

A Japanese Example

The Japanese approach uses the repulsion magnetic concept, which causes the air gap to increase with increased vehicle speed, reaching a 4-in. clearance at 300 mph. The vehicle is entrapped in a U-shaped guideway and supposedly cannot escape. A loss of power would cause the vehicle to drop down onto wheel sets at very high speeds.

CONCLUSION

Both the German and the Japanese concepts have advantageous technical and safety features. Only after close scrutiny can determinations be made that could lead to design modifications or additional safety provisions. Additional issues that must be addressed are the following: high-speed switching; egress from an elevated guideway during emergency conditions;

use of cryogenics on the vehicles; effect of magnetic field on the human body; acceleration and deceleration rates; and all of the other typical safety issues such as vehicle structural integrity, braking, train control and communication, electromagnetic interference, and electrical hazards.

REFERENCE

1. Railroad Passenger Equipment Safety, a Report to Congress. Office of Safety, Federal Railroad Administration, U.S. Department of Transportation, Jan. 1984.

Publication of this paper sponsored by Committee on Intercity Passenger Guided Transportation.

Electrification of the Tumbler Ridge Branch Line in British Columbia, Canada

PER ERIK OLSON

ABSTRACT

The North-East Coal Development and Transportation Project in British Columbia, Canada, is a major undertaking that is costing about \$2.5 billion (1983 Canadian dollars). The exploration incorporates development of large coal and mineral resources in a completely unpopulated area, founding of a new townsite, and construction of a railway branch line with long tunnels through the Rocky Mountains to haul coal almost 1000 km to a newly constructed unloading facility on the Pacific Ocean at Prince Rupert. The electrification of the Tumbler Ridge Branch Line (TRBL) and its technological spinoffs are discussed in this paper. The transportation and energy-technical background is reviewed along with the considerations leading to use of a 50 kV overhead electrification system and thyristor controlled locomotives. The technical-economic benefits and the future outlook are discussed. British Columbia Railway Company is the first railroad to electrify a heavy-haul route in North America in the past 50 years. It has used and advanced the most modern technology available in the world. The TRBL project was completed in less than 3 years, ahead of schedule and below budget.

The 50-kV, 60-Hz electrification of the 130-km main line railroad is the main topic discussed in this paper. However, the \$500 million (1983 Canadian dollars) construction cost of the electrified Tumbler Ridge Branch Line (TRBL) is just a part of a \$2.5 billion project for coal production that also includes upgrading 800 km of British Columbia Railway Company (BCRC) and Canadian National Railways' (CNR) connecting trackage, building a new townsite for 6,000 future inhabitants, and constructing a modern port and coal loading facilities on the North Pacific

Ocean coast of British Columbia at Prince Rupert. Thus, exploration of coal resources in northeastern British Columbia is a major undertaking.

The map in Figure 1 shows the general location of this immense transportation project. It is essential to note that before the North-East Coal Development and Transportation Project was started, the entire area from Dawson Creek in the northern sector to the Fraser River in the southern sector was completely wilderness, devoid of rural roads, power transmission lines, and communication facilities. It is

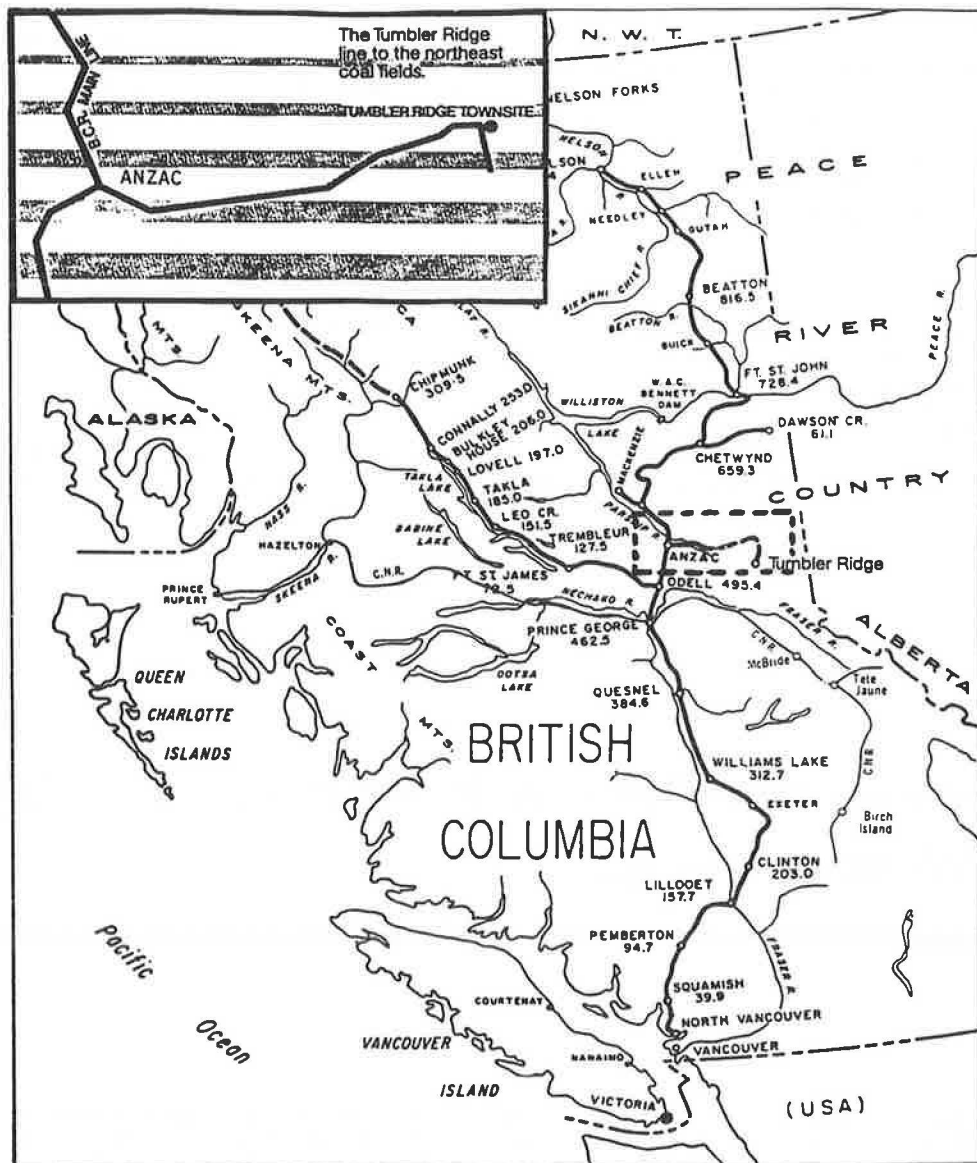


FIGURE 1 Map of British Columbia showing location of electrification project.

therefore a significant achievement to have completed the project within 3 years after the decision in early 1981 to begin; the first coal train delivery to Prince Rupert was in November 1983.

SOCIOECONOMIC BENEFIT

This enormous transportation project carried out by the government of British Columbia has resulted in major socioeconomic benefit to the area. Although the main objective was to transport coal from the mines to the port at Prince Rupert, the results have been (a) installation of a cost-effective electrified railroad, (b) mineralogical development of a vast wilderness, (c) creation of a modern city, and (d) construction of a high technology port facility on the North American Pacific coast.

As an integral part of the North-East Coal Development and Transportation Project, TRBL significantly contributes to the overall socioeconomic benefits of the transportation project. It is not only a fast, efficient, and reliable transportation link for enhancing development of mineral resources east of

the Rocky Mountains, but it also uses renewable energy resources for its power. Further, this electric railway incorporates the capability for diversified freight handling as well as potential for passenger operation in the future.

TRANSPORTATION CONSIDERATIONS

Contracts for development of the north-east coal block call for mining 8 to 10 million tons of metallurgical coal annually and transporting it to the seaport of Prince Rupert on the Pacific Ocean, 1000 km from the mines. The map in Figure 1 shows the area where BCRC connects to CNR in Prince George. The new railway line stretches from Anzac to the mining area in Tumbler Ridge (see Figure 2). The new 130-km branch line passes over the continental divide near the center of the 9.1-km Table Tunnel. The length of Wolverine Tunnel is 6.4 km. The maximum gradient for a loaded train (westward) is 1.2 percent; the maximum gradient for an empty train (eastward) is 1.5 percent (see Figure 3).

To meet contract requirements, an average of

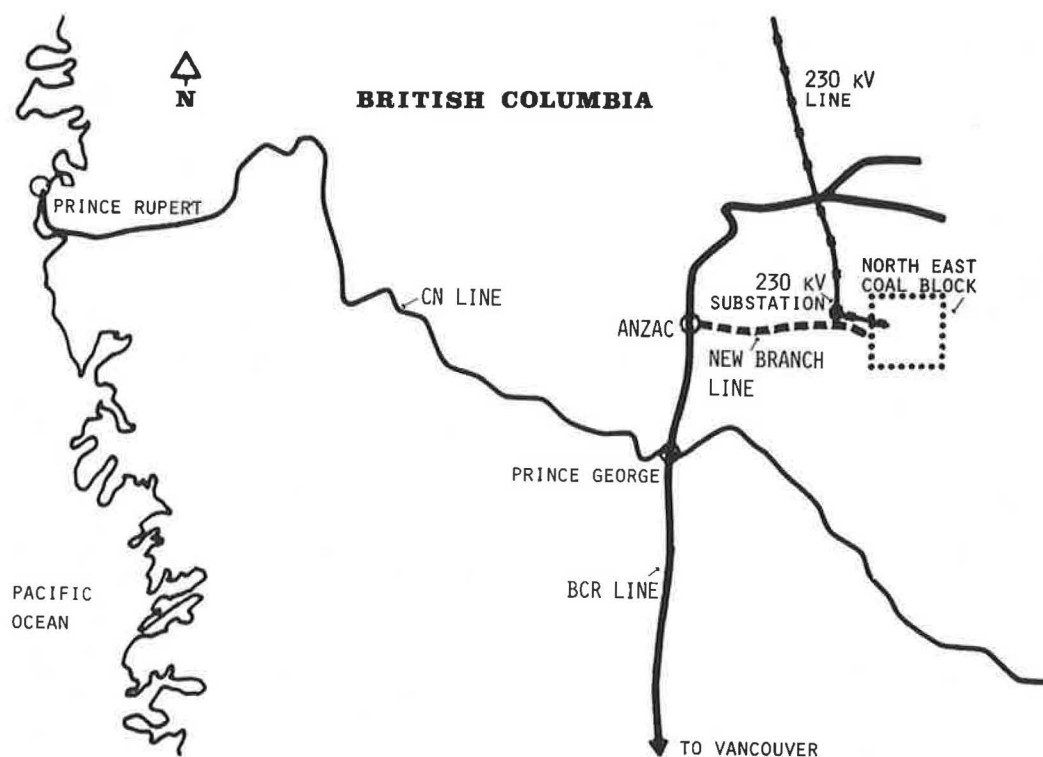


FIGURE 2 Map of northern British Columbia showing BCR and CNR lines along with the new railway line from Anzac to Tumbler Ridge.

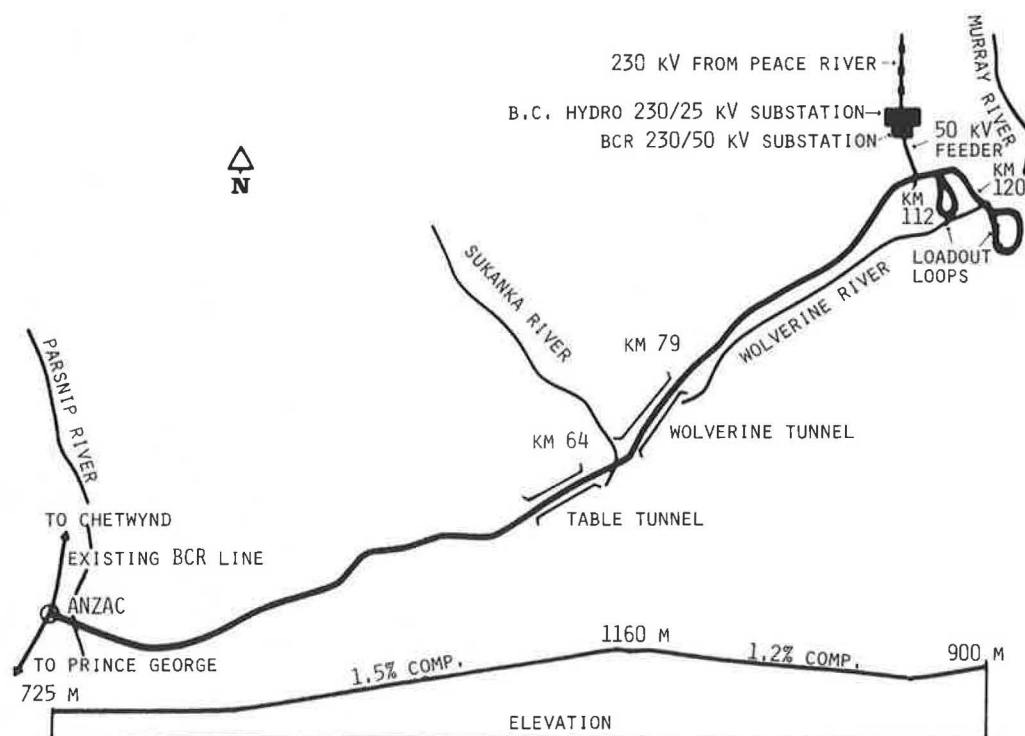


FIGURE 3 Location map and profile of Tumbler Ridge Branch Line.

33,000 tons of coal per day must be delivered. Three unit trains, each consisting of 98 cars with a loaded weight of 13,000 tons, are required. At least five six-axle, 3,000-hp diesel-electric locomotives (SD40) are required to power this train in nonelectrified territory. Each of these diesel locomotives has a

total weight of approximately 200 tons. The new electric locomotives now in operation each have approximately 6,000 hp available and weigh less than 180 tons. These technical advantages of the electric locomotives over the diesels were important considerations in the decision to electrify TRBL.

However, the primary concern was the need to supply sufficient fresh air for combustion and cooling while diesel locomotives move heavy trains through long tunnels. A single diesel locomotive can develop almost full power on a heavy grade in tunnel operation. In a multiple-unit train with many diesels the temperature around the second unit and following units increases, oxygen becomes more rare, and combustion is impeded. The resulting output is thus reduced; this can cause the train to stall, which results in numerous operational complications. The health risk for the crew operating trains in tunnels was another consideration.

Therefore, the use of five or six 3,000-hp diesel-electric units in the long summit Table Tunnel would require heavy investment in ventilation equipment, electromechanical control apparatus, and power supply. The cost to operate continuously all of the ancillary support equipment in a remote area, which has limited wintertime access, was also considered. The estimated \$12 million cost for this equipment was another of the major factors that influenced the decision to electrify TRBL.

PLANNING AND STUDIES

It is interesting to note that in 1909 an electrified railway summit tunnel was constructed through the Cascade Mountains in Washington State by Great Northern Railway. This electric railway in the Rocky Mountains was abandoned in 1956. In 1969 BCRC conducted a study for the electrification of 750 km of railroad that runs from North Vancouver to Prince George. At the same time CNR conducted a study for the potential electrification of its line through the Rocky Mountains.

As one step in the development procedure of British Columbia's exploration of the northeast coal block, the provincial government and BCRC conducted a feasibility study in 1976. At that time electrification was considered as an alternative and dropped. After screening various alternative routes for rail transportation, the Anzac route (Figure 2) was selected in 1977 for detailed study. In 1980 the study of the Anzac route was adopted, and the decision was made to proceed with exploration of access roads and preparation of necessary documents for construction of the first 30 km of the system. This phase of the project was budgeted at \$455 million and was scheduled to be completed in 1983.

The electrification studies carried out by the Transportation Development Centre of Canada and the Railway Association of Canada early in 1981 triggered the decision to electrify TRBL. Major project milestones are listed in the following chronology of TRBL.

Date	Milestone
January 13, 1981	Access road contracts awarded
July 20, 1981	Preliminary grade work started
December 8, 1981	Major tunnel contracts awarded
March 16, 1982	First blast in Wolverine Tunnel completed
April 5, 1982	First blast in Table Tunnel completed
August 5, 1982	Decision to electrify ratified
August 20, 1982	Short tunnel contracts awarded
December 1, 1982	Mile-50 Tunnel holed-through
December 11, 1982	Mile-53 Tunnel holed-through
May 28, 1983	Wolverine Tunnel holed-through
August 21, 1983	Table Tunnel holed-through
September 9, 1983	Grade construction completed
October 21, 1983	Last rail bolted
November 1, 1983	Last spike driven
November 1, 1983	First diesel coal train operated

Date	Milestone
November 16, 1983	First electric locomotive (No. 6001) delivered
December 1, 1983	Electric locomotive trials began
March 1, 1984	Electric train operations began
June 6, 1984	Formal inauguration of TRBL took place

ELECTRIFICATION

Main line railroads in North America have been subjected to electrification feasibility studies ever since the Northeast Corridor system was electrified early in the century. BCRC is the first main line railroad to electrify since the 1930s. With the exception of the narrow gauge iron-ore railway in South Africa (Sishen-Saldana), the TRBL electrification is the first 50-kV, 60-Hz (industry-frequency) railway installation in the world.

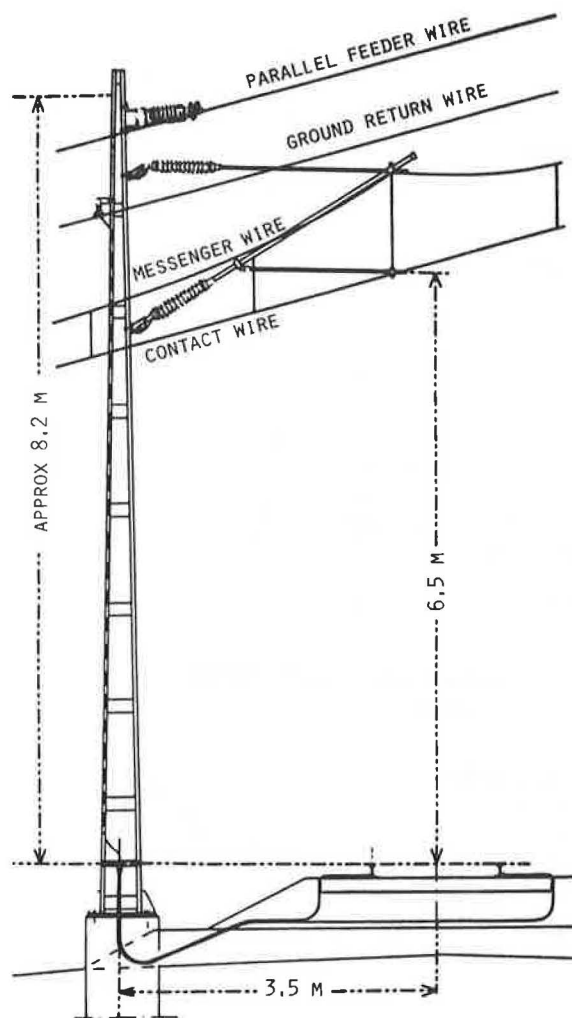
The approach of the TRBL railway was to install an electrification system based on proven concepts, incorporating the most advanced engineering design available. This was necessitated by the climate of the area that TRBL was penetrating: an area in the Rocky Mountains with heavy winter snowstorms, generally characterized by an arctic climate. The power distribution system--the overhead catenary system (OCS)--was derived from the Swedish State Railways' (SJ) design, originally installed in 1914 north of the polar circle in Scandinavian Lapland. The electric locomotive was also derived from accepted solid state technology as a result of close cooperation between North American and Swedish railroad industry suppliers. The specific electrotechnical aspects of the design of electrification have been reviewed during several sessions of the Institute of Electrical and Electronics Engineers (1-3).

One of the major reasons for choosing 50 kV as the line voltage was the option to use an existing 230-kV power line to supply all energy necessary for the 130-km, heavy-duty freight railroad. This option reduced significantly the investment cost for the power supply. The decision to use 50-kV power was supported by computer simulations of power demand, voltage drop, and capacity under various operating criteria. The rationale for feeding power to the railroad from its extreme northeastern end and adding to a series capacitor to compensate for the 30-percent catenary impedance at the center of the line has been justified in full scale testing and in service operation.

Figure 4 shows a typical catenary system cross section and Figure 5 shows a 6,000-hp GF6C locomotive. In the chart in Figure 6 characteristics of a GF6C locomotive are given together with a tractive effort versus speed curve. The technical and operating management at BCRC suggest that one GF6C locomotive is operationally equivalent to two 3,000-hp diesel-electric SD40 locomotives.

A test program to validate the contracted values was carried out simultaneously with electric operation in early 1984. So far these tests have verified the specified acceleration, capacity, power factor, and so forth. Further, system response to perturbations and harmonic feedback from the 50-kV catenary to the 230-kV power line network has been studied and results were satisfactory.

The OCS uses a solid copper contact wire and a stranded copper messenger wire. The construction has proved to be adequate for speeds up to 100 km/hr and is designed to handle four pantographs simultaneously. A 50-kV feeder wire mounted on the catenary poles is parallel with the catenary system. The ground return circuits consist of the earth, the rails, and a ground return conductor installed on



Wire arrangement of the OCS.

MESSANGER WIRE	70 MM ²	COPPER
CONTACT WIRE	107 MM ²	COPPER
PARALLEL FEEDER WIRE	125 MM ²	ACSR
GROUND RETURN WIRE	125 MM ²	ACSR

FIGURE 4 Typical catenary cross section.

the outside of the catenary poles. Because there are no long cables or open wires, the system does not employ booster transformers (Figure 7).

The OCS is divided into sections over its entire length with remote-local disconnects. This enables sections of the system to be isolated for maintenance while allowing other sections, the loadout loops for example, to remain energized (see Figure 7).

DESIGN AND COST OF OVERHEAD CONTACT SYSTEM

Of primary concern in the electrification of a specific railroad is the energy supply and distribution to the motive power along the line. In the case of TRBL as mentioned earlier, it was possible to energize the total system from one location, thereby minimizing the cost of expensive high-voltage (230-kV) feeder lines. Therefore, attention was concentrated on the OCS to optimize its design, construction, and maintenance requirements.

The concept of the overhead contact system was based on designs tried and proven by SJ in climatic conditions similar to those in northeastern British Columbia. During the detailed design phase, the



FIGURE 5 6,000-hp GF6C locomotive.

Swedish designs were adapted wherever possible to North American standards as well as to the specific requirements of TRBL.

The overhead contact system is composed of two major subsystems: the mechanical subsystem, which consists of poles, cantilevers, and tensioning devices; and the electrical subsystem, which consists of the contact wire, the ground wire that is electrically connected to the track, and the messenger-dropper system that maintains the contact wire at the correct height above the rail as well as forms part of the electrical circuitry. [This is described in detail in Andersson et al. (2).] Generally approved construction methods were used in most cases. However, for foundations, a unique method was used for all but a few of the catenary masts.

The BCRC Engineering Department undertook design of the foundation. Because of the newly filled subgrade and high cost of concrete at the construction site, there was reluctance to recommend poured concrete foundations in holes augered or dug with a backhoe. Driven steel piles or precast concrete foundations were considered potentially suitable and tests were carried out by loading prototype foundations with the structures bolted to them. The driven steel pile was found to be satisfactory, which enabled the design to proceed with one standard length of mast for each of four different mast cross sections. The steel piles were driven into the subgrade by a truck-mounted pile driver. This pile driver proved capable of installing between 20 and 50 foundations per day; it could thereby cover from 1.0 to 2.5 km per day for a single-track catenary.

The newly designed 50-kV catenary system penetrates an area where severe climatic conditions and operating demands that required special design arrangements had to be considered. Some interesting OCS design features of this installation are those used for:

- Section insulator and neutral sections,
- Weight tensioning,
- Insulated overlaps,
- OCS at load-out loops, and
- Tunnel design.

Some of these features and their arrangements at the coal load-out silos are shown in Figure 8. The OCS arrangement to facilitate loading the coal cars is shown in Figure 8(a), and the OCS arrangement at the coal loading hopper is shown in Figure 8(b). Coal and train handling in the loading area will be fully

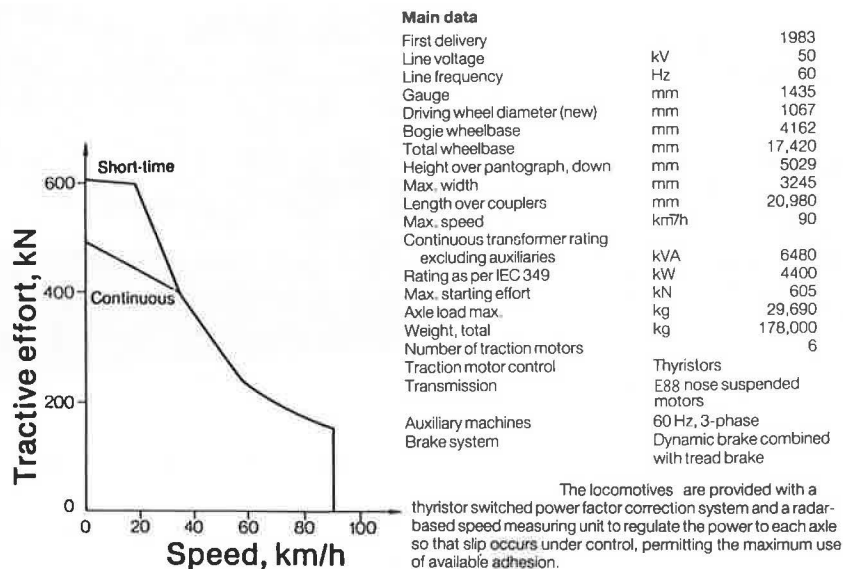


FIGURE 6 Tractive effort versus speed curve and GF6C locomotive characteristics.

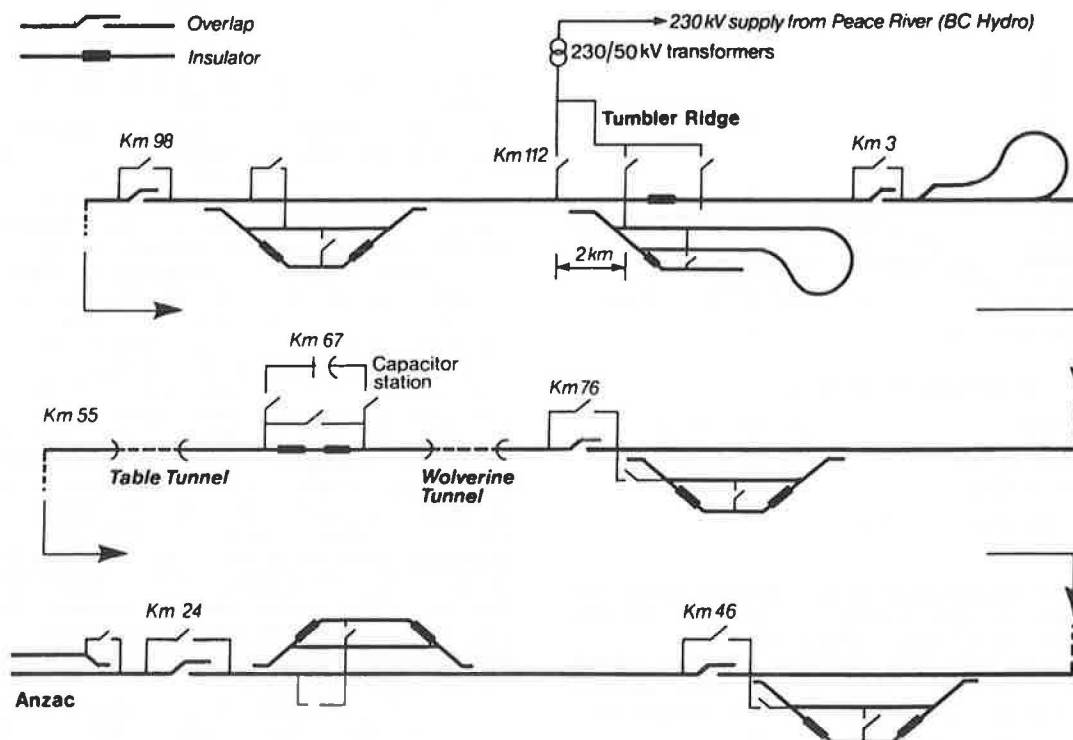


FIGURE 7 General arrangement of power feed to the catenary and the sectioning of the system.

automatic and controlled by advanced computer systems.

For the total OCS at TRBL some of the typical procurement and installation costs were as follows (1982-1983 Canadian dollars):

Supporting Structure	Cost (\$)
H-beam steel piles	378-397
Precast concrete pedestals	500-555
Installation of steel piles	237
Installation of concrete pedestals	475
Steel masts	341-882
Erection of masts	70
Total cost of one mast	948-1,862
Portal structures (material)	2,275-2,459

Mechanical Components and Assembly	Cost (\$)
Special casting and fabrications	951,000
Insulators	666,000
Cantilever tubing	111,000
Tunnel supports	154,000
Nuts and bolts	143,000
Other items	119,000
Subtotal	2,144,000

Electrical Components and Assembly	Cost (\$)
Contact wire	875,000
Messenger wire	632,000
Earth and feeder wire	251,000
Other fittings	381,000
Subtotal	2,139,000

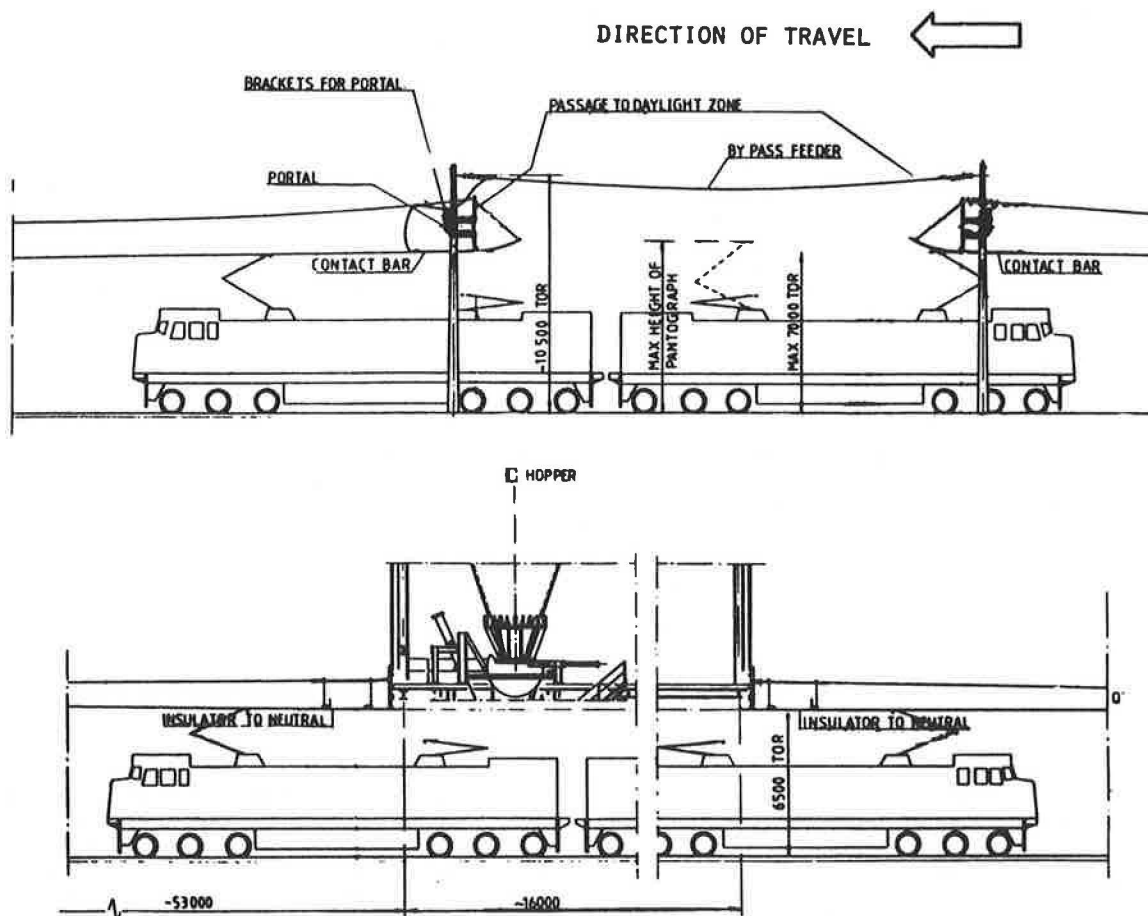


FIGURE 8 Some design features of OCS and arrangement at coal load-out silo.

The installation cost--excluding substations, the capacitor station, and 50-kV feeder line from the substation--is approximately \$100,000 per single track kilometer. There are about 168 km of single track OCS.

ECONOMIC BENEFITS: ENERGY AND TECHNICAL ASPECTS

There are two principal energy-related benefits now being derived from the electrified operation of TRBL: the efficient use of energy to transport coal from the mines to the BCRC main line and the use of hydrogenerated electricity instead of nonrenewable fossil fuel. Additional benefits are obtained from reduced locomotive maintenance and elimination of the need for tunnel ventilation systems. Using the electrical system is also environmentally cleaner and less noisy than using diesel power, and requires only nominal maintenance effort.

The energy consumption estimates presented in this section were derived from a series of computer analyses based on the number of locomotives, train length, train weight, and track gradient. The figures show the projected energy use during the coming years. Field data collected and analyzed thus far have shown good agreement with the computer analyses. Converting from diesel to electrical energy is expected to provide an annual saving of approximately \$1 million (1982 dollars) by 1986, when the mines will be producing coal at their planned capacity of 8 to 9 million tons per annum.

Use of electrical energy instead of diesel energy will reduce energy consumption by 63 percent, which will make use of electrical energy almost three

times as efficient as use of diesel fuel. It is estimated that during a 10-year period the electric locomotives will save almost 100 million liters of high-grade diesel fuel in transporting 80 to 90 million tons of coal through the Rocky Mountains. Translation of energy efficiency between different types of internal combustion and electric prime movers is a complex process. Efficiencies of various types of transportation equipment are presented in Table 1.

The diesel engine energy efficiency is 23 percent, compared with 90 percent for the compensated, thyristor-controlled electric locomotive. The BCRC has conservatively calculated an efficiency of 27 percent for the diesel electric locomotive and 75 percent for the electric locomotive. The BCRC fuel consumption estimates shown here are based on projected annual tonnages.

Year	Trips	Diesel Fuel (L)	Diesel Fuel (GJ)	Elec- tricity (kw/hr)	Elec- tricity (GJ)
1984	700	6,540,000	252,000	25,900,000	93,000
1985	881	8,823,000	317,160	32,597,000	117,175
1986	953	8,903,000	343,080	35,261,000	126,750

The annual fuel savings are calculated to be \$289,000 in 1984, \$603,000 in 1985, and--when the mines are delivering coal at their contracted capacity from 1986 on--\$729,000. Estimated annual savings from using electric power rather than diesel fuel are shown in Table 2. The data in Table 2 indicate that substantial savings in fuel cost can be realized from the use of electrically powered locomotives.

There are many other cost benefits to be realized

TABLE 1 Comparison of Transportation Equipment Efficiencies

	Diesel Oil From:		Petrol From:		Electricity from Oil, Coal, Nuclear Power		Hydro Power
	Oil	Coal	Oil	Coal	Condensing	Backpressure ^a	
Efficiency of conversion to usable energy (percent)	94	33	94	33	35	85	100
Efficiency of refueling, charging-discharging (percent)	100	100	100	100	66 ^b -90	66 ^b -90	66 ^b -90
Efficiency of engine and motor (percent)	23	23	17	17	75 ^c -90	75 ^c -90	75 ^c -90
Efficiency of transmission engine and motor wheels (percent)	85	85	85	85	85-95	85-95	85-95
Total energy remaining for propulsion (percent)	18	7	14	5	15-27	36-65	42-77
Regeneration, 20 percent of total efficiency	18	7	14	5	18-32	43-78	50-92

^aIncluding heat.^bAccumulator.^cContact-resistor system.

TABLE 2 Estimated Annual Savings of Diesel Fuel Compared with Electric Power

Year	No. of Trips	Cost of Diesel Fuel (\$000s)	Cost of Electric Power		Total Cost of Electric Power (\$000s)	Savings (\$000s)
			Energy Charge (\$000s)	Demand Charge (\$000s)		
1984	700	1,793	581	923	1,504	289
1985	881	2,257	731	923	1,654	603
1986	953	2,443	791	923	1,714	729

from use of electrification. First, locomotive maintenance costs are expected to be reduced by \$350,000 per year (compared with maintenance costs of using diesel-powered locomotives). Elimination of the requirement for tunnel ventilation systems will result in a further operating-cost reduction of \$200,000 per year. Assuming the maintenance cost of the electrical power system to be \$300,000 per year, the net savings for 1986 and succeeding years will be about \$250,000. This, together with fuel cost savings, yields a total saving of almost \$1 million per year in 1986 and in succeeding years, when the mines are delivering coal at their contracted capacity.

By examining the capital cost figures it can be observed that the electrification of the line has resulted in an additional cost of \$12 million. BCRC estimates that this cost will be recovered in 13 years. If the energy savings credits are included, the cost will be recovered in 8 years.

SUMMARY AND OUTLOOK

Electrification of TRBL represents only 5 percent of BCRC's 20 percent involvement in the \$2.5 billion North-East Coal Development and Transportation Project in British Columbia. Nevertheless, electrification is a major technical achievement that can provide significant cost benefits in the future. The project was carried out in a short time period and was completed ahead of schedule and below budget. The introduction of high-voltage electrification and modern solid-state controlled electric locomotives will provide the railroad industry in North America a valuable data base for performance of a modern electrified railroad operation for heavy loads under adverse conditions. It is too early to draw conclu-

sions from the TRBL operation, but so far the tests and operating experience have been favorable. Many technical questions will arise and their resolution will serve as guidelines for future railroad electrification development in North America.

ACKNOWLEDGMENT

The author wishes to express his thanks to the officers of BCRC, his colleagues of CPCS, CANAC, and Swederrail Consulting, as well as the members of the TRB Committee on Rail Electrification Systems, all of whom have made significant contributions to this paper.

REFERENCES

1. P. Bridge and G.T. Fisher. 50 kV Electrification of the Tumbler Ridge Branch Line. Joint Railroad Conference, Chicago, Ill., Vol. 2, April 1984.
2. B. Andersson, L. Lundin, and L.C. Tait. Design of the 50 kV Overhead Contact System for the British Columbia Railway Tumbler Ridge Branch Line. IEEE Industry Applications Society, Mexico City, Oct. 1984.
3. G.T. Fisher and G.B. Furst. 50 kV Electrification of the Tumbler Ridge Branch Line Conceptual Design. Presented at 18th Annual Meeting of IEEE Industry Applications Society, Mexico City, Oct. 1983.

Publication of this paper sponsored by Committee on Rail Electrification Systems.