ELECTRIC-WIRING, DIAGRAMS AND SWITCHBOARDS

Electric-Wiring, Diagrams and Switchboards

BY

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A Work on the Theory and Design of Wiring Circuits; being a Practical Guide for Wiremen, Contractors, Engineers, Architects, and others interested in the application of Electricity to Illumination and Power. Contains Special Chapters on the Design of the Switchboard for Lighting and Power; and on the Sizes of Wire necessary for Alternating Current Circuits of Single, Two, and Three Phase with various degrees of Inductance. Gives the important features now found in all large Power and Lighting Equipments, including the Converting Apparatus in connection with Single, Two, and Three Phase Currents. Calculations and Examples all limited to the use of Arithmetic in the Treatment of both Direct and Alternating Current

CONTAINS ONE HUNDRED AND FIVE ILLUSTRATIONS SHOWING THE PRINCIPLES AND TECHNICS OF THE ART OF WIRING

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PREFACE

THE contents of this book cover the fundamental facts of wiring, as well as such of the practise as its modest proportions could be well expected to embrace. It is not offered to the reader as a scientific treatise—though its statements will be found able to bear the light of scientific investigation—but as a technical work, in which the author has made an effort to present the underlying principles of wiring in language suited to the comprehension of the general reader. Though framed in accordance with the technical requirements of the art of wiring, the subject matter has been presented with the idea and intention of making the reader independent of it as soon as possible. Though a mastery of the principles of rational wiring go hand in hand with its practise, it is frequently found easier to gain the practise than the theory. But it is also true that the best equipped in this particular field of work are those whose power lies within the head and hand, to an extent which makes them independent of text-books or other references. To gain this much-to-be-desired equipment, a knowledge of what is best and most useful must be obtained. What the author considers to be just such knowledge, is presented here in a logical form, as far as its various successive steps are concerned.

The elementary relationship of volts, amperes, and ohms is given first consideration; then the pivotal point of drop of potential is emphasized and expanded, and the first applications of this idea brought, as is believed, clearly to the reader's attention. Means of calculating drop, finding the circular mils of the wire, and arriving at its numbered gauge size without a table are given. This may be regarded as the primary object of the book, and will be considered by wiremen who master this method as well worth the slight labor involved. The further expansion of the simple circuit into others of a more complex type represents the next stage of progress. From this step on, the subject matter leads into a consideration of the principles of switchboard design, with reference to shunt and compound wound generators. The apparatus employed on switchboards is of great importance in electric lighting. Though, as is commonly supposed, the switchboard represents the means by which all important circuits are concentrated and controlled; it is also the measuring and protective, as well as the distributing center of the electric light or power system. Wiring embraces this, as well as the moulding and pipe work, as will be readily understood by the intelligent reader. It is incompletely treated, however, unless the meaning of alternating current phenomena which relate to wiring; as well as simple arithmetical methods of getting the sizes of wire for such circuits, also receive careful attention.

In this respect, the pages of this volume will prove of the utmost value to the student, wireman, or contractor. It is not to be inferred from this, that such knowledge is at a high premium; but it may be inferred that such knowledge is often inaccurate, incoherently arranged, and frequently useless. For such reasons as these the latter part of the book was written, and it is hoped that it will fulfil the purpose held in view. All that the author cares to claim is the manner of presentation; as it is well known that the greater responsibility for those formulas and their derivations, which are the veritable foundations of the science of electricity, must fall upon such masters as Ohm and Helmholtz.

NEWTON HARRISON.

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CONTENTS

CHAPTER I

PAGE

Introduction—Purpose of Wiring—Ohm's Law—Drop of Potential—Meaning of a Milfoot—Meaning of a Circular Mil—Calculation of Drop—Calculation of the Sizes of Wire for a Given Drop—Wiring Rules—Calculation of Resistance for Branch Circuits—What is Power and How Estimated 15

CHAPTER II

Carrying Capacity of Wires—Effects of Heat upon Resistance—Allowance for Heat—A Simple Electric Light Circuit—Wire of a 10 Lamp Circuit with Drop Analyzed —The Wiedemann System of Lighting and Its Defects —The Wiring Table—How to Prepare a Table of Sizes and Circular Mils—Examples of the Application of the Wiring Table and Formula—Calculation of the Drop per 1,000 Feet per Ampere 40

CHAPTER III

Elements of a Wiring System—Meaning of Mains, Feeders, Branches—Proportioning the Drop in the Various Parts of the System—The Center of Distribution—Examples of the Effects of Drop in Parts of the Circuit—Equaliz-

PAGE

ing the Pressure—Dynamos for Incandescent Lighting —Effects of Changes in the Field of Dynamos upon the Lighting—A Wiring System with Four Centers of Distribution—The Life of a Lamp 63

CHAPTER IV

Measurement of Resistance—Principle of the Wheatstone Bridge—Balancing the Resistance of Four Lamps—Measuring a Lamp Hot and Cold—Measuring Insulation Resistance—The Insulation Resistance of Buildings Wired for Electric Lighting—The Three Wire System Compared with the Two Wire—Calculating the Three Wire System of Wiring—Circuits of a Three Wire System with Two Centers of Distribution—Calculation of Pounds of Copper for Mains or Feeders 87

CHAPTER V

Types of Motors—Connections of Motors—Meaning and Reason for Back Electromotive Force—Use of a Starting Box—Method of Connecting Up a Shunt Wound Motor—Horse Power of Motors and Efficiencies—Efficiency of Motors and Size of Wires—Advantage of High Pressures—The Alternating Current for Lighting—Meaning of Frequency or Cycles 112

CHAPTER VI

Reasons for Employing Conduit—The Use of Cleats—The Use of Moulding—Iron Armored Conduit—Enameled Iron Conduit—Brass Armored Conduit—Asphaltic

PAGE

Paper Tube or Plain Conduit—Flexible Woven Conduit—Flexible Metallic Conduit—The Use of Bends, Elbows, Outlet and Junction Boxes—Directions for Installing Conduit—Conduit Jobs and Their Accessories—Schedule for Wiring Systems 124

CHAPTER VII

Requirements for Iron and Steel Armored Conduit—Laying Out a Conduit System—The Insulation of Conductors—Mechanical Work—Insulating Materials—Concealed and Exposed Work—Insulation Resistance—Grounded Wires—Soldering Solution—A Distribution Sheet for Laying Out Wiring 143

CHAPTER VIII

The Light of Incandescent Lamps—The Power Consumed by Lamps per Candle Power—Candle Power and Coal—Effect of Low Pressure on Light—Effects of Globes on Light—Size of Room and Number of Lights—Use of Side Lights and Chandeliers—Color of Room Decoration and the Lighting 158

CHAPTER IX

Switchboards and Their Purpose—The Parts of a Switchboard—Connections of a Shunt Wound Generator—The Circuit Breaker—The Rheostat—Connections of a Compound Wound Generator—Fuses—Connections of Two Shunt Wound Generators and Switchboard—Equal Pressures for Both Dynamos—The Bus Bars—

PAGE

Back View of Switchboard Showing Wiring Connections for Two Shunt Machines—Connections of Compound Wound Machines Showing Bus Bars and Equalizer Bar in Service—Over Compounding—The Series Winding and Its Purpose 168

CHAPTER X

Generators for Alternating and Direct Current Lighting—Character of Lighting Done—The Switchboard for Two Compound Wound Generators—Connections to Instruments—Switchboard for Control of Six Floors and Two Elevators—Connecting Two Shunt Dynamos According to the Three Wire System at the Switchboard—Switchboards for Electrolytic Work 188

CHAPTER XI

Panel Switchboards—Street Railway Switchboards—Connections of Compound Wound Generators in a Power House to Switchboard and Instruments—Lightning Arresters—The Panels and Their Functions—Station Fires through Lightning—The Generating, Feeding and Metering Sections 198

CHAPTER XII

Testing—The Ground Detector—Testing with a Voltmeter—Use of the Magneto for Testing Insulation—Locating Grounded Circuits—Damp Basements—Use of Insulators—Weatherproof Wire—Cables—Rotary Converters—The Applications of Rotary Converters—Efficiency of Converters 209

CHAPTER XIII

PAGE

Important Features of Alternating Currents to Consider—Losses in a Line—Inductance Explained—Inductance with Alternating Currents—Resistance Compared with Inductance—Effect of Resistance and Inductance on an Alternating Current—Effect of Capacity on an Alternating Current 223

CHAPTER XIV

Calculation of Reactance—Value of Induction Reactance—Value of Capacity Reactance—Calculation of Impedance in a Circuit—The Unit of Self Induction—The Power Factor 233

CHAPTER XV

Circular Mils for Alternating Current Mains—Value of C for Single Phase Currents—Circular Mils Calculated for Single Phase Circuits—Circular Mils Calculated for Two Phase Circuits—Circular Mils Calculated for Three Phase Circuits—Average Power Factors—Weight of Copper—The Induction Motor—Synchronous Motors—Rotaries in Power Transmission—Rotaries in Electric Light Stations—Two and Three Phase Alternator Connections 242

CHAPTER I

INTRODUCTION.—PURPOSE OF WIRING.—OHM'S LAW.—DROP OF POTENTIAL.—MEANING OF A MILFOOT.—MEANING OF A CIRCULAR MIL.—CALCULATION OF DROP.—CALCULATION OF THE SIZES OF WIRE FOR A GIVEN DROP.—WIRING RULES.—CALCULATION OF RESISTANCE FOR BRANCH CIRCUITS.—WHAT IS POWER AND HOW ESTIMATED.

Introduction.—Wiring is now one of the most important departments of electrical engineering. In the last 15 years it has developed from a comparatively haphazard attempt to conduct current to the various lamps in a building into a systematized code of principles and practices based upon the rulings of the Board of Fire Underwriters, in conjunction with the recommendations of the most prominent society of electrical experts in the United States.

It has in fact assumed an importance in the building arts second to none. No large structure is erected at present without provision being made in the plans for electric wiring. In many cases it has entirely superseded gas and is the only means of lighting considered.

The development of the art of wiring has meant the development of industries dependent upon it for their existence. Immense amounts of capital are in use for the manufacture of insulated wire of many descriptions; for the manufacture of sockets, switches, cut-outs, lamps, lampcord, iron pipe conduit, and a host of smaller appliances essential to the installation of a wiring system. The experimental stage has been passed and electric wiring and electric lighting have entered into the administration of the affairs of our large cities as an economic measure required for public safety and convenience. So we enter, as it were, upon a new era in the application of electricity for electric light and power, and this has had enormous influence upon the development and progress of every large city and town.

Regarding the practice of wiring from such standpoints, it is easy to understand the importance to be attached to those principles which lie at the very root of the subject. When it is remembered, that the greater part of the wiring is still to be done in thousands of homes and buildings of the future; that the universal application of electricity for electric lighting will become a fact as soon as the price of electricity is within the means of the humbler classes, and finally that its hygienic benefits are so pronounced both in summer and winter that it must in the course of time be regarded as an indispensable adjunct to home comfort; it will be seen that the art which will reach its greatest development and application in that direction for that purpose is electric wiring.

Statistics may be found in a variety of magazines showing the enormous growth of electric lighting in the United States, but one of the most unique records is that of the fan motor load which is experienced at certain hours of the day in large cities during the summer months.

Recently the New York Stock Exchange expended thousands of dollars in the construction of an equipment, largely electrical, for keeping the air of the exchange 10 degrees cooler than the air of the street during the heated period. Fans 12 feet in diameter are employed for this purpose attached to powerful motors. The air is filtered as it passes through into the exchange thus relieved of every particle of dust.

Purpose of Wiring.—It is not only the distribution of current which is kept in view by laying out a wiring system, but the proportioning of the sizes of wire employed so as to limit the loss of pressure from point to point as required. In the lighting of incandescent lamps it is necessary to supply a definite pressure to the terminals in order to produce the requisite light. The incandescent lamp is peculiarly sensitive to changes of pressure, losing a large percentage of its illuminating power with a slight drop in pressure and gaining rapidly in candle power as the pressure increases. The life of the lamp is seriously affected by more than the necessary pressure; it rapidly blackens and soon becomes valueless unless such irregularities are checked in the power supply.

Ohm's Law.—Few discoveries of modern times rank in importance with the discovery of Ohm's Law. A study of the principles of electric wiring cannot be carried on without the reader possessing a thoroughly intelligent conception of the meaning and application of this law.

The law in itself is exceedingly simple, and expresses the relationship between amperes, volts and ohms. In order to understand the law the first thing to be done is to gain a knowledge of what is meant by a volt, an ohm and an ampere. In order to do this satisfactorily, illustrations must be employed which though not presenting an ideal simile, yet will serve to convey the idea in view.

Volts.—When a current of electricity passes through a circuit it is set into motion by what is termed electromotive force. If it is impossible to imagine water or steam or any other fluid passing through a pipe without pressure, it is likewise impossible to imagine a current flowing through a circuit without electromotive force. In other words, the force which moves or tends to move electricity is electromotive force.

Electromotive force is measured in volts just as steam pressure comparatively is measured in pounds. The general expression, electromotive force and its measurement in volts, may be understood by reference to the general expression, pressure and its measure in pounds.

Amperes.—If a certain quantity of electricity can be delivered by a current in one second it is because the current has a certain strength. If the current is capable of delivering twice as much in one case as another in one second, it obviously possesses twice the strength. A unit quantity of electricity is called a coulomb. The question now is, what is a coulomb? It can be answered in a practical manner by stating that every particle of copper, silver, gold, nickel or any other metal in an electroplating bath is carried over and deposited on the articles to be plated, thickly or thinly, according to the number of coulombs that have been employed. For instance, one coulomb per second will carry over one-twenty-ninth of an ounce of copper in an hour. Each coulomb always carries over a definite quantity. Each second the same amount is carried over, so that in the course of one hour (or 3,600 seconds) a weight of copper equal to one-twenty-ninth of an ounce has been deposited.

A current of electricity which will give one coulomb per second has a strength of one ampere. This means that a current of one ampere will plate over a weight of copper equal to one-twenty-ninth of an ounce per hour. If the current has a strength of two amperes it will plate twice as much per hour, and so on. A current of the strength of five amperes will give five coulombs per second, ten amperes ten coulombs per second, etc., as indicated in the table:

TABLE SHOWING RELATION BETWEEN COULOMBS AND AMPERES.

Strength of current. Amperes.	Coulombs per second.
1	1
2	2
3	3
4	4
5	5
10	10
50	50
100	100

TABLE SHOWING RELATIONSHIP BETWEEN COULOMBS, COPPER DEPOSITED AND STRENGTH OF CURRENT.

Amperes.	Coulombs.	Hours.	Pounds.	Ounces.	Grains.
1	36,000	10			180
5	180,000	10		2	26
10	360,000	10		4	52
20	720,000	10		8	104
30	1,080,000	10		12	156
40	1,440,000	10	1		208
50	1,800,000	10	1	4	260

It is of great importance to grasp the meaning of Ohm's Law, not only as an abstract relationship between current, electromotive force and resistance, but as a physical relationship, which may be proved by illustration in many ways. The following tables are illustrative of the application of Ohm's Law in three successive cases in which the current remains constant, the volts constant and the resistance constant. The influence of this condition is interesting in each table and shows that either amperes, volts or ohms can be calculated by knowing the other two, as follows:

Table I—Amperes = volts ÷ ohms.
Table II—Volts = amperes × ohms.
Table III—Ohms = volts ÷ amperes.

Table I. $C = E \div R$.

CURRENT REMAINS CONSTANT.

Amperes.	Volts.	Ohms.
10	10	1
10	20	2
10	30	3
10	40	4
10	50	5

Table II. $E = C \times R$.

VOLTS REMAIN CONSTANT.

Amperes.	Volts.	Ohms.
10	100	10
20	100	5
30	100	3·333
40	100	2.5
50	100	2.0

Table III. R = E ÷ C.

OHMS REMAIN CONSTANT.

Amperes.	Volts.	Ohms.
10	100	10
20	200	10
30	300	10
40	400	10
50	500	10

In the cases cited E is divided twice, once by R and once by C, and R and C are multiplied together. So it is easy to remember that the two factors multiplied together are the two which are respectively

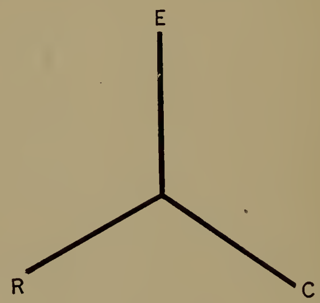

FIG. 1.—Diagram of Ohm's Law.

divided into E to get either C or R. For instance E ÷ by either C or R = either R or C, and C × R = E, which might be represented by the following sketch:

The two lower ones multiplied give E (Fig. 1); the upper one, divided by either of the lower, gives the remaining character. It is very convenient to those unaccustomed to algebraic forms to carry an image in the mind as indicated above with the method of handling it.

Drop of Potential.—A fact with which every one should be familiar is that it is impossible to transmit power from place to place without a loss. If steam is sent through a pipe to run an engine, the longer the pipe the greater the loss of power before the steam is utilized. The smaller the diameter of a pipe the greater the waste of power in transmitting. The same principle applies to wire rope transmission, in which a very large percentage of power disappears between the points sending and receiving it, as in the case of cable car systems, passenger elevators, etc.

A wire conducting electric power is subject to the same law, which manifests itself in two ways; first, the pressure or voltage diminishes; secondly, the wire develops heat. The loss of pressure, which may be shown by the voltmeter, can be readily calculated by Ohm's Law:

$$\text{Drop} = \text{amperes} \times \text{ohms}.$$

For instance, if the problem were given: what is the drop of potential in a line of 10 ohms resistance carrying a current of 10 amperes? the answer would be

$$\text{Drop} = 10 \times 10 = 100 \text{ volts}.$$

Rule.—To calculate the drop in a line multiply the amperes by the ohms.

TABLE SHOWING DROP IN A LINE.

Size of wire No. 10 B & S.	Amperes.	Ohms.	Drop in volts.
1,000 feet	10	1	10
2,000 feet	10	2	20
3,000 feet	10	3	30
4,000 feet	10	4	40
5,000 feet	10	5	50

It is evident from an inspection of the table that the drop increases as the resistance or current increases. The loss of power in a line can be diminished by reducing the current in the line or reducing the resistance of the line.

Resistance of Wires.—The resistance of a wire depends upon the length of the wire, its diameter or cross section, and the metal of which it is composed. Resistance is a native property, such as elasticity, ductility, malleability, and depends upon the quality or purity of the metal, or the mixture composing the alloy, as in the case of german silver wire.

If conductors had no resistance, no power would be wasted in transmitting current. In addition, a very small voltage would be sufficient to send heavy currents through a wire. On account of the resistance of a wire being governed by its geometrical dimensions, certain rules have been adopted by means of which the resistance of copper wires of any length or cross section can be readily calculated. The basis which can be employed is the resistance of one foot of copper wire, one one-thousandth of an inch in diameter, commonly called a milfoot, which has a resistance of a little less than 11 ohms. The term mil is employed because it means a thousandth of an inch, or a thousandth part, and refers in this case to a round wire of the diameter above mentioned. If two such wires are placed side by side the resistance is reduced to one-half, three such wires will reduce it to one-third, etc. In other words, a rule may be stated as follows:

Rule.—The resistance of a wire of fixed length is inversely proportional to its cross section.

It is customary to call a wire of one mil diameter a circular mil; a wire of two mils diameter would therefore have four circular mils; a wire of three mils diameter, nine circular mils, etc.

TABLE SHOWING RELATION BETWEEN RESISTANCE AND CROSS SECTION.

Circular mils.	Ohms.	Feet.
10,000	1.0	1,000
20,000	.5	1,000
30,000	.3333	1,000
40,000	.2500	1,000
50,000	.2000	1,000

It is not necessary to show how the resistance increases or diminishes as the wire increases or diminishes in length, while retaining the same cross section in circular mils, because it is obvious that a current must move through twice as much resistance in 1,000 feet of wire as 500 feet of the same cross section. As a proof of this fact the drop of potential with a given current in a fixed cross section is just twice as great with twice the length of wire, but as drop of potential equals $C \times R$ it is evident that if the current remains constant the drop in both can only increase or double if the resistance doubles.

A simple and practical rule can be deduced from these facts which will assume the following form:

Rule.—The resistance of a wire is proportional to its length in feet and inversely proportional to its cross section in circular mils.

Table Showing Relation Between Resistance, Cross Section and Length.

Circular mils.	Ohms.	Feet.
10,400	10	10,000
5,200	10	5,000
2,600	10	2,500
1,300	10	1,250
650	10	625

Calculating Drop in Volts.—In a single circuit the calculation of the drop of pressure is made by using Ohm's Law in the form previously given: $E = C \times R$, or volts drop = amperes $\times$ ohms. For instance, what is the loss of volts in a simple circuit whose resistance is 10 ohms carrying a current of 3 amperes? According to the rule drop in volts = 10 ohms $\times$ 3 amperes or 30 volts. If the circuit is supplying current to lamps, then the volts are 110 where the current enters; where it leaves in the above case, it would be 30 volts less, or only 80 volts (Fig. 4); 30 volts disappearing through the effect of the resistance and current.

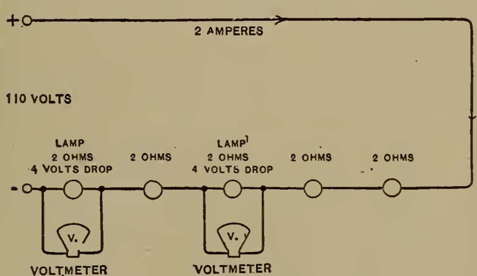

FIG. 2.—Lamps in Series, 4 Volts per Lamp.

In the sketch (Fig. 2) the lamps are shown in series with each other; that is, the same current passing through one lamp after the other. As two amperes pass through each lamp as indicated, and as each lamp has two ohms resistance, the drop between the ends of each lamp would be $2 \times 2 = 4$ volts. Voltmeters are shown in position across the terminals, each giving a reading of four volts, which is a reading of the drop taking place in the lamp. An experiment of this kind can be tried with five 110 volt lamps arranged as shown. Only one voltmeter is necessary for readings from every lamp. When they have all been obtained their sum will equal the total voltage applied.

Series Electric Lighting.—A very practical example of the above case of series lighting can be found in high tension arc lighting (Fig. 3), so uni-

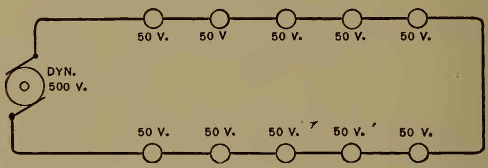

Fig. 3.—High Tension Arc Light System, Series Wiring.

versally employed in large cities. The lamps are placed on street corners as a rule, and extend through the city in this manner for a distance of several miles. A current of about 10 amperes is employed, and each lamp has the equivalent of a resistance of 5 ohms. According to these figures each lamp will have a drop of 50 volts; therefore, if 10 lamps are lit, 500 volts are required, for 20 lamps 1,000 volts, 40 lamps, 2,000 volts, etc. In a lighting system of this kind all wiring is done in series, in contradistinction to incandescent light wiring, which is done in multiple. The difference between the series system and the multiple system of wiring is readily illustrated by a simple sketch (Fig. 4).

Fig. 4.—Incandescent Light System, Multiple Wiring.

Multiple Wiring.—In a multiple circuit the current divides up; each part of the circuit taking current according to its resistance, as shown by Ohm's Law. In the cases mentioned three amperes divide up into three separate currents of one ampere apiece. The current divides as shown because the resistance of each branch will not permit any more to pass through.

Example: The lamps each take 1 ampere at 110 volts, what is the resistance of each lamp? Referring to the table previously given, it will be seen that this is a case where volts and amperes are given to find ohms. According to the rule, volts divided by amperes gives ohms; therefore 110 divided by 1 gives 110 ohms per lamp.

What is Meant by Percentage of Drop.—The drop in either a series circuit or a multiple circuit is calculated from the amperes and ohms of the circuit. A very simple formula is employed for the purpose of obtaining the size of wire in circular mils, in which a stated loss of volts occurs. For instance, if a building is wired for incandescent lights, it is customary to make an allowance beforehand for the drop in volts. This allowance may be 2 per cent., 3 per cent., etc., as the circumstances warrant. If 110 volts are supplied to the lamps, 2 per cent. or 2.2 volts will be purposely wasted in the circuits before it reaches the lamps. The lamps will therefore receive only 107.8 volts. In using the formula the number of volts to be dissipated in the circuit under consideration must be given.

Formula: Circular mils = feet of wire × amperes in wire × 11 ÷ volts drop in wire.

Example: Take a circuit 250 feet long carrying 10 amperes, in which 3 volts drop will be allowed, how many circular mils cross section must be supplied for the wire? According to the above, a circuit with a 250 foot run must have 500 feet of wire, giving circular mils equal to $500 \times 10 \times 11 \div 3 =$ 18,333. The formula is given in symbols in the following form:

$$\text{C. M.} = \frac{11 \times F \times A}{V},$$

where F = feet of wire, A = amperes, 11 is a constant, V = volts drop and C. M. = circular mils. The constant 11 is the resistance in ohms of 1 mil foot of copper wire.

TABLE SHOWING EFFECT OF PERCENTAGE OF DROP ON CIRCULAR MILS OF WIRE REQUIRED.

Formula: $\frac{11 \times F \times A}{V} = C.\ M.$

Amperes.	Percentage of drop.	Circular mils.	Feet of wire.	Volts drop.
10	1	100,000	1,000	1.1
10	2	50,000	1,000	2.2
10	3	33,333	1,000	3.3
10	4	25,000	1,000	4.5
10	5	20,000	1,000	5.5

Volts for lighting = 110.

The volts supplied are supposed to be fairly constant; the amperes may vary according to the number of lamps burning. The amount of copper is well represented by the circular mils in each case where the percentage of drop is varied. With 5 per cent. drop only one-fifth of the copper required in the first case is necessary.

Sizes of Wire and Circular Mils.—The sizes of wire are known by reference to the number of circular mils they represent and vice versa. The number of circular mils of a round wire may be obtained by squaring the diameter of the wire in mils.

For instance, a wire one-tenth of an inch in diameter is $\frac{100}{1000}$, or 100 mils in diameter; the square of 100 mils is $100 \times 100 = 10{,}000$ circular mils.

Resistance and Circular Mils.—For practical purposes it is safe to assume 11 ohms resistance for a wire 1 foot in length and one circular mil in cross section. Therefore the resistance of a wire 1 foot long and having two circular mils cross section will be one-half of 11 ohms or 5.5 ohms. On this basis fewer circular mils to a wire mean more resistance and more circular mils mean less resistance. The resistance of wires can be calculated by a simple formula which expresses the idea just stated in a concise form.

Formula: Resistance in ohms equals feet of wire $\times$ 11 $\div$ circular mils.

Example: For instance, what is the resistance of 100 feet of wire of 1,000 circular mils? The answer is, ohms equals $100 \times 11 \div 1{,}000 = 1.1$ ohms.

From the foregoing it is not a difficult task to arrange a table showing the relationship existing between the length of a wire, its cross section in circular mils and its resistance in ohms.

Table Based Upon the Formula, Showing the Relation Between Ohms, Feet of Wire and Circular Mils.

$$\text{Formula: } R = \frac{11 \times \text{ft. wire}}{\text{Circular mils.}}$$

Circular mils.	Ohms.	Feet wire.
1,000	11.0	1,000
2,000	5.5	1,000
3,000	3.666	1,000
4,000	2.75	1,000
5,000	2.2	1,000
10,000	1.1	1,000

With the number of feet of wire constant, the resistance is inversely proportional to the circular mils. For instance, with C. M. = 1,000, R = 11 ohms, but with C. M. = 10,000, R = 1.1 ohms, showing that with 10 times the cross section the resistance becomes one-tenth.

Resistance in Multiple.—Calculating the joint resistance of a number of resistances in multiple can be accomplished at once if the resistances in multiple are equal in the first case, or by a simple calculation if the resistances in multiple are unequal in the second case.

Resistances are Equal.—When resistances are in multiple and are equal to each other take the resistance of one and divide it by the number of resistances.

Example: For instance, take a circuit consisting of 20 lamps in multiple each having a resistance of 100 ohms, what is the total resistance? The total resistance is equal to the resistance of one lamp, which is 100 ohms, divided by the number of lamps, which is $100 \div 20 = 5$ ohms.

EQUAL RESISTANCES IN MULTIPLE.

$$\text{Formula: } R = \frac{\text{resistance of 1 branch}}{\text{number of branches.}}$$

Number of resistances.	Resistance of each.	Total resistance.
50	1,000 ohms	20 ohms
40	800 ohms	20 ohms
30	600 ohms	20 ohms
20	400 ohms	20 ohms
10	200 ohms	20 ohms
5	100 ohms	20 ohms

In dealing with incandescent lamps a fact to be remembered is that the resistance of the lamp cold is much greater than its resistance hot. A 16 cp., 110 volt lamp cold, has a resistance of 450 ohms; when it is burning its resistance drops to about 120 ohms. Therefore if a bank of lamps is measured cold, when in multiple, the resistance will be much higher than when its total resistance is calculated from the volts and amperes required when lighted.

Resistances are Unequal.—When resistances in multiple are unequal a simple calculation is employed. The rule is as follows: The total resistance is equal to the reciprocal of the sum of the reciprocals of the resistances. The practical application of the rule can be best shown by a case in point. Example: What is the resistance of the following resistances in multiple: 5, 10, 15 and 20 ohms? According to the rule

$$R = 1 \div (\tfrac{1}{5} + \tfrac{1}{10} + \tfrac{1}{15} + \tfrac{1}{20}).$$

In other words, add the fractions together whose numerators are now one, and whose denominators are the various resistances in multiple. In the above case $R = 1 \div \frac{25}{60} = \frac{60}{25} = 2.4$ ohms. It will be noted that the resistance of a group of unequal resistances in multiple is always less than the lowest resistance of the group. For instance, in the case just given the total resistance 2.4 ohms is less than the lowest resistance of the group, which is 5 ohms. Adding up the reciprocals of the resistances and inverting the fraction explains the above process. To illustrate, take the resistances 1, 2, 3, 4 and 5 ohms in multiple, what is their total resistance? If the reciprocals are added together the fraction obtained is $\frac{137}{60}$. Inverting this fraction gives the answer $\frac{60}{137} = .438$ ohm. If the various resistances in multiple are fractional they must be treated in the same manner, although the reciprocal of fractions such as $\frac{1}{2}$ is 2, $\frac{1}{4}$ is 4, etc.

UNEQUAL RESISTANCES IN MULTIPLE.

$$\text{Formula: } R = 1 \div \left(\frac{1}{\text{R of 1st branch}} + \frac{1}{\text{R of 2d branch}} + \text{etc.} \right)$$

Resistance in multiple. Ohms.	Sum of reciprocals of resistances.		Total resistance. Ohms.
1, 2, 3	$1+\frac{1}{2}+\frac{1}{3}$	$\frac{11}{6}$	.545
1, 2, 3, 4	$1+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}$	$\frac{25}{12}$	.480
1, 2, 3, 4, 5	$1+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}$	$\frac{137}{60}$	.438
10, 20, 30, 40, 50, 60	$\frac{1}{10}+\frac{1}{20}+\frac{1}{30}+\frac{1}{40}+\frac{1}{50}+\frac{1}{60}$.	$\frac{147}{600}$	4.081
$\frac{1}{2}, \frac{1}{4}, \frac{1}{3}, \frac{1}{8}$	$2+4+3+8$	17	.0588
$\frac{1}{10}, \frac{1}{20}, \frac{1}{30}, \frac{1}{40}, \frac{1}{50}$	$10+20+30+40+50$	150	.00666

Examples of Drop of Potential.—The drop of pressure in a circuit is not the only instance of a waste of energy met with in actual practice. The dynamo is also affected in its most vital part by the passage of a current through conductors, which while performing the function of generating electromotive force, are at the same time acting in the capacity of conductors which possess resistance and develop drop in the operating machine. The part referred to is the armature, and allowance must be made for this deficiency when the dynamo is running at one-quarter, one-half, or full load. Take the case of a 100-light generator; its amperes at 110 volts pressure are approximately 50, if the armature resistance is one-tenth of an ohm, the drop at the indicated points of load will be respectively:

Drop at one-quarter load $= 12.5$ amperes $\times .1$ ohm $= 1.25$ volts.

Drop at one-half load $= 25.0$ amperes $\times .1$ ohm $= 2.50$ volts.

Drop at full load $= 50.0$ amperes $\times .1 = 5.00$ volts.

It is but natural to suppose that this will have its effect upon the candle power of the lamps. At full load a 110 volt lamp will receive only 105 volts, which will mean a great depreciation in illuminating power, sufficient perhaps to make electric lighting on this basis an expensive luxury.

A modern dynamo is built to automatically build up its electromotive force as the load increases. Such dynamos are called compound wound dynamos, and are of immense service in comparison with the older type, in which regulation was only obtained by hand.

In an electric light system the following items must be considered:

Drop in the armature.
" " switchboard.
" " mains.
" " feeders.
" " branches.

The drop in the armature need not be considered as part of the drop in a wiring system, although indirectly it contributes to the difficulty of solving special problems. Loose joints and poor connections were a source of great danger and loss of power, in wiring of the past decade, but the severe inspection of to-day has obliterated such evils. It is within the province of a treatise on wiring to embrace all questions relating to the passage of the current after leaving the dynamo. As the ultimate object of wiring is to limit the waste of power and the amount of copper employed, as well as to secure good candle power for the lamps, data on all three is of the utmost importance in the consideration of wiring for power and distribution of power.

Calculation of Power.—Power is calculated in watts. Watts are equal to the product of volts by amperes. If either the volts or amperes of a circuit are increased or diminished, the power will be correspondingly increased or diminished. For instance, what is the power obtained from 110 volts and 25 amperes? The answer is $25 \times 110 = 2{,}750$ watts. The watts can be still further transformed in horse-power by dividing them by 746. There are 746 watts in a horse-power, therefore 2,750 watts $\div 746 = 3.68$ horse-power, generally denoted by the symbols hp.

Power Table, Showing Relationship Between Watts, Volts and Amperes.

Volts.	Amperes.	Watts.	Horse-power.	Kilowatts.
1,000	100	100,000	134.0	100
500	200	100,000	134.0	100
250	400	100,000	134.0	100
125	800	100,000	134.0	100

Kilowatt.—The kilowatt simply means 1,000 watts, and roughly represents 1⅓ hp. Manufacturers rate their dynamos on this basis instead of speaking of their horse-power or lighting capacity in lamps. The power consumed by an incandescent lamp varies from 3 to 4 watts per candle power. A 16 cp. lamp takes from 48 to 64 watts. A horse-power would supply power for from 11 to 15 lamps, depending upon their rating per candle power.

CHAPTER II

CARRYING CAPACITY OF WIRES.—EFFECTS OF HEAT UPON RESISTANCE.—ALLOWANCE FOR HEAT.—A SIMPLE ELECTRIC LIGHT CIRCUIT.—WIRE OF A 10 LAMP CIRCUIT WITH DROP ANALYZED.—THE WIEDEMANN SYSTEM OF LIGHTING AND ITS DEFECTS.—THE WIRING TABLE.—HOW TO PREPARE A TABLE OF SIZES AND CIRCULAR MILS.—EXAMPLES OF THE APPLICATION OF THE WIRING TABLE AND FORMULA.—CALCULATION OF THE DROP PER 1,000 FEET PER AMPERE.

Carrying Capacity of Wires.—If the drop of potential in electric light wires was the only thing to be feared, it would be a matter of concern only to the consumer of electricity and the power company. The candle power would not be up to the standard, and the waste of power in the conducting wires would represent a heavy percentage of the cost of transmission. But this is not all, and the matter is of importance to the community as well, because when excessive energy is wasted in the conducting wires, not only does it become manifest as drop of pressure but as heat. The danger of an unusual rise of temperature in the wires is removed by the limitations imposed on contractors in the United States. These may be found in the National Electrical Code of the Fire Underwriters.

Rubber Covered Wires.—The wire employed in electric wiring is protected by a rubber covering, the name generally applied being "rubber covered wires." A rise in temperature of 30 degrees F. is allowed in such wires, and as this means an increase in resistance and therefore an increase in drop, the following table is given for the purpose of illustrating this fact:

EFFECT OF TEMPERATURE UPON RESISTANCE OF WIRES AND DROP OF PRESSURE.

1,000 feet No. 10 B. & S. = 1 ohm.			
Current.	Increase in temperature.	Increase in resistance.	Increase in drop.
10	10 degs. F.	.022 ohm	.22 volts
10	20 degs. F.	.044 ohm	.44 volts
10	30 degs. F.	.066 ohm	.66 volts
10	40 degs. F.	.088 ohm	.88 volts
10	50 degs. F.	.110 ohm	1.10 volts
10	75 degs. F.	.165 ohm	1.65 volts
10	100 degs. F.	.220 ohm	2.20 volts

This table is based upon the increase in resistance in a copper wire due to an increase in temperature. A rise of 1 degree F. means an increase in resistance of .0022 per cent. (nearly $\frac{1}{4}$ of 1 per cent.). The formula employed is as follows:

Formula: Resistance at an increased temperature = resistance of wire in ohms $\times$ .0022 $\times$ rise in degrees Fahrenheit + the resistance of the wire.

To illustrate, supposing a wire has 5 ohms resistance and the rise in temperature is 20 degrees F., what is the resistance? The resistance = 5 × .0022 × 20 + 5 = 5.22 ohms. The resistance of wires of other metals than copper can be calculated by the same formula provided the constant is obtained from the table of constants given under the heading of "Temperature Coefficients."

TEMPERATURE COEFFICIENTS.

PERCENTAGE INCREASE OF RESISTANCE PER 1 DEGREE FAHRENHEIT.

Percentage.	Metal.	30 degrees F.
.002156	Copper	.06468
.002517	Iron	.07551
.000244	German-silver	.00732
.001372	Platinum	.04116
.002167	Aluminum	.06501

Calculation of a Simple Circuit.—Because the lengths of wire connected to each lamp are different, the resistance of each circuit and therefore the drop of pressure is different. In the circuit illustrated, the drop of each lamp becomes greater the further it is removed from the source of the supply of power:

For instance (Fig. 5), lamp No. 1 has 100 + 100 = 200 feet of wire connected to it, and lamp No. 10 has 200 + 180 + 180 = 560 feet of wire in its circuit. The other lamps have lengths of wire in their circuits lying between 200 feet and 560 feet.

For this reason it is evident that the resistance in circuit with each lamp is different and therefore the

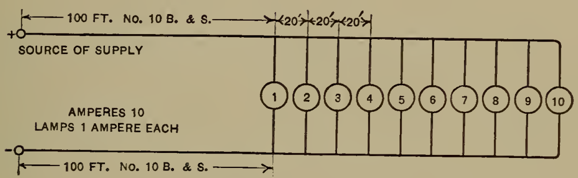

Fig. 5.—Analysis of a 10 Lamp Circuit.

drop is unequal throughout the line. Using No. 10 wire and allowing one ampere per lamp gives the following data:

Circuit of 10 Lamps Taking 1 Ampere Apiece. Size Wire, No. 10 B. & S.

Position of lamp.	Feet of wire.	Resistance. Ohm.
No. 1	200	.200
No. 2	240	.240
No. 3	280	.280
No. 4	320	.320
No. 5	360	.360
No. 6	400	.400
No. 7	440	.440
No. 8	480	.480
No. 9	520	.520
No. 10	560	.560

Current in the Wire.—The drop in the wire cannot be calculated by merely multiplying the main current by the various resistances of the various circuits given above. An examination of the circuit will show that the connecting wires of lamp No. 1 carry 10 amperes, while the connecting wires of lamp No. 2 carry 10 amperes and 9 amperes. This unequal distribution of current in the connecting wires which lead up to all of the lamps and the difference in drop in each lamp is shown in the following table:

Distribution of Current in Connecting Wires of a Simple 10 Lamp Circuit.

Position of wire.	Current in wire.	Resistance of wire.	Drop in volts.
	Amperes.	Ohm.	
Between source and lamp No. 1..	10	.200	2.000
Between No. 1 and No. 2.........	9	.040	.360
Between No. 2 and No. 3........	8	.040	.320
Between No. 3 and No. 4.........	7	.040	.280
Between No. 4 and No. 5.........	6	.040	.240
Between No. 5 and No. 6.........	5	.040	.200
Between No. 6 and No. 7.........	4	.040	.160
Between No. 7 and No. 8........	3	.040	.120
Between No. 8 and No. 9.........	2	.040	.080
Between No. 9 and No. 10.......	1	.040	.040

The last column of this table shows the drop due to the current and connecting wires of each lamp, but it does not show the total drop of the lamp. To illustrate, the first lamp has a drop of 2 volts, because its connecting wires carry the full

10 amperes and have a resistance of .2 ohm. The second lamp, however, is different; its drop is greater, because it not only meets with the drop of the first lamp, but that of its connecting wires lying between lamps No. 1 and 2, equal to .36 volt. Lamp No. 2 therefore has a drop equal to 2.36 volts, and lamp No. 3 will have a drop equal to lamp No. 2 plus the additional drop it experiences in its connecting wires lying between lamps No. 2 and No. 3, amounting to .32 volt, or a total of 2.36 + .32 = 2.68 volts drop for lamp No. 3.

Drop of Each Lamp in a Simple 10 Lamp Circuit, Current 10 Amperes. Size of Wire, No. 10 B. & S.

No. of lamp.	Drop from source to lamp.	Total drop in volts.
	Volts.	
1	2.00	2.000
2	2.00 + .36	2.360
3	2.00 + .36 + .32	2.680
4	2.00 + .36 + .32 + .28	2.960
5	2.00 + .36 + .32 + .28 + .24	3.100
6	2.00 + .36 + .32 + .28 + .24 + .20	3.400
7	2.00 + .36 + .32 + .28 + .24 + .20 + .16	3.560
8	2.00 + .36 + .32 + .28 + .24 + .20 + .16 + .12	3.680
9	2.00 + .36 + .32 + .28 + .24 + .20 + .16 + .12 + .08	3.760
10	2.00 + .36 + .32 + .28 + .24 + .20 + .16 + .12 + .08 + .04	3.800

It is of the utmost importance to carefully follow the items given in this table and their relation to the main facts. The table shows that in any circuit of the character shown in the illustration the drop increases from the source to the last lamp.

Lamp No. 1 has a drop of 2 volts, lamp No. 10 a drop of 3.8 volts, and between these two occur increases in drop, due to the causes above specified.

The purpose in view in making an analysis of wiring is to find the best methods to employ in laying out the circuits, for the purpose of keeping the drop as uniform as possible among the lamps. This task can only be accomplished intelligently and therefore economically, for the problem is as much commercial as scientific, by following certain general principles in mapping out the most important circuits.

The Wiedemann System.—The purpose of the Wiedemann system (Fig. 6) was to connect each

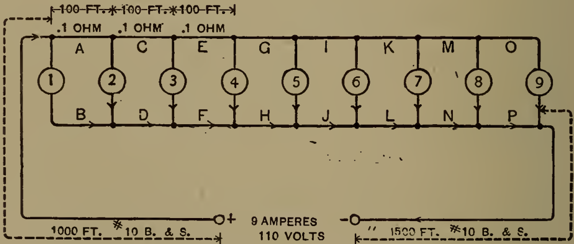

FIG. 6.—Wiedemann System of Wiring.

lamp in the system with an equal length of wire. By this means every lamp represented individually a circuit of equal resistance, and it was believed that the drop of each lamp would be alike.

By following the length of circuit through each lamp in the sketch it will be seen that each lamp is supplied with current through 2,300 feet of No. 10 wire. Take lamp No. 1 for instance, starting from the positive pole the current passes through 1,000 feet of wire, then through the lamp, then through B, D, F, H, J, L, N, P (which are the connecting wires between lamp and lamp on one side of the circuit of 100 feet apiece) and finally through the indicated 500 feet of terminal wire. The total length met with for lamp No. 1 is therefore 1,000 feet + 800 feet + 500 feet = 2,300 feet total. Tracing the circuit through lamp No. 2 will give 1,000 feet + A + D, F, H, J, L, N, P + 500 feet = 1,000 + 100 + 700 + 500 = 2,300 feet for lamp No. 2. Following the circuit through for each lamp will show exactly the same length of wire connected to each one. If there is the same length of the same size of wire connected to each lamp, the resistance in circuit with each lamp must be the same. The question now arising is this: Will the lamps have equal drop and therefore burn with equal candle power, or is the drop in the circuit of each lamp different? This question can be best answered by an investigation of the drop met with in the circuit of each lamp. To discover the drop in the circuit of each lamp, the resistance and current must be known. In the sketch the resistance is known, so the problem is reduced down to a statement of the number of amperes in each part of the circuit of each lamp.

Amperes in Lamp Circuits.—To find the amperes in each lamp circuit refer to the sketch beginning with lamp No. 1. Because every lamp has the two terminals of the circuit, respectively 1,000 feet and 500 feet to consider alike, they will be left out of consideration for the present and particular attention paid to the current in the connecting wires met with in the circuit of each lamp. Following the 9 amperes along from the + pole it is seen that 1 ampere passes through lamp No. 1 and enters connecting wire B, leaving 8 amperes to pass through connecting wire A. Another ampere passes through lamp No. 2 and enters con-

Connecting wire.	Amperes.	Drop in volts.
Positive wire.		
A	8	$.1 \times 8 = .8$
C	7	$.1 \times 7 = .7$
E	6	$.1 \times 6 = .6$
G	5	$.1 \times 5 = .5$
I	4	$.1 \times 4 = .4$
K	3	$.1 \times 3 = .3$
M	2	$.1 \times 2 = .2$
O	1	$.1 \times 1 = .1$
Negative wire.		
B	1	$.1 \times 1 = .1$
D	2	$.1 \times 2 = .2$
F	3	$.1 \times 3 = .3$
H	4	$.1 \times 4 = .4$
J	5	$.1 \times 5 = .5$
L	6	$.1 \times 6 = .6$
N	7	$.1 \times 7 = .7$
P	8	$.1 \times 8 = .8$

necting wire D, returning with the ampere from connecting wire B. The following table will clearly show the distribution of current in the connecting wire of the circuit.

It is now a simple task to discover the drop met with in the circuit of each lamp. For instance, lamp No. 1 meets with a drop of .1 volt in B, .2 volt in D, and in F, H, J, L, N, and P respectively, a drop of .3 + .4 + .5 + .6 + .7 + .8 volt or a total of 3.6 volts. Lamp No. 1 has its circuit through B, D, F, H, J, L, N, and P; lamp No. 2 its circuit through A, D, F, H, J, L, N, and P, and lamps Nos. 3, 4, 5, etc., as shown in the following table:

No. of lamp.	Circuit of lamp.	Total drop of lamp.
1	B, D, F, H, J, L, N, P...	.1+.2+.3+.4+.5+.6+.7+.8=3.6
2	A, D, F, H, J, L, N, P...	.8+.2+.3+.4+.5+.6+.7+.8=4.3
3	A, C, F, H, J, L, N, P...	.8+.7+.3+.4+.5+.6+.7+.8=4.8
4	A, C, E, H, J, L, N, P...	.8+.7+.6+.4+.5+.6+.7+.8=5.1
5	A, C, E, G, J, L, N, P...	.8+.7+.6+.5+.5+.6+.7+.8=5.2
6	A, C, E, G, I, L, N, P...	.8+.7+.6+.5+.4+.6+.7+.8=5.1
7	A, C, E, G, I, K, N, P...	.8+.7+.6+.5+.4+.3+.7+.8=4.8
8	A, C, E, G, I, K, M, P...	.8+.7+.6+.5+.4+.3+.2+.8=4.3
9	A, C, E, G, I, K, M, O ..	.8+.7+.6+.5+.4+.3+.2+.1=3.6

According to the above data lamp No. 5 has the greatest drop and will therefore burn the dimmest. Its loss is 5.2 volts, then come lamps Nos. 4 and 6 with a drop of 5.1 volts apiece, then lamps Nos. 3 and 7 with an equal drop of 4.8 volts, lamps Nos. 2 and 8 with 4.3 volts drop and finally lamps

Nos. 1 and 9 with equivalent drops in pressure of 3.6 volts. The middle lamps burn dimly, the ones on each side a little brighter, the lamps on each side of these a little brighter, etc. If the number of lamps arranged as shown in the sketch are even, the two middle ones will burn equally bright, the candle power increasing from these two in pairs equally to the two ends of the circuit. An experiment with a bank of 20 lamps connected up as shown on a 110 volt circuit will demonstrate the fall of candle power from the ends to the middle of the circuit. It is therefore evident that in the Wiedemann system although each lamp is in circuit with the same amount of resistance, because the current is different in the connecting wires the drop of each lamp is different from its neighbor as shown.

The Wiring Table.—The manufacture of wire for electric light and power purposes has meant the utilization of a variety of wire gauges; among which, the most important is the Brown and Sharpe, commonly indicated as the B. & S. gauge. These gauges differ from each other in their sizes and the circular mils corresponding to these sizes. If the B. & S. gauge is taken as the standard, all the sizes of wire in this particular gauge can be shown to arbitrarily arise from a consideration of the No. 10 size. This has approximately 10,400 circular mils cross-section and a resistance of about 1 ohm per 1,000 feet.

An examination of the B. & S. table will show the following interesting facts, of which practical use may be made in the development of a table for ready reference that will be almost identical with the wire manufacturers. In the first place, every three sizes of wire mean that the circular mils have either doubled or halved. For instance, a No. 10 wire, B. & S., has 10,380 circular mils; if a No. 7, which is three sizes larger, is compared, it is found to possess twice as many circular mils or 20,760. On the other hand, comparing a No. 13 wire, which is three sizes smaller, only one-half the circular mils, or 5,190, are found. The same process can be carried on with respect to No. 10 B. & S., for every size given in the regular wire table, such as Nos. 13, 16, 19, 22, etc., as well as Nos. 7, 4, 1,000, etc.

It is well to know that the numbers corresponding to the different sizes of wire do not correspond numerically to the circular mils they represent. The circular mils of a wire diminish according to the table as the number of the wire increases. A No. 0 wire has more circular mils than a No. 10; or a No. 13 wire has less circular mils than a No. 10, etc. These facts are best understood by a careful survey of the wire table as printed by the well-known manufacturers:

Gauge No. B. & S.	Diameter in inches.	Cross section. Circular mils.
4–0	0.4600	211,600
3–0	0.4096	167,800
2–0	0.3648	133,100
1–0	0.3249	105,500
1	0.2893	83,690
2	0.2576	66,370
3	0.2294	52,630
4	0.2043	41,740
5	0.1819	33,100
6	0.1620	26,250
7	0.1443	20,820
8	0.1285	16,510
9	0.1144	13,090
10	0.1019	10,380

The above figures give all sizes of wire as indicated from No. 10 B. & S. to No. 4–0, in other words, all of the larger sizes. According to the empirical rule just given No. 7 wire must have twice the circular mils of No. 10; No. 4 twice the circular mils of No. 7, etc., as shown below:

No. 10.......10,380 C. M., according to table.
No. 7......twice No. 10 B. & S., or 20,760 C. M.
No. 4......twice No. 7 B. & S., or 41,520 C. M.
No. 1......twice No. 4 B. & S., or 83,040 C. M.
No. 3–0 ...twice No. 1 B. & S., or 166,080 C. M.

The intermediate sizes, such as the sizes that lie between No. 10 and No. 7, No. 7 and No. 4, etc., are found as follows: The difference in circular mils between No. 10 and No. 7 is 10,380; these are divided up equally between the three sizes, namely, Nos. 9, 8 and No. 7 gauge. Dividing this difference into three parts gives $10{,}380 \div 3 = 3{,}460$ circular mils. If 3,460 circular mils are added to No. 10, No. 9 is obtained as shown below:

$$
\begin{aligned}
\text{No. } 10 &= 10{,}380 \text{ circular mils} &&= 10{,}380 \\
\text{No. } 9 &= 10{,}380 + 3{,}460 &&= 13{,}840 \\
\text{No. } 8 &= 10{,}380 + (2 \times 3{,}460) &&= 17{,}300 \\
\text{No. } 7 &= 10{,}380 + (3 \times 3{,}460) &&= 20{,}760
\end{aligned}
$$

This process must be followed out in arriving at the size of wire if the circular mils are given, or if a table is to be developed for practical purposes. The circular mils obtained by this method are such that they will show clearly the size required. A comparison of the circular mils of the manufacturers' table and the above circular mils will demonstrate this fact.

Regular wire table.	Calculated sizes.	Difference.
No. 10.......10,380	No. 10.......10,380	0
No. 9.......13,090	No. 9.......13,840	750
No. 8.......16,510	No. 8.......17,300	790
No. 7.......20,820	No. 7.......20,760	60

In spite of apparently large differences in area as shown by Nos. 9 and 8, between the regular table and the calculated sizes, the nearest sizes manufactured to those calculated are Nos. 9 and 8 of the regular table. This removes any doubt of the practicability of the method. The other half of the table giving the sizes from No. 10 to No. 16, which are the lesser sizes, is subject to exactly the same rules:

Gauge No. B. & S.	Diameter in inches.	Cross section in circular mils.
10	0.1019	10,380
11	0.09074	8,324
12	0.08081	6,530
13	0.07196	5,178
14	0.06408	4,107
15	0.05707	3,257
16	0.05082	2,583

A point of difference arises, however, when size No. 13 is to be obtained from No. 10; in other words, when passing from a larger to a smaller size of wire. In this case the difference is to be subtracted instead of added. This means the recollection of the following rule:

Rule.—In passing from smaller to larger sizes of wire add the difference; in passing from larger to smaller sizes of wire subtract the difference.

To illustrate this fact, No. 10 wire differs from No. 13 wire as 10,380 circular mils differ from 5,190 circular mils. This means that each intermediate size from No. 10 to No. 13 varies one-third of 5,190 circular mils or 1,730 circular mils from its neighbor as indicated below:

Size wire.	Circular mils.
10	10,380 $= 10{,}380$
11	$10{,}380 - (\frac{1}{3} \times 5{,}190) = 8{,}650$
12	$10{,}380 - (\frac{2}{3} \times 5{,}190) = 6{,}920$
13	$10{,}380 - (\frac{3}{3} \times 5{,}190) = 5{,}190$

Although the size and circular mils are obtained very readily by a little practice with the above method, it is very important to know how to get the resistances as well. This is not any more difficult than the preceding, assuming a resistance of 1 ohm per 1,000 feet of No. 10 wire. As the resistance of a wire is inversely proportional to its cross-section in circular mils, a No. 13 wire which has 5,190 circular mils or one-half as much cross-section as a No. 10 would have twice the resistance per 1,000 feet or 2 ohms. A table can be constructed based on this principle as follows:

Ratio of C. M.	Size of wire.	Circular mils.	Resistance in ohms.
1	10	10,380	1.0000
2	7	20,760	.5000
4	4	41,520	.2500
8	1	83,040	.1250
16	3—0	166,080	.0625

The intermediate resistances are obtained by the same rule as that giving the circular mils. For instance, the resistance of a No. 9 and 8 is obtained by subtracting one-third of one-half of the difference in passing from the smaller sizes to the larger, and in adding one-third of one-half the difference in passing from the larger sizes to the smaller.

If No. 10 has 1 ohm per 1,000 feet, then No. 7 has .5 ohm per 1,000 feet and the difference is .5 ohm. This difference is divided by 3, giving .1666 ohm. In other words, the subtraction of .1666 ohm from No. 10 will give No. 9; subtracting .1666 ohm from No. 9 will give No. 8, etc., as indicated below:

Size wire.	Resistance per 1,000 feet.
10	$1 = 1.0000$
9	$1 - .1666 = .8334$
8	$1 - (2 \times .1666) = .6668$
7	$1 - (3 \times .1666) = .5000$

For sizes which run the other way, that is, from a larger to a smaller size, addition is necessary. The following figures are correct in passing from No. 10 to No. 13:

Size wire.	Resistance per 1,000 feet.
10	$1.0000 = 1.0000$
11	$1 + (\frac{1}{3} \times 1) = 1.3333$
12	$1 + (\frac{2}{3} \times 1) = 1.6666$
13	$1 + (\frac{3}{3} \times 1) = 2.0000$

By carefully following the method as described, entire independence of the regular wire table results. It is possible to arrive at the size, circular mils and resistance of any wire by a short calculation or a mental estimate, which not only saves time, but is an immense advantage to those employing such principles as given as a means of daily livelihood. A few examples will show the application and value of the process in a simple wiring system:

Example.—What is the size and circular mils of the wire required to conduct 30 amperes over a 350 foot run (Fig. 7) at a drop of 2 per cent., the pressure being 110 volts?

The data is as follows:

Drop	2.2 volts.
Length of wire	700 feet.
Amperes	30

According to the formula:

$$\text{C. M.} = \frac{700 \times 30 \times 11}{2.2} = 105{,}000.$$

The practical question arising is this, what is the resistance per 1,000 feet and size corresponding to the answer? This is the method, starting from No. 10 B. & S.:

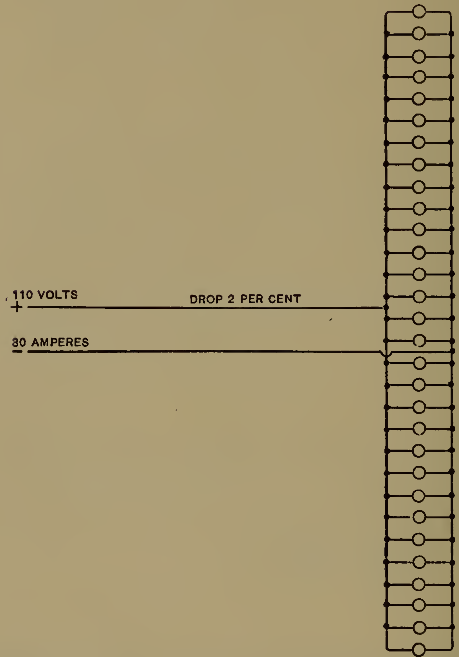

FIG. 7.—Estimating Circular Mils and Size of Wire Without Wire Table for Reference.

No. 10	10,380	1	ohm per 1,000 feet.
No. 7	20,760	.5	ohm per 1,000 feet.
No. 4	41,520	.250	ohm per 1,000 feet.
No. 1	83,040	.125	ohm per 1,000 feet.
No. 3—0	166,080	.0625	ohm per 1,000 feet.

It is evidently between No. 1 and No. 000, and if one-third of the difference is added, or 27,680 circular mils, 110,720 are obtained corresponding to a No. 0 wire. The resistance of this size is .125 ohm minus one-third of the difference in resistance between the two sizes. The resistance of 1,000 feet of No. 0 wire is therefore approximately .1042 ohm. If 1,000 feet = .1042 ohm, then 700 feet = .073 ohm.

Applying the law that $E = C \times R$ to check the answer, the drop is found to be 30 amperes $\times$ .073 ohm = 2.19 volts.

In the above, the nearest size manufactured is No. 0, and this size would have to be employed even though a difference of 5,000 circular mils existed.

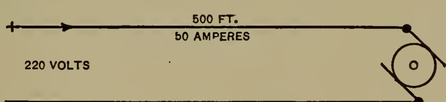

FIG. 8.

Example.—A power line is being run a distance of 500 feet (Fig. 8) to a 220 volt motor, taking 50 amperes with a drop of 5 per cent., what is the size of wire, etc.?

$$\text{C. M.} = \frac{1{,}000 \times 50 \times 11}{11} = 50{,}000.$$

No. 4 = 41,520.
No. 3 = 55,360.

The nearest size is No. 3 B. & S. and the resistance is approximately .209 ohm per 1,000 feet. The drop is therefore $.209 \times 50 = 10.45$ volts, a little short, but still to the advantage of the contractor. A table may be prepared which will save a great deal of time if properly used, in which the drop in volts per ampere per 1,000 feet is given as follows:

Size wire.	Drop in volts per 1,000 feet per ampere.
10	1.0000
7	.5000
4	.2500
1	.1250
3—0	.0625

Taking it the other way toward the smaller sizes the figures are in near approximation.

Size wire.	Drop in volts per 1,000 feet per ampere.
10	1.0000
13	2.0000
16	4.0000

The intermediate sizes and the drop corresponding to them on this basis would give a complete table as follows:

Size wire in B. & S. gauge.	Volts drop per 1,000 feet per ampere.	Size wire in B. & S. gauge.	Volts drop per 1,000 feet per ampere.
4—0	.0523	6	.4166
3—0	.0625	7	.5000
2—0	.0833	8	.6666
1—0	.1041	9	.8333
1	.1250	10	1.0000
2	.1666	11	1.3333
3	.2082	12	1.6666
4	.2500	13	2.0000
5	.3333	14	2.6666

Any number of simple problems in wiring can be worked out by means of this table, such as the following: If a circuit is to be installed to lose 10 volts per 1,000 feet, carrying 30 amperes and a total drop of 50 volts, what is its size and length? The answer would be 5,000 feet of No. 5 B. & S.; because a loss of 10 volts per 1,000 feet, with 30 amperes, means a loss of .3333 of a volt per ampere per 1,000 feet, corresponding to the size given above.

The sketch (Fig. 9) shows the general idea dia-

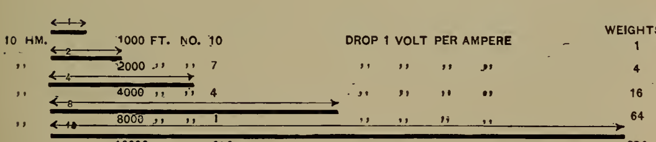

FIG. 9.—Relative Lengths and Weights of Wire of Equal Resistance.

grammatically, also the relative weights of copper. This last item is of immense importance in connection with the drop, because in some cases where but little drop of voltage is very desirable the cost is prohibitive. The weight of copper required to wire a building at 2 per cent. drop is exactly twice the amount required to wire a building at 4 per cent. drop. The saving in copper, by using a higher pressure, is apparent from the following figures:

DISTANCE 500 FEET WATTS = 10,000, DROP 5 PER CENT.

Size.	Volts.	Amperes.	Circular mils.	Relative weight of copper.
4—0	100	100	211,600	32
1—0	200	50	105,800	16
3	400	25	52,900	8
6	800	12.5	26,450	4
9	1600	6.25	13,225	2
12	3200	3.125	6,612	1

This relates more particularly to power transmission but is very instructive in showing how the choice of wire, as regards its size, is greatly dependent upon the policy pursued in planning the installation.

CHAPTER III

ELEMENTS OF A WIRING SYSTEM.—MEANING OF MAINS, FEEDERS, BRANCHES.—PROPORTIONING THE DROP IN THE VARIOUS PARTS OF THE SYSTEM.—THE CENTER OF DISTRIBUTION.—EXAMPLES OF THE EFFECTS OF DROP IN PARTS OF THE CIRCUIT.—EQUALIZING THE PRESSURE.—DYNAMOS FOR INCANDESCENT LIGHTING.—EFFECTS OF CHANGES IN THE FIELD OF DYNAMOS UPON THE LIGHTING.—A WIRING SYSTEM WITH FOUR CENTERS OF DISTRIBUTION.—THE LIFE OF A LAMP.

Elements of a Wiring System.—The analysis of a wiring system discloses three fundamental elements (Fig. 10), called mains, feeders and branches. These parts are subject to the same calculation for the discovery of the drop taking place in them as any simple circuit previously described. In laying out a wiring system these elements must be carefully considered and a great deal of discretion is necessary in making allowance for the distribution of the total drop in each part. If, for instance, the total drop is 10 volts, and this is to be divided up between the elements above mentioned, the average drop in mains, feeders, and branches would be 3.333 volts. But there is no fixed rule for this conclusion and the drop in the elements of a wiring system must be left largely to the judgment and experience of the contractor. To the contractor such questions arise in connection with this fact as: What is the cost of copper? What is the cost of labor? The labor question is by far the most important one, because it would be easy to show by comparing the cost of materials included under the head of mains, feeders and branches as well as the moulding or tubing in which they would be laid with the cost of labor in installing them, that labor is of the first importance. One hundred dollars worth of materials may cost anywhere from $50 to $200 or more to install. It would be difficult indeed to attempt to give iron-clad rules for determining these relationships, but perhaps the best that can be done is to follow the common-sense rule of laying out the work so that the labor bill is low. Where it is possible to have a greater drop, and, consequently a lighter wire, and in some cases less labor in handling it, the choice becomes self-evident. When the cost of labor is equal in both cases, saving can only be attempted with the copper and the reverse, namely, when the cost of copper is equal in both cases saving must be attempted in the labor. Perhaps this idea can be best illustrated by a practical case (Fig. 11). Suppose 100 amperes are to be supplied to a set of feeders and branches, will it be necessary to use one or two pair of mains? If the wires are to be laid in moulding and run a distance of 100 feet, a calculation will show the size of wire required. According to the method a knowledge of the drop to take place in the mains is necessary. If the entire drop is 3 per cent., an arbitrary choice of 1 per cent. can be considered, which at the usual voltage of 110 would mean 1.1 volts. The circular mils required are then $100 \times 200 \times 11 \div 1.1 = 200{,}000$, corresponding to a No. 4—0 wire whose diameter is .4600 of an inch. If the wires are run straight ahead there is a possibility of using such a heavy wire but where there are bends, it is much more advisable to run two mains of 100,000 circular mils apiece or about No. 0 wire. This is true where moulding is used, although many might raise objections to this conclusion on the grounds that it costs less to run a single line of 200,000 circular mils than two lines of 100,000 circular mils apiece. This matter can only be decided by experience and even then a decision would rest largely upon the character of labor employed, which naturally involves questions of strength, skill and speed in the performance of duties.

If a single line of 200,000 circular mils is installed there is a saving in cost of material and labor, provided it takes less time to run the wires. A flexible cable might be employed and labor saved, but the wire costs more, so the point to be considered of cost of wire or material and cost of labor is in a practical sense a part of the triple question involved under the head of drop, material and labor.

The arbitrary choice of 1 per cent. for the drop in the mains might have been made 2 per cent.;

in which case the sizė of wire being one-half or 100,000 circular mils, the doubt disappears; but only 1 per cent. drop is left, and it is imperative to divide this up between the feeders and branches. If, putting the copper here, means more labor distributed among a variety of wires, than putting it on the mains, then this is where less drop is most expensive. In the following sketch the elements of a wiring system are shown:

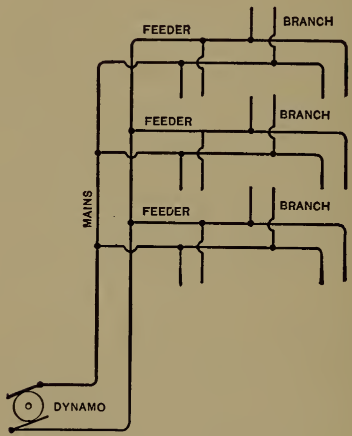

FIG. 10.—Elements of a Wiring System.

In some cases the wires rising through the building are called "risers," which would give four elements instead of three, called mains, risers, feeders and branches. If the number of amperes are not too great the above system is satisfactory as in the case of a small factory. Where it is necessary to conduct a heavy current to each floor of a building the design is changed in this respect; the number of risers are increased. It is likely in such a case, the number of feeders are also increased,

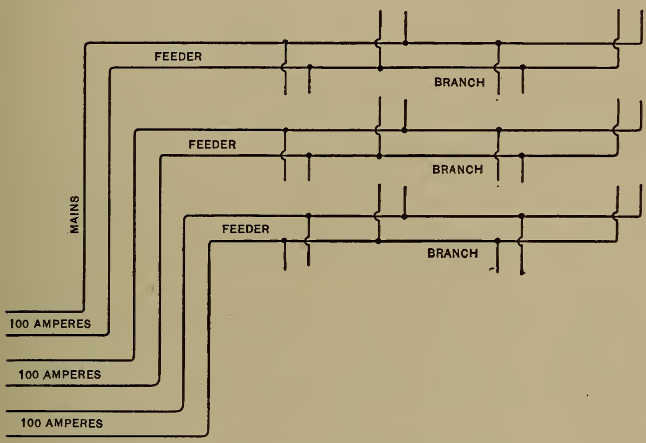

FIG. 11.—System with Individual Mains.

and in all probability the number of branches. But the difference is only in degree, that is to say, the new design would merely be a repetition of the last sketch. A case like this would arise where about 100 amperes are to be used on each floor of a three-story building, as shown in the above illustration:

The foregoing sketches become very elaborate when a large structure is to be wired and every circuit is shown in the drawing. In many cases where the total drop is very small, for instance, 2 per cent., it is very difficult to divide the drop up between the various parts of the system in a scientific manner. The fact of greatest importance is this: that if a certain drop takes place in a building it is due to a certain resistance and a certain current. Although more copper may be used in one part than another, it is evident that the sum total of copper will remain the same although its disposition will change. It is a good policy to make an allowance for overload in the mains and risers, in which case the drop will be less in the mains than any other part of the circuit in proportion to the rest. If for instance 2 per cent. is to be lost in drop and only $\frac{1}{2}$ of 1 per cent. in the mains, this would leave $1\frac{1}{2}$ per cent. for the rest of the circuit. Calculation will show how the sizes of wires would vary under these circumstances. The circular mils of the mains, risers, feeders and branches, on the basis of one estimate, can be compared with the circular mils estimated on a different basis, that is, a different arrangement of the percentages of drop equal to the total allowed. The following case is of interest in illustrating this idea:

Example.—What sizes of wire are required to equip a building for electric lighting at 110 volts pressure, with a 3 per cent. drop, consisting of two floors (Fig. 12) taking 50 amperes apiece; the length of mains 50 feet, length of feeders 50 feet, and length of branches 25 feet.

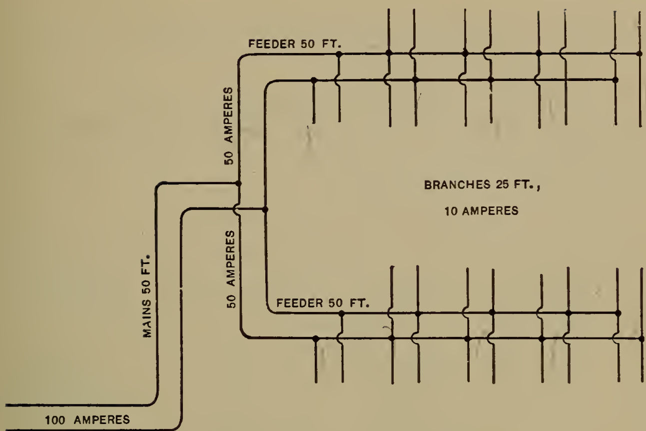

FIG. 12.—Wiring System for Two Floors.

The total drop is 3.3 volts, which may be divided up between the three elements equally for trial figures and for purposes of comparison as follows:

Mains 100 feet wire, mains 1.1 volts drop, mains 100 amperes:

$$\text{C. M.} = \frac{100 \times 100 \times 11}{1.1} = 100{,}000.$$

Feeders 100 feet wire, feeders 1.1 volts drop, feeders 50 amperes:

$$\text{C. M.} = \frac{100 \times 50 \times 11}{1.1} = 50{,}000.$$

Branches 50 feet wire, branches 1.1 volts drop, branches 10 amperes:

$$\text{C. M.} = \frac{50 \times 10 \times 11}{1.1} = 5{,}000.$$

Arranging this data in the form of a table will show more clearly the comparison referred to and will embrace all conditions of drop, high and low, for each element of the circuit:

Per cent. drop in volts.	Mains 100 feet. Circular mils.	Feeders 100 feet. Circular mils.	Branches 50 feet. Circular mils.
.1	1,100,000	520,000	55,000
.2	520,000	260,000	27,500
.3	366,667	173,333	18,333
.4	275,000	130,000	13,750
.5	220,000	104,000	11,000
.6	183,334	86,667	9,166
.7	157,143	74,285	7,857
.8	137,500	65,000	6,875
.9	122,222	57,777	6,111
1.0	110,000	52,000	5,500

If possible a table of this character should be drawn up for the various important parts of a wiring system as it will enable an accurate idea to be gained of the size and cost of installation as the percentage of drop in each element is modified.

In the previous example the drop is equally divided between the elements constituting the circuit. If this is not the case the results may be tabulated for convenience and comparison as before. As will be observed the total drop according to the figures is the total allowed, namely, 3.3 volts. All the data is obtained from the last table:

COMPARATIVE TABLE.

	Drop.	Circular mils.	Size wire.
Mains	.5	220,000	4—0
Feeders	1.0	52,000	3
Branches	1.8	3,055	15
Mains	1.0	110,000	0
Feeders	.5	104,000	0
Branches	1.8	3,055	15
Mains	1.1	100,000	0
Feeders	1.1	50,000	3
Branches	1.1	5,000	13

A choice of wires is presented with which the wiring can be successfully accomplished. The first results in the table cannot be used because they call for the use of a 4—0 wire. The second set of results are fairly uniform with the exception of the No. 15 wire, which is too small and forbidden by the Fire Underwriters. The last set of results are more satisfactory yet capable of further rearrangement to get the correct result. If it is possible to obtain a fair degree of uniformity in the sizes of wire a great advantage is gained as moulding or tubing can be bought to correspond and the work is, in a sense, simplified.

Center of Distribution.—In laying out a wiring system, one of the most important features is the selection of the center, or centers, of distribution. A wiring system is in many respects like a nervous system in its branches and ramifications, but the most interesting fact is the similarity between the ganglions in the nervous system and the centers of distribution in the wiring system. From these points, not only does the current become distributed, but the pressure is delivered as nearly uniform as possible to the various lamps or outlets at which it is utilized. An examination of the wiring of a large building discloses the fact that at one or more points on the floor, panel boards are in use, from which many lines run to lamps, or groups of lamps on the same floor. In smaller buildings the distribution may be different. One panel board may suffice for more than one floor, or, in other words, the centers of distribution are fewer, because the demand for current at given points is less.

Example.—A single case may serve to illustrate the advantage gained by choosing a center or centers of distribution so far as the question of drop is concerned. Suppose a line 1,000 feet long consisting of No. 10 wire is supplied with current at 110 volts pressure and 10 lamps are to be lit at each end of the line; which is the best way of feeding current to the line so as to keep the drop at a minimum? If the current is supplied from one end, the drop would be $C \times R =$ current of 20 lamps $\times$

resistance of 2,000 feet of No. 10 wire $= 10 \times 2 =$ 20 volts. According to these figures the lamps nearest to the point at which the current enters would receive 110 volts minus 10 volts or 100 volts, and the lamps at the distant end 1,000 feet away would receive 10 volts less or only 90 volts. This would mean a heavy reduction in candle power and the failure of the plan as a successful wiring system. On the other hand, supposing the current is fed into the middle of the line, making this the center of distribution instead of the end, the conditions would then be different and the drop greatly reduced. Under these circumstances the current travels from the middle of the circuit 500 feet to each end of the line. The drop for each group of 10 lamps at either end of the line is then equal to: Current of 10 lamps $\times$ resistance of 1,000 feet of No. 10 wire $= 5 \times 1 = 5$ volts drop. This means a great reduction in the drop for the lamps, uniformity of pressure for the lamps, and a much more efficient use of the copper employed in the line. If, instead of feeding into the middle of this 1,000 foot circuit, two lines or feeders are run 250 feet away from the ends, the drop for each group of lamps becomes: Current of 10 lamps $\times$ resistance of 500 feet of wire $= 5$ amperes $\times \frac{1}{2}$ ohm $= 2.5$ volts drop.

The above figures are instructive in showing how the point or points from which the current is distributed will influence the light or drop of the lamps. The following table indicates the effect of these changes:

Ohms.		Length of No. 10 wire. Feet.	Am-peres.	Drop in volts.
2	Feeding at one end.......	2,000	10	20
1	Feeding at middle........	1,000	5	5
$\frac{2}{3}$	Feeding at $\frac{1}{3}$ from end....	666	5	3.333
$\frac{1}{2}$	Feeding at $\frac{1}{4}$ from end	500	5	2.500

This idea is of the utmost value in street railway work, which in many respects possesses all the qualifications of a wiring system. The trolley wire is one leg of the circuit and the tracks the other, and between the positive and negative wires thus indicated, instead of lamps, as in the system of incandescent light wiring, trolley cars are running. The current these cars take is the cause of a heavy drop on the line, which is to a large extent reduced by connecting into the line at definite points, feeders which supply both current and pressure where it is most necessary. By this means, a comparatively uniform pressure is preserved throughout the line under all conditions of load.

Equalizing the Pressure.—The choice of centers of distribution is for the purpose, as previously explained, of equalizing the pressure. In house wiring, apartment houses and hotels particularly, differences in the illuminating power of lamps is prohibitive. It is necessary to use many centers of distribution to accomplish this object. In the following sketches (Figs. 13, 14 and 15) may be seen the development of this idea, as illustrated by

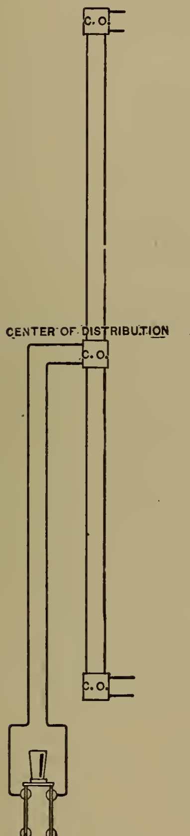

FIG. 13.—One Center of Distribution.

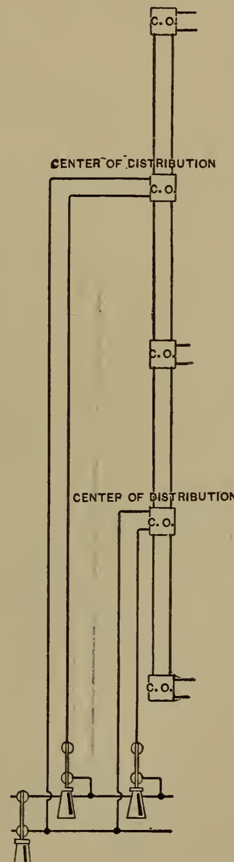

FIG. 14.—Two Centers of Distribution.

the case of one, two, three and more centers of distribution.

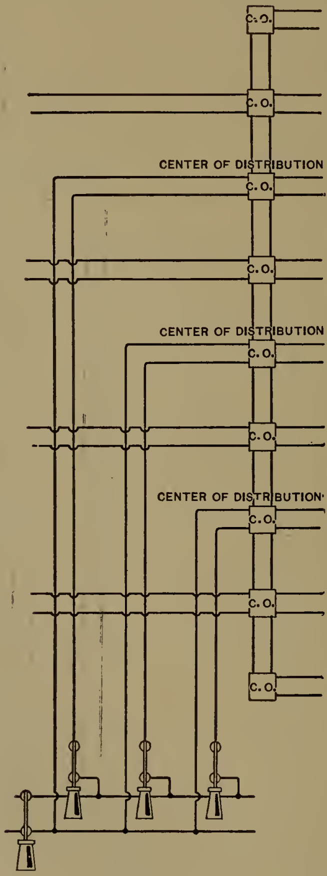

FIG. 15.—Three Centers of Distribution.

Sub-centers of Distribution.—The main centers of distribution are of first importance in laying out the wiring system, but then come the second or sub-centers of distribution (Fig. 17), which are the means of transmitting the power to the lamps, etc., at approximately the pressure of the main centers of distribution. The same phraseology might be aptly applied with reference to mains, feeders, branches, etc., calling those which perform the same function in a secondary sense, sub-mains, sub-feeders, sub-branches, etc. The problem of distributing the drop in the various elements of such a system in a practical, economical and scientific manner becomes a more difficult task as the various complexities of the system increase. The principle must be rigidly adhered to of calculating the drop for every line and part of the circuit, so that the total drop does not exceed the amount allowed for in the specifications. As a general rule the mistake is made of not estimating the total drop from the source of supply through the circuit to the lamps it ends in as shown by the following simple sketch (Fig. 16) illustrating this important point in the calculation of wiring:

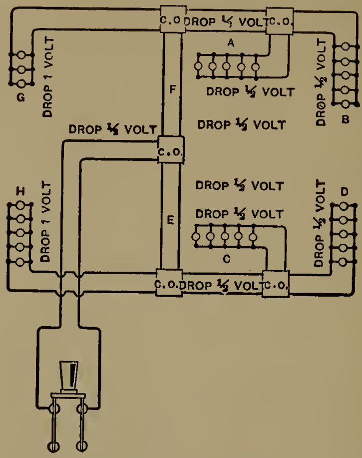

FIG. 16.—Wiring Diagram Showing the Drop Limited to Two Volts.

The drop from the source of supply to any group of lamps does not exceed 2 volts, as shown by tracing the circuit from the switch to the center of distribution.

From the switch through E to C = 2 volts.
From the switch through F to A = 2 volts.
From the switch through F to B = 2 volts.
From the switch through F to G = 2 volts.
From the switch through E to H = 2 volts.
From the switch through E to D = 2 volts.

The limit of 2 per cent. need not be observed so carefully in houses or buildings with their own generating plant. In such cases the pressure may drop 4 or 5 volts without any inconvenience on account of the character of the dynamo installed and the extra pressure generated to obviate this difficulty.

Dynamos for Incandescent Lighting.—The class of dynamos employed for incandescent lighting are called shunt wound and compound wound. The shunt wound dynamo can produce a rise or fall in pressure by field regulation. In order to grasp this fact it is necessary to understand the fundamental principle relating to the generation of electromotive force, which may be popularly expressed in the following words: Electromotive force is developed by a certain motion of conductors in a magnetic field or a certain motion of lines of force through a conductor. In other words, electromotive force is developed in a dynamo by motion, magnetism and conductors. A very simple formula expresses the relationship between these elements, based upon the manner in which a volt is generated.

A volt is generated by the cutting of 100 million lines of force in one second. The formula is constructed with the idea of giving the correct answer with any number of conductors, with any degree of motion and with any number of lines of force.

Formula for calculating the EMF. of a dynamo: The electromotive force is equal to the revolutions of the armature per second $\times$ the number of conductors on the armature $\times$ the number of lines of force passing through the armature, or

$$\text{E. M. F.} = \frac{\text{speed per second} \times \text{lines of force} \times \text{conductors}}{\text{100 million.}}$$

It is expressed in symbols in the following form: $E = N \times c \times n \div 100{,}000{,}000$ where $N =$ lines of force, $c =$ conductors and $n =$ speed per second in revolutions.

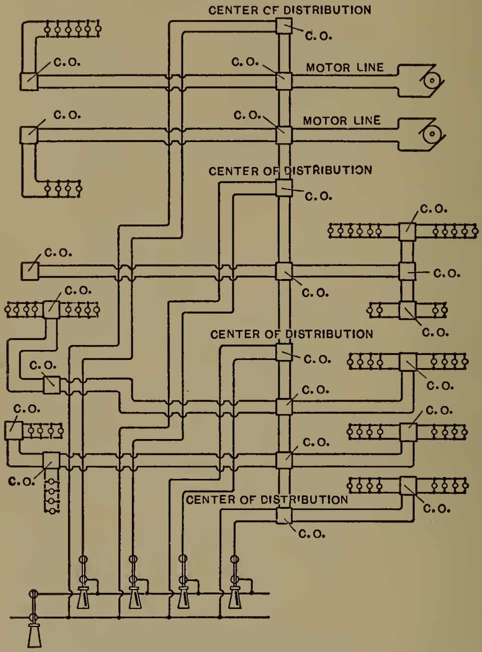

FIG. 17.—Four Main Centers of Distribution and Sub-centers.

The entire purpose of this analysis is to show what a shunt machine is, and how it regulates its pressure, so that its relative importance to the wiring of a building and the lighting may be better understood. The EMF. may be increased or diminished by increasing or diminishing the conductors on the armature, the strength of field or the revolutions per second. As a general rule, the lines of force are increased or diminished to produce corresponding changes in the EMF. This is accomplished by using a device called a resistance box connected in circuit with the winding of the magnets. If the handle of this box is turned one way or the other, the current is controlled, increased or diminished, and thus affects the power of the magnets, strengthening them or weakening them accordingly. If the dynamo must develop more pressure, the magnets are made to develop more magnetism by increasing the current passing through them, or vice versa.

The meaning of this formula is best understood by developing a table showing with what combinations of magnetism, speed and conductors 110 volts can be generated in a dynamo:

Revolutions per second.	Conductors.	Lines of force.	Volts.
100	110	1,000,000	110
50	110	2,000,000	110
50	55	4,000,000	110
25	55	8,000,000	110
12.5	55	16,000,000	110
25	27.5	16,000,000	110
10	55	20,000,000	110

Taking the above figures as a basis for estimating, the EMF. could be held constant while an infinite variety of combinations would be possible in producing the same result. The lines of force are shown to vary from 1,000,000 to 20,000,000, with corresponding changes in the speed and conductors, thus passing from the class of machines called high speed to another class called slow speed generators. If the first line of figures is examined, the speed is indicated as 6,000 revolutions per minute and 110 conductors; to produce 1 volt additional at the same speed additional lines of force equal to 1,000,000 ÷ 110 or 9.091 are required. In other words, any change of pressure taking place in a dynamo, if not produced by a change in the speed or conductors is conveniently produced by a variation in the number of lines of force supplied to the armature.

In the following table the changes in magnetic field required to produce a change of five volts in the pressure are shown with the speed and conductors constant:

TABLE SHOWING CHANGES IN VOLTS THROUGH CHANGES IN FIELD.

Extra volts.	Revolutions per minute.	Conductors.	Field strength.	Volts.
0	6,000	110	1,000,000	110
1	6,000	110	1,009,091	111
2	6,000	110	1,018,182	112
3	6,000	110	1,027,273	113
4	6,000	110	1,036,364	114
5	6,000	110	1,045,455	115

The resistance box connected to the field coils, as above mentioned, will therefore be the means of increasing the dynamos EMF., but not necessarily the pressure it sends out. If the armature of a dynamo is regarded as part of a wiring system it is quite evident that, like any other conductor, an increase of current will mean an increase of drop. This being the case, the dynamo loses its own pressure as it is called upon for more and more current, so that if its original pressure was 110 volts, with only one lamp in circuit its pressure would be considerably lower at one-quarter, one-half and full load. The drop in the armature is not the only influence at work tending to lower the pressure of the dynamo. As the armature carries more current it becomes a stronger and stronger electro-magnet whose action upon the field in which it spins around is destructive. It reduces it systematically and so effectively, that if external means were not employed to compensate for this phenomenon, electric lighting would become a difficult, if not an impossible task on a commercial scale. In shunt wound dynamos the regulation of pressure is accomplished by varying the field in the manner described and this obviates the evil effects of drop in the armature due to its resistance and the current it carries and the magnetic armature reaction which also takes place. But to regulate in this manner it is necessary to be in constant attendance upon the dynamo, unless some assurance is made that the changes in load will not take place rapidly, or unless the dynamo is of immense proportions and its armature, therefore, of such low resistance, that an increase of hundreds of amperes must occur before any severe drop is felt. Regulation of pressure can be carried out practically and automatically by means of automatic dynamos called compound wound dynamos. These machines are so constructed, particularly their winding, that when the two losses, of drop and armature reaction take place, the dynamo automatically increases its own strength of field without the aid of any resistance box. A treatise on wiring is hardly the place to go into the technical features of dynamo construction, except so far as they relate to the main point, the wiring problem; but it is evident that the wiring problem is to a large extent the problem of electric lighting, and this in itself calls for a thorough understanding of the differences in purpose of construction and operation of the generators employed. In the compound wound dynamos, to briefly conclude this explanation, the regulation is automatically accomplished by sending the main current around the field coils so that as this current increases or diminishes the strength of the magnets it circulates around, will also increase or diminish, and consequently the dynamos will produce more volts only when the armature produces more current.

It is of the utmost importance to remember that the shunt wound and compound wound dynamos are used for central station, street railway and private plants all over the United States for the generation of direct current. Many changes have taken place, so that the above statement does not hold true for all cases, or for the most modern plants. It does hold true, however, for such plants as are installed in public buildings, hotels, apartment houses, etc. The large station of the Edison Company at Pearl and Elm streets, New York, has several big generators, shunt wound, with resistance boxes in use for regulation in operation there.

The wiring of buildings calls for a consideration of the above facts so that provision can be made in the distribution of the drop for the higher and lower pressure in the upper and lower parts of it. For instance, if a 110 volt generator is installed, of the automatic type, and it is over compounded, this means that it may produce 115 volts at one-quarter or one-half load, and then fall slightly as the load increases to 112 volts or a trifle more or less. In this case, considerable drop can be provided for in the wiring of the lower half of the building. Where provision is ordinarily made for a drop limited to two volts, at least twice that drop can now be experienced with a corresponding saving in copper in wiring the lower part of the structure.

The resistances of the various mains, feeders and branches must be carefully calculated in consequence of this in order that the drop takes place, otherwise the lamps will deteriorate rapidly through excess pressure. Incandescent lamps are built to give a certain candle power with a certain terminal pressure applied. If this pressure is too great the current increases to such a point that the life of the lamp is endangered by the overheating of the filament. The filament *loses* its resistance as it is heated. A 16 cp. 110 volt lamp cold has a resistance of about 450 ohms; when it is incandescent its resistance is about 225 ohms. As the filament is heated more and more its resistance becomes greatly reduced and five or ten more volts than the lamp is supposed to take greatly increases the current, the temperature and the light, and cuts down the period of usefulness. About 600 or 700 hours, represents the effective light-giving period. It may, of course, be made to last much longer by keeping the pressure down below its proper value, but while the life of the lamp is increased the cost of the light produced in this manner is very heavy as compared with the cost at the correct pressure. A few figures will illustrate this point clearly. If it costs $5,000 a year to produce 50,000 cp. in a building, including wages, depreciation of machinery, coal, etc., and the engineer tries to save the lamps by running the pressure low, he probably cuts down the light 25 per cent. although full candle power is paid for. He saves an annual expense for new lamps of about $600, but throws away, so to speak, $1,250 worth of light. Lighting under these circumstances is a failure, giving no satisfaction for the money invested and represents the worst phase of false economy.

CHAPTER IV

MEASUREMENT OF RESISTANCE.—PRINCIPLE OF THE WHEATSTONE BRIDGE.—BALANCING THE RESISTANCE OF FOUR LAMPS.—MEASURING A LAMP HOT AND COLD.—MEASURING INSULATION RESISTANCE.—THE INSULATION RESISTANCE OF BUILDINGS WIRED FOR ELECTRIC LIGHTING.—THE THREE WIRE SYSTEM COMPARED WITH THE TWO WIRE.—CALCULATING THE THREE WIRE SYSTEM OF WIRING.—CIRCUITS OF A THREE WIRE SYSTEM WITH TWO CENTERS OF DISTRIBUTION.—CALCULATION OF POUNDS OF COPPER FOR MAINS OR FEEDERS.

THE laying out of circuits in many respects comprises all that may be said about electric wiring, with the exception of a recognition of those principles which include a practical knowledge of the measurement of resistance. The measurement of resistance is not limited to the measurement of the metallic resistance, but includes the insulation resistance as well. To measure any resistance calls for a knowledge of the fundamental principle involved in the theory and operation of the Wheatstone Bridge.

The Wheatstone Bridge. — The Wheatstone Bridge is employed for the measurement of resistance and consists of a kite shaped arrangement of resistances in which each arm of the kite or bridge is a different resistance. In order to grasp the true significance of this device, a brief review of the situation with regard to resistances in multiple must be considered. According to Kirchoff's law, the total resistance of any number of resistances in multiple can be readily calculated. Not only is the resistance estimated, but the current in each branch, and consequently the drop, is readily calculated.

In the following sketches (Figs. 18, 19 and 20) the resistance and current are given; consequently

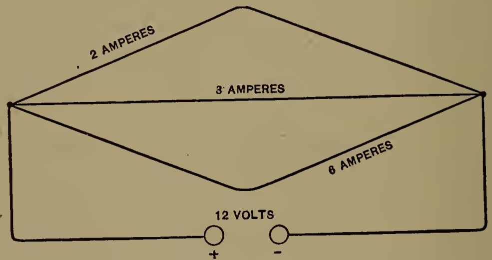

FIG. 18.—Current in Each Branch.

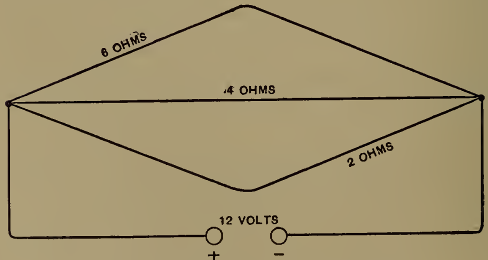

FIG. 19.—Resistance of Each Branch.

the drop in each branch is 12 volts respectively; that is to say, the application of 12 volts to a resistance of 2, 4 and 6 ohms, would mean a current of 6, 3 and 2 amperes and a drop in each circuit of 12 volts. Such being the case, the investigation of the conditions that exist in a circuit composed of resistances forming loops in multiple is similar in many respects to the conditions that exist in a Wheatstone Bridge.

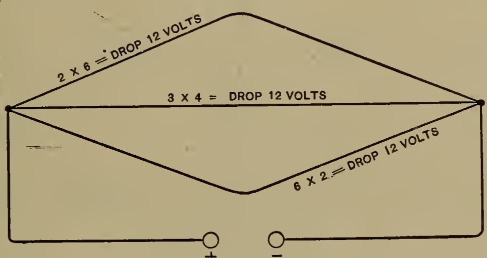

FIG. 20.—Drop in Each Branch.

In a Wheatstone Bridge there are two resistances in multiple connected across by a galvanometer or some instrument of equivalent delicacy which indicates the existence of certain conditions. These conditions can only exist when the resistances bear a certain numerical relationship to each other. The relationship is simple and instructive and can be expressed by the conventional formula A : B as C : D, when A, B, C and D represent the four resistances obtained by connecting across the loop by a galvanometer as shown in Fig. 21.

The real meaning of this remarkable relationship is, that when the ratio of A to B is the same as the ratio of C to D no current passes through the

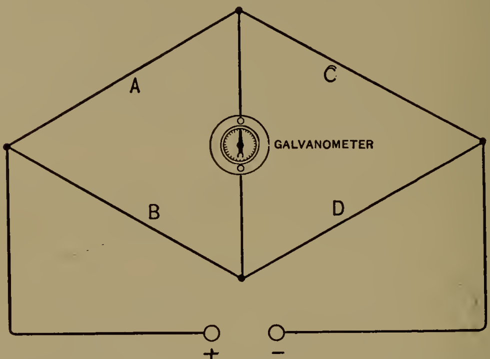

Fig. 21.—Wheatstone Bridge Obtained by Connecting Across with Galvanometer.

galvanometer circuit and the bridge is said to be balanced. The explanation of the effect of this interesting condition is to be found in a careful examination of the various drops occurring in the different parts of the circuit designated at A, B, C and D. If values are given to the resistances (Fig. 22) comprising the respective parts of the Wheatstone Bridge as shown, the following conditions exist:

Arm A drop 50 ohms × $\frac{1}{2}$ ampere = 25 volts.
Arm B drop 100 ohms × $\frac{1}{4}$ ampere = 25 volts.
Arm C drop 150 ohms × $\frac{1}{2}$ ampere = 75 volts.
Arm D drop 300 ohms × $\frac{1}{4}$ ampere = 75 volts.

In other words, an examination of the theory and practice of the Wheatstone Bridge is merely an examination of the principles underlying the theory and practice of electric wiring. In the illustration it is shown that the points to which the galvanometer is connected are points at which the drop is equal and it follows that these are the only points in the circuit at which the galvanometer will

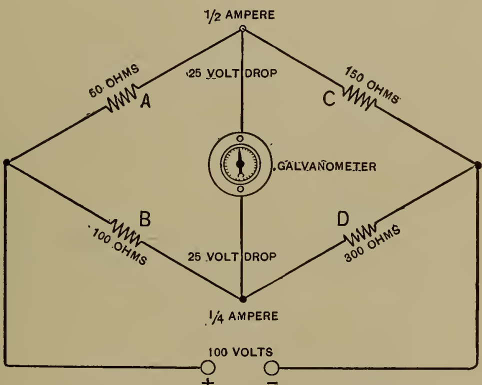

FIG. 22.—Calculating the Drop in a Bridge.

remain at rest. It is therefore only necessary to provide a current and resistance at those points at which the galvanometer is connected whose product is equal at each end and the measurement of resistance becomes a practical possibility.

In the practical application of the Wheatstone Bridge for the measurement of resistance the three arms as they are called, A, B and C, are utilized as follows: A and B are adjusted to a fixed ratio such as 1:2, 1:10 or 10:1,000, etc. C is then manipulated until a balance is struck, that is, until the galvanometer or indicating instrument is at rest. The conditions that then exist are that the arms express the ratio of A:B as C:D. In such a case as this D is the resistance to be found and it can only be found by balancing the bridge. To balance the bridge the unknown resistance is inserted in that part representing the D arm, and when the correct ratio is established the process is completed. The resistance of fields, armatures and other circuits is readily measured by means of the "Bridge" with an accuracy that is without its parallel in other allied sciences.

One of the most instructing of experiments is that of constructing a Wheatstone Bridge of incandescent lamps (Fig. 23) and noting the fact that

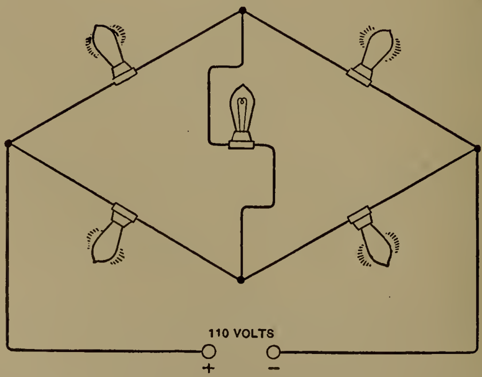

FIG. 23.—Bridge of Incandescent Lamps, Middle Lamp Will Not Burn.

when the lamps in the four arms are burning the middle lamp will not burn.

The entire situation can therefore be summed up in a word, that the drop must be equal in the A and B arms and the indicator or galvanometer will be at rest, and in order to secure this condition of affairs the resistances of the different arms must express the ratio of A : B as C : D.

Examples.—If the A arm is 10 ohms, the B arm 100 ohms, and the C arm 99.9 ohms, what is the D arm? According to the ratio $D = B \times C \div A = 100 \times 99.9 \div 10 = 999$ ohms. Or the problem may be given in this form: The resistance of a telegraph line is to be measured; the A and B arms are set at the ratio of 10 to 1,000, the telegraph line consists of two loops of equal length and resistance, if the C arm causes a balance when it is 5 ohms, what is the resistance of each loop of the telegraph line? Applying the formula $D = 1.000 \times 5 \div 10 = 500$ ohms; but D = the resistance of two loops in multiple, therefore each loop is equal to 1,000 ohms.

Another example may be found in measuring the resistance of an incandescent lamp hot and cold. If the A and B arms represent the ratio of 10 to 1,000, and the C arm reads 4.5 ohms, what is the resistance of a lamp in the D arm? The lamp would have a resistance of 450 ohms cold but its resistance hot would be much less because when at incandescence it takes half an ampere and the resistance would be therefore $110 \div \frac{1}{2} = 220$ ohms.

Almost any resistance high or low can be measured by the Wheatstone Bridge provided the galvanometer is delicate enough. The range of application reaches from .001 of an ohm to one million ohms with great accuracy, or a ratio of about 1 to one billion.

Measuring Insulation Resistance.—The measurement of insulation resistance is one of the most important features of electric wiring because of the requirements of the Board of Fire Underwriters, who represent the insurance companies, and the requirements, self-imposed, by the contractor's conscience.

Strange as it may seem to the uninitiated even the rubber or gutta percha covering of wires possess a certain degree of conductivity. Where wire is used in large quantities this conductivity makes itself felt to such an extent that the resistance between the copper wire and its covering is greatly reduced in proportion to the amount of wire used and the quality of the insulation employed. It is through this fact that the question of insulation resistance has arisen and requirements have been imposed limiting the amount of current and the insulation resistance in strict proportion to each other. In order to clearly convey an adequate idea of the meaning of insulation resistance as compared with metallic resistance a few illustrations will be necessary.

Suppose 1,000 feet of No. 10 B. & S. wire are considered with a rubber covering of the regular character employed for insulated wire; the metallic resistance is only 1 ohm, but the insulation resistance may be anywhere from 100,000 to 1,000,000 ohms. Supposing the insulation resistance is taken at 100,000 ohms, then the question arises, what is the insulation resistance per foot, per yard and per hundred feet? This question can best be answered by means of an illustration (Fig. 24) conveying the correct idea.

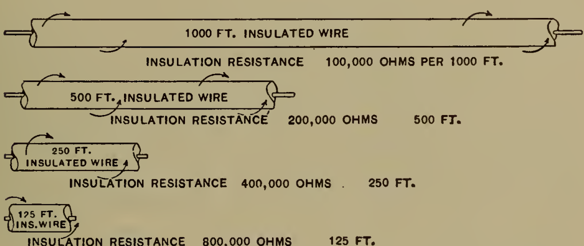

FIG. 24.—Insulation Resistance of Various Lengths of Wire.

The insulation resistance as shown by the illustration follows just the reverse rule of the metallic resistance. The insulation resistance increases the shorter the wire. If the data suggested by the above sketches is tabulated the following figures occur:

Length of wire. Feet.	Resistance of insulation. Ohms.
1,000	100,000
500	200,000
250	400,000
125	800,000
100	1,000,000
50	2,000,000
10	10,000,000
1	100,000,000

The lesson taught by the above results is this, that the insulation resistance of each foot of wire must be very high in order to give a high general insulation resistance. The resistance of the wire may reach the same figure as the insulation resistance if enough of it be used as shown by the following figures:

No. 10 B. & S. Feet.	Resistance. Ohms.	Insulation resistance. Ohms.
1,000	1	100,000
2,000	2	50,000
10,000	10	10,000
100,000	100	1,000
300,000	300	333
1,000,000	1,000	100

The insulation resistance falls below the metallic resistance according to the above figures when the length of wire becomes greater than 300,000 feet of wire. This amount of wire seems enormous, but when the amount of wire installed in a World's Fair is considered and the wire installed in a 20-story skyscraper in New York City the drop in insulation resistance is a foregone conclusion. The question of insulation resistance is not merely that of the wires installed in a building, but also relates to power lines. The necessity for the use of relays in telegraphic service is largely due to the fact that the current leaks away in transit from one station to the other. As an example of this, supposing a telegraphic line 1,000 miles in length is considered. Wherever it is supported there is a glass insulator of at least 5,000,000 ohms (5 megohms) resistance. Every 200 feet (Fig. 25) another pole is erected,

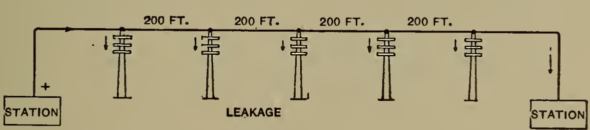

FIG. 25.—Conditions Existing in a Long Distance Line.

making about 25 insulators to the mile. Over a distance of 1,000 miles 25,000 insulators are necessary. This means an insulation resistance of 5,000,000 ÷ 25,000 = 200 ohms over the line from end to end. This is under the best of conditions, when for instance the air is dry and the insulators clean, but in wet or stormy weather the conditions are different. The insulation resistance of not only telegraph poles and lines but power lines as well drops considerably and a heavy leakage is apt to result. In the case of telegraph lines copper wires and high grade insulators may prove of some avail, but where serious leakage occurs with high tension power circuits a grave risk is incurred, beside which the mere question of the cost of power wasted loses its significance.

Measurement of Insulation Resistance.—To measure a resistance of millions of ohms or megohms calls for a delicate and high resistance galvanometer and a box of high resistance coils (Fig. 26). As shown in the sketches, the first process

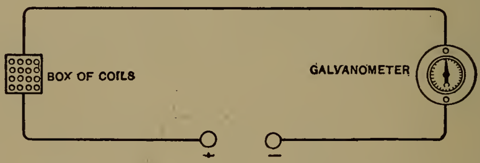

FIG. 26.—Connections for First Reading.

is to connect the coils and galvanometer in series. Supposing the coils are unplugged and represent 200,000 ohms and the galvanometer gives a reading of 20 divisions. The next step is to substitute the insulation resistance for the box of coils. The coil of wire is taped at one end and then immersed in a boiler of water or any other convenient metal receptacle (Fig. 27). The free end is connected in circuit and the metal vessel likewise connected as shown. The second reading may now be taken, it will be very low in all probability. If it is 1 division, then the resistance must be 20 × 200,000 ohms = 4,000,000.

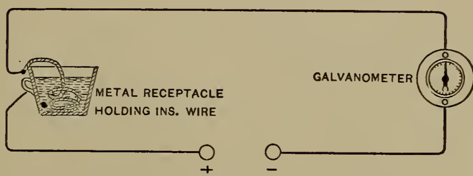

FIG. 27.—Connections for Second Reading.

The current which has actuated the galvanometer has found its way through the insulation resistance of the wire and therefore the galvanometer indicates the respective quantities of current which flow when 200,000 ohms is in circuit in one case and the unknown insulation resistance in the other case. Interesting examples can be given in connection with the wiring of buildings as follows:

Example.—What is the insulation resistance of a building using 20,000 feet of wire, the insulation resistance per foot being 10 megohms? The answer is readily obtained by dividing 20,000 feet into 10,000,000 ohms giving the result 10,000,000 ÷ 20,000 = 500 ohms. In other words, the following fact appears: That as the wire increases in length its metallic resistance *increases* but its insulation resistance *decreases*.

Kinds of Insulation.—The insulating material in vogue for the covering of copper wires may be roughly divided into four general classes. First, rubber; second, gutta-percha; third, composition, and fourth, cotton covering. The last, namely cotton, is in use for magnet and armature wire; the first is generally employed for electric light wire which is usually advertised as rubber covered wire. Cotton covering saturated with paraffin is used in enormous quantities for bell and annunciator work, but a great deal of wire covered with composition is also employed for this purpose. Atlantic or submarine cables are generally protected by gutta-percha coverings from the action of water but, in the course of time, changes in the character of the insulation take place and the rubber, gutta-percha, and particularly the composition coverings break down and the insulation resistance rapidly diminishes. The deterioration is not of serious consequence if the wires are well protected in moulding or conduit, but in old-fashioned buildings, wired ten or more years ago, the risk of fire due to the general deterioration not only of the insulation but the switches, sockets, etc., is very great. The requirements of the Board of Fire Underwriters can be had on application, and a review of the conditions imposed will show the necessity for the selection of the best switches, sockets, wire and conduit in the equipment of a building for electric lighting. The systematic tests for insulation resistance which should be carried on will be a good indication of the value of the materials employed. If the lines are free from grounds and similar defects and the insulation resistance keeps falling it is a sign of the defective nature of the insulating covering of the wires.

The Three-wire System.—The two-wire system has been developed into a method of wiring, through which a great saving in copper is made. The employment of this method, under the title of the "three-wire system," by the present lighting company in New York City, and its installation as the wiring of thousands of private and public buildings establishes it as an economical and practical means of distributing current for electric lighting.

The idea involved is that of making a more efficient use of the copper than would be possible in the method of employing only two wires for electric lighting, as previously described. To illustrate theoretically and practically the advantages of the three-wire system reference must be made to the general principle underlying power transmission and its relation to the pressure in volts at which it is transmitted. The principle is stated as follows:

Principle.—The weight of copper required for the transmission of a given amount of power is inversely proportional to the square of the pressure. By this is meant, that if 100 hp. is transmitted at 100 volts pressure, and a certain weight, say 2,000 pounds of copper, is required, then at twice the pressure or 200 volts only one-quarter or 500 pounds of copper would be necessary. The following table is instructive in showing how advantageous it is to use high pressures for the transmission of power in comparison with low pressures as far as the saving of copper is concerned. Taking the case of 100 kilowatts to be transmitted at 100 volts over a thousand foot run the following data appears:

Volts.	Circular mils.	Kilo-watts.	Length of wire. Feet.	Weight of wire. Pounds.	Drop. Volts.
100	440,000	100	2,000	2,666	5
200	110,000	100	2,000	667	10
400	27,500	100	2,000	167	20
800	6,875	100	2,000	42	40
1,000	4,400	100	2,000	27	50
2,000	1,100	100	2,000	7	100

The remarkable reduction in the size of wire required for the transmission of 100 hp. at 100 volts and at 2,000 volts, namely, 440,000 circular mils and 1,100 circular mils, is an object lesson in finance to builders of power transmission lines. The requirements for insulation naturally increase, but the cost of erecting the wire becomes much less on account of its lightness. A heavy line requires strong supports and great expense is involved if storms affect the stability of the line while in service. This is largely obviated where a light wire is run, that is to say, where a high pressure is employed.

The three-wire system installed by the Edison Company in the streets of New York consists of a network of copper embracing all of the downtown or business territory and following up the main thoroughfare, Broadway, with extensions to either side, thus covering an extensive area. If the three-wire system were not employed, that is, if the two-wire system were in its place at present, nearly three times as much copper would be in use to transmit the same amount of power. If, for instance, the above company has $1,000,000 worth of copper underground with the three-wire system, with the two-wire system there would be almost $3,000,000 worth installed. The principle, therefore, has immense economical and practical advantages over the two-wire and in the following explanation the facts relative to this saving will be made clear:

Suppose 100 lamps are to be lit on a 100-foot run at 110 volts pressure, then the size of wire according to the rule at a 2 per cent. drop would be 5,500 circular mils or a No. 13 wire B. & S. gauge. If the voltage is doubled then 220 volts would call for every two lamps to be in series (Fig. 28),

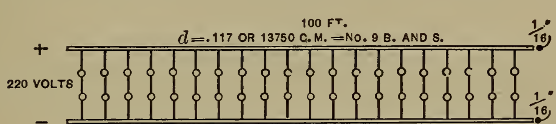

FIG. 28.—220 Volt Two-wire System Feeding 100 Lamps in Groups of Two in Series with 2 Per Cent. Drop.

which would mean 50 sets of lamps of two in series, requiring only one-half the current of the other circuit of lamps. The first circuit called for 50 amperes for 100–110 volt lamps on a two-wire circuit or 55,000 circular mils. The second circuit with every 2 lamps in series and 220 volts pressure, calls for only 25 amperes. The drop in the second circuit is 2 per cent. or 4.4 volts while it is only 2.2 volts in the first circuit. In the second circuit, therefore, with 220 volts pressure, not only is one-half of the current required, which reduces the circular mils one-half but twice as many volts can be lost, which reduces the circular mils again to one-half. In other words, if a 220 volt pressure is used with the lamps arranged in groups of two in series, as shown, only *one-quarter* of the circular mils and therefore the weight of copper need be employed.

But in the sketch shown, the number of lamps can be divided by 2; if one should burn out, the other connected to it would also go out, and this would make the system impracticable. Another reason why the system previously mentioned would be useless is where the number of lamps are unequal, that is, not divisible by two. The use of the neutral wire shown in the sketch (Fig. 32) entitled "The three-wire system balanced," does away with both of these difficulties. In the sketch (Fig. 29) the three-wire system is shown unbalanced and the use to which the neutral wire is put in such a case. Its function is merely to take up and transmit the current of the difference between the two sides of the circuit. If the neutral

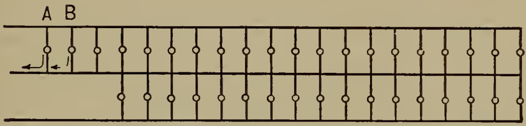

FIG. 29.—The Three-wire System Unbalanced, Showing the Use of Neutral Wire with Respect to Three Lamps.

wire were not employed, the amount of copper used at 220 volts, with groups of two lamps in series, would be only one-quarter, but with the neutral wire, for purposes of illustration, the same size as the two others, the amount of copper used becomes $\frac{1}{8}+\frac{1}{8}+\frac{1}{8}=\frac{3}{8}$ of what would be required to light

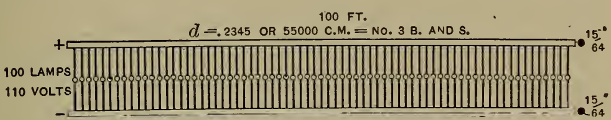

FIG. 30.—Two-wire System. Size of Copper Wire. Lighting 100 16 Candle Power Lamps, 2 Per Cent. Drop.

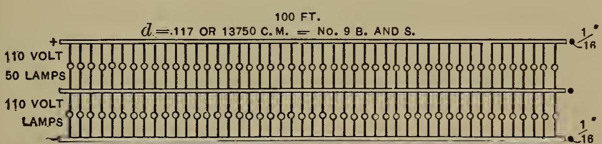

FIG. 31.—Three-wire System. Size of Copper Wire. Transmitting the Same Power, 2 Per Cent. Drop.

the same number of lamps at 110 volts by the two-wire system. The exact difference in the size of copper is shown by the sketches (Figs. 30 and 31) both as regards diameter in inches and circular mils in cross section.

A simple calculation for obtaining the size of wire with a three-wire system with the same *percentage* of drop as a two-wire system is to employ the old formula with 4 in the denominator as follows: Circular mils = amperes × length of wire in feet × 11 ÷ volts drop in line × 4, or, symbolically,

$$\text{C. M.} = \frac{11 \times \text{feet} \times \text{C}}{4 \times \text{E}}.$$

As regards the neutral wire in the laying out of a street system, such as is employed in New York, it is not as thick as the two outer wires but considerably less. The reason for this may be found in the fact that the lighting company will not turn current on the premises unless the lights are well balanced, therefore the amount of current carried by the middle wire is very small and its cross section in consequence is much less than the two outer wires. If the balance is fairly even throughout the district supplied with current, the generators connected to the circuit (Fig. 32) will carry equal loads; should a great difference of balance exist, however, the load would become very heavy on one machine to the exclusion of the other and its injury would result. If the balance is on the average fairly good, the saving of copper through the neutral wire being small is greater, and instead of .375 of the copper being used, less will be required as compared with a two-wire system. The same general ideas are carried out in the equipment of a building for a three-wire system as for a two-wire, with the addition that particular

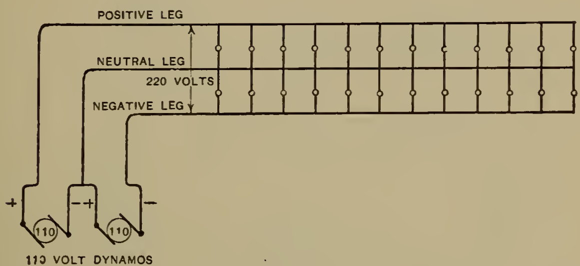

FIG. 32.—The Three-wire System Balanced.

care is taken to keep the circuits balanced. In the following illustration (Fig. 33) is shown the general scheme of a three-wire system, lamps equally balanced, and special motor lines of 220 volts apiece. The idea can be still further carried out for a more extensive and more complicated circuit. The neutral wire in a perfectly balanced system is hardly necessary except in such cases as a few lights more are kept burning on one side of the circuit than on the other.

Combination of Two and Three-wire Circuits.— In many instances where private plants are installed, the danger of a break-down has led the proprietor to make provision for such an emergency by having the wiring done so as to take current from the street if necessary, without risking the lamps in ordinary use. This is accomplished by equipping the building with the three-wire system but making the neutral wire of twice the cross

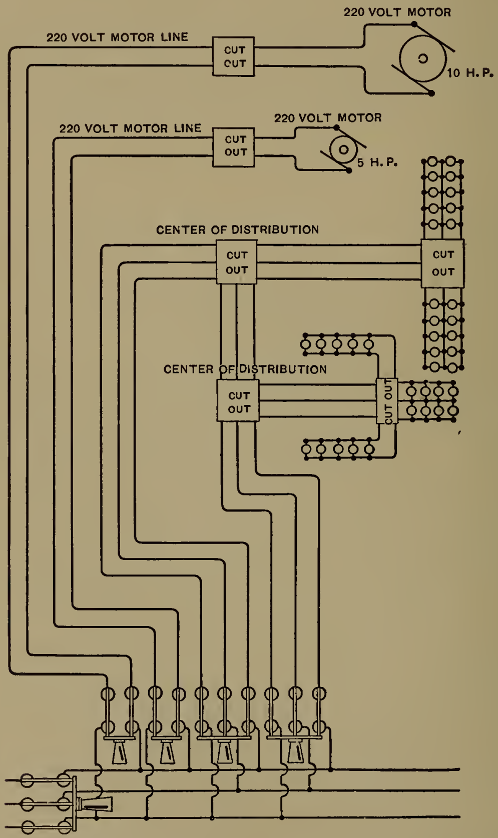

FIG. 33.—Three-wire System with Two Centers of Distribution

section of the two outer wires. By this means both a 110-volt two-wire system and a 220-volt three-wire system are combined (Fig. 34) and the equip-

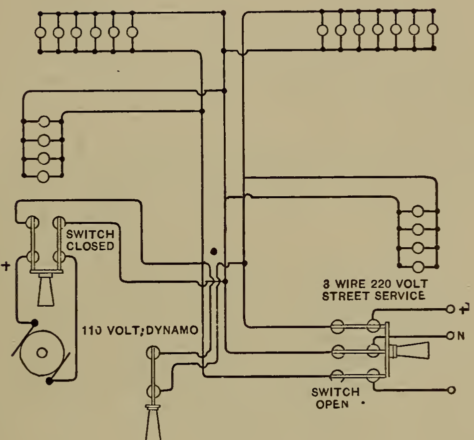

FIG. 34.—Combination of Two and Three-wire System for Protection Against Break-down of Private 110-Volt Two-wire System.

ment will work admirably on either, if the circuits are balanced. There is a distinct saving of copper by this method of wiring over the two-wire system, because according to the figures previously given, three wires, if of equal size, represent .375 of the copper which would be required in a two-wire system of equal capacity. Each wire is therefore one-eighth, and if the middle wire is twice the circular mils of the other two the total will be $\frac{1}{8}+\frac{1}{4}+\frac{1}{8}=\frac{1}{2}$, or .50. In other words, a building wired according to the above requirements is still using only one-half the copper otherwise required by a two-wire system.

In handling heavy wires it is frequently necessary to be able to calculate the weight of the wire, as for instance in considering the mains and feeders of a large installation. The formula for doing this is as follows:

$$\text{Pounds per foot of copper} = \text{circular mils} \div 62.5 \times 5{,}280 = \frac{\text{C. M.}}{62.5 \times 5{,}280}.$$

By leaving out the 5,280 the weight of copper per mile is obtained and the formula becomes: Weight in pounds per mile = C. M. ÷ 6.25. In power lines for motors or lighting, this calculation is very valuable, as in the preparation of estimates many means are adopted to keep the weight of copper down.

Example.—As an example of the above, suppose 200 hp. is to be transmitted one mile at 500 volts and 5 per cent. drop, what is the size and weight of the wire?

$$\text{The circular mils} = \frac{300 \times 10{,}560 \times 11}{25} = 1{,}393{,}920.$$

$$\text{The weight per mile} = \frac{1{,}393{,}920}{62.5} = 22{,}303 \text{ pounds for a}$$

single wire or a total of 44,606 pounds per mile.

$$\text{The weight per foot} = \frac{1{,}393{,}920}{62.5 \times 5{,}280} = 8.44 \text{ pounds.}$$

The above figures are indicative of the necessity of estimating drop as high as is consistent with good engineering or the weight of the copper becomes excessive.

The law promulgated by Lord Kelvin years ago reads as follows: The cost of copper must be such that the interest on the investment shall not exceed the cost of wasted power in the line. The meaning of this is that with $100,000 spent for copper in a transmission system only $6,000 worth of power should be wasted, because this represents the interest on the investment.

CHAPTER V

TYPES OF MOTORS.—CONNECTIONS OF MOTORS.—MEANING AND REASON FOR BACK ELECTROMOTIVE FORCE.—USE OF A STARTING BOX.—METHOD OF CONNECTING UP A SHUNT WOUND MOTOR.—HORSE POWERS OF MOTORS AND EFFICIENCIES.—EFFICIENCY OF MOTORS AND SIZE OF WIRES.—ADVANTAGE OF HIGH PRESSURES.—THE ALTERNATING CURRENT FOR LIGHTING.—MEANING OF FREQUENCY OR CYCLES.

The subject of wiring is closely related to power transmission both as regards the wiring and the motors operated from distant sources of power. It is within the scope of wiring treated as a science as well as an art to consider the motor and briefly outline its principles of operation and construction. Motors are generally divided up as far as continuous current circuits are concerned into three great classes as follows:

The Series Wound.
The Shunt Wound.
The Differentially Wound.

This classification relates to the winding of the magnets or fields, as they are commonly called. The manner in which the field is affected by the current flowing through its coils is indicated in the above tabulation and sketches (Figs. 35, 36 and 37).

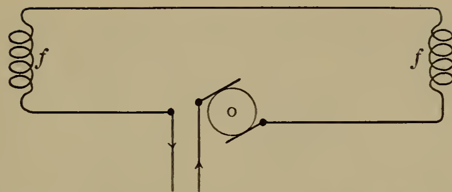

FIG. 35.—Connections of a Series Wound Motor.

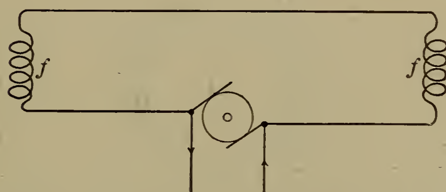

FIG. 36.—Connections of a Shunt Wound Motor.

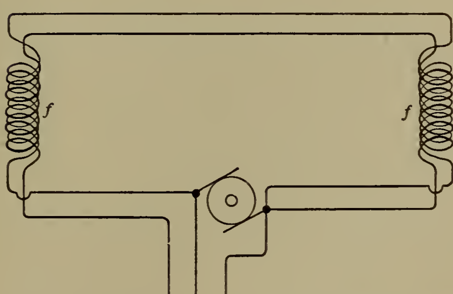

FIG. 37.—Connections of a Differentially Wound Motor.

The Principle of the Motor.—The motor and dynamo are reversible machines, the dynamo transforming mechanical energy into electricity, the motor transforming electrical energy into mechanical force. Any well made dynamo will operate successfully as a motor, in fact there is in many cases only a difference in name between the two machines. A dynamo is a machine in which the movement of conductors through the magnetic field (Fig. 38) means the development of electro-

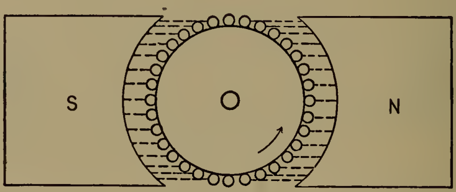

Fig. 38.—Conductor Cutting Lines of Force.

motive force. As these conductors produce more current the source of mechanical energy is called upon to deliver more power until a balance is established. In a motor the same conditions exist in a reverse manner; the demand for more current takes place automatically until sufficient enters to do the work required by the outside load, whereas in the dynamo the extra lamps or motors turned on represent the demand for more current, and hence more mechanical energy. In the motor the extra current automatically and instantaneously augments as extra strain is put upon the motor. In the motor as well as the dynamo conductors rotate in a magnetic field. The consequence is that electromotive force is developed which in the case of the dynamo is utilized for lighting, etc., but in the case of the motor this electromotive force is opposed to the electromotive force sending a current through the armature and is therefore called the "back EMF." The armature of a motor is simply an electro-magnet which experiences a series of attractive pulls, when current enters its winding through the action of the commutator and the position of the brushes.

The commutator and brushes constitute an automatic switch which sends the current into certain coils in certain positions on the armature. These coils magnetize the core of soft iron and a powerful tractive effort develops between the armature and the magnetic poles which embrace it. Summing the phenomena up, therefore, the action in a motor is simply the attraction between opposite magnetic poles which results in continuous rotation. As far as the mechanical results are concerned this is about all that need be said in a brief review of the situation, but the reactions occurring within a motor call for recognition in the scheme of wiring and reference must therefore be made to them.

Effect of Back emf. upon Wiring.—The armature of a motor cannot instantaneously spin around at a high rate of speed, when current is turned on, therefore it cannot generate a back EMF. in time to stem the flood of current which will pour through it. A heavy flow will take place because the resistance of the armature is too low to prevent it. It is necessary to interpose between the armature and the line a resistance (Fig. 39) sufficiently great to check any unusual flow of current. In the shunt and differentially wound motors this is imperative; in the series wound motor it is only necessary under

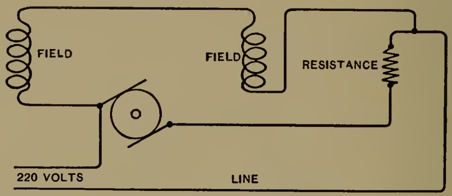

FIG. 39.—Principle of the Connections of a Shunt Motor.

certain circumstances. The current is restrained until the armature has gained sufficient speed to generate the required back EMF. to establish a balance between the power entering the motor and the effort called for by the load. The resistance is then cut out and the motor regulates its own influx and efflux of current by the back EMF. and this in its place is regulated by the load. In the following sketch (Fig. 40) a shunt motor is shown with the starting box interposed when the armature begins to rotate. The boxes are so constructed that the final movement of the handle cuts out all resistance and connects the motor to the mains.

Points About Motors.—In the wiring of a shunt motor the fields must be on *first* and the pole pieces must be tested to discover this fact. Next, the current must pass into the motor through the resistance box and the armature will start slowly. The final throw of the handle of the starting box must not cause any unusual development of speed. A series motor must never be started without a load on. If this rule is not observed the motor will ro-

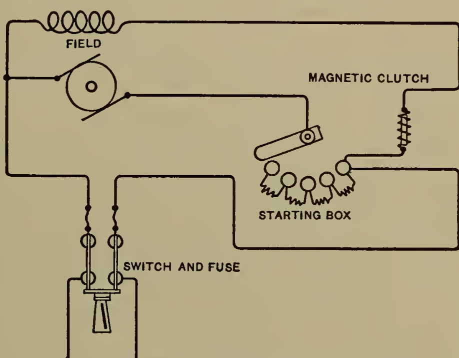

FIG. 40.—Practical Connections of a Shunt Motor.

tate at an enormous rate of speed, each accession of speed developing a velocity which will only cease by the opening of the switch or the destruction of the motor.

A differentially or compound wound motor represents a combination of the two windings. The principle involved is this: that by weakening the field of a shunt motor the speed of the armature increases. In consequence, the current in the series coil of the motor tends to reduce the strength of field and increase its speed when the load tends to diminish it.

Efficiency of Motors.—The efficiency of the motor is twofold, the electrical efficiency and the commercial efficiency. The electrical efficiency is the ratio between the back EMF. and the impressed or external EMF. The commercial efficiency is the ratio between the power given out by the motor and the power it absorbs. Unless a motor has a high electrical efficiency it cannot have a high commercial efficiency. The back EMF. and therefore the electrical efficiency can be calculated in the following manner: Multiply the resistance of the armature by the current and subtract the product from the impressed EMF. to get the back EMF. For instance, suppose a motor has an armature resistance of .01 of an ohm and takes 50 amperes at 110 volts, what is the back EMF.? According to the above principle $50 \times .01 = .50$ and subtracting .5 from 110 gives 109.5 back EMF. The electrical efficiency equals $109.5 \div 110$ or 99.5 per cent. If the power developed in this case equals 5 hp. then the commercial efficiency equals $5 \times 746 \div 5{,}500 = 3{,}730 \div 5{,}500 =$ 67.5 per cent.

In motor wiring calculations the commercial efficiency is of the greatest consequence if given in connection with the EMF. of the motor. The circular mils required for a motor line can be calculated if the horse power of the motor, its efficiency, the voltage, the length of the line and the drop are given. The formula for calculating the circular mils is as follows:

$$\text{C. M.} = \frac{\text{HP. of motor} \times 746 \times \text{length of wire} \times 11}{\text{volts of lines} \times \text{drop} \times \text{efficiency in \%}}.$$

Taking a practical case, what are the circular mils of a motor line with the following data:

HP. of motor = 10.
Length of run = 200 feet.
Volts of line = 220.
Drop of line = 10 volts.
Efficiency = 80 per cent.

C. M. = $10 \times 746 \times 400 \times 11 \div 220 \times 10 \times .80$ = 18,650 or a No. 7 B. & S. To check the results find the resistance of 400 feet of No. 7 wire and multiply by the current, which in this case is approximately 50 amperes.

Resistance 400 feet No. 7 = .2 ohm. $.2 \times 50 = 10$ volts drop as indicated above.

The efficiencies of motors vary very much, but the average efficiency of the general run of direct current motors can be summed up in the following figures:

Horse power.	Efficiency.
1	70 per cent.
2	75 per cent.
3	80 per cent.
4	82 per cent.
5	85 per cent.
6	87 per cent.
7	88 per cent.
8	89 per cent.
9	90 per cent.
10	91 per cent.

A comparative table showing the relationship between the efficiency of a motor and the size of wire required will be instructive in showing how a low efficiency and high efficiency motor affect the contractor's expense in wiring:

Efficiency of motor.	Circular mils.
50 per cent.	29,840
55 per cent.	27,127
60 per cent.	24,866
65 per cent.	22,938
70 per cent.	21,314
75 per cent.	19,893
80 per cent.	18,650
85 per cent.	17,553
90 per cent.	16,577

The above table is built from the problem just given with a 10 hp. motor and 80 per cent. efficiency, only the efficiencies are varied to show the change in the size of wire required. This problem is of the utmost importance, particularly in power transmission, where the weight of copper when heavy horse powers are transmitted becomes enormous unless limited by high pressures and efficiencies. The weight of copper can be likewise developed with respect to the efficiency as shown in the following table, in which one mile of wire is considered, a 10 hp. motor and 500 volts pressure:

Efficiency.	Weight in pounds per mile.
50	1,109
60	924
70	792
80	693
90	616

The tendency on all sides is to adopt high pressure systems which represent a combination of direct and alternating current machinery.

The Alternating Current.—In the lighting of incandescent lamps alternating as well as direct current is employed. The alternating current differs from the direct current in so far as it consists of a series of systematic impulses or waves which rush back and forth in the circuit a certain number of times a second. The dynamo generating an alternating current becomes an alternator simply because it has no commutator, the armature winding ending in two rings instead of being connected to copper strips insulated from each other. The direct current dynamo also generates an alternating current, but this current is modified in the sense that its impulses are all sent along in the same direction by means of the commutator and brushes. The original name for the commutator was rectifier, because it rectified the impulses. There are various characteristics to alternating currents which must be known in the handling of them for commercial purposes.

The frequency or number of periods per second is the term used to define the number of complete reversals (Fig. 41) of current per second. Each

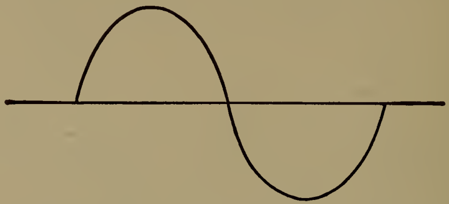

FIG. 41.—Rise, Fall and Reversal of Electromotive Force in an Alternator.

complete reversal is due to the wire passing two poles—a north and a south pole. While passing

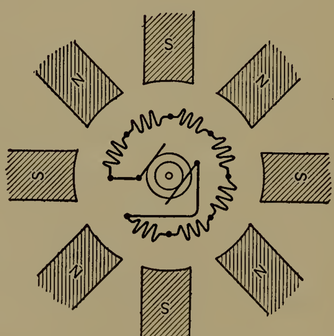

FIG. 42.—Elements of an Alternator.

before the north the current flows in one direction (Fig. 42), and when passing the other in the opposite direction. The frequency or number of periods per second can therefore be calculated in the following manner:

Frequency. — The frequency = revolutions per second $\times$ one-half the number of poles. For instance, what is the frequency of an alternator with 8 poles and a speed of 30 revolutions per second? Frequency $= 30 \times 4 = 120$ reversals. The utilization of an alternating instead of a direct current is due to many advantages in transmission possessed by an alternating current system over a direct. This first manifests itself in a great saving in copper and power, secondly in cost of construction of both dynamos and line. In connection with wiring the question which arises is this, "Is the line inductive or non-inductive?" In other words, are coils in any way associated with the circuit so as to develop reactive electromotive forces or not. It is therefore necessary in preparing the plans of an alternating current lighting and power system to be sure that the circuits are free from disturbing inductive influences.

CHAPTER VI

REASONS FOR EMPLOYING CONDUIT.—THE USE OF CLEATS.—THE USE OF MOULDING.—IRON ARMORED CONDUIT.—ENAMELED IRON CONDUIT.—BRASS ARMORED CONDUIT.—ASPHALTIC PAPER TUBE OR PLAIN CONDUIT.—FLEXIBLE WOVEN CONDUIT.—FLEXIBLE METALLIC CONDUIT.—THE USE OF BENDS, ELBOWS, OUTLET AND JUNCTION BOXES.—DIRECTIONS FOR INSTALLING CONDUIT.—CONDUIT JOBS AND THEIR ACCESSORIES.—SCHEDULE FOR WIRING SYSTEMS.

Reasons for Employing Conduit.—Twenty years ago electric lighting had not impressed business men sufficiently with its advantages and practical value to represent anything more than an experiment. The dynamos were in a comparatively crude condition and their regulation imperfect. A very small portion of the city's area was strung with electric wires, and in consequence thousands of poles and an aerial network greeted the eye, composed of electric light wires, high tension and low, telegraph wires and telephone wires. These wires crossed each other and frequently high tension currents poured into low tension lines, and the wiremen engaged in repairing circuits were often the subjects of tragic scenes. Deaths became so recurrent through confusion and accident that the municipality decided to pass laws to avoid future trouble and demand that all wires be put underground. One of the first to observe this law long before it was passed, due largely to the necessity of the occasion, was the Edison Lighting Company. It placed its wires underground in iron pipes and employed junction boxes and outlet boxes, in what was perhaps the first underground conduit system in New York City and in all probability in the United States. The repeated fires attributed in many cases to electric light wires brought the attention of the Fire Underwriters to residences, business houses, and public buildings with the result that much wiring already installed was condemned and a new code of rules framed which included the use of what was then called "interior conduit" for house wiring. At first merely paper tubing soaked in asphalt was used, then the tubing was armored with brass, and finally further protection was sought against mechanical injury by the use of iron pipe conduit, at present greatly in vogue.

Conduit Wiring.—The different kinds of wiring are included under the heads of

1—Knob or insulator wiring.

2—Cleat work.

3—Moulding work.

4—Conduit work.

For exposed work the first three methods (Figs. 43, 44, 45 and 46) may be employed although the third, moulding work, is the most ornamental of

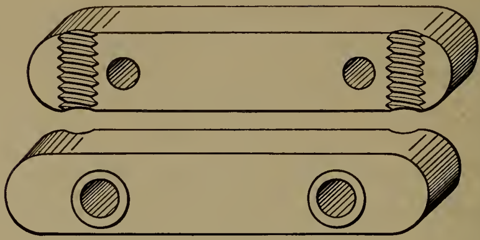

FIG. 43.—Porcelain Cleats.

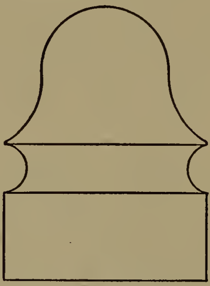

FIG. 44.—Knob Insulator.

FIG. 45.—Cleat Carrying Wires.

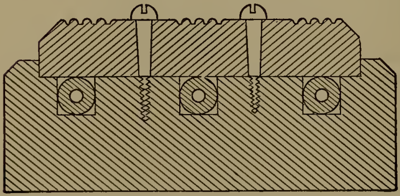

FIG. 46.—Moulding Carrying Wires.

the three. The last, conduit work (Fig. 47), is done either exposed or concealed. If exposed, as is the case in the railway stations connected to the

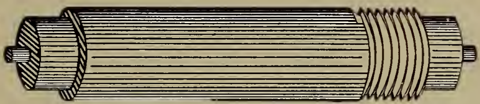

Fig. 47.—Conduit Carrying Insulated Wire.

electric elevated service of New York City, no architectural difficulties present themselves; but where the work is concealed, questions arise of a more complicated nature. An old building or one recently constructed may be wired for electric lights and conduit installed. In this case the walls and ceilings must be grooved and the floors torn up, making an exceedingly expensive and troublesome job for the contractor, attended with many risks. On the other hand the conduit may be installed in a new building before the plasterers get to work. In this case the work can be done with comparative ease and facility and a corresponding cheapness in cost. In either case the plan of wiring must be carefully worked out on paper so that no delays are experienced on this score. Where conduit is used different diameters of pipe must be employed because of the varied diameters of the wires. There are many different kinds of conduit turned out by the principal manufacturers, but they may all be generally grouped under the headings of Iron Armored Conduit, Brass Armored Conduit, Flexible Metallic Conduit, Flexible Non-metallic Conduit, Asphaltic paper, or composition, called Unarmored Conduit.

The installation of a conduit system is practically equivalent to the equipment of a house with pipes, exposed or concealed as the case may be, through which wires are fished after the pipe work is completed. The necessity for using conduit of the correct size need hardly be commented upon. The greatest difficulty will be experienced if the pipes catch or grip the wires when they are fished through, and it is imperative therefore to only use the correct diameters, leaving nothing to chance in this respect. It occasionally happens in tall buildings that when mains or feeders are pulled through a conduit having several bends enormous force is necessary. This may be due to a kink in the wire or the bends or elbows in the pipe. A wire may slip through a pipe easily, yet catch if an elbow or two present themselves. A liberal allowance in pipe diameter will obviate this and save time and necessarily labor and expense if considered in advance in the wiring plans.

The standard sizes of conduit are given with reference to the inside diameters of the different samples. The inside diameters of iron armored conduit as given by one of the foremost manufacturers are as follows:

IRON ARMORED CONDUIT.

Inside diameter.	Outside diameter.	Inside diameter.	Outside diameter.
$\frac{7}{16}$	.675	$1\frac{4}{10}$	1.90
$\frac{1}{2}$	.84	$1\frac{8}{10}$	2.375
$\frac{7}{10}$	1.05	$2\frac{1}{4}$	2.875
$\frac{9}{10}$	1.31	$2\frac{3}{4}$	3.500
$1\frac{1}{4}$	1.66		

This conduit is made of standard weight iron pipe and the same rules are followed in installing it that relate to wiring in general. Whenever different sizes of wire are to be connected a cutout must be installed and the circuits therefor radiate from or converge to panel boards. This is entirely in line with any other system of wiring whether knob, cleat or moulding. The iron armored conduit consists of iron pipe lined inside with insulating material, either a bushing or a composition in the form of a paint or enamel.

Enameled iron conduit is the name especially applied to iron pipe with an insulating enamel inside. As a general rule manufacturers guarantee that their product will bend without breaking or cracking the enamel. The inside and outside diameters are as follows:

Enameled Iron Conduit.

Standard size pipe. Inches.	Actual internal diameter. Inches.	Actual outside diameter. Inches.
½	.62	.84
¾	.82	1.05
1	1.04	1.31
1¼	1.38	1.66
1½	1.61	1.90
2	2.06	2.37
2½	2.46	2.87
3	3.06	3.50

The brass armored conduit consists of a composition of compressed paper saturated with an insulating solution and then protected on the outside with brass sheathing tightly embracing the inner thicker walled tube of conduit proper. The sizes of this material are as follows:

Brass Armored Conduit.

Inside diameter.	Inside diameter.
5/16 inch.	¾ inch.
⅜ inch.	1.0 inch.
½ inch.	1¼ inch.
⅝ inch.	1½ inch.

In choosing conduit for a job care must be made in the selection that the wire can be pulled through freely, otherwise great difficulty will be experienced when this point of the work is reached.

The asphaltic paper tube runs into smaller sizes than the others. It is called plain conduit and represents the first type of tubing employed years ago for the protection of wires as a substitute or equivalent for moulding. The sizes are as follows:

Asphaltic Paper Tube or Plain Conduit.

Inside diameter.	Inside diameter.
$\frac{1}{4}$ inch.	1 inch.
$\frac{5}{16}$ inch.	$1\frac{1}{4}$ inch.
$\frac{3}{8}$ inch.	$1\frac{1}{2}$ inch.
$\frac{5}{8}$ inch.	2 inch.
$\frac{3}{4}$ inch.	$2\frac{1}{2}$ inch.

Unarmored like the above is the tubing called the American Circular Loom Conduit. It consists of woven insulating tubing, flexible in character and of great convenience in bridging over other circuits. It is used to a great extent for switchboard work and is extensively used for general wiring. Where wires are exposed and turns are to be made it finds ready application. Before the insurance laws became so far reaching and iron pipe was required, the flexible conduit enjoyed undisputed supremacy in the commercial field. The inside diameters are given in the following table:

FLEXIBLE WOVEN CONDUIT.

Inside diameter.	Inside diameter.
$\frac{1}{4}$ inch.	$\frac{3}{4}$ inch.
$\frac{3}{8}$ inch.	1 inch.
$\frac{1}{2}$ inch.	$1\frac{1}{4}$ inch.
$\frac{5}{8}$ inch.	

In conjunction with the woven conduit there is also the flexible metallic conduit which is exten-

FIGS. 48 and 49.—Method of Securing Flexible Metallic Conduit.

sively employed in wiring (Figs. 48 and 49). The sizes as regards the inside diameters are as follows:

FLEXIBLE METALLIC CONDUIT.

Inside diameter.	Inside diameter.
$\frac{5}{16}$ inch.	$\frac{3}{4}$ inch.
$\frac{3}{8}$ inch.	1 inch.
$\frac{1}{2}$ inch.	$1\frac{1}{4}$ inch.

With all metallic conduits whether flexible or not there are employed junction and outlet boxes (Figs. 50, 51, 52, 53 and 54). They are either round

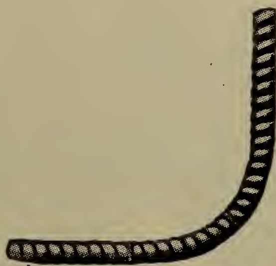

FIG. 50.—Bend.

FIG. 51.—Coupling.

FIG. 52.—Elbow Clamp.

lined or square lined and serve for the purposes indicated by the names; either to allow wires to pass out for lamps, chandeliers, etc., in which case outlet boxes are used, or to act as boxes in which junctions are made between circuits, hence the title.

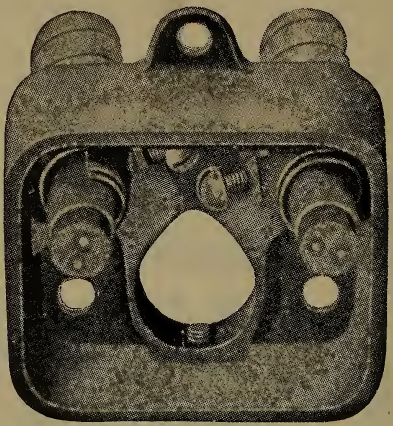

FIG. 53.—Outlet Box.

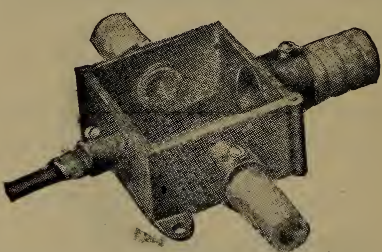

FIG. 54.—Junction Box.

A unique combination of both wire and conduit in one has been introduced to the wiring world under the name of flexible steel-armored conductors. The purpose of this invention is primarily to develop a system by which wires can be installed where an ordinary conduit system would be a failure. The ease with which wiring can be installed when the conductors are so protected represents a saving in labor that relieves the problem of what might otherwise be regarded as unusual expense. Then in such cases where wires could not be safely or securely installed the application of this system becomes an absolute necessity. To quote from the manufacturers' catalogue "the flexible steel armored conductors (Figs. 55 and 56) are of

FIG. 55.—Flexible Steel Armored Conductors.

special value for use under conditions, which would make difficult, if not impossible, the installation of a conduit system. The steel armor affords ample protection against ordinary mechanical injury, and conductors so armored can easily be drawn or fished into a building between partitions and under floors. In such cases no fastenings are required

Fig. 56.—Steel Armored Flexible Cord.

except at the outlets. When so installed, these conductors may be removed, if desired, as easily as the wires could be drawn from a conduit. The lead-covered, steel-armored conductors are of special value in damp places, such as breweries, dye houses, stables, etc., and are specially recommended with twin conductors for marine and underground work."

The conduit generally installed is held in place by means of fasteners or straps.

The lengths of conduits are joined together by couplings. When the flexible conductors are twin or three conductors their special adaptability for marine service becomes pronounced. They are generally made of stranded wires, that is, many fine wires together to give flexibility to the conductor. The sizes are as follows:

FLEXIBLE STEEL ARMORED (SIZES).

Twin.	Marine work.	Single conductor.
14	14 Twin.	10
12	12 Twin.	8
10	10 Twin.	6
8		4
6		2
		1

The couplings for ordinary conduit work run through a variety of sizes extending from $\frac{1}{4}$ up, depending on the character of the conduit, whether iron armored, brass armored or flexible, etc. In addition, elbows are employed where bends or turns are to be made. The various elements of a conduit system can be included under the following classification:

Character of conduit.	Accessories.
Iron armored.	Iron elbows. Iron couplings. Plugs. Lock nuts. Tees. Caps. Malleable iron unions. Straps.
Brass armored.	Elbows. Couplings. Straps.
Plain unarmored.	Elbows. Couplings. Straps.

The flexible metallic conduit system calls for about the same accessories as the iron armored, the only difference being the flexibility of one in contrast with the other, and therefore the absence of elbows. Whenever special devices are to be employed, the manufacturers are only too happy to give full information and, if necessary, to make such changes or improvements as are required. Each conduit system calls for a special set of tools and it is necessary to possess experience and skill to properly install a conduit system and handle the tools relating to it. The time allowed for installing a conduit system of the concealed type is necessarily limited by the fact that the plasterers follow the electrical workers. Such being the case little time is left to rectify mistakes; should they be discovered after the plaster has been laid the contractor will be put to considerable expense. In many important cases the plans are either drawn up or at least vised by a competent consulting engineer to facilitate the completion of the work and rest the responsibility for it.

There are many kinds of wiring which must be done to fulfill the requirements of the specifications. These specifications cover the character of wiring and the number of outlets as well as the purpose for which they will be used.

The system of wiring to be employed is also specified and must be carefully planned out and observed in the subsequent work.

WIRING SYSTEMS.

Three-wire system, iron conduit, direct current.

Two-wire system, iron conduit, direct current.

Two-wire system, iron conduit, alternating current.

Two and three-wire system, iron conduit, for direct and alternating current.

The last system refers to a combination wiring plan, the wires protected in conduit, to be connected to either the three-wire system of the street service or a private two-wire plant in the building. A schedule can be prepared which will include the general method of wiring, the system of conduit work, the exact voltage to be supplied and the character of the current—whether direct or alternating.

System.	Schedule.	Volts.
Two-wire.	No. of mains. No. of feeders. No. of risers. No. of sub-mains. No. of branches.	110

A more elaborate schedule can be worked out comprising all the details of a wiring proposition, but for general practical purposes the above is sufficient.

According to an authority, from whose words the following definition and requirements are taken with reference to the purpose in view in using conduits "The object of a tube or conduit is to facilitate the insertion or extraction of the conductors, to protect them from mechanical injury, and as far as possible from moisture. Tubes or conduits are to be considered merely as race ways, and are not to be relied on for insulation between wire and wire, or between the wire and the ground." Conduits themselves must meet with certain requirements before they can be considered fit or safe to use.

Although many types can be selected, the conditions for their installation and for governing their selection may be better understood with reference to the following limitations:

GENERAL REQUIREMENTS FOR CONDUIT.

I. The conduit between junction box and junction box must be continuous.

II. It must be continuous between junction box and fixtures.

III. It must be composed of such material or be of such construction that neither the insulation of the conductor or the insulation within the tube itself will be ultimately affected or deteriorated.

IV. The conduit must be of such material that it will resist the effects of heat; it must not ignite or burn through the overheating of fusion of wires within it.

V. It must be strong and hard enough to resist blows of hammers, the action of saws, or the points of nails or screws. It must, in fact, be able to resist mechanical injury due to these causes without collapse or fracture.

VI. It must be capable of being installed as a complete pipe or conduit system without conductors so that all heavy work on the building can be completed before the wires are pulled through their respective tubes.

It might be added with reference to these facts that the risk of installing more than one wire in a tube is so great as to be, except where particularly specified, forbidden by the Fire Underwriters. Where specially approved steel or iron conduit is installed, permission to use twin conductors or two conductors in the conduit is a matter of discretion on the part of the authorities. When iron or steel armored conduit meets with the approval of the Fire Underwriters it must be able to meet such requirements as are embodied in the following chapter.

CHAPTER VII

REQUIREMENTS FOR IRON AND STEEL ARMORED CONDUIT.—LAYING OUT A CONDUIT SYSTEM.—THE INSULATION OF CONDUCTORS.—MECHANICAL WORK.—INSULATING MATERIALS.—CONCEALED AND EXPOSED WORK.—INSULATION RESISTANCE.—GROUNDED WIRES.—SOLDERING SOLUTION.—A DISTRIBUTION SHEET FOR LAYING OUT WIRING.

Requirements for Iron and Steel Armored Conduit.—*a.* When the tube is grounded to one leg of the circuit and the wire to the other, the volatilization of all or part of the wire when it is "burnt out" must not injure the tube.

b. The insulating protective coating inside the tube must not become soft at a lower temperature than 158 degrees F. (70 degrees C.).

When water is boiled inside the tube it must not dissolve the constituents of the insulation but must remain in its original condition.

c. The effect of immersion or soaking in water for a few days must not so affect the mechanical integrity of the insulating material that it becomes weak and therefore useless.

d. The insulation resistance of the tube must remain high, if the length of tube is bent and filled with water and a test made at the end of three days. The insulation resistance under these circumstances between the metallic pipe and its contents must not fall below 1 megohm.

In order to continue the remarks to be made in general about conduit, its requirements and its installation it may be further stated that all conduit ends projecting must be filled with an insulating compound to protect its contents from moisture and deterioration. This practice must be followed out at the junction boxes as well, and particular attention must be paid to all joints which according to requirement must be made moisture-proof and air-tight.

As regards the finishing of the ends of projecting conduits, these must extend at least 1 inch beyond the mortar or plaster because of the possibility of moisture and foreign matter otherwise entering the tube. If necessary, this projection may be subsequently cut down, but it must project at least $\frac{1}{2}$ inch beyond the wall surface when said surface is finished. These requirements are entirely in line with the dictates of practice and reason and mean the avoidance of trouble, both with regard to the choice of conduit and its installation.

Laying Out a Conduit System.—In laying out the plans of a conduit system certain responsibilities rest with the architect as well as the consulting engineer or contractor. The demands made upon the contractor and consulting engineer relate to the mapping out of the work and its subsequent installation. That of the architect relates to the provisions made in the construction for the reception of the conduits in a convenient and practical manner. The architect's duties consist, therefore, in making provision when preparing the plans of the building, for such ducts, pockets and channels as may be required for the conduits and the electric light and power lines they carry.

Insulation of Conductors.—The great danger of grounds and short-circuits in buildings may be reduced to a minimum if the general principle is followed out when installing wires of regarding their installation, however good, as non-existent. If wires are installed in buildings, whether in conduit, moulding or on insulators as if they possessed no insulation, but were bare, then the precautions taken would be so far reaching that the risk of faults from grounds or poor insulation is negligible.

Mechanical Work.—Too much stress cannot be laid upon the necessity for as perfect mechanical work as can be done. The details of soldering and connecting wires, the taping of wires and the proper method of securing the conduit—all of these belong to the field of purely practical work calling for experience and skill on the part of the employes. Efficiency can only be secured if every portion of the conduit and conductor undergoes a careful inspection during the development of the work and during its completion. The best point from which to start, whether the wiring or conduit is being installed, is the center of distribution.

After one or many have been selected, by a careful examination of the conditions, then it is necessary to select the correct points at which the switches and cutouts controlling the different circuits are to be placed. In order to render such positions accessible for ready handling in case of short-circuits, grounds, breaks or other faults, panel boards are generally employed. These boards are miniature switchboards at which all the circuits of a part of a floor, or of one or two floors, converge. They are the sub-centers of distribution of a large building.

Insulating Materials.—Perhaps one of the greatest problems in electric wiring has been the selection of the correct insulating materials for electrical work. In order that an insulating material may meet with the proper consideration before trial it is necessary that it should be

1. An insulator.
2. Non-combustible.
3. Non-absorbent.
4. Non-hygroscopic.

There are many insulators and insulating materials now in use which are apparently immune from shortcomings in this respect, but a close examination will reveal the fallacy which a rigid test would make certain. In the wiring world insulating material is used for switchboards, insulators, and insulation of the following materials: Marble, slate, porcelain, glass, mica.

The marble and slate are used for switches, panel boards and switchboards. The marble is entirely used for switchboards. The mica is employed for the covering of cutouts and in a compressed form for sockets, etc. The porcelain and glass are employed for general insulating purposes. The covering of wires differs from this, in that it consists of rubber or gutta-percha, but the strict requirements for insulation whether of wire, switches, switchboard or other devices are not any too high where special work is to be done.

Special Insulation.—In damp places, where moisture is constantly soaking in to all materials, such as dye houses, breweries, stables, pulp mills, laundries and acid manufactories, where fumes are exercising a deleterious effect, special insulation is required on wires, which is described thoroughly in the following paragraph:

The wire must have a solid insulating covering of at least $\frac{3}{64}$ of an inch in thickness, and this covered with a strong and tightly fitting braid. It must be difficult to burn or ignite and must possess insulating power sufficient to show 1 megohm after exposure through submersion to the action of water for two weeks, at a temperature of 70 degrees F., or after three days' exposure through submersion to the action of lime water and the passage of a current of 550 volts pressure for three minutes. It is necessary in addition to expose such wire to the direct action of those liquids or fumes to which it will be subjected.

Concealed and Exposed Work.—Wiring that is either concealed or exposed represents the two cases where the allowance of current for the wires is different for the same amount of lighting. By this is meant that a wire of a given number of circular mils cannot carry as much current for concealed work as for open or exposed work.

In exposed work the air freely circulates around the wire and its radiating power is not limited by being surrounded by conduit or moulding. Such radiation as generally occurs takes place through the insulation into the outer air:

Concealed wires in conduit.		Open work on insulators.	
Gauge No. B. & S.	Amperes allowable.	Gauge No. B. & S.	Amperes allowable.
0000	218	0000	312
000	181	000	262
00	150	00	220
0	125	0	185
1	105	1	156
2	88	2	131
3	75	3	110
4	63	4	92
5	53	5	77
6	45	6	65
8	33	8	46
10	25	10	32
12	17	12	23
14	12	14	16

The relation of current to insulation resistance has also been established by law as regards insurance. The insulation resistance of the mains, feeder branches, etc., must not fall below a certain figure of at least 100,000 ohms. The entire wiring installation must not represent less than the insulation resistance given in the following table:

Amperes.	Insulation resistance.	Amperes.	Insulation resistance.
10	4,000,000	200	200,000
25	1,600,000	400	100,000
50	800,000	800	50,000
100	400,000	1,600	25,000

The manner of development of the table is quite evident after a slight examination of the relationship of the figures to each other. The basis is 4 megohms for 10 amperes, which would mean a corresponding sub-division of the resistance for any other greater current. For 20 amperes the insulation resistance is one-half, for 50 amperes one-fifth, etc., as indicated.

Many detailed requirements have been established by practice relating to the essential elements of a wiring equipment. They relate to such important articles as switches, cutouts, fixtures, etc. As regards the last, particular attention must be paid to the question of insulation resistance, where the fixtures supply gas as well as electricity. In this case the fixture is insulated from the gas pipes or ground connection by means of an insulating joint. The requirements read as follows: "Insulating joints to be approved must be entirely made of material that will resist the action of illuminating gases, and will not give way or soften under the heat of an ordinary gas flame. They shall be so arranged that a deposit of moisture will not destroy the insulating effect, and shall have an insulating resistance of 250,000 ohms between the gas pipe attachments, and be sufficiently strong to resist the strain they will be liable to in attachment."

Perhaps the most fruitful cause of grounds and short-circuits may be found in fixtures and sockets unless the utmost care is taken during their installation to remove such possibilities by strict adherence to the observed code.

Grounded Wires.—When it becomes necessary to ground wires, when lightning arresters are installed or protective devices are employed for telegraph, telephone, fire, district messenger, and burglar alarms or their equipment, the ground wire must be connected to a gas or water pipe and connection made beyond the first joint by soldering. If such a ground connection is impossible a ground must be made by means of a metallic plate or a collection of loose wires or pipes buried in moist earth. The ground wire in this case must not be smaller than a No. 16 B. & S. and must be supported as though it were a high potential wire to the final earth connection. The protective device is of an electromagnetic character and saves the circuits to which it is connected from a sudden rise of current and pressure due to the crossing of signaling and message-conveying wires with power or electric light circuits. It is inclosed in a waterproof metallic case and is placed outside the building, or if placed inside, the wire leading into it through the wall must be carefully protected by approved insulating bushing. A very useful solution for soldering wires may be made up from the following formula. It is recommended that after use the joint be carefully wiped to remove all traces of the acid and thereby prevent subsequent corrosion:

Solution of zinc saturated..........	5 parts.
Glycerine........................	1 part.
Alcohol	4 parts.

The solution of zinc is obtained by taking a 6 oz. bottle and half filling it with hydrochloric acid. Then slowly drop in pieces of granulated zinc until the ebullition ceases. The solution then obtained corresponds to the first item of the formula just given. The joint is first heated with a blow-pipe or soldering iron after being carefully cleaned to expose the bright metal and the solution is applied with a stick and the solder will immediately flow freely.

A very good plan is to follow a certain system as regards the position of every light in the building. Such a plan may be embodied in the form of what could be called "A Distribution Sheet" on the following order:

Distribution Sheet.

Cutouts.	Floor.	No. of lights—1.			No. of lights—2.			No. of lights—3.			Total lamps.
		Ceiling.	Wall.	Switches.	Ceiling.	Wall.	Switches.	Ceiling.	Wall.	Switches.	
2	1	0	1	1	2	0	1	0	3	0	6
1	2	1	0	0	0	2	0	3	0	1	6
	3										
	4										
	5										
	6										
	7										

The idea of this sheet is to conveniently locate the position of all lights for ready reference and to hold the plan of the wiring in as explicit and condensed a form as possible. The importance of this cannot be overestimated when the wiring of a 20-story building is considered with its numerous outlets. In order to facilitate the work an outlet sheet is convenient to use. It is of a much simpler character than the above and may be laid out in this form:

Floor.	Outlets.	Purpose.
1	10	Lighting.
2	8	Lighting.
3	6	Lighting.
4	7	Lighting.
5	5	Lighting.
6	9	Lighting.
7	2	Motors.
8	3	Lighting.
9	6	Lighting.
10	4	Lighting.

In laying out the position of the conduit, the exact knowledge of the position of each outlet and junction box is a matter of great importance. Mistakes in the wiring plan in this respect on a big job may mean considerable delay, confusion and expense. Both these sheets may be extended to cover any number of floors, and from them estimates can be prepared for future work as regards labor and material.

It is often the custom to estimate on conduit jobs, whether open or concealed, as well as moulding and insulator work, at so much per outlet, or so much per lamp completely equipped. In any case a list of the material required must be prepared and the cost of labor, to form a clear conception of the absolute cost. The items to be included in this list are based upon the character of the work, whether insulator, cleat, moulding or conduit. In each case various essentials are different, particularly when concealed work is done. In this case the estimate must cover the additional cost of labor involved in ripping up floors, grooving the walls and cutting out a place in the walls for panel boards.

Panel Boards.—In general house wiring the circuits are all led to a given point on one floor if the floor is small, or, if it is large, several of these points are employed at which panel boards are installed. Panel boards are merely slate boards on which small switches are systematically arranged for the control of the branch circuits on the floor and on which the fuses controlling those branches are mounted.

They are built for two and three-wire mains (Figs. 57 and 58) with branches on both sides of

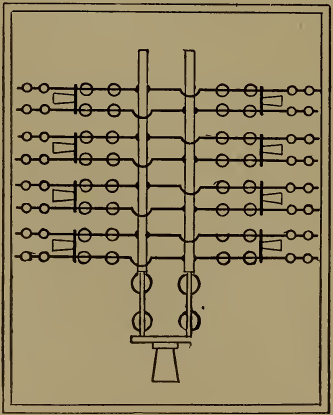

FIG. 57.—Panel Board for Two-wire System.

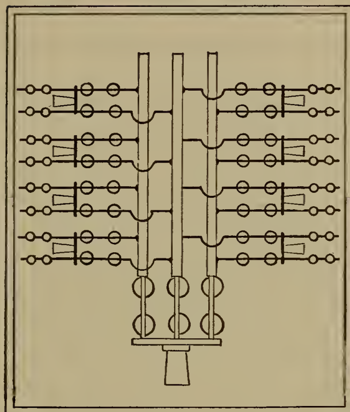

FIG. 58.—Panel Board for Three-wire System.

the mains. In the illustrations are shown two panel boards as described, one for a two-wire system with two wire branches, the other for a three-wire system with two wire branches. In many cases a main switch is also mounted so as to give control to the entire floor or section of the floor as the case may be. In many respects these panels might be aptly termed secondary switchboards as they control the circuits at the points of distribution.

UNDERWRITERS' REQUIREMENTS REGARDING SWITCHBOARDS AND PANEL BOARDS.

Switchboard:

a. Must be made of non-combustible non-absorptive insulating material, such as marble or slate.

b. Must be kept free from moisture, and must be located so as to be accessible from all sides.

c. Must have a main switch, main cutout and ammeter for each generator. Must also have a voltmeter and a ground detector.

d. Must have a cutout and a switch for each side of each circuit leading from board.

Tablet and Panel Boards:

The following minimum distance between bare live metal parts, bus-bars, etc., must be maintained between parts of opposite polarity, except at switches and link fuses, as follows:

When mounted on the same surface—0–125 volts, $\frac{3}{4}$ inch; 126–250 volts, $1\frac{1}{4}$ inch. When held free in the air—0–125 volts, $\frac{1}{2}$ inch; 126–250 volts, $\frac{3}{4}$ inch.

Between parts of the same polarity:

At link fuses—0–125 volts, $\frac{1}{2}$ inch; 126–250 volts, $\frac{3}{4}$ inch.

At switches or inclosed fuses, parts of the same polarity may be placed as close together as convenience in handling will allow.

It should be noted that the above distances are the *minimum* allowable, and it is urged that greater distances be adopted wherever the conditions will permit.

The spacings given first apply to the branch conductors where inclosed fuses are used.

The spacings given second apply to the distance between the raised main bars, and between these bars and the branch bars over which they pass.

The spacings given third are intended to prevent the melting of a link fuse by the blowing of an adjacent fuse of the same polarity.

For further and more detailed reference to the requirements of the National Board of Fire Underwriters the National Electrical Code must be consulted. A copy of this may be obtained from the Fire Underwriters of any large city.

The routine work of a wiring problem is plain sailing, but the difficulties and unexpected expenses arise when special positions are required for lights and switches.

CHAPTER VIII

THE LIGHT OF INCANDESCENT LAMPS.—THE POWER CONSUMED BY LAMPS PER CANDLE POWER.—CANDLE POWER AND COAL.—EFFECT OF LOW PRESSURE ON LIGHT.—EFFECTS OF GLOBES ON LIGHT.—SIZE OF ROOM AND NUMBER OF LIGHTS.—USE OF SIDE LIGHTS AND CHANDELIERS.—COLOR OF ROOM DECORATION AND THE LIGHTING.

Light of Incandescent Lamps.—The importance of considering in its proper aspect the light of lamps of the incandescent type, is due to the relationship between voltage and candle power in these lamps. To obtain the maximum light from the minimum power is not so much an object as to obtain durability or lasting qualities in the lamp. As lamps grow old they deteriorate and the light grows dim, so that to obtain the correct candle power such an accession of power is required as to make the production of such light a most uneconomical proceeding. The efficiency of a lamp, or the relation between the light it gives and power it consumes, are matters of the utmost importance not only in its construction but in its utilization as well. In speaking of power, both volts and amperes must be considered, therefore, when greater or less voltage is supplied to lamps or when the percentage of the normal is below or above 100 per cent., the power consumption and the candle power vary accordingly. Tables have been prepared by many manufacturers covering these features, but they generally relate to the ratio of candle power to watts. This is given in the form of a given number of watts per candle power, and the average lamp consumes from between 3 to 4 watts per candle power. In the following table some figures are given expressing the relationship between light and power for a consumption of power which varies from 1 to 4 watts per cp.:

TOTAL WATTS = 64.

Watts per cp.	Total cp.
1.0	64.00
1.5	42.66
2.0	32.00
2.5	25.60
3.0	21.33
3.5	18.29
4.0	16.00

The practical basis is about 3.1 to 3.5 watts per candle power and on this relationship of power to light the following lamps, their candle power and wattage are given:

WATTS PER CP. = 3.1.

Candle power.	Total watts.
100	310
50	155
32	99.2
16	49.6
8	24.8

These figures are bound to vary after the lamps have been in use a certain number of days. After prolonged use the lamps appear smoky and give a poor and inefficient light, which is due to the increased resistance of the filament. But if more than the normal pressure is supplied the light though brilliant is in the end very expensive because of the subsequently rapid injury to the lamp and its exceedingly poor return for the power. The normal voltage of a lamp therefore changes; gradually rising as the life of a lamp goes on and thereby increases the watts per candle power and drops the efficiency lower. A lamp lasts much longer if the voltage is a little lower, and acts more satisfactorily as a light producer in the end as far as the expense for lamps is concerned. But the danger lies in the voltage being too low and the light too dim. Then the practical efficiency of the lighting plant is affected. If the drop in the wires cause this, the wiring is a failure, but if the dynamo pressure is too low it should be increased. As an illustration of the enormous practical importance of this fact in electric wiring and electric lighting, take a 110-volt lamp of 16 cp. and run it below its normal pressure. Let the voltage be limited to about 104.5 to 105.5 volts and measure the candle power. It will not exceed 12 cp. In other words, a slight reduction in voltage to the lamp means a great drop in candle power, and if ten or twenty thousand dollars are spent to obtain a certain amount of candle power and 25 per cent. is wasted by low pressure the remaining candle power is obtained at a heavy expense. The only item to counterbalance this is the saving in lamp cost. The saving in lamps must therefore be balanced up against the value of the lost light on such a basis. In all probability a 25 per cent. cut in candle power will not pay when compared with the cost of lamp renewals. Take a 1,000 light 110 volt plant at an estimated cost of $10,000. If 25 per cent. of the light is wasted in order to save lamp renewals then the light of 250 lamps, at a pressure of about 106 volts, is practically thrown away. The cost of 1,000 lamps is about $200 at 20 cents apiece, or higher, as the case may be according to prevailing market rates. The value of the light of 250 lamps, if supplied outside, is at least $100 a month. Estimating the life of these lamps at 600 hours and burning them 5 hours a day, it would mean 130 days or about a four months' steady run before they completely failed. If run at a low voltage they might last longer and only mean renewals twice, instead of three times a year. The cost of this is about $400, which can be compared with the $1,200 worth of light thrown away by low voltage. If the *coal pile alone* is considered, it will be seen that the amount of coal required for 1,000 lights at 5 lbs. per horse power hour would be, on the basis of 12 lamps per horse power, as follows:

If 12 lamps = 5 lbs. per hour,
then 1,000 lamps = 83 × 5 = 415 lbs. per hour.

On the estimate of 5 hours' lighting a day the total weight of coal consumed amounts to 5 × 415 = 2,075 lbs. or about one ton. This coal may cost various prices per ton, but if $4 is taken as a fair price for good coal, then the expense in this direction amounts to about $1,200 for 300 working days in the year. Of this amount 25 per cent. or $300 worth is systematically thrown away by the low voltage being employed to save lamp wear. Each lamp renewal costs $200, and it seems at the best all that can be done is to reduce the number of lamp renewals from three to two per annum. This means a saving of only $200 in lamps as compared with $300 worth of coal which is burned and wasted. The depreciation of the plant is not considered nor the interest on the investment, nor the fact that the labor paid for each year could do the extra lighting without extra trouble, etc. Another feature of the case is the fact that if the light is poor extra lighting must be done to supply the required illumination, as the practical basis for ordinary rooms should be about 16 cp. for every 50 or 75 square feet of floor space, depending upon the tone of the decorations and wall paper. The appended table, giving figures taken from the records of the largest manufacturers of lamps in the United States with additions by the author, shows the fall of efficiency with the voltage and the heavy reduction in the illuminating power of the lamp:

RATE OF 3.1 WATTS PER CP.

Percentage of the correct lamp pressure.	Percentage of the correct candle power.	Watts consumed per cp.	Candle power of a 100 cp. lamp.
90	53	4.68	53
91	57	4.46	57
92	61	4.26	61
93	65	4.1	65
94	69.5	3.92	69.5
95	74	3.76	74
96	79	3.6	79
97	84	3.45	84
98	89	3.34	89
99	94.5	3.22	94.5
100	100	3.1	100
101	106	2.99	106
102	112	2.9	112
103	118	2.8	118
104	124.5	2.7	124.5
105	131.5	2.62	131.5
106	138.5	2.54	138.5

The figures show that in the case of a 100 cp. 110 volt incandescent lamp between the voltages of 99 and 116.6 the candle power varies from 53 to 138.5 or almost as 1 is to 3.

The various types or shades and globes also govern the amount of effective candle power obtained. It is a well-known physical fact that the various colors of glass are more or less absorptive, and may reduce the amount of useful light to such a degree as to render useless efforts to better it. The following figures relate to this fact with respect to the globes and the degree of absorption:

Character of glass.	Percentage of wasted light.
Ordinary pane glass	about 10 per cent.
Cut or pressed glass	from 10 to 15 per cent.
Ground glass	from 25 to 40 per cent.
Opalescent glass	from 25 to 50 per cent.
Red glass	from 30 to 60 per cent.
Blue glass	from 15 to 30 per cent.

The depth of color in the glass is a prime factor in determining the degree of absorption. A great deal of candle power can be produced, and wasted by the use of poor globes, thus nullifying advantages of good wiring and regulation.

Choosing Globes.—In choosing globes several points must be taken into consideration which might be tabulated in the following manner:

1—Cost of globes.

2—Diffusion of light.

3—Degree of absorption.

4—Artistic design.
5—Fragility.

By the use of a little common sense the selection of such important articles can be made with a definite purpose in view. Many of the best looking globes are poor light transmitters and the converse. As a general rule the cost and design are the predominating factors, whereas the effective diffusion of the light and the degree of absorption are perhaps of more importance from an economical and practical standpoint in the long run.

The area of the lighted room as well as the height of the ceilings next lead to the determination of the answer to the question: "How shall the lamps be distributed and how many must be used?" Take a room 20 feet in length by 15 feet in width and 12 feet high. The floor area is $20 \times 15 = 300$ square feet; and the wall area equals $15 \times 12 \times 2 = 360$ added to $20 \times 12 \times 2 = 480$ or a total of 840 square feet. In order to illuminate this room successfully side lights must be employed and a chandelier. Allowing one 16 cp. lamp for every 50 square feet, in the case of a parlor or drawing room a six-light chandelier is required. If side lights exclusively are employed the figures used with reference to the walls would be 100 square feet per 16 cp. lamp or an allowance of about 8 lamps. When the lighting is divided up between the side lights and chandelier about four side lights and four chandelier lights are the best to employ. This would mean the utilization of about 100 cp. from the chandelier after it passes through the globes and 130 cp. from the side lights if used exclusively; or a total amount of candle power equal to at least 130 if distributed throughout the room. It is therefore evident that the *distribution* of the light is of more importance than the quantity, and a great deal of power can be ineffectively used to light a room where one-half as much, consumed in properly arranged lights, would give greater satisfaction. The absorptive power of the globes must be considered in practical lighting particularly where it is necessary to bring out decorative effects at night.

If the general tone produced by the decorators' art in fine apartments is blue, pink or red, the lighting must be done by choosing positions and globes to augment this effect and not to produce a disagreeable impression through inattention to such details. If red, blue or other colored globes are employed and full illumination is required the lost percentage of light must be added in the number of lamps or the candle power of the globes.

It is well for those desirous of making of wiring an art as well as a trade to study the requirements of the business and social world in order to succeed in meeting the demands they make upon the contractor. The great dry-goods and department stores, the public buildings, the theatres, the churches and the home—these are not easy problems that relate alone to the putting in of wires. They call for greater knowledge, which in its highest form goes hand and hand with the dictates of art and fashion. To produce not merely light, but a uniform light is the main idea, and in great auditoriums a careful study of conditions is the only way of meeting with any degree of success. The candle power is dependent entirely upon the voltage and to keep this up to the standard as well as to control the groups of lights, or, in other words, to obtain *control* and *regulation* of the light with one or more dynamos in lighting plants, the switchboard has been universally adopted.

CHAPTER IX

SWITCHBOARDS AND THEIR PURPOSE.—THE PARTS OF A SWITCHBOARD.—CONNECTIONS OF A SHUNT WOUND GENERATOR.—THE CIRCUIT BREAKER.—THE RHEOSTAT.—CONNECTIONS OF A COMPOUND WOUND GENERATOR.—FUSES.—CONNECTIONS OF TWO SHUNT WOUND GENERATORS AND SWITCHBOARD.—EQUAL PRESSURES FOR BOTH DYNAMOS.—THE BUS BARS.—BACK VIEW OF SWITCHBOARD SHOWING WIRING CONNECTIONS FOR TWO SHUNT MACHINES.—CONNECTIONS OF COMPOUND WOUND MACHINES SHOWING BUS BARS AND EQUALIZER BAR IN SERVICE.—OVER COMPOUNDING.—THE SERIES WINDING AND ITS PURPOSE.

Switchboards. — As the switchboard represents the connections which are made to obtain convenient control of the circuits and in the case of several generators to effectually combine and direct their output, it is supplied with switches, measuring instruments, circuit-protecting devices and regulating devices. These may be considered in their order—

1—Switches,
2—Meters,
3—Circuit breakers,
4—Rheostats,

further additions being merely secondary accessories not required by the code.

A switchboard cannot be designed until the circuits leading to and from it have been carefully drawn out so that the number of switches, meters, circuit breakers and rheostats are fully known. It is not the practice to put up a board and then attach the wires, because the stony character of the material calls for careful drilling, and in addition, the size of the stone or marble slab must be determined from the apparatus to be attached to it. This can be obtained from the schedule or list of the circuits and the character of the generators to be connected.

Connections of a Shunt Wound Generator.—The essential connections of a shunt wound generator relate to the armature and field connections and the devices connected to them either for purposes of regulation, protection or measurement.

As shown in the illustration (Fig. 59) the connections of a shunt wound generator call for a rheostat in series with the field circuit; a main switch which controls the entire current supply and the two essential measuring instruments, an ammeter and a voltmeter. The ammeter is in series with the main circuit and indicates the total flow of current. The voltmeter is in multiple with the main circuit and indicates the voltage at the switchboard.

Protection.—The circuits are protected individually by means of fuses and collectively by means of a circuit breaker. There is a main switch, which, when opened, cuts off all communication between the dynamo and lighting circuits. This is also fused and acts as a protective device, but the device which is accepted as most reliable and con-

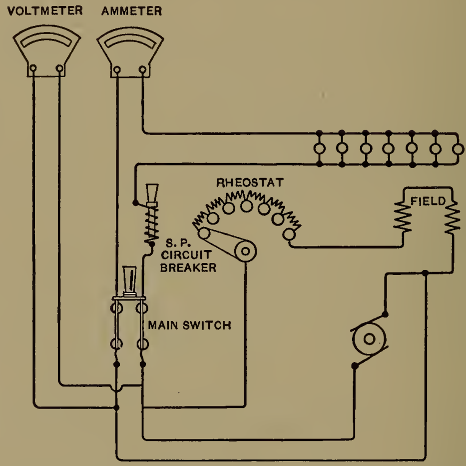

FIG. 59.—Connections and Accessories of a Shunt Wound Dynamo.

venient is the automatic electro-magnetic circuit breaker.

Circuit Breaker.—An automatic circuit breaker consists of a helix of heavy copper wire through which the full volume of the current circulates. This helix attracts an iron core whose pull is resisted by a powerful spring. The magnetic pull and the spring balance each other under ordinary conditions. When a heavy short circuit occurs, the pull of the helix, and consequently of its core, becomes so great that the spring is overcome and a latch gives allowing the main line switch to fly open. This switch is so constructed that it opens instantaneously and without arcing and acts as the most efficient circuit protector in daily practice.

Rheostat.—The rheostat is in series with the field winding and the main line is tapped at both poles to supply it with current. An examination of the sketch will show that the field and rheostat in series, are together in multiple with the armature terminals, so that the regulation of the dynamo can be readily accomplished by following the connections and mounting the rheostat on the switchboard. The rheostats in general use for switchboard connection are of the enamel type, that is, composed of iron or composition wires buried in enamel and attached to a flat metallic frame with considerable radiating surface. They occupy little space and have added greatly to the equipment of the switchboard.

Connections of a Compound Wound Generator.—The sketch (Fig. 60) shows a difference between the connections only in so far as the series winding is concerned. The same devices are in use, namely, a rheostat, a circuit breaker, a main line switch and meters to register current and voltage. The series winding also carries the total current of the lamps, and final connections must be made to this effect. On nearly all switchboards there is provided a pilot lamp, which gives the light or pressure straight from the dynamo, and in addition a ground detector which is merely a lamp with one leg grounded and a push button in circuit to show the presence of a ground. It is so constructed that

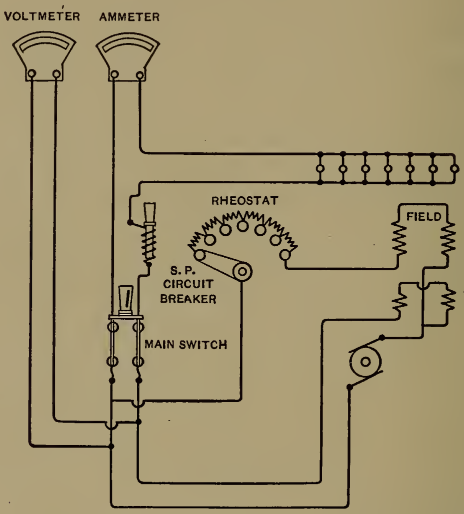

FIG. 60.—Connections and Accessories of a Compound Wound Dynamo.

both legs of the circuit can be tested. The switchboard of both machines can be so designed that the street service can be turned on by use of a double poled and double throw switch. The compound wound generator is almost exclusively employed in private plants and for street railway work on account of its automatic regulation.

Fuses.—The fuses in general use for switchboards are of the approved non-arcing type. Fuses of this character are surrounded by an envelope or tube of incombustible material, within which the melting or volatilization of the fuse may take place without the spattering of metal or the deposition of fumes on the polished switchboard. In total

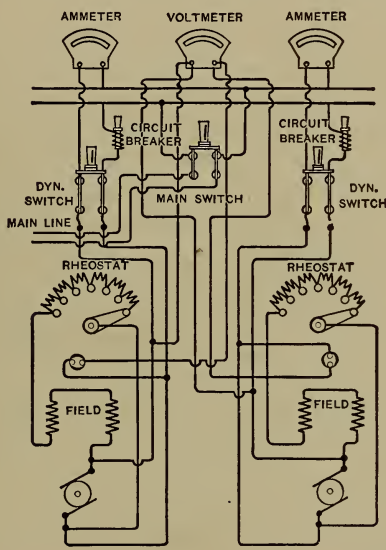

FIG. 61.—Diagrammatic Connections of Two Shunt Dynamos in Multiple.

these items comprise the essentials and accessories of an ordinary switchboard for a single shunt or single compound wound machine.

Connecting Two Shunt Wound Dynamos.—The method of connecting two shunt wound machines in multiple is shown in the sketch (Fig. 61). A certain amount of care must be exercised, because both are generators of electromotive force, and in consequence conditions result which would be dangerous if disregarded when both machines are in operation. Both machines may run as follows:

First—Both at equal pressure.

Second—Both at unequal pressure.

Third—One as a dynamo and one as a motor.

In order to have both run at an equal pressure, first one is allowed to run until its EMF. is correct, the switch of the other machine being open, then the process covers the following as regards the other. The second machine is brought up to speed and its pressure made to tally with the first machine. This is accomplished by means of the regulating device or rheostat, whose action is recorded by the voltmeter. By means of these two devices the pressures are made to correspond with great exactness, before the main switch from the second dynamo is thrown in. When both dynamos are of equal pressure the main line switch is thrown in and this immediately calls upon the two dynamos for power. If they are alike in construction the variation in load will not be very great, but this is not apt to be the case, and the pressure of each must be again regulated until they are approximately correct. This is an operation requiring some skill and practical experience before it is done quickly and without risk.

Unequal Pressures.—The risk mentioned is that due to the unequal pressures, which cause the loads on the machines to be unequal and thereby throws too much on one and too little on the other. This is apt to cause overheating of the armature and if sustained over a long period a possible burn-out. Another danger is present however, and this is due to the fact that one may run as a motor if its pressure falls very far below the other.

Under these circumstances the fields will remain as before, and the dynamo will continue to run in the same direction as a motor, because the current is now entering the armature in the opposite direction. This experiment can be readily tried with a small experimental shunt dynamo. The machine may be used as a generator with separately excited fields. If a reverse current is suddenly switched into the armature it will continue to run in the same direction as a motor. In the sketch (Fig. 62) two bus bars are employed to which the main line switch is connected and from which the pressure at the generators is readily obtained. The entire regulation in the case of two or more shunt wound dynamos running in parallel consists in looking out for the equal distribution of the load by means of the regulating rheostats. In the sketch is shown the appearance of the switchboard with all the instruments and switches mounted. Two push buttons are used for testing for the pressure of each dynamo respectively. The bus bars are also in evidence, and in this case they simply consist of solid bars of pure copper to which all three switches are joined by copper bars.

It is easy to see this connection in practice in the other sketch. First the two dynamo switches which convey the current from the dynamos to

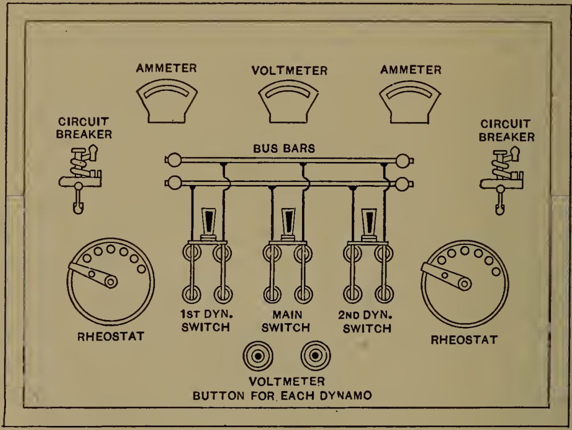

FIG. 62.—Front View of Switchboard of Two Shunt Dynamos in Multiple.

the bus bars; then the main line switch through which the total current passes to the lighting or motor circuits. Each of the dynamo circuits has in series with it a circuit breaker, which protects the dynamo to which it is connected from an abnormal load. There are non-arcing fuses mounted on the switches as an additional protection. It is also possible to have but one circuit breaker in the main line and thereby dispense with the two used in connection with the dynamos, but individual protection for each machine is by far the best policy in general switchboard design. The use of two voltmeters instead of one is also the best practice although not absolutely necessary.

The rear view of the switchboard is shown in the next sketch (Fig. 63) with the connections to

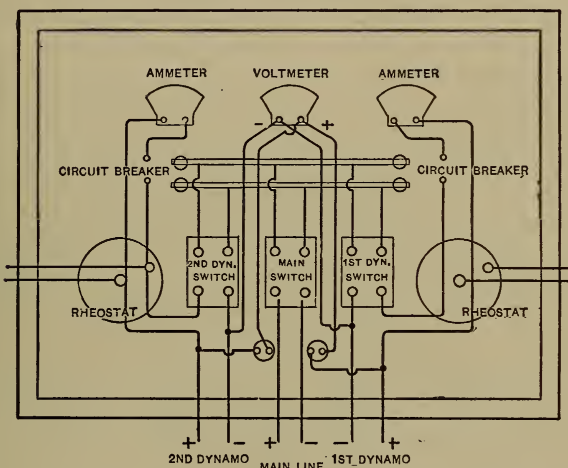

Fig. 63.—Back View of Wiring Connections of Two Shunt Dynamos in Multiple.

the different devices on the face of the board. In all cases where a single voltmeter is used with push button contacts from each dynamo care must be taken that each pole is connected right or a short circuit will result at the voltmeter binding posts or poles. The main circuit from each dynamo runs through the ammeter in series with which is the circuit breaker as shown. Two conductors of flexible cable lead the current from each dynamo respectively into its controlling switch and thence into the bus bars. From the bus bars through the main switch the current is led out to the distributing circuits. In this case the circuits on the different floors are not individually controlled from the switchboard. If it is necessary to do this, the switchboard becomes a little more elaborate and the switches controlling the different floors must be shown on the face and back of the board.

The control of different floors by means of the switchboard is required in complete equipments. A case of this kind is exhibited in the illustration (Fig. 64) where six separate circuits, each with its main switch, compose one section of the switchboard.

The back (Fig. 65) and front appearance are shown, with all apparatus mounted in its place, and all wiring connections complete. It must be understood that if there are many changes in the load the switchboard will not help to regulate it. It only serves as a convenient place on which to group the different devices and at which to concentrate all the principal circuits. If the variation of load due to changes in the number of lights on the different floors is very marked, it will be necessary to regulate by the rheostat as often as required. In some plants of this description this is inevitable and represents one of its greatest drawbacks. If this rheostatic regulation is not attended to, the load upon the machines will dis-

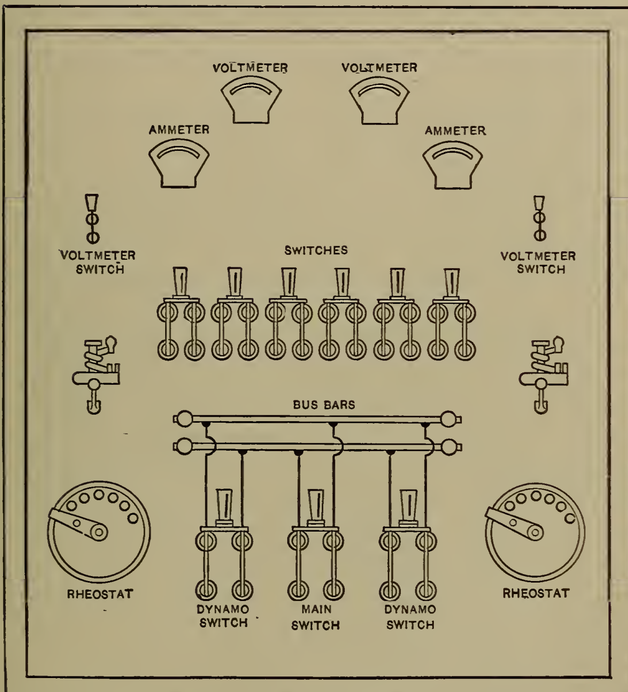

FIG. 64.—Front View of Switchboard with Two Shunt Dynamos in Multiple, Showing Mains to Various Floors.

tribute itself unevenly, and may affect their speeds if the difference in balance is too great. In this case an overload would result, on either one or the other dynamo, and the circuit breaker will act, cutting open that circuit, as the case may be.

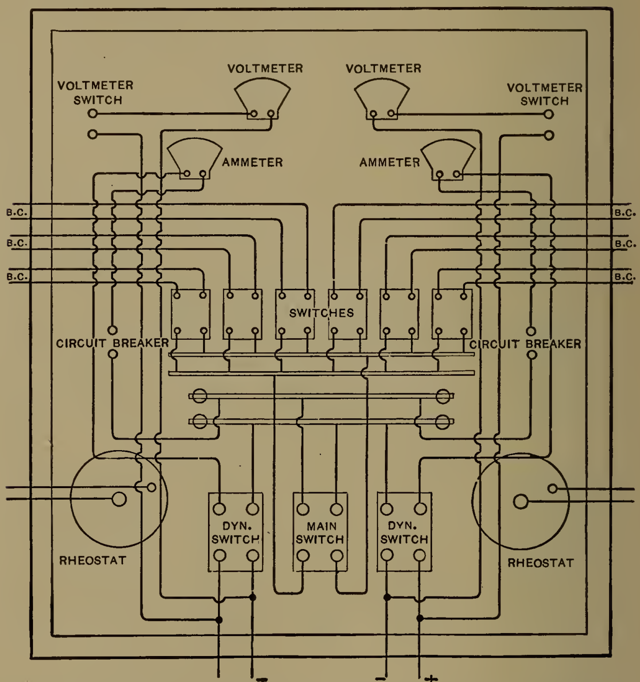

Fig. 65.—Back View of Switchboard with Two Shunt Dynamos in Multiple, Showing Wiring Connections to Mains from Bus Bars.

The only satisfactory way in which two generators can be run automatically with safety under all reasonable changes of load, and still preserve the pressure at its proper value, is by installing two compound wound dynamos, and attaching them in multiple to the switchboard as shown. Both shunt and compound wound dynamos are included under the technical appellation "constant potential machines," but they differ from each other, as has been previously pointed out, in their field windings. One has merely the ordinary shunt winding, the other has also a shunt winding, but a series winding in addition. In fact a compound wound dynamo, as far as its windings are concerned, consists of a series wound and shunt wound generator with their windings, as it were, superposed upon each other.

The Equalizer.—The automatic regulation is accomplished by the series coil, and it is therefore necessary when two machines of this type are connected in multiple to secure the correct action of each by means of what is commonly termed an "equalizer bar" (Fig. 66). This bar simply connects one brush of each dynamo to the corresponding brush on every other dynamo connected to the series coils. In the case represented only two dynamos are in multiple, and it will be seen that the equalizer bar in this case was from the upper brush of one dynamo to the upper brush of the other; but it will be noted that this upper brush also feeds into the series coil of each dynamo respectively. If this idea is carefully followed out the diagram will also show that the upper brush of each generator can send its current either into the series coil or into the equalizer bar. If the potential at each of these brushes is alike, the equalizer bar carries no current; but if the pressure generated by one dynamo is a little higher than

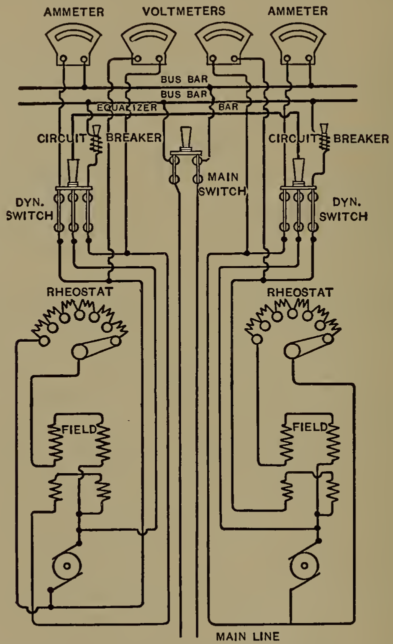

Fig. 66.—Diagrammatic Connections of Two Compound Wound Dynamos in Multiple, with Equalizer Bar Connected.

the other, due to the fact that the speed of either one has diminished, or the load on one is greater than that on the other, then, current from this brush of higher potential, will flow through the equalizer bar into the series coil of the other dynamo. The effect of this is to strengthen its magnetic field, thereby increasing its electromotive force and in this manner augmenting the pressure until both machines in this respect are in equilibrium. But it is also evident that when one machine builds up the series coil of another in this manner, it is at the expense of its own, therefore as the pressure of one machine rises, the pressure of the other machine falls until both are *equalized*. The equalizer circuit should be closed before the other circuits, and to accomplish this it is often the practice to either have a separate switch in this circuit, or to provide a longer blade to the middle of the switch shown, so as to close this first as described. The two main wires running across in the last sketch, are bus bars of heavy copper, and feed the main line, or supply current, to a variety of switches connecting with the various floors or circuits of the building. The equalizer should be of very low resistance, otherwise the drop through it may rise too high, if for any reason it ever carries a considerable volume of current. By having it of ample cross section, the regulation may be carried to a fine point. In large plants, where several thousands of amperes may be generated, a sudden variation in load will be the cause of a heavy current flowing, which might develop a heavy drop in the "bar," if the resistance is not low. For instance, a resistance of .001 of an ohm, with a current of 100, 1,000 and 2,000 amperes respectively, means a drop of $\frac{1}{10}$, 1 and 2 volts. This is very much accentuated, if the resistance of the bar is more, which, in some instances, it is very likely to be.

Series Fields.—The adjustment of the series coil is also a matter of the greatest practical importance. The amount of current it carries may be too great or too small. If this is the case, it is now the practice to regulate with a shunt placed in multiple with the series winding, to vary the current within certain limits.

This variation of the current is necessary because in some instances the ampere turns of the series coil are too great. It is not practical to cut down the turns after a dynamo is completed, but it is very easy to shunt part of the current and thereby reduce the magnetic effectiveness of the series coils. The adjustment of the pressure of a compound wound dynamo is thus made possible within very fine limits by this means. When it is desirable to over-compound a generator, the regulating of the resistance of this shunt is a rapid and practical process. In tests where the regulation of a dynamo is limited by specifications to a few volts, from no load to a full load of 500 amperes, such adjustment as this is appreciated in a commercial as well as a scientific sense.

Over Compounding.—A dynamo is said to be over compounded if the series coils more than compensate for the various losses in the way of drop in the armature and armature reaction. A dynamo is over compounded, so that it will generate enough extra pressure to equal the drop experienced in the conducting wires. The theory of the compound wound dynamo fully covers this ground, yet it may be condensed into a convenient form under the following headings:

PURPOSE OF THE SERIES WINDING.

First—To compensate for armature reaction which cuts down the useful lines of force.

Second—To compensate for the drop caused by the armature current flowing through the armature winding.

Third—When over compounding, to compensate for the volts drop in the main lines and feeders.

Fourth—To provide automatic regulation for all loads.

The over compounding may be from 5 to 10 per cent. of the normal pressure, but this is largely governed by the percentage of drop in the wiring system. The method of compounding in general is of importance with respect to the wiring proposition, for the reason that regulation at different points of load if ineffective will mean poor lighting. Where the entire plant must be installed, as well as the wiring, the selection of the dynamo, whether shunt or compound wound, cannot be intelligently made unless a full knowledge of the requirements of such a machine are in possession of the purchaser. It is advisable to select an over compounded machine and modify the degree of the over compounding by manipulating the german silver shunt attached in multiple with the series coil. If the resistance of this german silver shunt is increased, the over compounding will increase, that is to say, more current will flow through the series coils. But if the resistance of this auxiliary shunt is diminished, then less current flows through the series coils and the additional voltage they are the means of generating is cut down. Under ordinary conditions a compound wound dynamo simply preserves externally a uniform pressure, but if the drop outside will not allow of this condition prevailing then over compounding is resorted to and the building up of pressure takes place externally, hand in hand with the increase of the load.

Street Railway Plants.—Compound wound generators are used exclusively in street railway power houses. In stations of this character a sudden change in load of from 100 to several thousand amperes is not an unusual occurrence, and for that reason the utter futility of installing any other class of direct current generators has been repeatedly exemplified in the early history of street railway practice. The compound wound dynamo is the only practical solution of the lighting problem for private plants and street railway service, and its automatic regulation in well-designed machines leaves but little to be desired. In street railway service the large switchboards are well equipped with automatic circuit breakers to avoid burn-outs.

The compound wound dynamo particularly requires the installation of these devices, because when short-circuited all the effects of an abnormal load are in evidence and *the pressure is preserved.*

Serious damage would result if this, at times of terrific strain, were not relieved by means of the circuit breakers. It is not alone the dynamo which is concerned in such a case but the engine as well, parts of which are apt to give or at least be permanently affected by an abnormal load.

CHAPTER X

GENERATORS FOR ALTERNATING AND DIRECT CURRENT LIGHTING.—CHARACTER OF LIGHTING DONE.—THE SWITCHBOARD FOR TWO COMPOUND WOUND GENERATORS.—CONNECTIONS TO INSTRUMENTS.—SWITCHBOARD FOR CONTROL OF SIX FLOORS AND TWO ELEVATORS.—CONNECTING TWO SHUNT DYNAMOS ACCORDING TO THE THREE WIRE SYSTEM AT THE SWITCHBOARD.—SWITCHBOARDS FOR ELECTROLYTIC WORK.

Switchboards.—The immense number and variety of the switchboards employed for electric light and power purposes for both alternating and direct current, require some classification with regard to the character of the lighting as well as the type of generator employed. The following headings may prove convenient in this respect:

SWITCHBOARD DESIGN.

Character of generators.	*Character of lighting.*
1. One shunt wound dynamo.	Low tension arc and incandescent.
2. Two or more shunt wound dynamos.	Low tension arc and incandescent.
3. One compound wound dynamo.	Low tension arc and incandescent.
4. Two or more compound wound dynamos.	Low tension arc and incandescent.

Character of generators.	*Character of lighting.*
5. Two or more shunt wound dynamos connected for the three-wire system.	Low tension arc and incandescent.
6. Two or more shunt wound dynamos connected for a combination two and three-wire system.	Low tension arc and incandescent.
7. One or more series dynamos each with separate circuit.	High tension arc lighting.
8. One alternator single phase.	Low tension arc and incandescent.
9. Two or more alternators single phase.	Low tension arc and incandescent.
10. One or more alternators two or three phase.	Low tension arc and incandescent.

The last class of generators are employed for power transmission at exceedingly high pressures and in this respect they are better known than as generators for electric lighting.

To lay out the design of a switchboard, it is absolutely necessary to become familiar with all the requirements of practice and the apparatus employed for that purpose. The low tension, direct current apparatus differs essentially from the high tension, direct and alternating current. The higher departments of switchboard design call for an intimate knowledge of the subject, and the proper protection and control of circuits and the care of the generator, whether direct or alternating, is largely dependent upon the amount of skill shown in the construction of the switchboard. A variety of technical works are at the command of the reader and systematic visits to large power stations will soon develop a familiarity with the subject which will show the relationship existing between station management and switchboard design.

A satisfactory method is to lay out the plan of the switchboard so that the marble or slate can be drilled to receive the instruments and switches.

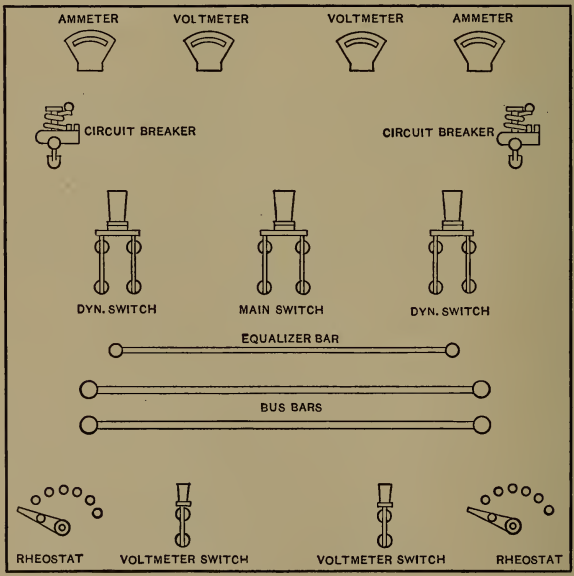

FIG. 67.—Front View of Switchboard of Two Compound Wound Dynamos in Multiple.

These must then be carefully mounted and connected up according to the sketches of the back view. Errors can be readily corrected on the drawing board and the sketches must be carefully ex-

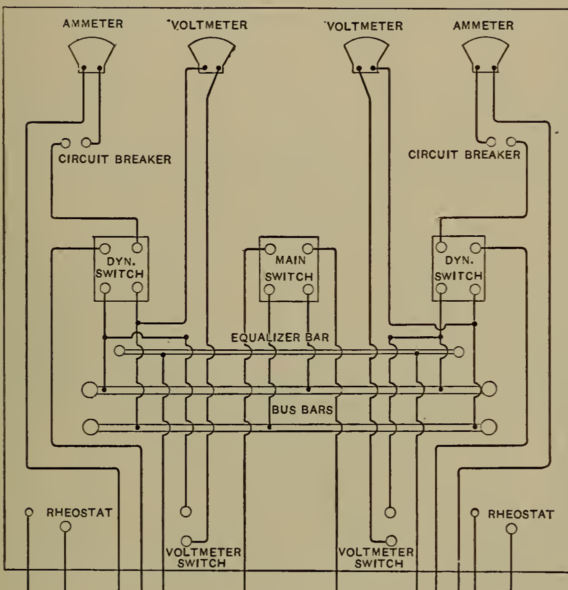

FIG. 68.—Back View, Showing Wiring Connections of Two Compound Wound Dynamos.

amined to detect errors before the board is drilled. In the series of sketches (Figs. 67 and 68) supplied many items shown are more or less arbitrary.

For instance, having the switches in the upper or lower part of the switchboard, using single-pole or double-pole circuit breakers, controlling all main circuits from the switchboards or where they are used, etc. (see Figs. 69, 70, 71 and 72).

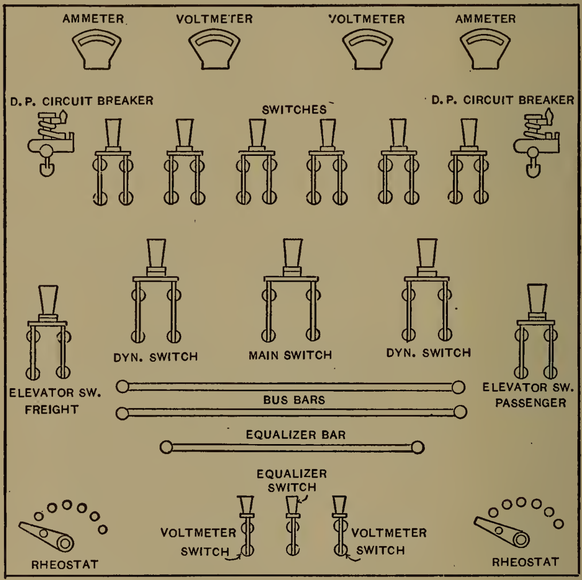

FIG. 69.—Switchboard of Two Compound Wound Dynamos in Multiple. Switches of 6 Floors and 2 Elevators.

It will be found that the architects' or consulting engineers' specifications will govern all this. If advice is needed, a practical switchboard manufacturer is the best man to consult.

Panel Switchboards.—Not only instruments and switches, but finished panels can be obtained complete from the manufacturer. These panels are in themselves small switchboards although sold under the names of generator panels, rheostat panels,

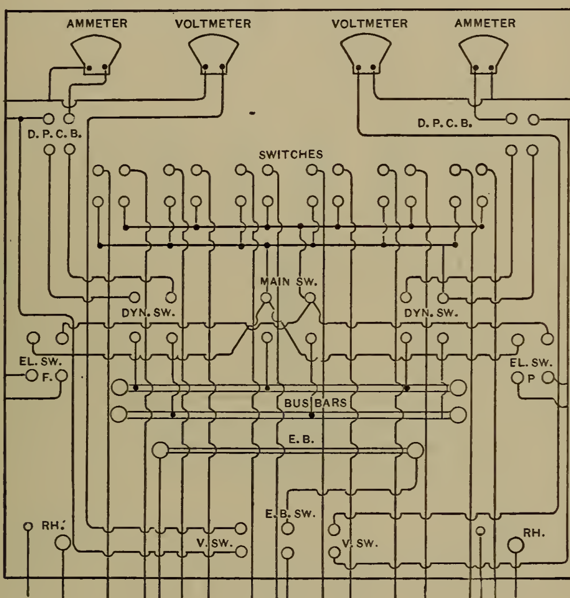

FIG. 70.—Back View of Switchboard, Showing Connections to Equalizer Bar, Switches and Meters.

load panels, feeder panels, fuse panels and blank panels. These panels are about 5 feet by 2 feet, although the feeder and fuse panels are about one-half the length of the others.

The generator panels are made for either a single generator or designed so that further additions will allow of more than one generator to be run in multiple. The generator panel consists of

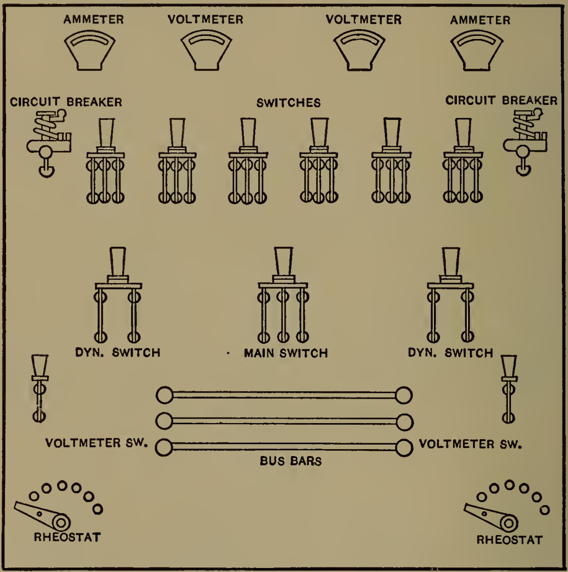

FIG. 71.—Two Shunt Dynamos Connected According to the Three-wire System.

measuring instruments, ground detector, circuit breaker, switch and generally a lamp and shade. They are made of a capacity of from 200 to 3,000 amperes. A rheostat panel is used for the purpose of mounting the rheostat on its back, the contacts and arm appearing in the front. The load panel carries voltmeter and ammeter; the voltmeter of the illuminated dial dead beat differential type; the ammeter also with illuminated dial. The volt-

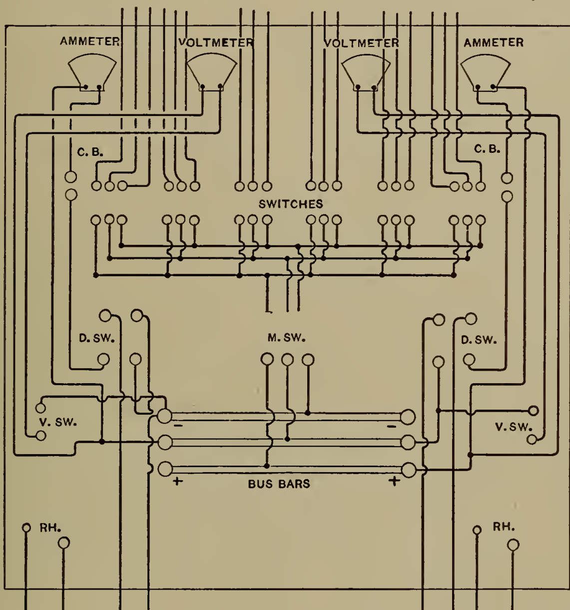

FIG. 72.—Back View of Connections of Two Shunt Dynamos Operating on the Three-wire System.

meter is mounted on a swinging bracket and is used: first, for measuring the potential of the bus bars; second, for measuring the difference between the potential of the bus bars and that of the dynamo about to be connected. When this last is being accomplished the voltmeter is swung out at right angles to the switchboard and the dynamo tender adjusts the rheostat until the voltmeter reads zero. When the differential voltmeter reads zero the generator switch is thrown in. Load panels are built of a capacity reaching from a few hundred to 15,000 amperes. The feeder panels carry ammeters, circuit breakers and switches. The circuit breakers may be single or double-pole, the ammeters one or many according to the capacity of the panel, which is naturally governed by the carrying capacity of the switches. Only switches may be mounted in special cases on the feeder panels where many circuits must be accommodated in a limited space. The fuse panels are supplied with fuse holders and should carry protected fuses of the most modern non-arcing type. Their capacity ranges from 240 to 1,800 amperes and over, the fuses 60 to 450 amperes apiece. Where blank panels are supplied, either empty sections are to be filled out or a special purpose is held in view.

The so-called direct current lighting and power switchboards, described fully in the bulletin sheets of the leading electrical manufacturers, are generally limited to a pressure of 750 volts. The switchboard is built up by assembling the various panels and connecting together by means of flat bars of aluminum, copper or standard sized wires. The bus bars are supplied specially and provision is made in the panels for their attachment. The cheapness and convenience of this style of sectional switchboard has recommended it strongly to the attention of contractors and prospective proprietors of private plants.

Switchboards for Electrolytic Work. — Generators developing heavy currents for electrolytic work were left out of the list on account of the infrequency with which the design of a switchboard for that purpose arises. In a switchboard installed for this class of work switches were designed to carry 6,000 amperes apiece. In this case the switches can be single-poled because of the low pressure. Wherever connections are made the greatest care is necessary to secure a low resistance joint. Heavy copper bars are employed to conduct the current from point to point. The back of the switchboard when finished was provided with triple copper bars, each bar slightly separated from its neighbor to give radiation whenever the current was conducted from point to point. Great copper refining and plating plants are equipped with switchboards of this character.

CHAPTER XI

PANEL SWITCHBOARDS.—STREET RAILWAY SWITCHBOARDS.—CONNECTIONS OF COMPOUND WOUND GENERATORS IN A POWER HOUSE TO SWITCHBOARD AND INSTRUMENTS.—LIGHTNING ARRESTERS.—THE PANELS AND THEIR FUNCTIONS. — STATION FIRES THROUGH LIGHTNING. — THE GENERATING, FEEDING AND METERING SECTIONS.

Panel Switchboards.—The panels composing the essential parts of a switchboard, such as the generator panel, load panel and feeder panel, call for the further classification of switchboards with reference to these facts.

In street railway service particularly the two great divisions of apparatus and parts of the switchboard are the generating section and the feeding section. Dividing the switchboard up into panels is convenient in a practical sense and very instructive from a technical standpoint. All the apparatus relating to the generator, covering the instruments previously named, are placed on one panel, as shown in the sketch (Fig. 73). When large switchboards are erected, the generator panels are placed on the right hand side, the feeder panels on the left.

It is customary to place the load panels between the two. The illustrations readily convey this idea, showing generator, feeder and load panels with the equipment supplied by the largest manufacturers of electric light and power apparatus in

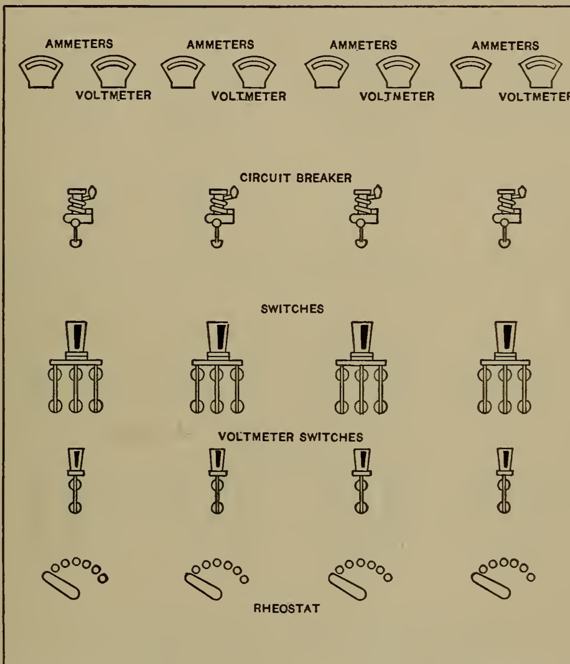

Fig. 73.—Front View of Generator Switchboard.

the United States. The generator panels may be supplied with either one double-pole or two single-pole switches for the following reasons: If a double-pole switch is employed a current capacity of not more than 600 amperes is allowable with this special design. When two single-pole switches are supplied the panel is constructed to have a current capacity of from 800 to 2,000 amperes.

The ammeters on these panels are all made of a greater capacity than the panel as a whole. The possibility of a continued overload calls for the employment of ammeters reading as high as 50 per cent. above the rated capacity of the panel.

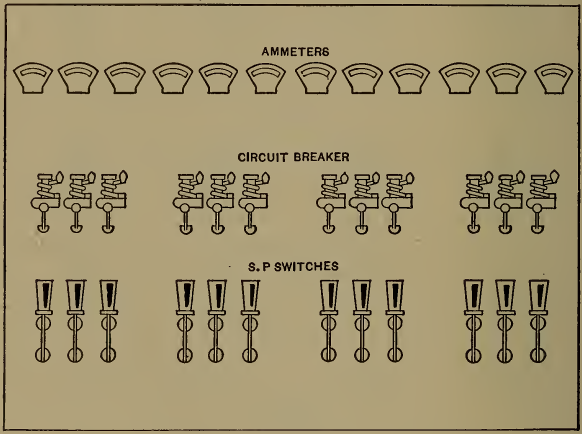

Fig. 74.—Front View of Feeder Switchboard.

Where the generator panel has a double-pole switch mounted on it a double-pole circuit breaker is also employed. The load panel carries an ammeter and a voltmeter. This voltmeter is used to give the bus bar reading ordinarily or it is indispensable where another generator is to be put in multiple.

In this case it acts differentially, giving the *difference* between the pressure of the generator and the bus bars, as previously described. A recording wattmeter giving the total external consumption

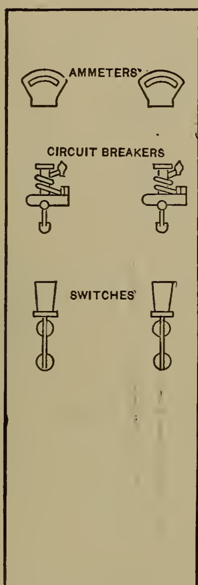

FIG. 75.—Feeder Panel (Front).

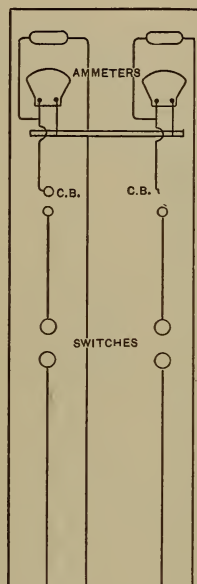

FIG. 76.—Feeder Panel (Back).

of amperes or watt hours is also connected below in many cases. The feeder panel (Fig. 74), with its single-pole switches and ammeters, circuit breakers and lightning arresters (frequently mounted on the back), represents the distributing department of a large switchboard. In street railway service this system of designing and connecting switchboards has proved a matter of incalculable value. The front and back view of a feeder panel is shown

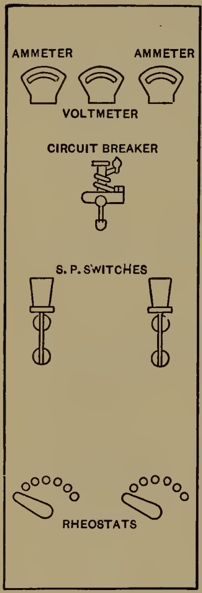

FIG. 77.—Generator Panel (Two Circuit).

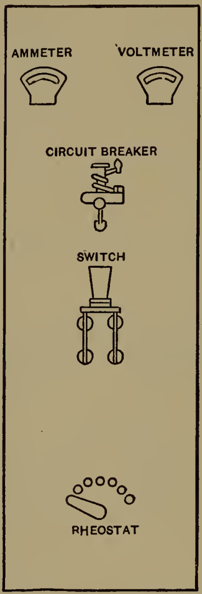

FIG. 78.—Generator Panel (One Circuit).

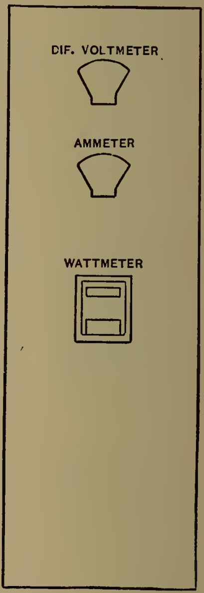

FIG. 79.—Load Panel.

(Figs. 75 and 76), with the lightning arresters in place. The appearance of a panel switchboard (Fig. 80) consisting of two generator panels (Figs. 77 and 78), one load panel (Fig. 79) and three feeder panels is shown, carrying out the idea of

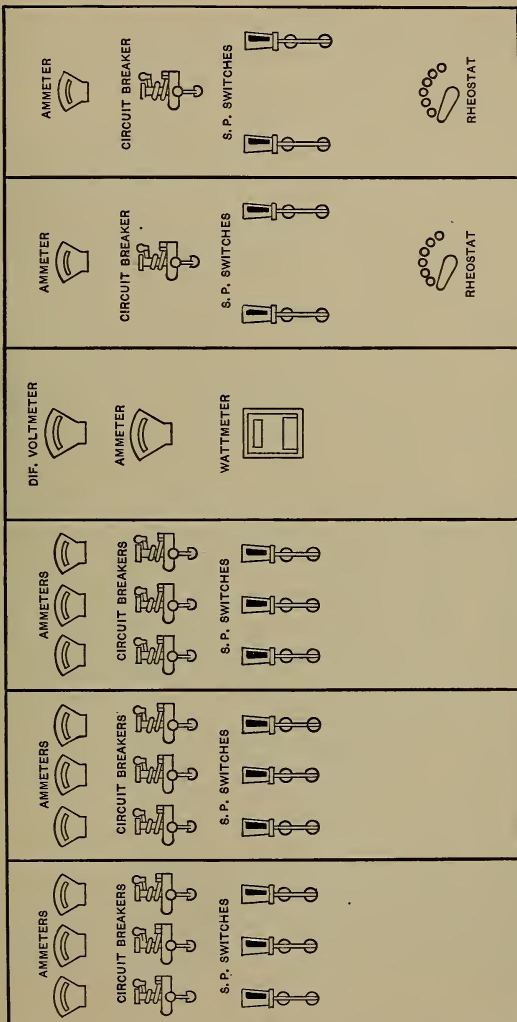

FIG. 80.—Panel Switchboard, Showing Relative Position of Generator, Load and Feeder Panels.

placing the generator panels to the right, the feeder panels to the left, and the load panel (Fig. 80) between.

Street Railway Switchboard.—The ideas carried out by the preceding series of principles relating to switchboards are embodied in the illustration (Fig. 81) showing the connections of three compound wound generators operating in multiple to feed a street railway system. The front view of the switchboard really represents two switchboards, which might be called the primary or generator board in compliance with the last proposition relating to this classification; the other, the secondary switchboard, would necessarily be called the distributing or feeder board. In many stations the upper one is mounted on a platform above the first with a passage way for the attendant.

A new feature to the reader is the upper line of lightning arresters protecting the outgoing feeders. The entire wiring plan of this switchboard is laid out from the generators to the generator board and then to the distributing section. It is a well-known fact that in street railway service the trolley line is reinforced during its entire length at regular intervals by connection with a system of feeders. By this means the pressure is kept at its normal value along the route and the speed of the cars preserved. Both track and trolley line are dependent upon this feeding system, which does not materially differ from that employed for incandescent lighting. The apparent complexity of the switchboard is entirely due to the multiplicity of circuits. The key to the situation is a careful study of the fundamental principles underlying the theory

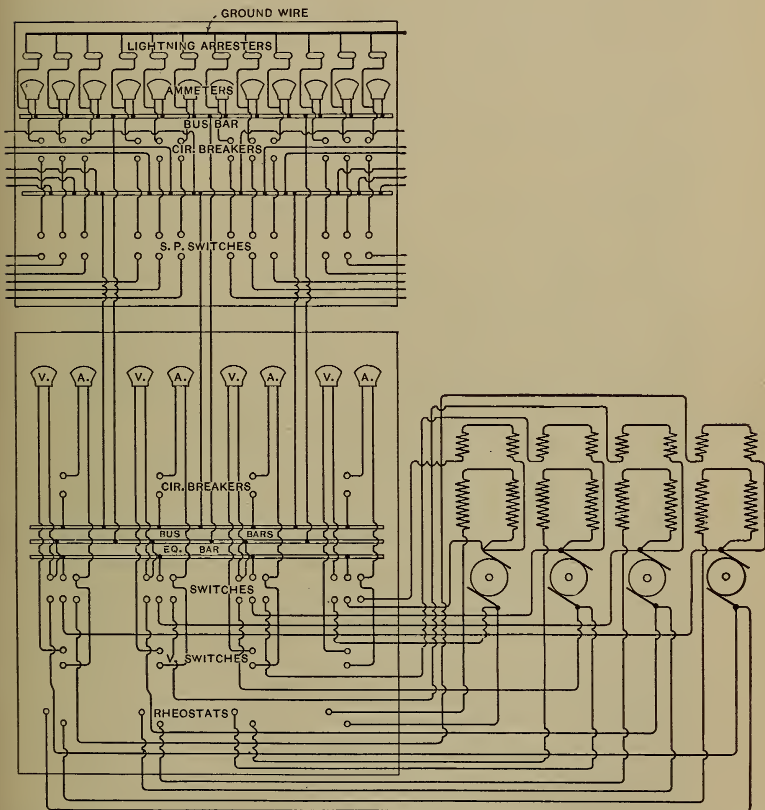

FIG. 81.—Back View of Generator and Feeder Switchboard, Showing Dynamos in Multiple.

and construction of switchboards. In street railway service particularly the conditions of "drop" and "leakage" require constant study and attention. The switchboard, as far as the generators' and feeders' sections are concerned, is no more than a means of sending out a uniform potential all over the system. In this respect a street railway system is resolved down to a wiring proposition, with many feeders and necessarily many centers of distribution.

General Principles of Switchboard Construction. —The design of a switchboard, to be conducted intelligently, must cover the ground indicated not only by these and other sketches, but, in particular, the general idea that all designs must represent. These facts, as relating to that idea, are crystallized in the synopsis conveniently arranged for future reference found at the end of this chapter.

Whether a switchboard be designed for direct or alternating current it would be wise to consult some such plan as the above before proceeding to lay out the apparatus and circuits. For switchboards for incandescent lighting and street railway service a departure could not be made from the system indicated.

Lightning Arresters. — Lightning arresters are employed for the protection of alternating as well as direct current circuits. The injury electric light and power circuits are exposed to under certain conditions are, first, short circuits; second, grounds.

By means of the lightning arrester protection against either of these breakdowns through lightning discharges is afforded. The lightning arrester (Fig. 82) offers protection against a sudden rise

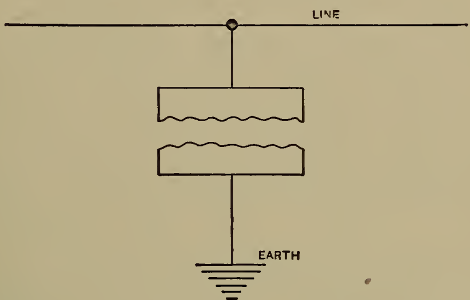

FIG. 82.—Principle of the Lightning Arrester.

of potential in the lines by the use of, first, an air gap; second, a dead ground.

In well constructed lightning arresters the air gap can be so adjusted that a rise of voltage beyond a certain anticipated value will bring about a discharge. The danger arising in lightning arresters is due to the possibility of arcing. This will, in many instances, take place after an enormous burst of potential, which, leaping the gap leading to the earth, provides a gaseous path for the current of the generator unless the insulation is perfect. When lightning strikes a station unprovided with adequate protection it may leap between wires of opposite polarity, which wires, if near enough, will develop an arc. In several notable instances it was believed that lightning supplied the flame and the fire to destroy the station. A little consideration of the direct possibility of a high pressure discharge causing an arc will readily account for the destruction of property which ensues. In such cases the station supplies the power with which to burn itself down. The line is therefore provided with a pressure vent whenever danger may arise through exposure to discharges of this character. This is merely an air gap leading to the earth. Where a lightning discharge possesses a very high frequency it is well known theoretically and practically that the apparent resistance of a copper wire becomes so great that an air gap is preferable. On some such lines as this lightning arresters are designed for the protection of light and power circuits.

TABLE

Principle of Switchboard Construction for Shunt and Compound Wound Dynamos.

Generating section.	Metering section.	Feeding section.
Switches. Circuit breakers. Bus bars. Ammeters. Voltmeters. Rheostat.	Differential voltmeter. Ammeters. Wattmeter.	Switches. Circuit breakers. Bus bars. Ammeters. Lightning arresters.

CHAPTER XII

TESTING. — THE GROUND DETECTOR. — TESTING WITH A VOLTMETER.—USE OF THE MAGNETO FOR TESTING INSULATION.—LOCATING GROUNDED CIRCUITS.—DAMP BASEMENTS.—USE OF INSULATORS.—WEATHERPROOF WIRE.—CABLES.—ROTARY CONVERTERS.—THE APPLICATIONS OF ROTARY CONVERTERS.—EFFICIENCY OF CONVERTERS.

Testing.—Faults develop in electric light circuits and must be discovered and removed. The most flagrant sources of trouble are short circuits and grounds.

Short circuits are caused by the crossing or touching of wires. Grounds caused by wires in contact with gas pipes are what is generally called a good earth connection. Breaks in the wires are evident when the lamps will not burn. Short circuits or crossed wires cause the fuses to blow. Poor connections in the wires occurring where soldering between ends has taken place is due to the resistance of the joint. High resistance frequently is found where wires are held under screws and washers, as in cutouts, switches, sockets, etc.

Operation of the Ground Detector.—For detecting heavy grounds, ground detectors are mounted on the switchboard. The ground detector for a two-wire and three-wire system operate according to the following principle: Two lamps are connected in series across the two main wires. The connecting wire *between* the two lamps is grounded by running a wire from a gas or water pipe and soldering it to this connecting wire. Under ordi-

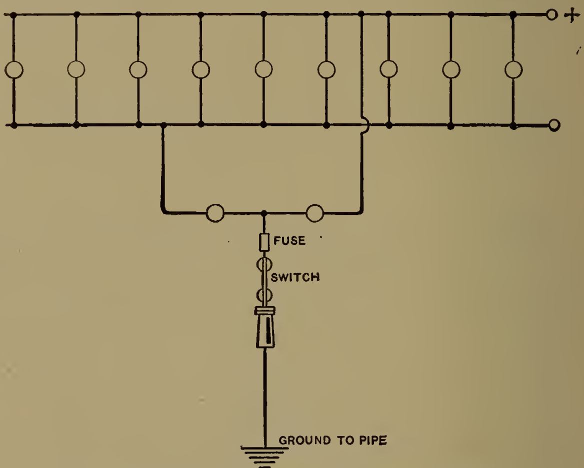

Fig. 83.—Ground Detector for Two-wire System.

nary circumstances when both wires are free from grounds the lamps burn with equal brightness. If the ground is on one leg of the circuit the lamp connected to the other leg burns more brightly, and vice versa.

A switch is connected, as well as a safety fuse, between the earth and the two lamps. This switch is left open except when a test of this character is conducted. The illustration (Fig. 83) shows the general arrangement of the ground detector for a two-wire system with lamps, switch and fuse mounted.

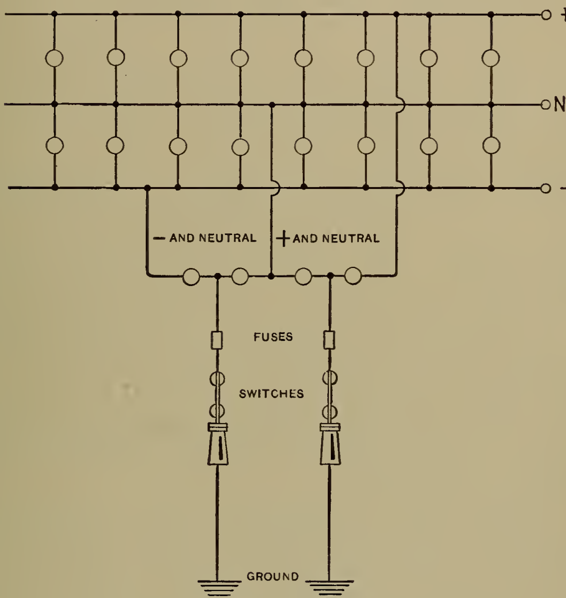

FIG. 84.—Ground Detector for Three-wire System.

In the next sketch (Fig. 84) is shown the general arrangement of the wires in a ground detector for a three-wire system.

If by any mistake both switches are closed at one time a short circuit will occur, because both of the outer legs are thrown into communication and short circuited by that means. Therefore it is necessary to be careful in testing to open and close *only one* switch at a time and after using it to leave it *open*.

The illustration shows how the fact of a ground occurring on either the neutral or negative wire will make the lamp on either the negative or neutral wire light up brighter than its neighbor. The same is true of the lamps connected to the positive and neutral wires. If a ground occurs on the positive wire the lamp connected to the neutral wire will light up brighter than its neighbor, and the reverse. The danger from grounds arises more from the risk of fire than anything else. If two wires of opposite polarity of the same circuit are grounded the leakage is in proportion to the resistance of each or both grounds.

In street railway practice the danger from grounds is found in the corrosion of pipes through electrolytic action.

Testing with a Voltmeter. — The voltmeter is employed in about the same manner as the lamps. It is connected between the earth and one leg of the circuit. If the other leg is grounded current will flow up into the voltmeter from the earth or from the other wire into the earth. Whichever wire gives a reading indicates that the other wire is grounded. The grounds may be roughly classified as high resistance grounds, low resistance grounds and dead grounds. A high resistance ground runs into thousands of ohms; a low resistance ground into hundreds of ohms and a dead ground means absolute contact between one wire and the earth through a gas or water pipe, etc. If the insulation is high the voltmeter will not read, but if medium or low the reading will be in proportion.

Using the Magneto.—The magneto is more frequently employed for line testing than any other piece of apparatus. One wire from the magneto is connected to a gas or water pipe and the other to each wire of the circuit in turn.

If the magneto rings, a ground is present on the other wire. This method of testing while generally employed is sometimes deceptive, because perfect insulation may provide certain electrostatic conditions which will cause the magneto to receive a return static discharge from the circuit which may cause it to ring. As this is more an exceptional than a common case due consideration may be made for it. Magnetos for testing are so constructed by means of the winding that they will ring through 1,000, 5,000, 10,000, 15,000, 20,000 and 35,000 ohms. They are made to ring through higher resistances than this and are marked according to their capacity in this respect. A ground which can be rung through by a magneto is therefore of the same resistance as the rating of the magneto or less. If an attempt is made to discover a ground in a heavily wound coil, such as the field coil of a dynamo by ringing a magneto through it, the experiment will be unsuccessful, for the reason that the rapid reversal of current from the magneto cannot penetrate the numerous turns of the coil.

This is due to self-induction and will make it appear by the silence of the magneto as though no ground were present.

This fact is of importance in testing any circuits connected to inductive devices for grounds.

Locating Grounded Circuits. — To locate a grounded circuit each branch must be tested systematically. This is accomplished by disconnecting each circuit from its cutout or from the panel board to which it is connected. By testing each one in turn the grounded circuit is sure to be located and then the wires may be examined to discover the cause. Abraded wires are often the cause. Defective insulation on the inside and outside of the conduit is another. Moisture, corrosion and damp walls and plaster are a frequent cause of trouble. Wires touching on the parts of chandeliers and fixtures must be regarded as among the chief causes of trouble and annoyance. The voltmeter is the most scientific and, therefore, the most accurate instrument to use for this purpose. Where the ground is heavy neither the voltmeter or magneto are required. Two lamps in series connected to the circuit in the following manner can be employed: One leg of the circuit is connected to the end wire of the two lamps and the other end to the earth through the medium of a gas or water pipe. This is repeated with the other leg of the circuit. The process is continued throughout every circuit until the fault is discovered.

The magneto proves exceptionally valuable in locating breaks in a line. This is indicated by the magneto not ringing. Where the continuity of the circuit of a series arc light system is to be tested the two ends of the circuit are connected to the magneto directly and the test made. Poor connections at fuses will cause heating, frequently sufficiently high to melt the fuse. It is therefore best to examine the fuses before exploring the rest of the circuit for breaks. It is good practice to test for grounds every day in order to avoid trouble. In large hotels and apartment houses where the chandeliers and fixtures are continually handled breaks and grounds happen often enough to necessitate this requirement.

Damp Basements.—The grounds in damp places are naturally apt to be frequent, due to obvious causes. It is not always best to install a conduit system in this case, but a knob insulator equipment with rubber-covered wires. Sockets of insulating material must also be employed and fuse blocks must be protected from exposure to dampness by boxing.

Insulators.—The knob porcelain insulators and porcelain cleats in use for electric light wiring must be designed with reference to the mechanical strain to which they will be subjected as well as the insulating properties they are supposed to possess.

The glass as well as the porcelain insulators must be designed with reference to strength and insulation. The element of strength is secured by consulting the mechanical requirements in the way of proportioning the diameter, length, diameter of the hole or orifice to receive the wooden peg or screw, etc. The insulating power is obtained through its dependence on the nature of the material, the distance from the wire to the screw or pin and the extent of the hygroscopic power of the glass or porcelain. The materials employed are

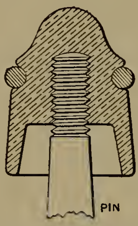

FIG. 85.—Single Petticoat Insulator.

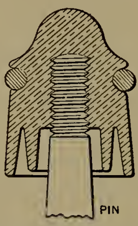

FIG. 86.—Double Petticoat Insulator.

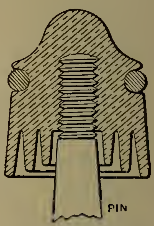

FIG. 87.—Triple Petticoat Insulator.

too well known to require repetition and their hygroscopic power is something unavoidable, but means may be taken to improve the insulating power of the material by the following scheme of construction:

The petticoat, that is to say, the part of the insulator which acts as a hood to the pin, may be doubled or tripled, as shown in the sketches (Figs. 85, 86 and 87), so as to increase the distance the current must travel from the wire to the pin, through the film of dust or moisture which is bound to collect on its surface according to the weather and age of the insulator. Very often for high potential circuits of over 5,000 volts oil insulators are used. In these, the edge of the insulator is turned up forming a channel in which oil is placed to increase the resistance in the path of an escaping current.

Weatherproof Wire.—This wire is used in places such as the name indicates, where the weather can get at it. The wire is made of a certain number of layers of braided cotton-covering soaked in a highly insulating compound. By this means insulation is obtained and protection against wet as well. In large cities where wires are mainly underground, in the form of lead-covered cables, different insulation is employed. But for electric light wires in the country, arc and alternating, and for street railway feeders, this wire is extensively employed.

Cables.—The manufacture of cables is an elaborate process and the coverings of the wires they contain are varied according to the system peculiar to that particular phase of the art. The copper conductors are frequently covered with rubber compound which insulates the wire from the lead sheathing. If the pressure they carry is high the insulation is thicker. It generally varies from about $\frac{1}{8}$ to $\frac{3}{8}$ of an inch. In the case of other cables, the conductor is wrapped around with tough paper soaked in an insulating compound which gives it flexibility as well. A third class of cables for electric light and power might be described as consisting of weatherproof wires incased in lead tubing. The woven covering of the wires in this case consists of a jute or cotton braiding saturated to excess with a black insulating compound which is supposed to resist moisture and not to deteriorate with age. It is imperative to have a lead sheathing so thick that porosity is absent, as that would invite moisture to enter and rapidly destroy the integrity of the cable.

Rotary Converters. — The development of the wiring system of a large central station is in many respects due to the introduction of a variety of new appliances whose use has led to economic changes of immense benefit to the installation as a whole. Among the appliances or devices to be thus considered the rotary converter possesses a leading interest. It has without doubt caused a change in engineering and station methods of the most far-reaching consequence. A rotary converter is a composite dynamo and motor combined in one machine. If continuous current is sent into it an alternating current can be developed of two or three phase and, conversely, if an alternating two or three-phase current is sent in a direct current will be generated. In other words it is a transforming device which receives an alternating and gives out a direct, or receives a direct and gives out an alternating current. In order to obtain this elasticity of operation a single generator frame is employed within which rotates an armature so wound that it can receive a two or three-phase current at one end or a direct current of from 110 to 550 volts at the other end. The large power stations whose object it is to transmit current for street railway power and lighting purposes can accomplish this object by the use of the rotary converter. In addition, all the generating units, as the phrase goes, can be installed under one roof and the power from this central station distributed with economy and efficiency from various points at which such power would be useful, called sub-stations. By erecting substations, whose function it is to transform and distribute the power, instead of building power stations a great element of expense is removed and a satisfactory commercial solution is given to the problem of the distribution of power.

Various Equipments.—Many plants have been installed of immense proportions, in which these machines for transforming alternating into direct and direct into alternating current were the means of bringing about investments of millions of capital. The Niagara Falls Power Company now generate and deliver 50,000 hp. to the various factories and work shops, hotels and houses in Niagara Falls and adjacent cities and towns. Over 30,000 hp. is drawn from the main power station and converted into continuous current for operating the street railway lines as well as for light and power in the cities of Buffalo and Lockport.

The leading power stations in Greater New York operate on the same general principle. In these main stations the process of developing the electrical energy is carried on, then the power as a high-tension, alternating current is sent to various substations in which it is transformed into a comparatively low pressure direct current. Among the institutions to which reference is made may be mentioned the power plants and substations of the Manhattan Elevated Railway Company, the Metropolitan Street Railway Company and the Rapid Transit Company whose equipment for the tunnels is one of the greatest as well as one of the most elaborate in the annals of engineering. These developments in electrical engineering are only possible through the recognized efficacy of the "rotaries" as they are called.

Application of Rotaries.—Under the following headings the most important applications of the rotary converter are given as cited by the bulletin of the Westinghouse Company.

I. It may be supplied with alternating current and will deliver continuous current.

II. It may be supplied with continuous current and will deliver alternating current.

III. It may be connected to alternating current mains and operate as a simple synchronous motor.

IV. It may be connected to continuous current mains and operate as a simple continuous current motor.

V. It may be driven by mechanical power as a generator and develop alternating current.

VI. It may be driven by mechanical power as a generator and deliver continuous current.

VII. It may be driven by mechanical power as a generator and deliver both alternating and continuous current at the same time.

VIII. It may be connected to continuous current mains and deliver mechanical power from a pulley on the shaft and at the same time deliver from its collector rings an alternating current.

IX. It may be connected to the alternating current mains and deliver mechanical power from a pulley on the shaft and at the same time deliver from its commutator a continuous current.

Although generally employed for the purpose of transforming the character of the current and the pressure, converters can be operated in multiple or two of them can be connected so as to supply a three-wire system.

Efficiency.—On account of the high efficiency of the rotary converter, as high as that of a dynamo or motor of equal size, the electric light and power problem has been, to a large extent, solved. The regulation and sparking are about the same as would be found in an ordinary generator of equally good design. The Edison Company of New York, whose original plant was entirely composed of 110 volt dynamos operating on the three-wire system, has had in use for many years rotaries, by means of which one station can relieve another when overloaded, or can help to distribute equally the power from one generating center to another without the necessity arising for the erection of new power houses, except through the natural causes of greatly increased demand.

CHAPTER XIII

IMPORTANT FEATURES OF ALTERNATING CURRENTS TO CONSIDER. — LOSSES IN A LINE. — INDUCTANCE EXPLAINED. — INDUCTANCE WITH ALTERNATING CURRENTS.—RESISTANCE COMPARED WITH INDUCTANCE. —EFFECT OF RESISTANCE AND INDUCTANCE ON AN ALTERNATING CURRENT.—EFFECT OF CAPACITY ON AN ALTERNATING CURRENT.

Important Features.—Alternating currents present a different class of phenomena when transmitted and transformed than that form of electrical energy termed direct. The frequency of an alternating current, or the rate at which it moves back and forth in the circuit; the nature of the alternating current wave, whether its growth is relatively rapid or slow; the resistance of the circuit and the degree to which magnetic effects can manifest themselves: all of these constitute important features (Fig. 88) in the consideration of alternating currents, requiring definition and elucidation.

Losses in a Line.—Whenever electricity is transmitted from point to point, by the establishment of a circuit, certain losses are sustained and difficulties developed which may be classified as follows:

1. Losses in the line due to the current and re-

sistance, included under the title of C^2R or heat losses; and $C \times R$ or drop.

2. Difficulties in the line, due to the rate at which the current reverses.

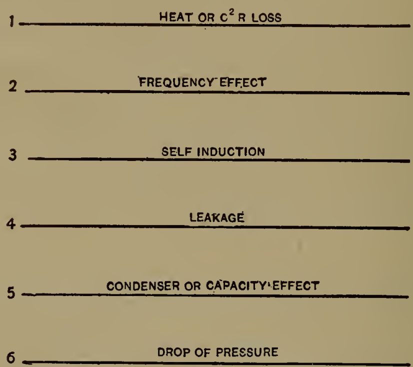

FIG. 88.—Important Features of a Circuit Carrying Alternating Current.

3. Difficulties in the line, due to the amount of magnetism or inductance developed along its length, or in certain parts of it.

4. Waste of power, due to the deficiencies in the insulation employed around the wire, or on the insulators supported on poles.

5. Difficulties due to the electrostatic effects in the line through its operation as a condenser.

It may be stated at once that capacity or condenser effects, in comparison with the effects of self-induction, produce opposite results. Thus, capacity encourages the free flow of current, while inductance retards it. Neither the capacity or electrostatic effects, or the inductive effects are wasteful as far as the dissipation of energy is concerned Resistance wastes or degrades electrical energy, but not capacity or inductance. Resistance in a circuit develops heat if the current can operate conjointly with the pressure. When the current and pressure do not operate simultaneously, it is due to the effect either of self-induction or capacity.

Inductance.—The rapid reversal of the current in any electric circuit means the rapid reversal of the lines of force with which every circuit carrying a current is surrounded. No change can occur in the value of the current in a circuit without producing a proportionate change in the lines of force surrounding it. The mere fact that lines of force embrace a circuit, or, after embracing it, either increase or diminish in number, due to the increase or reduction of the current, means the development of an electromotive force, either instantaneously and then ceasing; or, due to a series of changes in the current value, lead to continued and corresponding electromotive forces through the said changes of current. In other words, the interlinking of magnetic lines of force with a circuit, which is inevitable when the current enters or leaves, causes an effect to be produced in the circuit called self-induction. It is an electromotive force (Fig. 89) that opposes any increase of current in a circuit, even when it first enters; and it likewise opposes a discontinuation of the current when it is diminished or cut off. In the first instance, the current cannot enter at once at its full value; in the second instance, it cannot leave at once, but tends to continue flowing for a short period of time.

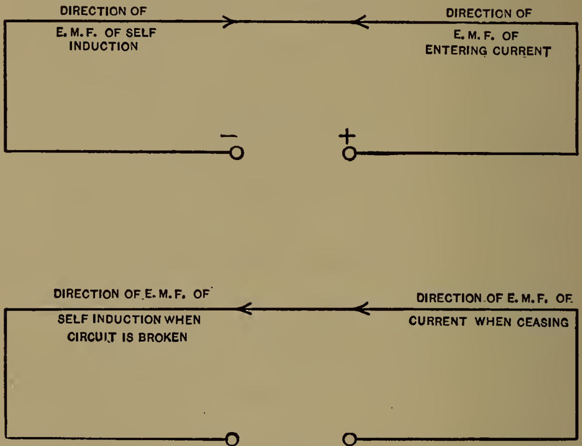

FIG. 89.—Opposing and Similar E M F of Self-induction Where Current is Made and Broken.

An Alternating Current and Inductance.—These few words about inductance have a very important bearing upon a circuit carrying an alternating current. An alternating current not only alternates, that is, reverses in direction a certain number of times a second, but it consists of a number of waves following fast after each other, each wave moving in an opposite direction to that preceding or succeeding it. At any given instant only one wave is impressed upon the line, creating a positive and negative polarity. But an instant after, another wave, whose poles are opposite to the first, permeates the circuit. Thus it is evident that each wave represents a growing value of the current (Fig. 90) until it reaches its highest point; and then

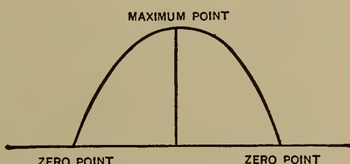

FIG. 90.—Curve Showing the Rise from and Fall to Zero in a Single Wave of E M F.

a diminishing value, until it ceases to be. This zero point is the point at which a wave begins to grow reversely (Fig. 91) either in one direction or the

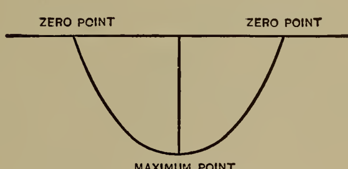

FIG. 91.—Curve Showing the Rise from and Fall to Zero in a Single Wave of E M F in the Opposite Direction.

other. And it is during these changes, in the rise and fall (Fig. 92) of the electrical energy in the line, that inductance plays its part. It operates in the circuit in such a manner that the tendency of the current to grow in value, as rapidly as it is produced in the generator, is temporarily checked. The electromotive force, as it were, is already oper-

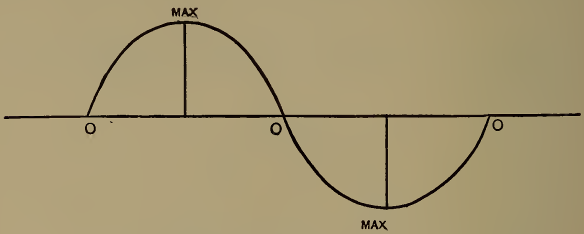

FIG. 92.—Curve Showing a Complete Cycle of EMF.

ating upon the circuit, or, as the phrase goes, is impressed upon the circuit for a definite though short period of time before the current flows in response to its influence, and in proportion to the resistance of the said circuit. Even when it does flow, its

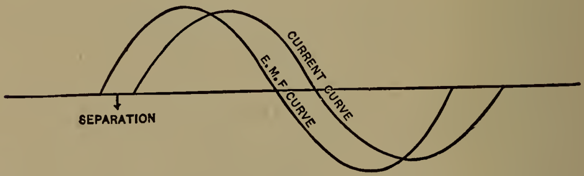

FIG. 93.—Effect of Induction in Separating the Current and EMF.

value, due to this condition of affairs, is necessarily checked (Fig. 93) the more—the more rapidly the waves act upon and leave the line. In other words, the faster the waves move back and forth, the greater the effects of inductance.

Inductance as Compared with Resistance.—The ohmic resistance of a line is distinguished from that resistance due to inductance by naming one *resistance* and the other *reactance*. It is perfectly evident that a conducting line made of copper can become deficient in conducting properties if it is exposed to the influence of so rapid a series of alternations that the reactance actually prevents more than a small percentage of the energy to pass. The resistance, therefore, is only one of the elements in a line, limiting the free flow of electricity. The additional effects of the rapid reversals of current and the inductance or capacity must be considered in conjunction with the resistance. In a line embraced by a given number of lines of force, the false resistance will naturally increase the more rapidly the current in each individual wave increases or diminishes. But the current in each wave or half alternation can only vary in value quickly if the wave itself is passing back and forth quickly. From this standpoint the greater the number of waves per second in any circuit the more rapidly the current rises to its maximum from zero, and the more rapidly it falls back to that point. Thus the frequency with which an alternating current passes back and forth is one of the fundamental reasons why the combined effects of resistance, inductance capacity, and this said frequency, produce more reactive effects. The more slowly the waves travel back and forth, the less is this influence a paramount one. The name given to this combination of influences is impedance. It is a value which takes the place of ohmic resistance alone in calculations of current in circuits traversed by alternating waves of electrical energy.

Effect of Resistance on an Alternating Current.—It may be distinctly stated that ohmic resistance has the same effect upon an alternating current as that experienced by a direct current. It reduces it in each case, as pointed out by Ohm's Law. Although other secondary effects take place, they are distinct from those arising due to the length of the copper wire, its cross section in circular mils and its temperature.

Effect of Inductance on an Alternating Current.—Another fact to be known is that inductance has the effect of retarding the flow of current entering a line. Its action is such that the electromotive force tending to send a current through the circuit is effectively opposed. This develops a condition similar to that existing through a higher ohmic resistance in the line. For this reason it is termed the reactance of inductance or induction reactance, and can be expressed in its equivalent in ohms. Inductance does not dissipate energy as ohmic resistance, but it affects the impressed EMF. It is a secondary pressure, due entirely to changes taking place in the current. It acts to reduce the effectiveness of a current wave as far as the EMF. of said wave is concerned. It will act in this manner when the current is rising from zero to its maximum value. As each complete alternation consists of two waves it is evident that, although one sweeps through the circuit in an opposite direction to the other, there is a zero point to each from which the current rises to its greatest strength. During this growth of the current, inductance is operating against the impressed EMF. The lines of force of the current have created it as an evidence of a change of current strength. This change is most emphasized when the current passes the zero mark. At this point it is not only diminishing until it disappears, but it reverses and grows in an opposite direction. The impressed EMF., therefore, cannot deliver a current proportional to itself at once. An interval elapses before the current wave it is to pass through the circuit follows after it. This is called the lag of the current. It naturally becomes more emphasized as the inductance becomes more manifest.

Effect of Capacity on an Alternating Current.—In a circuit with capacity the current leads. The EMF. in this case follows after the current. In the case of inductance the current follows after the pressure. Instead of a weak and increasing current, as with inductance, there is a strong and diminishing current with capacity. The lag of the current behind the EMF. in the case of inductance in the circuit, is replaced by a lag of the EMF. after the current, in the case of capacity in the circuit. In this case the current has "lead" instead of lag. Both inductance and capacity affect the value of the current, and the difference of phase between the EMF. and current. Inductance affects the circuit, with an entering current, as though a greater resistance were present; capacity affects a circuit with an entering current as though a lesser resistance were present. Capacity therefore produces the effect of less resistance, but not less than the ohmic resistance itself. The value of capacity in connection with inductance, is its effect in reducing the inductance. In other words, inductance and capacity are the antithesis of each other in circuits traversed by alternating currents. When present in a certain relationship one destroys the effects of the other.

CHAPTER XIV

CALCULATION OF REACTANCE.—VALUE OF INDUCTION REACTANCE.—VALUE OF CAPACITY REACTANCE.—CALCULATION OF IMPEDANCE IN A CIRCUIT.—THE UNIT OF SELF INDUCTION.—THE POWER FACTOR.

Calculation of Reactance.—The calculation of the two reactances, due to self induction and capacity in the circuit, is given in terms of the frequency and henries of inductance for the induction reactance; and in terms of the frequency and capacity in farads for the capacity reactance. Both may be given numerical values which can be used in obtaining results for circuits through which an alternating current passes, conforming in the character of its waves to those falling within the scope of the formulas.

Value of Induction Reactance. — Although the frequency of an alternating current may be given in reversals or waves per second, the calculation of the induction reactance calls for the multiplication of this value by a quantity equal to 2π or 2×3.1416 equal to 6.2832. The result of this will be as follows:

Where f = frequency or complete alternations per second,
$\pi = 3.1416$,
L = inductance in henries of circuit,

then the reactance due to the self induction and frequency will be $2 \times \pi \times f \times L = 6.2832 \times f \times L$.

Example.—If the inductive reactance is to be calculated for a circuit, having a self induction of 5 henries, through which an alternating current passes of a frequency of 125 per second, then the reactance $= 6.2832 \times 125 \times 5 = 3927$.

This value represents the equivalent of an equal number of ohms with an increasing current in the circuit, but it will not dissipate nor degrade energy during its development in the said circuit.

Value of Capacity Reactance.—Reactance caused by capacity is calculated in terms of the frequency and farads. The value of the reactance is given by the formula:

$$\text{Capacity reactance} = 1 \div 2 \times \pi \times f \times K$$

$$\begin{aligned} \text{where } \pi &= 3.1416 \\ f &= \text{frequency of alternations} \\ K &= \text{capacity in farads.} \end{aligned}$$

this gives a value of $\dfrac{1}{6.2832 \times f \times K}$ to the reactance.

If a circuit has a capacity of $\frac{1}{100}$ of a farad and the frequency is equal to 125 cycles a second, then the reactance will be:

$$\frac{1}{6.2832 \times 125 \times \frac{1}{100}} = 1 \div 7.854 = .127.$$

In the application of this formula it is evident that the lower the value of the capacity the greater the reactance. For instance, if $K = \frac{1}{1000}$ instead of $\frac{1}{100}$, then the reactance becomes greater, or 1.27. In other words, the greater the capacity of the condenser, or the greater the electrostatic capacity of the line, the less the reactance. But the less the capacity, the greater the reactance. In fact, with a very small capacity, the reactance would be practically as great as though only inductance was present. If the capacity in a circuit = 10 microfarads, or $\frac{10}{1000000}$ of a farad, and the frequency is 120 per second, then on the same terms the reactance would be equal to $1 \div 6.2832 \times 120 \times .000010$, which is equal to $1 \div .00754 = 132.6$. In calculations of capacity reactance, the capacity must not be used in the formula as anything else than a fractional or decimal part of a farad. Microfarads cannot be used as units but only as so many millionths of a farad.

Calculation of Impedance in a Circuit.—The conditions developed in a circuit carrying an alternating current are due to three distinct influences. These influences are combined together in producing an impedance to the free flow of current. They consist of, *first*, the well known effects of ohmic resistance; *second*, the reactance due to inductance; and *third*, the reactance due to capacity.

If the three are combined in the form of a simple formula the following is obtained:

$$\text{Impedance} = \sqrt{\text{ohms}^2 + (\text{Inductive reactance} - \text{capacity reactance})^2}.$$

The result obtained by calculation is what has been called spurious or false resistance, but it is merely the ohmic resistance and reactance acting conjointly. If, for instance, the resistance of a circuit = 10 ohms, the induction reactance = 50, and the capacity reactance = 30, then the result would be as follows:

Impedance =

$$\sqrt{10 \times 10 + (50 - 30)^2} = \sqrt{100 + 400} = \sqrt{500}$$

or 22.3.

In other words, although the circuit has only 10 ohms resistance due to the wire itself, the reactances build its apparent resistance up to 22.3. If the capacity reactance was so low as to be negligible in this case, the impedance would become $\sqrt{100 + 2500}$, or about 51. It is readily seen that if the ohmic resistance of a circuit or line is very low, then the reactance is all the resistance experienced by the current. For instance, if the resistance is only 5 ohms, then the square of 5 compared with the square of 50 becomes less important. If the line resistance is only 1 ohm, then $\sqrt{1 + 2500}$ is practically the square root of the reactance squared. In other words, *when low resistance and high inductance exist, the resistance may be neglected.*

The Unit of Self Induction, the Henry.—Definitions of various kinds are given to express the meaning of the henry or unit of self induction. Though primarily caused by the development of lines of force around a circuit, either when the current is increasing or diminishing, a specific effect must be produced to entitle the circuit to that qualification. The circuit must be so constituted that if the current increases or diminishes one ampere in a second an electromotive force of 1 volt is thereby produced. By this is meant that the number of turns of wire, or at least the length of the wire, will be embraced, interlinked, or cut by a certain number of lines of force in a second. These lines of force, developed in the course of a second by the current changing to the extent of 1 ampere, will operate upon the circuit, producing a degree of inductance called 1 henry and represented by the letter L. In a circuit carrying an alternating current, the current and pressure wave consists of a start from zero, a rise to a maximum, and a fall to zero. During the rise from zero self induction is in opposition to the impressed EMF. Also, during the fall from its maximum value to zero, the self induction tends to prevent the reduction of EMF. The case thus presents itself of *an opposition to the impressed* EMF. during the rise from zero, *twice* during each complete cycle; also the tendency of the self inductive effect to prevent the impressed EMF. reaching zero, twice during each complete cycle. Dividing a cycle up into four quarters of 90 degrees apiece, the first and third quadrants show a back pressure to the impressed EMF., the second and fourth quadrants show a forward inductive pressure with the impressed EMF. It is quite evident that this phenomenon will cause so great a gap, as it were, between the impressed EMF. and current, if much inductance is present, that in wiring circuits and power lines the degree to which this affects the total watts must be known.

The Power Factor. — The degree of electrical separation between the EMF. and current is measured by an angle. This angle represents a short period of time, also an angle with respect to the entire cycle of 360°. If it equals 90°, the circuit is not carrying a useful current. Each quadrant is 90° (see Fig. 94); each half cycle 180°; and the whole cycle 360°.

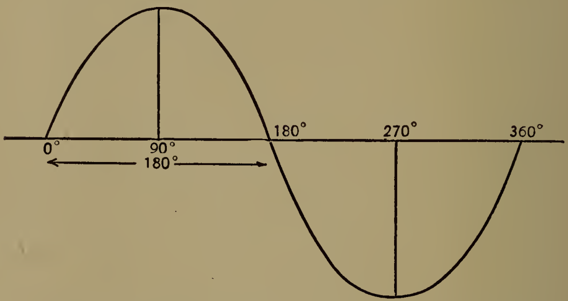

FIG. 94.—The 360° Representing a Complete Cycle.

The pressure noted in a voltmeter or the current noted in an ammeter is not the highest value of either. As the lowest is zero, it is evident that the average or mean value must be between the two. The wattmeter, therefore, records the power passing through it, not the product of the maximum value of the volts and amperes of the alternations, but the effective values. In direct current work, multiplying amperes by volts gives watts at once. In alternating current work, multiplying volts by amperes is not enough, even though their effective values may be found. The EMF. and current may not appear simultaneously in the circuit. They may differ in phase from each other by an angle called ϕ (Phi) (see Fig. 95). If the two elements

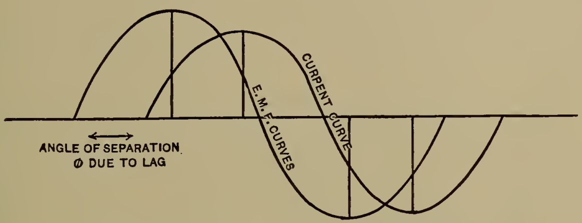

Fig. 95.—Lag of Current Behind EMF.

of power are separated from each other by quite an interval of time, then ϕ is a large angle. If the time is very short, ϕ is small. The reason why ϕ is considered at all is because it expresses the degree to which the volts and amperes of the circuit coöperate. It is a measure, in a way, of the amount of inductance present.

A Wattless Current.—In an non-inductive circuit there is no ϕ; in a circuit with much induction, in fact too much, ϕ will indicate so great a lack of coöperation between E and C, that no power will be available, even though a high pressure and a large current are noted on separate meters. This is a case of a *wattless current*, and a comparison made between the true power and the apparent power would be readily discerned by means of what is called the cosine of ϕ, or the power factor. When the EMF. impressed upon the line and the current are so related through the absence of inductance or capacity that they operate simultaneously, then the cos. $\phi = 1$, or the power factor is at its highest value. If inductance is developed in the line, the cos. ϕ is less than 1; in fact, as the inductance is increased the value of cos. ϕ diminishes toward zero.

This is simply a diagrammatic way of representing the manner in which the lack of coöperation of E and C is made apparent. The less they coöperate, or the greater the lag, the more nearly the angle ϕ approaches 90°. In utilizing the power factor, the volts and amperes are multiplied together and by the cos. ϕ.

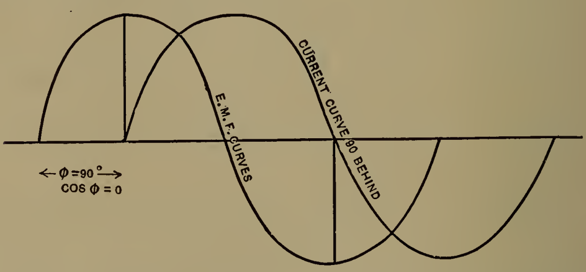

FIG. 96.—A Wattless Current where the EMF. and Current Are 90° Apart, through Induction.

For instance, if the angle of lag is 0°, then cos. $\phi = 1$, and $E \times C \times 1 = E \times C$. But if the angle of lag $= 90°$ (Fig. 96), then cos. $\phi = 0$ and $E \times C \times 0 = 0$, or there is no power. Between these two limits of zero and 1, the power factor will vary for every circuit carrying an alternating current. If the power factor of a circuit is not known, and there is pronounced inductance present, the exact value of the power is problematic. In circuits supplying current for light or power the presence of machinery or apparatus containing inductance may diminish the available amount of power. In the following table the value of the cosine is given corresponding to the angular values of 0° to 90°:

VALUE OF THE COSINE OF ϕ FROM 0° TO 90°.

Angle in degrees.	Cosine.	Angle in degrees.	Cosine.	Angle in degrees.	Cosine.	Angle in degrees.	Cosine.	Angle in degrees.	Cosine.	Angle in degrees.	Cosine.
0	1.000	16	.961	32	.848	47	.682	62	.469	77	.225
1	.999	17	.956	33	.838	48	.669	63	.454	78	.208
2	.999	18	.951	34	.829	49	.656	64	.438	79	.191
3	.998	19	.945	35	.819	50	.643	65	.422	80	.174
4	.997	20	.940	36	.809	51	.629	66	.407	81	.156
5	.996	21	.934	37	.798	52	.616	67	.391	82	.139
6	.995	22	.927	38	.788	53	.602	68	.374	83	.122
7	.992	23	.920	39	.777	54	.588	69	.358	84	.105
8	.990	24	.913	40	.766	55	.574	70	.342	85	.087
9	.988	25	.906	41	.754	56	.559	71	.326	86	.070
10	.985	26	.899	42	.743	57	.545	72	.309	87	.052
11	.982	27	.891	43	.731	58	.530	73	.292	88	.035
12	.978	28	.883	44	.719	59	.515	74	.276	89	.017
13	.974	29	.875	45	.707	60	.500	75	.259	90	.000
14	.970	30	.866	46	.695	61	.484	76	.242		
15	.966	31	.857								

CHAPTER XV

CIRCULAR MILS FOR ALTERNATING CURRENT MAINS.—VALUE OF C FOR SINGLE PHASE CURRENTS.—CIRCULAR MILS CALCULATED FOR SINGLE PHASE CIRCUITS.—CIRCULAR MILS CALCULATED FOR TWO PHASE CIRCUITS.—CIRCULAR MILS CALCULATED FOR THREE PHASE CIRCUITS.—AVERAGE POWER FACTORS.—WEIGHT OF COPPER.—THE INDUCTION MOTOR.—SYNCHRONOUS MOTORS.—ROTARIES IN POWER TRANSMISSION. — ROTARIES IN ELECTRIC LIGHT STATIONS.—TWO AND THREE PHASE ALTERNATOR CONNECTIONS.

Size of Wire in Circular Mils for Alternating Current Mains.—The size of a conductor carrying an alternating current is calculated with reference to the power factor by the following formula:

Circular mils = $D \times W \times C \div p \times E^2$,
in which W = watts delivered,
D = length of run,
p = loss in line in per cent. of power delivered,
E = volts between receiving end of circuit,
C = 2,160 for direct current,

but varies according to the following, for single phase, two phase and three phase currents:

Value of C for single phase currents with power factors of the values given as follows:

Power factors	100	95	90	85	80
Value of C	2,160	2,400	2,660	3,000	3,380

Example.—To find the current and circular mils required for a circuit delivering 10,000 watts, at a pressure of 100 volts, of a run of 1,000 feet.

Current = $W \times T \div E$ where
T = 1.25 for single phase,
= .62 " two "
= .72 " three " with a power factor of 80.

For single phase, therefore, calling this power factor 80:

$$\begin{aligned} \text{Current} &= 10{,}000 \times 1.25 \div 100 \\ &= 12{,}500 \div 100 \\ &= 125 \text{ amperes.} \end{aligned}$$

Circular Mils with Single Phase.—Circular mils for single phase are then calculated by the formula in which they are equal to $D \times W \times C \div p \times E^2$ where

D = 1,000 ft. = length of run,
W = 10,000 = watts delivered,
C = 3,380 = constant employed with a power factor of 80,
p = 10 per cent. = loss in line in per cent. of power delivered.
$E^2 = E \times E = 100 \times 100 = 10{,}000$ = pressure at the receiving end squared.

$$D \times W \times C \div p \times E^2 = 1{,}000 \times 10{,}000 \times 3{,}380 \div 10 \times 10{,}000, = \frac{33{,}800{,}000{,}000}{100{,}000} = 338{,}000$$ circular mils, with 10 per cent. drop, representing a wire equal to a No. 000000 B. & S.

The above calculations for a single phase system of wiring can be applied to the finding of the circular mils required for either a feeder, main, or branch. In each case the *constant C* must be adopted according to the power factor of the circuit. If, in the last case, the power factor was 90 instead of 80, the constant would have been 2,660 instead of 3,380. The circular mils would have been as follows:

$$\text{Circular mils} = \frac{1{,}000 \times 10{,}000 \times 2{,}660}{100{,}000} = 266{,}000,$$

instead of 338,000. The difference between the two results is due to the difference in the power factors of the hypothetical circuits respectively.

Circular Mils with Two Phase.—The value of the current in a two phase circuit may be found by the formula $W \times T \div E$, where

T = .62 for two phase circuits with power factor of 80,
W = watts delivered,
E = volts between the receiving ends of the circuit.

If, for instance, 10,000 watts are to be delivered at a pressure of 100 volts over a run of 1,000 feet, then the current in any leg of the circuit would be $10{,}000 \times .62 \div 100 = 6200 \div 100 = 62$ amperes.

Values of T with Different Power Factors.—For calculating the current in circuits of single, two and three phase circuits the following table, giving the values of T, will prove very useful with different power factors. It will be noted, that the variable value of T for the different cases specified, increases as the power factor diminishes.

	Power factors.				
	100	95	90	85	80
Value of T for single phase	1.00	1.05	1.11	1.17	1.25
Value of T for two phase (4 wire)	.50	.53	.55	.59	.62
Value of T for three phase (3 wire)	.58	.61	.64	.68	.72

By means of this table the value of the current in a three phase circuit, as well as a one or two phase, may be found, with circuit conditions giving a power factor of from 80 to 100.

In the case of a three phase circuit, delivering 10,000 watts at a pressure of 100 volts, the current, with a power factor of 80, would equal $10{,}000 \times .72 \div 100 = 7200 \div 100 = 72$ amperes. The constant .72 is taken from the table under the power factor 80. If the power factor had been 85 or 90, etc., the constant corresponding would have been selected accordingly.

A table by means of which the circular mils of any phase of current may be readily found is given in the following, under the title of "Values of C."

In this, as well as in other instances, it has been found advisable, for the sake of simplicity, to present useful figures in a tabular form. The convenience of this method is discovered wherever arbitrary values are apt to be used, instead of those based upon correct scientific data. The values of C, it will be noted, increase with the diminishing values of the power factor.

TABLE.

	Power factors of circuits.				
	100	95	90	85	80
Values of C for single phase circuits........	2100	2400	2660	3000	3380
Values of C for two phase circuits (4 wire)	1080	1200	1330	1500	1690
Values of C for three phase circuits (3 wire)	1080	1200	1330	1500	1690

In this table may be found the constant which can be used in finding the circular mils of a two phase circuit by the formula: Circular mils $= D \times W \times C \div p \times E^2$. Taking the last case of 10,000 watts sent 1,000 feet at a pressure of 100 volts with 10 per cent. drop and with a power factor of 90, then the size of wire equals the following:

Circular mils of two phase (four wire) circuit =

$$D \times W \times 1{,}330 \div p \times E^2,$$

where D = 1,000 ft.,
W = 10,000 watts
C = 1,330 (see table)
p = 10
$E^2 = 100 \times 100 = 10{,}000.$

Circular mils $= 1{,}000 \times 10{,}000 \times 1{,}330 \div 10 \times 10{,}000,$
$= 13{,}300{,}000{,}000 \div 100{,}000,$
= 133,000 or a No. 00 B. & S. with a 10 per cent. drop.

If the power factor is 85, then the constant becomes 1,500 instead of 1,330, and the resulting size of wire larger as shown by the calculation:

$$\text{Circ. mils} = 1{,}000 \times 10{,}000 \times 1{,}500 \div 10 \times 10{,}000,$$
$$\text{or circ. mils} = 15{,}000{,}000{,}000 \div 100{,}000,$$
$$= 150{,}000 \text{ or a No. 000 B. \& S. gauge.}$$

Circular Mils with Three Phase.—Calculating the current and circular mils for three phase circuits is as simple with the use of constants as in the case of single and two phase circuits. As already stated, the power factor of the circuit governs the value of the constant. Assuming a power factor of 90, in the case of 30,000 watts, sent a distance of 5,000 feet at a pressure of 1,000 volts with a 10 per cent. drop, the current and circular mils would be as follows:

Current in amperes $= W \times T \div E$, where $W = 30{,}000$, $T = .64$ (see table giving values of T with power factor of 90), and $E = 1{,}000$: then

$$\text{Current in amperes} = 30{,}000 \times .64 \div 1{,}000$$
$$\text{current in amperes} = 19{,}200 \div 1{,}000 = 19.2.$$

The number of circular mils required will be equal to

$D \times W \times C \div p \times E^2$, in which the following values are found:

D = 5,000 ft., length of the power line,
W = 30,000 watts delivered at the farther end,
C = 1,330 for (3 wire, 3 phase), according to table,
p = 10 per cent.
$E^2 = 1{,}000 \times 1{,}000$ = volts at rceeiving end squared,

therefore the circular mils = 5,000 × 30,000 × 1,330 ÷ 10 × 1,000,000,
circular mils = 199,500,000,000 ÷ 10,000,000,
circular mils = 19,950 or a No. 7 B. & S. gauge.

A change of power factor will bring about another result. As, for instance, a power factor of 80 instead of 90, which makes the constant (see table) 1,690 instead of 1,330, and gives a result as follows:

Circular mils = 5,000 × 30,000 × 1,690 ÷ 10 × 1,000,000,
circular mils = 253,500,000,000 ÷ 10,000,000,
circular mils = 25,350 or a No. 6 B. & S. gauge.

Average Power Factors for Circuits.—The circuits employed for lighting, power or combination work naturally have different power factors.

1. For instance, in regular lighting the power factor will vary from 90 to 95 per cent. If synchronous motors are installed as well, the power factor may diminish, but it will average up between these figures.

2. For electric lighting and induction motors the power factor will be lower, somewhere between 85 and 90 per cent. The reason for the reduction is found in the inductance introduced into the circuit by the motors.

3. Where only induction motors are operated on the circuit the power factor will fall again to a lower value, lying between 80 and 85 per cent.

In calculations of the current in one, two and three phase circuits great care must be taken not to confuse the constants employed. The same care must be exercised in calculating the circular mils of similar circuits. The advantage of knowing the current in the conductors is found in comparing the respective weights of wire needed for house lighting or power transmission in various instances.

Weight of Copper.—After finding the size of wire in circular mils, its weight is readily determined in pounds from the table giving circular mils, resistance, etc., in fact, from the wire table direct, which will supply the information in pounds per thousand feet. A very simple and rapid way is to divide the circular mils by 62.5 to get the pounds per mile. For instance, a mile of No. 10 B. & S. copper wire of 10,400 circular mils = 10,400 ÷ 62.5 = 166 pounds of copper per mile.

The Induction Motor.—This motor requires no exciter and will start from rest with a moderate load. It differs from the type called synchronous in that it is started on two or three phase circuits by means of specially constructed transformers, called auto-transformers (Figs. 98 and 99), which permit it to receive a low pressure when beginning to speed up. An ordinary two way switch will be sufficient to control the current when starting and stopping, in conjunction with the auto-transformers. When running idle, an induction motor takes only sufficient current to operate itself and supply certain inherent losses.

It consists of a stationary *field* or stator within which rotates the part developing the mechanical power (Fig. 97) called the *rotor*. As the magnetic field sweeps around, as it were, its influence upon the rotor is to pull it around as well. This is due to the development of induced currents in the rotor,

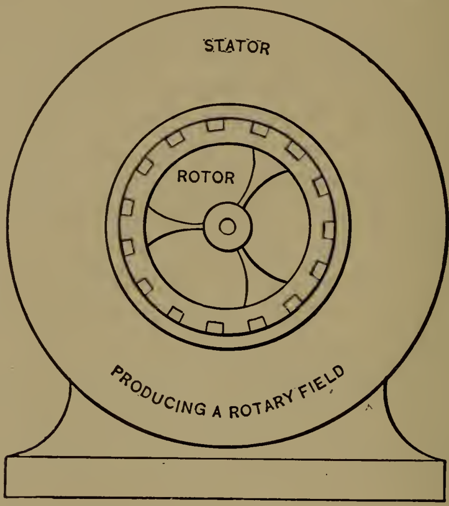

FIG. 97.—Elements of an Induction Motor.

in virtue of which a reaction occurs which manifests itself as rotation, giving it in consequence the name of induction motor. The ratio of the revolutions of the rotor to the revolutions of the stator, that is, of the rotating magnetic field it produces, is a measure of the efficiency. If speed of field = B and speed of rotor = A, then if B = 1,000 and A = 900, the efficiency equals 900 ÷ 1,000 = 90 per cent.

Rotors may be of the type called squirrel cage, or they may have collector rings. In both instances a starting resistance is supplied. This resistance cuts itself in and out automatically when the motor starts from rest. Where the rotor has collector rings, an external speed controlling resistance is employed. Wiring circuits of a two and three phase induction motor are shown in Figs. 98 and 99.

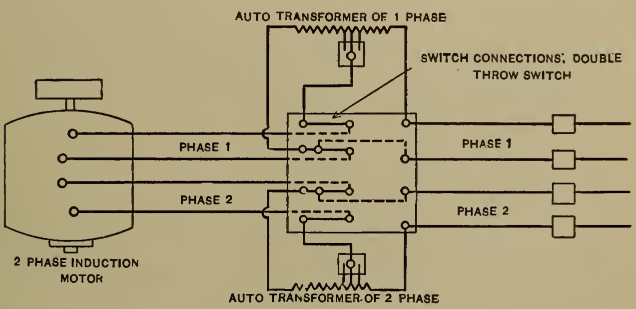

FIG. 98.—Connections of a Two Phase Induction Motor, Showing Connections of Auto-transformers to a Starting Switch.

A single phase induction motor requires to be started either by hand, by machine, or by splitting the single phase by special means, so that it acts like a two phase current temporarily, until the rotor is up to speed.

Synchronous Motors. — This motor must be started from rest, and possesses an exciter to energize its field. It possesses collector rings and brushes, and cannot be brought up to speed unless all load is removed. It is really a small alternator speeded up, when fed with current, until it gets into synchronism or step. If the motor is so over-

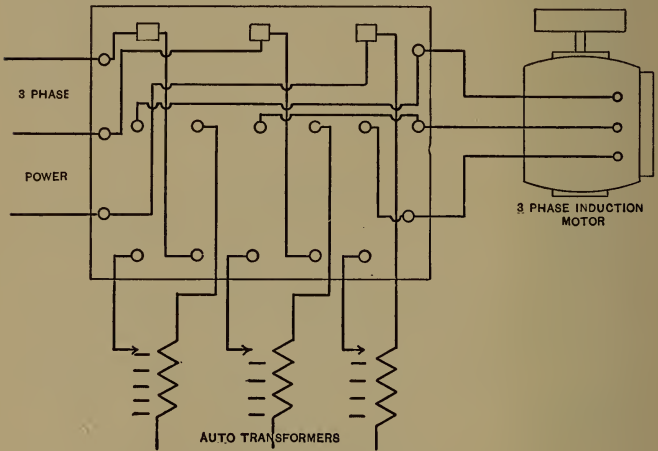

Fig. 99.—Switch Connections of a Three Phase Induction Motor Showing Auto-transformers in Position.

loaded that its speed drops sufficiently for it to fall out of step, it will cease turning altogether. A drop in the voltage will cause the same result. An extra starting device, supplied with power from a foreign source, is necessary in throwing it into rotation. For this purpose an induction motor with split phase device, a gas engine, a direct current motor, if convenient, or a clutch receiving power from a line of belting, is utilized.

Rotaries in Power Transmission.—In the accompanying sketch (Fig. 100) is shown the wiring plan of a power transmission plant with rotary converters in circuit performing the function for which they were designed, viz., the transforma-

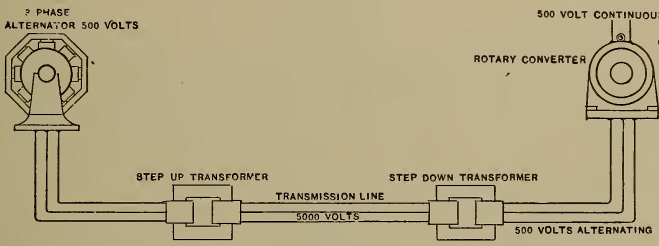

FIG. 100.—Elements of a Power Transmission Plant.

tion of alternating into continuous current at the receiving end, and the transformation of low pressure alternating into high pressure alternating by means of alternating current transformers at the transmitting end. The alternating current transformer consists of a magnetic circuit embracing two coils, a high and low pressure coil. By means of this device (Figs. 101 and 102) the pressure and amperes are converted either higher or lower, the total watts, with the exception of those naturally lost during the process, remaining the same. The transformers are termed step up transformers and step down transformers according to the purpose involved in their design.

The windings of transformers are in the same proportion as the electromotive forces they generate. That is to say, if the primary winding receives 40 volts and has 40 turns the secondary winding to give 8 volts must have 8 turns. This

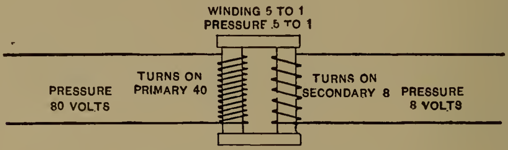

FIG. 101.—Principle of Transformer Winding.

gives a ratio of 5 to 1, and is termed "ratio of transformation."

Rotaries in Electric Light Stations.—The application of rotaries, as previously stated, has, in a measure, solved the problem of power distribution with

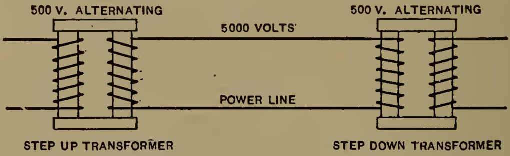

FIG. 102.—Step up and Step down Transformer in Service.

reference to the use of sub-stations and the degree of assistance one large central station can give to other smaller stations in various parts of the city supplying the same circuits. The transformer and the rotary have been the direct means of bringing about a revolution in lighting methods in direct current stations.

In the illustration (Fig. 103) is shown the machinery employed and way in which rotaries play their part in regard to the generation of direct

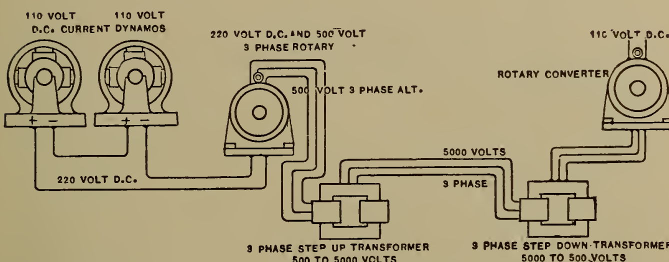

FIG. 103.—Method of Distributing Power to Sub-stations as Employed by the Edison Company.

current and its subsequent distribution to a substation, if it represents a surplus of power or if the distant station is approaching a point of overload. In either case the system is of incalculable benefit as regards elasticity and economy. By adopting this system on a large scale the necessity for any other than a large central station disappears. It becomes the center or nucleus of a number of substations, which distribute the electricity after receiving it, through the medium of rotaries, to the outlying circuits in their vicinity.

Two Phase Lighting System.—As this system relates to power transmission and electric lighting it must be included as a method which practice has shown to be of leading importance. By means of two or three phase currents, as already stated, it is possible to utilize self-starting alternating current motors. Formerly, all alternating current motors were started by some external means, such as an engine or a direct current motor, or a means was found, as previously mentioned, of developing in a simple alternating current, called a single phase current, the equivalent of two phases, by which an alternating current motor became self-starting. The two and three phase current, however, is generated and utilized because it may be used not only for electric lighting but for motors without any accessories in the way of starting devices making them fundamentally self-starting. The general plan of the connections of a two phase alternator to the four lines by which its power is transmitted, as given by the Westinghouse Company, is shown in the illustration (Fig. 104). The auxiliary field is obtained by transforming the alternating into direct current by means of a commutator and sending this current into the additional field winding designated.

The Three Phase System.—The plan of connections relating to this system is also shown (Fig. 105) with auxiliary field connections as in the two phase system. In addition to the ordinary winding the auxiliary winding is employed, giving rise to the expression "composite winding." The additional coil of the series transformer receives

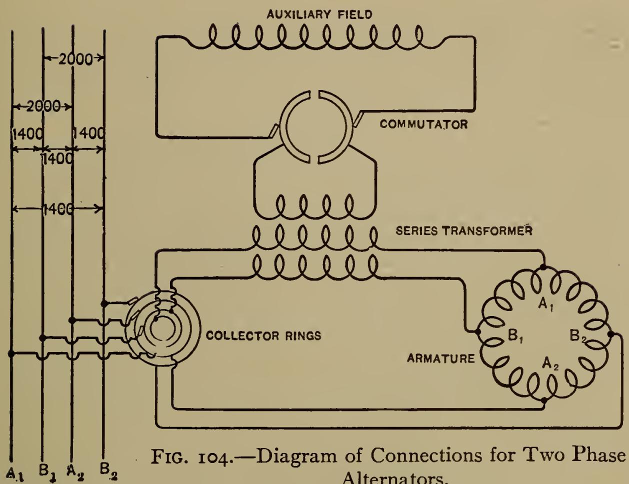

FIG. 104.—Diagram of Connections for Two Phase Alternators.

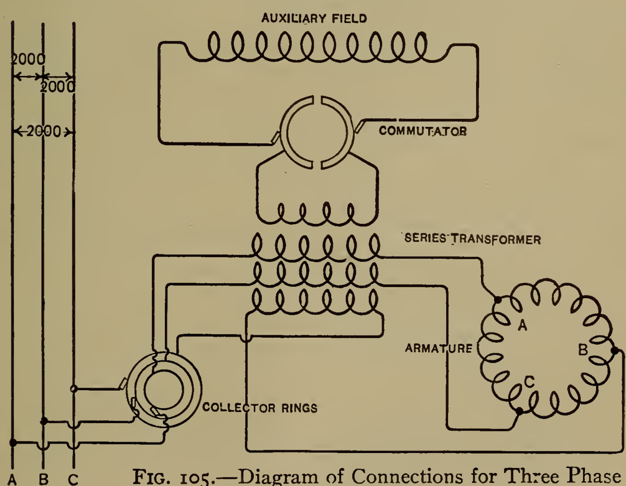

FIG. 105.—Diagram of Connections for Three Phase Alternators.

a low potential current proportional to the main current. This current when rectified acts upon the field of the alternator through the auxiliary winding.

It depends upon whether the main purpose is electric lighting with motor circuits incidental, or whether it is entirely a power supply for motors as to the wiring at the switchboard for a two phase system. A choice may be made of two methods:

First—All four-wire circuits if motors are the principal purpose.

Second—All three-wire circuits if lighting is the main object.

In the second case the three wires, A_1, B_1 and A_2 or B_1, A_2 and B_2 are tapped. Transformers are connected and the pressure lowered to the point required.

INDEX

A

Absorption of light by globes, 164.
Accessories of conduit, 138.
Adjustment of arresters, 207.
Alternating current, effect of capacity on an, 231.
Alternating current, effect of inductance, 230.
Alternating current, effect of resistance, 230.
Alternating current, line losses, 224.
Alternating current mains, size of wire for, 242.
Alternating current waves, 229.
Alternator connections for three-phase, 257.
Alternator connections for two-phase, 257.
Alternator elements, 122.
Amperes allowed in conduit work, 148.
Amperes allowed in insulator work, 148.
Amperes with a given insulation resistance, 149.
Analysis of a ten-lamp circuit, 43.
Analysis of a 220-volt system, 103.
Analysis of dro in ten-lamp circuit, 45.
Analysis of switchboards, 199.
Analysis of Wiedemann system, 47, 48.
Angle of lag, 239.
Apparatus of lighting circuits, 176
Apparatus of switchboards, 168.
Application of rotaries, 220.
Application of shunt and compound wound dynamos, 84.
Application of Wheatstone bridge, 91.
Arc light system, 28.
Area lit and candle power, 163.
Arresters, lightning, 201.
Arresters, mounted, 201.
Armored conduit in damp places, 136.
Assembling a panel switchboard, 196.
Asphaltic paper conduit, 128.
An alternating current meeting inductance, 226.
Auto transformers, 249.
Automatic dynamo, 171.
Auxiliary field, 256.
Average power factors, 248.

B

Back EMF. of motor, 115.
Back pressure of inductance, 226.
Balancing the bridge, 92.

Balancing a three-wire system, 104.
Bends of conduit, 128.
Bends, couplings, elbow clamps, 133.
Branches, feeders, mains, 66.
Brass armored, accessories of, 138.
Brass armored conduit, 128.
Bridge of lamps, 92.

C

Cables, 217.
Calculation of back EMF., 118.
Calculation of capacity reactance, 234.
Calculation of drop, 24.
Calculation of impedance, 235.
Calculation of mains, feeders, branches, 68.
Calculation of power, 38.
Calculation of resistance of wires, 25.
Calculation of reactance, 233.
Calculation of a simple circuit, 42.
Calculation of two-phase mains, 244.
Calculation of weight of wire, 110.
Calculation of wires for three-wire system, 106.
Calculating unequal resistances in multiple, 35.
Calculating a power line, 59.
Candle power of commercial lamps, 160.
Candle power and pressure, 161.
Candle power per watt, 159.
Capacity of generator panels, 194.
Capacity and inductance, 232.
Capacity in a line, 224.
Capacity reactance calculated, 234.
Carrying capacity of wires, 40.
Center of distribution, 72.
Centers of distribution, table of, 74.
Central station lighting, 85.
Chandeliers, use of, 166.
Character of glass and light, 164.
Choosing conduit, 130.
Choosing globes, 164.
Circuit breaker, 170.
Circuit breakers in power plants, 187.
Circuit of ten lamps, analyzed, 43.
Circuits tested, 209.
Circuits, with average power factors, 248.
Circular mils and drop, 31.
Circular mils, drop and sizes, table of, 71.
Circular mils and size, by wiring table, 53.
Circular mils, feet of wire and ohms, table of, 33.
Circular mils for two-phase, 244.
Circular mils for three-phase, 247.
Circular mils for single phase, 243.
Classification of grounds, 212.
Cleats, knobs, moulding, 126.

Coal consumption, 162.
Coal and lamp wear, 162.
Combination fixture work, 150.
Combination of two- and three-wire circuits, 107.
Combination of two- and three-wire system, 109.
Commercial and electrical efficiency, 118.
Comparison of inductance and reactance, 236.
Comparison of size of wire with two- and three-wire system, 105.
Comparative table of drop circular mils and sizes, 71.
Comparative table of regular and calculated sizes, 53.
Complete cycle, 238.
Complete panel switchboard, 203.
Compound generators, speed of, 182.
Compound wound dynamos, 84.
Compound wound generator connections, 171.
Concealed work, 147.
Conditions of switchboard design, 189.
Conduit concealed and exposed, 127.
Conduit in new buildings, 127.
Conduit in old buildings, 127.
Conduit, kinds of, 128.
Conduits or tubes defined, 140.
Conduit requirements, 141.
Conduit system, laying out of a, 144.
Conduit wiring, 125.
Connecting two-shunt wound generators, 173.
Connections of shunt generator, 169.
Connections of street railway switchboard, 205.
Connections of two-phase motor, 251.
Connections of three-phase motor, 252.
Control and light regulation, 167.
Control of floors, 178.
Converters, rotary, 218.
Copper deposited by one coulomb, 19.
Copper required for alternating current wires, 249.
Copper saved, 62.
Cost and percentage of drop, 65.
Cost of installation and material, 64.
Cost of light and life of lamp, 86.
Cost of lost light, 161.
Cosine of angle, value of, 240.
Cosines, table of, 241.
Couplings for joining conduit, 136.
Covering of wires and cables, 217.
Cross section and resistance of wires, 25, 61.
Current in branch circuits, 88.
Current distribution in wires, 44.
Current in each part of the circuit, 43.
Current in the wire, 43.
Current, lag of, 228.

Current, a wattless, 239.
Cycle, zero points of, 227.

D

Damp basements, 215.
Day's light and coal, 162.
Degradation of electrical energy, 225.
Degrees of a cycle, 238.
Definition of angle of lag, 239.
Definition of the ampere, 18.
Definition of the mil, 25.
Definition of a period, 122.
Definition of tubes or conduits, 140.
Definition of wiring, 15.
Detecting breaks in line, 215.
Determination of two-phase circuits, 258.
Development of wiring table, 51.
Diagram of four centers of distribution, 80.
Diagram of limited drop, 78.
Diagram of shunt generators in multiple, 173.
Diagram of three-wire system, balanced, 107.
Diagram of wattless current, 240.
Differential voltmeters, 195.
Differentially wound motor, 113.
Distribution of current in wires, 44.
Distribution of lamps, 165.
Distribution of power by rotaries, 221, 222.
Distribution of power, 255.
Distribution, sub-centers of, 77.
Distribution sheet, 152.
Drilling the marble, 190.
Drop affected by temperature, 41.
Drop calculated, 24, 26.
Drop in the armature, 83.
Drop in branch arms, 89.
Drop in buildings, 85.
Drop and circular mils, 31.
Drop and size of feeders, mains, branches, 68.
Drop of potential, 23.
Drop per 1000 feet per ampere, 60.
Drop in Wiedemann system, 49.
Dry goods and department stores, 166.
Dynamos for incandescent lighting, 79.
Dynamos, shunt and compound wound, 84.

E

Effect of back EMF., on wiring, 115.
Effect of capacity on an alternating current, 231.
Effect of center of distribution on drop, 73.
Effect of frequency, 228.
Effects of high pressure on light, 160.
Effect of inductance on an alternating current, 230.
Effect of overload, 180.
Effect of resistance on electricity, 225.

Effect of resistance on an alternating current, 230.
Effect of volts on weight of copper, 102.
Efficiency of motors, 117.
Efficiency of motors and circular mils, 120.
Efficiency of motors and weight of wire, 121.
Efficiency of rotary converters, 221.
Electric light system, items of, 37.
Electric lighting, rotaries employed for, 254.
Electrolytic work, switchboards for, 197.
Elements of an alternator, 122.
Elements of a transmission plant, 253.
Elements of a wiring system, 63.
EMF. formula for dynamos, 79.
Enameled iron conduit, 129.
Equal resistances in multiple, 33.
Equalizer bar, 181.
Equalizing generators, 183.
Equalizing the pressure, 74.
Equipment of streets with three-wire system, 103.
Estimating circular mils and gauge number, 58.
Estimating on conduit work, 153.
Example of center of distribution, 72.
Examples of drop of potential, 36.
Exposed and concealed conduit, 127.
Exposed work, 147.

F

Factors, power, 246.
False resistance, 229.
Features of alternating currents, 223.
Feeders, branches, mains, 66.
Feeder panel, back and front, 202.
Feeder panels, 196.
Feeder switchboard, illustrated, 200.
Feeding system of street railway, 204.
Fire underwriters, approval of conduit work, 142.
Flexible cord, steel armored, 136.
Flexible metallic conduit, 128.
Flexible non-metallic conduit, 128.
Flexible tubing, 131.
Floors controlled, 178.
Formula for calculating EMF. in dynamo, 79.
Formula for calculating size of wire, 30.
Formula for effect of heat on wires, 41.
Formula for induction reactance, 233.
Formula for impedance, 235.
Formula for three-phase wiring, 247.
Formula for three-wire system, 106.
Forward pressure of inductance, 226.

Frequency, 123.
Frequency, effect of, 228.
Front and back of feeder panel, 202.
Fuses, 172.
Fuse panels, 196.

G

General principles of switchboard construction, 206.
Generation of EMF., 114.
Generator panels, 194.
Generator switchboard, illustrated, 199.
Generators equalized, 183.
Getting size of wire in electric lighting, 57.
Globes and light, 164.
Ground detector, 171.
Ground detector, operation of, 209.
Ground detector, principle of, 210.
Ground detector for three-wire system, 211.
Grounded circuits, location of, 214.
Grounded wires, 150.

H

Henry, unit of self induction, 236.
High tension arc lighting, 28.
Hooded insulators, 216.
How ground is detected, 212.
How the EMF. is varied, 81.
Hygienic benefits of electric lighting, 16.

I

Illustration of sub-station distribution, 255.
Impedance, calculation of, 235.
Incandescent lamps, 85.
Incandescent lamps, light of, 158.
Incandescent lighting, dynamos for, 79.
Individual mains, 67.
Inductance and capacity, 232.
Inductance in an alternating current circuit, 226.
Inductance compared with resistance, 229.
Inductance, with entering current, 237.
Inductance and lag, 231.
Inductance with leaving current, 237.
Inductance, principle of, 225.
Induction motor, 249.
Induction motor parts, 250.
Induction reactance, 233.
Installation of conduit, 145.
Installation and material, cost of, 64.
Insulation of conductors, 145.
Insulation of insulators, 216.
Insulation, kinds of, 99.
Insulation protected, 100.
Insulation resistance, 94.
Insulation resistance, limit of, 149.
Insulation resistance measured, 98.
Insulation resistance of tall buildings, 97.

Insulation resistance of wire, 95.
Insulating joints, 150.
Insulating materials for electrical work, 146.
Intermediate sizes of wire calculated, 56.
Iron armored conduit, 128.
Iron armored, accessories of, 138.
Iron conduit requirements, 143.
Items of an electric light system, 37.

J

Joints, soldered, 151.
Joining conduits by couplings, 136.
Junction boxes, 134.

K

Kilowatt, meaning of, 39.
Kinds of conduit, 128.
Kinds of insulation, 99.
Kinds of wiring, 125.
Kirchoff's law, 88.

L

Lag defined, 239.
Lag of the current, 228.
Lag and inductance, 231.
Lamps, distribution of, 165.
Lamp efficiency, 160.
Lamp filaments, 86.
Lamps in series, drop calculated, 27.
Large power stations, 220.
Lamp rating, 159.
Laying out a conduit system, 144.
Length of wire and drop, 26.
Life of a lamp, 17.
Life of lamps and cost of light, 86.
Light and efficiency, 160.
Light and globes, 164.
Light effect with shades and globes, 164.
Light obtained from low pressure, 163.
Light of lamps, 158.
Light per square foot, 163.
Lightning arresters, 201.
Lightning arresters, principle of, 206.
Lighting by the three-wire system, 101.
Lighting circuits, apparatus of, 176.
Lighting circuit, power factors, 248.
Lighting system, two-phase, 255.
Limited drop diagram, 78.
Limit of insulation resistance, 149.
Line capacity, 224.
Line losses, with alternating currents, 223.
Load panels, 195.
Locating grounded circuits, 214.
Lost light, cost of, 161.
Lamp pressure, 17.

M

Magneto, testing with, 213.
Mains, feeders, branches, 66.
Marble for switchboards, 147.

Meaning of a coulomb, 19.
Meaning of a kilowatt, 39.
Meaning of L, 237.
Meaning of self induction, 225.
Meaning of the volt, 18.
Measurement of insulation resistance, 98.
Measurement of volts, 18.
Measuring resistance of lamp, hot, 93.
Mechanical work of conduit installation, 145.
Method of calculating circular mils for motors, 119.
Method of getting all wire sizes, 50, 51, 52, 53, 54, 55, 56, 57.
Mil defined, 25.
Motor connections, 113.
Motor, induction, 249.
Motor line, calculation of, 59.
Motors, efficiency of, 117.
Motors, single phase, 251.
Motors, synchronous, 251.
Motors, types of, 112.
Mounting apparatus on slate, 191.
Mounting of lightning arresters, 201.
Movement of waves, 229.
Multiple circuits, 33.
Multiple connections of two-shunt machines, 173.
Multiple wiring, 29.

N

Names of switchboard sections, 193.
National electrical code, 157.
Neutral wire, 104.

O

Ohms, circular mils, and feet of wire, 33.
Ohm's law, 17.
One and two centers of distribution, 75.
Operation of the ground detector, 209.
Outlet and junction boxes, 134.
Over compounding, 184.
Over compounding, per cent. of, 185.
Overload effect, 180.

P

Panel boards, 154.
Panel board requirements, 156.
Panel switchboards, 192.
Panel switchboards analyzed, 198.
Parts of switchboards for D. C. generators, 208.
Per cent. of over compounding, 185.
Percentage of drop, 29.
Percentage of drop and cost, 65.
Period defined, 122.
Petticoat insulators, 216.
Pilot lamp, 171.
Plain unarmored, accessories of, 138.
Plan of lighting and switches, 152.
Points about motors, 116.

Potential, drop of, 23.
Power calculated, 38.
Power, distribution of, 255.
Power factors, 246.
Power factors for lighting circuit, 248.
Power factors, table of, 245.
Practical connections of a shunt motor, 117.
Pressure and illumination, 161.
Principle of lightning arresters, 207.
Principle of the ground detector, 210.
Principle of the motor, 113.
Principle of the three-wire system, 101.
Principle of wiring a shunt motor, 116.
Protection of circuits, 169.
Protection of insulation, 100.
Purpose of analysis of wiring, 46.
Purpose of equalizer, 181.
Purpose of flexible steel armored conduit, 135.
Purpose of rotaries, 219.
Purpose of series winding, 185.
Purpose of two-phase currents, 256.
Purpose of wiring, 17.

R

Rating of lamps, 159.
Reactance, calculation of, 233.
Rear view of switchboard, two-shunt machines, 177.
Reasons for employing conduit, 124.
Recording wattmeter, 201.
Regulation and control of lights, 167.
Regulation of EMF., 81.
Reinforcement of trolley line, 204.
Relationship between coulombs and amperes, 20.
Relationship between coulombs, copper, and amperes, 20.
Relationship expressed by Ohm's law, 18.
Relationship of watts, volts, and amperes, 38.
Requirements for conduit, 141.
Requirements for iron conduit, 143.
Requirements for steel-armored conduit, 143.
Resistance and circular mils, 32.
Resistance and cross section of wires, 61.
Resistance and inductance compared, 236.
Resistance effected by temperature, 41.
Resistance in multiple, 33.
Resistance of equalizer bar, 183.
Resistance of insulation, 94.
Resistance of lamp measured cold, 93.
Resistance of wires, 24.
Rheostat, 171.
Rheostat as a regulator, 83.
Rheostatic regulation, 179.

Risk in connecting shunt generators, 174
Rotaries, application of, 220.
Rotaries for power distribution, 221.
Rotaries in electric lighting, 254.
Rotaries in power transmission, 252.
Rotary converters, 218.
Rotor, 249.
Rotor of motor, 250.
Rubber-covered wires, 41.
Rule for calculating equal resistances in multiple, 34.
Rule for constructing wiring table, 54.

S

Safe operation of generators, 181.
Saving in copper, 62.
Schedule for wiring system, 140.
Sections of switchboard, 193.
Self-starting alternating current motors, 256.
Separate mains, 67.
Separation of EMF. and C., 228.
Series, coil of generator, 181.
Series, electric lighting, 28.
Series, fields, 184.
Series, field shunt resistance, 186.
Series, wound motor, 113.
Shunt dynamos, 83.
Shunt generator, connections of, 169.
Shunt resistance of series field, 186.
Shunt wound motor, 113.
Single and double pole circuit breakers, 192.
Single phase calculations, 243.
Single phase motors, 251.
Sizes of wire and circular mils, 31.
Sizes of wire calculated by rule, 55.
Size of wire for alternating current mains, 242.
Size of wire for motors calculated, 118.
Size of wire with two- and three-wire systems, 105.
Slate drilled for apparatus, 190.
Soldering fluid, 151.
Special insulation, 147.
Speed of compound generators, 182.
Squirrel cage rotors, 251.
Station fires through lightning, 208.
Stator of motor, 250.
Steel armored conduit requirements, 143.
Steel armored flexible cord, 136.
Step down transformers, 253.
Step up transformers, 253.
Strain on insulators, 215.
Street railway, generator and feeder, switchboard sections, 205.
Street railway plants, 186.
Street railway switchboard, 204.
Sub-centers of distribution, 77.
Sub-divisions of a railway board, 204.
Sub-station distribution, 255.

Sub-stations, rotaries for, 255.
Sub-stations, use of, 219.
Switchboards, 168.
Switchboard apparatus, 168.
Switchboard design, 188.
Switchboards for electrolytic work, 197.
Switchboard for lighting, 176.
Switchboard for street railway work, 204.
Switchboard marble, 147.
Switchboard, rear view of connections of two shunt machines, 177.
Switchboard requirements, 156.
Switchboard with control of floors, 178.
Synchronous motors, 251.
System of wiring for two floors, 69.

T

Table of amperes in wiring and insulation resistance, 149.
Table of asphaltic paper conduit, 131.
Table of brass armored conduit, 130.
Table of copper and insulation resistance, 96.
Table of cosines, 241.
Table of coulombs and amperes, 20.
Table of different centers of distribution, 74.
Table of distance, watts, drop, and size, 62.
Table of drop and circular mils for branches, 70.
Table of drop and circular mils for feeders, 70.
Table of drop and circular mils for mains, 70.
Table of drop in a line, 24.
Table of drop per 1,000 feet per ampere, 60.
Table of efficiency and circular mils for motors, 120.
Table of enameled iron conduit, 130.
Table of feet of wire and insulation resistance, 96.
Table of flexible metallic conduit, 132.
Table of flexible steel armored conduit, 137.
Table of flexible woven conduit, 132.
Table of floors, outlets and purpose, 153.
Table of gauge number and drop per 1,000 feet per ampere, 61.
Table of horse power and efficiency, 119.
Table of iron armored conduit, 129.
Table of intermediate sizes of wire, 56.
Table of lamp drop in Wiedemann system, 49.
Table of power factors, 245.

Table of relationship of watts, volts, and amperes, 38.
Table of resistance, cross section, and length of wire, 26.
Table of resistance and cross section of wires, 25.
Table of sections of switchboards, 208.
Table of sizes of wire, 55.
Table of temperature coefficients, 42.
Table of turns, speed, lines of force and volts, 81.
Table of unequal resistance in multiple, 36.
Table of volts and light efficiency, 163.
Table of watts per candle power, 159.
Table of wiring, 50, 51, 52.
Table showing effect of field changes on volts, 82.
Table with amperes constant, 21.
Table with ohms constant, 22.
Table with volts constant, 21.
Temperature affecting resistance and drop, 41.
Temperature coefficients, 42.
Testing circuits, 87, 209.
Testing with a magneto, 213.
Testing with a voltmeter, 212.
Telegraph lines, insulation resistance of, 97.
The alternating current, 121.
The power factor, 238.
The resistance box, 83.
The three-wire system, 101.
The wiring table, 50, 51, 52.
The Wheatstone bridge, 87.
Theory of the Wheatstone bridge, 90.
Three centers of distribution, 76.
Three-phase alternator connections, 257.
Three-phase, calculation of wire for, 247.
Three-phase circuit, 245.
Three-phase motor connections, 252.
Three-phase system, 256.
Three-wire panel boards, 155.
Three-wire system for lighting, 101.
Tools for conduit work, 138.
Transformers, auto, 249.
Transformers, step down, 253.
Transformers, step up, 253.
Transformer, winding, 254.
Transmission plant, elements of, 253.
Two-phase alternator connections, 257.
Two-phase circuits determined, 258.
Two-phase lighting system, 255.
Two-phase mains, calculation of, 244.
Two-phase motor connections, 251.
Two-floor system of wiring, 69.

Two-wire panel boards, 154.
Two-wire system ground detector, 210.
Two-wire 220-volt system, 103.
Type of glass and effective light, 164.
Types of motors, 112.

U

Unarmored conduit, 128.
Unbalanced three-wire system, 104.
Underwriters' laws for panel boards, 155.
Underwriters' laws for switchboards, 155.
Unequal resistances in multiple, 34.
Unit of self-induction, 236.
Use of bridge, 91.
Use of bus bars, 175.
Use of chandeliers, 166.
Using solder for joints, 151.

V

Value of capacity reactance, 234.
Value of cos. of angle, 240.
Value of induction reactance, 233.
Various power equipments, 219.
Ventilation of New York Stock Exchange, 17.
Voltmeter, differential, 195.
Volts lost and length of wire, 26.

W

Waste of light through globes, 164.
Wattless current, 239.
Watts per candle power, at low pressure, 163.
Waves of alternating EMF., 227.
Weatherproof wire, 217.
Weight of copper and efficiency of motor, 121.
Weight of copper for mains, 249.
Weight of copper and pressure, 102.
Weight of wire calculated, 110.
Wheatstone bridge, theory of, 90.
Wheatstone bridge, resistances, 89.
Wiedemann system, 46, 47, 48, 49, 50.
Wiedemann wiring analyzed, 47, 48.
Wires, calculation of resistance of, 25.
Wires, carrying capacity of, 40.
Wires, cross section and resistance, 25.
Wires, rubber covered, 41.
Wire sizes for open and concealed work, 148.

Wires underground, 125.
Wiring defined, 15.
Wiring formula, 30.
Wiring by the Wiedemann system, 46, 47.
Wiring for three-wire system, 108.
Wiring for single phase, 243.
Wiring systems for conduit, 139.
Wiring system, elements of, 63.
Wiring table developed, 52.
Wiring table rule, 54.
Wiring with steel armored flexible conduit, 135.
Winding of transformer, 254.

Z

Zero points in one cycle, 227.

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