all resistance cut out, the motor tends to maintain constant speed, and thus impose heavier peaks on the power station, than would series D.C. motors, in which the torque is greater at lower speeds.

The former objection is to a slight extent overcome by the cocatenated, tandem, or cascade system of control, which requires the use of an auxiliary motor. In this system, for full speed the main motor is alone in circuit; for half speed the main rotor is connected to the stator of the auxiliary motor, and each supplies half the mechanical energy; for intermediate speeds, as at starting, resistances are introduced first into the auxiliary rotor circuit, and then into the main rotor circuit for above half speed.

It will be readily appreciated that the necessary switching of the three phases is complicated, and that one of the main advantages of the ordinary induction motor, in the absence of moving contacts is lost.

Again, at least two trolley wires are required, and this makes the overhead work costly and difficult. These disadvantages notwithstanding, a great deal of useful work has been done on this system in Europe, where on mountain lines in Switzerland and northern Italy, use was made of the property of polyphase motors of supplying current to the line when running at above synchronous speeds, as on down grades, and at the same time braking the train. On such lines also the stops are infrequent, and the inefficiency of the starting method is not material. I have lately heard that the braking of the trains by the above method is now abandoned, as the fluctuations produced on the generating station were too great. This system was brought prominently before the English public in connection with the proposed conversion of the London underground lines to electric working, the two companies concerned each advocating a different system; one a polyphase system to be installed by Ganz & Co., of Buda Pesth, and the other the General Electric multiple-unit D.C. 600 volt system. The matter was finally submitted to arbitration, the present Colonial Secretary being the arbitrator, and the question decided in favour of the multiple-unit system about three years ago, the conversion being now about completed.

One of the best known examples of the application of polyphase motors for traction work, is the Valtellina Railway, near Milan, in Northern Italy, where seventy-two miles of a railway operated by steam were converted in September, 1902. Current for working this line is generated and transmitted at 20,000 volts, 15 cycles three phase, from water power at Morbegno, and stepped down in nine substations to 3,000 volts, at which potential eleven separate sections of line are fed. There are two overhead trolley wires, the rail constituting the third phase.

Both passenger and freight trains are run, the latter attaining a speed of forty miles per hour on the level, while the freight locomotives are capable of hauling a 500 ton train at nineteen miles per hour on the level. There are seventeen regular stations on the line, and eight additional stopping places. The cascade method of control is used, and all the switches are operated by compressed air. The arrangements for feeding the different sections are such, that it is impossible for two trains to move on the same section in the same direction at one time, as each train leaves the section behind it dead, re-establishing the circuit as it passes into the next section; while if the signals are set against a train, the current is cut off the section ahead, and if the train still endeavours to enter the section, as it might on a down grade, the brakes are automatically applied.

The objection to the use of two or three trolley wires in the polyphase motor systems could be overcome by the use of a polyphase motor with one winding short-circuited: but this type of motor has, of course, a very small capacity for its weight, a low power factor and weak starting torque, but a lot of experimental work has been done in the endeavour to improve it.

In 1901 Heyland and Latour independently demonstrated the practicability of operating three-phase motors at unity power factor at some one load, by the addition of a commutator to the rotor or armature. Shortly afterwards Winter and Eichberg made an advance on this idea, by which the speed could be economically controlled, current being supplied to the rotor windings of a polyphase motor by brushes bearing on a commutator, a variable voltage being supplied for this purpose by an induction regulator. From this polyphase motor a similar single phase motor was developed.

In this motor the stator resembles that of the ordinary induction motor, while the rotor and commutator are practically identical with the armature and commutator of a direct current motor, except that for a given voltage the commutator is larger, main brushes bear on the commutator at the neutral point as usual, while midway between them are sets of short-circuited brushes, the main function of which is to provide a path for induced currents, which, together with the main single-phase current, produce a resultant M.M.F. in quadrature with the M.M.F. of the stator winding. A magnetic field is thus produced, the rotation of which is at such a rate as to decrease the rotor inductance as the speed increases, effacing it completely at synchronous speed; thus, for any voltage applied to the motor terminals, the power factor will, at some one load, be equal to unity. A second function of the short-circuited brushes is to render the commutation of the main brushes practically perfect at all speeds, but that of the short-circuited brushes, on the other hand, is only perfect at synchronous speed, and is poor at starting. The important disadvantage of the Latour-Winter-Eichberg motor is due to the use of these secondary brushes, which increase the friction and the contact C^2R losses, and thus necessitate the use of a larger commutator; on the other hand its power factor is high.

The Westinghouse-Lammé-Finzi type of single-phase motor is practically a series D.C. motor with a laminated field. To improve the power factor and commutation, there is added a compensated winding in quadrature with the ordinary field, and located in slots in the pole faces, This winding neutralises the armature reaction, its ampere turns being practically equivalent to those of the armature. It thus introduces an extra C^2R loss, which disadvantage is offset in comparison with the first type by the smaller commutator.

The third type of single-phase motor is the repulsion motor, invented by Elihu Thompson, and developed by Schichter and Steinmetz. In this there is no direct connection between the armature and field, the brushes being short-circuited, so that the commutation is good, while the field can be wound for high potentials: It has, however, a lower power factor than the other types, and less starting torque.

The points of difference between these three types of commercial single-phase motors are not many or great, and in making a comparison between the single-phase motor and the D.C. motor for traction work, they may be considered the same.

The main points of inferiority are briefly as follows:—a considerable hysteresis and eddy current loss in the stator or field; a greater commutator loss, due to the desirability of employing lower commutator voltages and thus a larger commutator; these in addition to the special losses in particular types mentioned before. The efficiency at all loads and more particularly at light loads is less than that of the D.C. motor, while the commutation is poorer. The whole motor has to be larger for the same output to lessen the internal losses, and to provide the greater field insulation required. The power-factor in actual service is considerably less than unity, while the auxiliary apparatus is heavier and more costly than that required by the D.C. motors.

As an off-set to these disadvantages we have regulation by voltage control and the consequent elimination of the rheostatic losses of the D.C. motor; saving in copper and in the first cost, operating expenses and losses in substations; simple and effective regenerative braking, and the avoidance of electrolytic troubles.

The speed torque characteristic is about the same as for the D.C. motor, but there is a greater drop in the conductors due to reactance, this being especially noticable in the rail return, as shown in the following figures giving the comparative resistances of the same line and track with direct current, and alternating current at twenty-five cycles.

	D.C.	A.C.	Ratio $\frac{A.C.}{D.C.}$
Two trolley wires in series.. ..	·318 ..	·47 ..	1·31
One trolley wire and double track..	·167 ..	·259 ..	1·55
Two trolley wires and double track	·088 ..	·155 ..	1·76
Double track alone	·0174 ..	·114 ..	6·55

These figures were taken on the Ballston division of the Schenectady railway which is equipped for single-phase working, a trial run having been made on August 19th last. For 4 miles out of the 15½, the cars operate on the 600 volt D.C. system, and for the remainder on a 2,200 volt A.C. trolley wire suspended by the catenary suspension which has come to be the standard for such lines. The car is 43 feet over all, seats 44 passengers, and weighs complete 30 tons, being equipped with two 50 h.p. motors wound for 200 volts, permanently connected in series and supplied from the 400 volt secondary of an 80 k.w. transformer cooled by the motion of the car.

The following comparative results with the A.C. and D.C. motors on a straight run of level track are instructive.

	D.C.	A.C.
Length of run	1·6 miles.	1·6 miles.
Weight of car	31·55 tons.	31·55 tons.
Time	180 seconds.	180 seconds.
Average current, power on ..	229 amps.	346 amps.
Average volts	606 volts.	425 volts.
Volt ampéres at full speed ..	96 volt ampéres.	110 volt ampéres.
Volt ampére hours per ton mile ..	86·3.	125·5.
Average speed	32 m.p.h.	32 m.p.h.
Schedule speed, inc. 15 sec. stop..	29·5 ,,	29·5 ,,

The first line to be operated under commercial conditions by series single-phase motors is the Spindlersfeld-Niederschoenweide line, near Berlin, which is a branch about $1\frac{1}{4}$ miles long, of the Government steam railway system, and was up to 1903 operated by steam. On this line the trolley potential is about 6,000 volts at 25 cycles and Winter-Eichberg motors are used, wound for the full potential. The trolley wire is suspended by a catenary and the operation has been quite successful, the energy consumption being 41 watt hours per ton kilometer with a power factor of 82·3 per cent., as against 43·6 watt hours per ton kilometer for a train equipped with D.C. motors, the average speed being 34·4 k.w. per hour; the lowest value of the power factor during acceleration is 80 per cent.

The same type of motor has also been in use on the Stubaithal line, in the Austrian Tyrol, since August, 1904, the trolley potential being 3,000 volts at forty-two cycles, reduced to 450 or 525 volts by a transformer placed on the car, so that the cars can be used in the city of Innsbruck where the trolley potential is 450 to 525 volts. The operation at this comparatively high frequency is quite satisfactory.

I understand that the Westinghouse Co. is preparing to equip several lines in the United States with the Lammé type of single-phase motor, so that it may now be considered that the single-phase system is commercially successful, and any troubles that may arise will no doubt be eradicated as more experience is gained.

This being granted, the choice between the single-phase and the D.C. systems will in any case depend upon the relative expenditure for equipment, maintenance and operation, and these expenditures will vary with the length and nature of the line, and upon the amount and kind of traffic.

The two great advantages of the single phase system are the saving in copper due to the high voltage, and the elimination of the rotary converter. The saving by its use will thus depend upon the length of the line, and on the total power required, as well as the density of traffic, though, as the A.C. car equipments cost more than D.C. equipments of the same capacity, the total difference in cost will depend upon the number of cars.

The rotary converter losses in the D.C. system are, to a certain extent, counterbalanced by the lower efficiency of the A.C. motors, but the efficiency of the A.C. control during acceleration is on the average higher than that of the D.C. with its rheostatic losses, so that the frequency of the stops has to be taken into consideration.

Taking into account the greater drop in voltage on the A.C. system, due to inductance in the trolley wire and rail, it may be taken roughly that 1,000 volts A.C. is equivalent to 600 volts D.C., as far as copper is concerned, and therefore, to secure the full advantages of the A.C. system, it is necessary to employ a trolley potential as high as 3,000 or 5,000 volts, and this increases the cost of the overhead line and fittings.

The limitations imposed by the space available on the cars for the motors must always be borne in mind, and owing to the difficulty of winding A.C. motors for low speeds, the D.C. system will generally be more applicable for slow speed locomotives for freight and switching service.

The use of the single-phase system, with its high trolley voltage, obviates the difficulty of collecting large amounts of power for the cars, which led to the adoption of the third rail in the 600 volt railways. This is a very important advantage, as it would be impossible to use the third rail system in large railway yards and terminal stations, and this consideration was one of the most important in determining the use of the single-phase system in the proposed electrification of the London, Brighton and South Coast Railway, on which the use of a third rail at Clapham Junction was quite out of the question.

My brief sketch of the subject would be incomplete without reference to the high speed electric railway trials carried out on the Marienfelde-Zossen line in Germany. These trials were made with a view to determining the data for a regular electric railway service up to speeds as high as 200 km. (120 miles) per hour.

The German military authorities placed the Marienfelde-Zossen military line at the disposal of the Company which was formed to carry out the tests, and two cars were constructed, one each by the Algemeine Electricitäts Gesellschaft and the Siemens & Halske Co.; it being mainly due to the enterprise of these two firms that the experiments were so successfully undertaken, Siemens and Halske constructing the overhead line and the A.E.G. supplying the power and installing the transmission line.

The line was about fourteen miles long, the sharpest curve being 100 chains radius, and the steepest grade 1 in 200; the original permanent way consisted of light rails weighing 67 lbs. per yard, placed some on wooden and some on iron sleepers. After increasing the number of sleepers the trials were begun, and though it was not anticipated that this road bed would suffice for the higher speeds, the track stood perfectly well up to speeds of eighty miles per hour.

The track was relaid in the Summer of 1902, the new rails forty feet long, weighing 84½ lbs. per yard, being placed on eighteen fir sleepers; about three-quarters of the length of the line was fitted with guard rails, which prevented derailments and materially increased the strength of the track.

Three-phase current was used at 10,000 volts, with three overhead wires supported in a vertical plane about seven feet from the centre of the track, the wires being about forty inches apart. Each wire had a cross-section of ·155 square inches, and was divided into sections of about half-a-mile in length, and provided with lighting arresters and devices for automatically earthing the wire in case it broke.

Bow collectors were used, mounted on vertical masts placed at the ends of the cars; in the Siemens & Halske car the three collectors were placed on one mast at each end of the car, while in the A.E.G. car, the three bows were placed on separate masts, one behind the other, both arrangements proved satisfactory and no difficulty was experienced in collecting the currents.

The cars were about seventy feet long and were mounted on two trucks, each with three axles; there were four motors on each car, the centre axle in each truck being free. The axles were at first spaced 11 ft. 6 in. apart, and later about 15 ft. apart; no lateral oscillation was noticeable at speeds of over eighty miles per hour.

The motors on both cars were 250 H.P. each, the current being stepped down by transformers placed on the car and the speed controlled by resistances, which in the A.E.G. car were liquid, and in the Siemens & Holske's car metallic. Both air brakes and electric brakes were provided on each car.

The trials in 1901 were made at speeds up to 85 and 100 miles per hour records being obtained of the consumption of energy and the braking. In order to attain speeds of sixty miles per hour, starting distances of one-and-a-quarter to two miles were required, and times from 138 to 220 seconds, giving accelerations ranging from ·3 miles per hour per second to ·45 miles per hour per second, using from 700 to 1,000 H.P.

Running at fifty-five miles per hour the power taken was 140 K.W., and at eighty-seven miles per hour, 520 K.W.; the resistance was 8 lbs. per ton at seventy miles per hour. The highest speed reached was 130 miles per hour.

In connection with these figures, it is interesting to note that the track resistances are very low, and that in the earlier trials a point was reached at which they increased very rapidly owing to the instability of the road-bed.

It is of course known that for electric cars the resistances given by the ordinary formulæ are misleading; for ordinary city and suburban work however the train resistances are important, as the size of the motors is determined by the required acceleration and by the grades; but in high-speed long distance work the track resistance is of importance and it will therefore be interesting at this stage to compare the latest formulæ on the subject.

The Baldwin formula is

$$R = 3 + \frac{V}{6}$$

The Davis formula is

$$R = b + cV + \frac{dAV^2}{T}[1 + 0{\cdot}1\,(n - 1)]$$

Smith's formula is

$$R = 3 + 1{\cdot}67V + {\cdot}0025\,\frac{A}{T}\,V^2$$

where

R = train resistance in lbs. per ton of 2,000 lbs.

V = speed in miles per hour.

A = cross sectional area of car in square feet.

T = weight of train in tons of 2,000 lbs.

n = the number of cars.

b = 3·5 for heavily loaded freight cars.

4 for passenger cars or large electric interurban cars.

5 to 6 for light electric cars.

c = ·11 for heavy track.

·13 for medium track.

d = ·0035 for open platform cars.

·0024 to ·0030 for vestibuled electric cars (the lower figure being correct for the Zossen trials.)

In addition to measurements on the energy required for acceleration and running, experiments were also made in braking and very interesting results obtained.

Using metric dimensions.

Let f = coefficient of friction.

D = total pressure on the brake shoes.

M = mass of car $= \dfrac{weight}{g}$

R = rotating mass referred to circumference of wheel.

W = air and train resistance.

A = up or down grade of road.

p = retardation in metres per second.

Then the relation between the coefficient of friction and the retardation is :—

$$f\mathrm{D} + \mathrm{W} \pm g\mathrm{M}a = p\,(\mathrm{M} + \mathrm{R}).$$

The total pressure on the 24 brake shoes, after allowing for losses may be taken as 100,000 k.g.

Now the following results were obtained at different speeds :—

V = 20	k.m. per hour	... p = 1·7	... f = ·17
V = 60	„ „	... p = ·75	... f = ·064
V = 100	„ „	... p = ·60	... f = ·042

the values of f are thus less than those found by Westinghouse.

The air pressure on the front of the car was found to follow the formula

$$p = \cdot 07\mathrm{V}^2$$

where V = speed in metres per second, and p = pressure in k.g. per square metre placed at right angles to the direction of motion. Descriptions of these experiments have appeared in most of the technical journals, and full reports are to be published later.

It is to be regretted that I have been unable to draw my illustrations of the progress of Electrical Engineering from our own country, but it is natural that in these matters we should move more slowly, as we are so far removed from the centres of development.

At the same time the progress of electrical work in Australasia has been not unsatisfactory, not the least noteworthy step being the appointment at the Engineering School of a lecturer in Electrical Engineering, who I am glad to see has become a member of the Society without delay.

In the past year we have seen the streets of Sydney lighted with electric lights, and it is to be expected that the provisions made by the City Council for the supply of cheap electric power in the city, will lead to large developments in the installation of electric motors in factories and for lifts.

Then again, we have lately seen the inauguration of electric tramways in Auckland and Dunedin, and a start made with the systems at Christchurch and Fremantle, while the conversion of the horse trams in Adelaide to electric working is to be expected in the near future. The Victorian Railway Commissioners have under consideration the working of one of the suburban lines by electricity, while there have been some important installations of electrical machinery in the mines throughout Australia.

Intimately connected with the progress of electric traction is the the development of the steam turbine, both of the Parsons and Curtis types; a great number of the large electrical stations are now installing this type of prime mover.

The gas engine is now becoming an important competitor with steam engines for some installations, while for light railways and tramway extensions the petrol or other self contained motor car has lately come into prominence.

These are subjects which I am unable to go into within the scope of this address. but I hope that their undoubted importance will lead some of our members to present papers on them during the coming session.

It now remains for me, gentlemen, to thank you once again for the honour you did me a year ago in electing me your President, an honour which I for one esteem most highly.

I have now great pleasure in welcoming my successor, Mr. J. W. Roberts, B.E., to the Chair, and wish him a continuance of the kind support I have always received, and trust that the Society will have a prosperous year under his direction.