Engineering Study
Final Report

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The results presented in the report are at a conceptual level; no detailed engineering has yet been performed, nor has equipment been selected or an operational plan been defined.

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Executive Summary

Qulliq Energy Corporation (QEC) currently delivers electricity to approximately 15,000 customers in 25 communities across Nunavut using 25 standalone diesel power plants with total installed capacity of 76MW. Each community has its own independent generation and distribution system that does not have any backup from the utility grid.

Presently customers are installing distributed energy resources with the increasing trend on renewable and reducing overall cost with net metering introduction. Photovoltaic (PV) is generally the most suitable form of renewable generation in the present power distribution systems. However, this is changing the distribution system scenario. In an existing feeder, the amount of renewable generation facilities (RGF) accommodation is limited because of utility-established acceptable limits of higher voltage, voltage unbalance, harmonics, transformer rating, line thermal overloading, regulation equipment, protection coordination, feeder configuration, load profile and many more. It is important for feeder operation and planning to calculate the amount of RGF that can be hosted inside an existing feeder subject to satisfy voltage limit, thermal limit, harmonics limit, and protection criteria – often referred to as feeder hosting capacity (FHC) or hosting/integration capacity analysis. Thus, it requires an assessment of the distribution system's maximum capability for accommodating these resources integration without any overloading and voltage issues.

QEC is presently reviewing the FHC for distributed energy resources as well as investor based small solar plants that can be safely integrated without overloading the existing distribution systems.

The scope of the study is to calculate the maximum penetration of Renewable Generation Facilities (RGF) that can be hosted by Chesterfield Inlet Community Network without adding battery storage capacity to the system and without violating network voltage and thermal limits or the short-circuit capacity of installed equipment. The study calculates the maximum Feeder Hosting Capacities (FHC) without considering any upgrades to the network.

The main limitation of maximum RGF addition is the requirement of minimum diesel generation dispatch of 40% of the total diesel generation plant capacity when the 400kW generator is on standby.

The study concludes that RGF supply can be connected to the network buses as shown in Table 5 to satisfy the following criteria:

- Feeder currents are within the ampacities of the existing feeders. Hence, no changes to the existing feeders are required.
- Minimum voltage drops and network losses are achieved for each network feeder.
- The fault current at each network bus is within the order of magnitude of the fault current of the original network.

Table 5: Network Maximum RGF Penetration and Tie-in Locations

Network	Diesel Generation Capacity (1) (kW)	Maximum RGF Capacity (kW)	Tie-in Location	Minimum Voltage (2) (%)	Losses	
					(kW)	(kVAR)
Feeder 1	268	397.8	Pole 60501097	97.57	11.4	11.1
Feeder 2		445.8	Pole 60502071	98.14	4.5	9.9

(1) Based on 40% of the total diesel generation plant capacity when the 400kW generator is on standby.

(2) Calculated on the three-phase, high-voltage side of the load.

The recommended maximum RGF capacities are based on the maximum demand load obtained from QEC demand current metering information.

Overall analysis shows that the addition of RGF to the feeders at the locations indicated in Table 5 improves the voltage profile and reduces the operational losses of the network.

Harmonics, voltage stability, system stability and other required analysis are expected to be completed as per specific generation connection applications depending on type, size, location, and given parameters of the RGF. These RGF applications will be required to follow the applicable Technical Interconnection Requirements (TIR) accordingly.

The maximum RGF capacity can be divided/shared among different types of generation such as IPP, CIPP and Net Metering. However, it is assumed that QEC will ensure to balance of the new distributed generation on all three phases, particularly single-phase generation, or Net Metering generation.

1. Introduction

1.1 Background

Qulliq Energy Corporation (QEC) currently delivers electricity to approximately 15,000 customers in 25 communities across Nunavut using 25 standalone diesel power plants with total installed capacity of 76MW. Each community has its own independent generation and distribution system that does not have any backup from the utility grid.

Presently customers are installing distributed energy resources with the increasing trend on renewable and reducing overall cost with net metering introduction. Photovoltaic (PV) is generally the most suitable form of renewable generation in the present power distribution systems. However, this is changing the distribution system scenario. In an existing feeder, the amount of renewable generation facilities (RGF) accommodation is limited because of utility-established acceptable limits of higher voltage, voltage unbalance, harmonics, transformer rating, line thermal overloading, regulation equipment, protection coordination, feeder configuration, load profile and many more. It is important for feeder operation and planning to calculate the amount of RGF that can be hosted inside an existing feeder subject to satisfy voltage limit, thermal limit, harmonics limit, and protection criteria – often referred to as feeder hosting capacity (FHC) or hosting/integration capacity analysis. Thus, it requires an assessment of the distribution system's maximum capability for accommodating these resources integration without any overloading and voltage issues.

QEC is presently reviewing the FHC for distributed energy resources as well as investor based small solar plants that can be safely integrated without overloading the existing distribution systems.

1.2 Scope of Work

The scope of the study is to calculate the maximum penetration of Renewable Generation Facilities (RGF) that can be hosted by Chesterfield Inlet Community Network without adding battery storage capacity to the system and without violating network voltage and thermal limits or the short-circuit capacity of installed equipment. The study calculates the maximum Feeder Hosting Capacities (FHC) without considering any upgrades to the network.

A Protection coordination study could not be conducted as part of the scope of this study since ETAP does not allow presenting single and three-phase protective devices on the same time-current coordination curve. ETAP presentation will be limited to three-phase devices which cannot be considered as a proper representation of how the different devices will coordinate.

The RGF penetration study is conducted based on the data provided by QEC as mentioned in Section 2.1, the assumptions listed under Section 2.2, and the calculation procedures detailed under Section 2.4.

2. **Discussion**

The hosting capacity of a feeder is defined as the amount of load or generation that the feeder can incorporate without causing any adverse effects to the feeder.

This study is concerned with one type of hosting capacity: Maximum Hosting Capacity which is defined as the maximum amount of load or generation that can be added to a feeder without violating any of the feeder constraints.

2.1 Sources of Data

Network model and simulation parameters are set based on the following inputs provided by QEC:

- **Existing ETAP Model:**

  The ETAP model received from QEC is used to obtain generator model, protective relay settings, transformer impedances, and main cable lengths.

- **One-line Diagrams:**

  The Network model is built using the provided one-line diagrams. These diagrams are also used to obtain the connected load and phase connection of each customer.

- **Actual Relay Load Readings:**

  QEC provided tables showing the actual load demand based on readings recorded by protective relays. These reading are used to estimate the overall demand factor and the actual demand for each customer which is, in turn, used to calculate the load flow analysis for each RGF penetration study scenario.

2.2 Assumptions

- Since the specified AASC cables are not available in the standard ETAP library, AAC cables are used instead. The electrical and geometric characteristics of the selected cable are modified to match the AASC cable specifications provided by QEC.
- Harmonic analysis is not included in the current study. Feeder thermal limits are assessed solely based on the feeder ampacities provided by QEC.
- The boundary conditions for the voltage limits at all networks nodes (buses) are assumed to be +/-5%.
- QEC advised that most of the loads are non-inductive and that the overall power factor for each feeder is in the order of 0.99. For the purpose of this study, all loads are assumed to have a 0.95 power factor for more conservative values of load currents.
- Cables from the RGF sources to the recommended network tie-in locations are not considered in the study. Sizes and lengths of these cable shall be determined during detailed design based on the RGF location.

- Based on overhead line conductor parameters provided by QEC, resistance, reactance, and susceptance values for overhead lines are calculated using ETAP considering the following conductor configuration on the pole structure:
  - Conductor height: 34 ft.
  - Spacing between phases: 3 ft.

- Generator plant service loads are not considered in the analysis.

2.3 Network Configuration

The Chesterfield Inlet network is fed from a generation plant that consists of 320kW, 350kW, and 400kW generators with an output voltage of 600V. All generators are connected to a common bus and are used to provide power to two (2) feeders that are, in turn, connected to different customers, in addition to other service loads. Each of the two feeders has three (3) single-phase, 150kVA, 0.6/4.16 kV D/Y transformers to provide power to different customers.

In order to improve the reliability for customer power supply, feeders #1 and #2 are tied together using a normally open switch CHE1-TP12 located at pole 60501061. This switch closes in the case when one of the feeder breakers is out of duty due to failure or for maintenance purposes. Since the case where both feeders are connected to one feeder breaker does not represent normal network operation and is used only for maintenance purposes, this configuration is not included in the penetration study.

The existing network ETAP model is provided in Appendix 1.

2.4 Calculation Procedures

2.4.1 Load Parameters Calculations

QEC load recordings show that the maximum and minimum demand loads for each feeder are as set out in Table 1.

Table 1: Maximum and Minimum Recorded Loads

		Feeder 1		Feeder 2	
		Max.	**Min.**	**Max.**	**Min.**
Total (3-Phase)	**Amp.**	**596.6**	**279.1**	**558.1**	**235.8**
	kVA	**620**	**290**	**580**	**245**

It is assumed that the recorded values given are in kVA. Currents are calculated on the 600V side of feeder transformers.

Although the single-line diagrams provided by QEC show the maximum connected load at each customer node, these connected loads cannot be used for the penetration study since the voltage drop at different network buses will exceed 5%. The use of these loads requires changes to network cable sizes which is not part of the scope of this study. Therefore, network maximum and minimum loads considered are based on the metered values.

Since network loads are modeled with their connected load values, the maximum and minimum loads on each network feeder are considered by applying demand factors to each of the individual loads. The maximum and minimum demand factors associated with maximum and minimum demand loads are calculated as in Table 2.

Table 2: Demand Factors for Existing Network

	Max. Feeder Load (kVA)	Max. Demand Load (kVA)	Max. Demand Factor	Min. Demand Load (kVA)	Min. Demand Factor
Feeder 1	981.5	620	0.63	290	0.3
Feeder 2	641.4	580	0.9	245	0.38

The maximum feeder load is comprised of feeder connected load and feeder network losses. These values are obtained by running the load flow on the network considering connected load.

The above demand factors are applied to the ETAP model for customer loads by assigning different loading categories each representing a demand factor.

The overall demand factors for network loads and the name of ETAP loading categories assigned to them are listed in Table 3.

Table 3: ETAP Loading Categories for Different Demand Factors

ETAP Loading Category	Loading Type	Feeder 1	Feeder 2
Design	Connected	1.0	1.0
Winter Load	Max. Demand	0.63	0.9
Summer Load	Min. Demand	0.3	0.38

2.4.2 Design Constraints

Design constraints established by QEC are as follows:

- Minimum level of RGF feeder penetration is not less than 7% of the feeder minimum load. Therefore, the minimum output of an RGF when connected to different parts of the network will be as listed in Table 4.
- All diesel generators are running at 40% of their installed capacity while the largest generator is on standby. Therefore, the total contribution of the diesel generator plant is 268kW.
- Maximum hosting capacities for different feeders should not exceed the following values:
    - Feeders from each generator to main switchgear: 511.3 Amp.
    - Feeders from main switchgear to distribution transformers: 511.3 Amp for 250kcmil feeder and 339.8 Amp for 2/0 AWG feeder.
    - 1/0 AWG network lines: 247 Amp.

- #2 AWG network lines: 185 Amp.
- 4/0 AWG network lines: 383 Amp.

In addition to the above, the following design constraints are set to limit the changes to network parameters as a consequence of introducing RGF sources:

- The voltage at main and customer distribution buses is within +/-5% of the system nominal voltage.
- The maximum fault current at main and customer distribution buses is within the order of magnitude of the maximum fault current calculated for the original network.

Table 4: Minimum RGF Output

RGF Network Connection	Minimum RGF Output (kVA)
Feeder 1	20.3
Feeder 2	17.15

2.4.3 Calculation Methodology

The methodology used to calculate the maximum RGF penetration and the corresponding tie-in location that will achieve the maximum penetration while minimizing network operational losses and satisfying the design constraints is described below.

- An iterative process was carried out in calculating the maximum RGF that could be added to the distribution system. However, this quantified capacity was determined without any upgrades or further investment.
- At the end of the iterative process, the output of the simulations provided the RGF location and capacity as per different nodes in the distribution network by maximizing feeder holding capacity for the worst-case scenario. Moreover, as the reactive power support could also increase the hosting capacity, this was included in the analysis.
- Starting from the tail end location(s) which usually shows FHC, the maximum RGF capacity which can be integrated in the network was identified and the possible different appropriate locations were selected. Then, while keeping the diesel generation at the required minimum dispatch level, the RGF was scaled up based on each individual feeder, and the loading limits were monitored to check the maximum FHC that could be added at the specific location without the violation of acceptable limits.
- While scaling the RGF, voltage and thermal limits were monitored to ensure that none of these constraints were violated and to ensure that the network was not experiencing any reverse power flow.
- Sensitivity analysis was performed by studying the connection of the RGF to nearby nodes to verify that the selected node achieved the maximum penetration level and maintained low network losses.

It is important to note that scope of work of this study is limited to finding the thermal limits, voltage limits and short circuit limits which can be determined based on the available system. However, other QEC Technical Interconnection Requirements (TIR) requirements such as harmonic analysis, stability analysis, and voltage stability are very much dependent on the new RGF or new incoming generation plant parameters. These studies are expected to be completed by new developers as and when those parameters are available. It is recommended that new developers be required to meet QEC TIR requirements as well as general industry standards. This will ensure that appropriate technical evaluations in connection with establishing minimum standard limits of harmonic levels, voltage unbalance, system frequency, voltage stability, synchronicity, stability, and anti-islanding functionality are performed.

2.5 Results

The use of maximum connected loads is not considered in the penetration study since the voltage drop at many network buses will exceed 5% even when the loads are totally fed from the generator plant. Considering the connected loads will require changing some of the line sizes which is not part of the scope of this study.

Maximum and minimum demand loads are used based on actual metering readings and demand factors are calculated as detailed in Section 2.4.1.

2.5.1 Load Flow Results for Existing Network

Load flow results considering maximum demand load show that these loads exceed the capability of the main network components. This is shown on the single-line diagrams of Appendix 2.A and can be summarized as follows:

- Generator G3 (400kW) is overloaded with an output power 557.7kW.
- The cable between generator G3 and the main switchgear is overloaded since the current carried by this cable is 578A while the cable ampacity is 511.3A.
- Cables P-F1 and P-F2 between the main switchgear and the primary side of each 0.6/4.16kV feeder transformer are overloaded since the currents carried by these cables are 611.8A and 578.7A while the ampacities for these cables are 511.3A and 339.8A respectively.
- 0.6/4.16kV feeder transformers XFMR-F1 and XFMR-F2 are overloaded since the ratings of these transformers are 450kVA while the power delivered by these transformers to each feeder is 629.6kVA and 592.9kVA respectively.

It is recommended that feeder metering information provided to be revisited and verified by QEC.

2.5.2 Maximum RGF Penetration and Tie-in Locations

The study concludes that RGF supply can be connected to the network buses as shown in Table 5 and that the following criteria will be met:

- Feeder currents will be within the ampacities of the existing feeders (See Section 2.4.2). Hence, no changes to the existing feeders are required.
- Minimum voltage drop will be achieved for each network feeder.

- The fault current at each network bus will be within the order of magnitude of the fault current of the original network. This approximation is considered since information pertaining to the fault current withstand of existing network buses is not available.

Table 5: Network Maximum RGF Penetration and Tie-in Locations

Network	Diesel Generation Capacity [(1)] (kW)	Maximum RGF Capacity (kW)	Tie-in Location	Minimum Voltage [(2)] (%)	Losses	
					(kW)	(kVAR)
Feeder 1	268	397.8	Pole 60501097	97.57	11.4	11.1
Feeder 2		445.8	Pole 60502071	98.14	4.5	9.9

(1) Based on 40% of the total diesel generation plant capacity when the 400kW generator is on standby.

(2) Calculated on the three-phase, high-voltage side of the load.

The above recommended maximum RGF capacities are based on the maximum demand load obtained from QEC demand current metering information.

Load flow results for the existing network and for the case when the RGF source is added are shown in Appendices 2.A, 2.B, 3.A, and 3.B. Tables comparing bus voltages, maximum fault currents as well as line currents for the existing network and when the proposed RGF sources are connected are included in Appendices 4.A and 4.B. Maximum fault current is calculated for the existing network and for the case when the RGF source is added to verify that the fault current at any of the network buses does not significantly differ from the fault current of the existing network. Maximum short-circuit calculation results for each case are provided in Appendices 2.B and 3.B.

The study shows that the addition of RGF source to the selected nodes does not only improve the voltage profiles for each feeder network but also reduces the active and reactive power losses in the network as shown in Table 6.

Table 6: Voltage and Network Losses Comparison

Details	Without RGF		With Addition of RGF	
	Feeder 1	Feeder 2	Feeder 1	Feeder 2
Tie-in Location			Pole 60501097	Pole 60502071
Minimum Voltage (%)	94.01	92.2	97.57	98.14
Losses (kW)	23.0	33.6	11.4	4.5
Losses (kVAR)	44.1	44.3	11.1	9.9

3. Conclusion and Recommendations

RGF sources can be used to provide power to the distribution network to feed customer loads considering the maximum demand while keeping existing generator plant contribution at its minimum. Increasing generator plant contribution will improve the voltage drop further and will not cause adverse network performance.

The calculated maximum RGF capacity can be divided among different types of generation such as IPP, CIPP and Net Metering. However, it is assumed that QEC will ensure a balance of the new distributed generation in all three phases, particularly Net Metering generation.

The study recommends the following:

- Provided metering information for maximum demand load on each feeder shows that these loads exceed the capabilities of main network components as explained in Section 2.4.1. It is recommended that feeder metering information provided to be revisited and verified by QEC.
- Maximum and minimum demand factors for the loads connected to each feeder are calculated from the ratio of feeder connected load, including feeder losses, to the maximum and minimum recorded feeder loads, including feeder losses. Due to network topology, feeder losses are not linearly related to the feeder load. Therefore, although demand factors calculated may generate acceptable results, it is recommended to obtain the demand factors for each individual load as this will provide more precise results.
- Protection settings need to be provided based on the finalized design of the RGF sources.
- Harmonics, voltage stability, system stability and other required analyses are expected to be completed as per specific generation connection applications depending on type, size, location, and given parameters of the RGF. These RGF applications will be required to follow the applicable Technical Interconnection Requirements (TIR) accordingly.