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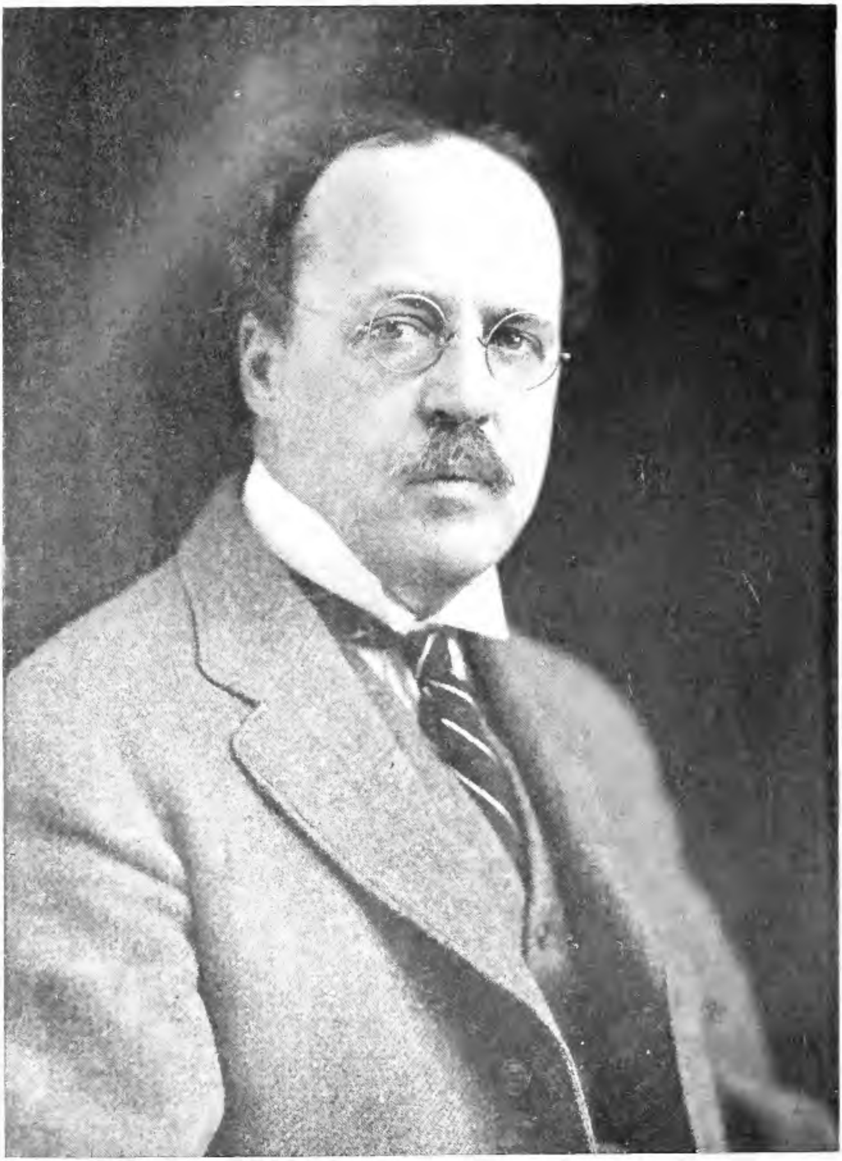

ALBERT G. DAVIS

Recently Elected a Vice-President of the General Electric Company

General Electric Review

RAILWAY ELECTRIFICATION AND THE NATION'S COAL PILE

We have discoursed at length in these columns on the advantages of railway electrification, but feel that we cannot too often refer to the great benefit that would result to all concerned, the railways and the public, were all of our trunk line railways converted to electric operation. The main obstacle is the tremendous cost involved, which a few years ago, with fuel cheap and plentiful, seemed out of all proportion; which today, with a shortage of coal and high prices, appears less formidable; and which in another decade, owing to serious depletion of fuel resources and the need for utmost economy, may be entirely justifiable.

Notwithstanding the superior performance of the electric locomotive, its cleanliness, and its ability to materially increase the freight capacity of the railroad, the compelling factor in effecting the changeover will, in all probability, be the problem of conserving the coal supply. It has been conservatively estimated that one pound of coal when burned under boilers in a modern electric power house will do the work of three pounds in the steam locomotive, and the showing is even better in such severe climates as that which exists in the Northwest. On the basis of present consumption this represents roughly a saving of one hundred million tons of coal annually.

Not only does electric operation permit of the most economical utilization of fuel, but what is more significant, it makes possible the use of hydro-electric power in many localities. It is indeed an unfortunate order of things that requires coal to be hauled half way across the continent to lift a train over the Continental Divide, when the topography of the divide is ready to provide hydro-electric energy, which itself may be partially recovered on the down grade by means of regenerative braking.

The pioneer work of the Chicago, Milwaukee and St. Paul Railway in this field is deserving of the highest praise for its constructive significance. The pronounced success of the initial installation over the Rocky Mountains during the past four years has hastened the completion of the electrification across the Cascade Range, making in all about 800 miles of electrified right-of-way. A new type of gearless passenger locomotive has just been built for operation over the latter section, and is described in this issue of the Review.

B. M. E.

ALBERT G. DAVIS ELECTED A VICE-PRESIDENT OF THE GENERAL ELECTRIC COMPANY

Albert G. Davis, patent counsel and manager of the Patent Department of the General Electric Company, was made a Vice-President of the Company on November 21, 1919.

Mr. Davis was born in Bangor, Me., in 1871, and was graduated from the Massachusetts Institute of Technology in 1893, with the degree of S. B. in electrical engineering, and from the National Law School of Washington, in 1896.

In the spring of 1894 Mr. Davis secured a position as assistant examiner in the patent office at Washington, and in 1896 resigned this position to open an office in the same city as patent attorney. During his residence in Washington, he took a course at the National Law School, from which he was graduated in 1896, as previously mentioned. He was admitted to the bar in the District of Columbia in 1897, and in December of the same year he accepted the position of manager of the Patent Department of the General Electric Company, succeeding Mr. George R. Blodgett.

At that time the electrical industry was just at the threshold of its great development and the patent situation was particularly important. Inventions were being made daily and many of them were offered to the large electrical manufacturers at fabulous prices. To select the wheat from the chaff was always a problem requiring not only the highest technical knowledge, but a keen, prophetic instinct as to the future development of the art. Subsequent history has shown that Mr. Davis' work in this capacity was attended with remarkable success, which rightly should be attributed to his natural qualifications and education.

While fulfilling the many duties of his position as patent counsel and manager of the Patent Department, Mr. Davis has not limited his activities, but has always taken a marked interest in questions of administration, engineering, and physical research, and was conspicuously active in the organization of the General Electric Company's Research Laboratory.

Mr. Davis' new office, although it naturally broadens his activities, does not affect his position as patent counsel and manager of the Patent Department; his promotion to Vice-President is a recognition of the valuable services he has rendered to the General Electric Company.

B. M. E.

A 3000-volt Direct-current Passenger Locomotive for the Chicago, Milwaukee & St. Paul Railway

By W. D. Bearce

Railway and Traction Department, General Electric Company

The original electric locomotives of the C., M. & St. P. Ry. were of the geared type, and differed for freight and passenger service only in the gear ratio. As is well known the performance of these locomotives has been entirely satisfactory; but the advantages of the gearless type of construction for passenger service as demonstrated by the gearless locomotives of the New York Central Railroad have led to the development of a similar type for the C., M. & St. P. Ry. These locomotives are now being placed in operation and will eventually replace the geared type of passenger locomotives, which will be assigned to freight service with a change of gear ratio. The mechanical and electrical features of these new locomotives are described in this article.—Editor.

The original electrification of the Chicago, Milwaukee & St. Paul Railway has now been operating for a number of years under the extremely bad weather conditions of the Rocky and Bitter Root Mountains and, as a result of the unqualified success of this Montana electrification, the same system will now be used to meet the severe grades and snow conditions of the Cascade Range. The motive power equipment of the original electrification consisted of 42 locomotives for freight and passenger service, and four switchers. Of this equipment, the freight and passenger locomotives differed from each other only in the gear ratio between the motors and driving axles.

The new 3000-volt direct-current locomotives, which are now being placed in operation for passenger service on the Othello-Seattle-Tacoma electric zone of the railway, are of an entirely different design. They are built distinctively for passenger service and possess some very interesting mechanical and electrical features. (The geared passenger locomotives will be employed for freight service with a change of gear ratio.) The new locomotives are of the bi-polar gearless type, with the motor armatures mounted directly on the driving axles. In this fundamental feature, they follow the design of the gearless locomotives which have given remarkable operating results during the past ten years on the New York Terminal of the New York Central Railroad. The chief advantage of this method of construction is the great simplicity of mechanical design which eliminates all gears, armature and suspension bearings, jack-shafts, side-rods or other transmitting devices. The remarkably low cost of maintenance of the New York Central locomotives over the entire period is attributed largely to the gearless type of construction.

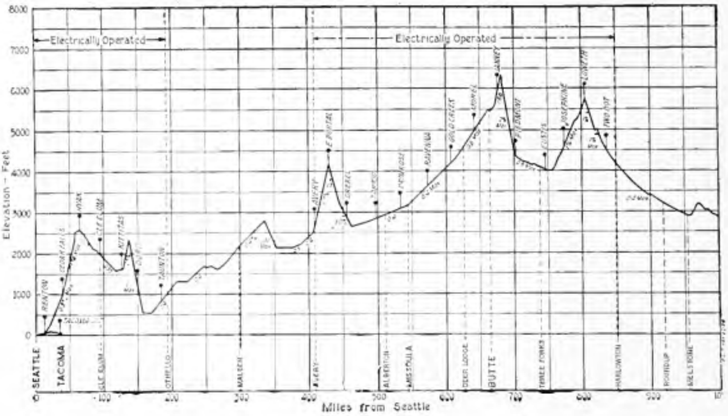

Fig. 1. Profile showing the Electrified Divisions of the C., M. & St. P. Ry. on the Rocky Mt. and Cascade Mt. Ranges. These electrifications now constitute nearly one third the length of this Railway from Chicago to the Pacific Coast

The new Chicago, Milwaukee & St. Paul locomotives weigh 265 tons each, with 229 tons on the drivers. They have fourteen axles, twelve of which are driving, and two guiding axles. The weight of the armatures and wheels is the only dead weight on the track, and this is approximately 9500 pounds per axle. The total weight on the drivers (458,000 pounds) is 86 per cent of the weight of the locomotive, but, being distributed among twelve axles, results in a weight of only 38,166 pounds per axle.

One of the most interesting and important features of the locomotive is the design of the leading and trailing trucks and the method of suspending the cab weight upon them. The successive trucks are coupled together in such a way as to dead-beat or break up any lateral oscillations which may be caused by inequalities of the track. The weight of the main cab is so supported on the front and rear trucks that any lateral thrust or kick of the leading or trailing wheel against the track is cushioned by the movement of the main cab which automatically increases the weight bearing down on the wheels at the point where the thrust occurs and automatically reacts to prevent any distortion of the track. The result of this design is such as to give riding qualities at high speeds which have probably never been attained before in a double-ended locomotive. Exhaustive tests on the General Electric Company's test tracks at Erie, Pa., have demonstrated the remarkable riding qualities of the new locomotive at speeds as high as 65 miles per hour, which is the limit of speed on the length of test track available. These tests also indicate that the locomotive will operate at much higher speeds with equal success.

The locomotive is designed for handling in normal service a 12-car train weighing 960 tons trailing against a grade of 2 per cent at 25 miles per hour. This performance requires 56,500 pounds tractive effort which is equivalent to a coefficient of adhesion of 12.3 per cent of the weight upon the driving axles. The wide margin thus provided between the operating tractive coefficient and the slipping point of the wheels, as well as the ample capacity of the motors, will allow this locomotive to haul trains of as many as fourteen cars in emergencies. For continuous operation, the locomotive is designed to operate at 42,000 pounds tractive effort at a speed of 25 miles per hour.

The total weight supported on the driving axles is practically the same as that on the

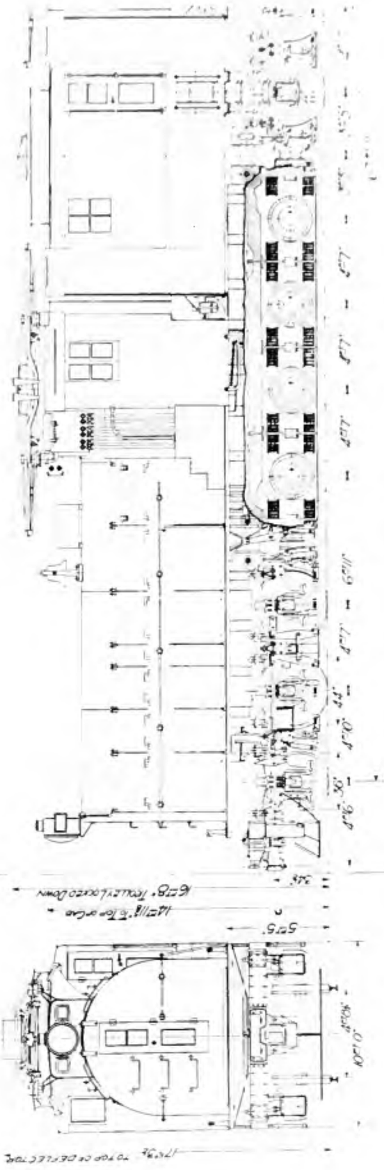

Fig. 2. End Elevation and Side Elevation of a Portion of the New 3000-volt, Direct-current Gearless Passenger Locomotive. One of the eight-wheel trucks with four motors is shown in section

present geared passenger locomotives, a total of 300 tons. Table I gives the principal dimensions, weights, and capacity of this new locomotive.

TABLE I

Length inside knuckles	76 ft. 0 in.
Length over cab	68 ft. 0 in.
Total wheel base	67 ft. 0 in.
Rigid wheel base	13 ft. 11 in.
Diameter driving wheels	44 in.
Diameter guiding wheels	36 in.
Weight electrical equipment	235,000 lb.
Weight mechanical equipment	295,000 lb.
Weight complete locomotive	530,000 lb.
Weight on drivers	458,000 lb.
Weight on each guiding axle	36,000 lb.
Weight on each driving axle	38,166 lb.
Number of motors	12
One hour rating	3240 h.p.
Continuous rating	2760 h.p.
Tractive effort; one-hour rating	46,000 lb.
Tractive effort; continuous rating	42,000 lb.
Tractive effort; two per cent ruling grade with 960-ton train	56,500 lb.
Coefficient of adhesion ruling grade	12.3 per cent
Starting tractive effort; 25 per cent coefficient of adhesion	115,000 lb.
Rate of acceleration starting two per cent ruling grade	0.48 m.p.h.p.s.

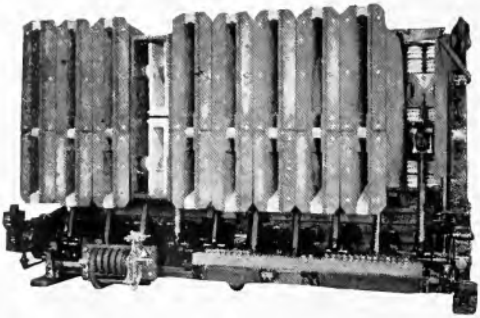

Fig. 3. Electro-pneumatic Series-parallel Switch for Changing the Connection of the Motors from Six in Series to Three in Series

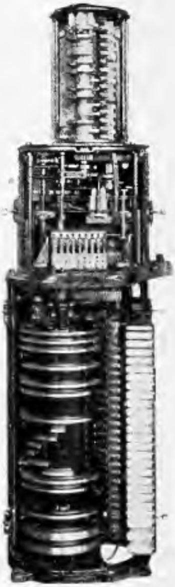

Fig. 4. Master Controller That, Through Low-voltage Auxiliary Circuits Actuates the 3000-volt Direct-current Switches

The control equipment for the new locomotive is similar in most respects to that now used on the original locomotives which have now been operating nearly four years. Modifications were, of course, necessary to comply with the different arrangement of motors. Advantage is taken of a new scheme of connections by means of which four of the main locomotive motors are utilized to furnish exciting current during regeneration, thus reducing the size of the motor-generator set used for control, accessories, and train lighting. An appreciable reduction in the weight of control equipment is obtained yet, at the same time, effective regenerative electric braking is provided on the down grades. The motor-generator set furnishes control current for operating the contactors and for charging an 80-volt storage battery which supplies lights and power for the accessory apparatus. The battery is, in general, similar to those used on the passenger coaches. The master controller is constructed in three sections arranged for both motoring and regenerating, all of the cylinders being suitably interlocked to prevent incorrect manipulation.

The motors are bi-polar, the two fields being supported upon the truck springs with full freedom for vertical play of the armature between the pole faces. Fig. 2 shows the outline of the locomotive with a sectional view of four of the motors indicating the location of the armatures and the magnetic section. For full-speed operation, the twelve motors are connected three in series with 1000 volts per commutator. Control connections are also provided for operating four, six, or twelve motors in series. Additional speed variation is obtained by tapping the motor fields in all combinations. Cooling air for each pair of motors is supplied by a small motor-driven blower. This arrangement avoids the heavy duct losses encountered with a single large blower.

As may be seen from the curves in Fig. 6, the gearless locomotive shows a much better efficiency at high speeds than the geared type, owing to the elimination of the gear drive. In passenger service, where there are long stretches of level track and stopping points are comparatively few, a much higher efficiency is obtained in all-day service. These curves show an efficiency at 50 miles per hour approximately 10 per cent higher than the geared type of locomotive.

The 3000-volt contactors and grid resistors are mounted in the curved end cab at each end of the locomotive. In one of these cabs there is also located the 3000-volt direct-current air compressor and storage battery. In the other is located a small motor-generator set and the high-speed circuit breaker. The operating cabs contain the master controller, indicating instruments, and a small air compressor operated from the battery circuit and having sufficient capacity for raising the pantograph when first putting the locomotive in operation. Near the controller are the usual air brake handles for the standard braking equipment.

The center cab is occupied by the oil-fired steam boiler for heating the passenger train and by accessories including tanks for oil and water, circulating pumps, and a motor-driven blower for furnishing forced draft. A slider pantograph, similar in construction to those now in use, is mounted on each of the operating cabs. This pantograph has two sliding contacts, giving a total of four points per slider with the double trolley. The pantograph and flexible twin trolley construction enable the locomotive to collect currents as high as 2000 amperes at speeds up to 60 miles per hour without noticeable arcing at the contact points. The second pantograph is held in reserve as a spare. Sand boxes, with pipes leading to each pair of driving wheels, are located directly beneath the pantograph outside the operating cab.

Fig. 5. Axle, Wheels and Arms

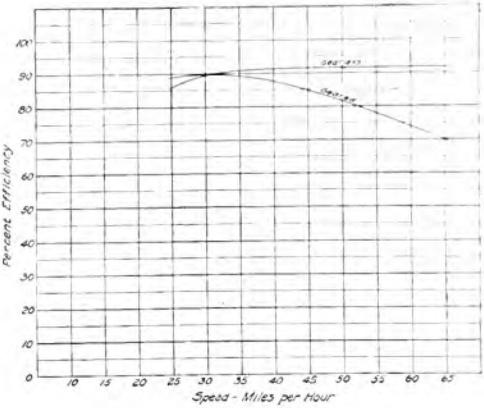

Fig. 6. Speed-efficiency Curves of Geared and Gearless Locomotives, showing the superior efficiency of the gearless type at passenger speeds

Fig. 1 is a continuous profile from Seattle to a point about 1000 miles east, including the Cascade electrification, the Harlowton Avery electrification and the intervening 220 miles. The new locomotives will operate over the section between Othello, Seattle, and Tacoma, including 17 miles of 2.2 per cent grade from the Columbia River west, and 19 miles of 1.7 per cent grade between Cedar Falls and the summit of the Cascades. The traffic over this division consists of the heavy main line transcontinental passenger trains "Olympian" and "Columbian," carrying from 8 to 12 steel passenger coaches which will be handled over the maximum grades without helpers. Freight pushers are already in operation on the 2.2 per cent grade, using two of the locomotives from the original electrification. It is expected that electrical operation during the coming winter will assist in overcoming many of the delays which are commonly met during winter operation in this district.

EXHIBITION TESTS OF 3000-VOLT DIRECT-CURRENT PASSENGER LOCOMOTIVE

As a demonstration of the performance of the new 3000-volt, direct-current bipolar gearless passenger locomotive, described in the preceding article, exhibition tests were run off at Erie, Pa., on November 7. This exhibition was witnessed by many prominent railroad representatives, including engineers from Canada, South America, France, Belgium, Japan, and Australia. In all, nearly two hundred visitors attended the tests which began at 10 o'clock in the morning and extended to late in the afternoon.

The high-speed tests were the first to be made and included a series of runs with about twenty passengers at each trip, operating at speeds as high as 65 m.p.h. This was the maximum speed possible on the test track, which is slightly less than three miles in length. Two standard passenger coaches were hauled for those passengers who did not ride in the locomotive cabs.

After luncheon, regenerative braking tests were made with two steam locomotives obtained from the New York Central Railroad for this purpose. One of these was a high-speed passenger locomotive of the Pacific type, having a total of 173,000 lb. on the six drivers. The second was a freight locomotive of the Mountain type, having eight driving wheels with a total of 234,000 lb. on the driving axles. The principal data on the two engines are as follows:

	K-2 Passenger	L-1 Freight
Wheel arrangement	4-6-2	4-8-2
Weight lb. engine and tender	421,000	509,500
Weight lb. engine	276,800	343,000
Weight lb. on driving axles	173,000	234,000
Maximum tractive effort (at starting) lb.	29,150	51,400
Diameter drivers	79 in.	69 in.
Total wheel base	36 ft. 6 in.	38 ft. 11 in
Rigid wheel base	14 ft.	18 ft.
Overall length, engine and tender	77 ft. 6½ in.	82 ft. 1⅝ in

For the regenerative braking tests the three engines were coupled together, the electric locomotive leading. After all three had accelerated to 25 m.p.h. the two steam engines made their best endeavor to push the electric locomotive faster but were prevented from doing so by the application of regenerative braking on the electric locomotive.

At times, as high as 2000 kw. was returned through the substation to the Erie Works. The laborious efforts of the two steam engines to maintain speed with the electric locomotive regenerating were most spectacular.

As a concluding event, a bucking test was made of the two steam locomotives against the electric in which the electric locomotive easily pushed back the two steam engines in spite of their throttles being wide open.

Among the railroad officials attending the tests were the following:

H. R. Warnock, Gen. Supt. of Motive Power; Chicago, Milwaukee & St. Paul Railway
H. K. Fox, Mech. Eng.; Chicago, Milwaukee & St. Paul Railway
C. T. Ripley, Gen. Mech. Inspector; Sante Fe Lines
E. Wanamaker, Elec. Eng.; Rock Island Lines
E. Marshall, Elec. Engr.; Great Northern Railway
C. F. Nutter, Elec. Engr.; Sante Fe Lines
D. W. Jansen, Elec. Engr.; Illinois Central Railroad
J. V. B. Duer, Asst. Engr.; Pennsylvania Railroad
W. F. Kiesel, Jr., Mech. Engr.; Pennsylvania Railroad
C. B. Keiser, Supt. of Motive Power; Pennsylvania Railroad
J. C. Mock, Signal Elec. Engr.; Michigan Central Railroad
A. R. Ayers, Supt. of Motive Power; New York, Chicago & St. Louis R.R. (Nickel Plate)
A. S. Ingalls, Gen. Mgr.; New York Central Railroad (Lines west of Buffalo)
E. B. Katte, Chief Engr. of Elec. Traction; New York Central Railroad
C. H. Quereau, Supt. of Elec. Eqpt.; New York Central Railroad
F. B. Wiegand, Signal Engr.; New York Central Railroad (Lines west of Buffalo)
W. O. Thompson, Supt. of Eqpt., New York Central Railroad (Lines west of Buffalo)
J. Chidley, Supt. of Motive Power; New York Central Railroad
B. R. Mac Bain, Asst. Gen. Mgr.; New York Central Railroad
W. D. Burnham, Ass't Elec. Eng.; B. & O. R.R.
S. B. Clement, Chief Engr.; Temiskaming & No. Ontario Railway
J. Murphy, Elec. Engr.; Railway Commission of Canada
C. P. Price, Elec. Supt.; Canadian National Railways
E. B. Walker, Elec. Engr.; Canadian National Railways
W. G. Hewson, Elec. Engr.; Hydro Elec. Pwr. Comm. of Ontario
J. G. Baukat, Mech. Engr.; Hydro Elec. Pwr. Comm. of Ontario

The visiting Consulting Engineers included Frank J. Sprague of New York, A. L. Drumm of Chicago, and R. H. Wheeler of New York.

The American Locomotive Company was represented by Mr. C. J. Mellin, Chief Designing Engineer and J. G. Blunt, Chief Mechanical Engineer.

Foreign representatives included:

Mr. L. Levi, Director General; Compagnie Francaise Thomson-Houston Company
Mr. R. Martin, Rwy. Engr.; Compagnie Francaise Thomson-Houston Company
Mr. H. Berger, Rwy. Engr.; Union Electrique, Belgium
Mr. J. Canivet, Tech. Representative; Compagnie Francaise Thomson-Houston Company
Mr. Solar; Chilian Government Commission
Mr. Edward J. Doran, Traffic Mgr.; New South Wales Govt.
Messrs. F. Ohashi and T. Nishioka, Shibaura Tramways Eng. Works, Japan

Prominent General Electric Company representatives included:

M. Griswold, Mgr.; Erie Works
G. E. Emmons, Vice Pres. & Gen. Mgr.; Schenectady Works
F. C. Pratt, Vice President
H. W. Darling, Treasurer
Langdon Gibson, Mgr.; Production Department
H. F. T. Erben, Asst. Mgr.; Schenectady Works
Wm. Dalton, Asst. Mgr.; Schenectady Works
W. B. Potter, Chief Engr.; Railway & Traction Department
A. H. Armstrong, Chairman; Electrification Committee
A. F. Batchelder, Locomotive Engr. and Designer of the Locomotive
E. D. Priest, Engineer of Railway Motors
F. E. Case, Engineer of Railway Equipment
and many others.

Electric Locomotive Connected for Regenerative Braking and Pushed by Two Steam Locomotives to Simulate the Effect of a Heavy Train Down-grade. At times as much as 2000 kw. was returned to the trolley circuit

Visitors at the Exhibition Tests, November 7, 1919, Erie Works

H. F. T. Erben J. M. Sherwin F. C. Pratt M. Griswold Frank J. Sprague C. J. Mellin F. Ohashi T. [illegible]

THE NEW 3000-VOLT DIRECT-CURRENT GEARLESS PASSENGER LOCOMOTIVE FOR THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

Electrical Characteristics and Testing of Dry Cells

ABSTRACT OF CIRCULAR 79 OF THE U. S. BUREAU OF STANDARDS

The so-called dry cell is about the commonest source of electricity, and its uses [illegible] and are increasing as the statistics of the manufacturer will show. Very little information has been published on the dry cell, and engineers, as a rule, know little about its construction and how it should be used to the best advantage. Circular 79 of the Bureau of Standards on dry cells is an up-to-date treatise on this form of primary battery, and as nothing has been published in the GENERAL ELECTRIC REVIEW on this subject, we have made a comprehensive abstract of the paper.—EDITOR

I. INTRODUCTION

The commonest form of primary battery is the so-called dry cell. The dry cell is extensively used for a great variety of purposes, but comparatively little information is available in convenient form regarding its construction and operation and the methods of using it to the best advantage. Dry cells differ in electrical characteristics as well as in size and construction, but they are often used indiscriminately without reference to the purposes for which they are best adapted. The most efficient service can only be obtained when proper attention is given to the selection of the cell for the kind of service for which it is designed.

The object of this paper is to describe briefly the various kinds of cells that are obtainable, to indicate the kinds of service for which they are adapted, and to describe the methods of testing them.

In the preparation of this paper the literature of the subject has been reviewed and studied, and liberal use made of material contained in a number of books.[1] The Bureau has also benefited by the information and experience obtained from the leading manufacturing companies.

Dry cells first appeared in this country about 1890, but several years elapsed before a reliable cell of American manufacture was on the market. Since then the industry has grown rapidly, as shown by the census statistics given in Table I, which applies to the larger sizes of dry cells. Flashlight cells are now made in greater numbers, but are not included in table in next column.

It is probable that the present annual production considerably exceeds a hundred million. This rapid growth of the industry has been due to the use of the larger sizes for ignition and telephone service, and of small sizes for flashlights. The use of the small cells for flashlight purposes has been made possible by the development of the miniature tungsten lamp.

TABLE I

THE PRODUCTION OF DRY CELLS IN THE UNITED STATES[2]

Year	Number	Value
1889..	1,946,688	$ 316,013
1904.	4,888,361	513,026
1909..	33,988,881	4,583,082
1914.	71,092,438	8,719,164

The modern dry cell is the outgrowth of the Leclanché cell, which is still used for some purposes. Leclanché described the cell[3] that bears his name in 1868. He expressed the voltage of his cell in terms of the copper-sulphate cell, and its internal resistance in terms of meters of iron wire of a certain diameter. He refers to the depolarizing action in his cell as combustion of hydrogen. The success of the Leclanché cell led to numerous attempts to make its electrolyte unspillable. Various absorbents and fillers, such as sand, sawdust, cellulose, asbestos fiber, plaster of Paris, and spun glass were tried by experimenters during the 20 years following. In 1888 Gassner[4] produced the first successful dry cell. His cell consisted of a zinc can serving as anode and also as the container for the cell, a carbon rod surrounded by the depolarizing mixture which was wrapped in cloth, and the electrolyte in the form of a jelly. The open-circuit voltage of this cell was about 1.3 volts, and its short-circuit current about 6 amperes. The dry cells in use today have been developed from this cell of Gassner.

II. THEORY AND CONSTRUCTION OF THE DRY CELL

The dry cell has been so designated because its electrolyte is contained in an absorbent material which permits use of the cell in any position. The cell is, however, not dry. In fact, one of the essential requirements in its

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[1] Especial acknowledgment is made of our indebtedness to Primary Batteries, by W. R. Cooper; and Practical Electricity, by W. E. Ayrton and T. Mather.

[2] Bureau of Census, Bull. of Elec. Mach. App. and Sup., p. 13, 1914.

[3] Leclanché, Mondes, *16*, p. 532, 1868; U. S. Patent 64113, Apr. 23, 1867.

[4] Cooper, Primary Batteries, p. 3, 1917; Ayrton and Mather, Practical Electricity, p. 192, 1912.

make-up is that it be sufficiently wet under all ordinary conditions.

1. Elementary Theory

Although the chemical reactions in the dry cell are not exactly understood, a brief discussion of the principal changes taking place at the electrodes can be given here. Since the Bureau has made no study of these reactions, it will be understood that this discussion represents only the generally accepted conclusions.

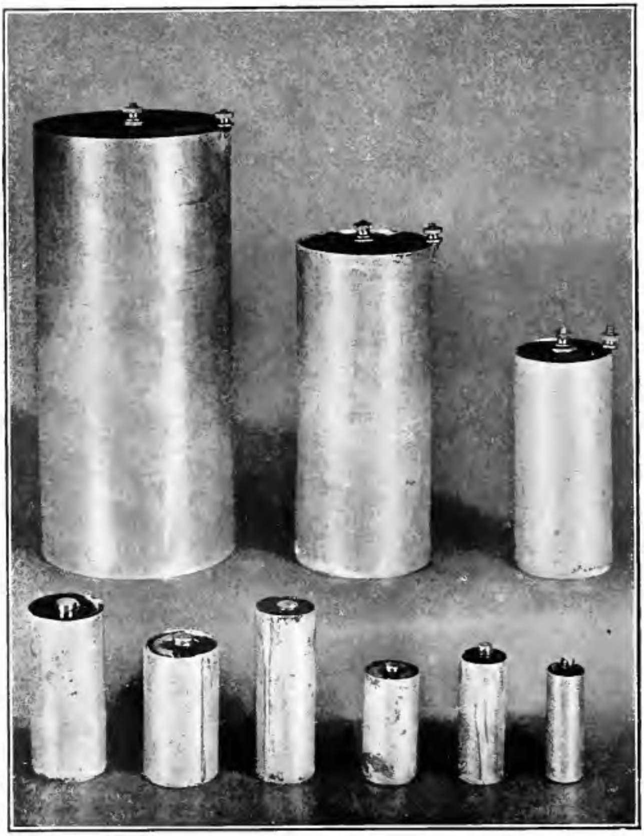
The relation of the principal parts of the cell to one another may be indicated as follows: Zinc metal as anode; solution of ammonium chloride; mixture of carbon and manganese dioxide as cathode.

The zinc in contact with the solution of ammonium chloride becomes *negatively* charged because of the departure of positive zinc ions Zn^{++} from its surface. As zinc dissolves in the solution, zinc ions, ammonia and hydrogen ions are produced, according to the ionic equations:

$$Zn + 2\ominus \rightarrow Zn^{++}$$

$$NH_4^+ \rightarrow NH_3 + H^+.$$

The carbon-manganese dioxide electrode in contact with the solution of ammonium chloride becomes *positively* charged. This fact may be explained in at least two ways.



Standard Sizes of Dry Cells Referred to in Tables III and IV

According to the first theory, hydrogen ions (H^+) are discharged at the surface of the composite electrode and render it positive:

$$2H^+ \rightarrow H_2 + 2\oplus.$$

The manganese dioxide rapidly oxidizes the hydrogen which would otherwise accumulate on the surface of the electrode and polarize the cell. The manganese dioxide (MnO_2) is thereby reduced to a lower state of oxidation, probably (Mn_2O_3):

$$2MnO_2 + H_2 = Mn_2O_3 + H_2O.$$

According to the second theory, the manganese dioxide gives tetravalent ions (Mn^{++++}), which are reduced during the action of the cell to ions of a lower valency and thereby furnish positive charges to the electrode.

$$Mn^{++++} \rightarrow Mn^{+++} + \ominus.$$

Aside from any theory, the fact remains that the manganese dioxide diminishes the polarization of the cell, and is at the same time reduced to a lower state of oxidation. If the *positively* charged electrode (carbon-manganese dioxide) is connected with the *negatively* charged electrode (zinc) by a wire, a current will flow through the wire from the carbon to the zinc. Within the cell the current will flow from the zinc through the electrolyte to the carbon-manganese dioxide.

2. Materials of Construction

Ordinarily, the zinc serves as the container for the cell. The electrolyte consists of a water solution of ammonium chloride (sal ammoniac), zinc chloride and other compounds characteristic of different types of cells. It is held partly in an absorbent material that lines the zinc container and partly in the mixture of ground carbon and manganese dioxide. The latter is bulky and occupies most of the interior of the cell. Sometimes the electrolyte is made into a jelly with such colloidal material as gum tragacanth, agar-agar, gelatin, flour, or starch. The electrolyte is therefore unspillable, whether the cell is completely sealed over the top, as is most common in American practice, or is provided with a vent for the escape of gas, as is common in European practice.

Between the zinc and the depolarizing mixture there must be a lining or partition which will permit electrolytic, but not metallic, conduction. The latter would be an internal short circuit. The different kinds of linings will be described later.

When the cell is new the surface of the composite carbon-manganese dioxide electrode may be considered to be [illegible] at the surface of this mixture next to the zinc. As far as the cell is discharged the manganese dioxide is reduced and the effective surface of the electrode travels toward the carbon rod which is in the center axially of the cell. This carbon rod only serves to conduct the current out of the mixture to the terminal.

(*a*) *Zinc.* The zinc used in the dry cell is rolled into sheets and cut to size before it is obtained by the dry-cell manufacturer in most cases. The thickness of the zinc is expressed by certain gauge numbers, each differing successively by 0.005 of a centimeter (0.002 of an inch); that is, No. 9 gauge is 0.045 of a centimeter (0.018 of an inch) thick. Above No. 10 gauge the successive thicknesses differ by twice this amount; that is, No. 12 gauge is 0.028 in. in thickness. The thickness of the zinc generally used for large dry cells is from 0.035 to 0.050 cm. (0.014 to 0.020 in.). For cells intended for long life the thicker zinc sheathing is used. Cells intended for heavy service are often made with thinner zinc than those for light service. In some cells thinner zinc is used, and sometimes the bottom of the cell is made of tin plate. For flashlight cells Nos. 5 and 6 gauge zinc is commonly used.

For electrochemical reasons zinc of a high degree of purity is desirable, but it is probably of equal importance that the metal have good mechanical properties, *i.e.*, high tensile strength and elongation. The sheet metal must be stiff enough to withstand the strain of the processes of manufacture, as well as those of ordinary usage. The carbon-manganese dioxide mixture is tamped into the can by machinery under conditions which may cause deformation or even splitting of a can of soft zinc. Zinc of a high degree of purity is frequently soft. Under ordinary usage the zinc container may occasionally burst during the discharge of the cell. Undoubtedly some of such failures of the zinc are due to local corrosion of the metal at certain points. This is sometimes caused at the lap in the paper lining.

It would be desirable to have the zinc anode corrode uniformly and only in amount equivalent to the electric current furnished to the external circuit; that is, 1.219 g per ampere-hour. In reality, however, the amount of zinc consumed exceeds this figure, because some zinc dissolves without producing current in the external circuit. Local corrosion of the zinc is caused by unevenness in the distribution of the electrolyte or in the fitting of the lining of the cell. This excessive corrosion or local action at certain points may also be due to impurities in the metal or inequalities in the structure of the metal, which produce differences of potential. These local differences of potential give rise to galvanic couples, and current flows from the zinc to the impurity. As this takes place the zinc is slowly dissolved, although no useful current is delivered by the cell. The effect of metallic particles on the surface of the zinc is somewhat mitigated by several factors. One of these is the so-called over-voltage for hydrogen discharge on some metals, another is the polarization of the local circuit, and a third is the formation of insoluble products which incrust the surface. When local action is due to internal short-circuiting of the cell, the deterioration is very rapid. This may occur when the paper lining is torn or when certain impurities which were in solution in the electrolyte are precipitated in the lining of the cell. Very small amounts of copper may cause this effect.

Amalgamation of the zinc has been resorted to by some manufacturers for reducing local action, but this is more common in the European than in the American cells. Amalgamation may weaken the zinc mechanically and render it brittle.

In some cases, variations in resistance of the mix may cause an unequal distribution of current over the anode surface, and thereby produce excessive corrosion of the zinc at different points.

(*b*) *Carbon-manganese Dioxide Mixture.*—This mixture composes the cathode of the cell, in which the carbon serves as conductor and manganese dioxide as depolarizer. The carbon rod may be considered as a collector of current from the carbon-manganese dioxide mixture. While some rods are fluted or corrugated and thereby have a larger surface than the cylindrical form, their greatest advantage is probably that they are less apt to become loose. A carbon rod of low resistivity is necessary, as an increase in the resistance of one or two thousandths of an ohm will appreciably decrease the short-circuit current of the battery.

The electrical resistivity of the manganese dioxide is so high, as compared with that of the carbon used, that it may be considered a non-conductor. The granulated carbon is therefore added to increase the conductivity of the mixture. Since in a given volume of mixture an increase in the proportion of carbon used means a corresponding decrease in the amount of manganese dioxide possible and therefore a shorter life of the cell it is highly desirable that the carbon have a low resistivity. The resistivity of the carbon depends upon its source, its heat treatment, and size of granules. It has been shown that a variation up to several hundred per cent in resistivity can be made by changing only the size of the carbon grains. Graphite, which has a lower resistivity than carbon, has sometimes been added to the mixture. For this purpose both natural and artificial graphite have been used. The latter is generally used and is preferred by most manufacturers.

As previously mentioned, the manganese dioxide diminishes the polarization of the cell and is reduced, during discharge of the cell, to a lower state of oxidation. The manganese dioxide used in dry cells is usually a refined ore. The efficiency of such an ore depends upon the percentage content of MnO_2 and possibly its state of hydration also.

Up to the beginning of the present war in 1914 most of the high-grade ore was imported from Russia and contained on the average about 85 per cent MnO_2. Since the interruption of this source, the principal importations have come from Brazil, Cuba, India and Japan. The domestic sources are at present small. It appears that the greater portion of present imports is from Brazil, as indicated in the following table taken from the United States Geological Survey Bulletin 666-C:

TABLE II

IMPORTS, IN LONG TONS, OF MANGANESE ORE

Year	Russia	India	Brazil
1913	124,337	141,587	70,200
1914	52,681	103,583	113,924
1915	......	36,450	268,786
1916	......	51,960	471,837

This table, however, represents the total imports of manganese ore, of which the amount used for dry cells is relatively a small part.

Ordinarily, specifications for manganese dioxide call for 85 per cent MnO_2 and less than one per cent iron. Since the Russian supply was interrupted, manufacturers have been compelled to use material containing a lower percentage of MnO_2 and much larger percentages of iron. Iron is usually considered detrimental to the cell, but there is a wide variation in opinion as to the amount which is permissible. The effect of copper in solution in amounts of only a few hundredths of one per cent is generally conceded to be fatal to the cell.

For small cells, artificially prepared manganese dioxide of a high degree of purity is used to a large extent and it is sometimes mixed with the natural ore for the larger cells.

The physical qualities of fineness and porosity are of great importance. In general it appears that an increase in size of the grains up to a certain limit reduces the internal resistance of the mixture of carbon and manganese dioxide, while a decrease in size of the grains increases the depolarizing power per unit weight of MnO_2. Since the depolarizing power depends upon the surface area of the manganese dioxide, a high degree of porosity is desirable.

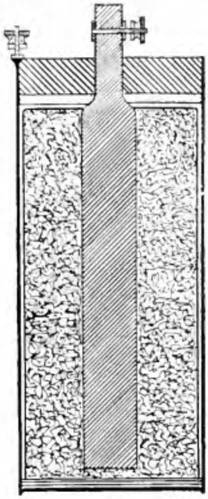


Fig. 1. Section of Paper-lined Cell

(c) *The Electrolyte.*—The electrolyte of the dry cell consists of a solution of ammonium chloride (NH_4Cl) to which zinc chloride ($ZnCl_2$) is added to reduce the corrosion of the zinc by the ammonium salt when the cell is not in action. Information regarding the degree of purity of these materials is not available. In general it is desirable that they be free from metals, viz., copper, lead, iron, arsenic, nickel, cobalt and antimony, which may cause local corrosion of zinc and free from negative radicals, viz., sulphates, which form compounds less soluble than the chlorides.

(d) *Insulation.* The electrodes are insulated from each other at the top of the cell by a layer of sealing compound which is usually a rosin sealing wax or a bituminous pitch. In either case a filler is generally added, but the nature of this filler is kept secret by most of the manufacturers. The sealing compound should make good mechanical contact with the zinc can and the carbon rod, but it is not desirable to seal the cell hermetically, as gases must escape during the operation of the cell. Other desirable qualities in the sealing compound are freedom from flowing in hot weather and excessive brittleness in cold weather.

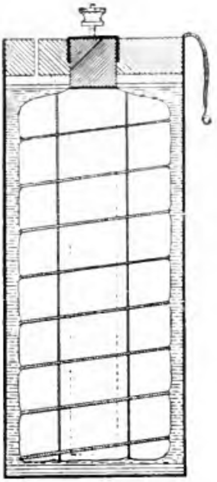


Fig. 2. Section of Bag-type Cell

Insulation of the zinc cans is usually provided by a cardboard tube or jacket which in the case of the ordinary cells, is called a carton. The carton ordinarily fits the cell rather loosely so that it is possible to remove the cell from it. In the case of most cells of foreign manufacture, and some of those made in this country, the carton is of waterproof material and is an integral part of the cell. This permits the more economical use of the zinc, since leakage of the cell is prevented at those points where the zinc becomes eaten through. The zinc may be very nearly consumed without the cell becoming useless.

3. Methods of Construction

(*a*) *Paper-lined Cells.*—The most familiar method of construction for the larger cells in this country is the so-called paper-lined method. Before the cell is filled with the depolarizing mixture, a lining of pulpboard usually consisting of sulphite fiber and ground wood is placed in the cell. This serves a double purpose. It is an absorbent for the electrolyte and it serves to separate the manganese-dioxide mixture from the zinc. After the manganese-dioxide mixture has been tamped into the cell around the carbon rod, the pulpboard lining is folded down over the top of it. Pulpboard is also put in the bottom of the cell, and sometimes a disk of non-absorbent pasteboard is added to protect the bottom of the cell from chemical action. Sometimes blotting paper and strawboard are used in lower-grade cells.

This method of construction, which is so common in America, is rarely found in cells of European manufacture. It has the advantage of cheapness in construction, since it requires less handwork, but it is generally recognized that the service capacity of these cells is not equal to that of the cells with bag-type construction (see below) when comparing cells of the same size and shape.

The section of a typical cell of the paper-lined type is shown in Fig. 1.

(*b*) *Bag-type Cells.*—These are so called from the fact that the manganese-dioxide mixture is contained in a cloth bag (English call it a sack), as shown in Fig. 2. The carbon rod with its surrounding mixture is wrapped in muslin and tied with string, forming a unit which can be placed in the zinc can, leaving sufficient space between the two for the electrolyte in the form of a paste. Spacers to separate the bag from the zinc can are desirable, but are not always used. These are commonly rubber bands in the small cells such as are used for flashlight batteries, or Manila cord, which is of considerable size in some of the foreign makes of cells. The solution of sal ammoniac and zinc chloride is thickened with flour or other similar materials, and may also contain other ingredients differing with manufacturers and kept secret by them.

This form of construction, which is rarely used in the larger cells made in this country except those of square cross section, is almost universally used in making the small flashlight batteries. This may be due to several reasons. This method tends to increase the life of the small cells, which is shorter than for the larger sizes even when standing on open circuit, and some of these cells are so small that most of the operations can be more readily done by hand than by machinery.

The bag-type cell is commonly made in Europe in the large sizes and has good lasting qualities. Two reasons which may partly account for this are (1) the relative cheapness of labor and (2) the fact that the practice of judging a cell by the magnitude of its short-circuit current, which is so commonly done in this country, is almost unknown in Europe. The bag-type cell as made in Europe does not give as large a short-circuit current as the paper-lined cell of equal size made in this country. Hence, to the average purchaser who thinks he is getting the most for his money from the cell that shows the largest short-circuit current, the European bag-type cell would be at a disadvantage. The value of this short-circuit test and also the fallacy that it may involve will be discussed under Section V.

(*c*) *Cells Without Paper Lining or Bag.*—These cells are found on the European market, but not in this country. A paste containing the electrolyte with considerable plaster of Paris or cement is forced into the zinc can by a plunger to form a thick lining to the can. It is then cooked until the mass has become nearly solid, when the plunger is withdrawn. The manganese-dioxide mixture is tamped into the cell.

(*d*) *Desiccated Cells.*—These cells are manufactured dry and require the addition of water before they are ready for use. Some of them are manufactured as paper-lined cells and others are of the bag type. Each cell is provided with an opening in the seal or center of the carbon rod through which the water necessary to make the cell active may be introduced. Some of them are also provided with a vent. Only two kinds of these cells are well known in this country, but others are now being developed. One of these, called a "reserve" cell, closely resembles an ordinary dry cell. The other, called the "add water," more nearly resembles some of the European types of cells. The latter is of bag-type construction with an inner zinc for the electrode. When in use it contains rather more electrolyte than the ordinary dry cell. Both of these designations are trade names and, for this reason, the Bureau has chosen, as a general designation for this type of cell, the English designation "desiccated cell." There are a considerable number of different brands of desiccated cells of European manufacture.

III. SIZES AND KINDS OF DRY CELLS

The dry cells manufactured in the United States fall naturally into the following general classes, which are distinguished from each other by the size and construction of the cells: Large-size cells containing the absorbent paper lining, small cells of the bag-type construction used principally for flashlights, desiccated cells to which water must be added and silver-chloride cells. These will be described in the pages that follow.

1. Large Cells with Absorbent Paper Lining

This class is typified by the familiar dry cell about 15 cm. (6 in.) high by 6.5 cm. (2.5 in.) in diameter. It includes, however, other sizes which are given in Table III. The sizes of these cells are often designated by numbers which express the height of the zinc can in inches, but this is not universally done by the various manufacturers.

This method of designating the sizes will be used because it is convenient and expresses an important dimension of the cells, so that when a No. 6 cell is mentioned a definite impression of the size of the cell is conveyed.

Of these five sizes the No. 6 is by far the most common and is made by all manufacturers, except a few who make flashlight batteries exclusively. Next to the No. 6, the No. 8 is the most common of the remaining sizes. The third size is the No. 4, leaving the No. 5 and No. 7 as unusual sizes which can not generally be obtained, except when specially ordered. The dimensions given in the table are the dimensions of the zinc cans. The terminals will add to the height about 1.5 cm. (⅝ in.), if of the flush-top type, and 2.5 cm. (1 in.) for the protruding carbon type. The diameters are for the bare cells without the carton; however, some of them run a little under size, according to the lapping of the seam when the can is made. Thus the No. 6 cell is made from a sheet of zinc that is cut 15 by 20 cm. (6 by 8 in.), but when made into a can for the cell the diameter is frequently somewhat less than the 6.5 cm. (2½ in.).

These batteries are usually the so-called round form; that is, they are cylindrical in shape. This form is the easiest to manufacture and is the most efficient for this type of construction. However, some manufacturers make the so-called square form, that is, cells with rectangular or square cross section. When made by the same process of manufacture, these square cells are usually not equal in service capacity to the round cells of the corresponding size. To obviate this difficulty as well as some technical points of their manufacture, these square cells are frequently made of the bag-type construction, in which case their electrical-service capacity is equal to that of the round cells of the same size, particularly on light service. It is not possible to tell from the outside of the cell whether it is of the bag-type construction. Most American manufacturers prefer to make the round form of cell. The round form of cell is preferable in the paper-lined construction, because the zinc is free from sharp angles and the corrosion of the zinc is more uniform. There is also less opportunity for the mix to become loose in the round cells and thereby lower the flash point. In general, the square cell will fit into the space occupied by the corresponding size of round cell. The square cells are not a regular product, but can be made in almost any desired size.

Cells of these sizes may be subdivided according to the class of service for which they are intended. They include cells for ignition and heavy service, intermediate cells for general purposes, and telephone or light-service cells. These cells are also put up in the form of batteries which are generally spoken of as multiple and series batteries. The particular characteristics of these cells will be described below. Fundamentally, they are all of the same type of construction.

TABLE III

SIZES OF DRY CELLS[*] (CYLINDRICAL FORM)

Size	Diameter in Inches	Height in Inches	Weight in Pounds	Diameter in Centimeters	Height in Centimeters	Weight in Grams
4	1½	4	0$\frac{13}{16}$	4	10	240
5	2	5	1$\frac{3}{16}$	5	12.5	540
6	2½	6	2	6.5	15	900
7	3	7	3½	7.5	18	1600
8	3½	8	5½	9	20	2500

[*] Standard sizes are the Nos. 4, 6 and 8.

but they embody features which make them peculiarly suited to the class of service for which they are intended. There is no reason why an ignition cell can not be used for telephone service, or vice versa, but to do so will not yield the maximum economical service of which the cell is capable, assuming that the cells are of equally good manufacture. Information has been furnished the Bureau which shows this to be true. Comparative tests were made of two brands of cells which may be designated as "ignition" and "telephone," both made by the same manufacturer. The ignition cell gave over 20 per cent more service than the telephone cell on the ignition test (see p. 1028), but the telephone cell gave nearly 20 per cent more service than the ignition cell on the telephone test.

(*a*) *Ignition and Heavy-service Cells.*—These cells are designed for use in the ignition of internal-combustion engines, lighting and other service requiring considerable current. The open-circuit voltage is approximately 1.5 volts. The current on short circuit, when the cells are new, is about 30 amperes on the average, but rarely less than 25 amperes as a minimum. They are intended for service that will exhaust them within a comparatively short time and are constructed to give the maximum current. The deterioration is more rapid than that of the telephone or light-service cells, when standing on open circuit. Sometimes they are made with a thinner-gauge zinc than the telephone cell.

(*b*) *Intermediate Cells.*—These cells have some of the characteristics of the ignition cells, on the one hand, and of the telephone cells on the other. They may be used either for ignition or telephone service. For general purposes they are convenient, having almost as low a resistance as the ignition cells and some of the lasting qualities of the telephone cell. The short-circuit current of these cells is slightly lower than for the ignition cells, the average being about 25 amperes, with the minimum about 20 amperes when the cells are new.

(*c*) *Telephone Cells.*—These cells are commonly called telephone or open-circuit cells. They are intended for light intermittent service, such as telephone, bell ringing and similar work. They will outlast the two classes of cells mentioned above when the use to which they are put does not exhaust them. The open-circuit voltage is the same as for the ignition cells, but the current on short circuit is considerably less, being slightly over 20 amperes on the average, with a minimum of about 16 amperes. It is not always possible for the ordinary purchaser to distinguish between the intermediate and the telephone cells, since the former are often labeled telephone and open-circuit cells, unless he is familiar with the names of the various brands. Cells of this class are usually manufactured in the smaller sizes; that is, Nos. 4, 5 and 6.

(*d*) *Multiple and Series Batteries.*—When two or more individual cells are combined to form a unit, it is called a battery. Batteries are made by several manufacturers and contain various combinations of cells connected together by soldered connectors. These are usually intended for some special class of service, as, for example, motor-boat ignition, and it is possible to buy these batteries inclosed in waterproof boxes, sometimes of metal, for the various standard ignition systems. The advantages to be derived from these batteries are numerous. They are water-proof; they require a minimum of time and trouble to put in service; they are free from the possibility of loose connections between the cells, impairing the service; and they represent the most efficient and economical grouping of cells for the purpose for which they are intended. They are sometimes designated by type numbers which indicate the brand of cell, the number of cells in series, the number of rows in parallel and the size of the individual cells. Such designations, however, are not universal in use or interpretation. Similar small batteries, not waterproofed, are also available for bell ringing, etc.

2. Flashlight and Miniature Batteries

These cells are commonly of the bag-type construction, and are usually combined into batteries for flashlights, ear phones and similar uses. The individual cells are of 15 or more sizes, differing sometimes by only trifling variations in the dimensions. This may have been due to the various sizes of flashlights put on the market some time ago. but certain sizes are becoming more common, so that now we may regard these as standard.

These cells are combined into batteries of various forms and sizes, for which certain diagrammatic figures have been generally adopted. No designation of size can be given, since each manufacturer has his own system of numbering them. For this reason it is often confusing in comparing cells of different makes. (See Table IV.)

The small cells are subject to more rapid deterioration than the larger sizes when standing on open circuit. Manufacturers usually date the cells either the day of manufacture or the expiration of the guaranty period. This date is often in code. The guarantees are seldom definite, but in view of the deterioration of the cells and the use or abuse to which they may be subjected, these guarantees, when not based on the open-circuit voltage, are perhaps as definite as they can be made.

3. Desiccated Cells

The object of these cells is to overcome the deterioration which is common to all dry cells when standing idle. Desiccated cells do not deteriorate so long as they remain dry. Their performance varies considerably with the method of construction. Those that most closely resemble the ordinary dry cell do not, in general, give as much service as the corresponding sizes of dry cells. Others [illegible] type construction and with double zinc wall and large amount of electrolyte will give considerably more. Some of the desiccated cells can be used as ordinary dry cells, but others with excess electrolyte and a vent hole are for use normally in an upright position. They may be easily handled, however, or even inverted momentarily without spilling the liquid. (Table VI.)

It is necessary to fill these cells with water several hours before use, and 24 hours may be necessary before the cell will give its maximum current on short circuit.

The open-circuit voltage of these cells is 1.5 volts and the short-circuit current may be 20 amperes or more in some cases, but it is usually lower.

4. Semi-dry Cells

A number of cells have been put on the market in the past which were called semi-dry,

TABLE IV

SIZES OF FLASHLIGHT CELLS*

Type No.	Diameter in Inches	Height in Inches	Weight in Ounces	Diameter in Centimeters	Height in Centimeters	Weight in Grams
1	$\frac{9}{16}$	$1\frac{9}{16}$	$\frac{1}{2}$	1.4	4.0	14
2	$\frac{9}{16}$	$1\frac{7}{8}$	$\frac{1}{2}$	1.4	4.8	14
3†	$\frac{5}{8}$	$1\frac{7}{8}$	$\frac{3}{4}$	1.6	4.8	21
4	$\frac{3}{4}$	$1\frac{3}{8}$	....	1.9	3.5	....
5†	$\frac{3}{4}$	$2\frac{1}{8}$	$1\frac{1}{4}$	1.9	5.4	35
6	$\frac{15}{16}$	$1\frac{1}{2}$	....	2.4	3.8	....
7†	$\frac{15}{16}$	$1\frac{13}{16}$	$1\frac{1}{3}$	2.4	4.5	38
8	$\frac{15}{16}$	$2\frac{1}{4}$	....	2.4	5.7	....
9†	1	$2\frac{7}{8}$	....	2.5	7.3	....
10	1	$3\frac{1}{2}$	....	2.5	8.9	....
11†	$1\frac{1}{4}$	$2\frac{1}{4}$	3	3.2	5.7	85
12†	$1\frac{1}{4}$	$2\frac{7}{8}$	$3\frac{1}{2}$	3.2	7.3	100
13	$1\frac{1}{4}$	$3\frac{1}{2}$	....	3.2	8.9	....
14	$1\frac{1}{4}$	4	....	3.2	10.0	....
15	$1\frac{1}{2}$	$2\frac{3}{4}$	....	3.8	7.0	....

*This table contains only the principal sizes of flashlight cells, but other sizes differ from these only by trifling dimensions. Six of the most important are designated as standard. In choosing these standard sizes the Bureau has been in consultation with some of the leading manufacturers.

†Standard size.

TABLE V

SIZES OF DESICCATED CELLS

Brand	Shape	Width or Diameter in Inches	Height in Inches	Weight in Pounds	Width or Diameter in Centimeters	Height in Centimeters	Weight in Grams
Reserve	Round	$1\frac{1}{2}$	4	$\frac{1}{2}$	4	10	185
Do	do	$2\frac{1}{2}$	6	2	6.5	15	908
Do	Oval	$\left\{2\frac{1}{4} \times 1\frac{3}{16}\right\}$	4	$\frac{1}{2}$	5.7 × 3	10	246
Addwater	Square	$2\frac{11}{16}$	$6\frac{1}{2}$	3	7	16.5	1362
Do	Round	$2\frac{1}{2}$	6	....	6.5	15	....
Waterlife	do	$2\frac{1}{2}$	6	....	6.5	15	....

but which did not differ materially from ordinary dry cells. There is, however, one brand at present on the market which is entirely different from the familiar dry cell.

These are 25 cm. (10 in.) high by 12.5 cm. (5 in.) in diameter and weigh 4.5 kg. (10 lb.). A steel electrode replaces the ordinary zinc electrode in these large cells. The open-circuit voltage is 9/10 and the short-circuit current is only 4 to 6 amperes. These batteries are intended for closed-circuit work where the drain is not in excess of 50 milliamperes, but can be used for larger currents on intermittent service. They are used in telephone and telegraph work.

5. Silver-chloride Cells

These are small cells having zinc and silver as the electrodes and are depolarized by a mass of silver chloride around the silver electrode. One brand is 6 cm. ($2\frac{3}{8}$ in.) high and 2 cm. ($\frac{3}{4}$ in.) in diameter, completely sealed at the top by plaster of Paris. The open-circuit voltage is 1, and they can deliver a current on short circuit of one half ampere, but they are intended for use where only small currents are required. The cells have a capacity of about $1\frac{1}{2}$ ampere-hours. These cells have good lasting qualities. They can also be made in smaller sizes. On account of the silver that they contain they are expensive, but have some salvage value after being used. These cells are frequently used in medical apparatus and some wireless apparatus.

Another manufacturer has made a larger size of silver-chloride dry cell. These are incased in hard-rubber cylinders with screwed-on top so that the cell may be opened and recharged when necessary. To relieve the pressure due to the formation of gas during the action of the cell, these are provided with a small rubber nipple on the top of the cell. The cells are 5 cm. (2 in.) in diameter and 10.5 cm. ($4\frac{1}{8}$ in.) high, to which the terminals and nipple add about 2 cm. ($\frac{3}{4}$ in.). These cells are intended for use in an upright position, but may be inverted without spilling any liquid. The zinc element is heavily amalgamated. The open-circuit voltage is about 1 volt per cell, and the maximum current which they can deliver is about 2.5 amperes. When the cell has stood on open circuit for some time, both the voltage and maximum current are lower than the above figures. Both rise after some current has been drawn from the cell. This is characteristic of both kinds of silver-chloride cells.

IV. ELECTRICAL CHARACTERISTICS OF DRY CELLS

1. Behavior in a Circuit

By the open-circuit voltage of a dry cell is meant the electromotive force of the cell when it is not producing any current. Such a measurement can be made on a potentiometer. If a resistance is connected across the terminals of a cell, a current will flow through the circuit from higher to lower potentials; that is, it flows from the carbon to the zinc. The current, however, does not begin with the carbon and end with the zinc, but flows through the cell also. It is evident, then, that within the cell the current flows from the electrode of lower potential to the electrode of higher potential, being made to do so at the expense of the chemical energy of the cell.

If a potentiometer be used to measure the potential difference at the terminals of a cell when it is discharging through an external circuit, it is found that the voltage measured is less than for the cell on open circuit. Designating the open-circuit voltage of the cell by E, and the potential difference at the terminals of the cell by E' when a current I is flowing through an external resistance R it is found that:

$$E' = IR \tag{1}$$

That is, Ohm's law is here applied to the portion of the circuit which is external to the cell. The difference $E-E'$, therefore, represents the voltage drop in the cell itself. Since the current is the same in the cell as in the external circuit Ohm's law shows that:

$$E - E' = Ib \tag{2}$$

where b is a quantity that represents the internal resistance of the cell itself.

Adding equations (1) and (2) the general expression for Ohm's law as applied to the entire circuit becomes

$$E = IR + Ib$$

or

$$I = \frac{E}{R+b} \tag{3}$$

The total resistance of the circuit is the sum of the external resistance of the circuit and the internal resistance of the cell. For the ordinary dry cell, when fresh, b is a small quantity and may usually be neglected in comparison with R, but as the cell is used up b increases and I decreases. When the cell is no longer able to perform its service, it will be found that while E has decreased somewhat, b has increased to many times its initial value.

The maximum current which a cell can deliver is by equation (3), putting $R=0$:

$$I=\frac{E}{b} \tag{4}$$

In making measurements, R can not be made exactly zero, since the shunt and lead wires of the ammeter must necessarily have some resistance. This resistance, however, can be made very small. In standard practice it is usually 0.01 ohm. When $R=0$, or nearly so, the value of I is called the short-circuit current of the cell.

Electrical power is the rate of expenditure of electrical energy and is measured in watts. The watt is the power when a current of 1 ampere flows through a resistance of 1 ohm. Consequently the number of volts multiplied by the number of amperes equals the number of watts; or, in general

$$IE=P.$$

The power derived from the cell at any time is therefore the product of its electromotive force E by the current which flows, I. Part of the energy is expended in the cell itself and part in the outside circuit. Since the current is the same throughout the circuit the expressions for the energy in the battery and outside of it are obtained by multiplying I by the fall in potential in each part of the circuit. Inside the cell, this is

$$(E-E')I=P_1 \tag{5}$$

Outside the cell, it is

$$E'I=P_2 \tag{6}$$

Referring to equations (1) and (2) above, the values for $(E-E')$ and E' in terms of current and resistance are obtained. Substituting these in equations (5) and (6) and at the same time adding these equations

$$P=P_1+P_2=I^2b+I^2R \tag{7}$$

Assuming that $R=0$ or is nearly so, I^2R also equals zero, leaving the equation for the power expended

$$P=I^2b.$$

This means that when the cell is delivering its maximum current (equation 4) all the power is expended in the cell itself and is dissipated in the form of heat. Although 30 amperes or more may thus be drawn from the cell, the current does no good except to indicate the condition of the cell. On the other hand, equation (7) shows that for any value of I which may be desired the smaller b is, the less power is wasted in the cell itself. For this reason a small value of b is desirable. The equation also shows that the power expended in the cell increases as the square of the current flowing, which indicates that the importance of making b small in cells intended for ignition and heavy duty is greater than in the case of telephone and light-service cells. Certain practical limitations enter in fixing the resistance of the cells which show that excessive short-circuit currents are not a desirable feature. This is because cells giving the largest short-circuit currents often, but not necessarily, deteriorate the most rapidly, and are therefore of service only for heavy duty which will exhaust them before their usefulness is impaired by the deterioration when standing on open circuit. The curves (Fig. 3), taken from a paper by Hambuechen[5], represent the relative deterioration of cells of differing short-circuit currents which were on the market a few years ago.

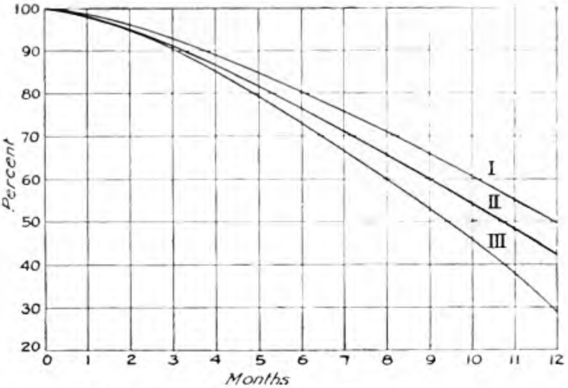


Fig. 3. Deterioration of Dry Cells on Open Circuit

Curves show Hambuechen's values for short-circuit current during 12 months expressed as percentages of the initial short-circuit current. Curve *I* for 20-ampere cells; Curve *II* for 25-ampere cells; Curve *III* for 30-ampere cells.

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[5] Trans. Am. Electrochem. Soc., 21, p. 300; 1912.

Some dry cells, which in the beginning show excessively large currents on short circuit, may increase in resistance so rapidly that they will give less service than other cells of the same size, but having smaller initial currents. The tendency in this country toward cells of very large flash currents has been partly due to a mistaken idea that the more current that can be drawn from a cell, the more service it will render. European cells generally are higher in internal resistance than American cells.

2. Internal Resistance of Dry Cells

From what has been said above about the resistance of the cell itself, it might be implied that b is a definite and constant physical quantity. Such, however, is not strictly the case. The resistance of a cell is ordinarily defined by the equation

$$\frac{E-E'}{I}=b \qquad (8)$$

but it can easily be shown that for various values of I different values of b are obtained apart from any consideration of polarization phenomena. By experiment it is found that the larger values of b correspond to the smaller values of I, but that for the currents ordinarily required of a dry cell the values of b are small and do not change very rapidly with changes in I. The practice of a few manufacturers to state the internal resistance of their dry cell to the thousandth part of an ohm is not to be commended, since it means nothing more than the open-circuit voltage divided by the short-circuit current, and it does not represent the resistance of the cell under working conditions.

When the cell is new, the resistance b is ordinarily small, but it increases with the age and use of the cell. This is not due to the drying out of the cell by evaporation as is often supposed, although that may be a minor cause. The reactions of the cell due to the passage of electric current result in the formation of double chlorides and basic chlorides, which probably take up water in their formation and also clog the pores of the paper lining or paste, as well as incrusting the surface of the zinc. In this way the available path for the flow of current is restricted and the resistance of the cell increased. As the cell is used, the MnO_2 is gradually reduced and the surface of the cathode moves inward as explained on page 1013. This makes the path between the zinc and the cathode a longer one, which also increases the resistance of the cell. The resistance of the cell increases slowly at first, but later increases very rapidly to large values; in some cases reaching hundreds of ohms.

3. Grouping of Cells

For most purposes dry cells are used in groups or batteries, the number of cells depending on the service required. It is desirable to arrange the grouping in such a way as to secure the most economical service. Two factors are involved in arranging the cells; one is the voltage requirement and the other the current requirement. When cells are connected in series—that is, when the positive pole of one cell is connected to the negative pole of the next and so on to the end of the row, Fig. 4, the voltage of the cells is additive. Two cells in series will give twice the voltage of one cell, and five cells will give five times the voltage of one, assuming that the cells, taken individually, are of the same voltage. If the voltage of one cell is E, the voltage of s cells in series is sE. When the cells are discharging, the voltage continually decreases. For this reason the number of cells required for a certain operation can not be estimated on the basis of 1.5 volts per cell. The average working voltage of the dry cells may perhaps be taken as 1 volt per cell. If the voltage required is 4 volts, this means 4 cells in series. Another rule that is sometimes useful when the voltage requirement is not known is to connect cells in series, adding one at a time until the apparatus can be made to operate; then add an extra cell for each group of three or a fraction. This works out to give the same result in the example just given.

The rate at which the voltage will decrease when the cells are in use will vary with the current and duration of the discharge. A cell which will give 40 hours' service under normal conditions will not generally give 20 hours' service under twice the load. It may not give more than 10 hours. (See Table IX.) On the other hand, if the load is made very light, the service actually rendered may be small because the deterioration of the cell becomes an important factor. As a guide

Fig. 4. Cells Connected in Series

to the proper use of the cell, the information obtained from one of the manufacturing companies is given in Table VI.

The current drain on the cells can be relieved when necessary by arranging the cells in parallel, or as it is also called "multiple." Cells are arranged in parallel by connecting the like poles together. Fig. 5 shows cells connected in parallel.

When more than three cells are involved in a series and parallel connection, there is a choice of arrangement. The cells may be arranged in several rows connected in series and then these rows connected in parallel (Fig. 6), or they may be arranged in parallel groups which are then put in series (Fig. 7).

TABLE VI
CURRENT DRAINS FOR ECONOMICAL USE OF DRY CELLS

Duration of Daily Discharge, in Hours	Maximum Drain on Each Row of Cells in Series, in Amperes
16–24	0.10
8–16	.15
4– 8	.25
2– 4	.50
1– 2	.75
1/2–1	1.00
1/4–1/2	1.50
1/6–1/4	2.00
Few moments	10–15

Mathematically, the result is the same in either case. The voltage of the battery as shown in both figures is five times the voltage of a single cell, and the current furnished by any one cell is only one third of the total current. The choice between the arrangements arises from the fact that one or more of the cells may fail before the others. For example, if any cell in each diagram should increase considerably in resistance, it would practically exclude one row of cells of the first diagram, Fig. 6, from service, reducing the battery to practically two rows. In the second case, Fig. 7, the battery would have four groups of three cells and one group of two cells, the effect of the bad cell being reduced to a minimum. In terms of resistance of the battery, the spoiling of the cell in the first diagram increases the resistance of the battery by 50 per cent, while in the second diagram it increases the resistance of the battery by only 10 per cent.

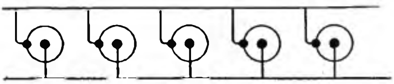
Fig. 5. Cells Connected in Parallel

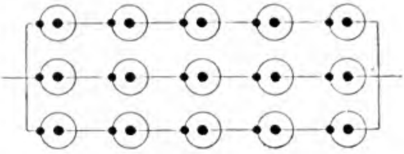
Fig. 6. Parallel of Series-connected Cells

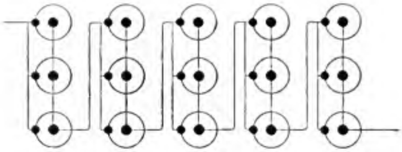
Fig. 7. Series of Parallel-connected Cells

As the internal resistance of the dry cells increases, the current which they will deliver to any given circuit will decrease. If there are n cells, arranged s cells in series and p rows in parallel, the electromotive force of the battery will be sE, and if each cell has a resistance of b, the resistance of the battery will be $\frac{sb}{p}$. Applying Ohm's law to a circuit containing such a battery, equation (3) becomes:

$$I=\frac{sE}{R+\frac{sb}{p}} \qquad (9)$$

The maximum current that the battery can supply (when the external resistance is zero) is:

$$I=\frac{sE}{\frac{sb}{p}}=p\frac{E}{b} \qquad (10)$$

which is analogous to equation (4) given on page 1021.

Whenever it may be necessary to use old cells for any purpose and the resistance of the cells has become of the same order of magnitude as the resistance of the external circuit, a choice arises between the series and parallel connections of the cells. If the resistance of the individual cells is less than the resistance external to the battery, more current can be forced through the circuit by putting the cells in series; but if the resistance of the individual cells is equal to the external resistance, the current is the same whether the cells are in series or parallel. If the resistance of the individual cell exceeds the resistance external to the battery, more current can be obtained by putting the cells in parallel.

4. Effects of Temperature on Dry Cells

Dry cells are affected by changes in temperature. Generally speaking, temperatures above 25 deg. C. (77 deg. F.), are detrimental. The effect of temperature on the electromotive force is small, and for most purposes can be neglected, but in other respects temperature changes produce effects that are more marked. These will be discussed in greater detail.

(*a*) *Effects of Temperature on Storage.*—Heat produces deterioration of dry cells in two ways. First, it tends to produce leakage; this may be observed when the sticky electrolyte has oozed out around the seal of the cell. Second, it increases the rate of the chemical reaction taking place within the cell. The deterioration of the cells is usually measured by the decrease in the short-circuit current with time when the cells are stored on open circuit. This is not a true criterion of the decrease in service capacity of the cells, but is the most convenient method of estimating the depreciation. In Table VII is given the percentage decrease in short-circuit current at the end of 10 weeks for cells stored at various temperatures. The figures have been taken from an article by Pritz.[6] The table shows that it is necessary to keep the cells as cool as possible while they are in storage or being shipped. Temperatures of 55 deg. C. or above are not likely to be reached under any ordinary conditions of storage.

TABLE VII

EFFECT OF TEMPERATURE ON THE SHORT-CIRCUIT CURRENT OF DRY CELLS STORED ON OPEN CIRCUIT

Temperature of Storage	Percentage Decrease in Short-circuit Current at End of 10 Weeks
5 deg. C. (41 deg. F.)	4.4
25 deg. C. (77 deg. F.)	10.0
35 deg. C. (95 deg. F.)	19.0
45 deg. C. (113 deg. F.)	25.0
55 deg. C. (131 deg. F.)	52.0
65 deg. C. (149 deg. F.)	71.0
75 deg. C. (167 deg. F.)	98.0

(*b*) *Effects of Temperature on Short-circuit Current.*—Between 10 deg. C. and 80 deg. C. (50 deg. F. and 176 deg. F.) the short-circuit current increases by approximately 1 ampere for each 10 deg. C. (18 deg. F.) rise. At the lower temperature it is somewhat greater than this and at the higher temperatures somewhat less. Cells which are frozen may show only small currents, but, according to Ordway,[7] they may be thawed out and become normal. If, however, the electrolyte becomes entirely solidified, the voltage and current are reduced to zero, and it is not certain whether they can become normal again after being thawed out.

(*c*) *Effect of Temperature on Service Capacity.*—For heavy service a moderately high temperature is desirable, but for light service a low temperature is necessary. The data of Table VIII are taken from Pritz,[8] showing the hours of continuous service from cells of the same manufacturer when discharged through various resistances until the closed-circuit voltage had fallen to 0.5 volt. The cells used for these measurements were probably the 6.5 by 15 cm. (2½ by 6 in.) size. Exactly the same figures for the 2-ohm and 32-ohm tests were also given by Ordway[9] in a previous paper.

Table VIII shows that 50 deg. C. (122 deg. F.) is the most favorable temperature when the external resistance is 8 ohms or less, and that 0 deg. C. (32 deg. F.) is the best for the low rates of discharge on continuous service. However, a word of caution is necessary in applying this table to actual use of cells. This is a continuous test, while cells are used ordinarily only part of the time. Hence, the heat that may seem to make the cell more efficient in some cases may also cause so much deterioration during the idle periods as to be disadvantageous. For example, Table VIII shows 160 hours' service at 50 deg. C. when discharging through 4 ohms; but this is less than seven days. Table VII shows that at this temperature the deterioration of the cell as measured by the short-circuit current is about 4 per cent per week on the average. If the cells were to be used over a period of several weeks, the hours of actual service obtainable would be much less than those shown in Table VIII. The obvious remedy is to keep the temperature lower.

5. Capacity of Dry Cells

Very little information that is exact is available on the capacity of dry cells. It is impossible to state their ampere-hour ca-

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[6] Trans. Am. Electrochem. Soc., *19*, p. 39; 1911.
[7] Trans. Am. Electrochem. Soc., *17*, p. 357; 1910.
[8] Idem. *19*, p. 39; 1911.
[9] Idem. *17*, p. 358; 1910.

TABLE VIII

HOURS OF SERVICE OF DRY CELLS DISCHARGING AT VARIOUS RATES AND TEMPERATURES

Temperature	RESISTANCE OF EXTERNAL CIRCUIT IN OHMS					
	2	4	8	16		
0 deg. C. (32 deg. F.)	40	80	270	560	1800	[illegible]
25 deg. C. (77 deg. F.)	60	94	260	700	1550	1600
50 deg. C. (122 deg. F.)	70	160	350	650	1250	1420
75 deg. C. (167 deg. F.)	65	158	315	615	1390	1700

pacity, as is done for storage batteries, because so much depends on the condition of the cells, the way they are made, the way they are used, and the arbitrary choice of an end point.

Under specified conditions, however, some information is available for the most common size of dry cell (6.5 by 15 cm.) or (2½ by 6 in.). Since dry cells are mostly used on circuits of which the resistance is constant or nearly so, the results are usually expressed as the number of hours or days that the cell will continue to give service on this circuit; that is, the number of hours until the impressed voltage has fallen to some value such that the current flowing is insufficient. It is customary therefore to express the capacity of dry cells as hours of discharge to certain arbitrary values of the voltage. Table IX taken from Ordway's[10] paper shows the number of hours of continuous service at various discharge rates to various end points.

This table shows clearly the gain in hours of service that is to be obtained by making the current drain light. For the end point 1.2 volts discharging through 2 ohms, 4.3 hours were obtained, but at one fourth this current the cell gave eight times the service and at one twentieth this current, 125 times the service.

When the cell is used intermittently, the actual service obtained to a given end voltage is ordinarily greater than when it is used continuously. Ordway[11] has shown that at light loads the deterioration of the cell on open circuit becomes a factor, so that the cell may be more efficient in the later stages of its discharge when the discharge is continuous.

In using Table IX it must not be assumed that when the voltage has fallen to one half its initial value that the cell is one half discharged. The true measure of discharge of the cell is the ratio of the energy delivered to the total energy contained, and this must be measured in watt-hours.

Ordway gives in connection with the material which we have used in Table IX a similar table expressing the capacity of the cells in watt-hours. His figures are given in Table X for No. 6 cells. It is seen that to obtain the same amount of energy at the higher rates of discharge it is necessary to carry the voltage to a lower point than is the case for smaller rates of discharge.

Just as the voltage is not a criterion of the service capacity remaining in the cell, so also the short-circuit current is not a true measure of the cell's capacity. Excessively large short-circuit currents when the cell is new do not indicate that such cells will give more service than others yielding average currents. These excessive currents which are sometimes produced for advertising purposes may be the result of harmful additions to the usual

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[10] Trans. Am. Electrochem. Soc., *17*, p. 352; 1910.
[11] Trans. Am. Electrochem. Soc., *17*, p. 354; 1910.

TABLE IX

HOURS OF SERVICE TO VARIOUS WORKING VOLTAGES FOR VARIOUS DISCHARGE RATES

End Point, in Volts	RESISTANCE OF EXTERNAL CIRCUIT IN OHMS						
	2	4	8	16	24	32	40
1.2	4.3	10	39	142	260	414	549
1.0	9.3	35	94	296	548	889	1148
0.8	16.5	51	143	414	751	1078	1550
0.6	28.2	76	225	954	1240	1600	1763
0.4	55	207	648	1197	1711	2280	2040
0.2	160	450	882	1318	1914	2626	3140

ingredients of the cell. With any given brand of cell, a test that shows, for example, a decrease of 40 per cent in the short-circuit current does not mean that 60 per cent of its service capacity remains. This matter is discussed more fully under the tests for dry cells on page following.

V. TESTING DRY CELLS

The difficulty in testing dry cells arises from the fact that the cells under varying conditions will yield different amounts of service. For this reason it is not possible to state the service capacity of any kind of dry cell in arbitrary figures, unless the test itself is practically the same as the use to which it is to be put. No way has been found as yet to make accelerated tests that shall include all the factors entering into the performance of the cells. Table IX has shown that as the load on the cell is increased the hours of service rendered by the cell are more than proportionately decreased. Accelerated tests do not include the important matter of the open-circuit deterioration. Intermittent tests are long continued and the results are generally not obtainable until after the cells from which the test sample was taken have lost a large part of their usefulness.

Except for current and voltage measurements which can be made quickly and without injury to the cells, the only feasible method of testing the cells seems to be to make frequent tests on various brands of cells. These tests can give information on the relative service to be expected from the different brands and indicate the quality of materials in use and the systematic efficiency of their manufacture. The current and voltage measurements will indicate accidental imperfections in the cells, if such exist, and, with certain restrictions, will indicate the age and condition of the cells. Tests for dry cells were described in considerable detail by Ordway[12] in this country and Melsom[13] in England.

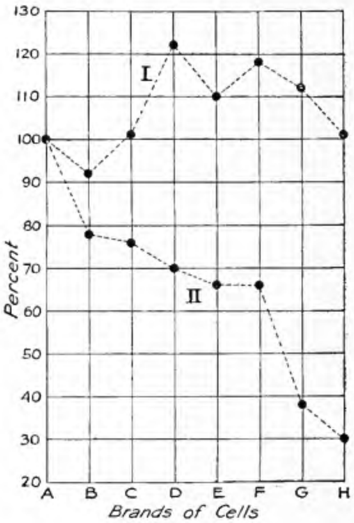

Fig. 8. Relative Short-circuit Current and Service Capacity of Eight Brands of Cells. (Observations by Pritz)

The points connected by dotted line *I* represent the initial short-circuit currents of the cells expressed in terms of brand *A*. Points connected by dotted line *II* represent the service capacity of the same cells also expressed in terms of brand *A*.

A committee of the American Electrochemical Society was appointed to investigate

TABLE X

ENERGY DELIVERED BY DRY CELL WHEN DISCHARGING CONTINUOUSLY THROUGH VARIOUS RESISTANCES TO VARIOUS END POINTS

(Expressed as watt-hours)

End Point, in Volts	RESISTANCE OF EXTERNAL CIRCUIT IN OHMS						
	2	4	8	16	24	32	40
1.2	3.7	4.3	8.1	15.2	18.8	21.7	23.8
1.0	6.7	13.0	16.5	26.9	33.4	39.8	42.0
0.8	9.7	16.3	21.5	32.8	40.3	44.6	50.6
0.6	12.5	19.4	26.6	48.9	49.5	52.7	53.2
0.4	15.4	27.3	39.1	52.6	54.3	58.2	54.8
0.2	19.8	32.6	41.5	53.3	55.2	59.3	57.1

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[12] Trans. Am. Electrochem. Soc., *17*, p. 341; 1910

[13] Trans. Faraday Soc., *8*, p. 1; 1912.

the subject. They made a report[15] in 1912 embodying most of the tests previously described by Ordway. The tests in general use today are essentially the same as were recommended at that time. Some differences, however, have been generally accepted, but these are differences of detail rather than principle. There are no tests that have been standardized and universally adopted.

1. Open-circuit Voltage Test

This is usually made with a voltmeter through which some current necessarily flows. It is therefore not strictly an open-circuit measurement, but the current which flows through the voltmeter is generally so small that the voltage of the cell is lowered by an amount which is negligible. An accurate voltmeter of at least 100 ohms resistance per volt of the scale divisions may be used for this purpose. The true open-circuit voltage of cells is most conveniently obtained by measuring them with a potentiometer, but this is possible only in the laboratory.

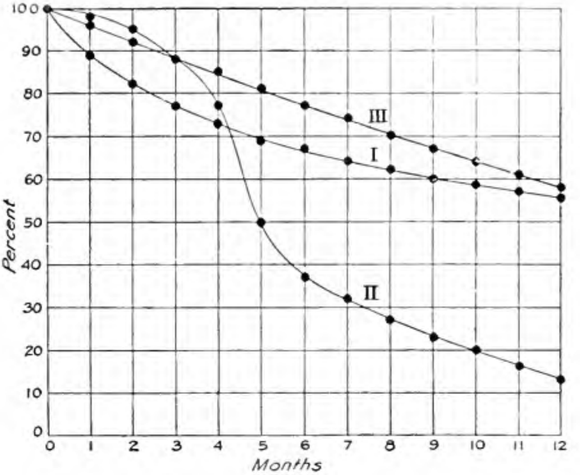

Fig. 9. Relation Between Deterioration in Short-circuit Current and Service Capacity for Cells Stored for Various Periods of Time on Open Circuit

Curve *I* shows deterioration measured by the short-circuit current test; Curve *II* by service rendered on the ignition test; Curve *III* by service rendered on the telephone test.

The voltage of a new unused dr[illegible] from 1.50 to 1.65 volts. Higher [illegible] are sometimes found, but do n[illegible] superiority of the cell. Lower voltages [illegible] 1.5 volts may indicate deterioration due [illegible] or short circuit or some other serious de[illegible]. The value of the open-circuit voltage test considered alone is small. It [illegible] indication of service capacity and it changes by only a small amount relatively during the life of the cell. One cell under observation at the Bureau for 16 years still shows 1.25 volts when measured on the potentiometer, although its resistance has increased so that a voltmeter measurement such as is described above shows only 0.30 volt.

2. Short-circuit Current Test

This test as described by the committee of the Electrochemical Society is commonly in use at the present time. A deadbeat ammeter accurately calibrated must be used. The resistance of the lead wires and shunt of the ammeter should have a value of 0.01 ohm to within 0.002 ohm. The maximum swing of the needle is taken as the short-circuit

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[14] Trans. Am. Electrochem. Soc., *21*, p. 275; 1912.

[15] Report of committee on dry-cell tests. Trans. Am. Electrochem. Soc., *21*, p. 278; 1912.

current of the cell. The lead wires are conveniently tipped with lead to make good contact and should be applied to the brass terminals of the cell. Results of tests vary with the temperature. They should be made only when the cell is at normal room temperature; that is, about 70 deg. F.

The value of this easily made test lies in its indication of the condition of the cell as compared with the normal value of cells of the same manufacture and brand. Thus, if the brand of cell is known to average 30 amperes when new and unused and the cell under test shows about this value, it is reasonably certain that the cell is in good condition. This test gives no indication of the service capacity of different brands of cell as is shown in Fig. 8, taken from a paper by Pritz[16] in which the short-circuit current of eight different brands is compared with the service capacity of the same cells.

Some cells manufactured expressly for long-continued service give only 18 to 20 amperes when new, so that it is obviously unfair to compare them with 30-ampere ignition cells. But a cell which should give 30 amperes initially, which gives only 18 amperes on short circuit, has lost a large part of its service capacity, at least for heavy drains.

The decrease in service capacity does not, however, follow the decrease in short-circuit current. In Fig. 9 are given comparative results at different periods extending over a year on cells stored on open circuit. The results as expressed by Curve I represent the short-circuit current as a percentage of the original value. Curve II shows the actual service that the cells can render on the standard ignition test at the periods shown. It will be noted that these results differ greatly from those of Curve I. Curve III shows the results of the telephone test on these cells at the same time. In this case the results follow the short-circuit deterioration more closely. The data for these curves has been obtained from one of the manufacturing companies.

The two tests outlined above are the only ones at present in use that can be easily and quickly made without destroying the cells. If made with a proper understanding of what is to be expected of the particular cells under test, they afford valuable information. Otherwise they may be misleading.

3. Intermittent Tests

These have been made to imitate the use of cells under average conditions. They are of three kinds—one representing heavy service and generally called the ignition test, the second representing light service and called the telephone test, and the third for flashlight batteries.

(*a*) *Ignition Test.*—Six cells connected in series to a circuit of 16 ohms are discharged for two periods of one hour each per day, the periods being 11 hours apart. The test is considered complete when the impulse current through 0.5 ohm at the end of a period of discharge falls below 4 amperes. This test has been somewhat modified in recent years by some manufacturers to permit using a smaller number of cells in the group. In such cases the resistance of the circuit and the coil for measuring the impulse current are reduced proportionately. The results of the test are expressed as the number of hours actual discharge to the end point.

(*b*) *Telephone Test.*—This test, as described by the committee mentioned above, consisted of discharging three cells connected in series through 20 ohms for two-minute periods each hour, 24 hours per day and 7 days per week, until the closed-circuit voltage of the battery at the end of a period of contact falls to 2.8 volts. This has been modified and supplanted by the so-called A. T. and T. telephone test which is as follows: Three cells connected in series are discharged through 20 ohms for 10 periods of four minutes each in 10 consecutive hours of six days per week. On the seventh day every other period is omitted. The end of the test is taken at 2.8 volts for the battery on closed circuit. The results are expressed as the number of days the test lasted.

(*c*) *Flashlight Test.*—The battery is discharged for a five-minute period once a day through a resistance of 4 ohms for each cell in series in the battery, until the working voltage falls to 0.75 volt per cell. The results are expressed as the number of minutes of actual discharge. At the present time the end point is generally taken as 0.50 volt per cell on closed circuit instead of 0.75 volt because the modern lamps are usable to a lower voltage. In making this test it is necessary to use fixed resistances of the proper value rather than small lamps because the lamps differ among themselves, and the resistance of the lamps changes by a large amount as the impressed voltage changes.

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[16] Trans. Am. Electrochem. Soc., *19*, p. 33; 1911.

4. Continuous Tests

These tests are simpler and quicker to make, but they do not afford such definite information about the value of the cells as the intermittent tests, because they do not bear a close relation to actual service either in the matter of the current drain or length of service. Continuous tests have been used more in Europe than in this country, possibly because so many of the European cells are of the bag-type construction with a very thick layer of paste which reduces the open-circuit deterioration.

(*a*) *Large-size Cells.*—For the No. 6 and larger sizes of cell, a satisfactory continuous test is to discharge the cell through a fixed resistance of 10 ohms until the voltage has fallen to some arbitrary figure which may conveniently be taken as 0.75 volt per cell. Continuous tests at large currents give very little information of value, but at small currents afford information about the uniformity of manufacture. Sometimes the continuous tests are modified by allowing a period of rest during part of the day. This, however, does not sufficiently approach the intermittent use in actual service to be of much value.

(*b*) *Flashlight Cells.*—Continuous tests of flashlight cells give information as to the relative manganese content, but do not take into consideration the important matter of open-circuit deterioration. It has been found by Gillingham[17] that the continuous discharge of flashlight cells through resistances of 2.75 ohms for each cell in series gives the best approximation to the actual life of the cell discharging at 0.35 ampere through a lamp. Burgess[18] has recommended continuous discharge of flashlight cells for 10 hours per day through 4 ohms per cell. The exact value which will most nearly approximate the burning conditions will, of course, depend on the characteristics of the flash lamps which have not been standardized. It is commonly found that flash lamps burning at their rated voltages take 0.30 to 0.35 ampere. Some lamps of low efficiency are on the market as well as some of very high efficiency. The latter will burn out quickly on a good battery, but are sometimes used to hide the deficiencies of a poor battery. The only accurate test of a flashlight battery is to discharge it through a fixed resistance of suitable value and not to use a flash lamp, as is often done.

5. Shelf Test

This test consists in storage of the cells on open circuit at room temperature over a considerable period of time during which the changing condition of the cells is ascertained by open-circuit voltage and short-circuit current readings. No definite end point is taken, but the results are expressed as per cent drop in amperage for certain periods of time. This is an important test, and should be made at as nearly a constant temperature as possible.

6. Other Tests

Besides the tests mentioned above it may be desirable to make other tests, such as will include other physical measurements, chemical examination, and the effect of shock and heat. For these no definite procedure has been established. A superficial physical examination will often serve to indicate certain defects, such as loose terminals, leaking seals, flaws in the zinc and loose cartons.

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[17] Trans. Am. Electrochem. Soc., *30*, p. 267; 1916.
[18] Idem., p. 257; 1916.

A Simple Electric Water Heater for the Utilization of Surplus Hydro-electric Power

By H. A. Winne

Power and Mining Engineering Department, General Electric Company

The simple and substantial electric water heater described in this article has been developed to take the place of fuel-fired water heaters in those industrial plants that are operated by isolated hydro-electric stations. As surplus electric power is ordinarily available under such conditions, the use of the electric heater will save the cost of the equivalent fuel minus the capital and depreciation charges on the heater.—Editor.

There are a number of industrial plants in this and other countries which have isolated hydro-electric generating stations. In almost every one of these plants the generating capacity exceeds the actual power requirements during the major portion of every day. Usually the water necessary to develop the surplus capacity is available during the greater portion of the year. The generating plant can be operated at full capacity at almost no increase in expense over that required to operate it at eighty per cent, or ninety per cent, or whatever percentage of full capacity is required in the off-peak periods. Therefore, if this surplus or "dump" power can be used or sold, the revenue obtained from its use or sale is practically one hundred per cent profit.

For industrial purposes, many of these plants require hot water or steam, and employ fuel-fired heaters or boilers to produce it. If the surplus or "dump" electric power were converted into heat and were used for heating the water in a simple rugged heater, the cost of the amount of fuel saved, less the capital and depreciation charges on the heater, would represent a net decrease in operating expenses.

Pulp and paper mills are representative of the type of plant under consideration. These usually obtain power from individual hydro-

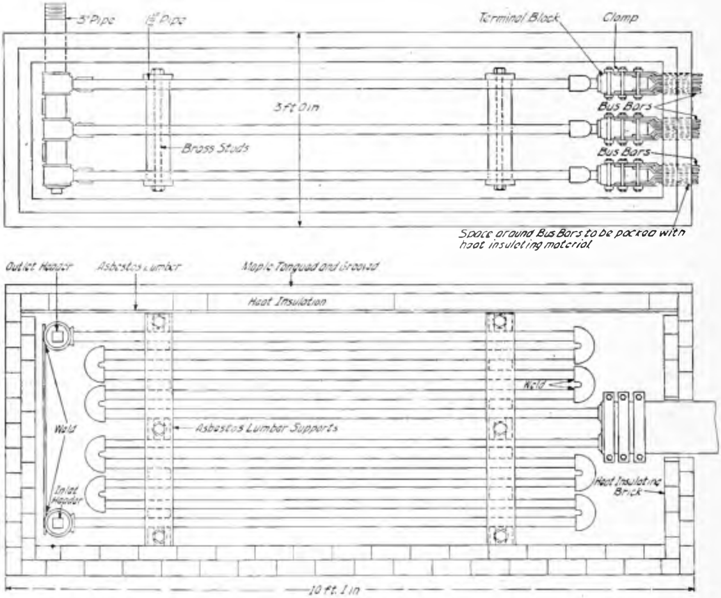


Fig. 1. Plan and Elevation of a 1000-kw. Pipe-type Electric Water Heater

electric plants. They require steam for drying paper and numerous other purposes, and some require hot water for washing pulp in the blowpits. An electric water heater can be utilized either to heat water for direct use in washing, or as a "temperature booster" in the boiler feed water line between the usual feed water heater and the boilers

Description of Heater

A very simple, rugged and inexpensive electric water heater can be built of ordinary standard wrought iron pipe. Briefly, the heater consists of a length of iron pipe, through which the water to be heated flows, and through the walls of which an electric current is passed. Since iron pipe has a considerable electrical resistance, the flow of current through its walls generates heat which is transmitted to the water.

A heater designed to absorb 1000 kilowatts of three-phase power is shown in plan and elevation in Fig. 1; while Fig. 2 is a diagrammatic sketch of the complete system of water and electrical connections.

This heater consists of three sections, in multiple so far as the hydraulic connections are concerned. Each section is built up of ten lengths of $1\frac{1}{2}$-inch wrought iron pipe, eight standard return bends, and one special return bend arranged for connection to busbars. These three sections are mounted side by side on asbestos lumber or other insulating supports, and are connected to the inlet and outlet headers *E* and *D*. All joints between the heater pipes and bends or headers, in addition to having standard pipe thread, and are welded to prevent any possibility of water leakage. The welding of the joints also provides good electrical contact, eliminating any possibility of overheating.

The heater is enclosed in a chamber, the walls of which are built up of heat-insulating brick, with a cover so arranged as to be readily removable for inspection. Owing to the relatively small dimensions of the complete heater this is an inexpensive method of reducing to a minimum the loss of heat due to radiation.

As shown in Fig 2, the heater may be connected in an existing water system to "boost" the temperature with almost no disturbance of the system. The insertion of two pipe T's and the valve *A* are the only changes required in the existing piping. The inlet and outlet pipes, *I* and *O*, of the heater are connected one to each of the T's, and have a valve in each pipe to provide a means for cutting the heater out of the system. When the heater is in use, valves *B* and *C* are open, and valve *A* is either wholly or partially closed, depending on the volume of water flowing through the main.

The circulation of water through the heater is assisted by the fact that the cold water enters at the bottom and the heated water leaves at the top.

The system of pipe connections shown applies particularly where the heater is to be used as a "temperature booster," as in a boiler feed water line or in the feed pipe to a tank supplying hot water for general purposes throughout the plant.

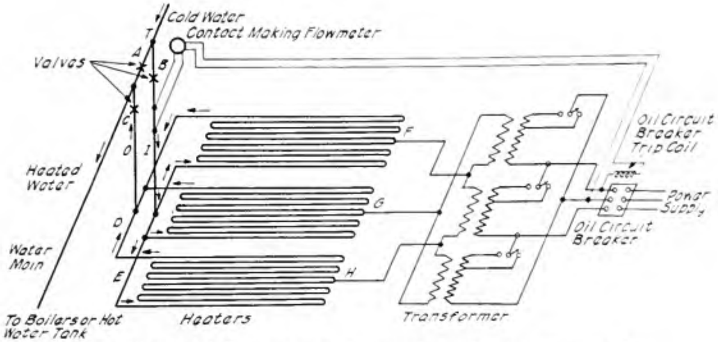


Fig. 2. Diagrammatic Representation of the Hydraulic and Electrical Connections of a Pipe-type Electric Water Heater

Flowmeter

An indicating flowmeter is connected in the inlet pipe, *I*, of the heater. This affords an easy means of determining the correct opening of the valve *A* to give the desired water flow through the heater.

In addition to being an indicating instrument, this flowmeter is provided with electrical contacts which open the electrical circuit whenever the flow of water decreases to a certain predetermined minimum value. The contacts are so designed that they may be easily adjusted to open the circuit at any water flow within the range of the instrument. They are connected with an auxiliary trip coil on the oil circuit breaker, in the power supply line, in such a way that when they open the oil circuit breaker will trip out. This automatic cutting off of the power, in case of reduction of water flow below a safe value, eliminates the possibility of overheating the heater.

If the flow of water through the main is not continuous and the heater is to be used intermittently, the flowmeter may be made to close the oil switch when the flow goes above the minimum safe value, as well as to trip it when the flow stops. This makes the operation of the heater entirely automatic.

Transformer and Switchboard

From the electrical line terminals *F*, *G*, and *H*, the three heater sections constitute three electrical resistances, connected together at the ends opposite the line terminals by the headers *E* and *D*. Since the three sections are similar, their resistances will be equal; and if the terminals *F*. *G*, and *H* are connected to a three-phase supply of suitable voltage, the power input will constitute a balanced three-phase load. Owing to the size of the pipes used, the voltage required will obviously be of a comparatively low value, and can best be obtained from a step-down transformer. On this 1000-kw. heater, 50 volts is required across the heater terminals. The step-down transformer is provided with taps for obtaining a lower secondary voltage, so that the power input can be reduced to 666 kw. when the full 1000 kw. of power is not available.

The transformer is a water-cooled three-phase unit, and occupies little floor space. Its low-voltage terminals are arranged for easy connection to the busbars leading to the terminals of the heaters.

The control equipment consists of a small panel mounting an oil switch, ammeter, watthour meter, and three double-throw disconnecting switches for changing taps on the transformer. These tap-changing switches are placed in a grille work enclosure, the door of which is so interlocked with the oil switch that no manipulation of the tap switches is possible while the oil switch is closed.

The entire equipment, heater, transformer, and switchboard, occupies a floor space eight by twelve feet, and a height of nine feet.

Operating Characteristics

At first thought it might seem that the operating power-factor of any apparatus using iron pipe to carry a heavy alternating current must necessarily be very low, but this is not the case. It is true that at current densities of the usual magnitude the ratio of reactance drop to resistance drop is high, with a consequently low power-factor. However, as the current density is increased the increase in resistance drop is at least as great as the increase in current density, and usually greater, owing to the increase in temperature and consequent increase in resistance of the conductor.

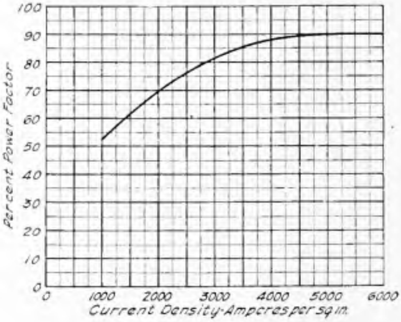


Fig. 3. Power-factor of an Iron-pipe Electric Water Heater for Various Values of Current Density in the Pipe

The reactance drop, however, does not increase in proportion to the current density, for the reason that the iron gradually becomes magnetically saturated as the current density is increased. Therefore as the current density is increased, the ratio of reactance drop to resistance drop gradually decreases, with a consequent increase in power-factor.

This effect is well brought out by the curve in Fig. 3. This curve is plotted from actual test results on a pipe type water heater, operating on a 40-cycle circuit. The heater is designed to operate at current densities high enough to take full advantage of the foregoing characteristic, with the result that a power-factor of 90 per cent is obtained on a 40-cycle circuit. On a 60-cycle circuit a power-factor of at least 80 per cent would be realized, while of course on 25 cycles the power-factor would be well above 90 per cent.

The operating efficiency of the equipment depends of course on the difference in temperature between the heater and the air of the room in which it is installed, the efficiency of the heat insulating inclosure, and the losses in the step-down transformer. Under average conditions the overall efficiency, including tranformer losses, should always be greater than 90 per cent.

Economics

The saving that can be effected by the utilization of "dump" electric power to heat water that would otherwise have to be heated by purchased fuel is in most cases sufficient to make the installation of a heater of the described type well worth while.

For example, we will consider the case of a certain paper mill. This particular mill has a hydro-electric generating plant having a total capacity of 6750 kw. The peak load on the plant at present is about 7200 kw., this peak lasting about two hours. During 15 hours of the day the plant operates at an output at least 1000 kw. below its capacity, and during six additional hours at least 666 kw. below capacity.

The paper mill operates five and one half days a week. Water is available for operating the plant at full capacity during thirty weeks of every year.

Calculating the total kw. hours of "dump" power available in one year we have the following:

Per day
1000 kw. for 15 hours = 15,000 kw-hr.
666 kw. for 6 hours = 3,996 kw-hr.

Total per day = 18,996 kw-hr.

Per week 5.5 × 18,996 = 104,478 kw-hr.
Per year 30 × 104,478 = 3,134,340 kw-hr.

One kw-hr. is equivalent to 3412 British thermal units. Assuming that the electric heater operates at 90 per cent efficiency, a figure which will be exceeded in practice, we have as the total number of B.t.u. delivered to the water by the above amount of power:

$$3,134,340 \times 3412 \times 0.90 = 9,625,000,000 \text{ B.t.u. per year.}$$

To determine the amount of coal that this amount of electrically generated heat will save, we will assume that the coal used has a calorific value of 14,000 B.t.u. per pound and that it is burned under a boiler at an efficiency of 70 per cent. Then, the useful heat generated by the combustion of one pound of coal is

$$14,000 \times 0.70 = 9,800 \text{ B.t.u.}$$

Therefore the total number of pounds of coal saved per year will be

$$\frac{9,625,000,000}{9,800} = 981,000 \text{ pounds or } 490 \text{ tons}$$

With coal at $6.00 per ton, the saving in cost of coal will be 6 × 490 = $2940 annually.

If sufficient water power were available so that the heater could be operated throughout the entire year on the outlined daily duty cycle, the annual saving in cost of coal would be $5096; while if the heater could be operated at full load during the entire time of operation of the mill throughout the year, the saving would be $6430.

The first cost of a 1000-kw. heater, installed complete, including transformer, switchboard, and all bus, cable, and piping connections is approximately $7500. Allowing capital and depreciation charges totalling 20 per cent, the net annual return on the investment, if the heater is operated only 30 weeks per year and on the daily duty cycle outlined, will be $1440, or 19.2 per cent. If operated 52 weeks per year, the return will be 48.0 per cent, and if operated at full load, 5½ days per week, 52 weeks per year, the net annual return will be 65.8 per cent.

Of course in these calculations the cost of power for the heater is assumed to be zero. This is the correct basis, where the heater capacity is only a small portion of the generating plant capacity, and where it is a question of running the generators partly loaded without the heater or more nearly fully loaded with the heater.

On the other hand, if additional generating capacity must be installed to take care of the heater, then the fixed charges on the power plant will be increased, and the heater must be charged with its share of the power costs. Under these conditions it would become a question of balancing the saving in fuel against the cost of power for operating the heater. If, owing to the geographic location of the plant the cost of fuel is high and the cost of power low, the installation of a heater will prove economical.

If the various factors are known, it can easily be determined whether the installation of an electric water heater will be economical. Let

C_c = cost per 2000-lb. ton of coal.
B.t.u. = B.t.u. per pound of coal.
$E_b = \dfrac{\text{per cent efficiency of coal burning boiler.}}{100}$
KW = maximum capacity of heater.
K_h = total kw-hr. input to heater per year.
$E_h = \dfrac{\text{per cent overall efficiency of electric heater.}}{100}$
F_c = annual fixed charges on electric heater.
C_k = cost per kw-hr. at which annual expense of operating heater will just equal saving in cost of coal.

Then

$$\frac{2000 \times \text{B.t.u.} \times E_b}{3412 \times E_h} \times \left(C_k + \frac{F_c}{K_h}\right) = C_c$$

$$\text{Or } C_k = \frac{1.7 \times E_h \times C_c}{\text{B.t.u.} \times E_b} - \frac{F_c}{K_h} \quad \ldots\ldots\ldots\ldots (1)$$

If the cost C_k figured from this formula is greater than the actual cost of power generation, then the installation of the heater will effect an economy in operating expenses.

To determine the actual net saving in dollars per year, let

C_a = actual cost of power per kw-hr.
S_n = net saving per year due to electric heater.

Then

$$S_n = (C_k - C_a)\, K_h$$

$$S_n = \left(\frac{1.7 \times E_h \times C_c}{\text{B.t.u.} \times E_b} - C_a\right) K_h - F_c \ldots (2)$$

To exemplify the use of this formula we will take the case of the paper mill previously considered, using 1000 kw. 15 hours per day and 666 kw. 6 hours per day, 5½ days per week, 30 weeks per year. The values of the various quantities in formula (2) are then

$C_c = \$6.00$
B.t.u. = 14000
$E_b = 0.70$
$K_w = 1000$

$K_h = 3{,}134{,}340$
$E_h = 0.90$
$F_c = \$1500.00$
$C_a = \$0.00$

Substituting these in (2) we have

$$S_n = \left(\frac{1.7 \times 0.90 \times 6}{14000 \times 0.70} - 0\right) 3{,}134{,}340 - 1500$$
$$= 2940 - 1500$$
$$= \$1440, \text{ which is the same result as was arrived at in the foregoing.}$$

Characteristics of Some Polyphase Transformer Connections

By L. F. Blume and A. Boyajian

Transformer Engineering Department, General Electric Company

As practically all electrical engineers are confronted at times with problems in transformer [illegible] the following article has been prepared to facilitate their ready solution. The article is in the nature of [illegible] itemized analysis of the properties of the usual polyphase connections of both transformers and auto-transformers. Even a passing inspection of this contribution will reveal its great usefulness as a [illegible] of reference.—Editor.

THREE-PHASE TRANSFORMER CONNECTIONS

I. Delta-Delta Connection

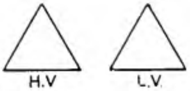


Fig. 1a

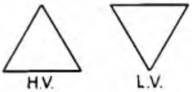


Fig. 1b

Advantages

1. Any three similar single-phase transformers can be connected in delta at their rated voltage, whereas it would not always be permissible to connect them in Y.

2. The bank can operate in open delta when one of the units is disabled, delivering 86.6 per cent of the rated kv-a. of the remaining two units. Shell-type three-phase units must have their disabled phase disconnected from the others and short circuited. Core-type three-phase units must have their disabled phase disconnected and open circuited, which, however, is not always practicable.

3. This connection is free from all third-harmonic voltage troubles. The primary and secondary deltas carry the third-harmonic magnetizing current which does not appear on the lines.

4. For relatively low voltages and high currents the delta connection gives a more economical design than the Y connection.

Disadvantages

1. The neutral cannot be derived.

2. Differences in the voltage ratios of the units cause a circulating current in both primary and secondary windings limited only by their impedances.

3. Differences in the impedances cause unequal load division among the unit.

4. For very high voltages the delta connection costs somewhat more than Y connection.

5. Connection of Fig. 1a cannot be multipled with that of Fig. 1b.

II. Y-Y Connection

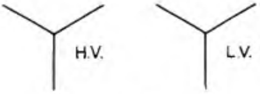


Fig. 2a

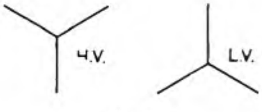


Fig. 2b

Advantages

1. The neutral can be brought out for grounding.

2. Differences in ratio and impedance of the units do not cause any circulating currents or appreciable unequal load division.

3. For relatively high voltages and small currents the Y-connection is generally more economical than the delta connection.

4. A short circuit in or on one unit does not cause a power short circuit; except a very large magnetizing current due to the over-excitation of the remaining units at 1.73 times rated voltage.

Disadvantages

1. The neutral is unstable.

2. The machines cannot be loaded single-phase line to neutral unless the neutral of the primary is connected to that of the generator.

3. There is a third-harmonic voltage from line to neutral (although it does not appear between lines) amounting to as much as 50 per cent in single-phase units, and shell-type three-phase units, and 3 or 4 per cent in core-type three-phase units.

4. If the neutral is grounded, this third-harmonic voltage may be aggravated by the capacitance charging current of the lines, and may also cause telephone interference.

5. The Y-Y bank can not operate temporarily with two units when one of the units is disabled.

6. A short circuit in or on one unit raises the voltage of the other units to 1.73 times normal value.

7. Fig. 2a will not multiple with Fig. 2b.

Recommendations

Due to third-harmonic voltage troubles, the Y-Y connection of high-voltage single-phase units or shell-type three-phase units is not to be recommended except under the following conditions in which a low-impedance path is offered to the flow of the third-harmonic excitation current and thereby the third-harmonic voltage is suppressed. Thus:

1. When the neutral of the primary Y is *permanently* connected to the neutral of the generator. If this connection is opened through any cause, the third-harmonic voltage reappears.

2. If the neutral of the secondary Y of a step-up bank is grounded and is also *permanently* connected to a grounded Y-primary delta-secondary transformer. The third-harmonic excitation current then circulates between the two banks. In this case, however: (a), telephone interference should be taken into consideration; and (b), if the Y-delta transformer is disconnected from the lines, or the ground on its neutral disconnected, or its delta opened, the third-harmonic voltage reappears on the former with the accompanying dangers of resonance.

3. If the secondary Y is *permanently* connected to a synchronous converter in diametric fashion. (See Section XXIV, Y-Diametric Connection.)

4. If the neutral of one Y is permanently connected to the neutral of a zigzag autotransformer (directly or through ground) on the same lines.

5. If auxiliary windings (called tertiary windings) are provided, connected in delta.

The Y-Y connection of core-type three-phase units is always safe whether grounded or isolated, so far as third-harmonic voltage stresses are concerned. However, when such a unit is grounded with a low-impedance return path such as mentioned above, the third-harmonic current in the neutral and lines will be appreciable (although not as large as with banks of single-phase units or shell-type three-phase units) and telephone interference may need consideration.

III. Y-Zigzag Connection.

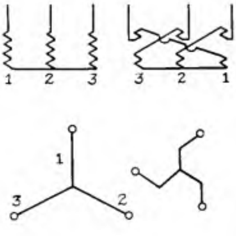


Fig. 3

Advantages

1. The neutral of the zigzag can be grounded without any third-harmonic voltage trouble. A third-harmonic voltage appears in each coil but not from line to neutral on the zigzag side.

2. The machine can be loaded with a single-phase load from line to neutral of the zigzag.

Disadvantages

1. The connection requires 15 per cent more copper for the zigzag than for the equivalent Y.

2. The regulation and efficiency are liable to be somewhat poorer than those of the equivalent delta-Y.

Recommendations

As a standard connection delta-Y is preferable to the Y-zigzag connection. The Y-zigzag connection, however, may be advisable in some exceptional cases as, for instance, when a change in system voltage is contemplated and the transformers may temporarily be operated delta-zigzag to be changed later on to Y-zigzag.

IV. Delta-Y Connection.

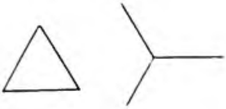


Fig. 4a

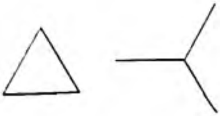


Fig. 4b

This is generally considered to be the most satisfactory three-phase connection.

Advantages

1. The neutral can be brought out both for grounding and for loading.

2. The neutral is stable, being locked by the delta.

3. The connection is practically free from third-harmonic voltages. The delta circulates the necessary third-harmonic magnetizing current.

4. Differences of magnetizing current, voltage ratio, and impedance in the different units are adjusted by a small magnetizing current circulating in the delta.

5. A short circuit in one leg of the Y does not affect the voltages on the secondary lines.

6. A single-phase short circuit on the secondary lines causes a smaller short-circuit stress on a delta-Y step-up bank than on a delta-delta connected one.

7. Connection of Fig. 4a can be multipled with that of Fig. 4b by properly selecting the leads.

Disadvantages

1. The delta-Y bank cannot operate temporarily with two units when one of the units is disabled.

2. A short circuit on or in one unit is extended to all three units.

3. If the delta is on the primary side and should accidentally become opened, the unexcited leg on the Y side may [illegible] the line capacitance and can [illegible]

V. Open Delta or V V Connection

Fig. 5

Advantages

This connection requires only two units and is, therefore, useful as an emergency connection.

Disadvantages

1. The internal power-factor being 86.6 per cent (assuming unity power-factor load) it can deliver only 86.6 per cent of its rated kv-a. capacity. Hence, it is not very desirable for continuous operation.

2. Load voltages become unbalanced under load, even with balanced three-phase load, the magnitude of the unbalancing depending on the impedance of the units and the power-factor of the load.

3. Parallel operation of two-unit banks with three-unit banks is uneconomical. Thus:

Number of Transformers	Connection			Three phase Capacity of Group in per cent of Single phase Rating
3	△			100
2	∧			86.6
2	T			86.6
6	△	△		100
5	△	∧		80
4	∧	∧		86.6
4	∧	∠		82
9	△	△	△	100
7	△	∧	∠	91
7	△	∧	∧	72
8	△	△	∧	88

4. Being electrostatically unbalanced, the V-V connection is not recommended for very high voltage systems.

VI. T-T Connection

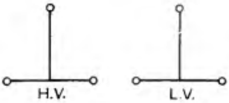


Fig. 6

Advantages

1. This connection is similar to the *V-V* in that it requires only two units.

2. The voltage across the teaser being only 86.6 per cent of that of the main, the core loss in this connection is less than in the *V-V* connection, assuming similar or interchangeable units.

3. The neutral point can be derived and brought out for grounding, although not for loading unless the two halves of the main are interlaced.

Disadvantages

1. Both primary and secondary sides require 50 per cent taps which are not required by the *V-V* connection.

2. The corresponding halves of the primary and secondary of the main must be interlaced, although the two halves of one winding need not be interlaced with each other unless the neutral is brought out on that side and it is desired to be able to load the neutral.

3. Similar to the *V-V* connection, the ratio of output to rating is only 86.6 per cent and the regulation is poor.

THREE-PHASE AUTO-TRANSFORMER CONNECTIONS

General Characteristics

Advantages

1. For a given output, auto-transformers are much cheaper than transformers. This economy is greater the nearer the high and low line voltages approach each other.

2. Auto-transformers give better efficiency and regulation than transformers. This advantage also increases as the ratio of high and low line voltages approaches unity.

Disadvantages

1. The high and low-voltage windings being continuous (i. e., in metallic connection), the low-voltage circuit and connected apparatus are liable to be subjected to abnormal voltages due to disturbances and grounds on the high-voltage circuit. This is particularly objectionable when there is a large difference between the high and low voltages.

2. Short-circuit currents at normal excitation of the unit are larger with auto-transformers than with transformers, and the more so the nearer the high and low voltages are alike. It often is impracticable to design auto-transformers to withstand the thermal and mechanical effects of short circuits.

Since, as the ratio of low-voltage line potential to high-voltage line potential decreases, the economy decreases and insulation dangers increase, auto-transformers are usually considered only when the low voltage is as much as 80 to 90 per cent of the high voltage. A low voltage not less than 50 per cent of high voltage may be considered a good engineering limit for the use of auto-transformers under very favorable conditions.

Recommendations

Auto-transformers may be recommended for isolated systems provided that the low-voltage circuit and connected apparatus are designed to withstand the high-voltage test potential. They may be recommended for grounded systems provided that the neutral of the auto-transformer also is grounded.

VII. Y-Connection

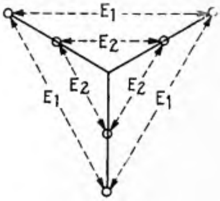


Fig. 7

Advantages

1. This is the most economical and therefore most common auto-transformer connection. The ratio of rating to output is $\frac{E_1 - E_2}{E_1}$ where E_1 is the high-voltage line potential and E_2 is the low-voltage line potential.

2. The neutral may be derived and grounded for the protection of the low-voltage circuit if the generator neutral also is grounded.

Disadvantages

1. Similar to the Y-Y conection of transformers (see Section II) there is a third-harmonic voltage from line to neutral. Single-phase and shell-type units are not recommended, especially if the neutral is to be grounded. Core-type three-phase units may safely be used either grounded or isolated.

2. The machines cannot be loaded single-phase from line to neutral. This is especially true for single-phase units and for shell-type three-phase units. Core-type, three-phase units may give tolerably good results. The best results are obtained by the zigzag connection.

VIII. V or Open-Delta Connection

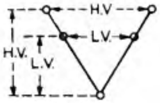


Fig. 8

1. This connection is free from third-harmonic voltage.

2. The ratio of rating to output is 15 per cent more than in the Y-connection.

IX. Delta Connection

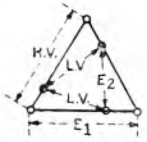


Fig. 9

This connection has characteristics similar to those of delta-delta connected transformers.

1. It is free from third-harmonic voltage.

2. The ratio of rating to output is $\frac{E_1^2 - E_2^2}{1.73\, E_1 E_2}$

3. For a given load, the ratio of the kv-a. rating of this connection to that of the Y-connection is equal to $\left(0.577 + 0.577\frac{E_1}{E_2}\right)$. Thus if the low-voltage line potential is 50 per cent of the high voltage, the delta connection requires 1.73 times the kv-a. rating of the Y-connection. Therefore, when the Y-connection is undesirable on account of third-harmonic voltage, the V or extended-delta connections figure out more economical than the delta connection.

X. Extended-Delta Connection

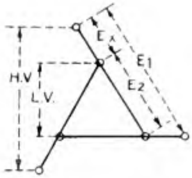


Fig. 10

The ratio of rating to output is $1.73\,\frac{E_x}{E_1}$, or

$$\sqrt{1-0.25\left(\frac{E_2}{E_1}\right)^2}-0.866\,\frac{E_2}{E_1};$$

where, E_x is the voltage of the extended portion, E_1 is the high-voltage line potential, and E_2 low-voltage line potential.

Recommendation

When the low-voltage is less than 92 per cent of the high voltage, the extended-delta connection requires a smaller rating than either the straight-delta or V-connections. When this ratio is greater than 92 per cent, the V-connection requires the least rating of the three.

XI. Zigzag Connection

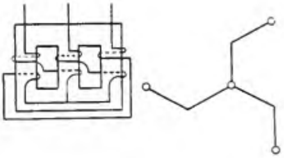


Fig. 11

1. This connection is used to derive a fourth wire for four-wire three-phase distribution systems, such as 2300/4000Y distribution systems, when this wire is not available at the generator or step-down transformer.

2. With balanced three-phase load, neither the neutral wire nor the coils carry any current.

3. An unbalanced load flows in the neutral and is distributed equally in all three phases.

4. The neutral may be grounded.

5. The neutral can also be used to derive the neutral of converters for the return of the unbalanced direct current in three-wire direct-current distribution systems. A straight Y could not be used for this purpose (excepting three-phase core-type units), it being necessary to prevent the saturation of the transformer core by direct current.

6. With the neutral grounded, a ground on one of the lines extends the short circuit to all three-phases.

XII. Extended Zigzag Connections

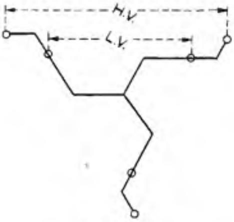


Fig. 12a

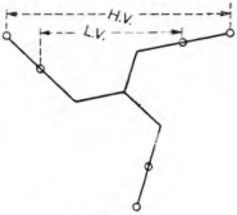


Fig. 12b

When it is desired to transform a given line voltage to some other value for four-wire distribution, either one of the two extended zigzags shown in Figs. 12a and 12b may be used. The first zigzag extension, Fig. 12a, distributes the neutral current equally in all three phases and maintains the position of the neutral (regulation) better than in the case of the straight extension, Fig. 12b. The latter is somewhat simpler to build, but does not completely eliminate the third-harmonic voltage from line to neutral and, in addition, has a poorer regulation for unbalanced loads.

THREE-PHASE TWO-PHASE TRANSFORMER CONNECTIONS

XIII. Balanced T or Scott Connection

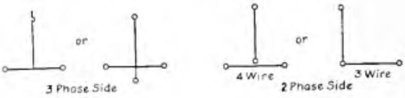


Fig. 13

Advantages

1. This connection requires only two single-phase units or one two-phase unit.

2. It is adaptable to either three-wire or four-wire two-phase service.

3. Both two and three-phase voltages can be obtained on the primary using only four line wires if the 86.6 per cent tap of the teaser is connected to the middle of the main.

Disadvantages

1. The two halves of the main winding on the three-phase side must be interlaced.

2. With interchangeable units, there must be provided one 50 per cent tap and one 86.6 per cent tap in each unit.

3. The three-phase side carries 15 per cent more current than that corresponding to the two-phase side, and, therefore, requires 15 per cent more copper.

4. If the interlacing of the halves of the three-phase side of the main is effected by using two coils in multiple on the two-phase side, then the latter also carries 15 per cent more current and therefore requires 15 per cent. more copper.

5. Combining the features of the above items 3 and 4, two single-phase units in Scott connection can deliver only 86.6 per cent of their combined single-phase kv-a. rating.

XIV. Woodbridge Connection

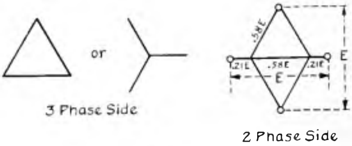


Fig. 14

Advantages

1. This connection has an internal power-factor of 100 per cent and will, therefore, deliver two-phase three-phase power equal to its single-phase rating.

2. The three-phase side can be connected delta or Y, making it possible to change the system voltage without discarding the transformers.

Disadvantages

1. This connection is not adaptable for three-wire two-phase service, and has, therefore, not become popular.

2. Taps are impracticable except on the three-phase side.

3. The multiplicity of windings required generally more than offsets the advantage in economy of material, and for this reason is very seldom used.

4. This connection requires three single-phase units or one three-phase unit.

COMBINED TWO AND THREE PHASE

XV

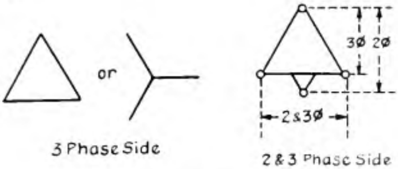


Fig. 15

Of the connection shown in Fig. 15, the straight three-phase side may be Y or delta. On the other side, both two and three-phase power may be obtained from four wires. It is suitable when the three-phase load is predominant. The dimensions of the smaller delta are 15 per cent of those of the larger delta, and the windings whose voltages are parallel are wound on the same core leg.

XVI

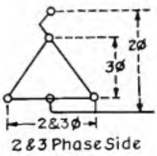


Fig. 16

The connection of Fig. 16 is similar to that of Section XV, except that it requires five wires instead of four.

XVII. Taylor Connection

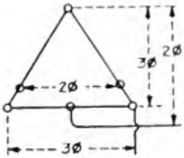


Fig. 17

This connection is similar to those of Sections XV and XVI, except that the two-phase three-phase side requires six wires.

THREE PHASE TWO PHASE AUTO TRANSFORMER CONNECTIONS

SCOTT CONNECTED AUTO-TRANSFORMERS

XVIII

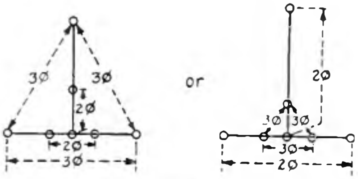


Fig. 18

Three-wire three-phase to four-wire two-phase.

XIX

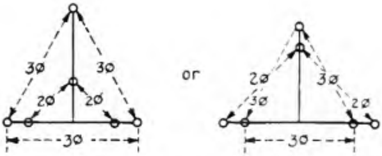


Fig. 19

Three-wire three-phase to three-wire two-phase.

XX

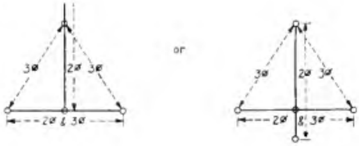
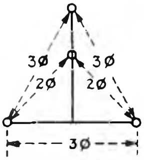


Fig. 20

This connection is the same as that of Section XVIII, except that the ratio of voltages is 1 to 1. The main carries only the teaser current which divides equally in the two halves of the main.

XXI

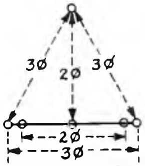


2 Phase Voltage
Equals 3 Phase
Voltage.

Fig. 21

This connection is the same as that of Section XVIII, except that the ratio of voltages is 100 per cent three-phase to 70.7 per cent two-phase.

XXII



2 Phase Voltage 86.6%
of 3 Phase Voltage. No
teaser required.

Fig. 22

This connection is the same as that of Section XIX, except that the ratio of voltages is 100 per cent three-phase to 86.6 per cent two-phase. The teaser then becomes unnecessary and can be left out, the bank operating with only one single-phase unit. One phase of the two-phase load takes the place of the teaser.

THREE-PHASE TO SIX-PHASE CONNECTIONS

XXIII. Delta-Diametric Connection

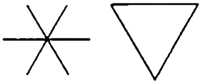


Fig. 23

Advantages

1. The delta connection of one side eliminates third-harmonic voltage troubles.

2. The diametric connection of the six-phase side requires only three coils as against six required by the double delta connection, and is therefore more economical.

3. The diametric connection lends itself more conveniently for starting-taps and switchgear.

4. The neutral of the diametric connection may be brought out to derive the neutral of the converter for three-wire d-c. service except in the case of split-pole converters.

Disadvantages

The bank cannot operate with two units when one breaks down.

XXIV. Y-Diametric Connection

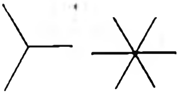


Fig. 24

This connection has the advantages of the diametric secondary, and is free from third-harmonic voltage phenomena when operating converters, except split-pole converters. In the first case, the third-harmonic excitation current circulates through the diametric coils and converter; in the latter case, the third-harmonic voltage is made use of in regulating the voltage of the converter and is then a desirable feature.

Recommendations

Delta-diametric and Y-diametric are the most common three-phase to six-phase connections. Whether the primary should be Y or delta is determined by either the convenience of design or the user's preferences.

XXV. Delta Double Delta Connection

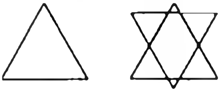


Fig. 25

Advantages

1. The bank can temporarily operate with two units when one breaks down.

2. The secondary side can be operated three-phase without change of voltage and will deliver one half rated load operating only one of the deltas. If the diametric is connected in delta for three-phase service, the voltage is increased 15 per cent but it will deliver full rated load.

Disadvantages

1. The multiplicity of coils in the secondary tends to make the cost somewhat higher than that of the diametric connection.

2. The double-delta secondary is ill-adapted for starting taps or for deriving the neutral of converters for three-wire d-c. service.

XXVI. Y-Double-Delta

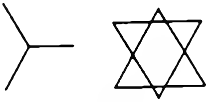


Fig 26

This is a possible connection that [illegible] used. It may have an advantage in design and cost if the three-phase voltage is [illegible] high and the six-phase voltages are low.

XXVII. T Double T Connection

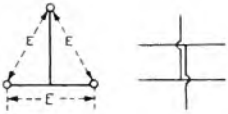


Fig. 27

This connection is not much used for three-phase to six-phase transformation on account of its low ratio of output to rating which, similar to *T-T* connection, is only 86.6 per cent; and it is also not well adapted for starting taps.

TWO-PHASE TO SIX-PHASE CONNECTIONS

XXVIII

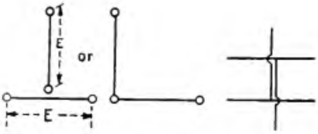


Fig. 28

This connection is the one commonly used for two-phase to six-phase transformation.

Single Light Compared with Cluster Units for Street Lighting

By S. L. E. Rose and H. E. Butler

Illuminating Engineering Laboratory, General Electric Company

This article deals with two types of ornamental incandescent street lighting unit, the old five-light cluster unit of ball globes and the modern single-light Novalux unit. It points out the inefficiency of the cluster unit and presents data to show why this type of unit should be discarded. The various equipments available for the single-light Navalux unit are a strong point in its favor, as these enable the many conditions of ornamental street lighting to be met successfully.—Editor.

"Comparisons of ornamental street-lighting systems must include an analysis of both the architectural, or esthetic, and the engineering features. One attempting to reach definite conclusions in a subject such as this will find his progress handicapped by the lack of definite standards by which to measure the various factors entering into the problem. The most one can do is to establish facts and thus make available information which will enable him to draw his own conclusions, attributing, in his opinion, the proper credit to these different factors. Other considerations demand the attention of the designer of an ornamental street-lighting system, such as the appropriation available for the work and the general character of the street; that is, the nature of the business establishments or residences bordering upon it, whether the street is used for commercial traffic or as a pleasure drive, whether it has shade trees, its width, etc. The degree to which these factors deserve consideration depends largely upon local conditions, and no attempt will be made to discuss them here, as no purpose would be served except the expression of the authors' personal opinions.

"The strictly architectural phase of the question also may be said to be to a great extent a matter of personal choice. No two designers would be likely to furnish the same design of standard, but it does not follow that they would condemn the design of a colleague. This leads one to believe that there must be some general rules which should be followed in order to satisfy architecturally the conditions of the problem. An effort to determine whether the single-light standard or cluster standard best meets the general conditions for ornamental street lighting has shown the single-light standard to be the favorite. It is claimed that the cluster adds too large a structure to the street, proving to be an obstruction and unsightly object; that the maintenance and initial cost of installation is high; and that outages have a very much more disturbing influence on the system as an ornamental whole, a partly illuminated standard being much more objectionable and noticeable than one entirely dark. In addition to eliminating the disadvantages of the cluster system, the single-lamp standard presents a more dignified ornament, adding to rather than detracting from the general appearance of the street under both day and night conditions. Leaving the question of esthetics to be argued pro and con by those most qualified to do so, the engineering side of the question demands attention.

"Engineering has to deal with the physical phases of the problem, which is capable of very accurate representation, and yet one finds among the profession an inability to agree as to what should and should not be. In investigating this branch of street lighting the authors have confined their consideration to the distribution of light, comparing equipments typical of the cluster and single-light systems."*

Since the foregoing was written, a number of new equipments have been designed and developed for the single-light unit, and it is the purpose of this article to give illumination data on these new equipments so that a comparison may be made between them and the cluster standards. Photographs of all the units compared in this article are shown in Fig. 1.

In some recent installations on wide business streets in large cities two or three modern high candle-power units have necessarily been placed on one pole in order to get the desired intensity, but they are mounted 25 to 30 feet above the street and therefore are not subject to the criticisms that are pointed out in this article concerning the old 5-light cluster mounted 10 or 12 feet high.

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* From "Ornamental Street-lighting Systems Compared," by H. E. Mahan and H. E. Butler, *Electrical World*, July 24, 1915, page 180.

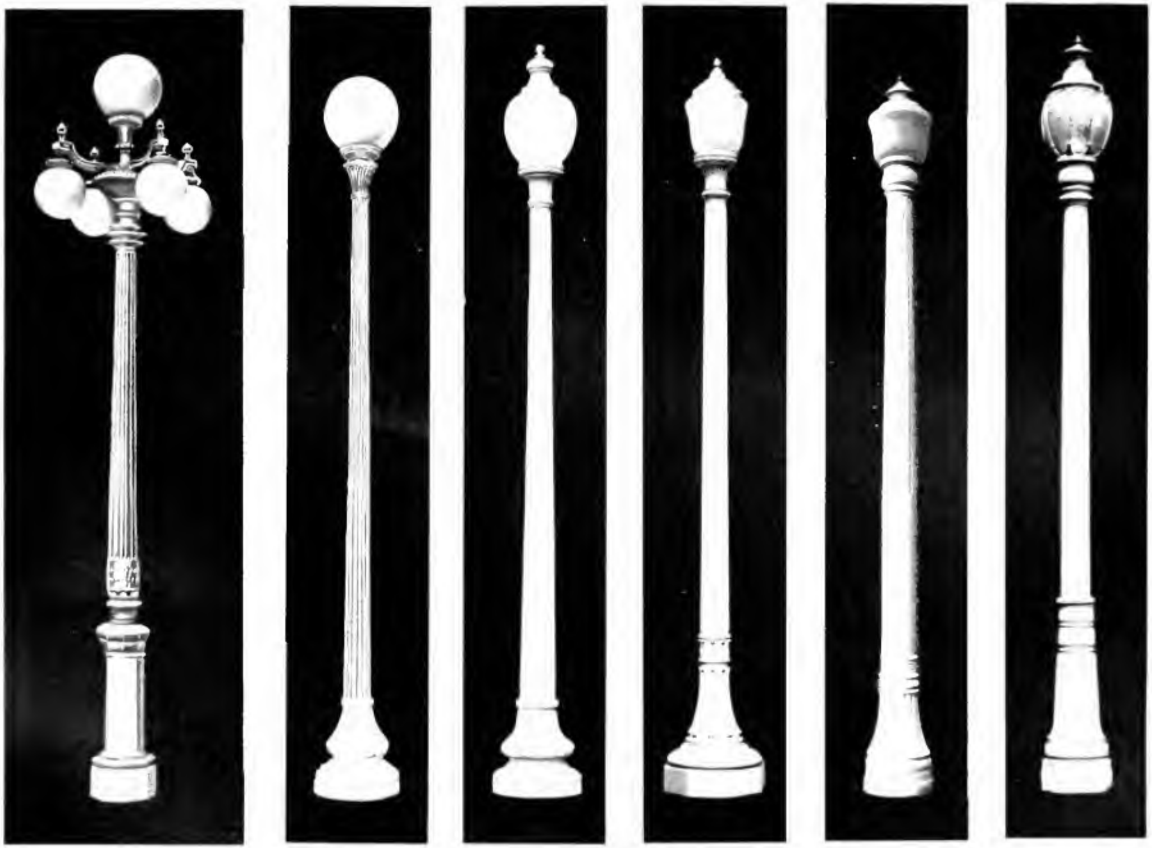


Fig. 1. Typical Cluster Unit and Variety of Single Lamp Units

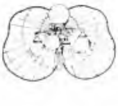
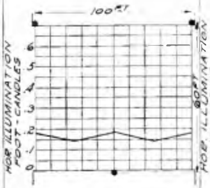
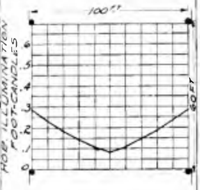
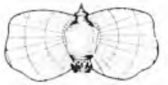
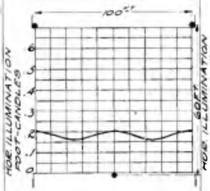
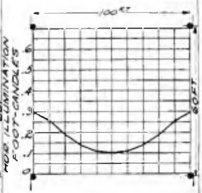
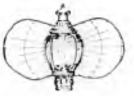
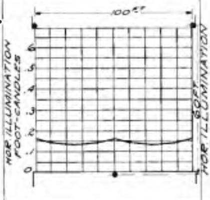
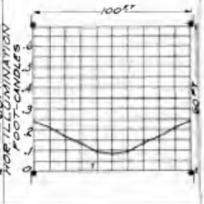
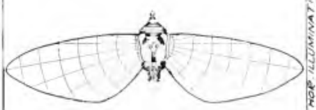
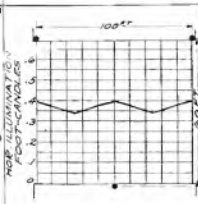
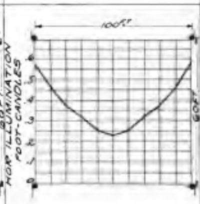
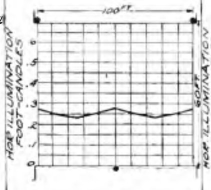
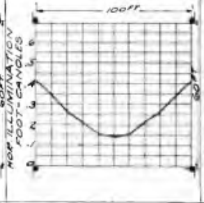
CANDLE-POWER DISTRIBUTION (DRAWN TO SAME SCALE)	LAMPS ARRANGED STAGGERED	LAMPS ARRANGED PARALLEL		WATTS PER LIN. FT.	AVE F.C	MAX F.C	MIN F.C	RATIO
SLIGHT CLUSTER MAZDA C SERIES LAMP 1-100 C.P. IN 13" ALBA BALL GLOBE-UPRIGHT 4-80 C.P. IN 9" ALBA BALL GLOBE-PENDENT 			STAGGERED	6.24	.168	.185	.145	.78
			PARALLEL	6.24	.168	.285	.088	.31
FORM 8 NOVALUX ORNAMENTAL UNIT WITH 600 C.P. MAZDA C SERIES LAMP, CARRARA GLASS GLOBE NO. 37 AND INTERNAL REFLECTOR 			STAGGERED	6.60	.182	.203	.164	.810
			PARALLEL	6.60	.182	.300	.102	.342
FORM 9 NOVALUX ORNAMENTAL UNIT WITH 600 C.P. MAZDA C SERIES LAMP, 8 PANEL CARRARA GLASS GLOBE NO. 90 AND INTERNAL REFLECTOR 			STAGGERED	6.60	.151	.159	.135	.85
			PARALLEL	6.60	.151	.240	.080	.334
FORM 8 NOVALUX ORNAMENTAL UNIT WITH 600 C.P. MAZDA C SERIES LAMP, STIPPLED GLASS GLOBE NO. 95 INTERNAL REFLECTOR AND HOLOPHANE PRISMATIC DOME REFRACTOR 			STAGGERED	6.60	.360	.400	.344	.860
			PARALLEL	6.60	.360	.580	.230	.400
FORM 9 NOVALUX ORNAMENTAL UNIT WITH 600 C.P. MAZDA C SERIES LAMP, 8 PANEL STIPPLED GLASS GLOBE NO. 90, INTERNAL REFLECTOR AND HOLOPHANE PRISMATIC DOME REFRACTOR 			STAGGERED	6.60	.250	.275	.233	.840
			PARALLEL	6.60	.250	.415	.143	.345

Fig. 2 Comparison of a Cluster Unit and Several Single Units for Street Illumination by the Series System

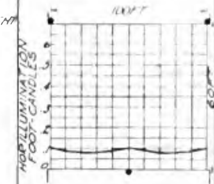
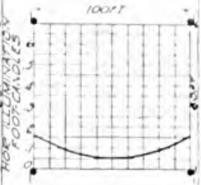
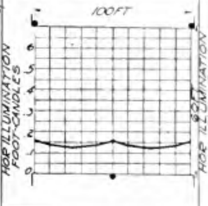
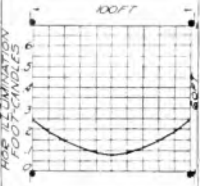
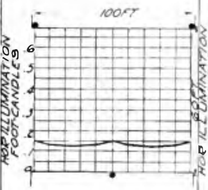
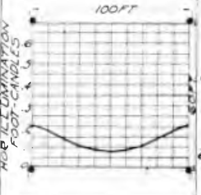
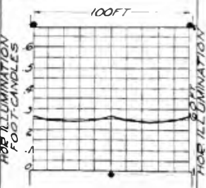
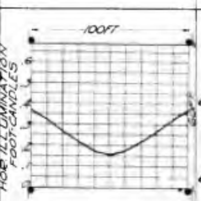
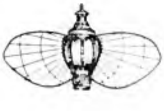
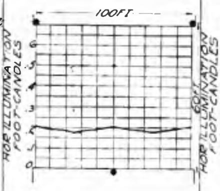
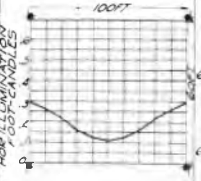
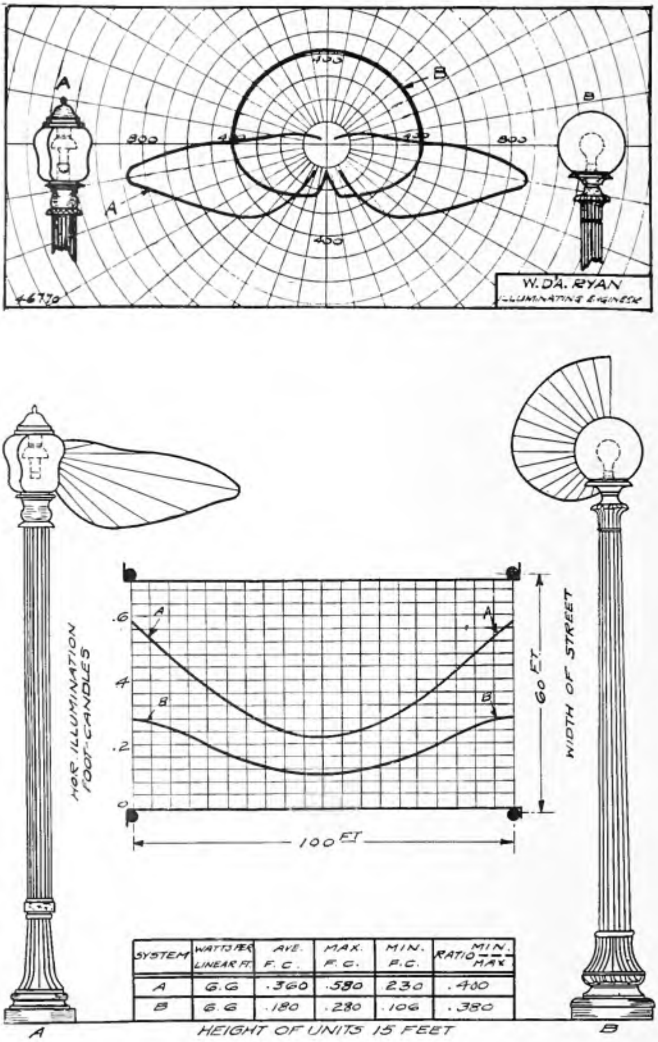
CANDLE-POWER DISTRIBUTION	LAMPS ARRANGED STAGGERED	LAMPS ARRANGED PARALLEL	WATTS PER SQ.FT.	AVE. F.C.	MAX. F.C.	MIN. F.C.	[illegible]
3 LIGHT CLUSTER 4-30 WATT MAZDA C MULT LAMPS, PENDENT IN 9" ALBA BALL + 100 WATT MAZDA C MULT LAMP, UPRIGHT IN 13" ALBA BALL. 			STAGGERED				
			6.00	.089	.104	.083	.800
			PARALLEL				
			6.00	.089	.138	.030	.317
FORM 9 NOVALUX ORNAMENTAL UNIT WITH 300 WATT MAZDA C MULT LAMP, CARRARA GLASS GLOBE NO.37 AND INTERNAL REFLECTOR 			STAGGERED				
			6.00	.140	.160	.130	.820
			PARALLEL				
			6.00	.140	.250	.080	.320
FORM 9 NOVALUX ORNAMENTAL UNIT WITH 300 WATT MAZDA C MULT LAMP, 8 PANEL CARRARA GLASS GLOBE NO.90 AND INTERNAL REFLECTOR 			STAGGERED				
			6.00	.132	.148	.124	.840
			PARALLEL				
			6.00	.132	.210	.078	.370
FORM 8 NOVALUX ORNAMENTAL UNIT WITH 300 WATT MAZDA C MULT LAMP, STIPPLED GLASS GLOBE NO.95, INTERNAL REFLECTOR AND HOLOPHANE PRISMATIC DOME REFRACTOR 			STAGGERED				
			6.00	.250	.265	.230	.865
			PARALLEL				
			6.00	.250	.370	.155	.420
FORM 9 NOVALUX ORNAMENTAL UNIT WITH 300 WATT MAZDA C MULT LAMP, 8 PANEL STIPPLED GLASS GLOBE NO 90, INTERNAL REFLECTOR AND HOLOPHANE PRISMATIC DOME REFRACTOR 			STAGGERED				
			6.00	.192	.200	.176	.880
			PARALLEL				
			6.00	.192	.300	.110	.370

Fig. 3. Comparison of a Cluster Unit and Several Single Units for Street Illumination by the Multiple System

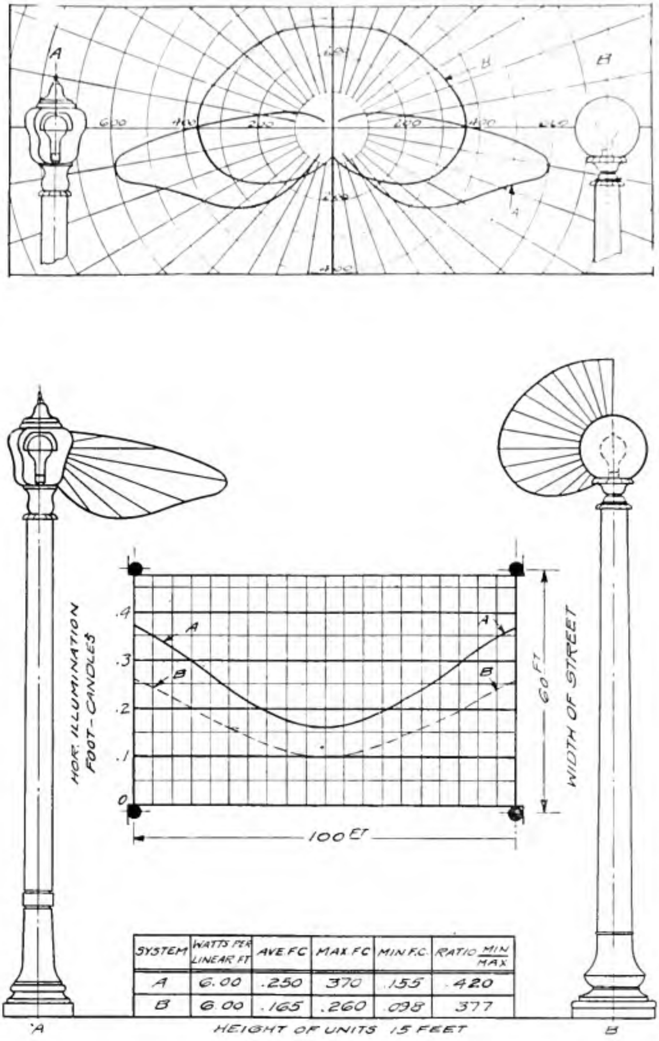


SYSTEM	WATTS PER LINEAR FT.	AVE. F. C.	MAX. F. C.	MIN. F. C.	RATIO MIN./MAX.
A	6.6	.360	.580	230	.400
B	6.6	.180	.280	.106	.380

Figs. 4-a and 4-b. Charts of Comparative Distribution and Illumination

A: Form S Novalux ornamental unit, three-section stippled globe, Holophane prismatic dome refractor, with 600-c-p. Mazda C series lamp
B: Novalux ornamental unit, Genco glass ball, with 600-c-p. Mazda C series lamp

Illumination calculated on street surface along center line of street. Height of units 15 ft.

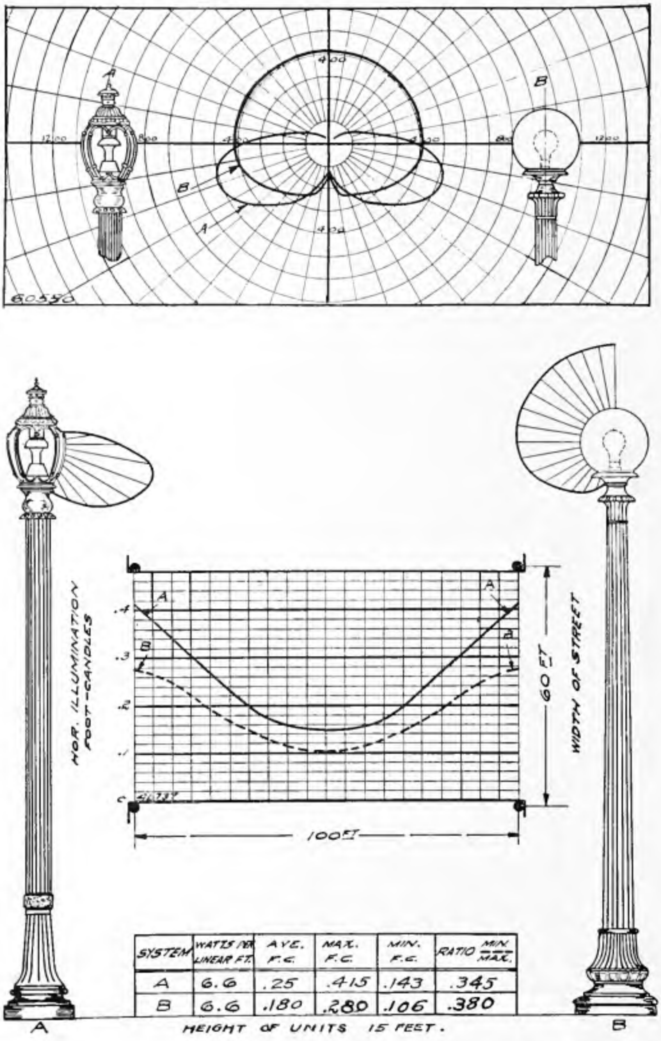


SYSTEM	WATTS PER LINEAR FT	AVE. F.C.	MAX. F.C.	MIN. F.C.	RATIO MIN/MAX
A	6.00	.250	370	.155	.420
B	6.00	.165	.260	.098	377

Figs. 5-a and 5-b. Charts of Comparative Distribution and Illumination

A: Form S Novalux ornamental unit, three-section stippled glass globe Holophane prismatic dome refractor, with 300-watt Mazda C multiple lamp
B: Novalux ornamental unit, Alba glass ball globe, with 300-watt Mazda C multiple lamp

Illumination calculated on street surface along center line of street. Height of units 15 ft.

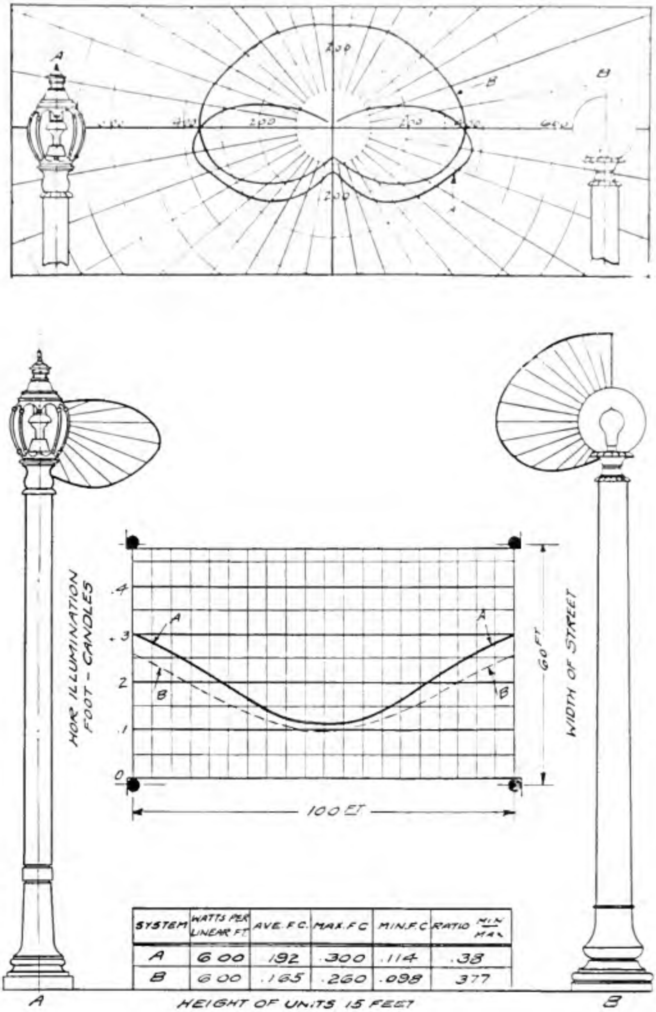


SYSTEM	WATTS PER LINEAR FT.	AVE. F.C.	MAX. F.C.	MIN. F.C.	RATIO $\frac{MIN.}{MAX.}$
A	6.6	.25	.415	.143	.345
B	6.6	.180	.280	.106	.380

Figs. 6-a and 6-b. Charts of Comparative Distribution and Illumination

A: Form 9 Novalux ornamental unit, eight-panel stippled glass globe, Holophane prismatic dome refractor, with 600-c-p. Mazda C series lamp
B: Novalux ornamental unit, Genco glass ball globe, with 600-c-p. Mazda C series lamp

Illumination calculated on street surface along center line of street. Height of units 15 ft.



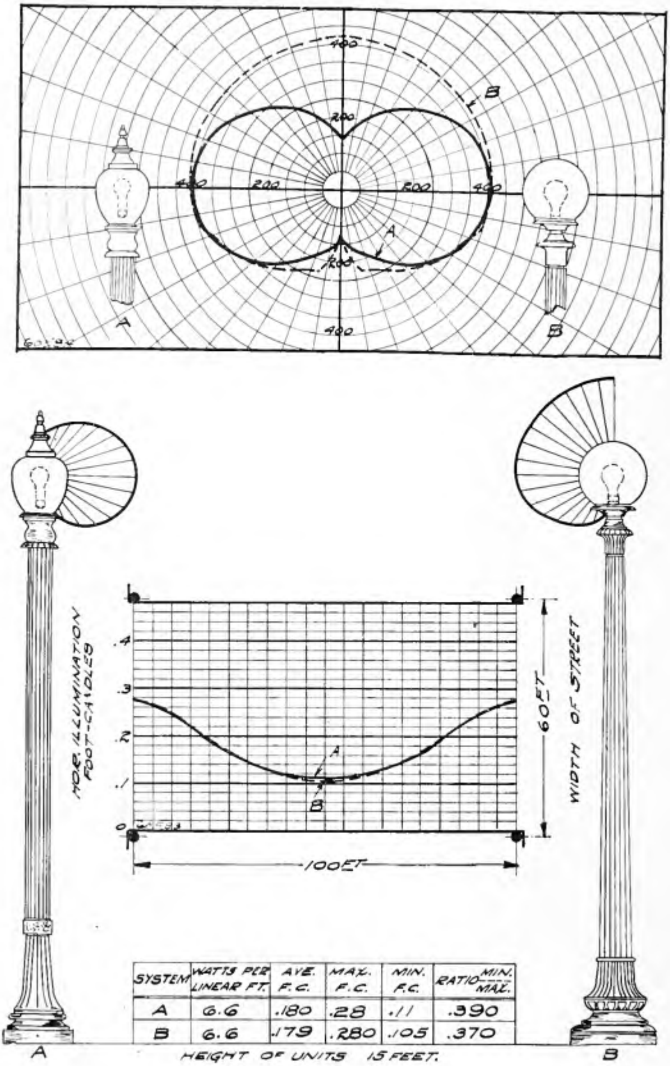
SYSTEM	WATTS PER LINEAR FT	AVE. F.C.	MAX. F.C.	MIN. F.C.	RATIO MIN/MAX
A	6.00	.192	.300	.114	.38
B	6.00	.165	.260	.098	.377

Figs. 7-a and 7-b. Charts of Comparative Distribution and Illumination

A Form 9 Novalux ornamental unit, eight-panel stippled glass globe, Holophane prismatic dome refractor, internal reflectors top and bottom, white porcelain enamel reflecting surface, with 300-watt Mazda C multiple lamp

B Novalux ornamental unit, Alba glass ball globe, with 300-watt Mazda C multiple lamp

Illumination calculated on street surface along center line. Height of units 15 ft.



SYSTEM	WATTS PER LINEAR FT.	AVE. F.C.	MAX. F.C.	MIN. F.C.	RATIO MIN./MAX.
A	6.6	.180	.28	.11	.390
B	6.6	.179	.280	.105	.370

Figs. 8-a and 8-b. Charts of Distribution and Illumination

A: Form 8 Novalux ornamental unit, Genco glass globe, internal reflector with 600-c-p. Mazda C series lamp

B: Novalux ornamental unit, Genco glass ball globe, with 600-c-p. Mazda C series lamp

Illumination calculated on street surface along center line of street. Height of units 15 ft.

When ornamental street lighting was first attempted there were no single units of sufficient candle-power intensity available and it was necessary to combine several smaller ones on a single pole; hence the cluster standard came into use. Even a five-light cluster was not a high candle-power unit in the modern sense, and therefore they were mounted on 10 to 12-foot poles.

This unit served its purpose at the time when there was no other unit available, but at the present time when more attractive and efficient units are on the market there is no excuse for extending present cluster systems or installing new ones and every reason why existing systems should be replaced by single-light units as rapidly as is practical.

There are several objections to the old five-light cluster unit as compared with the single-light unit, such as higher maintenance, too much glassware in view in the daytime, uneven appearance at night if one or more of the lamps is not burning, the spread of the arms tend to make the street appear narrower than it really is, etc. A number of small lamps are not as efficient light producers as one large lamp of equal wattage, and the efficiency of the cluster is still further reduced by the interference of the globes and arms which obstruct some of the light. With the single-light standard there are a number of equipments to select from to suit various conditions while with the cluster standard only one equipment is available.

Two charts have been prepared, comparing the cluster with various equipments of the single-light unit type, Fig. 2 using series lamps and Fig. 3 using multiple lamps. These charts show the characteristic candle-power distribution; the illumination along the center line of the street with two arrangements of units, staggered and parallel; a tabulation of watts per linear foot; average, maximum, and minimum foot-candles; and the ratio of minimum to maximum foot-candles which is a measure of the uniformity of the illumination.

These charts indicate the various types of distribution which may be obtained with the single-light unit. By using the most efficient equipment on the single-light unit with three-section stippled globe and Holophane prismatic dome refractor, the minimum illumination on the street is about 2½ times that from the cluster unit. Comparisons of the other equipments may be made from the charts.

In the article, "Ornamental Utilitarian Street Lighting Units," GENERAL ELECTRIC REVIEW, June, 1918, page 430, Fig. 1, a comparison was made between the single ball-globe unit and the single-light unit with three-section stippled globe and dome refractor with units on one side of street only which showed a great advantage in street illumination for the latter unit. In this article, Figs. 4-a and 4-b, the same two units are compared with units on both sides of the street with series lamps; Figs. 5-a and 5-b, the same units with multiple lamps. Figs. 6-a, 6-b, 7-a and 7-b compare the ball-globe unit with the single-light standard with eight-panel stippled glass globe and dome refractor both with series and multiple lamps, and it will be noted that the illumination on the street is superior with the modern type unit.

In some cases, however, it may not be desirable to use the stippled glass globe and dome refractor, and to meet these conditions a very fine ornamental unit is available which uses a diffusing glass globe of pleasing appearance and gives a little higher minimum illumination on the street than the single ball-globe unit. This comparison is made for the series lamps only, in Figs. 8-a and 8-b, but would also hold practically the same if multiple lamps were used. Of course the external appearance of the units is the same for series or multiple lamps.

Night and day photographs of typical installations of some of these units are given in Figs. 9 to 16 which will give some indication of the advantages for street illumination and general appearance of the modern type lighting units. A study of these charts convincingly reveals the fact that the modern Novalux single-light unit is not only more efficient than the older type of cluster units, but gives the street a much better appearance both by day and by night.

Fig. 9. Day View of Ornamental Street Lighting Installation with Cluster Units

Fig. 11. Day View of Ornamental Street Lighting Installation with Form 9, Novalux Ornamental Units, Sheboygan, Wis.

Fig. 10. Night View of the Illumination Produced by the Cluster Lamp Units shown in Fig. 9

Fig. 12. Night View of the Illumination Produced by the Installation of the Single-lamp Units shown in Fig. 11

Fig. 13. Day View of Installation of 250 c-p. Mazda Series Lamps in Alabaster Glass Ball Globes, Glenwood Blvd., Schenectady, N. Y.

Fig. 15. Day View of Installation of 250 c-p. Mazda Series Lamps in Form 8 Novalux Ornamental Unit, with Stippled Glass Globes and Holophane Prismatic Dome Refractors, Parkwood Blvd., Schenectady, N. Y.

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Fig. 13. Day View of Installation of 250 c-p. Mazda Series Lamps in Alabaster Glass Ball Globes, Glenwood Blvd., Schenectady, N. Y.

Fig. 15. Day View of Installation of 250 c-p. Mazda Series Lamps in Form 8 Novalux Ornamental Unit, with Stippled Glass Globes and Holophane Prismatic Dome Refractors, Parkwood Blvd., Schenectady, N. Y.

Fig. 14. Night View of the Illumination Produced by the Ball Units shown in Fig. 13

Fig. 16. Night View of the Illumination Produced by Single [illegible] shown in Fig. [illegible]

SINGLE LIGHT COMPARED WITH [illegible]

Fig. 14. **Night View of the Illumination Produced by the Ball Units shown in Fig. 13**

Fig. 16. Night View of the Illumination Produced by Single [illegible] shown in Fig. [illegible]

Cooling of Transformer Windings After Shut-down

By V. M. Montsinger

Transformer Engineering Department, General Electric Company

This article deals with the advantages and disadvantages of various possible methods of determining temperature corrections for the cooling of transformer windings after shut-down.—Editor.

General

To determine the average temperature rise of any type of electrical winding, the resistance method must be used. For alternating-current types of apparatus it is obvious that the resistance cannot be measured while the apparatus is under load conditions. Therefore, when subjecting a transformer to a heat test to determine its average temperature rise, it is necessary, after conditions have become constant, to disconnect the excitation and loading lines and to connect on a pair of resistance lines. The time required to change these connections and to allow for the direct current to become steady will ordinarily range from one to three or four minutes. The cooling of oil-immersed transformer windings during this period of time will range from approximately one to ten or twelve degrees C. In order, therefore, to determine the operating temperature it is necessary always to apply a correction to the observed temperature.

Although various methods have been proposed for making this correction, apparently very little if any information has ever been published* on the subject. It is the purpose of the writer to discuss in this article these different methods.

Cooling Curve Method

Under ideal conditions the "cooling curve" method, Fig. 1, is of course the most accurate. Ideal conditions, however, are not always possible under commercial conditions.

To obtain accurate results by the cooling curve method it is necessary either to obtain accurate readings within one or two minutes after shut-down or to plot the "rate of cooling" *vs.* "time" on semi-log paper, Fig. 2, for three or four minutes' time after the readings are reliable. This gives a straight line and hence the rate of cooling at any instant after shut-down can be determined. The sum of the rates for the time elapsed between shut-down and the time when reliable readings are obtained added to the temperature at this time gives the temperature at the instant of shut-down. For instance, according to Fig. 2, the average rates of cooling during the first and second minutes of the cooling curve in Fig. 1 are 0.9 and 0.74 deg C., respectively. 1.64 added to 54.6 deg., which is the temperature at two minutes after shut-down (Fig. 1), gives 56.24 deg. C., the temperature at the time of shut-down.

Any one who has had experience in taking cooling curves on transformer windings will agree with the statement that unless very special precautions are taken in taking the readings, or unless the readings are plotted on both coordinate and semi-log paper as shown in Figs. 1 and 2, it is possible to get almost any temperature at shut-down. This is well illustrated in Fig. 1 where the first three or four readings are so high that it would be practically useless to try to extrapolate back to shut-down time with any degree of accuracy without the use of semi-log paper.

The first three or four readings in Fig. 1 are high due to the inductive effect. That is, when direct current is suddenly thrown on a coil surrounding an iron core, the inductance in some cases delays the rise of current for a considerable length of time and if the current is read before this inductive effect disappears the result is that the indicated temperature is higher than the true temperature. The maximum time required for the inductive effect to disappear is about one minute after the switch is closed. This effect is not pronounced, however, on all windings, but possibly in one case out of every five, and is likely to occur with either the "drop in potential" or "Wheatstone bridge" method of taking resistance. Contrary to the usual impression, it is not always greater for high than for low-voltage windings; see cooling curves of 2200-volt distribution transformer windings, Fig. 13.

Furthermore, as cooling curves cannot be observed simultaneously on both the high-voltage and low-voltage windings, this method would require that two heat runs be made on each transformer.

The fact remains that although the cooling curve method is the most accurate when applied with laboratory care, it is rarely ever used because it is laborious and expensive.

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* See Proc. A.I.E.E., Apr., 1917, "Cooling of Oil-immersed Transformer Windings After Shut-down," by V. M. Montsinger.

Arbitrary Correction

By the arbitrary correction method a standard correction of, say one, one and one half or two degrees C. per minute is added for all sizes of any one type of transformer.

The advantages of this method are simplicity and ease of application. The objection is that it is liable to considerable error. Generally speaking, the copper loss of water-cooled transformers will vary from about six to 25 watts per lb. If an arbitrary correction of say two degrees C. per minute is adopted, Table I shows errors (plus or minus) which are liable to be made for this particular type of apparatus.

In cases where transformers operate on short-time overloads, or on duty-cycle operation, the error would naturally be greater than given in the table.

The foregoing method would also put a premium on using high current densities.

It does not seem advisable, therefore, to use this arbitrary method of correcting back to the instant of shut-down, for all types of oil-immersed windings. It can, however, be used for distribution transformers of 100-kv-a. and less capacity because the copper density does not vary to any great extent in these sizes.

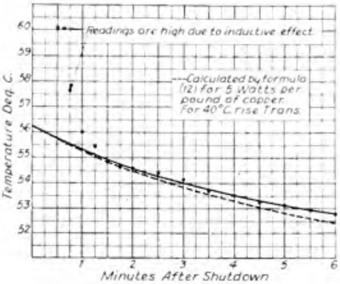

Fig. 1. Cooling Curve of High-voltage Winding of a 60 cycle 400-kv-a 5000 2300-volt Core-type Transformer

Theoretical Correction

A purely theoretical calculation [illegible] cooling after shut-down on a commercial basis is not feasible for the reason that it is too laborious. Furthermore, for oil-immersed windings, where the [illegible] of ambient temperature (oil in ducts and surrounding the coils) is not known and cannot very well be determined, it is extremely difficult if not impossible to calculate the rate of cooling by a theoretical formula.

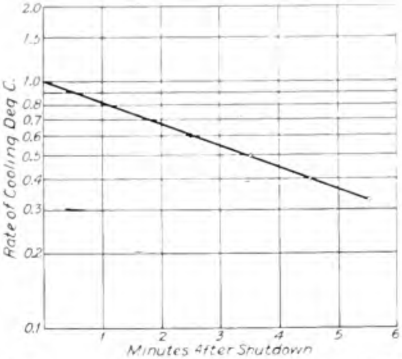

Fig. 2 Rate of Cooling Curve Taken from Fig. 1 and Plotted with Semi-logarithmic Co-ordinates

Partial Theoretical and Partial Empirical Correction Copper Loss Method

Due to the fact, however, that one troublesome factor, insulation, when considered from a theoretical standpoint has opposite and approximately equal effects on the cooling after shut-down, it is possible to neglect the insulation and use curves based upon a partially theoretical and partially empirical formula. For instance, an increase in insulation of copper windings, other conditions being the same, obviously *retards the rate of cooling* after shut-down. But, when insulation is added, the initial temperature is almost always increased and an increase in

TABLE I

Minutes After Shut-down	CALCULATED COOLING BY CURVES IN FIG. 7		Cooling by Arbitrary Correction of 2 Deg. Cent. per Minute	Maximum Error
	6 Watts per Lb.	25 Watts per Lb.		
2	2.0 deg. C.	8.0 deg. C.	4 deg. C.	4 deg. C.
4	3.5 deg. C.	12.5 deg. C.	8 deg. C.	4.5 deg. C.

the initial temperature, other conditions being the same, has the effect of *accelerating the rate of cooling* after shut-down. It so happens that these two opposite effects are so nearly equal (for a limited time after shut-down of course) that the effect of insulation can be entirely neglected. This greatly simplifies matters because with the selection of the proper empirical constant and insulation space factor a simple formula can be deduced from the theoretical formula and the only factors to consider are the time and the copper loss or watts per pound of copper, which is easily determined.

Theoretical Calculation of Cooling

When loss of heat energy is proportional to temperature rise, the cooling of a body takes place according to a "dieaway" curve which is expressed by the formula

$$\theta_t = \theta_o \epsilon^{-\beta t} \qquad (1)$$

in which

θ_t = temperature rise at any time t of the body over its ambient temperature.
θ_o = initial temperature rise or rise at shut-down.
ϵ = base of Naperian logarithms.
β = constant.
t = time.

Equation (1) may be put into a more convenient form by changing signs, adding θ_o to both sides and then putting $(\theta_o - \theta_t) = \theta$, where θ is the cooling in degrees centigrade. We now have

$$\theta = \theta_o \ (1 - \epsilon^{-\beta t}) \qquad (2)$$

Differentiating equation (1) with respect to time, when $t = 0$ the constant β is

$$\beta = \frac{\text{initial rate of cooling}}{\text{initial temperature rise}}$$

Initial Rate of Cooling

The initial rate of cooling depends upon the thermal capacity of the body being cooled. Transformer windings consist mainly of copper and fibrous insulation. The thermal capacity or energy in joules required to raise the temperature of copper one degree centigrade equals the weight of copper times the number of grams in one pound times the specific heat of copper times the number of joules in one calorie $= W \times 453.6 \times 0.0935 \times 4.185 = 177.5\ W$, where W is the weight in pounds. The rate of heat storage in copper which is the same as the initial rate of cooling in degrees per minute is $\frac{60 \times \text{watts}}{177.5\ W} = 0.338\ W_c$ where W_c is the watts per pound of copper.

The thermal capacity of most insulating materials *by volume* ranges from about one third to one half that of copper. Tests indicate that for impregnated insulations the value of one half is more nearly correct. For an insulated copper conductor or coil the initial rate of cooling is then

$$= 0.338\ W_c \left(\frac{2a}{A+a} \right) = \frac{0.676\ a\ W_c}{A+a}$$

in which

a = the cross sectional area of the copper
A = the cross sectional area of the copper plus the insulation.

We now have

$$\theta = \theta_o \left(1 - \epsilon^{-\frac{0.676 \frac{a W_c t}{A+a}}{\theta_o}} \right) \qquad (3)$$

Effect of Insulation and Initial Temperature Rise on Rate of Cooling

It is the difficulty, for the usual transformer winding complicated by oil ducts, etc., of determining accurately the initial rise that makes it difficult to calculate the cooling by this formula. For instance, for a transformer winding with numerous oil ducts the ambient temperature is the oil in the ducts and the oil surrounding the coil stack. While the oil surrounding the coil stack remains fairly constant for the first five minutes after shut-down, the oil in the ducts is moving through, just after shut-down, at the same rate it was before shut-down. Since this moving oil is influenced by the temperature of the coils, and since the temperature of the coils is decreasing after shut-down, the temperature of this oil in the ducts is also decreasing.

In other words, if we consider the temperature of the oil in the ducts as the ambient temperature, we have a constantly decreasing ambient temperature which would be troublesome to deal with in making calculations. On the other hand, if we consider the oil surrounding the coil stack (i.e., neglecting that in the ducts) as the ambient temperature, we must take into consideration the thermal capacity of the oil in the ducts. This also would be difficult to do because as previously stated this oil is not stationary. However, in the case of a single coil immersed in oil where conditions are not complicated by oil ducts fairly accurate calculations can be made by the use of formula (3).

For example, Table II shows the tested and calculated cooling (by formula 3) of two oil immersed cylindrical coils (*Fig. 3*) operated side by side under identical conditions, excepting that one had heavy insulation and the other light insulation. Both coils were wound on a foundation ring or cylinder, 40 mils in thickness, and consisted of 0.2×0.055-in. edge-wound conductor with a 21-mil two-side cotton covering. Fifteen layers of 0.012-in. varnished cambric was wrapped on both the inside and outside surface of one coil, while the other coil was given no extra insulation.

From Table II it will be noted that by both tests and calculations the coil with heavy insulation and high initial temperature rise at first cools at a slower rate than the coil with light insulation, but that finally the cooling becomes greater. Also both coils cool at approximately the same rate for the first five or six minutes. The results of these tests suggested to the writer that it might be possible to neglect both the insulation factor and the initial temperature rise of the coils in calculating the cooling after shut-down.

However, other conditions had to be satisfied before drawing this conclusion. That is to say, insulation is not always added in such a manner as to increase the initial temperature so greatly as in the foregoing case. This is true when the strand insulation is increased, the space factor being changed such that the surface loss (watts per sq. in.) is decreased. Or in other cases the coil may consist of several turns per layer with heavy layer insulation thus producing a thick coil. This latter style of coil is found mostly in distribution transformers of 100 kv-a. and less.

To make calculations by formula (3) of the cooling after shut-down of coils with different strand insulations (other conditions being the same) it is first necessary to establish the relation between strand insulation and the initial temperature rise for constant conditions. One effect of extra strand insulation is to increase the rise due to the added thermal drop, while another effect is to decrease the rise due to the fact that the coil surface loss is decreased (when the insulation between strands is considered as an effective radiating surface). It is interesting to note that under certain conditions it is possible to decrease the temperature rise by the addition of strand insulation. Such is not usually the case, for transformers, however, except possibly for a few turns on the line end of the high-voltage windings.

Fig. 3. Lightly Insulated Coil, on left, and Heavily Insulated Coil, on right, used in determining the effect of coil insulation on cooling after shut-down. The cooling curves are given in Figs. 8 and 9

The thermal resistance or temperature drop through fibrous insulation varies greatly, depending to some extent upon the temperature and kind of material but mostly upon its compactness. For solid fibrous insulation (i. e., when free from air or oil films between layers) the thermal resistance generally ranges from about 200 to 300 deg. C. per watt, per cubic inch.* For loosely wound layers, however, the thermal resistance

---

* This is the temperature drop in degrees centigrade when there is a flow of one watt per sq. in. through a one-inch thickness of insulation.

TABLE II

Insulation on Coil	$\frac{a}{1-a}$	H	θ	COOLING AFTER SHUT-DOWN IN DEGREES CENTIGRADE							
				2		4		6		8 Min	
				Test	Calc.	Test	Calc.	Test	Calc.	Test	Calc.
Light	0.395	22.9	15 deg.	8.1	8.3	12.8	12.1	15.3	13.7	—	14.4
Heavy	0.189	22.5	56 deg.	7.2	5.2	12.9	11.3	17.3	14.5	—	18.3

may be as high as 500 deg. C. per watt per cubic inch. Fig. 4 shows that the temperature drop through six layers of 0.012-in. varnished cambric ranges from 246 to 274 deg. C. per watt per cu. in., the variation apparently being due to different temperatures. This temperature drop was obtained by drawing a straight line through two internal temperature points obtained by imbedded thermocouples. A thermal resistance of 300 deg. C. per watt cu. in. should therefore be about right for the average strand insulation.

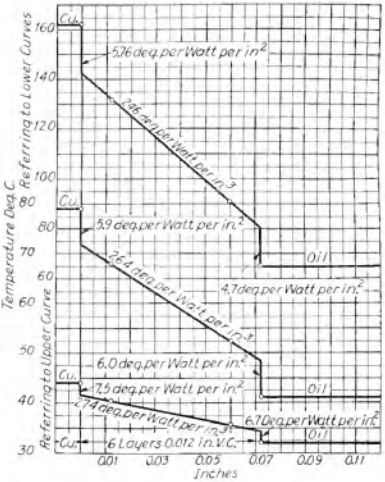

Fig. 4. Curves of Surface and Insulation Temperature Drops

The variation of temperature rise for various watts per sq. in. for a given coil with bare conductors is shown in Fig. 5. This shows that the temperature rise varies as the 0.7 power of the loss.

Fig. 6 shows a temperature rise curve made on a horizontal coil having a strand insulation consisting of 0.021-in. cotton (two-side thickness) and 0.010-in. horn fiber (on one flat side of strand) enclosed in 0.012-in. varnished cambric. The temperature rise again varies as the 0.7 power of the loss.

Other tests conducted on tall vertical coils indicate that the temperature rise over the *average* oil varies fairly closely as the 0.7 power of the loss. This law, however, should not be considered to apply to the temperature rise *over top oil* of a stack of either horizontal or vertical coils.

If we let W_s represent the watts per sq. in. coil surface, the following equation results:

$$\theta = K\, W_s{}^{0.7}$$

where K is a constant for any given coil.

At 25 deg. C. the watts per sq. in. of a coil with rectangular or square conductor is

$$W_s = 3.47\, C^2 dn\left(\frac{h}{s+h}\right)10^{-7} \qquad (4)$$

in which

$W_s = RI^2$ watts per sq. in. on two sides of the coil surface.

C = current density in amperes per sq. in.

d = depth of bare conductor in inches in direction of heat flow.

n = number of conductors in direction of heat flow.

h = thickness of copper strand at right angles to direction of heat flow.

s = thickness of insulation between copper strands which is included as a radiating surface.

Also at 25 deg. C. the I^2R watts per lb. W_c of copper is

$$W_c = 2.16\, C^2\, 10^{-2} \qquad (5)$$

Having established the foregoing we can now calculate the effect of strand insulation on the cooling after shut-down.

The equation of the line in Fig. 5 for a coil with bare strands is

$$\theta_o' = 1.95\,(10\, W_s)^{0.7} \qquad (6)$$

If we insulate the strands the initial rise becomes

$$\theta_o'' = 1.95\,(10\, W_s)^{0.7} + \rho i W_s \qquad (7)$$

in which

θ_o'' = initial temperature rise in deg. C. for any given value of W_s.

$\rho = 300$ = thermal resistance of insulation in degrees per watt per cu. in.

i = one side thickness of strand insulation in inches.

The cooling after shut-down is

$$\theta = \theta_o''\left(1 - \epsilon^{-\frac{0.676\frac{a W_c d}{A+a}}{\theta_o''}}\right) \qquad (8)$$

According to formula (8) and for 2800 amperes per sq. in. ($W_c = 20.2$ at 75 deg. C.) the cooling for 0.020, 0.050 and 0.080-in. strand insulation, added to the coil (Fig. 5) is as shown in Table III.

The cooling is so nearly the same (especially for the first two conditions) that for practical purposes the strand insulation and initial temperature rise could be neglected. The last coil has a lower space factor than is usually found in practice except for coils with several turns per layer.

There is also another style of coil which is not covered by the foregoing and that is a thick coil consisting of several turns per layer. This has the effect of causing a greater initial temperature rise for a given current density than for a single layer coil. The factor $\frac{a}{A+a}$, however, is usually considerably reduced (due to extra layer insulation) which partially compensates for the increased cooling after shut-down due to the effect of the high initial temperature rise. For instance, the windings of distribution transformers generally come under this class, and the factor $\frac{a}{A+a}$ is approximately 0.3 whereas for a single layer coil exposed to oil on both sides it is usually around [illegible] rule the thick coil will [illegible] denly cool off a little [illegible] layer coil, which [illegible] is usually exposed [illegible] consideration to [illegible]

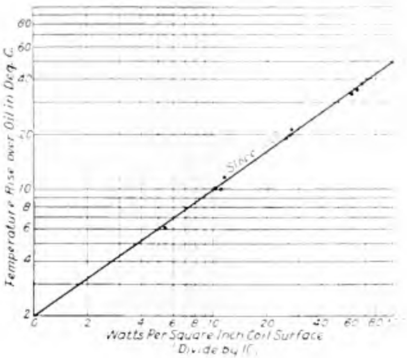

Fig. 5. Curve of Temperature Rise of Oil-immersed Windings

Coil in horizontal position with under side and edges blanketed to prevent escape of heat. Surface of coil bare except 0.010 in. Horn fibre between conductors.

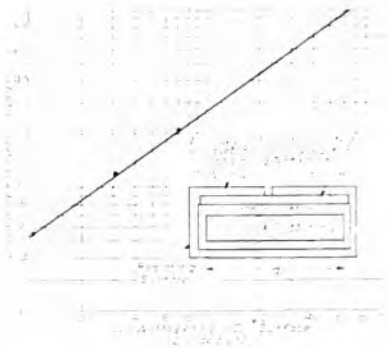

Fig. 6. Temperature Rise of Oil-immersed Winding. Horizontal Disk

temperature rise. A comparison is later shown between the tested and calculated (by copper loss formula) cooling of 10, 25, and 50-kv-a. distribution transformers.

Derivation of Partially Theoretical and Partially Empirical Copper Loss Formula

Reference has been made to the curve in Fig. 6 which shows the temperature rise for constant conditions, of the coil over oil *vs.* coil surface loss in watts per sq. in.

The equation of this line is

$$\theta_o'' = 5.2\,(10\,W_c)^{0.7} \qquad (9)$$

Combining equations (4), (5), and (9) we have

$$\theta_o'' = 7.27\left(W_c\,dn\frac{s}{s+h}\right)^{0.7} \qquad (10)$$

which combined with (3) gives

$$\theta = \theta_o''\left(1-\epsilon^{-\frac{\frac{c\,W_c\,t}{0.676\,(A+a)}}{\theta_o''}}\right) \qquad (11)$$

TABLE III

Stranding 2r Inches	$\frac{a}{A+a}$	W at 25 deg. C.	θ_o''	COOLING IN DEGREES CENTIGRADE FOR 1	2	3	4	5 Min.
0.020	0.438	0.81	10.8 deg.	4.6	7.2	8.8	9.6	10.2
0.050	0.364	0.65	12.1 deg.	4.1	6.8	8.6	9.8	10.6
0.080	0.305	0.54	12.8 deg.	3.6	6.1	8.0	9.3	10.3

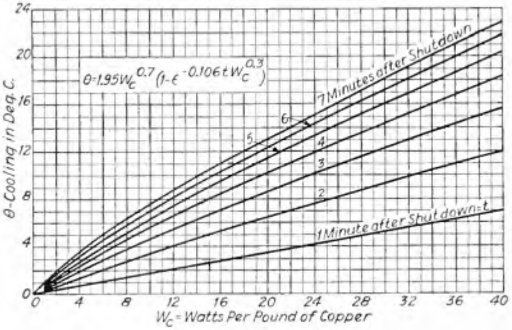

Fig. 7. Cooling Curves, Calculated by Formula (12), for Oil-immersed Windings

Putting the values of dimension of conductor as defined in formulas (3) and (4) and in Fig. 6 of

$d = 0.3$
$n = 1$
$h = 0.055$
$s = 0.055$
$a = 0.0165$
$A = 0.038$

in (10) and (11).

$$\theta = 1.95\, W_c^{0.7}\left(1 - \epsilon^{-0.106\, t W_c^{0.3}}\right) \qquad (12)$$

in which

t = time in minutes after shut-down.
θ = cooling after shut-down in deg. C.
W_c = watts per lb. of copper.

Equation (12) is shown in curve form in Fig. 7.

When the copper loss does not exceed 30 watts per pound the following rule approximates very closely the curves shown in Fig. 7. The correction in degrees C. is the product of the watts loss per pound of copper for each winding multiplied by a factor depending upon the time elapsed between shut down and the time of the temperature reading as given in the following table:

Time in Minutes	Factor
1	0.19
2	0.32
3	0.43
4	0.50

For intermediate values of time the value of the factor can be obtained by interpolation.

Figs. 8 and 9 show a comparison between the tested and calculated (by formula 12) values for 9.8 and 22.5 watts per lb. of copper of the lightly and heavily insulated coils shown in Fig. 3. It will be noted that the cooling as calculated by the partially theoretical and partially empirical formula checks more closely the observed values than the cooling as calculated by the theoretical formula (3), and shown in Table II.

Figs. 11 and 12 show a comparison between the observed and calculated (by formula 12) cooling of a stack of horizontal disk and vertical rectangular shell-type coils (Fig. 10) which were tested under the best conditions possible for obtaining quick readings. The coils were assembled without their cores to eliminate the effect of inductance previously

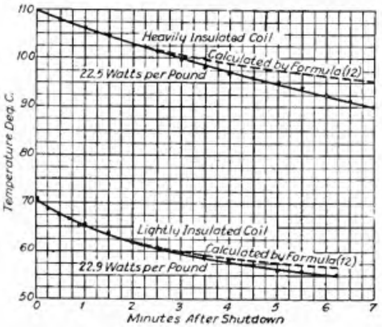

Fig. 8. Cooling Curves of the Oil-immersed Windings shown in Fig. 3. (Average oil approximately 55 deg. C.)

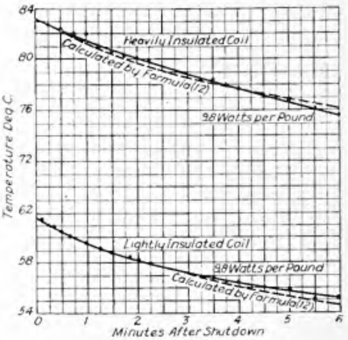

Fig. 9. Cooling Curves of the Oil-immersed Windings shown in Fig. 3. (Average oil approximately 50 deg. C.)

referred to. The current was held on the coils until the temperature rise of the coils over the oil had become constant as indicated by thermo-couples. By special switching arrangements, it was possible to obtain a reliable reading within 10 to 15 seconds after shut-down.

Table IV gives the variation in degrees C (plus or minus) that the cooling calculated by formula (12) differs from the cooling found by tests on disk, cylindrical, rectangular and regulator oil-immersed windings.

For the disk and cylindrical windings the plus and minus errors seem to be about equally divided for both two and four minutes after shut-down. For the rectangular windings the plus errors predominate which means that the tested cooling was slightly greater than the calculated. The same is true for the regulator windings. The fact that formula (12) checks so closely the tested cooling of regulator windings, which are partially embedded in iron slots similar to motor or generator coils, indicates that it should hold close enough for practical purposes for almost any type of oil-immersed windings.

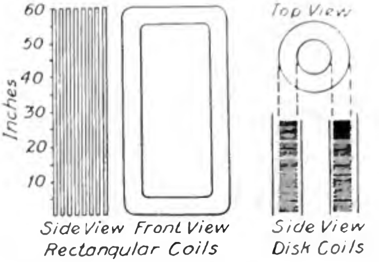

Fig. 10 Sketch of Windings Used for Determining the Cooling Curves shown in Figs. 11 and 12

This method of correcting back to shut-down has been in commercial use by the General Electric Company for the past five years. During this time the writer has had opportunity to check it up with cooling curves obtained on all types of oil-immersed windings and has never found that the calculated and tested cooling differed more than one or two degrees centigrade which is permissible considering the fact that the cooling of water-cooled transformers often amounts

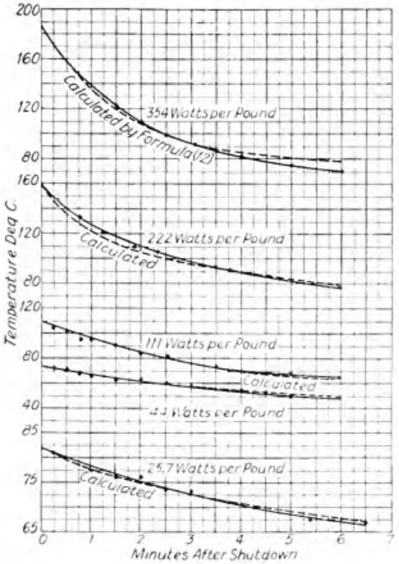

Fig. 11. Cooling Curves of the Oil-immersed Disk Windings shown in Fig. 10

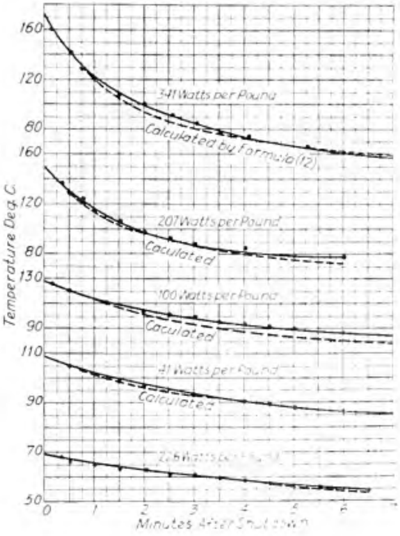

Fig. 12. Cooling Curves of the Rectangular Windings shown in Fig. 10

to ten or twelve degrees centigrade in four minutes.

The curves in Fig. 13, showing the cooling of 10, 25, and 50-kv-a. distribution transformers, are interesting because they show, as previously pointed out, that where the insulation space factor is low (and coils are thick) the cooling is, for a given current density, somewhat greater than for a coil with a low insulation space factor. Due to the fact, however, that the current density is always low for this type of coil the error in degrees even for four minutes time is never large. Furthermore, for this class of transformers (distribution) it seems more satisfactory to use an arbitrary rate of about one degree per minute for correcting back 55 deg. C. rise transformers. These curves show a rate of slightly less than one degree per minute for 50 deg. C. rise transformers. For 55 deg. transformers the rate of cooling would be approximately one degree per minute.

Cooling of Air-blast Transformers After Shut-down

Formula (12), as would be expected, does not hold for air-blast transformer coils. Fig. 14 shows the cooling of some coils of this type. These curves show that the cooling after shut-down is small and is at the rate of approximately one half degree centigrade per minute for thirty-five degree rise transformers. There is no reason, therefore, why an arbitrary correction of one degree centigrade per minute for fifty-five and sixty degree rise transformers could not be used without encountering serious errors.

Conclusions

(1) The cooling curve method of correcting back to the instant of shut-down is the

TABLE IV

COMPARISON OF COOLING BY TEST OF OIL IMMERSED WINDINGS WITH COOLING CALCULATED BY FORMULA (12)

Self- or Water-cooled	Kv-a.	Style of Winding	DEGREES CENTIGRADE			
			Variation of Test from Calculated Cooling			
			2 Minutes After Shut down		4 Minutes After Shut-down	
			Plus	Minus	Plus	Minus
Self	200	Cylinder	0.5		0.8	
Self	400	Disk		0.5		0.7
Self	1000	Cylinder	0	0	0	0
Self	750	Disk	0.5		0.8	
Water	3000	Disk	0		0.2	
Water	2500	Cylinder		0.5		0.9
Self	200	Cylinder	0.8		1.1	
Self	433	Disk	0.5		0.4	
Self	400	Disk		0.7		0.8
Self	135	Cylinder	0.1		0.1	
Self	750	Disk	0	0	0	0
Water	450	Disk		0.5		0.4
Water	2000	Disk	0.0		0.9	
Self	300	Cylinder	0.2		0.6	
Self	300	Disk	0.4		1.0	
Water	1000	Disk		0.7		0.8
Water	900	Cylinder		0.2		0.8
Water	750	Disk	0.6		0.7	
Water	750	Disk		0.2		0
Self	10000	Cylinder	0.3		0.6	
Self	750	Cylinder		0.5	0.1	
Water	5500	Rectangular	0	0	0.5	
Water	5500	Rectangular	0.2		0.3	
Water	6000	Rectangular	0	0	0.5	
Water	6000	Rectangular	0.3		0.5	
Self	46	Regulator	0.5		0.8	
Self	62.5	Regulator		0.1		0.2
Self	8.6	Regulator	0.3		0.7	
Self	17.25	Regulator		0.3		0.4
Self	62.5	Regulator	0	0	0.7	
Self	8.6	Regulator	0.2		0.9	
Self	46	Regulator	0.4		0.7	

most accurate when used with laboratory care but is not practical commercially because it is laborious and expensive.

(2) A fixed or an arbitrary rate of correction is not desirable for all types of oil-immersed windings, because of serious errors.

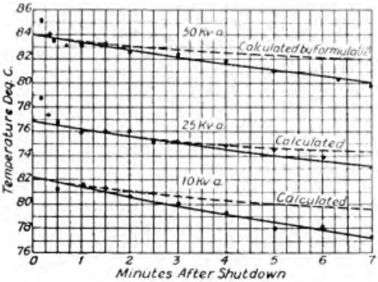

Fig. 13. Cooling Curves of 2200-volt, 50-deg. Rise Distribution Transformer Windings

(3) A purely theoretical correction is not possible on account of the difficulty in determining the proper base or ambient temperature of oil-immersed coils. Furthermore, if the base temperature could easily be determined, the method would not be simple enough for practical use.

(4) Curves (Fig. 7) based on a partially theoretical and partially empirical formula (12) is simple in application and can be used with results accurate enough for practical purposes for all types of oil-immersed transformer windings. However, for distribution transformers of 100 kv-a. and less, where the copper density is fairly uniform for the different sizes, an arbitrary rate of one degree centigrade per minute, providing the time does not exceed three minutes, can be used.

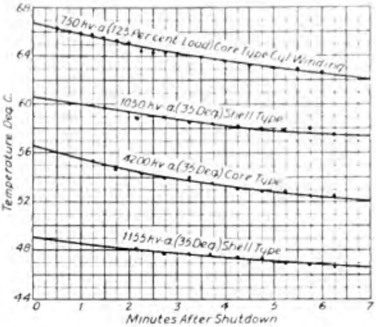

Fig. 14 Cooling Curves of Air-blast Transformer Windings. (Air shut off with load)

(5) For air-blast transformers an arbitrary rate of one degree per minute, providing the time does not exceed four minutes, can be used for correcting the temperature (by change in resistance) back to shutdown.

Edison and the Incandescent Lamp

AN ADDRESS TO GENERAL ELECTRIC EMPLOYEES ON EDISON DAY

By Chas. L. Clarke

To commemorate the invention of the first successful incandescent electric lamp by the greatest inventor of all the ages, the anniversary date, October 21, has been set apart as "Edison Day." At the Schenectady Plant of the General Electric Company, this year's recurrence of the day was celebrated by a parade, musical concert, and address. Mr. Chas. L. Clarke was well selected as the speaker, for he was intimately associated with Mr. Edison in his early work. The address described how Mr. Edison's futuristic ideas of electric lighting were in the early days commonly held to be preposterous, and how by his persistent efforts these same predictions have been fulfilled many fold. This foresight and productive ability, combined with other of his characteristics also described, increase our admiration for this great inventive benefactor of mankind.—Editor.

We are here to commemorate the invention, 40 years ago today, at Menlo Park, New Jersey, of the first practical electric lamp of such moderate illuminating power as to take the place of the ordinary gas burner for lighting our homes and similar uses.

That invention, represented in the incandescent electric lamp, was made by Thomas Alva Edison, whom a grateful world holds in high honor for thus giving to it one of the greatest boons, for its comfort and other civilizing influences, ever conferred by the brain and hands of one man.

Although this is not the only invention made by him to the world's benefit, for he has given to it improvements in printing and duplex telegraphy, the quadruplex telegraph, the carbon telephone transmitter by which the range of speech was at once immensely increased, the phonograph, the fundamental inventions absolutely necessary to a large and universal electric light and power system, his storage battery and motion picture apparatus, and many other inventions represented by considerably more than 1000 patents in the United States alone; nevertheless, it is appropriate on this occasion that attention be confined substantially to his lamp and matters most closely related thereto.

Beginning of Incandescent Lamp

Sir Humphrey Davy produced the electric arc early in the last century, but this discovery remained for years commercially unutilized because of the prohibitive cost of current from a chemical battery, which was the only known available source of electricity for this purpose.

Faraday, in 1831, led to its use by the discovery of magneto-electric induction and devised an electric machine which was the forerunner of the electric generators of today. But it was not until after 1870 that the electric arc lamp and the generator were sufficiently developed to be in commercial use for arc lighting on a scale worthy of much consideration.

Many efforts were also made to produce an economical arc lamp of small illuminating power suitable for home use, until it was finally and correctly pronounced impossible. Effort was also made to produce incandescent lamps, all of which were complete failures.

A Target of Ridicule

When it became known, in 1878, that Edison, already an inventor of fame, had undertaken to solve the problem, the so-called "sub-division of the electric light," he at once became the target of ridicule from many scientists, his business honesty was questioned from some quarters in the press, on the ground that it was a stock-jobbing scheme, and jealous gas journals added their hilarious share to the fun and derision poked at him from many quarters.

Well, he didn't succeed right away; on the contrary, he devised, human-like, some pretty poor lamps, but was learning a great deal about how the thing could not be done, thereby concentrating his efforts nearer to the objective point. The situation for a time was similar to that relating to another undertaking in which Edison was concerned, which led a friend to inquire: "Isn't it a shame that with the tremendous amount of work you have done you haven't been able to get any results?" "Results! Why, man, I have gotten a lot of results, I know several thousand things that won't work."

Edison's Efforts Rewarded

And all the time the scrap heap grew—nobody can pile one up faster or easier than Edison. At last his efforts were rewarded. On Tuesday, October 21, 1879, he had the audacity to carbonize a slender cotton thread and try it as an incandescent burner in an exhausted globe. The seemingly frail thing endured far beyond all expectation; besides it had the small surface necessary for a small light, and the long, slender filamentary body of high resisting carbon required for conductors of economic size. The lamp long sought, and in general considered impossible, was finally invented.

Edison has often been called a genius, and not altogether liking the misleading term, has said that to him genius consists of two per cent inspiration and 98 per cent perspiration that is, hard work. While, no doubt, there was at least 98 per cent of good hard work in inventing the lamp, does it seem possible that he would have thought of trying that slender carbonized thread had not a little bit of that two per cent of inspiration come into his head?

Improvements in Lamp Rapid

Now that the lamp was invented, he pushed its improvement and commercial introduction with his peculiar energy. Lamps with burners of carbonized bristol board were in commercial use by May, 1880, but bamboo was quickly substituted for the paper, as material for the burner with great improvement in durability and economy.

In the summer of 1881, the output had grown to 1000 lamps per day, whereupon Edison predicted that in 15 years the daily product would become 10,000 or 12,000,000 lamps a year, a guess which time proved to have been way under the mark.

Naturally, the incandescent lamp has been greatly improved in economy, by Edison and through the later inventions of others. The early bamboo filament lamps required about six watts per horizontal candle-power, at which time Edison said, "Just wait a little while and we will make electric light so cheap that only the wealthy can afford to burn candles," which has in fact practically become true. The average current required was later reduced to 3.8 watts, followed by the so-called squirted filament, in general use in 1892, requiring 3.1 watts, the Gem lamp, in 1906, with a filament carbonized by an improved process, which requires only 2.56 watts, the Mazda lamp, in 1911, made possible by the invention of die-drawn tungsten wire for the filament, which has brought the energy re-

Thos A Edison

quired down to 1.03 watts, and lastly the Mazda C lamp, with the tungsten filament in a bulb filled with inert gas, which has still further reduced the energy on the average to about 0.8 watt per horizontal candle.

Production Beyond Comprehension

The number of incandescent lamps annually made in the United States alone has become enormous, and almost beyond comprehension. The output of Mazda lamps is about 170 millions of all sizes from 10 to 1000 watts, of which nearly 13 per cent are of the Mazda C type, and in 1918, 20 millions of squirted and Gem carbon filament lamps were made. A grand total of about 240 millions of incandescent lamps of all kinds and sizes from the little miniature lamp to the largest Mazda C are now produced yearly in this country.

Edison a Smoker, but Abstemious Liver

Edison is a very human man, just about like the rest of us in general, but with some characteristics not altogether common. He uses tobacco both ways, and rather likes the second way the better, believing it affects the nerves less. But he can, nevertheless, smoke cigars filled with rags and hair without inconvenience, when busy on a problem, as proved by his smoking up a box full of that kind made specially for him to surprise someone else helping himself to another man's goods.

He believes in abstemious but generous diet in the sense of having a variety, but is careful in its selection, practically resisting meat as bad for the health and has always absolutely cut out alcoholic drink, also, by the way, what he calls "too much sleep."

Inventor, Not Scientist

He has never claimed to be a scientist, and prefers to be known as an inventor, seeking to devise things useful to man and of commercial value. He once said in substance that he could not spend his life in the scientific investigation of the fuzz on a bee but must be producing something of utility.

And on another occasion, when an assistant insisted that an unusually expensive piece of apparatus was necessary for a certain investigation, he remarked that no man could be a real inventor unless he could do everything with a jack knife and bean pot.

Honesty of Character

He is a man of tremendously hopeful temperament combined with honesty of character. Like most men who courageously attempt new things and take the lead, he has sometimes failed to succeed and money has been lost, but he has never hid behind his strictly legal rights to avoid payment of what he considered his justly moral debts. As an illustration to the point: An enterprise, which was promoted on certain of his inventions, failed because of the discovery of iron ores with which he could not compete, and the company stopped business with a loss of some millions of dollars put in and several hundred thousand dollars of debt. Edison paid off that debt personally, saying that no company in which he was actively concerned had ever failed to pay its debts, and this one must be no exception. This failure entailed on him at 50 years of age, a staggering personal loss, and yet, when things looked bluest, he brightly exclaimed: "Well, it's all gone, but we had a hell of a good time spending it," and then cheerfully went to work to pay off that debt.

He always has the courage of his convictions, and no one can bawl him out if he is convinced that he is in the right. He is ever ready to be convinced for good reason by the other fellow, but does not take kindly to the bawling process.

Moderately Rich

Edison is justly a moderately rich man but in comparison with the wealth which he has added to this world's goods, he has been one of the poorest paid men in money.

It is questionable whether any of us here, if remunerated according to the value of our work on the same scale as Edison has been paid, would have enough money to buy one square meal or a pair of cotton socks.

But a greater reward than money can measure is his—the gratitude, the honor and respect of everyone. He will go out of the world one of its greatest creditors, for which a respecting memory of him and his work will live through centuries to come.

In practically all electrical industry, the sound of every groaning machine, the hum of every wheel, the ring of every hammer, the rasp of the file, the roar of the furnace flame, are in large measure but the amplified echoes of the work that went on years ago in Edison's laboratory under his impelling energy, directed by this genius. And let us not forget that we, not Edison, are reaping the major return from his labor.

Let us hope that Edison may be with us, possessed of unabated mentality and sound physical vigor of which there is certainly every reasonable promise today, to join in celebrating the 50th anniversary of the birth of the incandescent electric lamp.