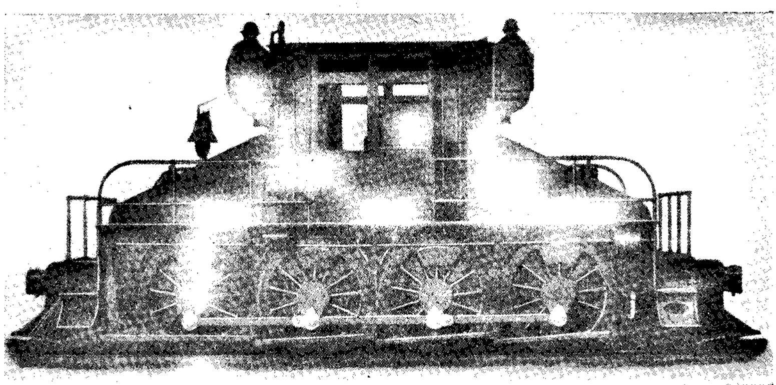
Sprague, Duncan and Hutchinson of a 1000 horse-power locomotive, with pilot control, for Mr. Henry Villard, proposed but not used for experimental operation near Chicago, and the larger locomotives built by the General Electric Company in 1895 for hauling regular trains through the tunnels in Baltimore.

BIRTH OF MULTIPLE-UNIT CONTROL

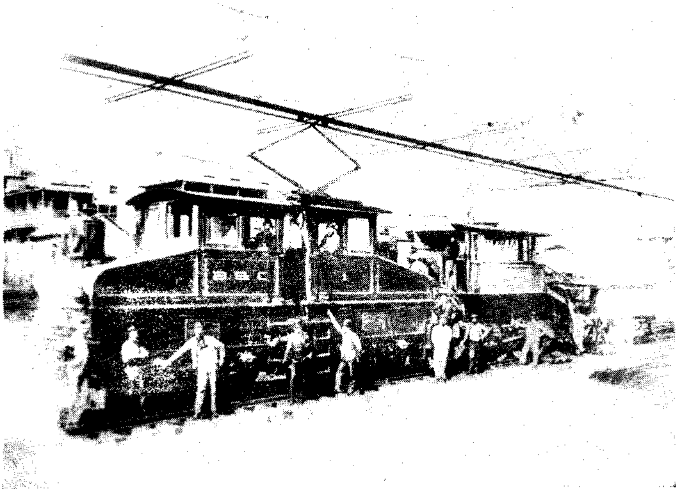
Neither the absorption of the Sprague Company in 1890 nor the subsequent taking up the development of the electric elevators had destroyed my interest in electric railways, and particularly the rapid-transit urban problem. For many years I had con-



1000 H.P. D.C. ELECTRIC LOCOMOTIVE, 1892; DESIGNED FOR MR. HENRY VILLARD BY SPRAGUE, DUNCAN AND HUTCHINSON, GEARLESS TYPE; PILOT CONTROL

tinually preached the virtues of an underground four-track express and local system, to be operated electrically, and as early as February, 1891, to silence the objections of a portion of the daily press and to block a proposed extension of the Manhattan Railway up Broadway, I offered in the New York *Evening Post,* under a possible forfeiture of $50,000, to install two electric trains within four months, one to be operated by an electric locomotive and the other by motors under the cars, at speeds up to forty miles an hour—the only condition being that if successful the costs would be reimbursed by whoever secured the rapid transit franchise.

All proposals for train operation which simply followed steam precedents seemed a pitiful falling short of the possibilities of electric operation. It happened that in the Postal Telegraph elevator equipment provision had been made so that any of the elevators could also be operated by switching the control from the car to a like control in the basement, with the collateral possibility of operating all six simultaneously, which test when first actually made resulted in an appalling confusion of unrelated movements because of the normal individuality of the equipments



General Electric D.C. Locomotives, Baltimore and Ohio Tunnel, 1895

and lack of means of coördination. While pondering over the electric railway problem the thought suddenly occurred: Why not apply this principle to train operation? That is, make up trains at any length by the combination of car units, without regard to number, end relation or sequence, a part of all of them equipped with motors but all with train lines, and to control the trains from either end of any car through master switches connected to the common train line.

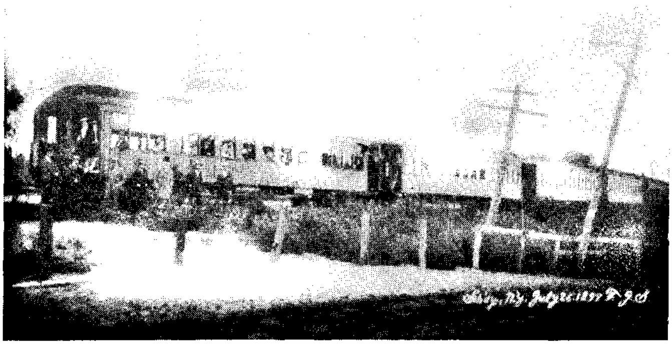
This conception, quite completely sketched in 1895 on some scraps of paper, marked the complete birth of this new method, then named and now everywhere known as the "multiple-unit system." Its wide possibilities instantly aroused my interest, for I saw the opening of a new epoch in electric railway operation. Here was a way to give a train of any length all the characteristics of a single car, with every facility of operation demanded by the most exacting conditions of service and capacity, and the means to combine even locomotive units of large capacities.

FIRST EQUIPMENT IN CHICAGO

After abortive attempts to get the privilege to demonstrate, at my own risk and expense, the advantages of the system on the Manhattan Road in New York, an opportunity suddenly arose in the spring of 1897, when I was requested to act as consulting engineer of the South Side Elevated Railway of Chicago. A brief inspection of the layout showed a field ripe for multiple-unit application, which was briefly explained to Sargent and Lundy, the engineers, and to Clark and Shepard of the General Electric Company, all old friends. A hasty report approved the steam plant; but the main feature of it was an argument in favor of the adoption of individual equipment under common control, in short, the "multiple-unit system," instead of the locomotive cars and trailer systems proposed by all the bidding companies. As evidence of confidence the report was supplemented by an offer to personally undertake the equipment on the general plan outlined, which met with the endorsement of the engineers. The contract was not concluded until after I left for Europe in connection with the Central London elevator proposal, and then only after a bitter contest with various companies and under most onerous conditions, supplemented by a demand for $100,000 bond for performance.

Among other things, work was to begin immediately on the entire equipment, and six cars were to be ready in two months for operation on a standard track, the manner of making the test to be prescribed by the officers and engineers of the road and to be to their satisfaction. Should the test not be concluded by the date set, or prove unsatisfactory, the contract could be cancelled. Further tests could be called for, and the remaining equipments were to be completed by specified dates. As soon as the power house and road were ready there was to be another test of not less than twenty equipments under service conditions, for a period of not less than ten days. Should this test prove unsatisfactory the right still remained for the railroad company to cancel the contract and to require waiver of all claims.

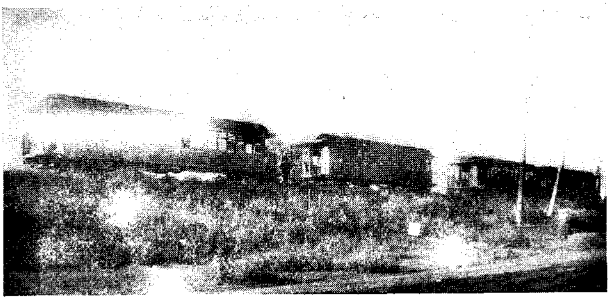
As return to New York was delayed until the middle of June, most of the instructions for the trial equipments were by cable, and the actual preparation was made within thirty days, despite a wholesale strike of the mechanics employed in the shops of the new Sprague Electric Company, which took over the contract.



6-Car Multiple-unit Train, Sprague, Schenectady, July 26, 1897

On July 11, 1897, two cars were put into operation on the tracks of the General Electric Company at Schenectady, and on July 26, the half-century anniversary of Professor Farmer's test of his model electric railway at Dover, my ten-year-old son Desmond operated a 6-car train in the presence of the officers and engineers of the South Side Elevated Road at Schenectady. In November a test train of 5 cars was put in operation in Chicago and was run through winter sleet, and on the 20th of the following April 20 cars, 17 of which (one in flames) were taken off during the day because of defective rheostats; but the last 3-car train pushed a stalled steam train around a curve. Three months later, a year after the Schenectady test, all steam locomotives had been abandoned and 120 multiple-unit cars were in operation, and the stock of the road had trebled in price.

The controllers for the original Chicago equipment were of the ordinary street car type, operated by pilot motors automatically retarded by any excess of current in the motors during acceleration. The train line contained three speed- and two direction-controlling wires terminating in reversible couplers at each end of the car. The disposition of these and their connection to the master switches was such that, whatever the number, sequence or end-relation of the cars, there was never any change in the connection of the speed circuits, but if any car was reversed the direction-controlling circuits were also automatically reversed. Whatever the grouping of cars, like movement of the master switch with reference to facing the track produced like relative direction

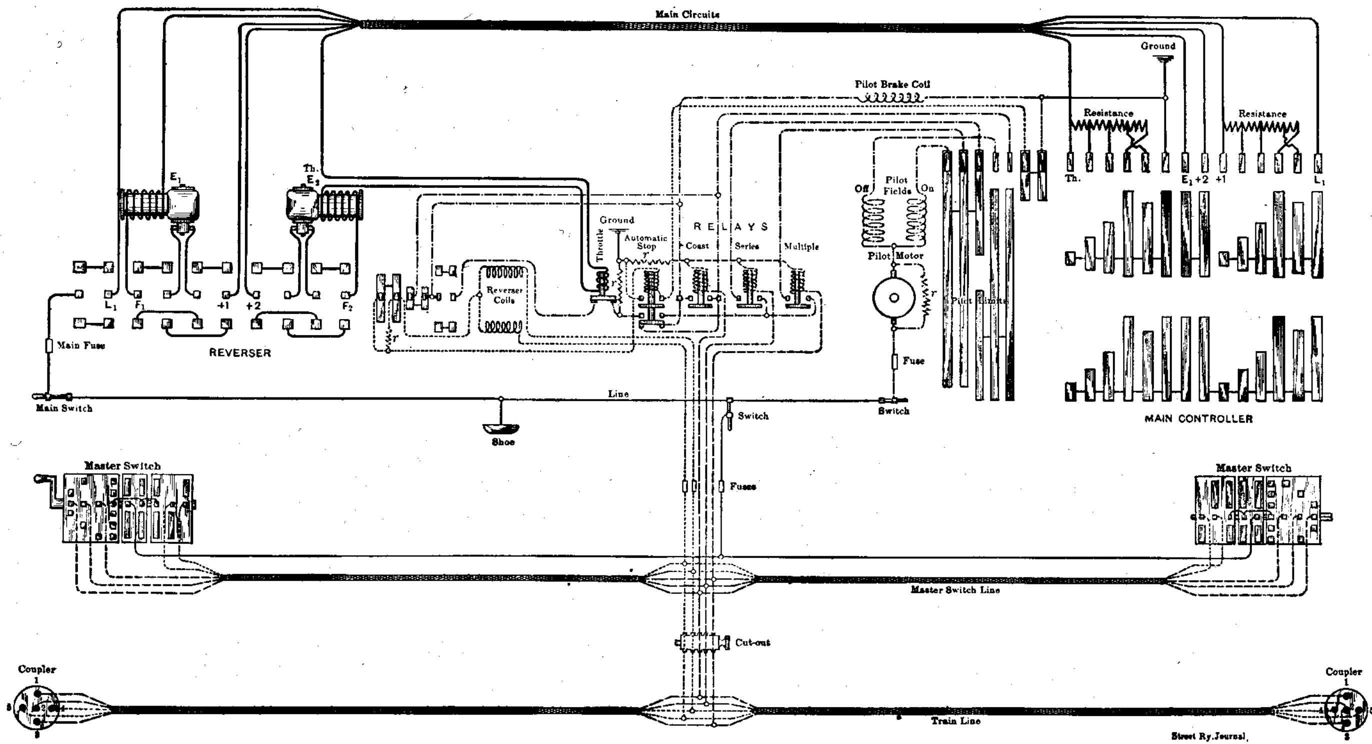


MULTIPLE-UNIT TRAIN BROKEN UP; SCHENECTADY, 1897

of movement. These principles are fundamental, whatever the changes of physical details. It is interesting to note that this original equipment is still in successful operation after over a third of a century.

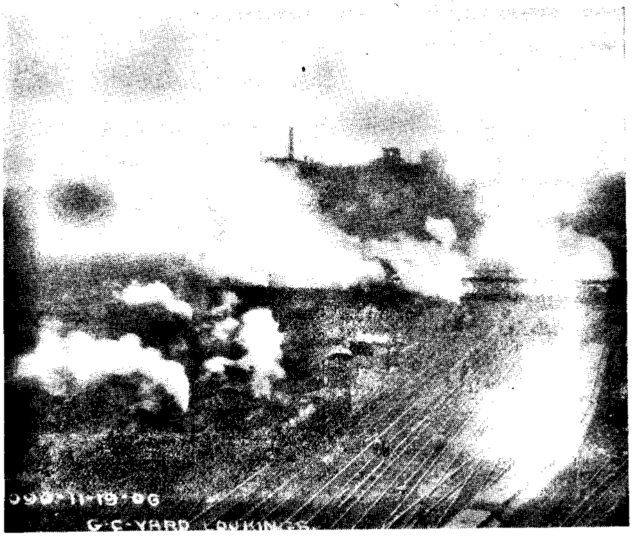
As an alternative physical construction the Westinghouse Company later used a step-by-step pneumatic motor to operate the controller, and then, on account of the increase of duty both the General Electric Company, which finally absorbed the Sprague Company, and the Westinghouse Company replaced the single cylinder form of controller by a combination of individual contactors each under a magnetic blow-out, although later there was a return to cylinder operation.

The multiple-unit system is now a fundamental, the world



SCHEMATIC DIAGRAM, MULTIPLE-UNIT SYSTEM

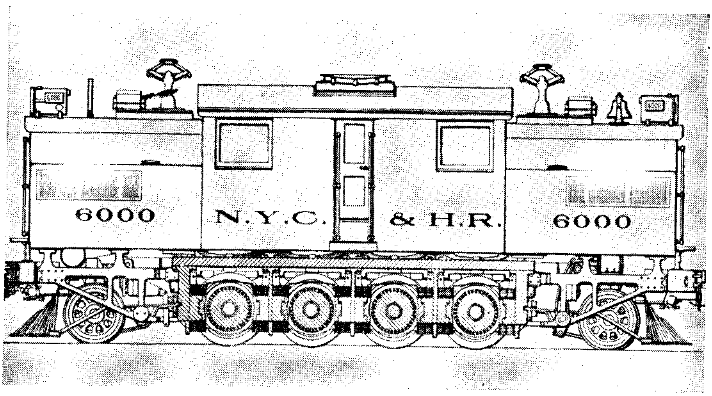
over, for all electric train operation where two or more equipped cars or locomotives are controlled from a common source, and its value in dense rapid transit service like the Elevated and Subway in New York is indicated by the enormous increase of capacity compared with any other method of operation, a result which could not be equalled in any other way on the present subway system alone for less than hundreds of millions of capital cost of construction.



OLD NEW YORK CENTRAL YARDS, 44—48TH STREET, NEW YORK
Before electrification

MAIN LINE ELECTRIFICATION

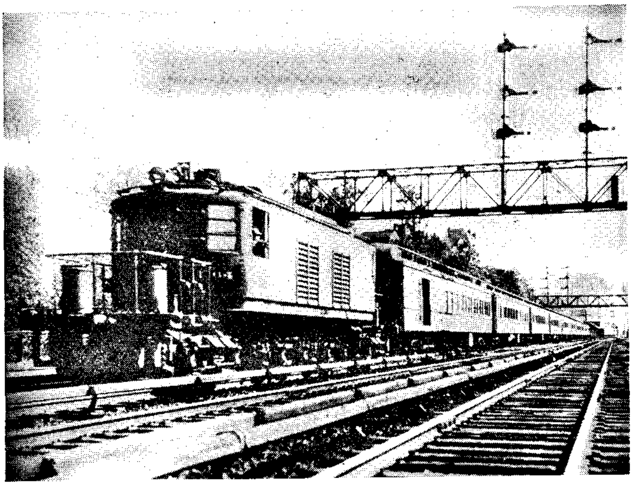
Following a grave accident in a smoke-filled yard tunnel of the New York Central Road, the first important step in American main line electrification was taken when a new station was planned, and electricity adopted at and for some distance from the New York Terminal, in 1902/3; and here again there was a radical departure in engineering practice. Up to that time all motors used for railway purposes maintained a fixed relation between the armature and the field, but when this project was finally taken up under the guidance of an Electrical Commission, presided over by the then vice-president, Mr. W. J. Wilgus, and of which commission I was a member, a plan for a new type of direct-current locomotive, proposed by Mr. Bachelder, was submitted by the General Electric Company. This called for the use of bi-polar motors the field magnets of which, carried in a horizontal plane, were supported by and made an integral part of the locomotive frame, and hence carried above the suspension springs. The armatures were rigidly secured to the axles, and the field magnets, with flattened pole pieces and a comparatively large air gap, were free to move vertically relative to the armatures. All



BACHELDER GEARLESS BIPOLAR LOCOMOTIVE, 1903/4; BUILT FOR THE NEW YORK CENTRAL RAILROAD; ARMATURE ON AXLE, BUT FIELD MAGNETS SPRING-BORNE

brackets and gears were thus dispensed with and the motor reduced to the simplest form. Although ridiculed by many engineers at the time, the new design was accepted and has proven entirely satisfactory. These locomotives were the first to be equipped with the multiple-unit control, so that two or more could be operated together the same as the suburban cars. On this equipment was first developed the protected under-contact third rail. This installation is also notable in being the first railway to use steam turbine generators.

In Europe important main-line electrification projects were carried out on the polyphase system, with a high degree of technical skill, by the Ganz Company on the Valtellina and the Simplon Tunnel lines. On these the axle mounting was abandoned, and the motors were carried on the locomotive frame, being connected to the drivers by side rods. In Switzerland, under the able guidance of Dr. Huber-Stockar, the state railways have been almost entirely converted on the single-phase system. In the general work on the Continent a very high degree of structural ability has been shown by European designers.

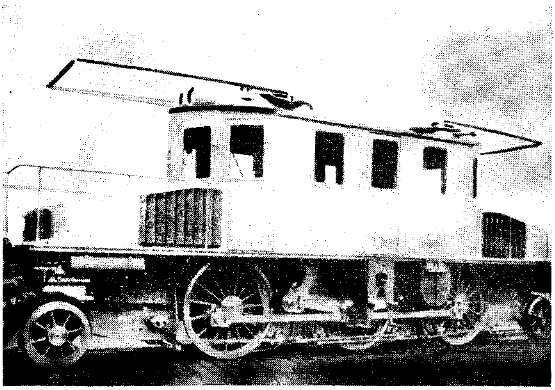


NEW YORK CENTRAL RAILROAD ELECTRIFICATION
A four-track section on main line south of Harmon, N. Y. showing "Twentieth Century" drawn by 130-ton gearless locomotive.

ALTERNATING VS. DIRECT CURRENT MOTORS

As already stated, in the early days of electric railroading it was apparent that at the electric pressures commonly used the field of operation would be restricted, not of course within ordinary city limits but when the distances became considerable. I had, therefore, advocated improvements looking to the raising of direct-current potentials, but for a long time this view was generally rejected.

Meanwhile, the system of polyphase alternating-current transmission, with conversion to direct current at substations through the intermediary of step-down transformers and rotary converters or motor generators, had been developed to such an extent that the field of operation from a single central station was materially broadened. Also, many engineers urged the abandonment of all consideration of the use of direct current for interurban and trunk-line operation, and the adoption of either polyphase or single-phase alternating-current motors, with direct supply at high potential on the trolley wire, speed control to be got by the use of a step-down transformer or otherwise. With this proposal was coupled the condition of low frequency and practical isolation of the railway problem from a general utility supply.

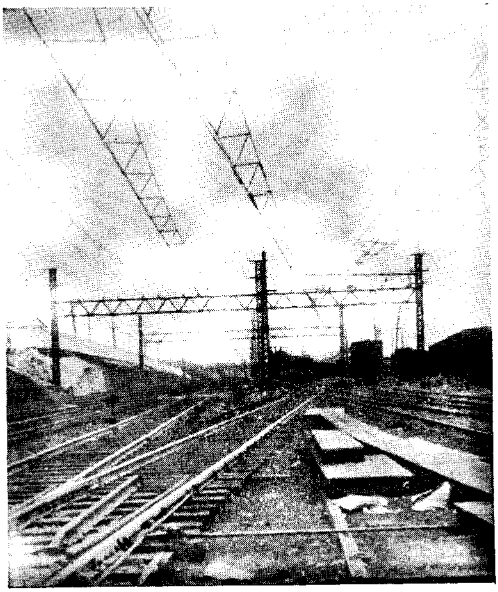


GANZ TWO-PHASE ELECTRIC LOCOMOTIVE, VALTELLINA LINE, 1902/4

Among the American engineers prominently interested in this development may be mentioned Lamme, Finze, Winter, Eichberg and Steinmetz. It was conducted along two or three different lines. One type, originally proposed by Thomson and known as the repulsion motor, had the field supplied direct at the full-trolley potential. This has been largely abandoned, although an alternative of this form was developed by European engineers, in which latter type a variable potential was supplied to the armature from a transformer.

A more successful type is the series-commutator motor, similar to the direct-current motor, except that the iron in the magnets is laminated to prevent loss and the pole pieces have an additional compensating winding across their faces. The high-tension current from the trolley is transformed to low tension on the locomotive, and speed regulation is obtained by the use of the rheostats or voltage variations on transformers. Naturally, there are many variations in detail introduced on the equipments actually installed for railway service.

The difference of opinion among American engineers and manufacturers, which was unfortunately not based upon possible



CATENARY TROLLEY ON NEW HAVEN ROAD; SINGLE PHASE

developments but largely upon assumptions, gave rise to bitter controversies, which rose to a climax at the time of the adoption of the single-phase series-commutator type of motor on the New Haven road, whose trains had likewise to operate over a considerable section of the New York Central tracks at their common terminal.

THE INTERPOLE MOTOR

Having been in the forefront of this controversy, the outcome has been of special interest. During a long period of doubt among many as to the results of single-phase operation, my attention was called to developments which had taken place in variable-speed, direct current motors for ordinary industrial purposes, by making use of my old interpole winding localized on small extra poles carried between the main poles of the motors, and in consequence I urged a test of this practice on railway motors. The results obtained were so remarkable that I saw the possibilities of a great increase in the potential which could be used in direct-current operation, and that if this improvement was carried to a logical conclusion the probabilities were that the economical requirements of the larger problems could be met with direct current motors. On account of the lack of capacity of the single-phase motor compared with like weight of a direct current motor, it was possible that it might be abandoned, and since its sole claim for use has been based upon the economy of installation and transmission, the direct current motor might maintain its supremacy, not alone upon urban and interurban roads but also in trunk line operation.

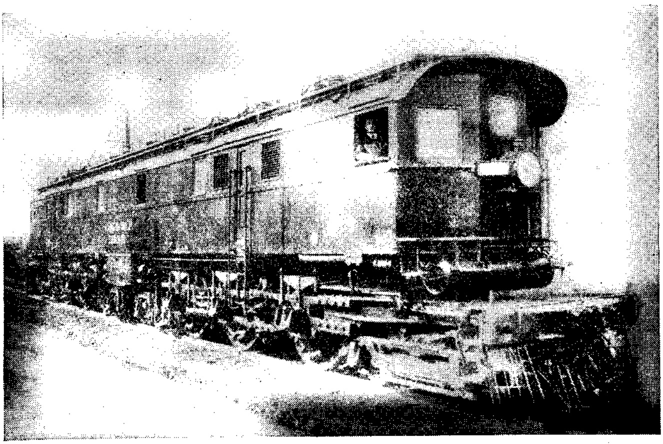
There was, indeed, the specific lack of capacity inherent to a single-phase motor, to combat which increased armature speeds were supplemented by air-blast cooling. But of course these were equally applicable to the more sturdy direct-current motor and were soon adopted for it, so that the relative capacities for equal weight efficiencies and heating remained about as originally indicated, at least where 25 cycles are used. Notwithstanding this general fact the single-phase system, which attained an early vogue in Switzerland, has continued to receive the support of the engineers of that country in its use on state railways, generally with 15,000-volt trolley supply, but at the low frequency of 15 cycles. Lack of relative motor capacity does not characterize the polyphase motor, and it has received the support of Italian engineers in several of their major installations.

In the United States a notable example of use of the latter was on the Great Northern Railway, now abandoned. One of the most ambitious attempts on this plan was that undertaken by two German companies, many years ago, on the Zossen Military Line, where was made the highest record for speed of a car carrying passengers—about 126 miles per hour—the current being collected at between 10,000 and 14,000 volts from three overhead wires by sliding contact. The multiplicity of conductors, however, distinctly militates against the polyphase trolley system as a solution of the larger railway problem, in spite of the high ratio of motive power to weight and the ready use of the motor for braking by regeneration.

Additional methods of using single-phase alternating current on the working conductor have been proposed and put into practice, but these eliminate the single-phase motors entirely. Among them is the introduction on the locomotive of apparatus for changing the energy of the single-phase trolley current into polyphase current to be used in polyphase motors, as on the Norfolk and Western Railroad. Means for conversion of alternating into direct current by the use of a mercury rectifier have been recently brought to a high degree of efficiency, first by engineers of the Brown-Boveri Company and then by American engineers, so that it is now possible to convert large capacities at high potential with great economy.

On the whole, the experience of the past twenty years seems to have demonstrated the soundness of the conclusions advanced with regard to direct-current development, for while a great railway system using single-phase motors at 25 cycles has maintained it, and it is being extended on to another trunk line system, many other single-phase motor installations have been abandoned. On the other hand, some of the most difficult and extended freight lines, at one time deemed by many engineers barred to direct-current operation, have adopted direct current at from 2400 to 3000 volts working potential, as illustrated by the Butte and Montana Railroad and the six hundred miles on the Chicago, Milwaukee and St. Paul Railway. Following in general a plan advanced in a study of electrification for the Sacramento Division of the Southern Pacific Railroad some years ago, the St. Paul uses the motors for regeneration and braking on down grades.

Nor is the vogue of direct-current operation confined to the United States, for French and English commissions have reported in favor of its adoption, and on the Midi Railway of France single-phase operation has been abandoned in favor of direct-current, the conversion of alternating current at the substations being effected by large capacity mercury rectifiers. The installation of the direct current system on the suburban lines of the D. L. & W. Railroad in the United States, with rectifiers operating at 3000 volts, has for the first time made possible a fair comparison of capital costs and operating results with those which may be achieved by recent important advances in A.C. motor construction.



TYPICAL DIRECT-CURRENT LOCOMOTIVE, 3000-VOLTS

THE FUTURE

It has been said that the throb of the locomotive was the heart-beat of civilization, and so the hum of the motor may well be considered a song of emancipation. Every country with expanding resources owes its growth and prosperity largely to the development of its arteries for transportation, and its future will in a large measure depend upon the efficiency with which such continue to respond to the demands made upon them. It has been predicted that with normal growth traffic requirements in the United States will double in a score of years, but many of the trunk lines are near capacity at terminals, and on portions of the right of way under existing conditions of operation. The transportation problem therefore promises to be one of the most serious. Increase of capacity is the vital need, to be achieved where possible along existing lines and by current methods, but where these fail then by the adoption of a motive power which permits material or even radical changes in train make-ups and operation, and increase of capacity.

The steam locomotive and its rival cannot be compared simply as machines, for there are inherent differences between them. However improved, the former remains a moving power plant, limited in maximum and continuous rate by the capacity of the boiler and a portable fuel supply. The fact that it is an independent entity has certain advantages, but likewise some disadvantages. The electric locomotive, on the other hand, is a transformer of electric energy created at distant power stations and transmitted to it by stationary conductors. Thanks to the "multiple-unit" system, any desired concentration of power units under a common control is possible, and any number of power plants, taking their energy from centuries-old and diminishing supplies of increasing cost, or the annually renewed "white coal" of the mountains, may be joined together in a common supply.

Already it has been conclusively demonstrated that with the electric locomotive mountain traffic may be handled with fewer units and at higher speeds; that it is capable of longer hours of continuous service under adverse weather conditions and with less terminal inspection and repairs; that train schedules may be increased not only because of the superior speed on heavy grades, but because of the elimination of waits for coal and water supplies and fewer lay-overs at a reduced number of passing points on single-track railroads; that there may be a material reduction of useless dead-tonnage; and that if there were universal electrification there could be saved at least one-half of the coal now used on railroads, which already amounts to a quarter of the total mined.

Among other outstanding facts it has also been established that any required amount of power may be transmitted over long distances with entire reliability and with limited losses;

that it may be stepped down from high to any required potential at local centers of supply; that it may be distributed thence in the form of single or polyphase alternating or direct current, the former by overhead conductors and the latter by both overhead and third-rail conductors; and that it may then be used in any form desired in the motive-power equipment,—in short, that electricity itself, a source of power whose character is still unknown, is at once the most docile, tractable and universal servant of man.

But despite the enormous advances made and the results already accomplished it would be folly for the electrical engineer or the railroad man to assume that the limits of invention or development have been reached, as evidenced by the steady march of improvement to meet new problems, and the recent remarkable prophecies of things to come. The mercury rectifier is one striking example, and the developments in electronics shown by the performance of the latest vacuum tubes are typical.

Urban and interurban electrification with the constant linking up of smaller systems into more extended ones, has gone on apace, but trunk line systems are still largely steam operated, and there are wide differences of opinion among engineers as to whether a single system will be dominant, and if so which one, or whether the varying conditions and demands will be best met by specific solutions.

The financial question involved in the large cost of equipment cannot but remain a factor which will often prove controlling, for electrical operation will not be adopted except there be a commensurate gain of some kind. Where coal at low unit cost is the source of power the gain in economy alone will rarely warrant the adoption of electricity on independently operated roads, but where coal is high in price or water power can be got at a reasonable cost there is a valid reason for the change.

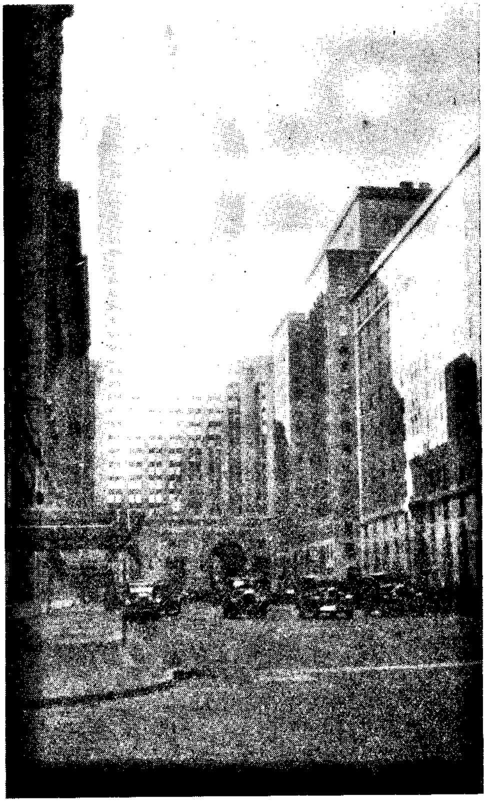
Excluding special cases, what ultimately will be constructively influential will be that need of increase in existing or available track capacity which I have already indicated, which is undoubtedly possible to a system which permits of individual and simultaneous control of a concentrated or distributed power plant greater than can be got by any other means, and can eliminate from its tracks the transportation of its fuel. It seems certain, however, that there must be coöperation in the important matter of power supply, and the general trunk line problem will appear less formidable with the elimination of the requirements of installation of individual power houses with their necessary reserves, and the use of current from great power plants properly linked together, which in addition to their reliability can make full use of the diversity factor in a multitude of demands.

As these pages are written news come of perhaps the most significant recent development in electric traction, the report of the English Government commission recommending the practically complete conversion of the steam roads of Great Britain on the ground of an economy which will pay a high return on an impressive capital cost,—by far the largest and most far reaching proposal in the electric railway industry.

THE DUAL ELEVATOR

It was inevitable that with the perfecting of the electric elevator there should be a rapid abandonment of both steam and hydraulic elevators, and with the addition of the traction type a quick response in a building development which the new method of operation had made possible. But with the resultant increase in the height of buildings and reduced effective floor to floor mileage of the elevators supplying the upper floors, at an expense which may run as high as $25,000 for a single long run elevator in an 85-story building, two-thirds of which is for space occupied, the cost of operation has approached prohibitive figures. To offset this, speeds have been increased until now 1200 feet a minute is planned on some existing installations, but to make use of the lower parts of the shafts of express elevators I some time ago developed a plan to double up the elevators in these shafts, so that, with absolute freedom of movement limited only by a definite approach to each other, two elevators could be operated on the same rails, one above the other, and thus cut down the space required. If successfully done it meant a possible saving in even normally high buildings of available rental space whose value would equal a good rate of interest on the total cost of the elevator plant, an amount which might run from $25,000 to over $200,000 annually in a single building.

This possibility of savings being stressed, a working model was



GRAND CENTRAL OFFICE BUILDING, NEW YORK, AND PARK AVENUE; LOOKING SOUTH

After electrification

erected in my New York laboratory some four years ago. At that time no building code would permit such a construction, and the idea was looked upon by many people as a sort of brain-storm. But arrangements were finally consummated so that a full sized commercial equipment (known as the Westinghouse-Sprague

Dual Elevator) has been constructed and approved, and building codes, under pressure of real estate owners and builders, are being changed to permit this type, which when generally adopted will again demonstrate to a degree not yet realized the possibilities of vertical traction and prove another milestone in progress.

Incidentally, this new departure will make necessary the use of *cause*—an excess in down acceleration—instead only of *effect*,—speed resulting from acceleration and time—as one of the means for initiating the operation of the car safeties, to get the quickest stop in the event of a broken cable or too close an approach of the cars, as well as manual means for operating the safeties in case of lack of control, as has been already demonstrated.

One is apt to consider electric traction only from the standpoint of horizontal movement, and in a great municipality like New York the benefits of urban transit and the possibility of under-water tunnels, but one needs only to view the city as it was in the Grand Central zone before the change to electric operation and the days of the modern skyscraper, to realize that the astounding growth of tangible wealth is largely due to "electric traction in space of three dimensions," and that it has had a greater influence upon the city's growth than any other single physical agency.