 and G2 with little change for G3. G2 is shown to have a decrease in running hours for higher loadings but an increase for lower loadings.

The results of this study show how energy modeling can give a clear picture of how a renewable project can affect a system. The project is expanding to include thermal energy storage and district heating in an attempt to utilize excess energy from the solar array and waste heat from the diesel plant. It is also clear that a project such as this can require the cooperation and partnership of multiple parties, whether they're utilities, communities, municipalities, or governments.

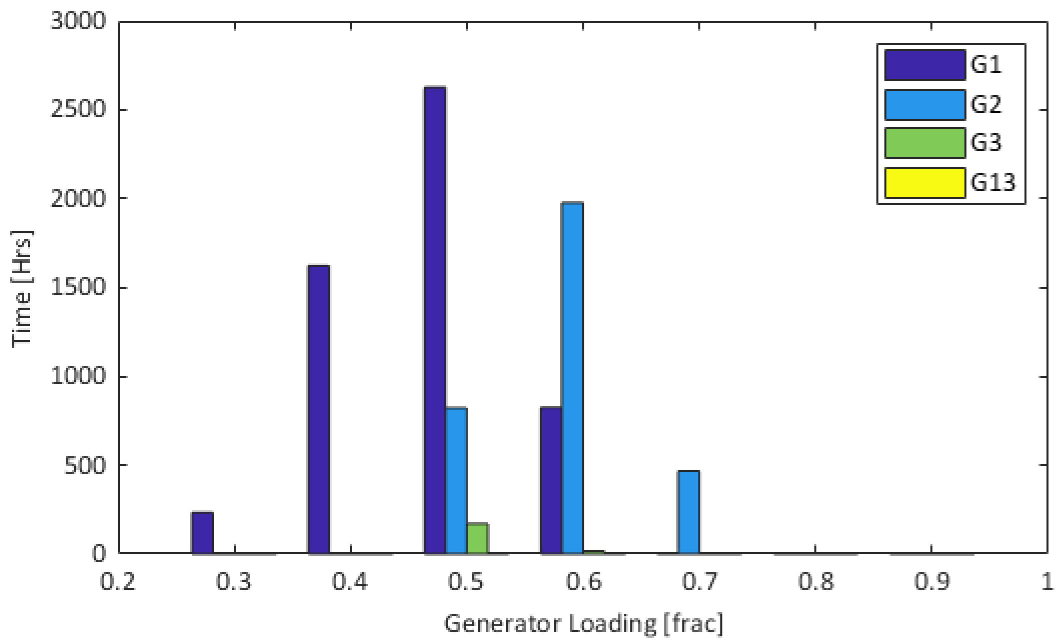


**Figure 10: The generator loading for the base case simulation [16].**

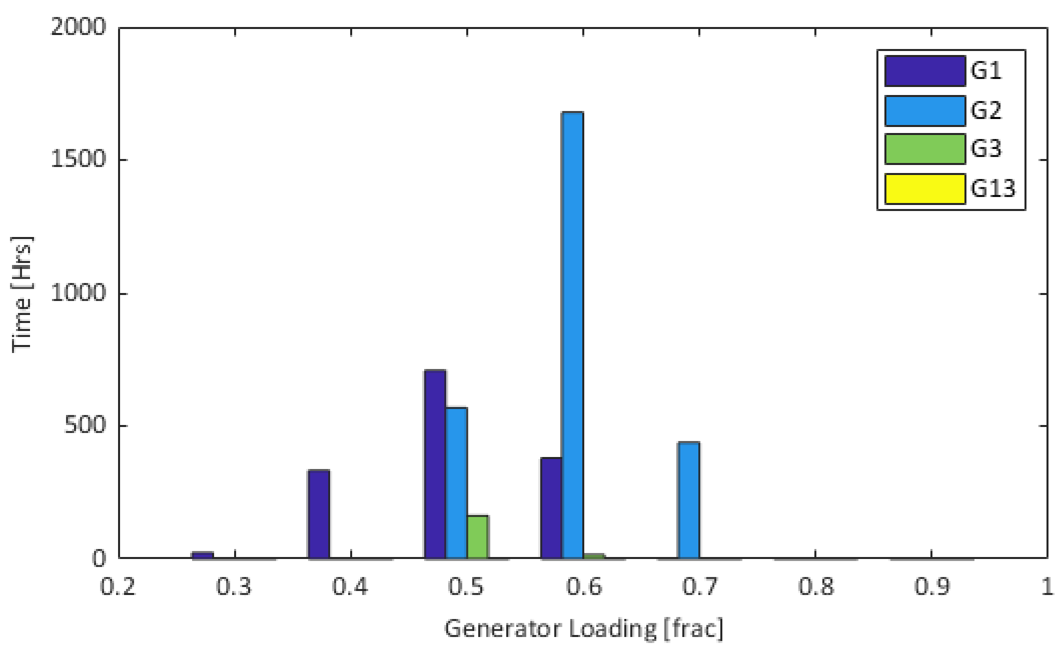


**Figure 11: The generator loading with the proposed solar plant and battery energy storage system [16].**

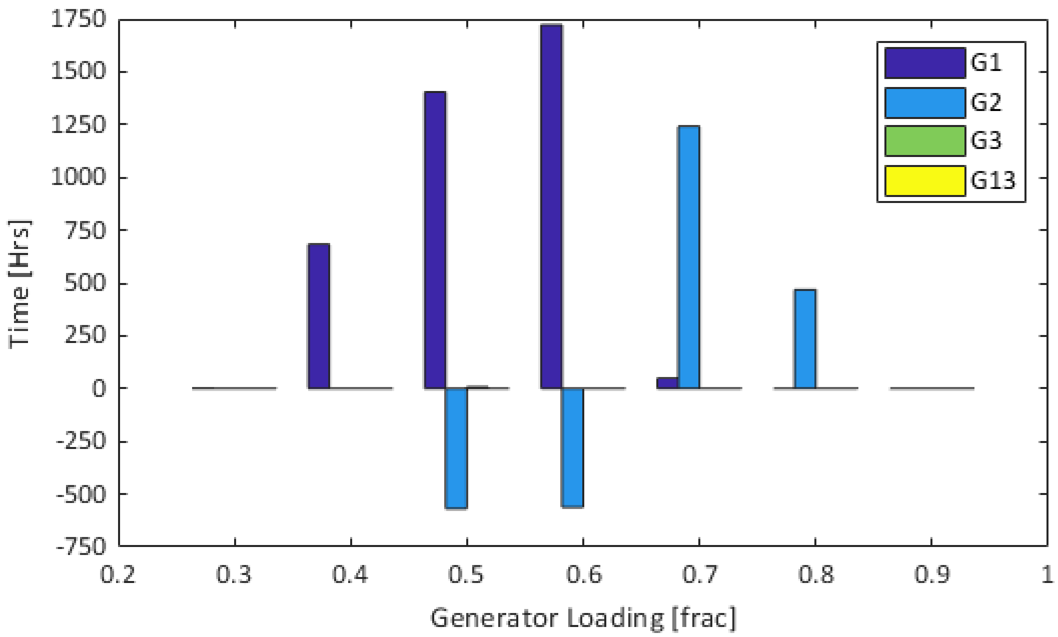


**Figure 12: The difference in generator loading between the base case and the proposed PV and ESS case [16].**

### 4.1.3 Cape Dorset Power System Impact Study

The Cape Dorset power system has had a new diesel generation plant constructed to replace the old plant. With the new plant, the distribution system was upgraded from $4.16kV_{LL}$ to $12.5kV_{LL}$. Instead of evaluating a specific project, this study analyzed how much renewables could be integrated with a point of interconnection in close proximity to the new diesel plant and without further investments in infrastructure upgrades to the existing system. The study examines both wind and solar resources through a parametric analysis. As with the Old Crow and Beaver Creek, the results presented here are selected results from the full study [17]. The total renewable energy contribution to the system, Figure 13, increases nearly co-linearly relative to solar capacity. While some variation is expected, it is imperceptible in the figure given the fraction of curtailed energy relative to total energy (curtailed and generated), as seen in Figure 14, has a maximum of less than 2.5% and a variation of less than approximately 1.5% for each wind capacity.

The fraction of curtailed energy increases with additional solar and wind capacity. Wind capacities of 200 kW and greater are shown to require curtailment. Wind capacities of 100 kW and less are capable of hosting various levels of solar without curtailment. The greatest renewable energy capacity without curtailment occurs with 100 kW of wind and 200 kW of solar.

The average energy penetration reaches as high as 21% of the total system demand, as shown in Figure 15. Similar to the renewable energy in Figure 13, average penetration is observed to increase in a co-linear fashion for varying wind capacities. Without curtailment, the highest average energy penetration is 8%.

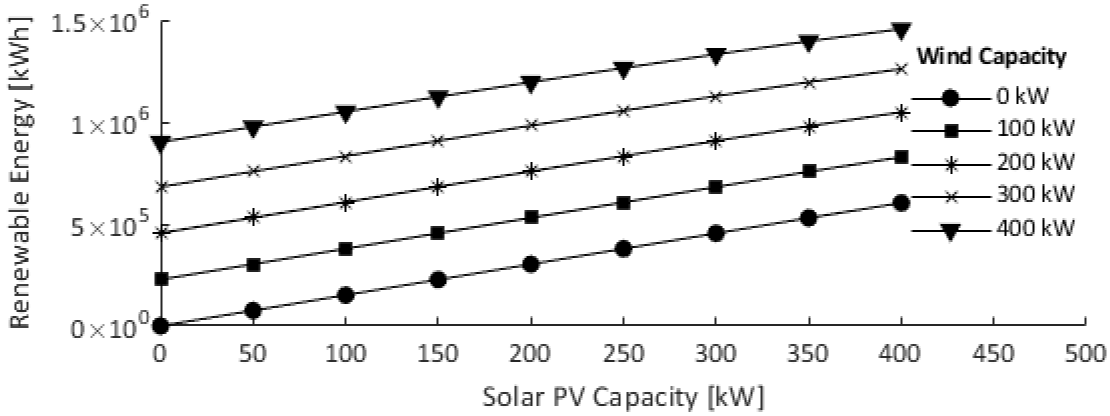


**Figure 13: Total renewable energy produced with respect to solar capacity.**

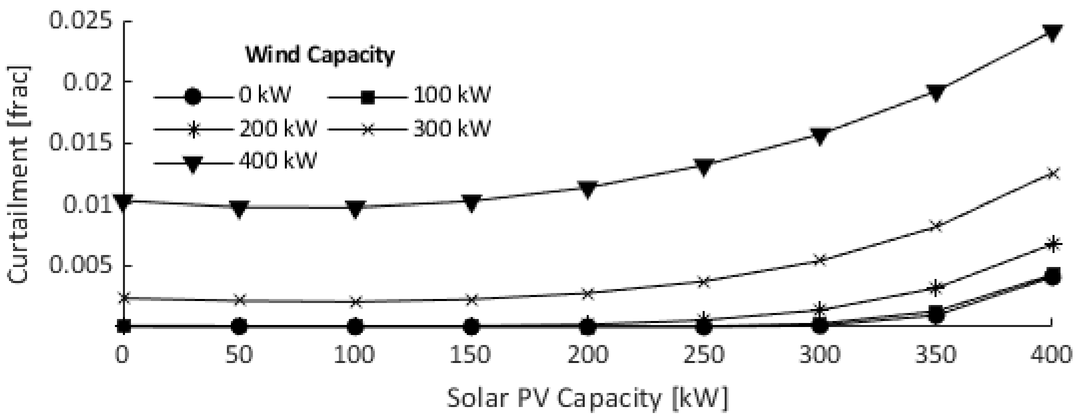


**Figure 14: Fraction of curtailed energy to total renewable energy produced with respect to solar capacity.**

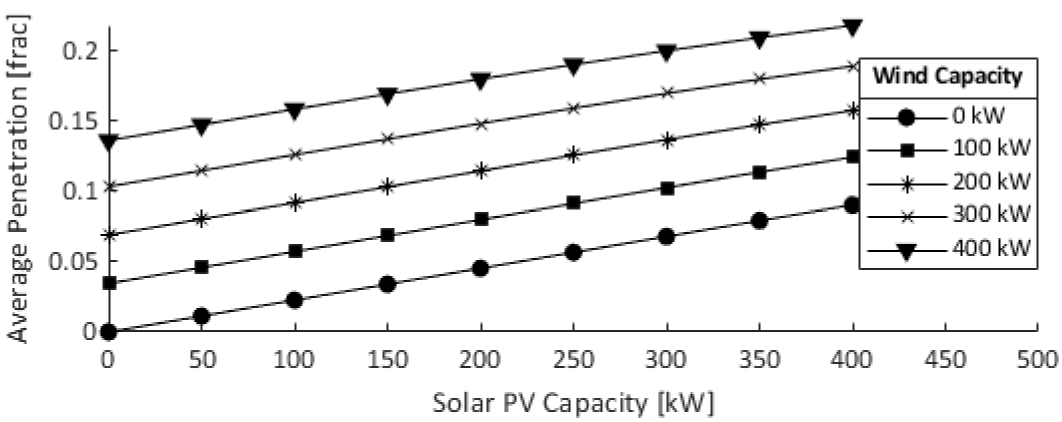


**Figure 15: Average penetration of renewable energy with respect to solar capacity**

The maximum instantaneous power penetration of renewable energy increases upwards to a common point for all wind capacities examined, as shown in Figure 16. The system has a common maximum penetration of renewable energy regardless of the total capacity. The minimum loading settings of the smallest generator dictate the required renewable resource curtailment to maintain energy balance.

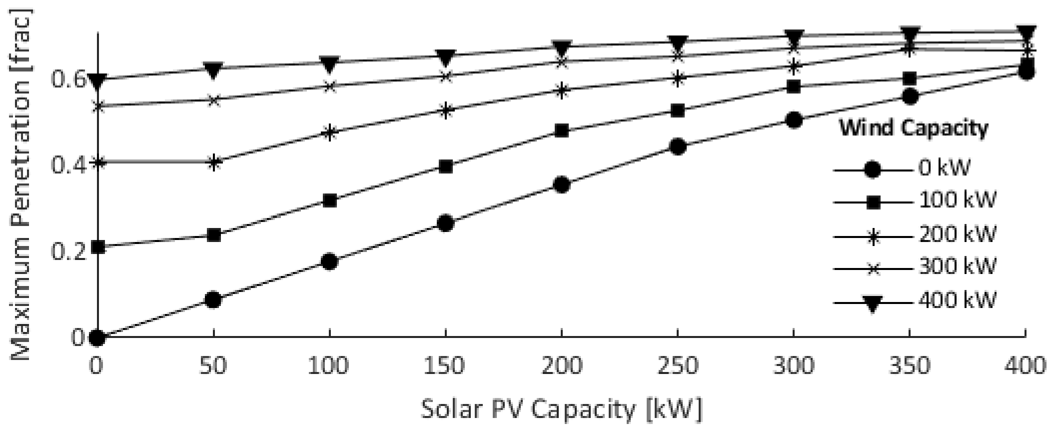


**Figure 16: Maximum instantaneous power penetration of renewables with respect to solar capacity.**

To ensure security of the system, the maximum renewable capacity at any given moment is limited to the minimum spinning reserve diesel generator in operation. According to the dispatch logic used by the utility, this gives a limitation of approximately 105kW for the smallest generator if the short-term overload of the generator is allowed to be used for spinning reserve, and 53kW if it is not.

The voltage throughout the Cape Dorset system is measured in the energy balance studies. The maximum, minimum, median and mean voltages are recorded for each electrical phase over one simulated year of operation. Simulations show that over- and under-voltages are not experienced on the system, which is largely due to the system voltage upgrade from 4.16$kV_{Li}$ to 12.5$kV_{LL}$. Figure 1, in Section 3.1, provides the maximum voltage in per unit for one phase in the Cape Dorset distribution system, as an example of how these results are shown.

The results of this study show that significantly higher penetrations can be obtained through curtailment to ensure both adequacy and security. It also highlights the importance of considering both power and energy when modeling the electric system. This form of control will of course have trade-offs in terms of energy curtailed but can allow for larger projects. As with Beaver Creek, there are also opportunities to couple the projects with thermal energy storage and district heating.

## 4.2 SYNERGIES WITH OTHER MODELS

The modeling of power systems has varying levels of complexity for differing types of models. All power system models require, at a minimum, information on demand, generation, and transmission & distribution. In a remote community, with the focus largely on distribution, it is also useful to have geographical data on locations of distribution poles and transformers. The data is, at its core, common between power flow software. For example, while it may take reformatting, the same data used to build a model in this tool can be used to build a model in OpenDSS or CYME/CYMDIST. The data used is specific to the power system itself, albeit with some commonalities between datasets for differing communities.

For example, one utility may use the same conductors and pole construction in multiple communities, therefore each of those communities will have the same overhead line parameters.

While the model may be based on electric power system industry standard models with data and parameters obtained from electric power utilities and original equipment manufacturers, the outcomes of the models can be used to help inform policy makers on the technical considerations to integrating renewable generation on diesel-powered isolated communities. Furthermore, it can make use of outputs of other models or provide some inputs for other models, including:

- Parametric studies on the capacity and type of renewables and/or energy storage required to achieve a desired reduction in fossil fuel consumption or greenhouse gas emissions. This could be used as an input to studies looking at policy, or it could use policies as an input to direct the studies performed and assess the outcome.
- Parametric studies on the impact of electrification of transportation on electric power systems. It could assess the impact of the number of electric vehicles, type of user, charge durations, etc. This could be used as an input to studies looking at policy, or it could use policies as an input to direct the studies performed and assess the outcome.
- Parametric studies on the potential for integrating thermal energy storage and district heating into electric power systems. This could be used as an input to studies looking at policy, or it could use policies as an input to direct the studies performed and assess the outcome.
- Investigating the impact of climatic conditions, such as changes in temperature and precipitation from climate models, on load growth and how that effects electric power systems.
- Consumption and generation profiles produced by other existing programs such as HOMER can be input into our model for either expanded studies or validation of existing studies.
- Energy storage dispatch models can be exported to Matlab or C++ script for use in other program environments.

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