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The Distributiton and Conversion of Received Currents — Source link

Henry G. Stott

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 22, 1901.

The 152d meeting was held this date at 12 West 31st Street, and was called to order by President Hering, at 8.30 P. M.

THE SECRETARY:—At the meeting of the Council this afternoon, the following Associate Members were elected:

Name.	Address.	Endorsed by
ALBIN, HENRY ALLISON	General Manager and Electrical Engineer, Concord St. Railway, Concord, N. H.	Chas. R. Cross. J. B. Smith. S. B. Paine.
BULL, ROBERT WILSON	Electrical Engineer, The New Jersey Zinc Co., (of Penn.) Palmerton, Pa.	Gano S. Dunn. F. V. Henshaw. Horace Dowie.
COOKE, GEORGE A.	Electrical Engineer and Supt., Hawaiian Electric Co., Honolulu, H. I.; residence, Chicago, Ill.	Wynn Meredith. A. M Hunt. A. Gartley.
EDMANDS, SAMUEL SUMNER	Assistant in Electrical Engineering, Ohio State University, Columbus, O.	F. C. Caldwell. H. B. Smith. E. E. Brown.
HOWE, WINTHROP KEITH	Assistant Engineer, Taylor Signal Co., 256 Delaware Ave., Buffalo, N. Y.	H. H. Wait. E. P. Warner. V. R. Lansingh.
JOHNSON, WALLACE CLYDE	Chief Engineer, The Niagara Falls Hydraulic Power and M'f'g. Co , Niagara Falls, N. Y.	J. F. Kelly. I. R. Edmands. S. B. Winchester.
MUDGE, ARTHUR LANGLEY	Electrical Engineer, Grand Trunk Railway Co., Montreal, Canada.	R. B. Owens. P. G. Gossler. R. M. Wilson.
PERRY, JOHN	President of I. E. E. (England) 34 Palace Gardens Terrace, London W. England.	W. J. Hammer. Ralph W. Pope. Carl Hering.
ROCKWOOD, DWIGHT CARRINGTON	Student, Westinghouse Elec. & M'f'g Co., Box 104, Edgewood Park, Pa.; residence, 954 Main St., Buffalo, N. Y.	Chas. F. Scott. John S Peck. H. L. Wallau.

SPARKS, CHAS. PRATT	Chief Engineer, The County of London Electric Lighting Co., Surrey, England.	Wm. J. Hammer Ralph W. Pope. Carl Hering.
STRONG, JAMES REMSEN	President, The Tucker Electric Construction Co., 35 South William St., N. Y.; residence, Short Hills, N. J.	H. A. Sinclair. T. C. Martin. W. D. Weaver.
SWINTON, ALAN ARCHIBALD CAMPBELL	Consulting Electrical Engineer, 66 Victoria St., London S. W. England.	Wm. J. Hammer. Ralph W. Pope. Carl Hering.
THOMAS, JOHN WILLIAMS	Construction Engineer, Electric Storage Battery Co., Hokendauqua, Pa.	Louis Duncan. C. T. Hutchinson Leonard Waldo.
THOMSON, GEO. ANDROS	Special Agent, The Adams-Bagnall Electric Co., 26 Cortlandt Street, New York; residence, Somerville, N. J.	J. J. Bellman. F. M. Pedersen. Horace Dowie.
VAN VLEET, ROY MITCHELL	Student, Westinghouse Elec. & M'f'g Co., Edgewood Park, Pa.; residence, Port Huron, Mich.	H. L. Wallau. Chas. F. Scott. Jno. S. Peck.

Total 15.

The following named Associate Member was transferred to full membership:

Approved by Board of Examiners, February 8th, 1901.

ARTHUR L. HADLEY, Electrical Engineer, Fort Wayne Electric Works, Fort Wayne, Ind.

At the meeting of the Council this afternoon, the following names were selected as the Council nominations for the coming election.

For *President*, Charles P. Steinmetz; for *Vice-Presidents*, Samuel Sheldon, George F. Sever, Michael I. Pupin; for *Managers*, John W. Lieb, Jr., Charles F. Scott, Samuel Reber, W. E. Goldsborough; for *Treasurer*, George A. Hamilton; for *Secretary*, Ralph W. Pope.

THE PRESIDENT:—The paper of the evening which is next in order is on the "Distribution and Conversion of Received Currents," by Henry Gordon Stott. I will call upon Mr. Stott to read his paper.

A paper read at the 152nd Meeting of the American Institute of Electrical Engineers, New York, March 22nd, 1901. President Hering in the Chair.

THE DISTRIBUTION AND CONVERSION OF RECEIVED CURRENTS.

BY HENRY GORDON STOTT.

Before proceeding to the subject proper of this paper it will be interesting to give a brief description of the apparatus and lines generating, transforming and conveying the current from Niagara Falls to the Terminal House at the city limits of Buffalo, where the overhead lines terminate and the underground distributing system for the various purposes to be hereafter described, begins.

The power received in Buffalo originates at the well known plant of the Niagara Falls Power Company at Niagara Falls, N. Y., in water driven turbines direct connected to 5,000 H. P. two-phase 2,200-volt 25-cycle generators. Ten of these generators are now installed, and a new wheel pit is being excavated on the south side of the surface canal, parallel to the present power house, for twelve more generators of the same size, which will give an ultimate total capacity of 110,000 H. P., and it is a very safe prophesy to say that every horse-power of it will be sold as fast as the turbines and generators can be installed, as the present installation of 50,000 H. P. is all contracted for, and already many customers find themselves in the position of Oliver Twist, and with no better results.

The 2,200-volt two-phase current is conducted into the Transformer House, where, after passing through time element overload circuit breakers, it enters two distinct banks of step-up transformers of the air cooled type, of an aggregate capacity of 12,000 K. W., which are arranged in pairs for the two-phase three-phase connection at the same time to change the pressure to 11,000 volts. Within a couple of months the secondaries, which are now in multiple, will be connected in series to give 22,000 volts as originally intended.

The 11,000-volt three-phase current from the secondaries of the two banks of transformers is brought directly out in cables on large special porcelain insulators set in iron fixtures in the air chamber, and then on the regular helmet type porcelain insulators on timbers on the wall. The lightning arresters are of the usual multi-gap type with reactive coils in series, and in a second type with an additional check to the current in the shape of carbon resistances to prevent the live current following the lightning discharge.

The two three-phase 11,000-volt circuits running on the same pole line to Buffalo, each consist of three bare stranded copper cables of 350,000 cm. area, forming equilateral triangles on each side of the pole, the sides of the triangles being three feet. In the run of 23 miles to Buffalo, the lines are transposed five times in order to equalize and minimize the inductive drop on all phases, and at Tonawanda where a branch line is taken off for Tonawanda and Lockport, lightning arresters are installed of a type similar to those used at Niagara Falls and Buffalo. During the first two years operation of this line, iron guard wires grounded at every alternate pole were used for protection from lightning, but so much trouble was caused by them falling on the lines that after striking a balance between the supposed protector and the known trouble, the result was so overwhelmingly against the former that the guard wires were taken down, and the interruptions due to line trouble very materially reduced. The remaining trouble on this part of the system was almost exclusively due to the ever present boy, who speedily discovered that by a little dexterity in the manipulation of an old piece of iron wire or hoop, he could produce brilliant Fourth-of-July effects at will. The cables were, at this time, only 18 inches apart, and an arc once established would travel backwards along the line with ease until the circuit breakers eventually opened at the Falls. This trouble was remedied very effectually by separating the cables three feet apart as at present, and at the same time arranging them so that they formed a triangle with the apex below instead of all being on the same plane as formerly.

At the Terminal House situated at the city limits of Buffalo, the lines now terminate in a common set of bus bars, and to these

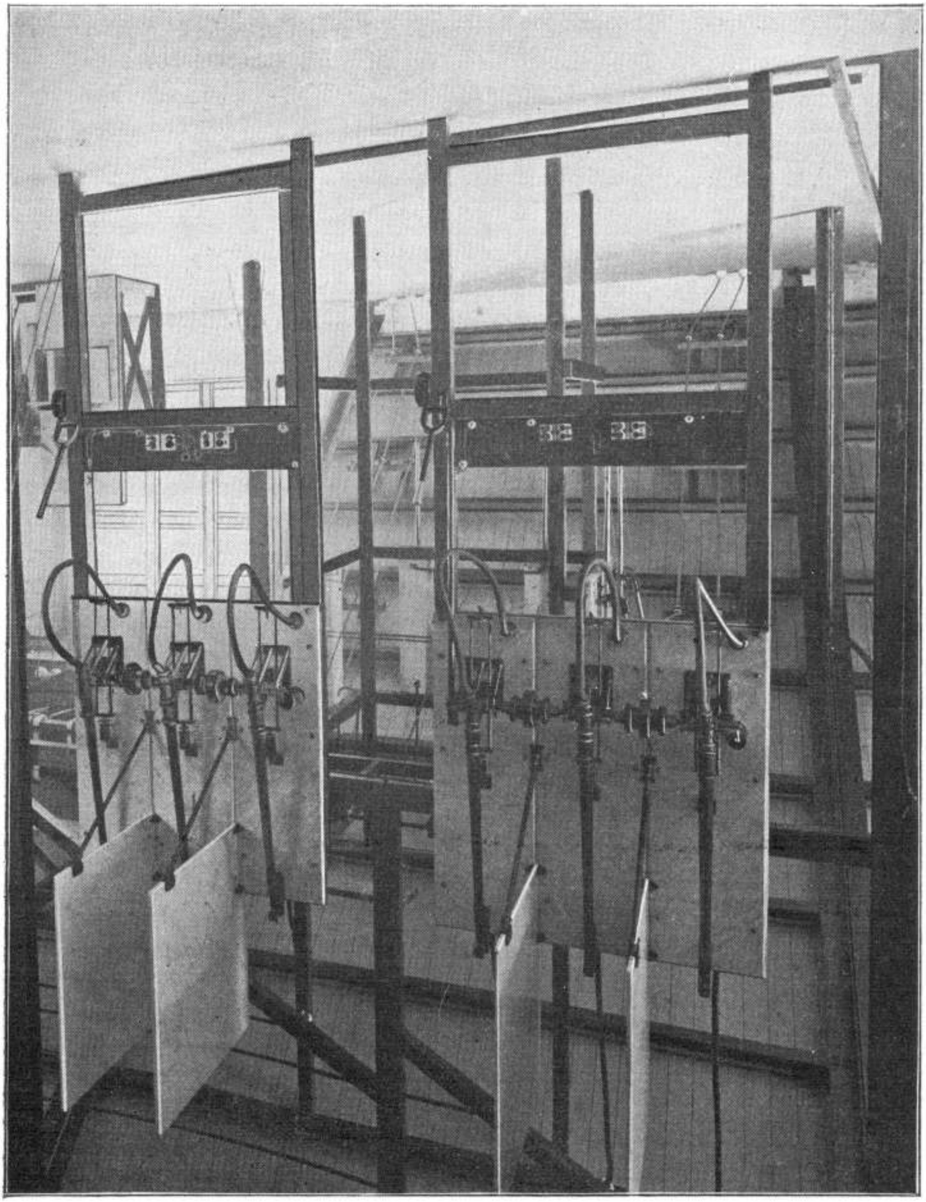


Fig. 1.

bus bars are connected the five three-conductor lead covered cables which lead to the various sub-stations.

Simultaneously with the increase of line pressure to 22,000 volts there will be installed in the Terminal House six 2,250 K. W. step-down transformers of the oil and water cooled type, reducing the pressure to 11,000 volts for distribution in the underground cables.

A third line is now being built from Niagara Falls to the Terminal House, following a different route, in order to give greater security of service, but as the present pole line is built with very heavy poles 90 feet apart, no great anxiety is felt as to the possibilities of even Lake Erie zephyrs combined with sleet, affecting it.

Following the current as it comes into the Terminal House on the 22,000-volt lines, we first come to the lightning arresters which are of the well known multi-gap type, the connections to each line having a reactive coil inserted to prevent the rush of static discharge being followed by a greater current, from the line, than the gaps of non-arcing metal can interrupt by cooling off the air and extinguishing the arc at the zero period of the wave. As an interesting fact it may be observed that the number of 1/32″ standard gaps necessary to prevent the current arcing across under normal conditions is not directly proportional to the pressure, but increases in the same ratio as the arcing distance in air of a single gap.

The high-tension circuit-breakers shown in Fig. 1 are of a very simple form, but one which has invariably given excellent results, being simply a long hollow wooden arm containing a flexible insulated conductor, which completes the circuit through copper contact blocks, with auxiliary carbon contacts for breaking the arc on. When the circuit-breakers open, the arm describes the arc of a circle giving a break of over three feet, and as the arc ascends rapidly, due to the currents of hot air generated by it, the length of the arc is rapidly increased until broken. The position of the marble barriers above the panel illustrate the height to which the arc may be expected to rise in extreme cases. After passing through the circuit-breakers the current is led to bus bars, and from these to the two groups of transformers only three cables being carried from the panels to each group of three transformers, as the delta connection is made at the terminals. The low tension, or 11,000-volt secondaries are connected in the same way to the bus bars on the secondary panels, and from here the five three-conductor lead covered cables distributing the current to the various sub-stations in Buffalo, receive their current after passing through the usual recording and indicating meters and circuit-breakers of the same type as on the 22,000-volt side. All these circuit-breakers have a time element device which can be regulated so as to make the circuit-breakers open only after a short-circuit has lasted a predetermined number of seconds; similar devices are used on all over-

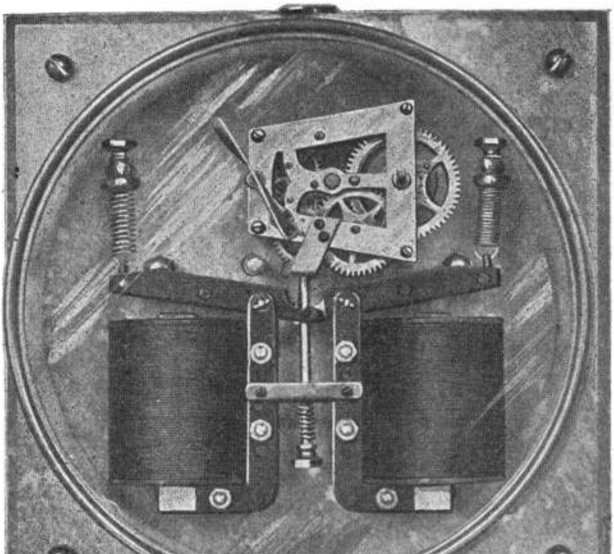


FIG. 2.—A view of one of the time element relays. The two coils are connected respectively with current transformers in two phases of the line. Either releases the clockwork which after a proper interval closes a local circuit through the tripping coils of the breakers.

load circuit-breakers, the time limit varying inversely as the distance from the source of power, in order to prevent the more distant stations shutting down the others.

We now come to the distribution and conversion of the current in Buffalo, but the scope of this paper will only permit of the more important and novel features being taken up and described in the briefest manner possible.

DISTRIBUTION.

Referring to the diagram, Fig. 5, showing the system of distribution connecting the seven sub-stations to the Terminal House, it will be seen that there are five three-conductor cables leaving the

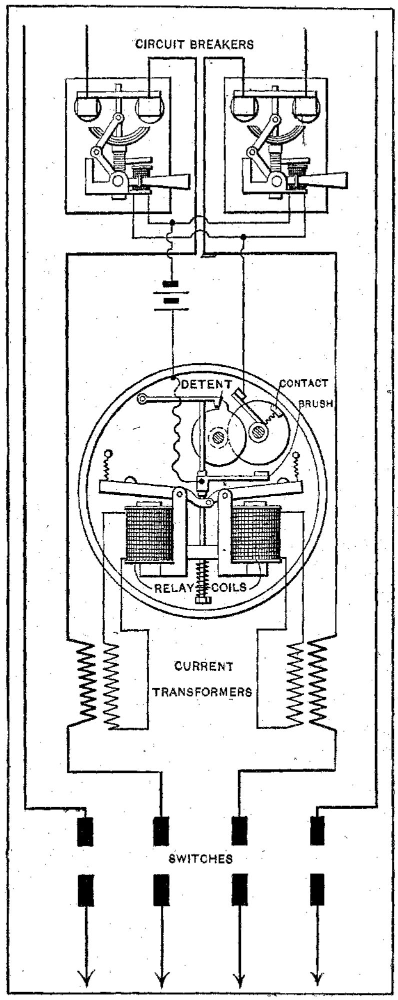


FIG. 2A.

Terminal House, each sub-station being connected to at least two cables, either one of which is capable of carrying the full load, and in the other stations having more cables, any two are capable of carrying the full load. The necessity for duplicate service to prevent shut-downs through cable trouble, is so obvious as to necessitate no further comment, but the automatic apparatus used to cut out the faulty cable is novel and interesting. Before describing the system, a brief description of the various circuit-breaking apparatus used will be in order.

Figure 1 shows a type of breaker used in the Terminal House and in sub-station No. 3, which has already been described; Figs. 2 and 2A, show one known as the shunted fuse type, in which the current is carried by a spring copper leaf brush which is forced into

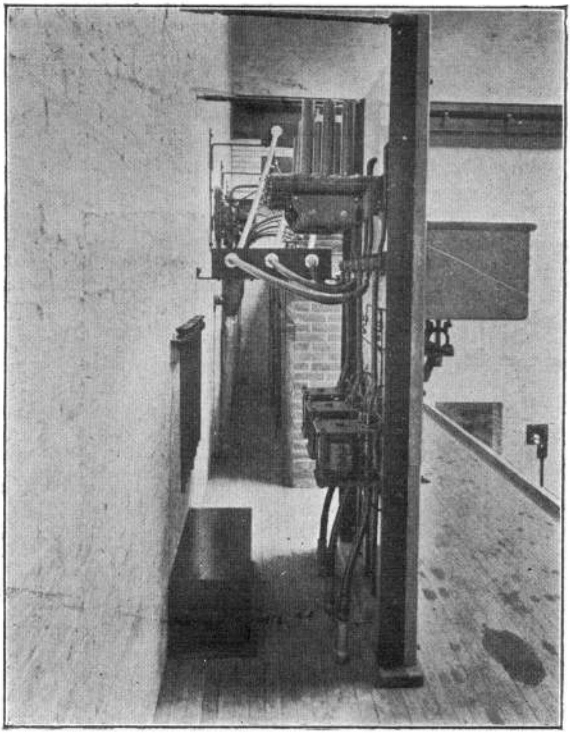


FIG. 2B.

contact with the copper blocks by means of a toggle joint lever. In shunt with this is a copper fuse wire 20″ long of No. 22 B. & S. gauge fastened in a groove in a stick having near each end brass contacts, which, when the fuse stick is forced into the receptacle mounted in the marble panel, forms a shunt on the circuit-breaker proper. The fuse stick is covered with fibre paper, and three holes are punctured through this paper, so that when the stick is in place in the enclosing wooden tube, the holes in the paper exposing the copper wire, are opposite three fibre chimneys. The gases formed by the melted copper escape with such force through these chimneys shown in Fig. 2B, that the arc formed after the circuit-breaker trips, is blown out with a noise resembling the report of a pistol.

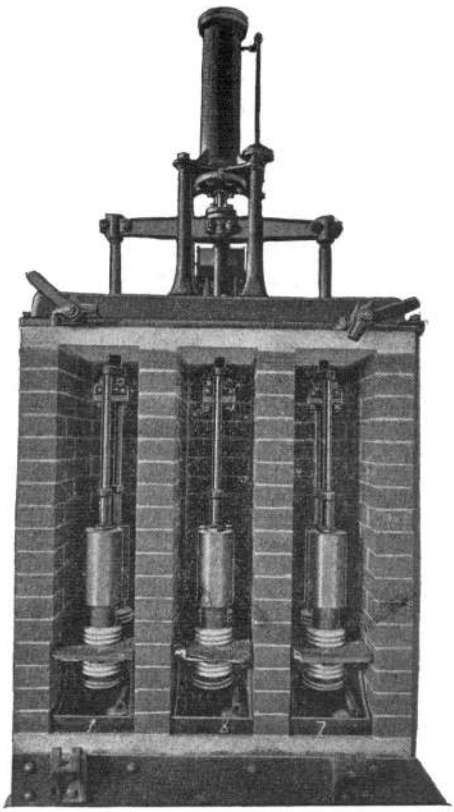


FIG. 3.

To reset the circuit-breaker, the switches in series with it are opened, the old fuse stick replaced by a new one, the circuit-breaker closed, and last of all the switches. This form of circuit-breaker has given excellent results on both 2200 volts and 11,000 volts. A time element relay is shown in Figure 2, which is used on the overload apparatus, the retardation being accomplished by a train of clockwork operated by an ordinary spring. The brake on the clock train (which is normally at rest) is released by either of the two magnets, one being connected to the secondary of a transformer in series with phase No. 1, and the other similarly connected to phase No. 2, the diagram showing the connections for a two-phase circuit. Variation of the time limit is accomplished by changing the angle of the air paddles on an axis normal to the spindle driving them.

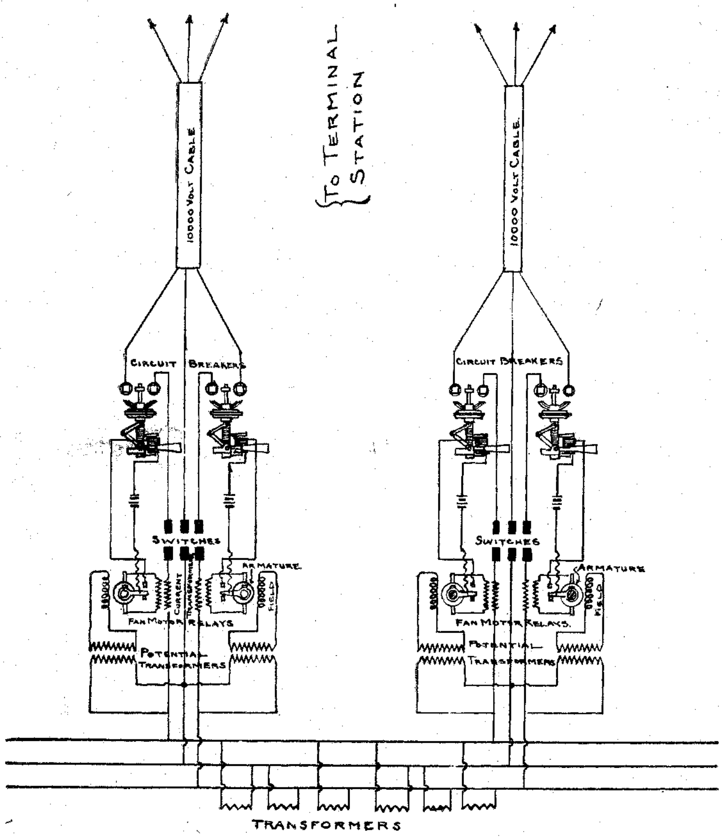


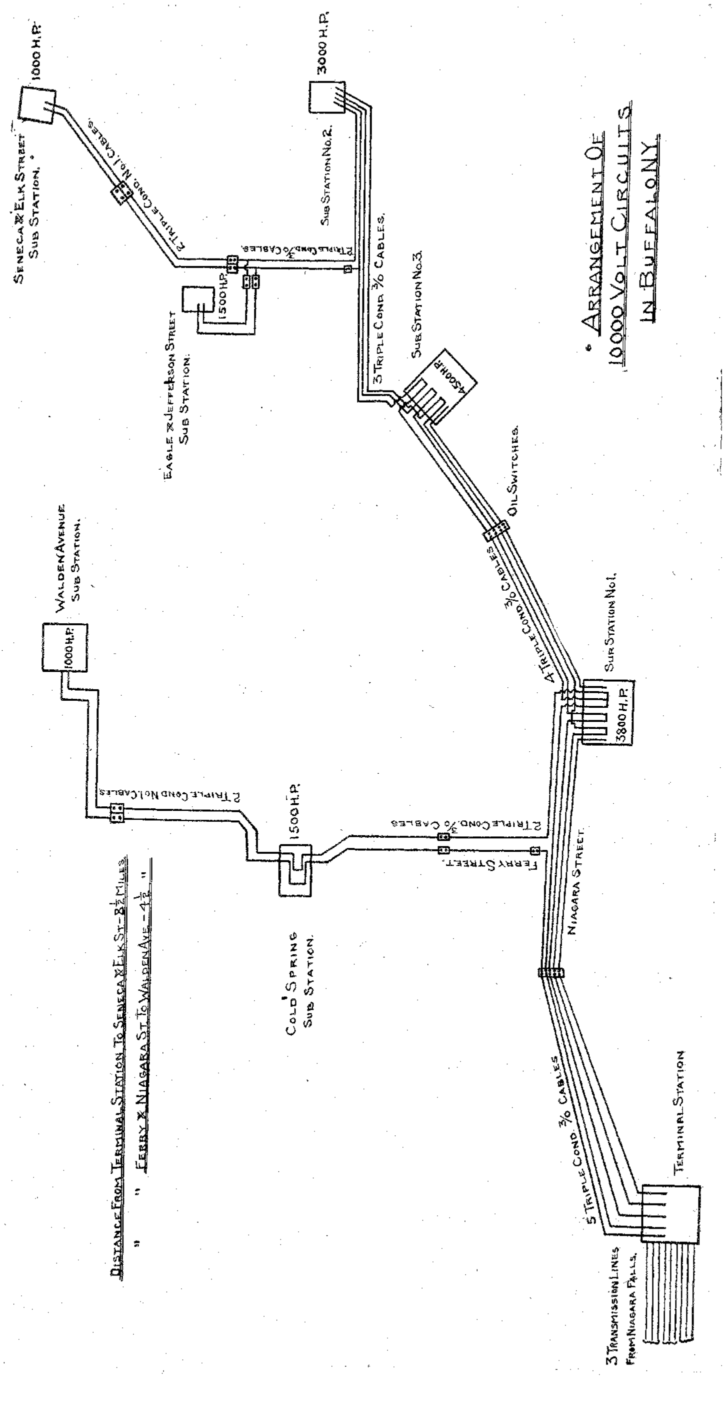
FIG. 4.

Figure 3 shows a third type of switch which may be operated by air, controlled by a relay or by any other agency, and consists simply of a U-shaped copper rod connecting two brass cylinders, with spring sockets, filled with oil. When the U-shaped rods are withdrawn from the copper receptacles at the bottom of the cylinders the arc is broken in oil in two places.

The cut illustrates the separation of the phases by means of brick partitions, so that in case of failure a short-circuit cannot take place. These switches have also given excellent results on all pressures.

It is quite obvious that any sub-station supplied from two cables in multiple through overload circuit-breakers, is thoroughly protected from damage due to failure of the apparatus in itself, but a few moments' consideration will also show that it is not protected from a shut-down due to one of the cables supplying it becoming defective, and thereby causing the second cable's circuit-breakers to trip, from current supplied through them to the short-circuit in the cable. To obviate this, the reversed current circuit-breaker has been devised, and the connections are shown in Figure 4. The circuit-breaker proper is of the same type as those shown in Figures 1, 2 and 3, but the novelty lies in the means of tripping it. The relay consists of a small direct current fan motor having laminated fields and armature, the armature circuit receiving current from the secondary of a transformer connected in series with one of the phases of one cable, the fields receiving current from a small constant potential transformer connected to the same phase. The armature shaft carries an arm whose play is limited between two stops, one of which is connected to the tripping coil of the circuit-breaker, the other stop being blank. Normally with these connections the torque exerted upon the armature is in such a direction that the contact arm attached to the armature shaft is strongly pulled against the blank stop, a spring assisting in this pull.

Suppose that a short-circuit comes on No. 1 cable, the conditions are now radically changed; the normal flow of current into the bus bars from both cables no longer exists, for No. 2 cable will now be feeding current into the short-circuit in No. 1 cable through the bus bars and circuit-breakers of No. 1, thereby reversing the direction of the flow of energy in the armature circuit of its relay, and as the field remains the same as before, the contact arm swings over rapidly, completing the local circuit and tripping the circuit-breakers, leaving the sub-station bus bars connected to the good cable only. The same action will take place at all the sub-stations to which this cable may be connected, and finally the overload circuit-breakers in the Terminal House will cut out the faulty cable entirely.



1000 H.P.
Seneca & Elk Street Sub Station.
2 Triple Cond. No. 1 Cables.
3000 H.P.
Sub Station No. 2.
2 Triple Cond. 3/0 Cables.
1500 H.P.
Eagle & Jefferson Street Sub Station.
3 Triple Cond 3/0 Cables.
Sub Station No. 3.
4500 H.P.
Arrangement Of 10000 Volt Circuits In Buffalo NY
Oil Switches.
4 Triple Cond. 3/0 Cables
Sub Station No. 1.
3800 H.P.
Walden Avenue Sub Station.
1000 H.P.
2 Triple Cond No. 1 Cables.
1500 H.P.
2 Triple Cond. 3/0 Cables
Ferry Street.
Niagara Street.
Cold Spring Sub Station.
Distance From Terminal Station To Seneca & Elk St - 8 1/2 Miles
" " Ferry & Niagara St To Walden Ave - 4 1/2 "
5 Triple Cond. 3/0 Cables
Terminal Station
3 Transmission Lines From Niagara Falls.

Fig. 5.

The five cables shown in Fig. 5, connecting the Terminal House with the sub-stations are all of the 3-conductor type, that is, have three 000 B. & S. gauge copper cables separately insulated under one lead covering, the three insulated conductors being twisted into a rope, and the interstices filled with jute yarns to give an even round surface for the lead to rest on.

Three of these cables are insulated with a wall of 9/32″ rubber mixture having 30 per cent. of pure Para rubber; one has a wall of $\frac{1}{4}''$ rubber mixture with 40 per cent. pure Para, and the fifth cable has on each conductor 13/64″ paper, and around the three insulated conductors an additional belt of 13/64″ paper. All the cables have a lead jacket $\frac{1}{8}''$ thick, over all, the outside diameter of cables being approximately $2\frac{3}{8}$ for the rubber and $2\frac{5}{8}$ for the paper.

Experience with the first four cables seems to indicate that a rubber insulated cable with 9/32″ wall, 30 per cent. pure Para, is perfectly reliable for 11,000 volts, but that $\frac{1}{4}''$ insulation even with a higher percentage of pure Para is not.

The 18 miles of paper insulated cable having only recently been installed, no conclusions can be drawn with safety, but as there are about 30 miles of the rubber covered cables which have been installed for from two to three years, the above conclusions would seem to be drawn from experience with a sufficient amount of cable to justify confidence in its reliability.

In the sketch showing the cable system it will be noticed that at several points "oil switches" are indicated; these are installed in water-tight iron boxes in the manholes, in such positions as to break the cables into sections of about one mile in length, so that in the event of trouble the fault may be readily localized and the bad section switched off in the manholes without interfering with the rest of the cable.

Glazed tile conduits are used, and have proved, when dry, to be an effectual safeguard against electrolysis, the only cases of trouble from the latter having occurred in manholes in which the cables were submerged in water. Considerable trouble was caused for a time by the breaking down of the rubber near the end of the lead covering where the cables were connected to the switchboards, and investigation showed that this was caused by the ozone generated by the static discharge taking place from rubber to lead, but this has been overcome by wiping on a large brass cable head to the lead sheath and thus greatly increasing the distance between rubber and grounded sheath, the cable head being filled with insulating compound poured in hot, a hard rubber separator keeping the rubber covered conductors away from the brass whilst the compound was solidifying. Reference to the diagram Fig. 5, will show that a further precaution has been taken at the two most important sub-stations, Nos. 1 and 3, to prevent interruption due to cable trouble, viz., to run loops from all cables into them instead of taps. By this means, if a fault should simultaneously develop in a section of one cable between these stations and in a section beyond either of them, cross-connections can be made very rapidly and easily, by means of which no cable will be overloaded for more than the short period necessary to make these cross-connections.

To sum up: The means adopted for protection to the distributing system are:

1. Time element overload circuit-breakers.
2. Reversed current circuit-breakers.
3. Sectioning switches in manholes.
4. Loop switches in principal sub-stations.

CONVERSION.

The 11,000-volt 25-cycle three-phase current distributed to the seven sub-stations in Buffalo is manifestly unfit for use in the supply of power or light without transformation in the former and conversion in the latter case, as 25-cycle is much too low a frequency for arc lighting, which promises to displace incandescent lamps to a great extent in the near future.

In discussing the various means employed to make this power available to the customer, we will begin with the simplest and then proceed to the more complex. The simplest and most efficient method is evidently to reduce the pressure by means of static transformers of large capacity and high efficiency, and deliver three-phase 2200-volt current to the various customers by means of a secondary network of cables. This is done in substations Nos. 1, 2 and 3, where 2200-volt three-phase current is delivered by underground and overhead cables to customers for use in malt houses, grain elevators, machine shops, dry docks, bakeries, tanneries and all sorts of manufacturing establishments to the extent of about 4,000 H.P. This power is utilized in the above places chiefly by means of induction motors, some of which receive the current directly at 2200 volts, but in the majority of cases at a reduced pressure of 440 or 220, the reducing transformers being supplied by the customer. For grain elevators, in which a large amount of fine dust of an explosive nature is present, the induction motor presents an ideal solution of the power problem as the safety and controlling devices can be located in a separate building, so that no spark can cause an explosion or fire. The efficiency of transformation with this system is evidently that of the transformers only, which in sizes of 250 K.W. and upwards is from 97.5 to 98.3 per cent. at full speed.

The largest user of power in Buffalo is the International Traction Company, which receives a total of 7000 H.P. in five sub-stations, No. 1, Cold Springs, Walden Avenue, Eagle and Jefferson streets, and Elk and Seneca streets, where the power is distributed to their 550-volt direct current feeders after being transformed from 11,000 volts to 375 volts and converted in rotary converters to 600-volts direct current.

An interesting comparison is the relative efficiencies and cost of static transformers and rotary converters as against motor generators receiving the 11,000-volt current direct into the motor, and converting it into 600-volt direct current by means of a generator coupled to the same shaft, and is given in the following table:

EFFICIENCIES: 200 K.W. UNITS.

	Transformer	Rotary	Combined	Motor	Generator	Combined
Full load.	97.5	93.0	90.67	95	92	87.4
¾ load.	97.1	92.5	89.81	94	91	85.54
½ load.	96.0	90.0	86.40	92	88.5	81.42

From the above table it will be seen that the transformer and rotary converter give 3.27 per cent. at full load, 4.27 per cent. at three-quarter load and 4.98 per cent. at one-half load better efficiency than the motor generator set.

The investment shows a saving in favor of transformers and rotary converters of about 19 per cent., so that for purposes such as railroad work, where no great refinement of regulation is required, the rotary is beyond doubt the best and most economical.

A view of a sub-station is given in Fig. 6, which is typical of all; the incoming current enters a three-pole oil switch, which is known as an emergency switch, and from there branches to several oil switches, each of which controls the primaries of three 150 K. W. static air-blast transformers connected in delta; the secondaries, also delta connected, go direct to the collector-rings of a 400 K. W. rotary converter, so that the three static transformers and rotary converter form one unit, being in fact started from the direct-current end and synchronized by means of small potential transformers on the 11,000-volt primaries.

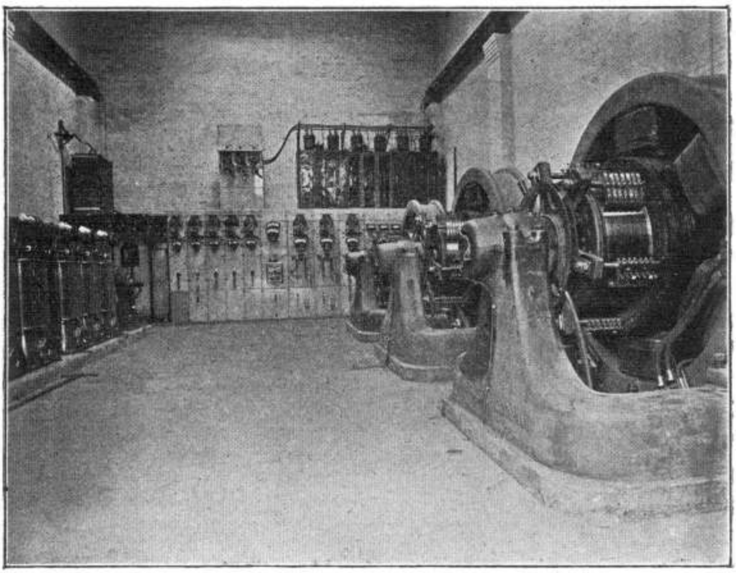


FIG. 6.

To provide for the emergency of a total shut down of the power circuits, those sub-stations which have no storage battery auxiliary from which direct current may be got for starting the rotaries, a small motor generatoı set is installed, consisting of a 30 H. P. induction motor direct-connected to a 20 K. W. 600-volt direct-current generator. This set is supplied with alternating current by means of a three phase oil-cooled transformer, reducing the pressure from 11,000 to 375 volts; as soon as the power is on the cables the induction motor is started, the small direct-current generator is connected to the bus-bars and one of the rotaries started and synchronized in the usual way, after which the motor generator set is shut down and the remaining rotaries started from the first. From the five sub-stations distributing power to the direct-current feeders great economy of distribution is obtained and an equality of pressure at practically every point of the system, which would be practically impossible with a single plant with 550-volt feeders covering the same distance. Storage batteries are installed at Sub-stations No. 1, Cold Springs and Eagle and Jefferson, having a total capacity for 1½ hours of 2,400 H. P.

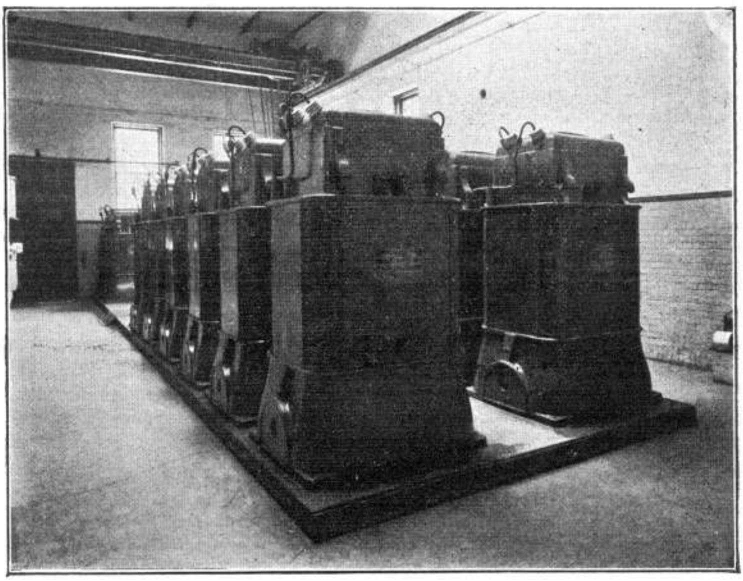


FIG. 7.

at 575 volts. They are used principally to help carry the peak load between 5 P. M. and 6.30 P. M. and to take up part of the extreme fluctuations of load through differentially wound boosters.

We now come to the last and most interesting plant connected to the transmission system in Buffalo, viz., that of the Buffalo General Electric Company, the transformer-house of which is marked "Sub-station No. 3" on the sketch showing cable system, in which 4,000 H. P. is received from the power company, and after being transformed to 360 volts is converted, by means of motor generator sets, rotaries, etc., into four different kinds of service—constant continuous current for street arc lighting, 60-cycle quarter-phase current for incandescent and arc lighting in the more remote districts, three-wire 220-volt continuous current for the down-town district, and 550-volt continuous current for power to motors, elevators, etc.

The transformer-house, built as an annex to the main station, has twelve 250 K. W. transformers, reducing the three-phase

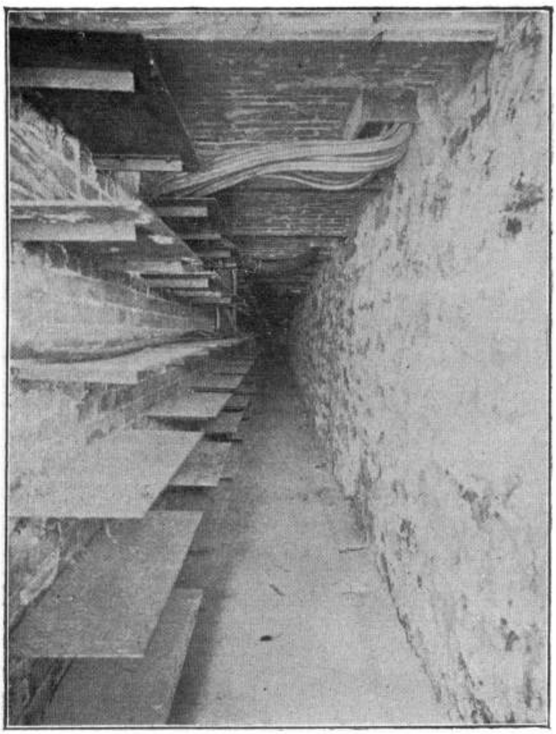


FIG. 8.

11,000-volt current to three-phase 360 volts. The transformers [see Fig. 7] are arranged in two rows instead of three as usually in order to facilitate the rapid exchange of one in case of trouble. By arranging them in this way the transformer has only to be raised half an inch by the hand-crane and then run out of the way to make room for the spare one, an operation requiring only an extremely short period compared to that necessary to lift the transformer over the others. The transformers stand over a brick air-chamber 30′ x 9′ x 7′ high, into which three 2 H. P. induction motors direct-connected to air-blowers force cool air, giving an even pressure of about half an ounce in all parts of the chamber. Access is had to the air-chamber through double air-tight doors, so that a man can work on the terminals or connect up a new group without interfering in any way with the air supply. Iron shelves on the outside of the brick walls of the air-chamber form supports for the primary cables leading to the switchboards on the one side and for the secondaries on

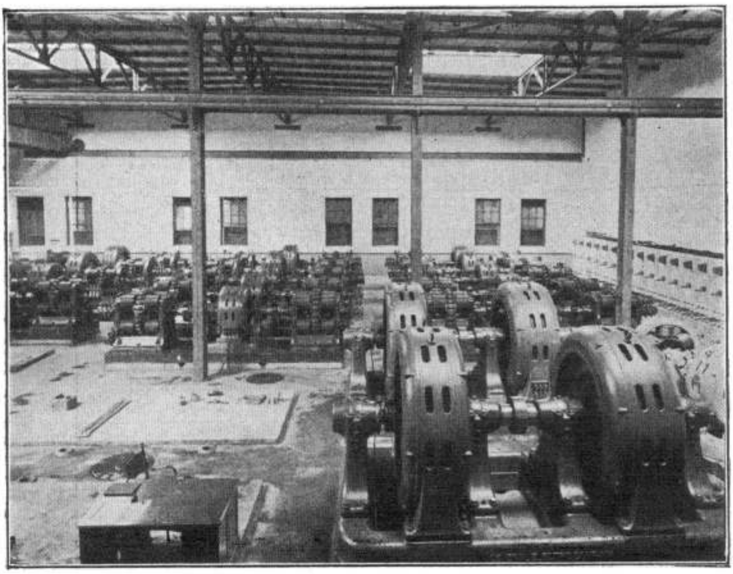


Fig. 9.

the other, giving wide separation for safety, similar to those in Fig. 8.

The transformers are connected to the primary and secondary switchboard panels by rubber insulated and lead covered cables; each transformer is wired single-phase to the panels, the delta connection being made after passing through spring expulsion type aluminium fuses on the primary side, and ordinary long break aluminium fuses with barriers on the secondary side, so that in the event of a transformer burning out it will cut itself out of circuit without affecting the other two of the same group.

The secondary current after going through the usual recording and indicating instruments, terminates in three heavy copper bus bars, extending the full length of the secondary board, to which are attached the cables bringing the current into the main building of the Buffalo General Electric Company.

In adopting the secondary voltage of 360, a number of points were taken into consideration, the principal one being that a large and healthy day load in 550-volt direct current motors was being supplied at the time steam was used for motive power, and could not well be discontinued, so that voltage was adopted which would permit of rotaries being run without any further transformation. This pressure besides being very safe for cables and motors, is a very economical one to build for, as it permits of the use of bar winding on all sizes, and as all motors are of the revolving field type, the question of carrying heavy current in the collector rings was left out. The only additional cost due to the low pressure was in the cables within the plant, and this was more than balanced by the saving in a further transformation for the 550-volt rotaries and in the additional safety of bar winding versus wire.

The power house, Fig. 9, is a building 91'x91', having a row of columns down the center, each half of the building being spanned by a crane traveling the full length with transfer points from one crane to the other.

In this building having 8281 square feet of floor surface are installed 6460 H. P. in motors, 6073 in generators, and 600 H. P. in rotaries, a total of 13,133 H. P. in electrical machinery, giving a floor space of 0.63 square foot per H. P. or 1.24 square feet per H. P. of generating capacity, including all regulating apparatus, switchboards, etc.

Apparatus for Street Arc Lighting.

At the present day if the problem of arc lighting for street purposes with 25-cycle three-phase current supplied, were to be placed before an engineer, several methods of solution would suggest themselves in the following order: 1st, rectifiers; 2d, motor generator sets, converting to 60 cycles constant potential with some form of transformer or reactive coil to regulate for constant current; 3d, motor generator set converting to constant continuous current; 4th, motor generator set converting to constant alternating current with series transformers and condensers.

The full load efficiencies of the four systems with comparative investments and full power factors are approximately as follows:

1	2	3	4
Rectifiers.	Motor Generators 60 Cycle.	Motor Generators Constant D. C.	Motor Generators Constant A. C.
88	83.94	78.9	86.6% Efficiency.
53	100	94	94 % Investment.
70	100	100	100 % Power Factor.

From the above table it will be seen that the rectifier leads in all respects save one, viz., power factor (the power factors given are those of the 25-cycle end, the receiver power factor

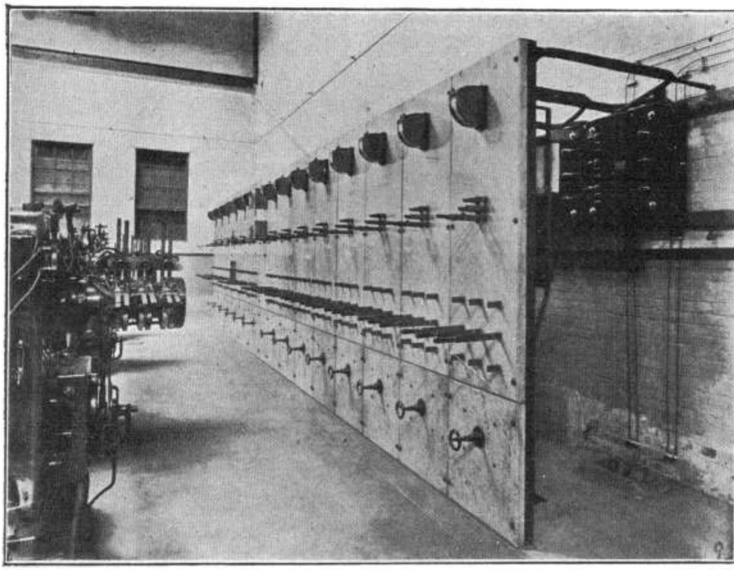


FIG. 10.

being of small importance), but in a system where the arc lighting forms a considerable portion of the system this is a serious feature, especially with generators not having good inherent regulation.

Owing to existing contracts with the city, the company was forced to adopt the third plan, but after the expiration of the present contract it will probably adopt the fourth plan, installing enclosed A. C. lamps.

The arc lighting equipment at present consists of 14 motor generator sets, each set consisting of one 150 K. W. revolving field type three-phase synchronous motor direct-coupled to two 125-light 9.6 ampere Brush arc generators, the motor being in the center, with a generator on each end, coupled by means of a very simple but effective type of insulating coupling, consisting of four arms or spiders on the motor-shaft and a similar number on the generator, compressing spring rubber rolls $3\frac{1}{2}''$ in diameter by $4\frac{3}{4}''$ long between them.

These motors are started in a very simple manner. The switchboard panel, shown in Fig. 10, controlling each motor, has mounted on it one ammeter, one double pole field switch

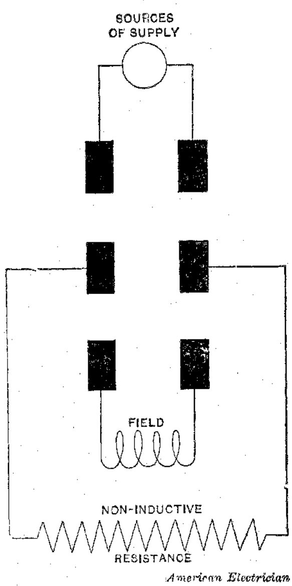


FIG. 11.—Circuits of switch shown in Fig. 10.

with discharge resistance as shown in sketch, Fig. 11, three single pole double throw knife switches and a rheostat. The fuse base is mounted on the back. Fastened to the wall behind each panel are the reactive coils for starting the motor.

To start the motor the three single pole switches are thrown down, thus connecting the motor armature to the bus bars through the reactive coils; the motor comes up to full speed in about 50 seconds, taking at the start about 150 per cent. full-load current. The time of attaining synchronism is determined by touching the blades of the field switch connected to the revolving fields on the discharge resistance clips and noting if any spark occurs. In the absence of any, the field switch *is closed*, exciting the fields and the single pole double throw switches turned up one at a time (the motor running single-phase meanwhile).

The spark at the discharge resistance terminals is of course due to the difference in frequency or slip between the impressed frequency and that due to the speed of the motor. At the start this gives about 2,200 volts, dying down in inverse ratio to the speed attained, to zero, at synchronism.

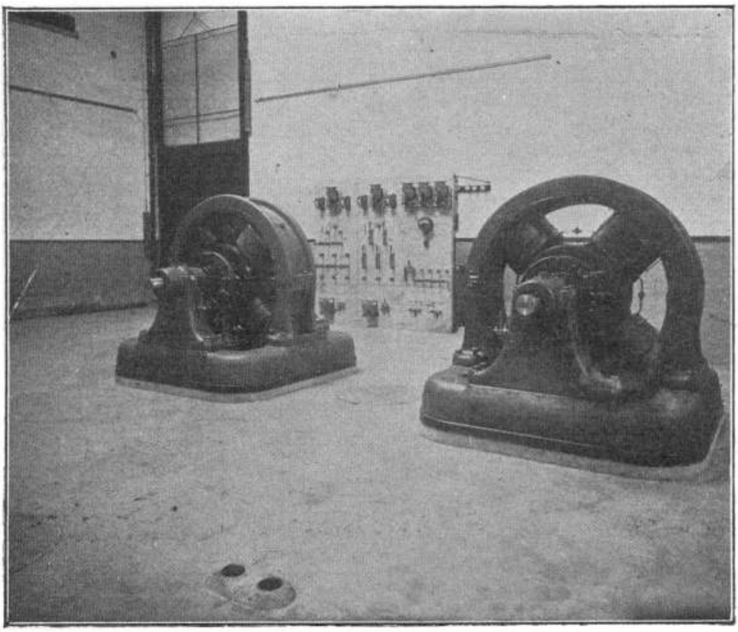


FIG. 12.

550-VOLT POWER SERVICE.

The 550-volt power service is supplied from rotary converters [Fig. 12], in the usual way, calling for no comment beyond the method of starting from the A.C. end which is done in exactly the same way as in the synchronous motors; the fields being stationary, a multiple blade switch is mounted on the frame of the machine to isolate each field winding, and thus break up the induced E.M.F. at starting.

60-Cycle System.

Three 500-K.W. three-phase synchronous revolving field type motors direct connected to 500 K W. revolving field 2200-volt quarter phase generators, furnish the current for this system. The feeders are connected to double throw oil switches, so that they can be thrown from one phase to the other to balance up the load, a further control of the voltage being obtained by means of regulators on each phase. Some rather unusual prob-

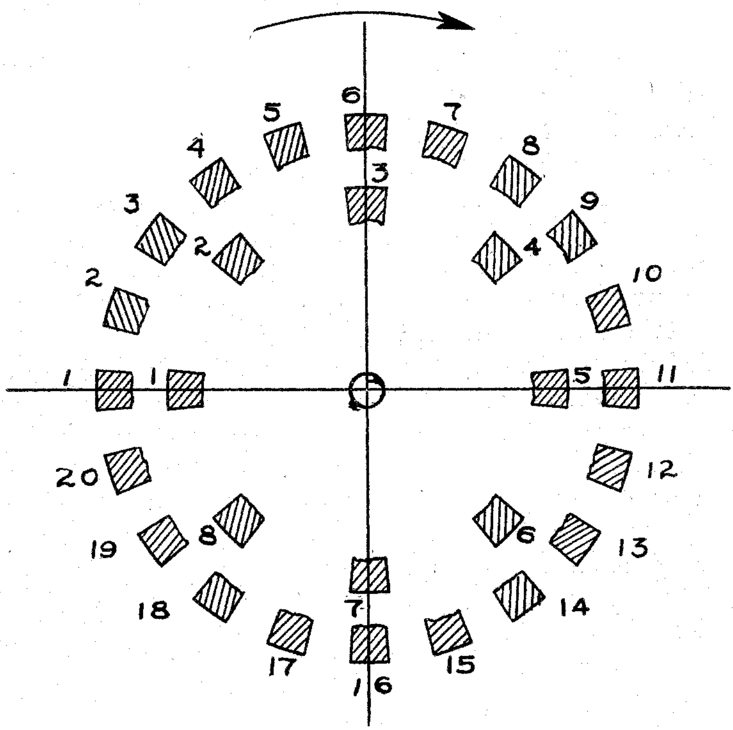


Fig. 13.

lems presented themselves in synchronizing these 60-cycle generators. The motors having eight poles and the generators 20, it is evident from the sketch, Fig. 13, that only every fifth pole of the motor will be the proper point to lock at. At first it was supposed that by opening the field switch on the motor that it would slip a pole when the generator field was excited, and the whole iron losses acted as load, but the voltmeter showing the resultant voltage between the bus bars and the ingoing generator refused to move. The synchronous motor was too good a hysteresis and reaction motor, but the solution was found in putting in a reversing field switch on the motor, thus causing it to slip a pole on each reversal. The inner circle, shown in Fig. 13, represents the motor poles, and the outer the generator. If the generator carrying load has its poles in the position 1, 1, at the moment the field switch on the motor about to go into service is closed, and the latter locks with 1, 1, in the position of 4, it is evident that we must reverse the motor fields several times in order to make it slip back to position 3, then 2, and finally 1. Whilst the position 3, 6, has a similar relation to the generator pole, to that of 1, 1, yet the polarity is reversed on the generator so that unless we reverse the generator field also, the motor must be made to slip to position 1, 1. Another peculiar feature was that supposing the bus bar voltage and that of the ingoing machine to be the same, and the machines apparently in phase, if thrown together the ingoing machine would not take more than a small fraction of the load, and no change of field strength of either motor or generator had any effect, beyond making the generator carry idle current.

We have here the peculiar combination of double synchronism, with mechanical connection besides, so that either machine may act as motor or generator according to conditions. The explanation is as follows:

The motor carrying the load sags behind a few degrees of phase, carrying with it the generator, but the latter having 2.5 times the number of poles of the motor, any sag of the motor is multiplied by 2.5, thus causing a difference of phase between the loaded generator and the unloaded one great enough to render division of load impossible. Increasing the field strength of the light generator merely results, under these conditions, in the unloaded generator supplying idle cross current out of phase with the bus bar current, and therefore not putting load on its own motor. Manipulation of the motor field rheostats can evidently accomplish nothing to bring the generators into phase.

The solution is a rather startling one, and is found in the use of oscillating currents. The in-going generator is excited to such a degree that the resultant voltage from it and the bus bars is equal to the latter; this means at half load on one, and the other light, an increase of 4 per cent. in voltage, indicating a phase angle difference of about 22.5 in the generators and 9° sag in the motor. The motor fields are weakened and the unloaded generator thrown on the bus bars. Owing to the difference of voltage and phase, the sudden closing of the circuit establishes strong oscillatory currents between the generators; these are transmitted mechanically to the motors and repeated, the amplitude gradually decreasing from a maximum value of 100 per cent. full-load current to zero as the equilibrium of the circuit is established. The whole time, from the moment of putting the unloaded generator into multiple to the disap-

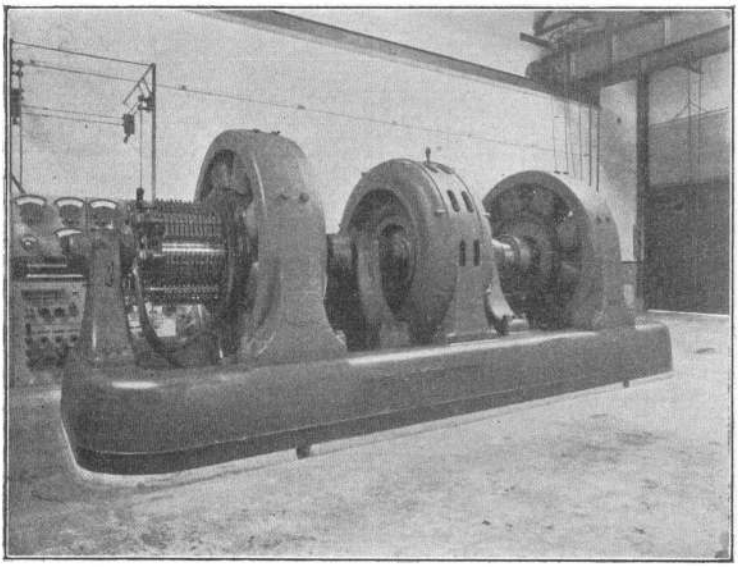


Fig. 14.

pearance of the oscillations, is usually about 45 seconds, during which the field strengths of the generators and motors are rapidly equalized, and the load will be found to be perfectly divided between the two generators, the mechanical oscillations having resulted in the only stable equilibrium possible under the conditions.

Exciters.

Before the installing of the storage battery it was necessary to have some quick means of getting continuous current, to determine the polarity of the rotary converters and energize the fields of the synchronous motors in case of a shut-down on the power circuits, and for this purpose two exciter sets consisting of 30-H. P. induction motors direct-connected to 20-K. W. 125-volt continuous-current generators were installed. Since the installation of the battery, all the exciting current is taken from it during the period of heavy load, for two reasons; first, to reduce the peak load; second, to automatically maintain an almost constant power factor of 98 per cent. leading, on the total load of the plant, due to the Edison load increasing (and bus bar pressure increasing correspondingly) simultaneously with the other station load and thus giving increased C. E. M. F. in the motors.

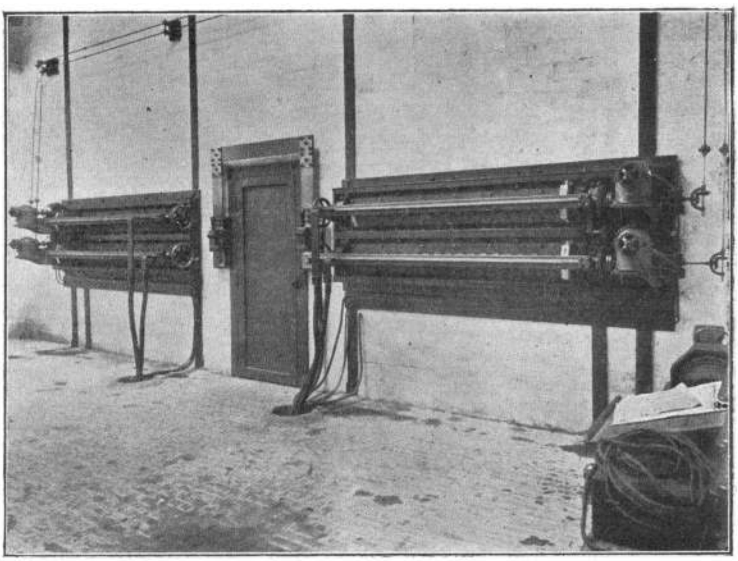


FIG. 15.

EDISON SYSTEM.

There are evidently two ways of converting three-phase 25-cycle current into 120 to 150-volt continuous current, one being by means of transformers with rotary converters, and the other with motor generator sets.

A comparison of the net efficiency of both systems for 200-K. W. units is given in the following table, the rotary including in its circuit some form of regulators capable of varying the voltage 25 per cent.:

	Motor Generator.	Transformers and Rotaries.	Difference.
Full load..........	87.40	89.87	2.47
Three-quarter load..	85.54	88.70	3.16
Half load..........	81.42	84.90	3.48

Owing to the additional regulating apparatus necessary with the rotaries, the first cost in either case is practically the same.

From the above efficiencies, rotaries would seem to be indicated as the best choice, but in an extensive power transmission scheme where nearly 50 per cent. of the load is used for railroad purposes, and the generators have a comparatively poor inherent regulation to enable them to withstand safely severe short circuits on the lines, rotaries have had to be abandoned for this service,

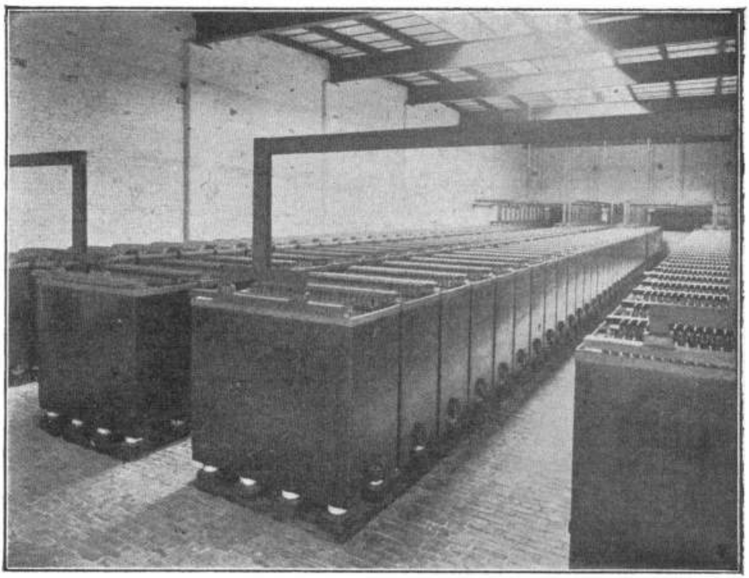


FIG. 16.

every fluctuation of the line potential being reproduced on the direct current side. Two 100 K.W. rotaries were installed, but additions have been made to the system only in motor generator sets, two of which are installed, the first of which is a direct connected set consisting of a 425 K.W. motor coupled to two 200 K.W. generators, [Fig. 14], having a very wide range of voltage to permit of charging the battery direct without the intermediary of a booster; the second, now being installed, is an 850 K.W. motor direct coupled to two 400 K.W. generators.

A 150 K.W. booster set consisting of a synchronous motor coupled to two direct current boosters is used for charging purposes, and for carrying long feeders. The storage battery has a capacity for one and a half hours of 6000 amperes at 150 volts, [Fig. 16], there being 75 cells on each side of the system with two 20 point end all switches [Fig. 15], on each side to give control of the pressure under varying load.

A peculiar point observed is that a motor generator set and rotaries operating in multiple on the direct current side, tend to regulate one another, with varying speed, for constant potential. The rotary being practically independent of speed; a fall of speed or frequency on a transmission system having a large amount of inductance reduces the reactance, and a rise in speed increases the latter so that but for changes in the impressed voltage the rotary should give the best results on a system driven from water power in which the governors must of necessity be sluggish. The motor generator, on the other hand, is independent of changes in impressed voltage, but sensitive, especially with undersaturated fields, to change of speed.

In concluding this paper the author wishes to express his obligations to the *American Electrician* for permission to use cuts; to Mr. P. F. Sellers of the Cataract Power and Conduit Co., for outline drawings, and to Mr. G. A. Harvey of the General Electric Co. for photographs.

Much matter, which could, under a strict construction of the title, have been put in has been left out, and matter which in the author's opinion is more interesting and practical substituted.

DISCUSSION.

Mr. Gano S. Dunn:—The portion of the paper referring to the use of rotary converters and motor generators was particularly interesting to me, because of some recent interest I have had in that matter. I notice on page 138, near the bottom, that after giving the different efficiencies of these two arrangements for transformation, Mr. Stott gives the difference in first cost as about 19 per cent. Now, two-phase rotary converters have an increased capacity over the corresponding direct current generator, and three-phase machines a still greater increase, and my figures have led me to believe that the difference in cost between motor generators and rotaries even on the two phase basis is greater than 19 per cent. I should like to ask Mr. Stott what was the mechanical arrangement of the motor generators on which that cost was figured. Was it simply a motor coupled to a generator, or were two armatures on one shaft supported by only two bearings instead of four, and were there any other features that would throw light on the small increase in cost relatively to the rotary converters?

Mr. Stott:—In reference to the small difference of cost, I should say that all this work is three-phase work, and that the price of rotaries include static transformers, whereas the price of motor generators does not.

After leaving the transformer house at Niagara Falls everything is three-phase from there onwards. The difference of cost was taken from actual figures, and I do not know exactly what to ascribe it to unless that the speed of the rotary converter was comparatively low, and the comparison probably would have come out more even, or rather a greater difference, had the speeds been more alike; that is to say, the speed of the rotary converter, as I remember, was lower than that of the motor generator set.

Mr. Calvin W. Rice:—I would like to ask if any data have been obtained in these experiments on the watts lost per duct foot in multiple duct construction?

Mr. Stott:—In reference to Mr. Rice's question, that is not one that is taken up in this paper, and I cannot answer that question off-hand, but a great number of experiments were carried on at Niagara Falls, the results of which I have not with me to-night, but I know, speaking from memory, it came out that when the ducts were in a greater number than 25, and were all filled with cables, that is to say, three-conductor three-phase cables, that it became almost impossible to get rid of the heat without some special means of ventilation. The test was made on conduits as actually laid with wires pulled through them, and run up to a temperature corresponding to what the dissipation of heat would have been with a three-conductor 2200-volt cable, and for that reason instead of supplying a large factory near the power house at 2200 volts it was decided on the strength of those experiments to supply them at 11,000 volts to get rid of this loss of energy in the cables. I am sorry I have not got the figures.

Mr. Rice :—I would like to ask if in practical operation you run paper cables at a higher temperature than you do rubber?

Mr. Stott :—The paper cables have only just been put in. They only went into operation about a month ago, so that they have not been forced at all.

Mr. C. P. Steinmetz :—I would like to ask Mr. Stott whether with the types of switches employed in the different stations, the open air long break switch, and the oil switch, he has noticed any difference in the action of those switches on the circuit, that is, whether sometimes one switch is more liable to cause rupture of the cable than the other, if such rupture occurs at all.

Mr. Stott :—I do not believe that there has been enough difference in the behavior of these switches to really be noticeable; that is to say, these interruptions to the cables have usually happened during the time the cable was in service, and not at the time of the interruption of the circuit. There is one point we noticed in cables breaking down, that the breakdowns almost invariably came from one to three days after an interruption. That is to say, the current had been thrown on that cable at full pressure, and we were afraid that some resonant effects had taken place, because an examination of the statistics of break-downs showed in almost every case that the break-downs occurred from one to three days of the time when the cables had been out of service and had been suddenly put into service at full pressure.

Mr. Elias E. Ries :—Mr. Stott states on page 138 that the largest user of power in Buffalo is the International Traction Company, which receives a total of 7,000 horse power in five sub-stations, which is first transformed from 11,000 volts to 375 volts, and then converted in rotary converters to 600 volts direct current, for supplying continuous-current railway motors. I would like to ask Mr. Stott whether or not the International Traction Company has ever attempted to use the alternating current for the direct operation of motors on cars instead of first converting it into direct current.

Mr. Stott :—No; that attempt has never been made.

Mr. Ries :—At our last meeting Mr. Hammer gave us a description of several electric railway installations in Europe in which the motors were operated by alternating currents, and it would be interesting, I believe, to the members present to hear of some tests made in this country with that object in view. Perhaps, our friend Mr. Steinmetz, might be able to enlighten us on that subject.

Mr. Steinmetz :—I can do that very well, because I have made very many tests on the use of three-phase motors on railroad cars. The first tests were made in 1894, running a trolley car around the factory yard, and we have run the car many times since, and tried various types of motors on our experimental railroad track, and have satisfied ourselves entirely that with the three-phase motor on a car you can get a rapid acceleration, you can get any starting torque you want, you can do anything you want to do, but the motor is in its electrical and mechanical character, essentially a shunt motor. It has a torque proportional to the current, and independent of the speed at constant field excitation. That is to say, if you want to start you require at the moment of starting the same current for a given torque as you require when running at full speed, and the rest of the power corresponding to reduced speed is merely wasted in the rheostat. Shunt motors, continuous current, have been tried a number of times in electric railroad service, and have always failed, and that was the reason why the three-phase railroad motor has not been introduced. It is decidedly inferior in starting, and in running at low speed, and in acceleration, to the continuous current series motor. Now, there is undoubtedly a considerable advantage in the induction motor for a railroad car, because you can eliminate the rotary converter and the substations, and can install stationary transformer stations. It has the disadvantage that you need two trolleys. There is in existence a double trolley road in the United States, and claimed to be very satisfactory, but I do not think that a second one has ever been built. You can imagine how beautiful it would be in the center of a city to run a double trolley system. The three-phase motor nevertheless might come in use going from city to city, because there you have no switches and crossings. You do not need to start and stop so frequently. The only trouble is these suburban roads always run into a city, and you do not want to dump the passengers at the outskirts of the city and have them wait for the next city car, as necessary if you changed to direct current and different motors there. That is one disadvantage of the three-phase motor.

Then the three-phase induction motor has a power factor. In railway service you could not run a thirty-second of an inch air-gap between the rotary and the stationary member of the motor. You have to have a little more generous air-gaps for mechanical reasons. The power factor is some 80 per cent. with the usual induction motor air-gap. You can imagine where that power factor goes to with a larger air-gap. That means so much more current over the trolley line, not only so much more current but lagging current, which causes so much more drop in the reactance of the line in addition to the resistance drop. In continuous current trolley lines we sometimes have enormous drops. If you have a heavy load on the end of a feeder, from 500 to 600 volts that you start out with, the voltage may go down even to 200 or 300 volts. Well, it means the cars go along slowly, but still they go, and they give any torque you want in starting. With the induction motor, the torque is proportional to the square of the voltage. Hence, if you run the induction motor trolley line at 600 volts average potential, and the voltage is 300, the car will not start. You get over that to a certain extent by raising the voltage on the trolley. But then you have the deviation from standard practice. Everybody knows what the 550-volt trolley does, and nobody knows what the 3,000-volt trolley will do, except on paper, and on experimental lines. All these difficulties and objections of special arrangements and new untried methods in practice have to be considered. Still the system would be introduced if there were any essential compensating advantages. Theoretically you can undoubtedly see some points wherein the three-phase road is really superior. Since I experimented in 1894, I thought, and all my friends agreed with me, that it would be very nice to install a three-phase railroad somewhere. So I and all other railroad engineers with whom I am acquainted have endeavored to find a place where we really have a reasonable excuse to install a three-phase railroad. Once we nearly had one, and at present we again see a chance where we might install one, where there is really a good reason for using it, but thus far I have not installed any. Taking all into consideration, the wide range of speed and power required in railroading, rather militates against induction motors, which give full efficiency only at full speed.

Still, there may be special cases, and I hope still to live long enough to find a few where induction motors are preferable. For instance, where you climb a grade running up the Rocky Mountains, one side up and the other down, or anything of that kind, where you can give uniform speed running down hill, running a little above synchronism, and therefore have the induction motor act as generator on the down grade; you have the advantage that you do not wear out the brakes. However, the experience of the Jungfrau Railroad, which, as you know, was built as a three-phase railroad, was not very favorable. They have very few cars running, and once in a while it happens that a car was running down, returning power, and no car going up to use the power, and the ultimate outcome was that they put in some remarkably complicated arrangements for electrically consuming the power. But then I fail to see what advantage a three-phase current has in this case.

It is true in Europe there are a number of three-phase railroads; but we cannot draw any analogy from that, for the railroad conditions are very different there. The rotary converter is absolutely unknown to European engineers. They have never found out what that thing is. Rotary converters are being rapidly introduced in Europe,—but the engineers there know nothing about them excepting that they believe they are no good. All the converters there are American made, or made at branch factories of American companies, and so where the power for a railroad has to be transmitted a long distance as polyphase current, the rotary converter being unknown, the Europeans have used three-phase motors on the car. Here in the States the rotary converter was installed and put into commercial service, in 1894, in the early days of long distance transmission, and became so familiar to everybody that when long distance transmission for railroads came into consideration, the ordinary standard continuous motor was used, and nobody was forced to get up a new system of railroad motors, which offered no compensating advantages, and so the three-phase railroad motor has not been introduced here, although I hope we might still see some experimental plants.

THE PRESIDENT:—Mr. Steinmetz' account was very interesting, but I think he is mistaken in one or two points. I do not think the Jungfrau railroad is a failure. When I visited it last summer I was told quite the contrary[1]; the part that is now in operation is paying excellent returns for the investment in that part. The company is, of course, not paying any dividends yet, because it is continuing the construction of the road. The constructors worked all the previous winter at it, and this year I believe they intend to work all summer, too. Concerning that device for running down hill which Mr. Steinmetz referred to as being very complicated, I would like to explain that it is used only as a safety device, so as to be able to run down hill in case the continuity of the trolley wires or contact with them, is bro ken. Moreover it is at present used only on one of the four locomotives as an experiment; with the system used on the others, if a car goes down hill and something happens at the power station or to the trolley lines, so that it could not send the power back into the trolley lines, it would have to descend with the aid of the brake-shoe, which is objectionable. It is to meet this emergency that this system of exciting with continuous current is used. Moreover, it is not complicated in the least; it is simply the addition of a very small continuous current dynamo, belted to one of the motors. In other respects the plant is exactly the same as before. It cannot be said therefore that it is a very serious complication.

Concerning rotary converters, Mr. Steinmetz was not correct in saying that they are absolutely unknown to European engineers. They are known and are used there, though much less frequently. The foreign engineers differ with us in estimating the relative advantages of the rotary converter and the motor generator. I saw a large rotary converter of German manufacture, installed in the large, new Berlin station, and the engineer who designed the installation said that if he had to do it over again he would install a motor-generator. That rotary converter was also of interest in that it could be regulated for vol-

[1] Since this discussion took place I have been informed by a Swiss electrical engineer, who is in a position to know, that this railroad will unquestionably be continued, and that the reports of its failure were started by those who wanted to buy a controlling interest in the stock.

tage. It was coupled on the same shaft with what might be called an alternator which was excited by the continuous current. The alternating current, before it went into the rotary, passed through this alternator and by variously exciting the field, the alternating current could be boosted up, or lowered in voltage, and in that way the voltage of the continuous current could be regulated without passing it through a second commutator.

Mr. Ries:—I would like to ask Mr. Steinmetz whether it is not mainly due to the fact that direct-current motors in this country are standardized and a regular article of manufacture, that progress in the development of alternating current railway motors is more backward here than it is abroad, rather than to the many alleged disadvantages of such motors which he has stated. We know that there are a great many losses and complications in the methods which are practiced at Buffalo, as Mr. Stott showed in his paper to-night, and wherever else the alternating-direct transmission system is installed. It has been the aim of electrical engineers to overcome those losses and to simplify the equipment so as to avoid the necessity of having so many intermediate transformations and so much attendance at rotary sub-stations, etc., which the static transformer would eliminate. I am under the impression, at least it has been so stated, that there is a lack of serious effort made here on the part of the larger manufacturing companies to avail themselves of the opportunities presented by the use of alternating current railway motors for purely selfish reasons, rather than owing to their few disadvantages. The question of double trolleys, etc.,—three-conductors, in the case of multiphase currents—would not be so serious a matter in large cities where the underground conduit is used; the track could be used as the third conductor very readily, and the other disadvantages mentioned are not deterrent. The question is whether or not the fact that direct current motors have become standardized, and are used so extensively on existing railway cars as to cause a reluctance on the part of manufacturing concerns to such a change, is not the principal reason that the United States is so far behind Europe in this respect.

Mr. Steinmetz:—There is undoubtedly in the relation between standard apparatus and special apparatus, a good deal of cause for the customer to fight shy of three-phase motors; but as far as the large manufacturing companies are concerned, there is no disinclination on their side against the three-phase induction motors on railroads. On the contrary there is a very great tendency toward that practice, and it has been pushed to a good extent. I am quite sure that the Westinghouse company has been trying, just as the company with which I am connected has for a number of years been trying, to install three-phase induction motors on railroads.

I may, for instance, state that an American company is at present installing a three-phase induction railroad in northern Italy, not in America. The Italians wanted three-phase, and so they got it. But if it were this country, I would not recommend three-phase. I do not see any reason, because continuous current could do just as well, and better; but this road is being built, and I am very glad of it. Another instance we had some years ago, where we wanted to build a three-phase railroad at cost price, and see it go. But at the last moment the customer put on the continuous current. If you come to the underground conduit, you must consider that even at 20-cycles, the ordinary iron rail offers against an alternating current an impedance which is from three to five times the ohmic resistance, which is not negligible. Still there is really no disinclination by American designing and consulting engineers, but all have been very favorably inclined to the three-phase induction motor for railroads, only there was no case in this country where it could be conscientiously recommended in preference to the continuous current motor.

MR. JOSEPH SACHS:—I think the acceleration of the induction motor in this case is such that we have ran ahead of the paper, and rather lost it in the background. I think that while we have all been most intensely interested in Mr. Steinmetz's discussion of the induction motor operation, we would be far more interested, if that were at all possible, to hear his discussion of the proposition that he had already mentioned, namely, the operation of protective devices on such systems as Mr. Stott has mentioned.

It seems to me that in the paper two peculiar forms of high potential protective circuit-opening devices are mentioned, and Mr. Steinmetz has already asked the question whether there was any difference in effect between the operation of a long drawn out arc circuit-opening device, and that of the quick circuit-opening device I think that is a question of intense interest to us all, and if Mr. Stott cannot give us detailed information thereon, that is,, with relation to the effect of such circuit-opening devices, upon transmission and generating and translating machinery, perhaps Mr. Steinmetz can, or some of our other members may be able to do so. I should very much like to hear from Mr. Steinmetz his opinion, regarding, for instance, the relative supposed effect of long drawn out arc circuit-opening devices over those that operate instantaneously.

MR. STEINMETZ:—Regarding this question I may say that in the comparison of the long drawn out circuit-breaking device and the quick break—that the quick break is the air-switch, and not the oil switch. It is frequently assumed that if you draw a long arc in the air, that there is a slow break in the circuit. That is not the case. There is no break quicker than the break in open air. Metal vapor being of very low resistance can draw an arc two or three feet long, having a drop of not more than a few hundred volts. If in a high potential circuit you draw an arc of three or four feet, there is hardly any voltage across the arc, until it breaks. But the break is extremely quick. A friend of mine has made some very nice photographic investigations of the nature of the break in a high potential circuit, with capacity in shunt, and found that a short circuit across a high potential circuit ruptures itself with extreme rapidity.

When the oil switch was experimented with, I was very greatly afraid of it due to the quick break in the oil. Experience and a very careful investigation on high voltage circuits has shown that the break of the oil switch at very high voltage, three, five or ten thousand, is not a quick break. Liquid is practically incompressible, and therefore the gas bubble which is formed there stands under enormous pressure and holds the arc up to the next zero value of current. At the next zero value of current the liquid pressure blows out the arc. It seems to be the action of the oil switch to hold the circuit up to the next zero value and then extinguish it. So that other things being equal, the probability is that the open air break is more dangerous and destructive than the oil break. Now, I have no complete experimental record of that except that in investigations which were made incidentally on the same plant at Niagara Falls, described in the paper, with 5000 horse-power behind. When trying a number of different breaks I found that the only switch which would open the circuit with the resistance and inductance in series, which never gave a rise of voltage, was the oil switch. That is not quite conclusive, because all I had was ordinary resistance and inductance, but no capacity. The conditions may change as soon as capacity enters. But I know that in all inductive circuits, with negligible capacity, the air switch is more dangerous than the oil switch. It may then be assumed in the absence of more complete data that the oil switch is the safer one, even in other cases.

I have investigated that lately, and I shall at one of the next meetings read a paper on the theoretical investigations of these high voltage phenomena which may occur in transmission lines during a sudden change of circuit conditions, as closing the circuit on the lines, or opening it, or short circuiting it.

Mr. Calvin W. Rice:—I would like to ask if the speaker of the evening has followed the articles written by Mr. Mordey on "Cable Work," and has had any experience along the same lines.

Mr. Stott:—I do not know what articles you refer to.

Mr. Rice:—The recent articles in *Engineering*, speaking about capacity in cables, and the amount of charging current.

Mr. Stott:—I have not read the articles in question.

Mr. John W. Lieb, Jr.:—I would like to ask Mr. Stott in regard to the reference he makes to the cables, on page 136. He states that a rubber insulated cable with 9/32″ wall, 30 per cent. pure Para is perfectly reliable for 11,000 volts; but that 8/32″ insulation even with a higher percentage of pure Para is not.

It seems to me that, with the difficulties which are encountered in the manufacture, and which can quite readily give rise to differences in thickness of dielectric greater than one-thirty-second, where such a deduction is drawn, it would seem rather to indicate that even the 9/32″ cable was perhaps insufficiently insulated, and that on the whole for such a high voltage there was not a sufficient margin of safety, and that the margin was sacrificed by the slight reduction of 1/32″. I should like to know whether that deduction was based on something else than the mere difference of 1/32″, because it seemed to me that with the variations that are likely to take place in manufacturing such a cable there ought to be a greater margin than one-thirty-second of an inch between an insulation thickness sufficient to secure perfect reliability, and one that is not. In this light I do not understand the conclusions arrived at by the author.

MR. STOTT:—With reference to these remarks, as stated in the paper, these are the general conclusions that we have been able to draw from the actual number of breakdowns during a period of three years. These cables have been used over three years, and were made by very reliable manufacturers, the best manufacturers probably there are in the United States, and we have had more breakdowns on that 8/32″, although it has been in a year less than the other two, and naturally we began to think that the puncture resistance was not so great with 8/32″ as it was with 9/32″, and there does seem to be a distinct difference, and that the 1/32″ makes a marked difference. These are from a record, very carefully kept, of all breakdowns. I am sorry that I cannot say whether it broke down to ground or between conductors, because after an 11,000-volts burn out there is not anything left to tell. But 1/32″ extra insulation seems to give very greatly increased reliability. That is, after the cable has been in use for a long time. By a long time I mean several months. There is another fact that possibly may have something to do with it, and that is whether 40 per cent. of pure Para is not too pure and deteriorates under pressure. Some experiments are being carried on that I know of as to the deterioration of insulation under a continued high pressure, and the loss of insulation, that is to say, the megohms as measured by the galvonometer, after a continuous application of high pressure, is very distinct. That is to say, there is a distinct fall in insulation as the test is continued. If at the end of ten days the insulation is 400 megohms, at the end of twenty days it will be down to perhaps half of that value and keep on decreasing. These experiments are not yet complete, but the tendency has been very marked in that direction, and apparently (from these experiments being carried on) the purer rubber is going that way faster than the less pure.

MR. CALVIN W. RICE:—I would like to ask if the dimensions of the cable are those in the specification or the dimensions observed by inspection of various lengths, and if 9/32″ means the least dimension that was observed in any of the product; also is the 30 per cent. cable made by one maker and the 40 per cent. made by another maker, and if there were tests made to determine whether there was exactly 30 per cent. or 40 per cent.

Mr. Stott:—In reply to these questions, the thickness of the wall was quite carefully measured, and these are the means of a great many measurements, so that it may be taken that these represent the mean thickness of the wall. As to the percentage of pure Para, that we have got to rely upon the manufacturer for. As you know, the analysis of rubber is an extremely difficult thing to perform, and you can get almost any result you like with those hydrocarbons.

Mr. Rice:—I would like to ask if these breakdowns occurred mainly in the cable or in the joints, and as to the possibilities of mechanical injuries as a cause for the breakdowns, or was the cable so destroyed that you could not tell whether there was mechanical injury or not.

Mr. Stott:—The breakdowns in almost every case in the cable referred to occurred in the middle of the section, or at least ten feet from a manhole, and the result was such that you could not tell anything about it. It just blew the whole cable to pieces.

Mr. H. D. Reed:—The conditions are so great and varied with the rubber in cables that I should think it would be necessary to determine whether that 1/32″ was the cause of these cables breaking down, that is, if a thirty-second less, rather than the treatment of the rubber itself, was the cause. Now, there are a great many grades of pure Para rubber, and the age of the rubber has considerable to do with it, also the length of time that the rubber is dried and cured before it is compounded, and the cleanliness of the rubber is a feature that enters very materially into the manufacture of cables. Now, I would be inclined to think that an 8/32 wall of 40 per cent. rubber would be safer than 9/32 of 30 per cent. rubber. From the experience I have had with cables, especially after a lapse of time, 40 per cent. rubber will be very much more durable than the 30 per cent. compound.

Mr. Sachs:—I am not familiar with the cable practice and transmission through cables, but it would seem to me, and it probably seemed to a great many others this evening, that the difference between 8/32 and 9/32 of an inch of insulation on a high potential cable is very small. The tendency to-day in engineering practice is to make everything "fool proof," and I think it also is in a great many cases necessary to make it mechanically and also electrically "fool proof." I should say if 8/32″ of insulation on a high potential cable were bad, that 9/32″ were almost equally bad, and if trouble was experienced with the 9/32″, I should add one or two more thirty-seconds of rubber, and get a little additional factor of safety.

Mr. Stott:—I would reply to Mr. Sachs' remark—there is another factor besides the factor of safety that enters into the question, and that is the matter of cost. A cable of 1/32″ extra insulation would probably send up the price 25 cents a foot.

Mr. Sachs:—Quite true. But I should think that the deterioration would in time affect the 9/32″ just as much as it previously did the 8/32″, that it was simply a question of time before the 9/32″ broke down, and if you added a few more thirty-seconds it would take a little more time to break down, and thus you might continue the life of the cable. That is simply my opinion of the matter. As I said, I am entirely unfamiliar with the practice.

[Adjourned.]