The expediency of electrification may therefore be summed up as desirable from two standpoints.

1. Increased track tonnage capacity provided by reason of heavier trains, higher speeds and reduction in the number of daily train movements.
2. The cost of electrification in many cases investigated is found to be considerably less than the cost of corresponding improvements with continued steam engine operation and there is, also, a return upon the additional capital charge incurred for electrification of from 15 to 20 per cent resulting from the savings in operating expense over steam operation.

Here then, is the economic force that is pushing the electric locomotive on public attention: Relief from track congestion can be found by electrifying for less money expenditure than in any other way, and in addition such economies in operation are secured as to pay a very attractive return upon the investment.

The construction engineers have accomplished the hardest part of their task. They have developed the electric locomotive to the point of a successful operating machine, possessing great reliability in service, very efficient in its conversion of electric into mechanical power and capable of hauling the heaviest trains at the highest speeds permitted by the profile and alignment of the track. The railroad operator has yet to be heard from, partly because no considerable stretch of track has been in operation until recently, but largely because it takes time to jar him loose from the traditions of a life time of service behind the steam engine.

PROGRESS OF HIGH VOLTAGE DIRECT CURRENT RAILWAYS

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The author shows the economic reasons that led to the adoption of higher potentials in railway work and points out that it is the inherent characteristics of higher potential direct-current apparatus that have led to its extensive adoption for interurban railways, and also, for the heaviest kinds of steam railroad electrification.—Editor.

Statistics, covering the progress in the art or industry measured by the extent of its use from year to year, are not only interesting and instructive, but if favorable, help inspire confidence in the stability of the industry and to secure the participation and co-operation of capital for continued progress.

A close study of the accompanying tabulated data of high voltage direct-current railways clearly indicates that the favorable showing is the outcome of general and successful use, and is not the result of local enthusiasm or individual prejudice. The installations are widely distributed and include all varieties of service. The results accomplished have stood the critical analysis of independent engineers and have exceeded the expectations of practical operators. In no case has the high voltage direct-current system been abandoned. On the contrary many roads have been converted from 600 volts d-c. or single-phase to high tension direct-current and in no case has the system failed to meet the economic success anticipated. Emphasis can especially be placed on the freedom from apparatus failures and low maintenance as contributing a large measure of the practical success.

The advent of the high voltage direct-current electric railway dates from 1907 when the first interurban line was equipped with 1200-volt apparatus.

Up to this time electric railways had experienced a phenomenal growth not alone in city service but also in suburban and interurban extensions.

The 600-volt system was universally accepted as the standard and the electric apparatus comprising it had been developed to a high state of perfection. Enthusiasm in electric railway construction was at high pitch and on every hand the city systems were being rapidly extended to the suburbs and in many cases elaborate interurban lines were built and being planned.

It soon became apparent, however, that promoters of these interurban projects had in many cases been too optimistic in their expectations of creating traffic and that new forms of competition, for which the automobile is chiefly responsible, were making such heavy inroads on the income that the financial outlook of the electric interurban was not a satisfactory one.

The generally increasing burdens due to new conditions and increasing demands of the public made the situation more and more acute. It became very apparent that to meet these new conditions it was imperative that some means should be evolved to lower the necessary investment and overhead charges if further extension of the electric interurban was to be made economically possible.

The new single-phase system was put forward as a solution and was immediately siezed upon rather extensively, but was not fulfilling its early promises because of a multitude of engineering difficulties and apparatus failures.

The 1200-volt system not only showed the necessary economic advantages but inherited the confidence derived from the long experience with its 600-volt prototype.

It embodied no new and untried theories and did not require the devoted nursing of over-enthusiastic patrons.

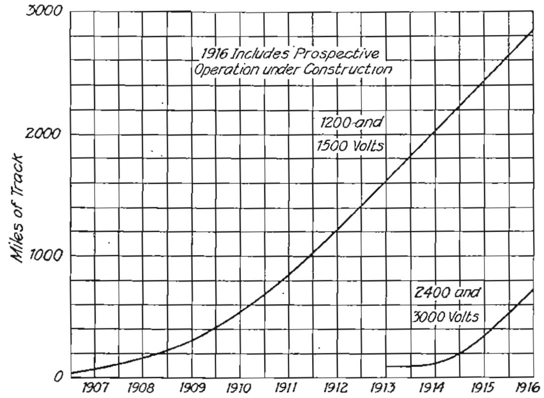
From the first it demonstrated its superior fitness and was generally adopted both for new roads and in place of other existing systems. As shown by the accompanying chart, the increase of mileage of the 1200- and 1500-volt roads (which may for present purposes be considered as of the same family) has been steady and continuous even through recent years of general business depression.

Today it is unusual to have any question raised as to the proper equipment for interurban lines. The 1200-volt system is standard just as the 600-volt system is standard for city lines.

The history and experience with the interurban problem naturally develops faith and enthusiasm for a similar application of direct-current principles to the still more important field of railway electrification. The experience of previous years had prepared railway engineers to better appreciate the economical relation between the unit demand for power and the supply voltage and had as well fitted them to produce apparatus suited to operate at higher potentials. It was realized that the large locomotives and heavy train units required for steam railway electrification both demanded and permitted higher operating potentials.

The first installation of 2400-volt equipment was on the Butte, Anaconda & Pacific Railway in 1912. The engineering features and designs involved some new elements and extensions of previous practice, but there was nothing fundamentally new and untried and the engineering problem was chiefly a matter of capacity.

This installation was made not so much to demonstrate the engineering accomplishment as the economic fitness and those most interested in the outcome were the railway officials who were formulating vast projects necessarily based on improved methods of propulsion over the most important lanes of the nation's traffic. The tremendous importance of a correct judgment



Growth in Miles of Track of High Potential Direct Current Railway

required the elimination of all exaggerated enthusiasm. The decision in favor of direct-current was the result of not only the highly successful demonstration but of the most searching inquiry and comparison with all other possible systems.

The practical results as well as the comparative possibilities were critically analyzed by the officials and engineers who had the heavy responsibility for transcontinental railroad operation and the decision must be accepted as beyond the possibility of prejudice or partisan enthusiasm.

The immediate practical success of the 2400- and 3000-volt apparatus resulted partly from the inherent ruggedness and flexibility of direct-current designs as well as from the absence of radically new features of construction.

The locomotives, although larger and more powerful than any yet constructed, adhered to the simple, rugged and thoroughly tried mechanical arrangement of motor drive and truck structure. Much study and many trials have been made in all parts of the world to find a driving connection between the motors and the driving axles that is superior to direct gearing. Preconceived limitations as to the unsuitability of simple gearing for heavy torque and a rather theoretical impression that an electric locomotive should follow steam locomotive practice led to trial construction using diagonal side rods, jackshafts and parallel rods of various forms. It may be that some such arrangements are necessary or desirable in certain situations but it is also very clear that direct gearing is amply able to accomplish all that can be needed for locomotives of great capacity, equal to handling the heaviest transcontinental trains. The use of twin gears, making the full strength of the gear teeth available; spring drive in the gears cushioning the hammer blow on the teeth and equalizing the stress between the gears; and advances in the quality of the gear steel, are the chief improvements over former practice that completely determined the suitability of the direct gear arrangement to this heavy duty.

Practical service amply emphasizes the excellence of direct gearing and demonstrates its superiority to other forms of drive.

Another feature that serves to mark the adaptability of direct-current is the regenerative braking which has been put into successful use on the Chicago, Milwaukee & St. Paul locomotives.

This is a feature that previously had been considered particularly suited to polyphase alternating-current motors exclusively. The control arrangement for regenerative braking, as well as the results accomplished on the Chicago, Milwaukee & St. Paul locomotives, are fully covered elsewhere in this issue and will be recognized in keeping with the simplicity and effectiveness of the direct-current system.

Particular attention is directed to the flexibility of this system of braking. The ability to utilize the electric brake over a wide range of speed and its ease of control make it far more useful than polyphase system of braking which is limited to a single speed.

The overhead contact system for the 3000-volt direct-current system retains the good features of the flexible construction previously used and adds to it increased current capacity. Its appearance, effectiveness and practical operation leave no room for criticism.

The substation apparatus corresponds closely with established practice and is perfectly adapted to the reverse transmittal of energy incident to the regenerative braking of the trains.

It is particularly instructive to note that in spite of may previous theoretical adverse comparisons with other systems the direct-current system, as actually installed and in successful service, compares most favorably with concurrent installations as to the spacing of substations, the kilowatts of substations per mile of track and the total cost of substations.

The Chicago, Milwaukee & St. Paul electrification has hardly been in operation long enough to give accurate statistics as to the economic results but the operating officials of the Railway are most optimistic and favorable expectations are justified.

As to the probability of developing still higher voltage systems it can only be repeated that 3000 volts seems to be adequate for the heaviest trunk line traffic and is likely to represent the true economic balance between cost of substations and feeder copper on the one hand and cost of locomotives on the other, and as well to present the greatest flexibility and the lowest operating charges. But 5000 or 6000 volts direct-current is a possibility if there arises a real field of usefulness for this further extension of the direct-current family.