Choice of Electrification for a Concrete Case

This Is a Supplement to W. S. Murray's Discussion Before the Canadian Society of Civil Engineers on A. H. Armstrong's Paper Entitled "The Engineering Problem of Main-Line Electrification"

[The Electric Railway Journal for Dec. 20 contained a telegraphed report of the discussion by W. S. Murray, formerly electrical engineer New York, New Haven & Hartford Railroad, on the paper "The Engineering Problem of Main-Line Electrification" which was presented and read by A. H. Armstrong before the Canadian Society of Civil Engineers at Montreal, Que., on Thursday evening, Dec. 18. Owing to the date of the meeting it was impossible to publish other than a condensation of Mr. Murray's remarks. The following paragraphs give a full account of this part of his discussion.—Eds.]

MR. MURRAY'S COMPARISON FOR A CONCRETE CASE

"Having shown the application of single-phase traction to extremely heavy and dense traffic on the New York, New Haven & Hartford Railroad, let us make a study of the relation of electrification costs to the density of traffic.

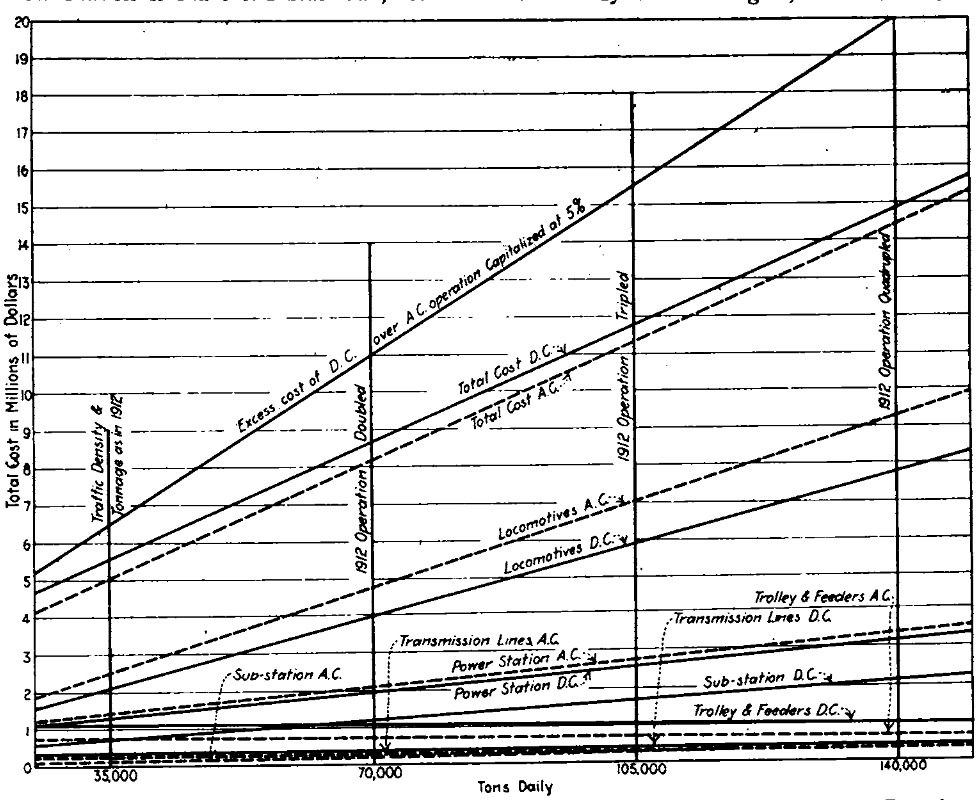

Fig. 1—A.C.-D.-C. Comparison—Relation Between Capital Costs and Traffic Density

"We must again resuscitate the single-phase system in order to compare it to d.c. working, and to avoid being charged with generalizing, an actual case will be selected. This concrete example is offered by a Western railway where the electrification territory comprises a route distance of 119 miles, or a total of 260 miles of single track, including a summit grade rising 3700 ft. with a maximum grade of 2.4 per cent for a length of 12 miles.

"The application of known cost constants of construction was made, and the efficiencies of generating, line and motive power apparatus were included in the consideration of this case. This comparison between the a.c. and the d.c. systems of train propulsion was made upon the basis that the total costs of electrification necessarily increase in proportion to the density of traffic. The curves developed in Fig. 1 start with the translation of 35,000 tons a day over a road 119 miles between terminals. These curves indicate the investment which is required to take care of an increase in density of traffic up to 140,000 tons per diem. The graphs themselves are perfectly self-descriptive in that they are segregated into the major factors going to make up a complete electrification, such as power station, transmission line, substations, feeder, trolley and locomotive costs, with, finally, a summation of the details. It is interesting to note the parallelism of the two lines which represent the total costs for the two systems. However, the grand economic advantage of the a.c. over the d.c. system of train propulsion is graphically expressed by the curve lying above the investment cost for the two systems, for this curve represents the capitalization of the difference in operating cost in favor of a.c. which can properly be charged against the d.c. system of train propulsion. This advantage, although great, is not comparable to that shown in Fig. 2, in which the relative advantages of the two systems are presented upon the very essential operating basis of the number of tons that can be delivered per hour per mile of track. I do not know that I have ever seen the relation of the two systems brought out in a way which shows so clearly the superiority of alternating current.

"Let us refer now to Fig. 2, remembering that the train speeds are entirely dependent upon the amount of voltage that is supplied to the current collectors of the electric engines, that we are dealing with a given weight of train over a given amount of track with a stated number of a.c. or d.c. substations and that the investment cost of the d.c. and a.c. substations is arranged in accordance with the intersection of the lines that represent an equality of cost for investment of apparatus versus cost of power. The average voltage curve of the line as one, two, three or four trains are operated can be plotted for the a.c. and d.c. contact wire. Thus, this diagram develops the average voltage of the line for the increase from the operation of a single train to the operation of four trains, and in turn it shows the decrease of speed which occurs in proportion to the drop in line voltage. It is, therefore, a simple matter to develop from the relative speed relation of the two systems the relative capacity of tonnage delivered per mile of track per hour for each system. This relative rate of tonnage delivered is made clear in the examination of the lines so marked in the figure. An inspection of the curves shows that for single-train operation the capacity of the a.c. system is four and one-half times that of the d.c. system, but that if the operation is increased to four trains in flight, the capacity of the a.c. system rises to six and four-tenths that of the d.c. system. In the consideration of these tonnage capacity curves, it should be emphasized that they apply to the field of heavy traction from which Mr. Armstrong has now so ruthlessly taken the single-phase system.

"Still holding to this specific case, it is interesting to refer to Fig. 3, in which the general efficiency of the two systems between the driving wheels of the electric engines and the generators of the power station is compared from two points of view. The first comparison reverses this order by tracing the cost of the electrical energy from the driving wheels of the electric engines to the generators of the power station. The reverse order offers a better opportunity to see the effect of efficiency at its various points of application in the chain. Ordinarily, if serial efficiency between two systems is stated at, say, 15 per cent, it is natural but erroneous to assume that the energy loss in one system is 15 per cent more than that of another. For example, it is noted on the curve in Fig. 3 that the serial efficiency of the a.c. system is 67 per cent, while that of the

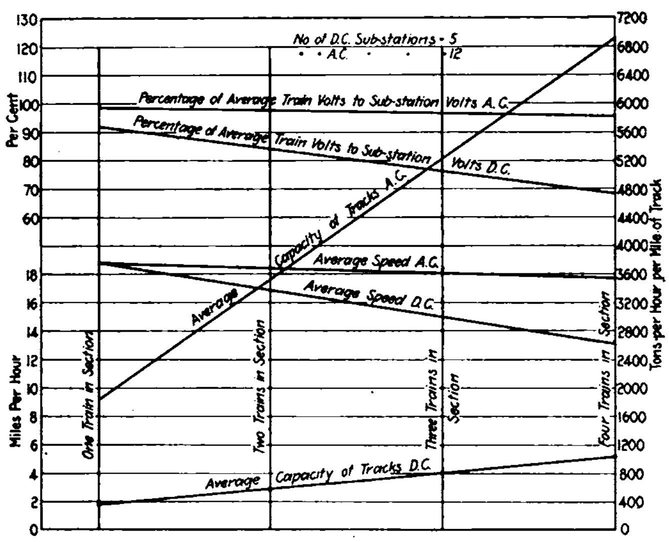

Fig. 2—A.-C.-D.-C. Comparison—Effect of Voltage Drop on Speed and Capacity of Trains

watt-hours required at each step for each system to produce the same train schedule, then on arriving at the power house we find that the generating requirement of the d.c. system is 55,000,000 kw-hr., whereas that of the a.c. system is only 45,000,000 kw-hr. From the ratio between these two amounts, it is seen that the power station which furnishes direct current to the locomotives will have to generate 22 per cent more energy than the power station

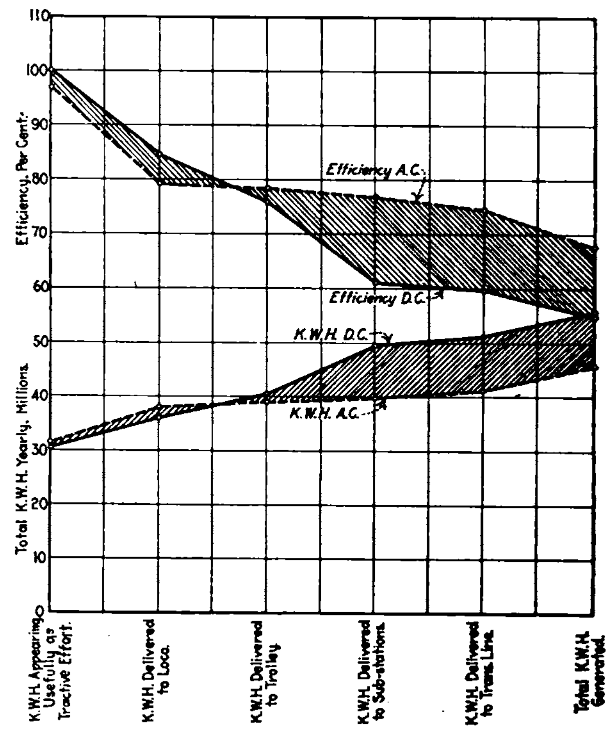

Fig. 3.—A.-C.-D.-C. Comparison—Efficiencies Between Power House and Locomotive

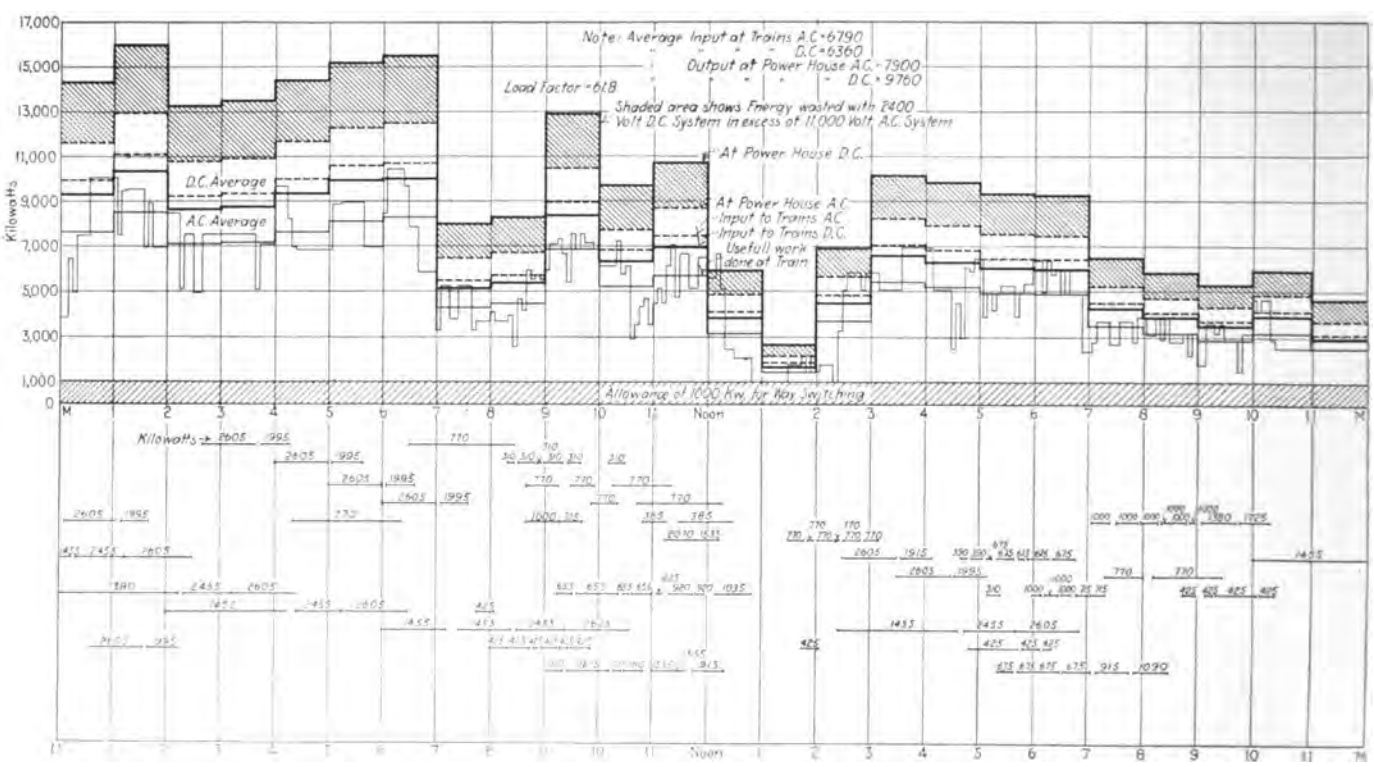

Fig. 4—A.-C..-D.-C. Comparison—Comparison of Train Energy Requirements for Given Schedule

d.c. system is 54 per cent. Apparently there is a difference of 13 per cent. But now observe that the a.c. system is really much more than 13 per cent superior, for if we refer to the area of the lower curve, which starts at the driving wheels of the locomotives, and integrate the kilo-

which furnishes a.c. energy to the locomotive. These figures are based upon the translation of 35,000 tons per diem between terminals 119 miles apart.

"The principles used in Fig. 3 may now be applied to another point of view, as recorded in Fig. 4. By referring to the lower part of this figure, the train schedule on the 119-mile section will be found indicated. With the weight and speed of trains known, the actual amount of wheel energy is developed and indicated. It is seen that the difference in weights of the a.c. and d.c. engines is credited in favor of the d.c. The demands for the two systems are so built up that the curve limiting the bottom of the shaded area represents the amount of energy which must be generated for a.c. train propulsion, while the curve limiting the top of the shaded area represents the amount of energy which must be generated for d.c. train propulsion. The area represented by the shaded section indicates the energy loss to which the railroad is subjected because of the use of d.c. train propulsion.

"While Fig. 1 indicates that the power station investment for the two systems is very nearly equated, it can be readily seen from Fig. 4 that a large amount of energy may be saved by using the a.c. system. For example, in the concrete case at hand there is a maximum machine difference of 3000 kw, which could well represent the size of one generating unit.

"To summarize, these curves show that the single-phase system of distribution of power provides a means whereby the railroad manager may feel the highest assurance that trains can be dispatched on time irrespective of track conditions, for it is shown that flights of trains may be dispatched from one up to four with insignificant effect upon the transmission system. On the other hand, the d.c. system of train propulsion, in the absence of proper spacing and resulting congestion, will have its capacity of tons delivered per hour per mile of track lowered to impracticable limits and thereby prove a severe handicap rather than an advantage to the railway operator. It follows, then, that for an equality of heavy traffic conditions the a.c. system of train propulsion can be installed for a lesser investment and with a very much higher economy of operation.

"It should be added here that the estimates made for the 119 route miles in question cover the use of three-phase generators supplying single-phase current and that the extra size of generators due to this practice was taken fully into account. Further, as to telegraph and telephone circuits, experience with single-phase lines has now indicated the method whereby they may be constructed to provide at no extra cost the automatic elimination of electromagnetic induction.

"I do not doubt that there may be isolated cases of short roads in localities with extremely favorable prices for sixty-cycle energy where the high-voltage d.c. system of train propulsion is applicable to heavy trains. Such an example is at present offered by the Butte, Anaconda & Pacific Railway. The development of large sixty-cycle central stations cannot possibly be an argument against the application of single-phase to railway electrification, for it is entirely feasible to change sixty cycles to a lower periodicity for railway application at a cost comparable to, if not less than, that required to transform it to direct current. It might be interesting to have Mr. Armstrong explain the insuperable difficulty in turning sixty-cycle into twenty-five-cycle energy when he eliminates with such ease the difficulties of its transformation into direct current. We admit that the rotary converter is more efficient than the motor-generator set, but we should be assured of Mr. Armstrong's conjoint admission that a.c. is more efficient than d.c. distribution. Strangely enough, however, he specifies motor-generator sets for the substations of 2400-volt d.c. systems, and these machines may well be fairly matched against the frequency changers with the advantage of higher efficiency for the latter."

Fig. 5—A.-C.-D.C. Comparison—View of Westchester Yard, New York, New Haven & Hartford Railroad, Showing Simple Overhead Single-Phase Construction

CONSTANTINOPLE ELECTRIC RAILWAY

On Aug. 4, 1913, the first electrified line of the Constantinople Street Railway was opened with an experimental service. This line, known as Tunnel-Chichli, is single track and gives a four-minute service with trains consisting of a motor car and two trailers. The company now has available forty single-truck motor cars for first-class passengers and seventy single-truck cars for second-class passengers; also twenty new trailers and thirty-one trail cars converted from horse service. The motor cars have cross seats for eighteen passengers and standing room for sixteen more. A movable partition isolates women passengers in accordance with Mohammedan custom. The electrical equipment per car includes two 40-hp commutating pole motors. The total weight of a motor car exclusive of the load is about 12 tons. On account of the grades, which are as high as 7.3 per cent, and the sharp curves all motor cars are equipped with track brakes and hand brakes, while trailers have hand and solenoid brakes. The complete system, comprising three routes with a total of 29 miles single track, will be supplied by a power station transmitting three-phase current at 9600 volts, fifty cycles, to three substations. One of these substations is equipped with two 400-kw rotaries and each of the others with three 400-kw rotaries. These were furnished by the French Thomson-Houston Company, the electrical equipment of the cars by the Siemens-Schuckert and Allgemeine companies and the overhead construction by the Allgemeine Company alone.