AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, November 22, 1901.

The 158th Meeting of the INSTITUTE was called to order at 12 W. 31st. St., New York City, with President Steinmetz in the chair.

THE SECRETARY:—At the meeting of the Board of Directors this afternoon the following associates were elected:

Name	Address	Endorsed by
CRAVATH, JAMES RALEY,	Western Editor, Electrical World and Engineer, 1139 Monadnock Block, Chicago, Ill.	W. D. Weaver. Ceil P. Poole. H. W. Blake.
CROSSMAN, GILBERT,	Telephone Engineer, Western Electric Co. 463 West St., residence 80 Washington Square E. New York City.	G. F. Atwood. O. A. Bell. G. A. Hamilton.
DUSENBERRE, GEORGE BROWN,	Assistant to Fourth Vice-President, Westinghouse Electric & Mfg. Co., Pittsburg; residence, Englewood Park, Pa.	L. A. Osborne. C. A. Terry. C. F. Scott.
EASTMAN, GEORGE NIAL,	In charge of Testing Laboratory, Chicago Edison Co., 139 Adams St., Chicago, Ill.	F. B. Badt. Saml. Insull. P. B. Woodworth.
FREUDENBERGER, WILLIAM	KAISER, Chief Electrician, The Colorado Fuel & Iron Co., residence, 209 E. Evans, Pueblo, Col.	A. E. Maccoun. H. B. Shaw. E. Friedlaender.
HAMILTON, RALPH BERGEN,	Manager, The Packard Electric Co. Ltd., St. Catharines, Ont.	A. A. Dion. Frederick Bedell. John Murphy.
HOOPES, MAURICE.	Mechanical Engineer, J. G. White Co., 29 Broadway; residence 30 East 39th St., New York City.	H. A. Lardner. W. B. Potter. H. J. Ryan.
KING, HARRY R.,	Electrical Engineer, Western Electric Co., Chicago, Ill.	H. S. Carhart. B. J. Arnold. H. H. Wait.
LANPHIER, ROBERT CARR,	Superintendent and Electrician, Sangamo Electric Co., Springfield, Ill.	L. Gutmann. W. S. Aldrich. William Esty.
LUDVIGSEN, HANS VALDEMAR,	Electro Chemical Engineer, Blaagaardsgade 17. Copenhagen; residence Straudvejen 119, Hellerup, Denmark.	W. J. Hammer. C. P. Steinmetz. R. W. Pope.

NESBIT, JOSEPH NEWTON	GRAY, Superintendent Winding Department, Warren Electric Mfg. Co., 416 Fulton St., Sandusky, Ohio.	W. J. Hammer. R. W. Pope. J. P. Jackson.
O'BRIEN, ALBERT DALLAM,	Assistant N. Y. & N. J. Telephone Co., 15 Dey St., New York City; residence 151 Columbia Heights Brooklyn, N. Y.	E. J. Houston. W. C. L. Eglin. A. E. Kennelly.
POTT, ARTHUR HENRY,	Consulting Engineer, with Preece and Cardew; residence 81 Cornwall Gardens, S. W. Queensgate, London, England.	W. H. Preece. W. M. Mordey. R. W. Pope.
REUTERDAHL, ARVID,	President and Chief Engineer, The Reuterdahl Electric Co.; residence, 366 Willard Ave., Providence, R. I.	W. J. Ballou. R. W. Pope. W. J. Hammer.
RUCHGABER, ALBERT FELIX,	Draughtsman, Rapid Transit Subway Construction Co.; residence 373 Carlton Ave., Brooklyn, N. Y.	C. E. Skinner. R. W. Pope W. J. Hammer
RUSSEL, EDGAR,	Capt. Signal Corp, U. S. A. War Department, Washington, D. C.	Samuel Reber. T. Wolcott. E. B. Ives.
SCHILDHAUER, EDWARD,	Engineering Department Chicago Edison Co., 139 Adams St., Chicago, Ill.	Samuel Insull. D. C. Jackson. B. Frankenfield.
SCHMIDT, LAMBERT,	President, The Lambert Schmidt Tel. Mfg. Co., 325 Broadway, New York City; residence 138 Schippen St., Weehawken, N. J.	Samuel Reber. T. Wolcott. E. E. Ries.
SOREN, TOWNSEND HODGES,	Electrical Engineer, General Electric Co., Schenectady, N. Y.	C. P. Steinmetz. E. W. Rice, Jr. H. G. Stott.
TANNATT, EBEN TAPPAN,	Managing Civil and Electrical Engineer, The Oahu College Trustees; P. O. Box 92 Honolulu, H. Ty.	W. J. Hammer. R. J. Pratt. C. P. Steinmetz.
VAN DYCK, WILLIAM VAN	BERGIN, Electrical Engineer and Contractor; residence 439 Manhattan Ave., New York City.	J. J. Bellman. G. A. Thomson. F. B. Crocker.
WEYMOUTH, THOMAS ROTE,	Electrical Engineer, International Hydraulic Co., 40 Wall St.; residence 80 Washington Square E., New York City.	R. D. Mershon. C. Van Deventer. C. C. Chesney.
ZWIETUSCH, EDWARD OTTO,	Electrical Engineer Telephon Apharat Fabric Petsch, Zwietsch & Co., Salzufer 7, Charlottenburg, Germany.	J. J. Carty. G. A. Hamilton. O. A. Bell.

Transferred from Associate to full Membership:

Approved by Board, of Examiners, October 11th, 1901.

CARL L. DE MURALT, Baden, Switzerland.

THE PRESIDENT:—Gentlemen, the topic for to-night's consideration is "Systems of Electric Light and Power Distribution." The problem of electric light and power distribution essentially consists in supplying from one primary generating station electric power to a number of customers in a form suitable for their demands. In its theoretical and simplest form a system of electrical distribution consists of the generating station and a system of distribution conductors, and in addition thereto controlling apparatus in the generating station and metering appliances at the customers' premises. Such stations and distribution systems of the theoretically simplest form, but still of very large magnitude, utilizing continuous current, are even in our day in successful commercial operation.

Since, however, according to the different applications, the electric energy is required in different forms, as for incandescent lighting, arc lighting and electric railways, etc., it becomes necessary either to install a number of separate and distinct distribution systems for the different forms of electric power, or to introduce into the system transforming apparatus. By the introduction of transforming apparatus the system of generation becomes more or less independent of the system of utilization, and hereby then the problem is created for the electrical engineers to decide which system of electrical distribution is the most suitable in each individual case. The conditions underlying the decision of the problem are, on the one hand, the reliability, efficiency and safety of the system as regards generation, transmission and distribution, and on the other hand, the utilization of as large a part of the total power as possible in the form generated, or with only few transformations or conversions.

Still more complicated the problem becomes in some instances by the introduction of extraneous conditions depending on circumstances not directly connected with the distribution, as for instance, where the power is received from a long distance over transmission lines, and by the limitations incident to long distance transmission, certain restrictions are imposed upon the generation and transmission of power. Hence to utilize as large an amount of power as possible without too many conversions or transformations, it becomes desirable to use the electric energy in a form which may not be as suitable or desirable as if the power were generated on the premises. It can be seen that—by giving here the one or the other feature a slightly greater prominence by either compromising between heterogeneous conditions, or by following one extreme without transformation and transforming the electric power for the other extreme—very different solutions can be reached of the same problem with almost the same satisfaction. Therefore it may not be astonishing that different engineers of equal prominence may reach, under individual conditions, exactly opposite points of view, although

naturally in a considerable number of features you will find a general agreement of opinion existing.

Since we have quite a considerable list of papers for discussion to-night, and the promise of a number of prominent speakers, it will be absolutely essential to restrict the time devoted to each paper to a maximum of ten minutes, and therefore not to read the paper *in extenso*, but in abstract.

I call upon Dr. Kennelly to make an announcement.

DR. ARTHUR E. KENNELLY :—Mr. Chairman and gentlemen : A circular letter has been issued, signed by Mr. Goddard, as the Secretary of the New England Insurance Exchange, in which certain additions are suggested to Rule No. 39 in the existing National Code, for constant potential circuits of over 3,500 volts potential. The suggested changes are: First, that such circuits—that is to say, extra high pressure circuits—should not be allowed overhead within 75 feet of any building, with a certain reservation for special cases; and, second, that they should not be allowed on the same poles with other wires, nor on the same side of the street or of the road with pole lines carrying other wires.

A copy of this letter having been sent to the INSTITUTE, a committee has been appointed by the President, consisting of Mr. Hammer, Mr. Sinclair and myself, to meet the members of Mr. Goddard's committee at their meeting on the 3rd of December next, and it is the wish of the Board of Directors, as expressed at their meeting to-day, that all members of the INSTITUTE interested in this rule, or in any other rules of the National Code which may call for modification, should communicate with the Secretary of the INSTITUTE, and express their views upon the subject in writing, with a view to the general consideration of the matter on the part of the INSTITUTE. It seems unlikely that such general consideration can be effected by the 3rd of December next, and it may be necessary to request the committee of the Board of Insurance Underwriters to extend the time for taking action, if such extension be possible; but I am asked to extend, on behalf of the President and the Board of Directors, the request that all members interested in this proposed new rule of the National Code should communicate with the committee through the Secretary of the INSTITUTE.

THE DISTRIBUTION BY THE THREE-PHASE SYSTEM AND THE OPERATION OF SINGLE-PHASE CIRCUITS BY IT.

BY W. L. R. EMMET.

Since the single-phase alternating distribution preceded the use of polyphase currents there has naturally been a tendency to continue its use, and a full appreciation of the advantages of polyphase currents has not been acquired by many of the practical men who handle distribution problems. The first uses of polyphase currents were for power alone, the old single-phase lighting systems being unchanged. As time has gone, however, the use of single-phase apparatus has steadily diminished, and the production of polyphase apparatus has increased; and although there is still some demand for single-phase generators, an investigation will show that the best informed electrical engineers have now discarded them altogether.

An extensive experience with a single-phase, two-phase, three-phase and other apparatus has led me to believe that for almost all purposes of lighting and power distribution the three-phase winding is the most desirable for central station generators, and that two-phase and single-phase windings have, in the great majority of cases, no good reason for existence.

It is not necessary to enumerate all the advantages of the three-phase system, but it may be said that among the reasons for its universal adoption are that the three-phase generator is better than the two-phase generator for single-phase operation, where single-phase operation is required, and, further, that the

three-phase generator when used as a single-phaser, is practically as good and as cheap as it would be if it had been designed particularly for single-phase uses. Thus it can meet the two-phaser or the single-phase on equal terms on their own field and at the same time can afford its own special advantages.

When a three-phase generator is to be operated on a single-phase circuit it is generally desirable to use a "Y" connected winding, although with certain types of windings the delta connection will give equally good results. With such a winding the three-phase machine, as ordinarily designed, will carry from 75 per cent. to 85 per cent. of its rated load in single-phase current between two conductors with the same heating which would be produced by operation at its rated capacity with balanced three-phase current. If motors or rotary converters are connected to a three-phase generator which is operating with single-phase load, these motors or converters will tend to equalize the load between phases and thus may increase the capacity of the system. When a three-phaser is partly loaded with single-phase currents between two of its wires the unused phases may naturally be loaded with other single-phase currents, thus giving various degrees of unbalancing between the three phases and, with normal heating, will vary from 75 per cent. to 100 per cent. of the total three-phase capacity.

The statement that the three-phaser will carry 75 per cent. of its rated load in single-phase current frequently leads the customer to ask: "Why should I buy such a machine to deliver single-phase current when I can get a single-phaser which will deliver its full-rated capacity with normal heating?" The answer to this question is that the three-phaser designed for a given single-phase output has about the same size and cost as the machine designed for single-phase alone, the apparent inconsistency lying in the fact that a three-phaser for a given output is cheaper and smaller than a single-phaser.

While purchasers of three-phase generators have frequently made special demand for large single-phase capacity, there are in point of fact, very few cases where it is necessary or desirable to operate three-phase machines exclusively on single-phase load. Companies that operate single-phase circuits can almost invariably divide their circuits roughly into groups, putting some of them on one phase and some on the others. The only portion of a lighting company's load, which cannot be advantageously

divided between the phases is the low tension, interconnected distributing system, if such a system is used. Even where such systems are used they never include the whole lighting distribution of the company, and there will always be outlying circuits which can be operated from other phases. There are also, in most cases, transformers for arc lighting and other kinds of single-phase load which can be put upon the least used phases, and which will thus tend to help out the balance of the system. Many purchasers think that it is necessary to buy a single-phase generator because they use single-phase circuits, whereas the approximate division of these circuits between the phases would involve no difficulty whatever.

Since the normal single-phase capacity of a three-phaser is about 80 per cent., since all motors and rotary converters tend to equalize the balance, and since there is always scattering single-phase load which can be conveniently put upon the lightly loaded phases, we may practically consider that the three-phase generator can be used at its rated capacity on any system.

If the three-phase generator is operated with single-phase load, or with seriously unbalanced load there will generally be a marked potential difference between its phases. The phase carrying load will show the drop in potential which such load would ordinarily occasion on a similar single-phase machine; one of the disused phases will generally show a higher voltage and the other a lower voltage. With machines of good inherent regulation, such as are now generally used for lighting purposes, these differences are small and can readily be taken care of by regulators in feeder circuits. Where three-phase generators are operated on single-phase, three-wire distributing systems, the general practice is to regulate the generator to give the desired voltage on the three-wire system, and to control by regulators the voltage of circuits connected to the other phases. The variations of voltage on these other phases may, in some cases, be actually a convenience, since between the three phases a voltage can often be selected which will nearly suit the requirements of any feeder.

Two systems of low tension distribution for lighting are used and recommended in connection with three-phase generators, viz.: the single-phase, three-wire system, and the three-phase, four-wire system. When the single-phase, three-wire system is used, the generator is generally somewhat unbalanced by the large demand for single-phase current which the three-phase wire system creates,

and the voltage is regulated with reference to the needs of the three-wire system. The primary circuits are so arranged as to deliver power through transformers to low tension network. The transformer secondaries are provided with three leads, one for the neutral and one for each of the outside wires. Since the drop in high tension lines is small, and since transformers can be put wherever they are needed, it is easy to arrange an alternating three-wire system in such a manner that it will give very perfect voltage distribution in all parts of the area which it supplies. In direct current, three-wire systems, we naturally have to deal with large and variable feeder losses, which, in spite of the most

FIG. 1.—Four-wire three-phase low tension system.

careful arrangements, must seriously interfere with the maintenance of good regulation. In alternating three-wire systems the regulation should, with intelligent handling, be practically perfect.

The other method which is available for low tension distribution with three-phase dynamos is the four-wire, three-phase system. This system is supplied from groups of transformers, with three in each, their secondaries being connected in "Y" from a neutral. The secondary voltage of each transformer is that suitable for the lamps which it is desirable to use. In action, this arrangement is equivalent to the ordinary three-wire system, except that it has three branches and a neutral instead of two branches and a neutral. The copper economy is practically the same in both, the advantage being slightly in favor of the four-

wire, three-phase system, since the neutral need not be quite so large. This system also has the advantage that its outside wires are available for operating motors. Another advantage is that it affords a balanced load to the three-phase generators, if the four-wire system is kept in balance.

The arrangement of these methods of secondary distribution is illustrated by Figs. 1, 2 and 3. From these diagrams it will be

FIG. 2.—Three-phase generator with single-phase three-wire low tension system.

seen that it is necessary to use four wires with either, if motors are to be operated. Where the single-phase, three-wire system is used, it is necessary to run a separate power wire which can be energized from a transformer, and which, with the outside wires of the three-wire system, affords three-phase currents for operating motors.

The four-wire, three-phase system cannot be advantageously used in all cases. Where it can be consistently used on a large scale it is probably the most desirable method of secondary distribution. It should not be used, however, where the conditions are such that the three-phase system must be seriously unbalanced by arc light transformers or other unavoidably unbalanced load. Generally it is not desirable unless its arrangement is complete and the whole plant is arranged and operated with reference to its use. In the rearrangement of existing plants it will gener-

ally be expedient to use the single-phase, three-wire system, operated from three-phase generators, as described above.

In distributing electricity over considerable areas it is desirable to keep in view certain general principles in order that proper voltage distribution may be obtained. Some of the variations which affect voltage regulation are controllable from the station, while others are beyond such control, and conse-

FIG. 3 — High tension four-wire three-phase system.

quently can be only partly equalized by the maintenance of a desirable average condition at the main station; even where controlling apparatus is provided in the main station the regulation may be imperfect unless considerable expense is incurred for labor necessary to the intelligent handling of such controlling mechanism. The following simple rules should always be kept in view when distribution systems are being arranged:

1st. Reduce the number of circuits to be regulated to a minimum. 2d. So arrange the system that variations not controllable from the main station are made as small as possible. 3d. Reduce the amount of total drop on all circuits so that frequent changes will not be necessary. 4th. Interconnect the load in large groups so that any variable load unit will be small in comparison to the whole of which it forms a part.

The proper application of these rules will generally lead to an arrangement where the number of feeders is small, each feeder carrying the maximum amount of power which it is desirable to transmit over a single line. Each feeder will supply a compact primary network, or a set of short primary branches, the loss beyond the feeder end being small so that a good voltage regulation at the feeder end will ensure good service to all the customers connected to that feeder. To get such a result the load must, of course, be connected near the feeder end instead of being scattered throughout its length.

A method of primary distribution has been used and advocated to a considerable extent which frequently lends itself very well to the accomplishment of the results above mentioned. This system is illustrated by the accompanying diagram. The "Y" connected generator is used with windings arranged to give about 2,300 volts between the neutral point and each outside wire. Such a generator may be loaded as if it were three separate single-phase machines, the neutral being used as a common return for all the circuits. The standard 2,300-volt transformers are adapted to use between the neutral and any of the outside conductors. The usual method of applying this system is to run out long four-wire feeders. At the end of each four-wire feeder there may be a loop or a branching of the four-wire system so that it is brought near to all parts of the area to be supplied. The transformers for lighting purposes are connected to short two-wire branches which connect to the four-wire feeder at or near its end, the arrangement of these branches being such as to give an approximately balanced load on the four-wire system. If the load is balanced there will be no current in the neutral. Even if the unbalancing is considerable the drop in the neutral will be so small that it will only slightly affect the voltage conditions. Regulators can be used in the main stations in each of the neutral conductor, and these in combination with compensated voltmeters can maintain the desired potential at the feeder end between each of the outside conductors and the neutral. The outside conductors should preferably be grounded in the main station so that the maximum voltage to ground on any of the transformers will be 2,300 volts.

With a rough approximation to balance we virtually have, by this system three-phase transmission at 4,000 volts, the voltage between the outside wires being about 4,000 when we have 2,300

volts between each wire and the neutral. The system thus affords means by which we can economically distribute over large areas without the use of step-up transformers.

When this system is used, it may often be desirable to operate lines in the immediate vicinity of the power station from single-phase branches, instead of running out the four-wire feeders. The neutral should simply be used as a common return where convenient, and the long lines should be so arranged that the common return will be as effective as possible. Wherever motors are used it is, of course, necessary to get access to all three of the outside conductors.

The great improvements which have recently been made in automatically regulated three-phase generators have made it economical and desirable to use such machines in many cases where direct-current apparatus would heretofore have been adopted. The alternator is simpler, more efficient and less liable to trouble than the direct-current machine, and it is often desirable to use it even where long distance transmission is not required. There are also many cases where the principal loads are found in the immediate vicinity of the installation, but where there are certain long branch lines which it is desirable to operate at high voltage. If low tension alternating current generators are used such transmission lines can always be taken care of by step-up transformers. The system recommended for such low voltage alternating distribution is the four-wire three-phase system operated from a low voltage "Y" connected alternator. The winding of the alternator is such that the voltage of lamps is provided between its neutral and its outside wires. A four-wire network is supplied from the machines through suitable feeders, the lights being operated in approximate balance between the outside wires and the neutral, and standard motors being connected to the outside wires where desired. If the standard 220-volt motors are used the desirable lamp voltage will be about 125 and with 440-volt standard motors 250-volt lamps will generally be suitable. The system of distribution with the higher voltage can be extended over considerable areas with small expense for copper, and is very desirable for mill lighting and many other purposes.

Such low voltage alternating work is desirable for railroad yards, summer hotel properties, colleges, private estates and other similar installations.