Alternating and Direct-Current Transmission on City Lines

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When requested by the executive committee to prepare a paper on "Alternating and Direct-Current Transmission on City Lines," I frankly stated that as I was not an electrical engineer and had had no experience with alternating current I did not feel competent to present the subject before the association. They in reply requested that I present the subject at least in such a manner as to bring forth a profitable discussion by the members of the association. This I have attempted to do.

The problem of transmitting power to outlying districts on city lines is one constantly confronting a large number of managers to-day. The steady growth of outlying districts and the increased suburban traffic incidental thereto, requiring larger and heavier cars and increased speed, have severely taxed the direct-current distribution. The manager finds his transportation department unable to provide sufficient cars to handle the increased traffic and maintain schedule speed; the cost of transportation large, due to necessary slow speed of cars; loss in transmission enormous, and must admit his present feeder system entirely inadequate to meet rapidly-growing demands made upon it. In attempting to meet these demands the usual course has been:

First—To add copper to the feeder system, which has already reached enormous proportions.

Second—To raise voltage on certain feeders by means of booster.

Third—Install storage batteries at ends of lines.

Fourth—In extreme cases to build an additional power station, located with reference to economy of copper.

Fifth—Install an alternating-current system in main power station and rotary sub-stations at convenient points.

The first four plans above mentioned lack flexibility, and extensions of any magnitude are attended, necessarily, with large outlay of copper, burdening the system with heavy fixed charges and large power house expense.

It is not within the province of this paper to take up the various methods for meeting these increased demands, but to try and set forth the main features of polyphase alternating transmission with rotary converter sub-stations working in connection with existing direct-current feeder system.

It is with exceeding interest that the railway manager has observed the development of polyphase alternating-current apparatus and the several and reliable methods of installing and handling high-voltage circuits of large power. It is now possible by means of rotary converters or motor generator sets to have as many feeding points or sub-stations, changing high-tension alternating current to 600-volt direct current, as may be found expedient, and this at a comparative small outlay and at a minimum charge for power house expense. Of course, the number and location of these sub-stations is determined by striking a balance between the cost of operation of the sub-stations, including interest, depreciation, attendance and fixed charges, and the interest, depreciation and fixed charges on the copper investment. In many cases the item of station attendance, otherwise the most serious of all, may be eliminated almost entirely by making the sub-stations a part of the car house, repair shop or ticket office, or even general office.

For long distances alternating transmission is now almost universally adopted where an entirely new plant is installed. The many weak points, which are always present in any new system, have been well worked out and remedied, and it would seem that the time has now come for companies using the direct-current apparatus to at least make future additions to plant with alternating-current machinery, and thereby avail themselves of economies offered by modern invention, still using their direct-current system within an economical range and the alternating current for the outlying districts, thus working the two systems in harmony with each other.

The alternating-current system, owing to its great flexibility, can very well be operated in connection with direct-current system, and lends itself particularly well to the solution of the problem of transmitting current to outlying districts. The generators can be wound for high potential, so that the cost of copper is comparatively small and a high efficiency maintained.

Alternating-current machinery consists of generator, step-up and step-down transformers and rotary converters, as now installed, seems simple in operation, and should require but very little more attention than existing direct-current machinery. The generator at the main power station should require even less attention than a direct-current unit of the same size—the step-up and step-down transformers requiring practically no attention. The rotary converters can be located at convenient points along the line; if in car house, or other points where an attendant is necessarily on duty at all times, little or no expense would be required. Starting up in the morning, shutting down at night, keeping the bearings lubricated and the occasional putting in of a circuit breaker being about all that would be required.

In installing an alternating-current system in connection with existing direct-current system it would seem wise to use a number of small rotary converters, located at load centers over the line. These machines can be so designated as to work in parallel with existing direct-current feeders—the rotaries caring for the average load, the direct-current feeders coming in to help care for sudden fluctuations, and in case of injury to any one unit the direct-current system would tide you over the difficulty. The load factor at the station should not materially change from that now existing with direct current, owing to the fact that even if there are violent fluctuations in the amount of power required from any one rotary, it is not likely that the maximum demand for power will occur simultaneously on the other rotaries, and if the machine is properly wound and connected in with existing direct-current system, direct-current feeders should go far toward equalizing the load between rotaries.

A temporary sub-station mounted on a flat car, which can be easily moved from point to point, will be found very convenient for the relieving of extreme and unusual loads which frequently occur in most cities during certain seasons of the year. Railways are required to move enormous crowds in a very short time, and that frequently at considerable distance from the power station. On account of the heavy and infrequent character of these loads and long length of feeder usually encountered, the copper necessary for the handling of this service by simple direct-current feed is prohibitive, and the series booster is frequently resorted to. Even with this device the first cost of installation is considerable, and owing to the resistance of ground return, a practical limit to the amount of power and distance to be covered is soon reached. A temporary sub-station divides the current returning in the track, reduces the drop to one-fourth of that obtained with a straight feeder, and permits much more satisfactory service to be given with less than one-fourth the amount of direct-current feeder copper otherwise required. Where the transmission voltage does not exceed 6600 volts it is possible to avoid step-down transformers, and thus decrease the weight of apparatus on the car by using an induction motor generator set, having this induction motor wound direct for high voltage. Besides reduction in weight, this arrangement possesses a further advantage over the rotary converter in that the direct-current voltage can be regulated by hand over a much wider range, allowing easy and accurate regulation of the load, which is frequently of great importance in putting the set into service where the line drop is very heavy. In determining the details of a system of this kind, the local conditions existing must be carefully considered; the districts through which transmission lines pass should largely govern the voltage; the center of load and convenience of attendance, the location of rotaries.

From such information as the writer has been able to obtain, the three-phase system seems to be the best adapted for railway work, because of its simplicity and economy in copper, as in each wire of the three-phase system two alternating currents, differing in phase, are combined, and the loss less than when the same power is transmitted by continuous single-phase or two-phase currents. The three-phase circuit requires but three wires, while four are necessary for a two-phase circuit—the same size wire being used in both circuits.

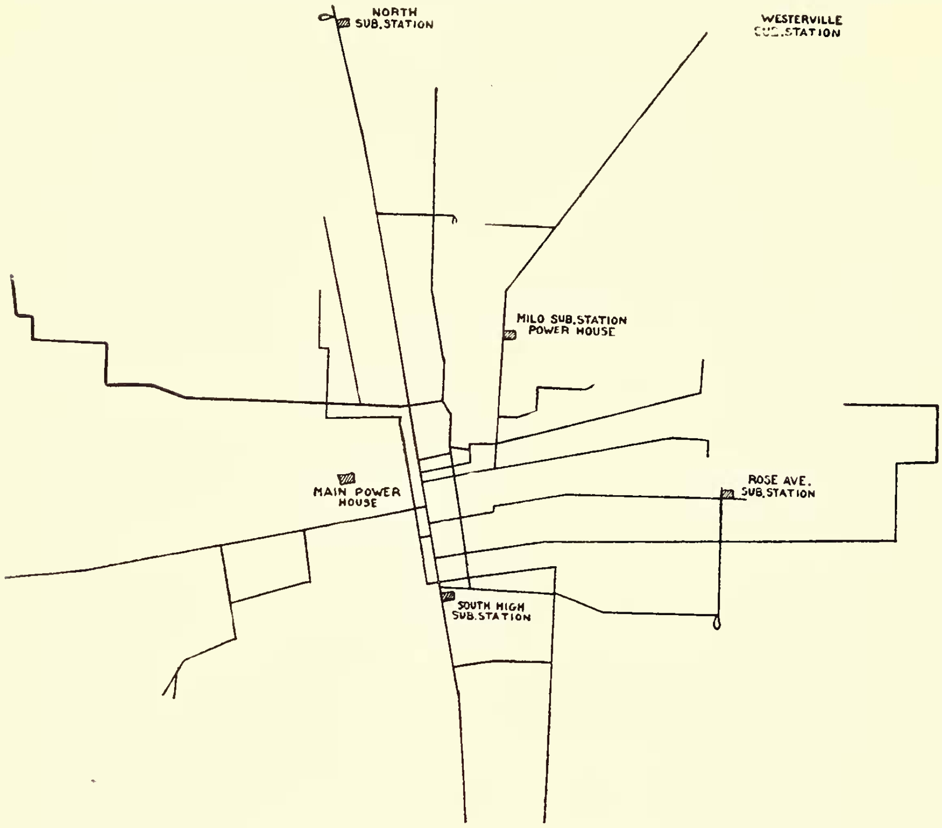
The 25-cycle apparatus has the advantage for railway work, the high inductive effects, troubles encountered in operating machines in parallel, and difficulty in obtaining slow speeds have caused the higher frequencies to be abandoned for this work.

Having thus attempted to outline the general characteristics of the three-phase alternating-current system employing rotary converters, it may prove of interest to show the intended application of these principles to the operation of railway lines in the city of Columbus, and the various economic considerations affecting the choice of system, number and location of sub-stations.

The Columbus Railway Company, with which the writer has been connected a number of years, now owns and operates two steam power plants, known as the Milo and Spring Street power stations. As you will note from the accompanying map, the Spring Street station is located near the center of the city, on the Scioto River, where all necessary water for condensing purposes can be obtained, and has the best railroad facilities for the handling of coal. The Milo station is located somewhat to the northeast of the center of the city, and where no water can be obtained save that which is pumped from artesian wells of limited capacity. The cost of producing current at this station is much higher than at Spring Street. The Milo station is used largely as reserve, and put into service only when demanded by heavy traffic to Minerva Park, Westerville or Fair Grounds.

The two stations are electrically connected by a heavy feeder system, so that under normal conditions during winter months the load of the whole system may be handled from Spring Street station, using, however, a series booster located 9 miles out on the Westerville line at Minerva Park to maintain voltage on the Westerville end.

There is at all times a steady load of considerable magnitude on the lines running out to the eastern suburbs, and during the summer months on the lines running north to Olentangy Park, a pleasure resort which is owned by the company, and which frequently attracts large crowds. These loads have continued to increase for several years past without making additions to feeder lines. Frequently during extreme traffic it has been found necessary to use the three M. P. 75-kw machines in parallel as a booster in order to handle traffic. This overloading of feeders has occasioned heavy loss in transmission. In order to determine just exactly what this average loss is, two wattmeters were calibrated together; one was then installed in the feeder line at the power station, the other where the feeder taps into the trolley—the difference in watts showing exactly the loss resulting in transmission, both in overhead copper and ground return. These meters have been installed for two weeks at a time under average conditions in outlying feeders which would be affected by the installation of an alternating system. The results show the loss to be equivalent to the following per cent of total load for an average 18-hour day:



LOCATION OF COLUMBUS STATIONS

East Long Street section	23	per cent.
East Oak Street section	31.2	" "
East Main Street section	27.4	" "
South High Street section	27.8	" "
North High Street section (park not open)	25	" "

Owing to the heavy peaks of loads from station to station, we were unable to get accurate results showing loss, but from results obtained estimate the average loss at 20 per cent. The loss on Westerville line varies from 40 per cent during the winter months to 60 to 75 per cent during the summer months. During the periods of heavy load, and when the maintaining of voltage is highly essential, the loss is far in excess of the above figures on all sections.

The capacity of both power stations is now frequently taxed to its utmost, and additional unit must soon be installed at Spring Street station; the entire feeder system of the road is now inadequate to meet the present demands, and must be increased at once. It is therefore proposed to install a 350-kw, 6600-volt, 25-cycle, three-phase, revolving-field generator, direct connected to engine, at the Spring Street power station, together with necessary exciter, generator panel and 6600-volt line panels for controlling the three outgoing feeder lines; to install a rotary converter sub-station at Oak and Rose Avenue car house to handle the loads on all eastern lines; one at Milo power station to handle normal station load, using the steam plant now at this station for reserve; and rotary sub-station at Minerva Park to handle park business during summer months, and through Westerville business during winter months. As the reserve capacity at Spring Street station will be small even after this unit is installed, it is highly important that the system be so arranged as to permit the distributing of load between all units in power station as may be desired. In order to make the maximum capacity of alternating-current unit available under all conditions it may be necessary to install a rotary converter station at South High Street car house, which is located near the center of load and easily connected with direct-current feeders, making it possible to relieve the overload on direct-current units and increase the load on the alternating unit.

In addition to the above permanent stations, it is proposed to use a portable sub-station, to be located normally at North High Street car house, to handle Olentangy Park travel during summer months, and when occasion demands this station can be quickly moved to help out other sub-stations. You will note that all sub-stations are to be located at car houses, and car house employees are expected to attend them in connection with their regular work.

The best engineering practice has limited the potential of transmission lines carried overhead through city streets to 6600 volts. There are a considerable number of lighting and railway companies in this country following this practice with perfect satisfaction, and with modern method of construction such a transmission line would be no more harmful or dangerous than the usual city arc-light circuit. It would, therefore, seem advisable to use this voltage on transmission lines—consisting of three No. 4 B. & S. feeders from Spring Street power station to Milo, a distance of 2 miles; to Rose Avenue sub-station, a distance of 3¼ miles; to North High Street sub-station, a distance of 4 miles, and to Westerville sub-station, a distance of 9½ miles.

With these sub-stations installed, the following amounts of feeder wire would be replaced by sub-stations, and available for use in reinforcing direct-current feeders not reached by sub-station feed:

Milo sub-station	43,890 pounds.
Rose Avenue sub-station	35,530 "
Westerville sub-station	73,620 "
Total	153,040 pounds.

At 18 cents per pound, this copper would represent a value of $27,547.20, from which deduct the value of high potential copper in place, $10,000, would leave $17,547.20 to be credited to the cost of the sub-stations and charged to increase in direct-current feeder system, which will be ample for present needs.

In the above estimate we have retained the present feeder copper on North High Street circuit, for the reason that sub-stations will be used for intermittent service only.

In considering the economies in alternating transmission, station installation need not be considered in this case, as the cost of alternating-current machinery will not materially differ from direct current. The cost of rotary sub-stations is estimated as follows:

Milo Station	$10,000.00
Minerva, or Westerville, Station	7,500.00
North High Street, or portable station	12,000.00
Rose Avenue sub-station	10,000.00
South High Street sub-station (if installed)	7,500.00
Total cost of sub-station apparatus	$47,000.00

To this should be credited $17,547.20, the difference between the cost of copper to be supplanted and high potential copper required, as this copper will be taken down and used for reinforcing sections which are still to be supplied by direct current, the investment being more than taken care of by economies resulting from increased capacity of direct-current lines. This leaves us an investment of $29,453.00, the interest on which should be taken care of by the saving in loss due to transmission.

Assuming the value of a kilowatt-hour of current at $.006, exclusive of fixed charges, the loss shown by wattmeter reading on sections to be fed by sub-stations, would amount to $5,365.00 yearly.

The plan as outlined above for transmitting current to these districts should keep the loss well within 15 per cent between main station and sub-station bus-bars, even during periods of heavy load, which would result in a saving of $3,804.00 in yearly transmission of average load from station to sub-station bus-bar. From this should be deducted the loss from sub-station bus to car. In this case, owing to the location of sub-stations and interconnecting of direct-current feeders, the loss will not exceed the loss now existing from point where direct-current feeders now tap and where wattmeter readings were taken to car; hence, we have $3,804.00, the net saving in cost of power due to high-tension transmission, being equivalent to 12.8 per cent on investment, which, from a financial standpoint alone, would seem to warrant the above-outlined plan of transmission, without considering the greatly increased facilities for handling of large crowds, the saving resulting in transportation department due to increased speed, and the ability to make future extensions of almost any magnitude without the attending losses and a large outlay for copper necessary with direct current.

The American Street Railway Association—The Purpose of Its Organization, and the Benefits Accruing to Investors in, and Operators of, Street Railway Properties by Membership Therein

BY G. W. BAUMHOFF, ST. LOUIS

The subject is, it is needless to say, a fruitful one, justifying a paper in keeping with the title, but appreciating brevity where facts only are desired, I shall endeavor to enumerate some of the many advantages of membership in this association to owners and operators of street railway properties.

A learned doctor once said, "Ignorance, pestilence and avarice make the human race akin." Substituting the word "ambition" for the last named, I am constrained to believe the same agency is responsible for the organization of this association; for if one person's knowledge of street railway affairs were as thorough as that of some others, the necessity would not exist for attendance at conventions to lay in a store of information to better fit oneself for such duties. Who will deny that disease among horses and the best means of guarding against the spreading of such pestilence and the care of horses was at one time the chief topic for discussion at our meetings? And is not "ambition" one of the chief incentives which prompts man to excel his neighbor and competitor in proficiency? Is it not a motive for seeking membership in an association which has witnessed the evolution of electric traction with its vast improvements, from the old-time animal traction; has seen it outdistance the cable, and is now looking forward with eager eyes to still greater achievements with this mysterious power, and to yet another change whereby to improve and perfect the system of street railway service? The founders of this association built not only wisely but with beneficial results to the street railway systems of this country far beyond their realization.

To the foresight and indefatigable energy of H. H. Littell, D. F. Longstreet and Thomas Lowry, from whose "Littell" beginning the association has passed through the "Long-street" of progress without "Lowr-ying" its usefulness, belongs the credit of the present efficiency and high state of perfection of the street railway systems of this country, which efficiency the entire world has adopted as its standard.

The growth of the association has been marvelous, the good it has accomplished inestimable. It doubtless represents, through its membership, a greater combined capital than any organization or association in the world, and through its channels has disseminated information resulting in the establishment throughout civilized communities of electric railway systems where no other service could be maintained, and in supplanting animal traction with its resultant saving in time. It has been the means of saving millions of dollars to many investors in street railway properties by information procured from papers and discussions at our annual meetings, particularly at a time when much doubt was involved as to the best system to adopt in changing from animal to mechanical traction.

It has been the means of bringing the executive and managing departments of street railway properties in closer communion with their employees, and is largely responsible for the improved condition of street railway employees generally to-day as compared with the period prior to its organization. Its aim has been, and is, to encourage, elevate and ameliorate the condition of that gallant and noble army of public servants, the street railway employees, than whom none are more loyal or devoted to their work.

Through the proceedings of its annual meetings it has laid the cornerstone of successful operations of the street railway systems of the world, and its gatherings are looked forward to with eagerness and assurances of greater additional knowledge concerning street railway improvements which are springing up like magic everywhere. It recognizes no creed, sect or nationality. The universal law of God is its guidance, and the greatest good to its members and the community they serve its ambition. Investors have long since realized the many advantages resulting from this association, and every company throughout this country should profit, not only by membership therein, but insist on being represented at its meetings.

The Street Railway Accountants' Association is an offspring from this organization, and arranges its annual meetings to harmonize with the time and place of those of the parent body. The formulation and standardizing of accounts now generally observed must prove of additional value to the investor and manager alike.

The appointment by this association of a committee on standardizing street railway supplies and material is another step in the right direction, which will doubtless prove of inestimable value to the investor and manager, and will, in the opinion of the writer, result in the formation of another branch of this association, bringing the mechanical department of the various railway systems in closer touch with the managing and accounting departments.

In conclusion, there is another auxiliary originating from this association, the importance of which must not be overlooked, the street railway press, through whose untiring efforts we are constantly advised of improved methods, forms a means for an interchange of ideas, and its work, when more generally appreciated, will, it is to be hoped, be substantially rewarded.

Capital Accounts From the Viewpoint of Investors and the Public

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Some recent catastrophes in railroad finances deserve particular discussion in a convention of railroad officers and accountants.

The Third Avenue Railroad Company, of New York, in February, 1900, passed into the hands of a receiver, its stock having declined from $242 per share to $45 within a year preceding, and annual dividends averaging 8 per cent having been paid in the five preceding fiscal years. So violent a decline in the market value of what had been regarded as a conservative investment stock shook public confidence, depressed prices of other securities, and produced conditions of financial panic. To those who had studied intelligently the annual reports of this company these results were not surprising; the wonder was that in the face of such reports investment buying could have raised the stock to so high a figure—for Third Avenue stock had not been a speculative one and, therefore, had not been the subject of market manipulation. A comparison of the reports of the company to the State Board of Railroad Commissioners for the five years preceding the receivership reveals clearly the cause of the company's downfall and makes almost incredible the apparent confidence which its friends had in the worth of its stock. In 1895 the change of motive power from horse to cable had been completed, the company had no floating debt except for current accounts, the outstanding capitalization (including both bonds and stock) was $13,600,000, the cost of road and equipment, including permanent investments, was $13,499,629, and the net income applicable to interest on capitalization was $1,129,994, or 8.3 per cent. On June 30, 1899, the capitalization outstanding had risen to $17,000,000, a floating debt had been incurred of $13,385,122, the cost of road and equipment and permanent investments (stocks of other companies) had risen to $30,424,990, and the net income applicable to interest on capitalization was actually less than in 1895, being $1,116,469, or 3.6 per cent. Yet during those four years all the net income above the interest on $5,000,000 of bonds was diverted to dividends on the capital stock and not a dollar was appropriated to interest on the remaining capitalization represented by $13,385,000 of floating debt. Presumably the interest on loans was charged to investment account, so as to leave net income enough to insure the continuance of dividends on capital stock. In brief, the company's directors in four years added to capital account nearly $17,000,000 (more than 100 per cent increase), without in-