High-Level Evaluation of Transmission Line Parameters and Energy Costs for Industrial Loads in Remote Locations

Éric Breault P.Eng.
& Maurice Brisson P.Eng.,

May 2016

Disclaimer

Executive Summary

When industrial clients plan the construction of new sites in remote locations with a limited duration of site operation, preliminary studies often consider local generation as the sole source of power supply. The option of an interconnection to the utility grid tends to be overlooked due to the higher initial investment and coordination as well as the assumed higher implementation delay. However, for a high-level cost comparison, the technical performance of the transmission system sometimes used as a reference may not even be compatible with the required application.

This paper presents a strategy to define the high-level transmission system parameters and to evaluate the equivalent energy cost for specific industrial sites in remote locations. The transmission system voltage is evaluated based on the industrial load and the distance up to the utility network. The main design parameters and limitations are presented, allowing the reader to understand the process behind this simplified design strategy. This paper is intended to be used by corporate members to determine if a more detailed study is required. The result may also be used as the transmission line design base case scenario.

BBA, a Canadian consulting engineering firm, has used a design strategy inspired by this simplified approach several times in the past for communities, power generation and industrial loads. These projects were located mainly in Canada but also in other parts of the world such as Africa. This strategy is especially used for mining projects such as Detour Lake, the second largest gold mine in Canada, where a new 180-km long 230 kV line was built to supply power to the mine. BBA received the Award of Excellence during the 2014 Canadian Consulting Engineering Awards Gala for its work related to this mine.

Table of contents

Introduction

St. Clair publication in 1953[1] evaluated the load-carrying ability (a.k.a. loadability) of transmission lines based on their length and performance criteria. St. Clair's curves were later modified by the Planning Department of the American Electric Power Service Corporation[2,3] and R. D. Dunlop, R. Gutman and P.P. Marchenko[4] to consider transmission lines higher than 345 kV and longer than 400 miles (644 km). Subsequent work[5,6,7] outlined the need to consider the transmission system as a whole and identified ways to mitigate some power transfer limitations.

The previously stated publications use transmission line characteristics that are determined only during detailed engineering. They can hardly be used by industrial clients to evaluate new projects planned at remote locations. This paper evaluates the optimal voltage level based on the load power (MW) and distance from the utility (km). Assumptions are used to guide the reader at a conceptual level and will be refined during subsequent design phases.

This guideline is divided in three steps in order to answer each of the following questions:

- What is the minimum transmission voltage level that can provide technically acceptable performances?
- What is the equivalent energy cost of the transmission line (¢/kWh), excluding the selling price of the utility?
- What is the new transmission line equivalent energy cost (¢/kWh) that could be used for comparison with the corresponding local generation cost?

Description of the Solution

Step 1: Minimum transmission line voltage

This criterion is inspired by the St. Clair loading curve as well as the R. D. Dunlop revised line loadability curve (heavy loading). The heavy loading curve is preferred to the normal rating curve as it is used to assess the economic viability of a transmission line for one specific load rather than planning the long term development of a network.

The heavy loading curve provides a load capability multiplier as a function of the distance. This multiplier is intended to be used with specific line characteristics. The values used to convert the multiplier into voltage levels are presented in Appendix A. Typical high-loadability industrial lines parameters are used to better represent the following technical limit of each voltage level.

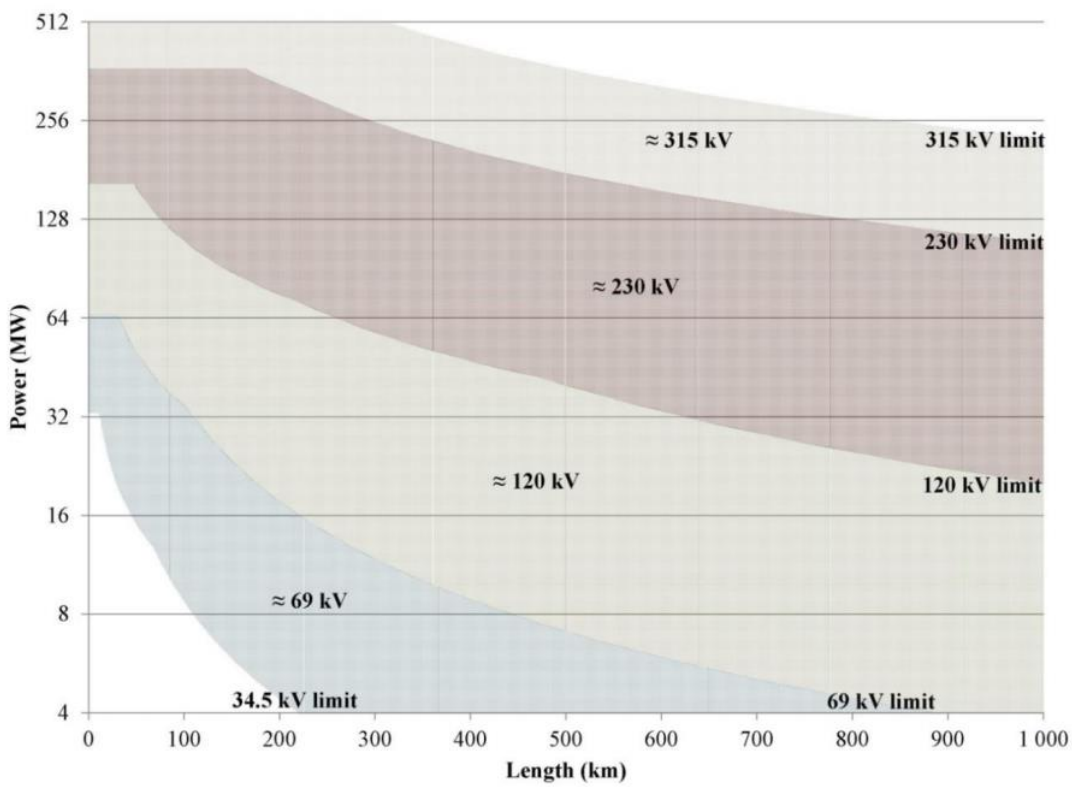

Figure 1: Minimum transmission line voltage level based on power (MW) and length (km)

Step 2: Transmission line equivalent energy cost (¢/kWh)

The transmission line equivalent energy cost (¢/kWh) can be estimated from the following parameters, even before the utility selling prices are known.

- Initial investment;
- Operation and maintenance;
- Discount rate (loan rate and risk);
- Transmission line losses;
- Loading per voltage level and distance.

Transmission lines cost per length is rarely published by their owners, except in special circumstances. Some costs published by utilities are presented in Appendix B and are adapted to better reflect industrial applications.

The following figure represents the equivalent cost of the transmission line for a ten-year site operation. It includes a discount rate in order to transfer the total expenses at year 0. These costs can easily vary up to ± 30%, depending on site conditions, design criteria and local contractor costs.

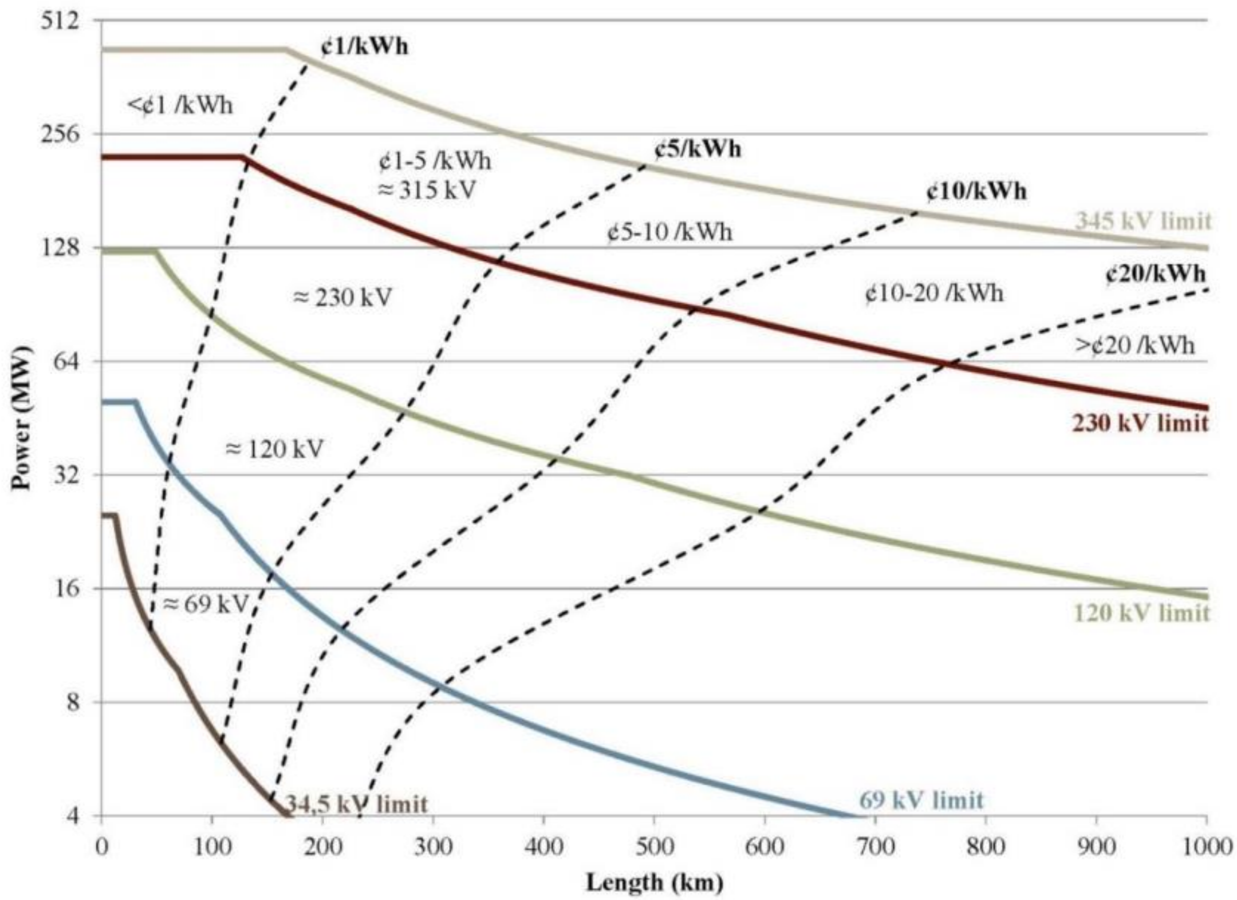

Figure 2: Voltage level (kV) and equivalent energy cost (¢/kWh) for a 10-year operation

Step 3: Total equivalent energy cost (¢/kWh)

The total equivalent transmission line energy cost may be compared to the corresponding cost for local generation. This comparison is expected to be more realistic if the local generation investment and operation/maintenance is included, as the transmission line should replace roughly 90% of local generation investment.

Recent projects suggest that the equivalent energy cost would be in the order of ¢30/kWh for diesel and ¢20/kWh for Liquefied Natural Gas (LNG). For such results, Figure 2 shows many areas were transmission lines could be more economical than local generation, even for industries with a 10-year scheduled operation.

The utility selling prices may be added to the previously obtained transmission line cost in order to estimate the total equivalent cost. The equivalent energy cost is obtained from the total of three separate costs in ¢/kWh, i.e. the transmission line equivalent cost, the utility selling price and the utility cost for power demand (monthly cost in $/kW converted into ¢/kWh). Equation 1 approximates this cost using reasonable simplifications, as the cost variation remains in the order of ±30%.

$$\left(\frac{¢}{kWh}\right)_{total} = \left(\frac{¢}{kWh}\right)_{line} + \frac{1}{(1-loss_{\%})}\left(\frac{¢}{kWh}\right)_{Utility} + \frac{1}{7.3\,LF_{\%}(1-loss_{\%})}\left(\frac{\$_{Monthly}}{kW}\right)_{Utility} \qquad [1]$$

Where:

$\left(\frac{¢}{kWh}\right)_{total}$ = Equivalent cost over the duration of the project, in ¢/kWh

$\left(\frac{¢}{kWh}\right)_{line}$ = Equivalent cost of the transmission line obtained from Figure 2 for a ten-year operation, in ¢/kWh

$Loss_{\%}$ = Loss percentage, previously assumed to be 5%

$LF_{\%}$ = Equivalent cost over the duration of the project, in ¢/kWh

$\left(\frac{¢}{kWh}\right)_{Utility}$ = Utility energy price, typically in the range of ¢3.5/kWh to ¢8/kWh in Canada

$\left(\frac{\$_{Monthly}}{kW}\right)_{Utility}$ = Utility demand rate, typically in the range of $7/kW to $15/kW in Canada

Benefits of the Solution

BBA Success Story: Detour Gold Mine

In the early phases of the Detour Lake new gold mining project, BBA and the owner evaluated the most economical source of power. A new 180 km, 230 kV line was preferred to the corresponding power generation for the main source of power. As the operation of the mining complex could not be started without the supply from the transmission line, BBA proceeded with the procurement of strategic materials as detailed engineering progressed. The commissioning of the whole transmission line was completed ahead of schedule, even in time to supply power during the construction of the mining complex. Detour Lake started its operation as the largest gold mine in Canada.

BBA was involved in the feasibility study, detailed engineering, equipment purchasing, technical support and commissioning of Detour Lake. For its overall work, BBA received the Award of Excellence[11] during the 2014 Canadian Consulting Engineering Awards Gala[12]. The current production of this gold mine now exceeds operating expectations, proving BBA's expertise in cost-effective and innovative solutions.

Figure 3: Detour Lake gold mine, Ontario, Canada

Conclusion

In this paper, the authors provide tools for industrial clients in remote locations to evaluate the merit of transmission lines compared to the equivalent local generation. This approach presents the minimum voltage level to be used for a specific application, the equivalent energy cost of the transmission line only and the total equivalent energy cost over the duration of the site operation.

The calculation can easily be adapted to any specific application. It is faster and less expensive than an approach that begins with software simulations. The subsequent design optimisation is also expected to be more efficient by discarding some options.

A transmission line may be more economical than local power generation for a many remote applications. Its design, procurement and construction can be integrated in the overall projects schedule without postponing the operation of the new industrial complex.

Acknowledgement

The authors wish to acknowledge the collaboration of Detour Gold for this work, and express their gratitude to all the personnel of the Detour Gold plant for their support and commitment to the success of the high-voltage transmission line commissioning. The permission for BBA to publish this paper is also appreciated.

References

[1] H. P. St. Clair, “Practical Concepts in Capability and Performance of Transmission Lines”, AIEE Transactions (Power Apparatus and Systems). Presented at the AIEE Pacific General Meeting, Vancouver, B. C., Canada, Sept. 1-4, 1953

[2] Federal Power Commission, “National Power Survey”, Part II, pages 45-47 and 144-145. U.S. Government Printing Office, 1964

[3] Federal Power Commission, “The 1970 National Power Survey”, Part IV, pages IV-2-9 through 17. U.S. Government Printing Offices

[4] R. D. Dunlop , R. Gutman and P. P. Marchenko “Analytical Development of Loadability Characteristics for EHV and UHV Transmission Lines”, IEEE Transactions on Power Apparatus and Systems, vol. PAS-98, no. 2, pp.606 -617 1979

[5] R. Gutman “Application of line loadability concepts to operating studies”, IEEE Transactions on Power Apparatus and Systems, vol. 3, no. 4, pp.1426 -1433 1988

[6] ABB Power T&D Company Inc., Electrical Transmission and Distribution Reference Book, Fifth Edition, ABB., 1997

[7] Demande R-3688-2009 – Réponses d’Hydro-Québec distribution à la demande de renseignements n° 1 de la Régie, 2008-04-23

[8] Décision D-2003-214 R-3512-2003 – Régie de l’Énergie - Decision concerning an application by the Electric Power Carrier and the Electric Power Distributor to connect the Cree village of Waskaganish to the electricity transmission system, pursuant to section 73 of the Act respecting the Régie de l’Énergie

[9] Capital Expenditure Forecast (CEF10), 2010/11 - 2019/20, Manitoba Hydro, November 2010 [10] TransÉnergie, Direction Planification et Développement des Actifs, Programme et stratégies du réseau principal, Étude d’intégration de 1000 MW d’éoliennes dans le territoire gaspésien

[11] BBA, “BBA Inc. honored at the 2014 Canadian Consulting Engineering Awards Gala”. Internet: http://www.bba.ca/acec-award-en.htm

[12] Association of Consulting Engineering Companies, “Detour Lake Gold Mining Project in Ontario”. Internet:

Www.acec.ca/events__awards/canadian_consulting_engineering_awards/2014-awards/awards_excellence/e1.html

About the Authors

Éric Breault, P.Eng.
Mechanical Engineer
eric.breault@bba.ca

Eric Breault obtained his Bachelor's degree in Electrical Engineering in 2009, with a specialized academic training course in Power Engineering at l'Institut en génie de l'énergie électrique (IGEE). Since then, Mr. Breault carried out power system studies and was involved in the design and optimization of more than 1,400 MW of wind farm projects. He also performed numerous technoeconomic studies for interconnections using transmission line systems. Moreover, Mr. Breault prepared master plans related to mining project developments. He acted as a project leader for various types of mandates in the design, construction, commissioning, and management of multidisciplinary teams and with various types of stakeholders.

Maurice Brisson, P.Eng.
Founding partner and electrical expert
maurice.brisson@bba.ca

Serge Naud, Process Control Engineer, has more than 30 years of experience as a consultant. He has worked in numerous industrial plants as an automation engineer and process control engineer. As a process control expert, he acquired vast experience in process control optimization, start-up, troubleshooting and development of new advanced control strategies for industries such as mining processes, pulp mills, power and boiler plants, petrochemical and pharmaceutical plants, chemical processes and refineries.

Appendix A: Assumptions for minimum transmission line voltage

The following table presents transmission lines used in industrial applications with high loadability in order to better represent the limit of each voltage level. For 230 kV and 315 kV, two conductors per phase are used to represent the maximum power transfer capability of each voltage level. One conductor per phase is used for the subsequent economic evaluation.

Table 1 : High loadability transmission line characteristics

Voltage level (kV)	Cond. per phase	Surge impedance (Ω)	Max. current per phase (A)
34.5	1 x 477 kcmil	300	550
69	1 x 477 kcmil	360	550
120	1 x 795 kcmil	380	750
230	1 x 795 kcmil	400	750
230	2 x 795 kcmil	275	950
315	1 x 1,272 kcmil	385	1,000
315	2 x 1,272 kcmil	285	1,300

The maximum current per phase includes a safety margin for the maximum continuous thermal limitations. The maximum voltage drop across the terminals is limited to 10%. For high-loadability lines, these criteria can limit the maximum power below the value obtained from the heavy loading curve. The most restrictive criteria are considered in Figure 1, which explains the point of inflexion of the 34.5 kV and 69 kV curves around 75-125 km.

Appendix B: Economical assumptions for transmission line voltage

Figure 2 is based on the following assumptions:

- 10-year site operation;
- Yearly operation and maintenance cost: 2 % of the initial investment;
- Yearly discount rate (loan rate and risk factor): 5%;
- Transmission losses: 5 % of the total power;
- Load factor: 90%;
- Power factor: 100%;
- Loading: 80% of the maximum loading per voltage level, per distance.

Table 2 presents published cost for each voltage level. The calculation to obtain unit costs in 2015 dollars assumes a yearly inflation rate of 2%.

Table 2: Published costs of transmission line per length based on voltage level

Voltage level (kV)	Unit cost (k$/km)	Year	2015 unit cost (k$/km)	Source
34.5 kV	206	2008	237	[7]
69 kV	252	2003	320	[8]
138 kV	414	2010	447	[9]
double-circuit 230 kV	530	1998	694	[10]
double-circuit 315 kV	680	1998	952	[10]

The following table presents costs that are more representative of industrial transmission lines.

Table 3 : Typical industrial costs of transmission line per length based on voltage level

Voltage level (kV)	Unit cost (k$/km)	Voltage regulation or compensation cost (k$/300km)	Explanation of the difference from the published cost
34.5	150	400	The reference price is for a line installed in heavy environmental conditions. Industrial 34.5 kV lines typically cost in the range of k$125-175/km
69	300	500	Cost provided as a reference very similar to industrial applications
138	450	1,000	Cost provided as a reference very similar to industrial applications
230	850	5,000	The reference price is very low, most likely due to the utility high volume discount and typical tower design
315	1,100	10,000	The reference price is very low, most likely due to the utility high volume discount and typical tower design

BBA.CA