CIGRE-XXX

2020 CIGRE Canada Conference
Toronto, Ontario, October 19-22, 2020

Diesel Generator Sizing for Remote Power Systems with Consideration of Renewable Energy

Spencer R.D. Sumanik, Jason Zrum, Michael Ross
Yukon University
Canada

ssumanik@yukonu.ca

SUMMARY

Diesel generators in northern communities must be sized to ensure sufficient adequacy and security for the electric power system. A diesel plant that is being constructed to replace an existing plant must ensure that the firm capacity of the plant meets the maximum load of the community while also able to effectively provide power at the minimum load. The plant must dispatch all generators to operate normally at capacities that align closely with their peak efficiency. By assuming the addition of renewable generation to the system, the sizing of the diesel generators in a new plant can be optimized for maximum renewable integration. Typical diesel generator plants in northern territories operate such that the generator transfers downward at 0.5 pu rated active power and upward at 0.9 pu rated active power This limits the penetration of renewable generation to 0.2 pu of the smallest generator, as sudden loss of the renewable cannot result in the generator exceeding 1.1 pu, the allowable short-term overload. Penetration of renewable energy is shown to increase with the optimization of the diesel generator sizes and dispatch of the generator plant. The optimization uses bounding criterion to ensure that firm capacity, generation continuity, plant security and operating reserve are met, while providing flexibility to increase penetration of renewable energy. The generator sizing optimization is of interest to Northwest Territories Power Corporation, where they will be replacing their diesel plant facility in Łútsël K'é, NWT. The community is also planning on integrating renewable generation, such as solar, wind, and storage. This analysis uses the Łútsël K'é system as a case study. The diesel plant sizing optimization must consider the constraints of ensuring reliable power, secure operating margins, and appropriate dispatch of resources with all possible operating conditions of the proposed microgrid system. Furthermore, the formulation optimizes the generator sizing and dispatch for maximum utilization of renewable energy in the system.

KEYWORDS
Adequacy, Hybrid systems, Microgrid, Optimization, Remote power systems, Security,

Introduction

Many communities in Canada's north are isolated from interconnected power systems and rely solely on diesel generators for their electrical energy [1]. Currently there is an interest in becoming less dependent on diesel energy in the north through the implementation of renewable energy [2]. Due to the remoteness and limited accessibility of many of the communities, reliability of these systems is held paramount. While there are other social, economic, environmental, and political considerations to a renewable energy project, technical barriers are often encountered that limit the size and scope of the renewable energy integration [3].

Diesel generator plants in the north consist of a minimum of three generators in order to ensure N-1 contingency. This guarantees that even if the largest generator is inoperable, the two smaller generators are capable of providing power even at peak demand. Therefore, the sizing of the respective generators are constrained by (1) and (2); (3) provides the sizing relations between the different diesel generators

$$G_1 + G_2 \geq P_{\max} \tag{1}$$

$$1.1 * G_3 \geq P_{\max} \tag{2}$$

$$G_1 \leq G_2 \leq G_3 \tag{3}$$

Where G_1 and G_2 are the active power rating (kW) of the smallest and middle-sized generators respectively, and G_3 is the active power rating (kW) of the largest generator. The largest generator, G_3, is multiplied by a factor of 1.1 in (2) as a safety factor and to account for a minimal amount of load growth the system may experience [4][5].

For larger systems, a contingency N-1-1 or N-2 is implemented [5]. For systems such as these a minimum of four generators are required. These systems are designed such that if the two largest generators are inoperable (due to failure of one generator while the other generator is offline for maintenance), the remaining generators are still capable of providing energy at peak demand. For the case with an N-2 contingency, (1), (2), and (3) must be valid in addition to the following sizing relations and constraints identified in (4) and (5).

$$1.1 * G_4 \geq P_{\max} \tag{4}$$

$$G_1 \leq G_2 \leq G_3 \leq G_4 \tag{5}$$

Where G_1 and G_2 are the active power ratings (kW) of the two smallest generators, G_3 is the active power rating (kW) of the second largest generator, and G_4 is the active power rating (kW) of the largest generator. Similar to the N-1 scenario, a safety factor of 1.1 is applied to the largest two generators in (2) and (4).

A commonly used diesel generator dispatch used in the north schedules the next largest generator when the current generator reaches $\alpha_n = 0.9$ of its rated loading, shown in (6).

$$p_n(t) \geq \alpha_n G_n \tag{6}$$

Where n is the generator number, $p(t)$ represents the active power output (kW) of generator n at time t, G_n is the rated capacity of generator n, and α_n indicates the threshold for an upward transition to a larger generator [6][7]. The downward transition is scheduled when the condition in (7) occurs.

$$p_n(t) \leq \beta_n G_n \tag{7}$$

Such that $\beta_n = 0.5$, where β_n indicates the lower threshold for a downward transition to a smaller generator. The upward and downward transitions indicate the operating threshold at which the online generator ramps down and the next largest (or smallest) generator transitions online during an upward (or downward) power demand in the system. This is the logic for the unit commitment in remote communities.

An intermittent renewable resource implemented in this system is limited by the amount of operating reserve in the system [8]. Should an intermittent resource disconnect or connect to the system instantaneously, the diesel generator plant must have sufficient operating reserve and ramping capabilities to maintain power balance and to avoid exceeding the limitations of the machines.

In the case of the dispatch logic described above, the worst-case scenario would be when the generator is operating nearest its transition points. When the generator is operating at 0.9 pu of its capacity, a sudden disconnection of a renewable generator cannot result in the generator exceeding its short-term overload of 1.1 pu of its name plate capacity. This limits the amount of renewable that can be implemented to 0.2 pu of the smallest diesel generator [9].

The community of Łútsël K'é NWT has a peak load of 330 kW and a minimum load of 100 kW. Using the aforementioned constraints for an N-1 contingency, the largest generator would be sized such that it is 1.1 times the maximum load; in other words, $G_3 = 363$ kW. A middle generator would transfer power to the larger generator at 0.9 pu capacity where the larger generator picks up at 0.5 pu, resulting in (8).

$$G_2 \geq \frac{0.5\, G_3}{0.9} \tag{8}$$

This results in a generator of a size $G_2 = 201.6$ kW. Using the (8) again for the smallest generator results in $G_1 = 112$ kW. With the industry standard dispatch logic used here, the maximum renewable capacity that could be implemented without infringing on the spinning reserve of the system is 20% of G_1, or 22.4 kW.

This is an extreme example, generation plants will often implement a small amount of hysteresis in the dispatch scheduling. This is done to reduce the amount of generator cycling in the case of the load fluctuating near a transition point. This is typically set such that $0.9G_2 > 0.5G_3$, however the transition points still remain at 0.9 and 0.5, thus introducing the hysteresis. Even if this were the case, the maximum allowable renewable resource is still 0.2 of G_1.

This analysis examines alternate methods of dispatching diesel generators to maximize the allowable renewables for a three-generator plant achieving N-1 contingency. Furthermore, this analysis explores designing a new diesel plant specific to the system to maximize the renewable penetration while meeting an N-1 contingency. Note that an N-1 contingency in a remote community does not mean automatic and seamless operation during an equipment failure. Instead, it means that the available resources have the capacity to re-energize the system after a contingency event. Thus, it is possible to operate with a single generator online.

Methodology

The mathematical optimization tool to maximize the allowable penetration of intermittent renewable energy begins by defining the system parameters of the maximum and minimum loads of the system $P_{\max}$ and $P_{\min}$ respectively. These provide the bounds of the system.

The maximum and minimum generator operating points, $O_{\max}$ and $O_{\min}$ respectively are set to reflect how the operator wishes to control each diesel generator. Setting the maximum operating value to 1.1, used in this analysis will allow the operating reserve calculation to extend into the short-term overload of the generator. A more conservative operation may set this value to 1.0, this will reduce the amount of allowable renewables, however the renewable capacity is such that if a sudden disconnection of this renewable would occur the operating diesel generator would not be required to enter short term overload operation. These can be changed to reflect how the operator wishes to control the generators. This analysis uses the values of:

$$O_{\min} = 0.3 \tag{9}$$

$$O_{\max} = 1.1 \tag{10}$$

In order for the system to meet the adequacy requirements the largest generator must be capable of meeting the maximum load. Therefore, the largest generator G_3 can be found through:

$$G_3 = M_s P_{\max} \tag{11}$$

Where M_s is the desired margin of safety. This is typically set to $M_s = 1.1$ [4] and that is the value used in this analysis.

The values of G_1 and G_2 are set to a range of possible values to create a two-dimensional sample space of values. A third dimension is added to create a three-dimensional sample space by varying the point at which G_2 transitions to the smaller generator G_1, β_2 using the same format as used in the previous section.

For each possible value of G_1, G_2 and β_2 the maximum renewable penetration on the system, R, is found. The first step is to find the upward transition points for G_1 and G_2.

$$\alpha_1 = \frac{\beta_2 \, G_2}{G_1} \tag{12}$$

And

$$\alpha_2 = \frac{\beta_3 \, G_3}{G_2} \tag{13}$$

In this analysis the downward transition point of the largest β_3 is set to 0.5 pu. Altering this parameter is shown to have an affect on the results, however this is not explored here.

To ensure that the generators are operated within an efficient range, values of renewables are not calculated where $0.6 > \alpha_1 > 0.9$ and $0.7 > \alpha_2 > 0.9$ [10].

The available spinning reserve for of both G_1 and G_2 are calculated for the upper and lower ranges of operation. For G_1 the upper and lower operating reserve U_1 and L_1 respectively, are calculated according to,

$$L_1 = P_{\min} - G_1 O_{\min} \tag{14}$$

And

$$U_1 = G_1 * (O_{max} - \alpha_1) \tag{15}$$

The upper and lower spinning reserves of G_2, U_2 and L_2, respectively, are found through.

$$L_2 = G_2 * (\beta_2 - O_{\min}) \tag{16}$$

And

$$U_2 = G_2 * (O_{\max} - \alpha_2) \tag{17}$$

To ensure that the system has sufficient spinning reserve in the case of a sudden connection or disconnection of the renewable resource the smallest of the four values is the maximum allowable renewable resource.

$$R = \min(L_1, U_1, L_2, U_2) \tag{18}$$

Discussion

The diesel optimization process is performed for the community of Łútsël K'é NWT as the community will be replacing their diesel generator plant in the near future [11]. By sizing the generators with the intention of maximizing renewable energy generation this optimization tool can be used.

The community is home to approximately 300 people many of whom are of the Łútsël K'é Dene First Nation [12]. The community has a maximum load demand of 330 kW and minimum load demand of 100 kW [13]. The maximum and minimum generator operating points are held at 1.1 pu and 0.3 pu respectively. The design margin of safety described above is set to $M_s = 1.1$. This results in a largest generator size of $G_3 = 363$ kW. Naturally, generator sizes this specific will not be available on the open market. This can be addressed by finding sizes that closely match these values and still meet the adequacy requirements.

The ranges for G_1 and G_2 are selected to be $130 \text{ kW} \leq G_1 \leq 182$ kW, and $205 \text{ kW} \leq G_2 \leq 255$ kW in steps of 1 kW. The transition point for G_2 is set such that $0.5 \leq \beta_2 \leq 0.6$. These inputs are provided to the optimization tool.

Figure 1 shows the maximum allowable renewable for each combination of G_1, G_2 and β_2. The white regions of each subfigure are the results that are removed to ensure that the generators are operated in an efficient and secure manner as described above.

Each case of varying the downward transition point is shown to have generator combinations that result in maximum renewable penetrations greater than 50 kW. A value of $\beta_2 = 0.61$ results in generator combinations for G_1 and G_2 of 137 and 239 kW respectively produce a maximum allowable penetration of 50.8 kW. This is the lowest maximum of all examined values of β_2. While a transition point of $\beta_2 = 0.55$ results in two generator combinations providing a maximum renewable penetration of $R = 53.2$ kW. Sizes for generators G_1 and G_2 of 139 and 231 kW as well as 140 and 231 kW respectively create a local maximum, of the highest found maximum for the examined values of β_2.

To host the maximum penetration of $R = 53.2$ kW for the aforementioned values of G_1 and G_2 the dispatch points between G_1, G_2 and G_3 must be varied, set according to **Error! Reference source not found.**. When compared to the industry standard dispatch it can be observed that the upward transition points of G_1 and G_2 have been decreased. This effectively increases the amount of available spinning reserve on these generators.

Table 1: Upward and Downward transition point for all three generators on the system shown as a fraction of their operating capacity.

Transition	G_1	G_2	G_3
Downward	N/A	$\beta_2 = 0.55$	$\beta_3 = 0.5$
Upward	$\alpha_1 = 0.7593$	$\alpha_2 = 0.8854$	N/A

G_1 does not have a downward transition value as it is the smallest generator on the system. G_3 similarly, does not have an upward transition value. However, should the load exceed the maximum capacity of this generator the plant would begin isochronous load sharing between two generators. However, when operating in this method the plant will lose its N-1 contingency capability.

Comparing the maximum value of renewable energy found through the optimization tool, 53.2 kW, to that of the industry standard, 22.4 kW, shows growth of 30.8 kW or a fractional increase of 1.375.

Conclusion

By altering the generator dispatch logic and matching the diesel generators the amount of renewable energy that can be hosted on the system can be increased without impinging on the system's spinning reserve. The optimization formulation shown in this paper finds the dispatch and generator combination that allows for the maximum renewable energy penetration for each individual remote power system without exceeding thresholds and abiding N-1 contingency. Using this optimization tool, a new diesel generator plant capable of meeting the community demand, an N-1 contingency, as well as maintaining spinning reserve at all points in the dispatch can be designed while also maximizing the renewable capacity the system can host.

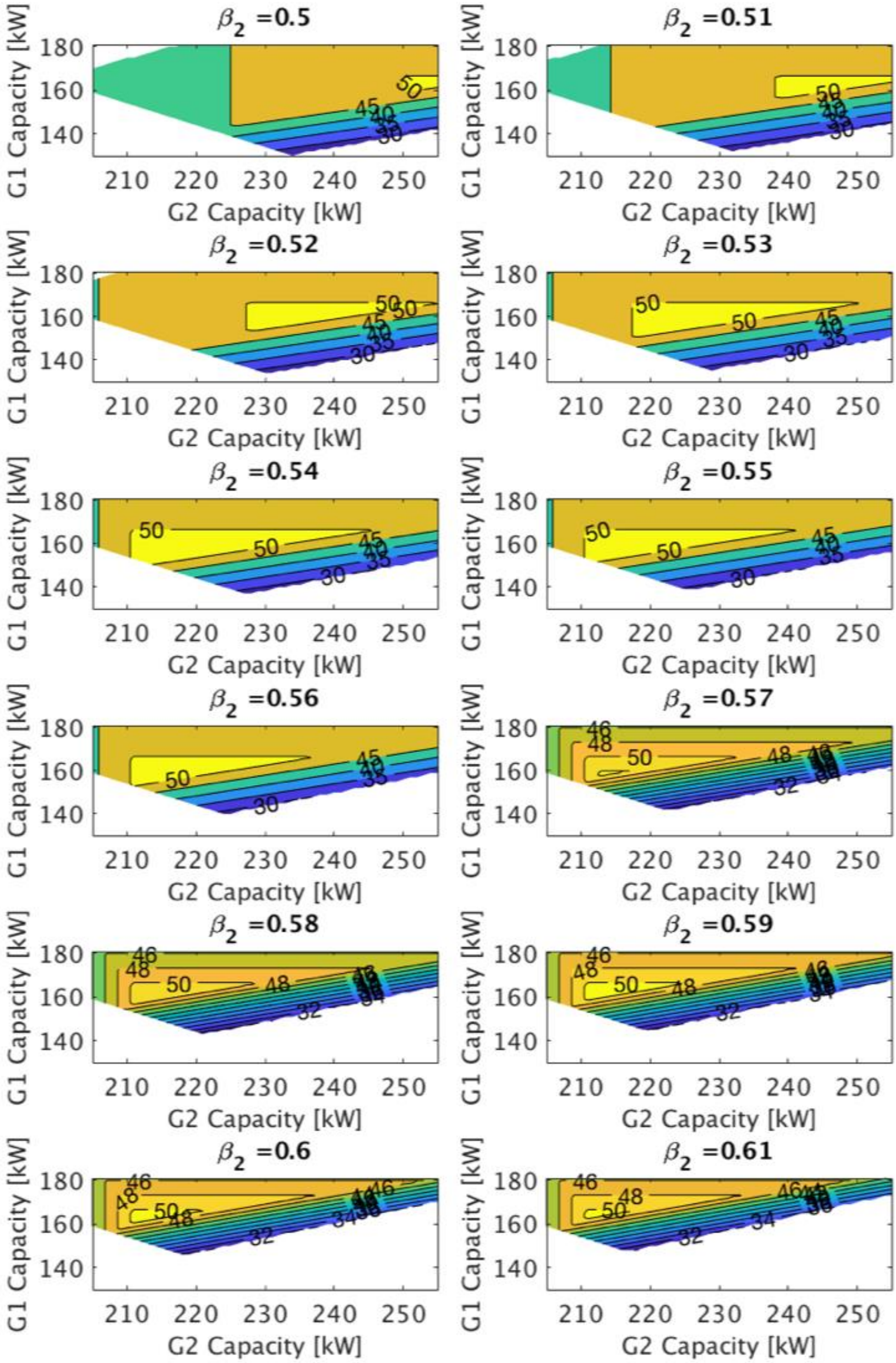

Figure 1: Two-dimensional contour plots for each varied β_2 ranging across all examined capacities of G_1 and G_2.

BIBLIOGRAPHY

[1] Standing Senate Committee on Energy, the Environment and Natural Resources, "Powering Canada's Territories," 41st Parliament, 2nd Session, June 2015. Available: https://sencanada.ca/content/sen/Committee/412/enev/rep/rep14jun15-e.pdf
[2] Rudyk M. "Feds pledge $20M to help Indigenous communities get off diesel power" CBC, Canadian Broadcasting Corporation, 2019
[3] J Zrum, S. Sumanik, M. Ross, "An Automated Grid Impact Study Tool for Integrating a High Penetration of Intermittent Resources on Diesel-based Isolated Systems," 47th Session Cigre Paris, 2018
[4] "Destruction Bay Unit 2 Replacement Sizing Criteria," ATCO Electric Yukon
[5] "Watson Lake Unit 3 Replacement Sizing Criteria," ATCO Electric Yukon
[6] "NTPC Engineering Standard Procedure," Northwest Territories Power Corporation, Aug 2017
[7] "Northwest Territories Power Corporation – Capacity/Reliability Planning Criteria Application," Northwest Territories Power Corporation, Nov 2004.
[8] S. Sumanik, J. Zrum, M. Ross, "Arviat Power System Impact Study," Northern Energy Innovation, Yukon University, Apr 2020.
[9] F. Mercure, J. Collier, et al. "Discussion Paper: Why are Renewable Limits Set at 20% in Isolated Northern Communities," Northern Energy Innovation, Yukon College, Aug 2018.
[10] L.L.J. Mahon, "Diesel Generator Handbook," Oxford Great Britain, Elsevier Butterworth-Heinemann, 2008.
[11] Tender," Northwest Territoires Power Corporation, www.ntpc.com/content/tender/2019/12/09/rfp-5056-new-diesel-generation-power-plant---lutsel-k'e-nt Accessed Mar 5, 2020.
[12] 'Lutsel K'e Statistical Profile' NWT Bureau of Statistics, statsnwt.ca/community-data/infrastructure/Lutsel K'e. Accessed Nov 6, 2019.
[13] Personal Communication with CTO, Northwest Territories Power Corporation, 'Lutsel K'e Data,' 2019.