On the basis of this theory we can account for the comparatively high conductivity of gels that contain but a trace of conducting material. We can also account for the marked difference in resistance of say two samples of commercial copper, whose chemical composition is identical, depending upon whether the impurity, such as sulfur, is uniformly dissolved in the metal or whether it forms a film ("cement") of copper sulfide around pure granules of copper. The latter case is to be regarded, as Bancroft suggested, as an emulsification of copper in copper sulfide. The high resistance of these surface films composed of say sulfide or oxide or arsenide accounts for the high resistivity values of copper containing but a trace of one or more of these impurities.

CONSERVATION OF RAILWAY RESOURCES*

By A. H. Armstrong

Railway and Traction Engineering Department, General Electric Company

The recent freight congestions have demonstrated the fact that the capacity of the steam railroads present equipment is insufficient to meet the service demands which are put upon it from time to time. The author of this article considers the means of increasing the capacity of the railroads—the installation of additional steam equipment, etc., *vs.* electrification. Continuing, he shows that electrification is the method dictated by economic reasons. Taking as an example the C., M. & St. P. electrification he discusses the features of high-voltage direct-current operation and then, generalizing, explains why this system is in excellent agreement with the ideas of future economic expansion of our big transmission systems and networks.—Editor.

The records of the past winter have strongly emphasized the limitations of our steam railroads and their lack of adequate motive power and rolling stock to take care of abnormal traffic conditions. Part of the failure of our transportation facilities is undoubtedly due to the restriction placed by the Interstate Commerce Commission on the one hand and to the growing demands of organized labor on the other. The result has seriously impaired the earning capacity of railroads and has rendered this form of security less attractive to the investor. Faced with the increasing difficulty of obtaining new capital to meet the demands of a growing traffic, steam road executives have been forced to adopt the hand-to-mouth policy of providing only the motive power, rolling stock, and track facilities absolutely required to meet the daily needs of normal traffic conditions. Any serious disturbance of the normal seasonal traffic movement, such as the congestion on Eastern Lines due to stoppage of foreign shipments by the submarine menace, results in such poor service that it almost reaches demoralization as evidenced by the records of the past few months.

Admitting the necessity for improved railroad conditions and also looking forward to a more favorable attitude by the government, which will attract to this form of investment the enormous new capital that must be expended during the next few years, there remains the all-important question as to how the needed additional facilities can be secured for the least increase in capital charge.

Perhaps the best way of approaching the matter is to gain a full appreciation of the fact that railroading as now undertaken is steam engine railroading, and present practice is built around the capabilities and limitations of the steam engine. Conserving our resources and making our country a self-supporting nation is the work of the immediate future; and not the least of such resources is the vast amount of new capital that has been brought to our shores during the past two years, a considerable portion of which it is hoped will be employed in rehabilitating our railroads. If this money is spent in the purchase of more steam engines, cars, and additional tracks, the railroads of the future will still be operated as steam engine railroads and the increased capacity of our lines may have been purchased at an almost prohibitive cost.

During the past decade of constantly increasing commodity prices there has been one conspicuous exception and that is the cost of electricity. Improvements in the efficiency of turbines, the establishment of large power houses with highly developed means of efficiently burning coal, and the economical development of water power in advantageous locations have all contributed to more than offset the increasing cost of manufactured products due to the rise in material and labor. The result is that today electricity is cheaper, is more reliable, and can be obtained over much wider areas than ever before.

* Abstract of Lecture by A. H. Armstrong, delivered at Massachusetts Institute Technology, Feb. 28, 1917.

The operation of the heaviest freight and passenger trains by electric locomotives has been demonstrated as entirely feasible. The record of reliability, the low cost of maintenance of the electric locomotives, and the flexibility of this new type of motive power to meet the varied conditions of haulage service leave no room to doubt that electricity is destined to play a most important part in the future development of our railroads. Not only can present steam service be easily duplicated as regards the weight and speed of trains hauled, but it has been demonstrated that the electric locomotive is free from many of the restrictions placed upon train operation by the steam engine, and that it makes possible train weights, speeds, economies and improvements in operation thus far unattainable by the steam engine operator.

The last link in the 440-mile electrification of the Chicago, Milwaukee & St. Paul Railway between Alberton and Avery over the Bitter Root Mountains has just been completed and placed in regular operation. To those having knowledge of the facts regarding the operation of the electric locomotives on this road, it is plainly evident that the quality of service rendered is far superior to that previously attained or possible with steam engines. The winter of 1915 and 1916 will go down in history as probably the most severe ever experienced in Montana. For over three weeks the thermometer registered between 30 and 40 degrees below zero, playing havoc with steam engine operation on the adjoining divisions but affecting the operation of the electric locomotives not at all. It was a most flattering testimonial to the skill and care with which transmission lines and trolley construction were installed that there were no failures during such extremes in temperature, especially when it is noted that the utmost simplicity and economy had been exercised in building these lines. In fact, the entire installation is characterized by its simplicity and complete absence of forms of construction which had not been previously thoroughly developed and demonstrated. The motors and the locomotives, the substations and the trolley construction were all amplified in magnitude from similar types in successful commercial operation and the result has been that the change from steam to electricity was made with no interruption in service and under climatic conditions that were extremely abnormal.

It was found that the regular steam engine crews could be instructed in three or four weeks so that they were fully capable of taking out a train alone with electric locomotives and of rendering efficient service. A working knowledge of the electrical apparatus was readily acquired and the strongest booster for electrification is the converted steam engineer who fully appreciates his better surroundings, the greater ease and safety in handling his train, and the greater reliability which the electric locomotive offers in maintaining his schedule. His knowledge of air brake operation is, of course, a valuable asset, the same type of equipment being used on both steam and electric locomotives. In the latter case, however, the air brake is relegated to be in reserve as all braking on down grades is effected by the electric locomotive which returns, in the case of the Chicago, Milwaukee & St. Paul, approximately 10 per cent of its power back to the trolley as the result of holding back the trains on down grades. Aside from the matter of economy of power thus effected, the real advantage of electric braking lies in the possibility of successfully handling more cars down grade, at higher speeds, and with much greater safety than has been possible with steam engines braking with air. The full force of this statement is not realized until one has ridden down the 21 miles of 2 per cent grade between Donald and Piedmont on an electric locomotive holding back a 3000-ton freight train, when the smoothness of operation, complete control of the train, and general feeling of security brings home a full appreciation of the valuable asset of regenerative electric braking.

In this country, with its ample supply of power available from coal or water, the fact of the decreasing cost of electricity is becoming fully appreciated as exemplified by the constant development of huge transmission systems fed from a number of available power sites. A frequency of 60 cycles is becoming more and more universal, and in a few years it bids fair to become the standard frequency for generating and transmitting power with the possible exception of a few restricted localities where 25 cycles is strongly intrenched. In many instances considerable advantage to the railroad company may result from the purchase of power from an outside company, rather than to assume the burden of first cost and the operation of a separate powerhouse devoted solely to supplying the railroad load. The economical generation and distribution of electricity is a highly specialized business in itself and when conducted on a large scale and supplying a diversified load makes possible great reliability and low price for power. Whether power is purchased outside or produced in a railroad power-house, it is entirely proper, however, to view the possible electrification of our steam roads from the standpoint of power generation and distribution at high-voltage three-phase 60 cycles, and a type of locomotive should be adopted that will best meet the severe requirements of diversified haulage and also permit of economical distribution and conversion of power derived from a 60-cycle source.

The direct-current series motors driving the axles of the St. Paul locomotives are admirably fitted to the requirements of the variable speed of trains so necessary in crossing the broken profile of mountain divisions, and at the same time permit of economical conversion through synchronous motor-generator sets operating at efficiencies as high as 92 per cent at full load and providing for practically unity power-factor at all loads. The combination of high-voltage direct-current motors and synchronous motor-generator sets fits in so admirably with both the service requirements of the railroads and the apparently accepted standard of 60-cycle power distribution as to justify the strongest claims for its recognition as the proper system for general steam road electrification. The flexible characteristic of the series motor best meets the variable speed requirements so necessary in the operation of trains over a broken profile and power for these motors can be obtained through synchronous motor-generator sets from a general distribution net-work without interfering with the commercial, industrial, and lighting load that may be carried over the same transmission circuits.

In even this land of apparently unlimited supply of coal the tremendous waste of fuel inherent in steam engine operation cannot much longer go unchallenged. It is food for serious thought to know that one-third of the coal now consumed on a steam engine will move the same tonnage by electric locomotives if burned in a large modern power-house suitably located with regard to condensing facilities. Local conditions may also be such as to permit of the advantageous combination of ample condensing water available at the mines, thus eliminating any charge for coal haulage and permitting the use of a low and cheap grade of fuel having only a local short-haul market. Aside from the low power rate which is made possible by such favorable local conditions, there is the universal benefit to the railroad of relief from the necessity of hauling its own coal which on mountain grade divisions may readily reach 8 or 10 per cent of the total ton miles hauled behind the engine as represented in coal and carriers.

We are so much accustomed to consider the tender as a necessary part of the steam engine that it is not until the coming of a type of motive power like the electric locomotive that it is realized just how great a part of the operating expense is incurred in hauling this non-revenue company tonnage. Just by the introduction of the electric locomotive a 10 per cent reduction in total gross ton miles hauled is effected on heavy grade divisions, or what is more to the point, an increase of 10 per cent in revenue ton-miles with no increase in the previous cost of operation.

In addition, the electric locomotive provides much needed track relief on mountain grade divisions due to its higher speed, both up and down grade, greater number of cars that can be hauled with safety, and the elimination of stops now necessary with steam engines to take on water, test air brakes, and the delays of a general nature incident to the necessities of steam motive power.

It is a conservative statement to make that the substitution of the electric locomotive for the steam engine will result in doubling the daily tonnage capacity of a mountain grade division with no addition to the previous track facilities and will, in addition, release a large amount of rolling stock by reason of the considerable reduction in running time effected. Under favorable local conditions, therefore, electrification may provide the needed improvements on certain railroad divisions with a lesser expenditure of new capital than would be required to purchase the same results by adding more steam engines and tracks. And finally, electrification effects economies over steam operation which offer an attractive direct return upon the investment and which is additional to the benefits resulting from future increased tonnage movement.

America is indeed fortunate in being provided liberally with vast resources. Imagine the predicament of having no coal deposits within our borders and being dependent upon outside sources for such a vital necessity. But that is just the case with Italy, and the World War has most convincingly brought home to her the absolute necessity of making proper provision for power under her own control. Fortunately, there is an abundance of water power available and it is quite probable that after the war Italy will attempt to make itself independent of foreign fuel supply, as far as possible, by developing to the fullest extent its own natural advantages of hydraulic power.

Such railroad electrification as has already taken place in Italy has been along the lines of three-phase induction-motor locomotives fed from a double overhead trolley. The development of the Alexanderson split-phase method of converting single-phase into multiphase power permits the elimination of one of the present objectionable double overhead wires should it be found expedient to retain the induction motor type of locomotive. In view, however, of the unquestioned success resulting in the almost universal adoption in America of the high-voltage direct-current series motor, the interesting question is raised whether the development of the Italian State Railways should continue along its early pioneer lines or if this is not a most opportune time to take advantage of the progress of the art and adopt the high-voltage direct-current motor as best fitting into the general requirements of universal electrification.

The present extent of electrified tracks in Italy is small in comparison with the large work to be undertaken in the near future and should not be allowed to become the determining factor influencing a decision as to the system best suited to the needs of all classes of railway service. The many power developments interconnected by a network of transmission lines will undoubtedly be utilized as well for lighting and industrial purposes, hence the necessary requirement that the fluctuating railway load fed from the same circuits shall not be a disturbing factor. The use of synchronous motor-generator sets supplying railway load has been so successful in minimizing any effect upon distribution lines carrying a mixed load that their adoption appears to be most desirable. In fact, by proper design and adjustment of field values, synchronous motors may actually be made to act as voltage stabalizers regardless of the fact that their local load demand may be very fluctuating.

The matter of cheap reliable power is vital to the success of railway electrication from both an economic and operating standpoint. The general adoption of 60-cycle distribution in this country makes it possible to interconnect adjoining transmission systems, thus opening up wide possibilities in providing cheap power for railway purposes already extending, in some instances, over several divisions. As such large consolidated transmission networks are usually fed from a number of power-houses, there is also offered a promise of reliable service hardly possible to equal with a railway power-plant except by the expenditure of a prohibitive capital investment. Electric power development and railway electrification, therefore, appear to be most closely related and full appreciation of this fact may do much to lead to a better understanding of the economic and operating advantages of the high-voltage direct-current motor for all classes of traction service.