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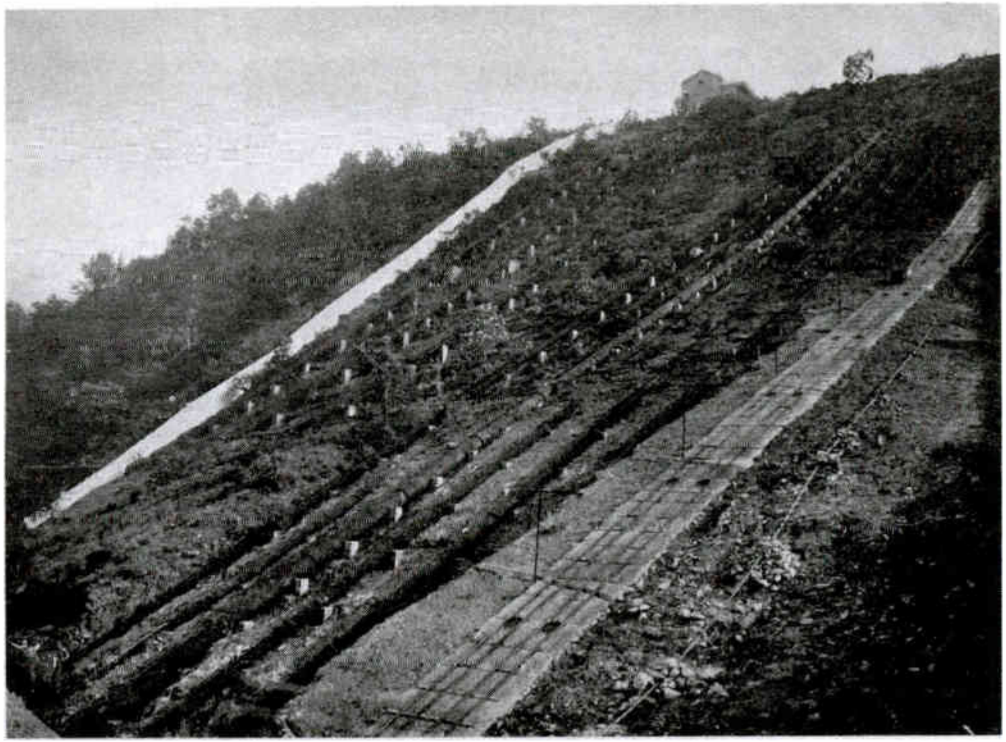

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GENERAL ELECTRIC REVIEW

With the present issue, the Review enters upon the third year of its circulation outside of the organization of the General Electric Company. Its reception by the electrical fraternity at large, and the support it has received have been most gratifying. With the new year more space will be devoted to distinctly practical articles, while theoretical articles will be restricted to those that have a direct bearing upon everyday practical engineering. The latest developments in the electrical engineering practice, new machinery, discoveries and inventions will be described and illustrated.

A modern manufacturing concern of the magnitude of the General Electric Company is a distinctly educational institution and partakes of many of the more important characteristics of a university. First, there are the student courses composed largely of graduates of technical schools and colleges who attend for the purpose of obtaining a practical knowledge of actual operating conditions with a greater variety of commercial apparatus than was possible with the comparatively limited equipment of the college laboratory.

The second feature of similarity lies in the research work that is carried on in the various laboratories. Few, indeed, are the universities that can devote such enormous sums as are annually expended by a large manufacturing company in purely scientific research, and there are few where the technical work is of a higher order. Many of the investigations carried on in laboratories of manufacturing plants would, if pursued in those of a university, entitle the investigator to the higher graduate degrees.

A third feature of similarity to the university is the dissemination of information in printed form. As the large university prints its theses, monographs and pamphlets, so the manufacturing concern publishes the results of recent development and improvements in engineering methods and practice, describing new apparatus which must be brought to the attention of the engineering fraternity, and setting forth its use, its characteristics, and its advantages. Herein lies the function of the General Electric Review—it is the medium for disseminating this information to the engineering profession.

Being in close touch with the experts of the General Electric Company, each of whom is in advance of the latest developments in his own line, the Review possesses exceptional opportunities for securing early and accurate information in practically every branch of electrical activity. For this reason, it can furnish information a year or more in advance of its appearance in the text books and elsewhere.

Of the series of articles on practical subjects scheduled for the coming year, one in particular, on the diagnosis and remedy of troubles with alternating current apparatus, should be of special value to the construction engineer, to the operator, to the central station man, the consulting engineer, and the student. Little has been written on this important subject, and that little is mostly scattered through various domestic and foreign magazines and books. We hope to make this series complete and to so arrange it that if a piece of alternating current apparatus goes wrong, the difficulty can be immediately located.

Mr. E. B. Raymond, General Superintendent of the Schenectady Works, will leave the employ of the General Electric Company on January 31st to accept the position of Second Vice President of the Pittsburg Plate Glass Company, and take charge of their manufacturing.

Mr. Raymond was born in Somerville, Massachusetts, and pursued his preparatory education in the High School of that place. He received his university education at the Massachusetts Institute of Technology, from which institution he was graduated in 1890, and the same year entered the employ of the Thomson-Houston Company, at Lynn, where he devoted two years to practical work and then entered the Railway Department to take charge of experimental railway work. Mr. Raymond later entered the Calculating Department, under Mr. H. F. Parshall, and when that department was discontinued at the time of the combination of the Thomson-Houston and Edison companies, became Assistant Engineer of the Chicago office, where he was engaged in construction work and in investigating operating troubles.

In the spring of 1895, Mr. Raymond came to Schenectady in the capacity of General Foreman of the department attending to erecting, testing, and the preparation of apparatus for shipment. Mr. Raymond was appointed to his present position of General Superintendent of the Schenectady Works in 1903, at which time the position was created. The duties in this position are defined in the following notice which was published at that time:

"In the absence of the Manager, the General Superintendent will be the ranking officer in charge of the works.

"Foreman will report to and be governed by instructions from the General Superintendent's office in matters pertaining to electrical and mechanical testing and inspection of apparatus and materials, corrections of defects that develop in manufacture, suggested changes in methods or design of apparatus, operation of machine tools, readjustment of facilities and help, as requirements may arise, shop discipline and other matters relating to the economical operation or general condition of departments."

With the departure of Mr. Raymond, the General Electric Company will lose one of the most able and popular members of its technical staff. While a rigid disciplinarian, he commands both the respect and affection of his men, all of whom have learned that with the General Superintendent they are always sure of a square deal.

Mr. Raymond is the author of a number of monographs on electrical and mechanical subjects, besides two text books that are used in various technical colleges.

Dr. Ernst Julius Berg, who for a number of years has been recognized as one of the leading engineers of the General Electric Company, recently accepted the position of Professor of Electrical Engineering and Head of the Department at the University of Illinois.

Dr. Berg was born at Ostersund, Sweden, in which country he resided until he reached his majority. His early education was received in the High School of his native town, and his technical education at the Royal Institute of Technology in Stockholm, from which he was graduated in 1892 with the degree of Mechanical Engineer. Upon completing his university course, Dr. Berg came to America and shortly thereafter entered the employ of the Thomson-Houston Company. Here his technical knowledge and manifest ability as an engineer was immediately recognized, and from a relatively subordinate position, he rapidly advanced to that of Dr. Steinmetz's assistant and chief coadjutor.

In the design and development of alternators, motors, rotary converters, and other alternating current apparatus; and in the solution of such problems as those arising from the use of the alternating current for railway operation, the parallel operation of alternators, the hunting of rotaries, etc., etc., Dr. Berg rendered particularly effective and valuable work. He contributed largely to the successful development of the steam turbine. For a number of years Dr. Berg has acted in the capacity of Consulting Engineer with the General Electric Company. To him were taken many of the more intricate and difficult problems

Dr. Berg is the author of numerous papers on engineering subjects, and his treatise on the transmission and utilization of electrical energy is a recognized standard. He also collaborated with Dr. Steinmetz in the preparation of the latter's well known "Alternating Current Phenomena." For the past two years he has held the position of Consulting Professor of Electrical Engineering at Union University and recently received the degree of Sc. D. from that institution.

A first-class practical engineer is a man diligently sought after in these days; first-class theoretical men who understand the mathematical theory of the science are more infrequently met, but the man who can combine these gifts—who is both a high grade practical engineer and a mathematical technician,—and who can use his theory in the practical engineering work is exceptional indeed. Finally, the one who, while possessing these characteristics of theoretical knowledge combined with practical engineering ability, can convey his information to others—who in other words possesses the qualifications of a teacher—is a *rara avis*. Such a one is Dr. Berg.

THE FIRST IMPORTANT HYDRO-ELECTRICAL DEVELOPMENT IN SOUTHERN ASIA

By H. P. Gibbs, M.A.I.E.E.

The Undertaking

In 1809, having decided to develop hydraulic power in the vicinity of the old village of Sivasamudram for the supply of electric current to the several gold mining companies on the Kolar gold field ninety-two miles away, the Government of Mysore despatched Capt. A. Joly de Lothbiniere, Royal Engineer (loaned to the State of Mysore by the Imperial Government), to Europe and America for the purpose of arranging suitable contracts for the equipment and erection of the power plant, and for the utilization of the available power.

As such work was an entirely new departure in India, Capt. Lothbiniere first made a tour of Europe and America, visiting the plants of numerous manufacturers to ascertain which company, in the matter of experience and facilities, was best qualified to carry through such a contract. A decision was made in favor of the General Electric Company of America for the complete electrical work, including generation, transmission and distribution, and Escher Wyss, of Zurich, for the hydraulic turbines. Each of these companies agreed to install its portion and complete one year's successful operation prior to accepanetc on the part of the Government.

Fig. 1. The Cauvery Falls

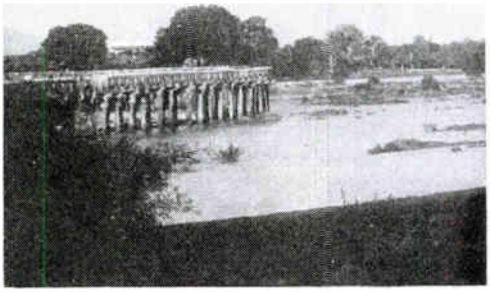


Fig. 2. Bridge at Sivasamudram

Arrangement was made with the firm of Messrs. John Taylor and Sons, on behalf of the several mining companies, for the consumption of a little over 4000 horse-power.

The Head Works

At a point approximately two miles above the Cauvery Falls and well above the swiftly descending rapids, a low diverting dam 4.2 ft. in height and 390 ft. in length was built of granite masonry, on a river bed of hard dolerite trap rock. This dam was built for the express purpose of diverting the entire supply of water to the channels during low water periods.

Intake Channels

The entrance to the two channels is equipped with suitable gates for regulating the flow of water, and, in addition, with a scouring sluice for preventing an undue accumulation of silt in front of the channel openings.

Channels

There are two parallel channels which follow the natural contour of the country, so that, although the distance down the river from head works to power house is but

2.65 miles, the channels are 3.375 miles in length. These two channels, when filled to a depth of 6.3 ft., pass 560 cubic feet of water per second, which quantity is sufficient to develop 18,750 h.p. at the turbine shafts. The normal gradient of the channels is 0.2 ft. in 1000 ft. For a distance of 1400 feet, the channels were cut through a spur of hornblende shist and were narrowed to a width of 12 feet with vertical sides, the slope or gradient being increased to 0.6 in 1000.

Fig. 3. Penstock Forebays

Forebays

The two channels terminate in a forebay which is built in two sections, one for the original installation of 6000 h.p. and the other for the first extension of 5000 h.p. Recently a second extension has been made, increasing the capacity of the plant by 2000 h.p., and making a total of 13000 installed electrical horse-power in generators.

The intake chambers for the penstocks are protected from debris by the usual iron rack and are regulated by gates of sheet iron on angle frames operated by hand wheels.

Penstocks

Each penstock is equipped at the top with an ordinary gate valve for individual control. Each pipe has two expansion joints and is supported at the bottom by a firmly anchored thrust block located just outside of the power house wall.

For the original plant, three penstocks were installed, each supplying two 1250 h.p. turbines, while subsequently each turbine has been supplied from a separate pipe. The penstocks are located on an incline having a slope of 1 in 2 for about half way, and 1 in 3 for the remainder of the distance. The average length of the penstocks is 920 feet, with an effective head of 382.5 feet.

The larger pipes are built in three sections, with diameters of 48, 45 and 42 ins. and respective thicknesses of $\frac{3}{16}$, $\frac{1}{4}$ and $\frac{5}{16}$ in. The smaller pipes are built in four sections, the different sections having diameters of 36, 33, 30 and 27 ins., and respective thicknesses of $\frac{7}{32}$. $\frac{1}{4}$. $\frac{1}{4}$ and $\frac{9}{32}$ in. The velocity of flow at the thrust blocks under normal full load conditions is 7.33 feet per second.

Fig. 4. Channels Through Rock Cutting

Turbines

As stated before, the turbines were built by Messrs. Escher Wyss, of Zurich, each turbine having a capacity of 1250 h.p. at 300 r.p.m., with a water consumption of 37½ cu. ft. per second. An interconnection between penstocks is made in the power house with a 10 in. pipe, which also serves the purpose of an exciter main. A similar connection from this pipe to the hydraulic regulators is made for use in emergencies, while the ordinary regulator supply is obtained from a separate service main of 10 in. diameter leading from the forebay, at which point settling tanks are provided to supply clear water in order that the wear of regulator valves and moving parts, due to gritty substance usually carried in the river water, may be avoided.

Regulators

Each turbine is equipped with two jaw nozzles, and the regulation is accomplished as follows: Each nozzle tongue is pivoted near its center, and the tendency to open, due to pressure underneath the tongue, is resisted by a corresponding pressure on a piston linked to the end of the tongue on the side of the fulcrum opposite to that on which the first mentioned pressure is exerted. The pressure on the top side of the piston is automatically varied by a regulating valve operated by fly-balls, allowing the nozzles to open and close according to requirements.

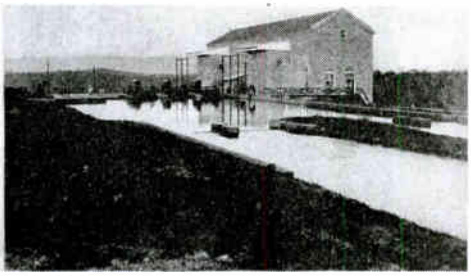


Fig. 5. Penstock Gates and Switch House

This regulator works well under conditions of flat load curve, but is naturally slow in responding to large and sudden fluctuations.

The governor is equipped with a hydraulically operated automatic relief valve, so that undue rise of pressure in the system is entirely eliminated when sudden shut-offs occur. This relief system has always proved reliable and efficient.

Fig. 6. General View of Development at Power House

Exciters

The generating station is equipped with three turbine-driven and two motor-driven exciters, each of 75 kw. capacity, 110/115 volts.

The generators consist of eleven 720 kw. units, and one 1500 kw. unit, all of which are driven at 300 r.p.m. and operated at 2173 volts, full load normal conditions. The stationary armatures are so arranged that they can be conveniently jacked along the base until clear of the revolving field, thus permitting of ready access to all parts. Up to the present, however (seven years' service), it has never been necessary to shift any of them.

Each generator is supplied with a panel equipped with oil switch, ampere meter, and synchronizing lamps. These switches are for use in emergencies only, as ordinarily the operation is handled from the step-up station, 400 feet above and 1200 feet away.

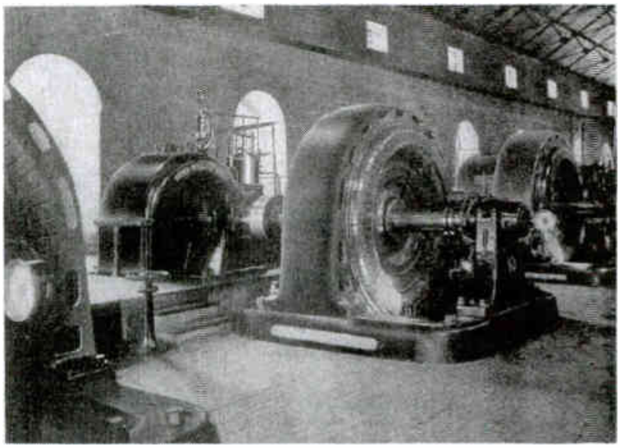


Fig. 7. Generating Units

The separation of the generating station and transformer house was made in accordance with the wishes of Government officers, as it was thought that men working above would be much less subject to malaria than those working in the generating station below. However, it has since been found that such an arrangement was unnecessary.

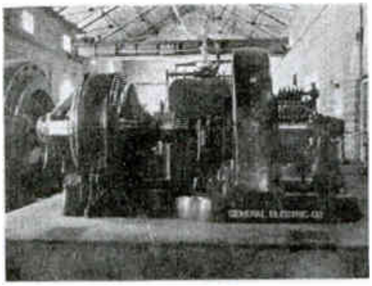


Fig. 8. Motor Driven Exciter

The entire site was at first very much infested with fever bacteria, but good water supply, drainage, sanitation, and clearing of undergrowth have combined to minimize the danger, and now fever cases among the staff are exceptional.

The field and armature cable of each machine are connected by individual cables to the low tension switchboard apparatus above. These cables, which are paper insulated and leaded, are carried on projecting stone shelves at the sides of a ventilated masonry duct. (See illustration page 2.)

Low Tension Work

The low tension switchboard is so arranged that all 2000 volt connections are confined to the basement, while low tension currents only are carried above, where the operator stands on watch.

General Electric Type TA regulators are used to good effect and with satisfactory results for regulating the voltage.

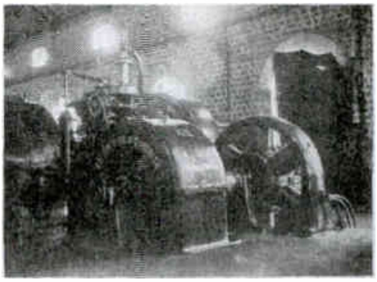


Fig. 9. Turbine Driven Exciter

After a thorough system of metering and control, the current is carried along to the low tension side of eleven banks of General Electric transformers; eight of these banks, each consisting of three single-phase 375 kw., 2173/35000 volt, air blast transformers, supplying the Kolar service; two banks, each of three 150 kw., 2173/35000 volt, oil cooled transformers, furnishing current for the Bangalore mines; and one bank of 125 kw., 2173/25000 volt, oil cooled transformers, supplying the service at Mysore. It will be noted that the latter bank delivers potential at 25000 volts instead of 35000, as for the other service.

High Tension Work

Each bank of transformers is equipped on the high tension side with a group of three single-pole double break oil switches set in masonry compartments, and can be isolated from the high tension bus-bars by means of knife switches. Each outgoing line is controlled by an automatic motor-operated three-pole switch of the standard General Electric type. These switches have proved entirely satisfactory. Knife switches are installed on both sides of the oil switches to provide a convenient means of isolating the latter for examination or adjustment.

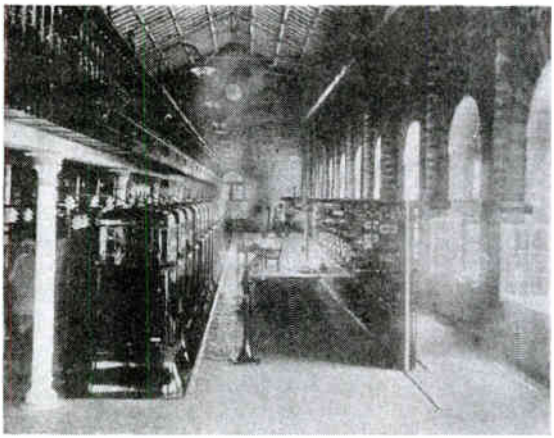


Fig. 10. Step-Up Station

Fig. 11. Exciter Panel

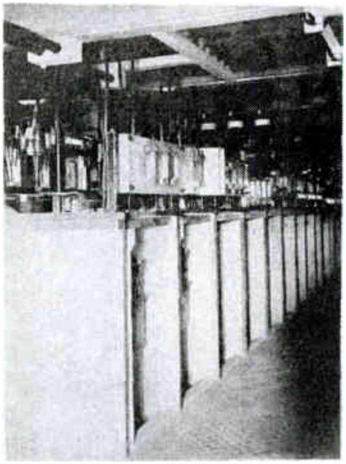


Fig. 12. Low Tension Switch Compartments

The lightning arresters are of the standard General Electric multiplex type and are located in the towers of the high tension outgoing lines. Suitable choking coils are also provided.

The lines enter through plate glass set in suitable frames, each glass having a six inch hole in its centre. These entrances have proved very satisfactory.

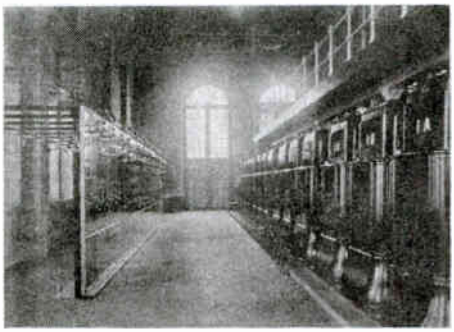


Fig. 13. Step-Down Station

Line Construction

There are three separate pole lines for the Kolar service. Two of these, as built during the first installation period, are made up of thirteen-foot lengths of extra heavy seven inch hydraulic pipe, and a seven inch square timber top seventeen and a half feet long. The timber is let into the round socket twenty-one inches, and the pole is then set six feet in the ground. This pole is expensive and deteriorates rapidly due to dry rot within the iron socket. These two lines carry No. 0 copper wire supported on single piece, five petticoat, white porcelain insulators made by Richard Ginori of Milan, Italy. The pins are galvanized iron and are secured with portland cement. The distance of transmission is ninety-two miles.

During the third installation period, a third circuit was built of No. 000 copper wire carried on wrought iron poles with angle-iron cross arms and Locke three part brown porcelain insulators.

In special work, spans up to 1020 feet have been built, using standard insulators and 6 strand hard drawn copper cable on a hemp core.

The Kolar gold field transmission lines are equipped with two section stations, dividing the three circuits into nine sections. These section houses are equipped with lightning arresters, and knife and oil switches. Here the lines can be connected straight through, independently or in parallel, and any section can be conveniently cut out for repairs without disturbing the general service. These station sites afford headquarters for the line inspectors and greatly facilitate the location of line trouble.

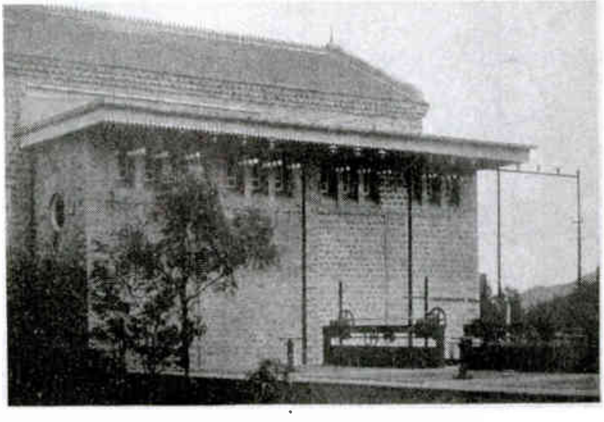


Fig. 14. High Tension Line Entrances to Step-Up Station

Sub-station

The power is received at the step-down

station at approximately 30000 volts and reduced to 2300 volts, which is the normal pressure of the distributing mains.

The Maharaja of Mysore (on left) and the late Dewar, Sir Sheshadri Iyer

The principal feature of interest in this sub-station is a one-thousand kilowatt synchronous motor running idle with heavily excited field. The leading current provided thereby maintains the power factor at the centre of distribution at from 0.91 to 0.93. Without this machine in circuit, the power factor averages 0.82. The advantage to be derived from this set in the matter of regulation of the system is obvious.

On the several mining properties of the Kolar gold field, 9000 h.p. from the Cauvery supply is employed in general mining operations, including the driving of air compressors, mills, stone breakers, work-shops, cyanide works, pumps and electrical hoists. The hoists are both above and below ground and are used in sizes up to 400 h.p. These hoists are driven by 3000 volt three-phase induction motors controlled by resistance in the rotor circuit. Their operation has proved to be satisfactory and economical. The principal winding is from a 3000 foot level, carrying a load of rock of 2 1/2 tons at 1000 feet per minute.

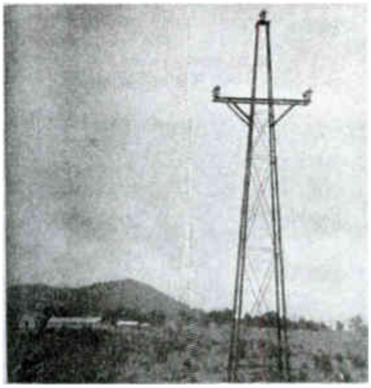


Fig. 15. Special Construction

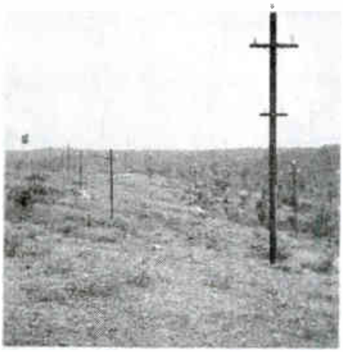


Fig. 16. Standard Construction

Financial

The original arrangement that the Government should install all distribution plants and operate the same for a period of one year prior to acceptance by the mines, applied only to the first installation. This included all distributing lines, motors, compressors, pumps, hoists, belts, ropes, buildings and foundation.

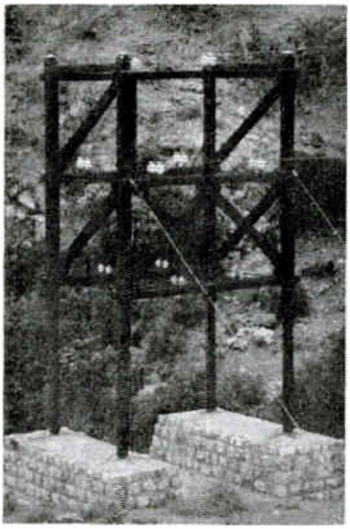


Fig. 17. Special Construction

The mining companies agreed to pay for the service on a flat rate, based on the normal full load consumption of motors. Therefore, it is perhaps needless to say that the load factor of the system is a remarkably high one.

The agreement covered ten years payment to be as follows:

First year	£29 per h.p. year
Three following years	18 " " "
Fifth year, up to	£24 per h.p. year
Five following years	10 " " "

It may here be said that of the first year's payment of £29, £11 was to recoup the Government for its expenditure on the distribution plant; so that the power payment was really £18, as in the second, third and fourth years.

The agreement as regarded the power of the second installation was the same as that of the first, except that the mines installed their own distribution plant and paid at the rate of £18 for the first year's supply. The agreement for the third installation provided for supply at the rate of £10 from the outset.

The result from the Government's point of view is highly satisfactory, although the mining companies concerned have profited to a considerably greater extent, owing to the necessity of an extremely long carriage of an inferior class of coal on which they were previously dependent.

Local Features

During the earlier construction period, work of such description was entirely new to the local people, which fact made it exceedingly difficult for the original construction staff; but the General Electric Company had chosen well, and sent able, hard working men for this special undertaking, with the result that the work was expeditiously carried out in spite of many obstacles.

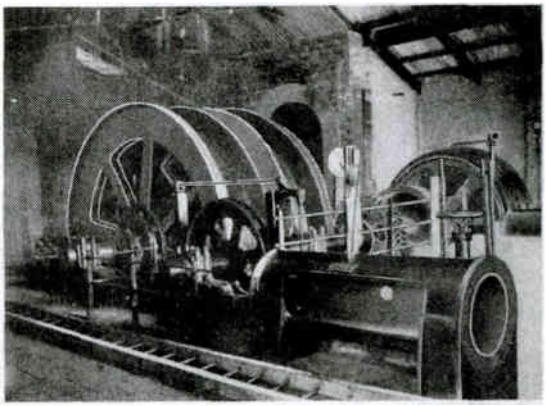


Fig. 18. 400 H.P. Electrical Hoist at Ovregum

Huge teams of bullocks might be regularly seen slowly wending their way along the hot and dusty 30 mile road, carrying the heavy machinery from the railway to the power house site, while the mighty elephant, ever ready, was frequently requisitioned to pull them out of difficult situations.

His Highness, the Maharaja of Mysore, and his able administrators, have often and deservingly been the recipients of congratulation and praise for their pluck and enterprise in carrying out this most successful installation, which was made possible through the far-sightedness and hearty co-operation of the firm of Messrs. John Taylor & Sons, of London, Agents for the Kolar Gold Field Mines.

Fig. 19. Team of Bullocks

In closing, it will not be amiss to say that when this development was planned, there were but few similar undertakings on record, so that the credit due to the above mentioned people is undoubtedly greater than would at first appear when considered from a present-day standpoint.

Fig. 20. The Mighty Elephant

The General Electric Company assumed so large a measure of responsibility that any failure must have been most severely felt by it; but as will be evident from the preceding paragraphs, the entire undertaking has proved a practically unqualified success for all concerned.

POWER FACTOR REGULATORS

By H. A. Laycock

It has become to be generally conceded that in commercial power and lighting work of the present day synchronous condensers are an absolute necessity to the central station manager, in order that the dead loss of power due to wattless current occasioned by heavy inductive loads may be eliminated. For this reason, synchronous motors are being installed on the majority of systems, even though in certain cases they have to run light, as the reduction in the cost of delivering power and the improvement in the voltage regulation of the systems more than compensate for the cost of the machines. However, in order that this regulation may be accurately obtained without the attention of an operator an automatic regulator should be employed. This article describes two forms of regulators that are arranged for power factor work. It does not matter materially whether the synchronous motors are running light, driving direct current or alternating current generators, or being used for power work, as driving conveyors, hoists, etc.

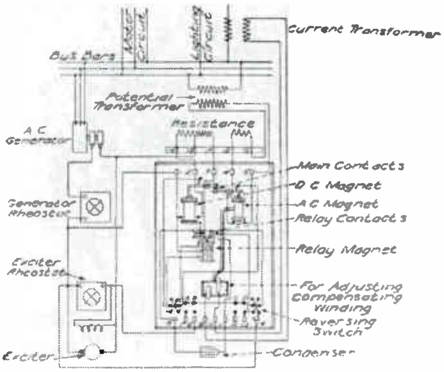


Fig. 1. Connections of Voltage Regulator for Maintaining Constant Power Factor on Line

Plants in which close regulation is desired should always have the generators equipped with voltage regulators; so that the first step is to obtain a constant voltage at the power station and thus relieve the synchronous condenser from doing more work than is necessary. This having been accomplished, the first and simplest method for the installation of a power factor regulator is shown in Fig. 1. This connection is identical with that of a voltage regulator connected to an alternating current generator; in this case, however, one of the standard voltage regulators is connected to a synchronous motor and improves the voltage of the line by increasing or decreasing the excitation on this synchronous machine, the cycle of operation being as follows:

Should the power factor tend to decrease at some point along the line, or at a point where the motor is connected, the voltage will of course have a tendency to fall, due to the low power factor

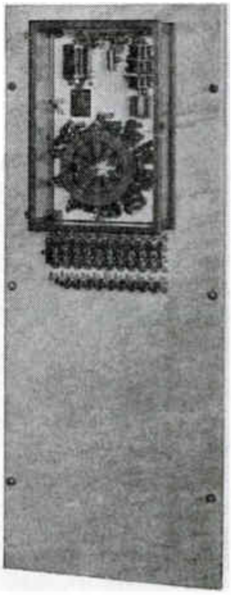


Fig. 2. Power Factor Regulator

conditions. But the alternating current regulating potential magnet is connected across the terminals of the motor, and thus when this voltage tends to fall the floating contacts are closed, which operation in turn closes the relay contacts, and builds up the exciter voltage. This increase in exciter voltage over-excites the fields of the synchronous motor and improves the power factor of the line, so that the voltage is maintained constant at this point.

By referring to connections in Fig. 1, it will be seen that the current transformer can be used if desired to overcompound or over excite the motor still more in order to give the line a leading current. This feature is especially advantageous where heavy fluctuations of inductive load occur between the central station and center of distribution.

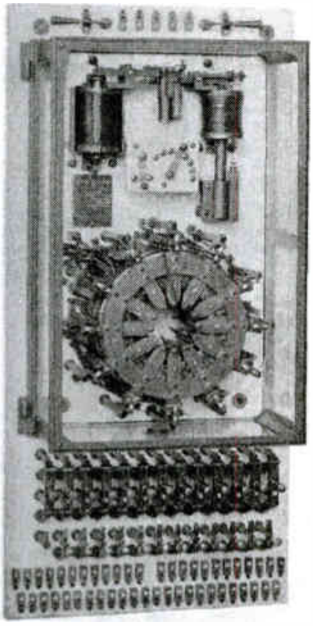


Fig. 3. 12 Relay Voltage Regulator for Power Factor Regulation

This regulator is designed with a safety stop, so that if desired the amount of excitation current that the motor will receive can be limited, thus making the machine safe against injury from excessive excitation.

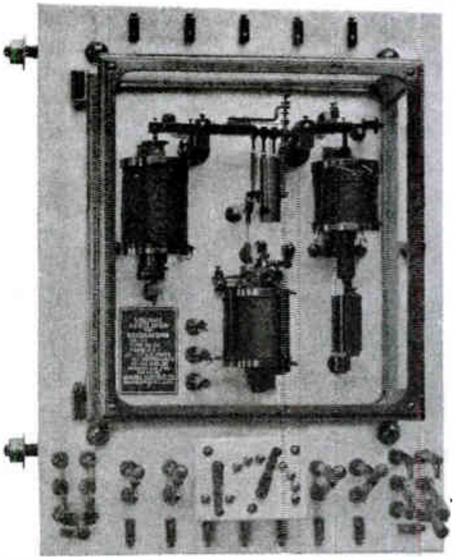


Fig. 4. Single Relay Voltage Regulator for Power Factor Regulation

Almost any number of these motors and regulators can be installed on a transmission line provided they are located far enough apart to secure sufficient reactance between the motors to insure parallel operation without hunting.

Figs. 2, 3 and 4 show the front views of the different types of TA regulators which can be used for improving power factor.

It will be noted that this arrangement of regulation does not hold a constant power factor on the synchronous motor but regulates the motor to help hold a constant power factor on the line.

CONSTANT POWER FACTOR REGULATOR

The appearance of the constant power factor regulator is shown in Fig. 2, while Fig. 5 shows the connections of the apparatus to a synchronous motor and exciter. In this apparatus, the control magnet consists of two stationary potential coils and one movable coil, which, with unity power factor, merely floats between the potential coils, the motor under these circumstances receiving a certain predetermined excitation.

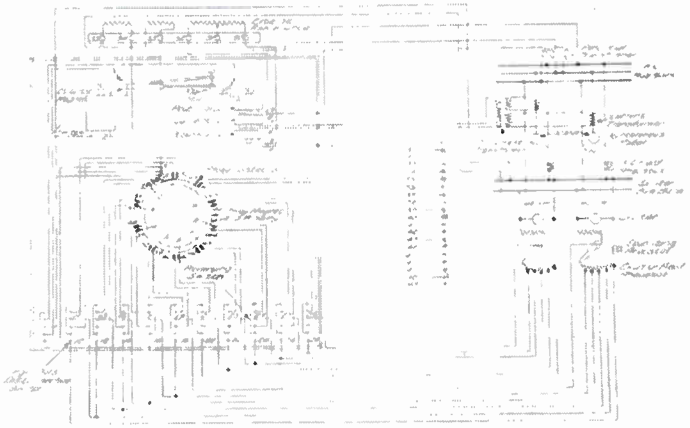


Fig. 5. Connections of Power Factor Regulator

The action of the regulator becomes evident from inspection of the vector diagram, Fig. 6: I_1, I_2, or I_3 is the current per phase, E_1, E_2, or E_3 is the corresponding e.m.f. Assuming that the current coil is in circuit with the phase designated I_1; it is then evident that if the current, for example, lags by the value I_0 or I_ϕ, the phase relations between the current in the current coil and that in the potential coils must necessarily change. A magnetic action is thus set up between the coils to which the movable current coil responds, closing the main contacts. This closing of the main contacts causes the relay contacts to close, thus increasing the excitation of motor and bringing the power factor back to unity, or to the point where the coils are balanced.

If instead of lagging, the current should become leading, the above cycle, of course, will be reversed; the current coil then moving in the opposite direction, opening the main contacts, and thus the relay contacts, and reducing the excitation of the motor.

If the regulator is set for unity power factor, the cycle of operation is similar to that of the voltage regulator, and since the contacts are operated at a high rate of vibration, absolutely perfect results can be obtained within the capacity of the motors and exciters.

In addition to maintaining unity power factor, it is also possible, by raising or lowering the current coil and thus changing its relation to one or the other of the potential coils, to hold any per cent. leading or lagging current that may be desired to meet the requirements for which the motors have been designed.

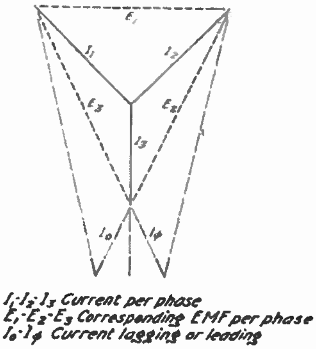


Fig. 6

Several installations of power factor regulators have been made in cases where synchronous motors are used for driving railway generators on which the load is subject to violent fluctuations. In such a case without regulator, the sudden changes in load would produce a very bad power factor on the line supplying the motor; Fig. 5 shows a typical installation of this kind. Here the regulator is designed with six relays which operate on two 45 kw. exciters supplying excitation current for two 1000 kw. synchronous motors driving railway generators. Installations of this kind are generally found to require a leading current with a power factor of 80 per cent., and when this is the case the regulator is set for this figure, with a safety device adjusted so that the excitation current is held to a certain predetermined amount, depending upon whether the fields are designed for 125, 250 or other voltage. These regulators, like the voltage regulators, are designed to operate over a range of exciting potential of 100 per cent. from minimum to maximum, and if the synchronous motor is properly supplied from the line, the range of excitation potential will be well within these limits. A motor should not receive a greater excitation than a standard alternating current generator, and it is to prevent a possible excess of excitation and consequent injury to motors that the limiting device is used.

COMMERCIAL ELECTRICAL TESTING

PART III

By E. F. Collins

Superintendent of Testing Department

Heating Tests

The test to determine the heating of a machine is a very important one and great care must be taken to obtain reliable temperatures. Any large machine requiring a considerable amount of floor space should have the room temperatures taken at four different points nearby, and at a sufficient distance away from the machine to be unaffected by heat from the latter. Two thermometers, one in air and one in a specially designed metal cup containing oil, are used at each point to measure the room temperature. Before starting a heat run, thermometers should be placed on all important accessible stationary parts, such as series and shunt field spools, pole tips, frame, etc., in the case of a direct current machine. In addition, thermometers should be placed between pole tips to register the temperature of the air thrown off from the surface of the armature and from the air ducts. Each thermometer should be attached with the bulb in contact with the part of which the temperature is required, the bulbs being covered with putty. Thermometers which are to register the temperature of air ducts should be so placed that the bulb cannot make contact with the iron laminations while the machine is running.

The machine should be shielded from currents of air coming from adjacent pulleys and belts. Unreliable temperatures are obtained when the machine is located so that another machine blows air upon it. A very slight current of air will cause great discrepancies in heating; consequently either a suitable canvas screen should be used to shield the machine under test, or the machine causing the draught should be shut down.

Overload heat runs require considerable attention. Where an overload is applied for one or two hours, it should be certain that normal load temperatures have been reached before applying the overload. The overload must be carried only for the specified time, since, in many cases, the temperature rises rapidly throughout the whole period of the overload. Hence lengthening or shortening the overload period a few minutes may make several degrees difference in the overload temperatures obtained. To avoid continuing an overload run for a longer time than that specified, arrangements for a sufficient number of thermometer and resistance measurements must be made well in advance of the end of the run.

During the heat run all conditions should remain normal, and the machine should be watched carefully for any undue heating of bearings or field spools, or for the appearance of defects. The wiring, holding down bolts, belt lacing, etc., must also be watched.

In making heating tests two methods may be used; *i.e., actual load tests* and *equivalent load tests*. Several different means for obtaining actual load tests may be employed, such as "water box," "circulating," "feeding back," "shifting the phase" and "induction generators."

The "water box" method, as the name implies, consists in driving the machine by either a motor or engine and loading it upon a "water box," or rheostat. (Fig. 11.) This method entails considerable expense, since all the power generated is lost. To obviate this loss and reduce the cost of testing, the "feeding back" method is used when possible, especially in the case of large d.c. machines and motor generator sets. In this method the total machine losses are supplied either mechanically or electrically from an external source. In the mechanical loss supply method, two machines of the same size and voltage are belted or direct connected together and driven by a third machine large enough to carry the losses of the set. Connections are made as shown in Fig. 12. If the machines have series fields, these should be connected to boost one another. Both machines should then be started up as generators and thrown together by closing the switch between them when the voltage across this switch is zero. The field of the machine that is to act as motor should then be weakened, which operation throws load on both machines. The speed is held constant by the loss supply motor. After running at the proper load for the specified time, temperatures should be taken and tests finished according to standard requirements.

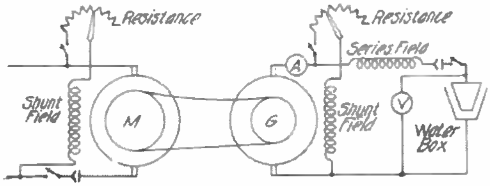


Fig. 11. Connections for Loading a D.C. Generator on a Water Box

If the machines are motors, the same connections should be made and the machines thrown together as before. The voltage of the system must be held by the machine running as generator. The only correct way of obtaining load is by changing the speed of the set, the brushes having previously been set in the running position. Usually the speed will have to be decreased, and the difference between full load and no load speed will be the normal drop in speed for the motors. Cases sometimes occur where the speed of the motor, due to armature reaction, increases with increase of load. In pumping back, this condition is shown by the motors taking an overload at no load speed, in which case the speed of the loss supply must be increased.

In the method of electrical loss supply, two machines are direct connected or belted together and the losses supplied electrically. Should two shunt motors be tested by this method, one machine should be run at normal voltage, current, speed and full field; the other motor to be run as a generator with a little higher current and slightly stronger field than for normal conditions. The fields of the generator may have to be connected in multiple. Connections should be made as in Fig. 13. The motor should be started first from the electrical loss supply circuit and its brushes shifted for commutation and speed. After exciting the field of the generator and adjusting the voltage between the machines to zero, the circuit is closed. The machines are loaded by increasing the field current of the generator. Care should always be exercised when shifting the brushes while the machines are under load, since a slight change in shift will at once change the load. After the heat run has been finished and all motor readings taken, the wiring should be changed and motor readings taken on the machine which ran as a generator.

When compound wound generators are being tested by this method the series field of the motor must be included or the load will be unstable.

Another method of "feeding back," often used, is to feed the entire load back on the main supply circuit from which the motor is run that drives the generator under test. If the main supply circuit is likely to vary in voltage, it may be necessary to insert resistances between the generator and supply. It sometimes happens that the no-load voltage of the generator is below that of

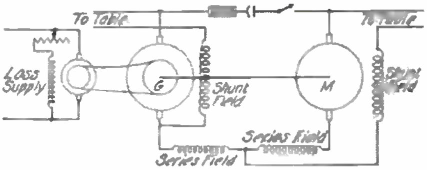


Fig. 12. Connections for Mechanical Loss Supply Pump Back

the supply. As changing the line resistances will have no effect at no-load, the generator voltage must be increased until it is equal to that of the main supply circuit. Having previously calculated the full-load field current from the no-load current and the ratio of compounding voltages, the machines are thrown together and full load put on the generator by cutting out the variable resistance.

Two similar motor generator sets can be tested very readily by the "feeding back" method. As an illustration, suppose each set consists of an induction motor and a d.c. generator. In this case connections are made as in Fig. 14. The a.c. and d.c. ends of the sets are respectively connected together, one set being run normally, and the other inverted. The induction generator feeds back on the induction motor, both taking their exciting current from the alternator (A) which supplies the losses. The sets are started one at a time from the a.c. end, and the d.c. ends paralleled by means of a voltmeter across switch P. The d.c. motor field is weakened until the ammeter in the d.c. line indicates that normal current is flowing. The weakening of the motor field allows the speed of the inverted set to increase just enough to load the induction generator, while it also decreases the counter e.m.f. of the motor a sufficient amount to allow full load current to flow in the d.c. circuit. This load must be closely watched, as it is unstable. Load unstability is a rather common occurrence in "feeding back," due to either variations in shop voltage or speed.

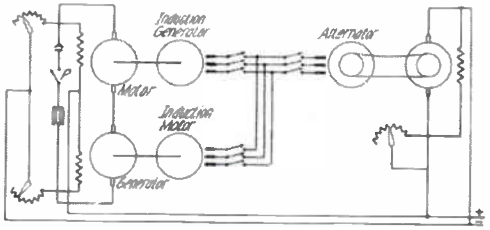


Fig. 14. Connections for Induction Motor Generator Set Pump Back

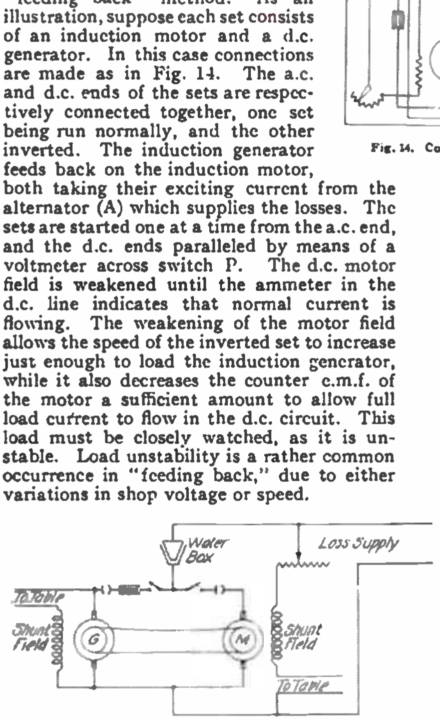


Fig. 13. Connections for Electrical Loss Supply Pump Back

It will be noted in the "feeding back" tests described, that it is necessary to weaken or strengthen one of the fields to obtain the load. To conduct the test with the same field excitation on both machines the armature of a separately excited booster may be connected in series with the armatures of the two machines being tested. The machines, connected so that they run at the same speed, are brought up to normal speed by means of the motor supplying the losses. The connecting switch is then closed and the booster field strengthened until normal current flows in the armature circuit, the field current being adjusted to give the same excitation on both fields. The voltage is held across the motor terminals by varying the speed of the loss supply motor. This method, known as the circulating method, is used particularly in the testing of series or railway motors. In the latter case the machines are geared to the same shaft.

Another method known as "shifting the phase" is used in testing two similar alternators or frequency changer sets. Two similar alternators may be direct connected by means of a coupling and driven by a motor to supply the losses. For example, let a three-phase machine be considered, the phases of which are shown diagrammatically in Fig. 15. The machines should be run at normal speed, the fields connected in series and separately excited to a value corresponding to the load at which it is desired to make the test. The value of this excitation should be calculated from the saturation and synchronous impedance curves. With phases A and A′ connected together, the voltage across phases b and b′ is read, the circuit closed, and the value of the current flowing observed. Knowing the voltage between phases a and b, a′ and b′ and b and b′. the angle of phase displacement may be readily obtained. Should the resulting armature current be considerably greater or less than that desired, a further trial will be necessary.

The current value will vary nearly as the angle of displacement, so that an approximate value of the angle desired can be found from the value of current and angle previously ascertained. When the value of this angle has been ascertained, the phase displacement should be changed, so as to obtain as closely as possible the desired value of current. With the machines still connected together as they were originally, the angle of phase displacement previously found will be increased 120 electrical degrees by connecting a' b. If a' c are connected, a still further displacement of 120 degrees is obtained. If with any of these connections, the field of one machine be reversed, a still further displacement of 180 degrees is made. With the connection which gives the nearest value of armature current to that required, a further adjustment may be made by shimming the stator of one or both machines up on one side and taking shims out on the other side. The circuits should then be closed and the heat run made for the specified time. Even with the angles of phase displacement possible with the various combinations of connections and field rheostats it may not be practicable to get the desired armature current. In this case, unbolt the coupling and shift the rotor of one machine around one or more bolt holes. The "cut and try" operations should then be repeated.

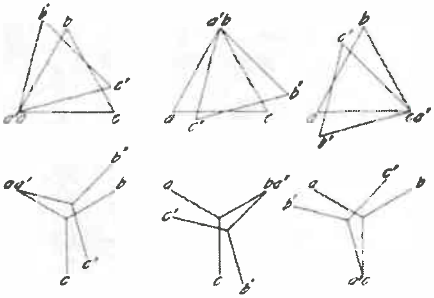


Fig. 15. Shifting of Phases Shown Diagrammatically

Although the method employed in this test may seem long and tedious, the results obtained are very satisfactory, especially where it is necessary to make an actual full load test.

The induction generator method is sometimes employed in making full load tests on induction motors. Two similar induction motors are belted together and run in parallel from the same alternator which supplies the losses. (Fig. 16.) In order to get full load on both machines, the diameter of the pulleys must differ by a percentage equal to double the full load per cent. slip.

In starting, the switches A are closed and the motor M allowed to come up to speed, until the speed of the motor running as a generator is above synchronism. The alternator field is opened momentarily, whilst the switches B are closed. The circuit in the alternator field is then closed again, and full load current flows through the two machines. No changes in load can be made without changing the pulley ratio and it is absolutely necessary that this ratio be correct in order to obtain full load.

Equivalent Load Tests

Very often it is found impossible to run actual load tests, especially on large machines, on account of limited facilities. Equivalent load tests have consequently been devised in which the heating of the machine at a certain load may be very closely ascertained without actually loading it. One of five different methods may be employed in making such a test; *viz.*, "open circuit," "short circuit" and "low voltage test," "circulating open delta" or "phase control."

Direct current machines can be satisfactorily tested by short circuiting the armature upon itself, or through the series field, so connected that it will not build up as a series generator. The shunt field is separately excited from an external source, until the required current flows through the armature, or armature and series field. This method is excellent for baking and settling the commutator. Amperes armature and field, and volts field should be read throughout the run.

In the case of alternators, the machine is run open circuited, with a field current that gives a predetermined percentage over normal voltage. The run should be continued until the rise in temperatures above the room temperature is constant, after which the machine is shut down and the final temperatures taken. The armature is then short circuited, the machine started again, and sufficient excitation applied to give a current in the armature of a certain percentage over normal. This run should also be continued until the rise in temperatures above that of the room is constant, after which the final temperatures are taken. The resistance of the field should be carefully measured before and after the open circuited run, that of the armature before and after the short circuited run, and the temperatures of the windings cold should also be recorded. During both runs volts and amperes field and speed should be recorded. During the open circuit run, volts armature are recorded, and during the short circuit run amperes armature.

On some of the large induction motors, only about one-fourth of the normal voltage is impressed. The machine is then loaded until the desired current flows in the stator, the run being continued as described above.

Another method of making an equivalent load test, used especially with turbo and other large three-phase alternators, is known as the circulating open delta run. The phases of the machine are connected in delta, one side of which is left open. The fields are excited to give the load desired, this excitation being determined from the saturation and synchronous impedance curves. Due to harmonics which may exist in the legs of the delta, an alternating cross current may flow in the winding. This is measured by an a.c. ammeter (with current transformer, if necessary) inserted in the opening of the delta. The difference between the square of this current and the square of the current with which it is desired to load the machine is found, and a direct current of a value equal to the square root of this difference is circulated through the winding. The run is then continued, a careful record of volts armature, direct and alternating amperes armature, volts and amperes field being made. It will be noted that the alternating cross current in one side of the right angled triangle and the direct current in the other are combined vectorially to obtain the load current desired.

Another method of loading an a.c. generator is to give it normal excitation and run an unloaded synchronous motor from its armature circuit. The field of the motor is varied to give a leading or lagging current in the armature circuit. This is known as the phase control method. The rise in temperature on the fields during open circuit run, and on the armature during the short circuit run, is practically the same as will obtain during operation under load. The rises in temperature obtained from a circulating open delta run are also so considered.

With induction motors, it has been found that the temperatures on low voltage runs when combined with temperatures at no load and normal voltage, give very nearly the same results as an actual load test.

Except in the case of commutating pole machines, it is often necessary to shift the brushes to get good commutation while under load. The point at which the best commutation is obtained is known as the running point. Its position should be plainly marked on both the rocker arm and the frame by means of a chisel.

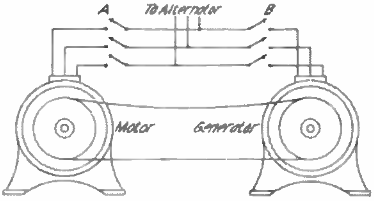


Fig. 16. Full Load Test on Induction Motors

It is the present practice to adjust all series field shunts cold, except in cases where a hot compound is expressly desired. This compounding consists in placing a shunt across the series field terminals, in order to obtain the proper voltage at no load and full load. The contacts of the shunt should be perfect. In making a no-load field setting on the machine, the voltage should be raised about 15 per cent. above normal no-load voltage, and then reduced to normal. With the rheostat left in this position, the load is thrown on, and if the compounding is high, the resistance of the german silver shunt should be reduced, a new no-load reading taken, and the operation repeated. This should be continued until the machine compounds according to specifications.

To take final temperatures after a heat run requires the greatest care. Arrangements should be made so that no delay results in placing the thermometers on the proper parts. Temperature readings should be made every few minutes until all temperatures begin to drop, when the thermometers may be removed When final temperatures are being taken the hot resistance of the machine should be measured. After all the necessary tests are made, the wiring should be removed and the high potential tests applied while the machine is still warm.

In calculating the rise of temperature by resistance the following formula is used.

Let Rt_2 = hot resistance of copper measured at the temperature t_2

Rt_1 = cold resistance of copper measured at temperature t_1

R_0 = resistance of copper at 0° C.

$$t_2 = \left(238 + t_1\right)\frac{Rt_2}{Rt_1} - 238$$

When using this formula it is assumed that 0.0042 is the temperature coefficient of copper at 0° C. The rise obtained from this formula should be corrected by one-half of one per cent. for each degree C. that the final room temperature differs from 25° C. This correction is added if the temperature is below 25° C. and subtracted if above. The temperature of the winding itself must therefore be very carefully observed, as well as that of the room, when the hot and cold resistances are taken.

It is often necessary to make a heat run on an a.c. machine at a specified power factor. To do this, in the case of a generator, the machine is loaded on water boxes connected in parallel with a synchronous motor. The motor merely floats on the line, its field being adjusted to give the desired power factor. Instead of loading the generator on water boxes, the motor is often belt or direct connected to a d.c. generator which feeds back onto the shop circuit.

Synchronous motors are run under load at a certain power factor by being driven from an a.c. source of power and loaded on a d.c. generator. When power factor runs are made, generators should always be run with lagging and synchronous motors with leading current, unless otherwise specified.

In addition to an ammeter and voltmeter, wattmeters should always be inserted in the armature circuit of the machine tested, in order to check up the power factor of the circuit.

Equivalent load heat runs are frequently made at a given power factor. In the case of an open circuit run, the excitation given the machine is a certain percentage over that which will give the desired voltage at the desired power factor and load. This excitation is determined from saturation and synchronous impedance curves. Short circuit runs are made with a certain percentage of excitation over that required to give the desired kilovolt-ampere reading.

Circulating open delta runs are made as previously described, an allowance being made for the proper excitation and armature current at the power factor desired.

(To be Continued)

HIGH VOLTAGE POWER TRANSFORMERS

By Edwin R. Pearson

The demand for transformers of greater capacities and higher voltages for power transmission work has been constantly increasing for a number of years. Comparatively a few years ago, the construction of a transformer of 50 kw., wound for 4,000 volts primary, was considered an achievement. Later on, a text book on transformers was issued showing a transformer of small capacity which stepped up to 10,000 volts, and the author cited this as an instance of the possibility of what *could* be done.

From such beginnings advancement has steadily continued so that at the present time single transformers of a capacity of from 4,000 kw. up are not at all unusual. There are installed on the lines of the Great Western Power Company, of California, a

3,750 Kw. Transformer, 128,500 Volts

number of 3-phase transformers having a capacity of 10,000 kw. each.

The constant potential transformer is the connecting link in every transmission system, which fact made it necessary for the designing engineer to keep pace not only with transmission developments but to show his ability to produce transformers of a voltage in excess of the demand. Voltages have increased gradually, until a considerable proportion of large transmission systems use voltages from 90,000 to 110,000. The latest advance in the art is outlined by the requirements of the Stanislaus Power Company, of California, the voltage in this case being a long step ahead of anything previously used. The Stanislaus Company's requirements are for 60-cycle, single-phase, water-cooled transformers of 3,750 kw. capacity, with a high tension voltage of 138,500 and a low tension voltage of 12,100.

The high tension windings of the transformers are so designed that voltages in several steps from 40,000 to 120,000 can be obtained with transformers connected in "delta"; the maximum voltage of 138,500 being obtained by "Y" connection. The low tension windings are also arranged for either 4,000 or 12,000 volts with "delta" connections. At all voltages, transformers will operate at full capacity.

In designing and building these transformers the standards set for smaller and lower voltage transformers have been fully maintained. Careful attention was paid to every feature of the design, the proper insulations, ducts and cooling surfaces being provided to insure uniform strength and cooling throughout all parts. The results of the tests show that these efforts were well directed, and while there was no fear of the outcome, considerable gratification was felt that no sign of weakness was evident throughout the severe tests. An insulation test of double the maximum line voltage: *viz.*, 280,000 volts, was applied between the high tension winding and all other parts for one minute

Inasmuch as these transformers are, as above stated, considerably in advance of anything else ever attempted, some details will doubtless be of interest. Efficiencies are 98.8, 98.7, 98.3 and 96.8 for full load, three-fourths, one-half and one-quarter loads respectively. In other words, the total losses at full load are approximately 1.2 per cent. of the rating The non-inductive regulation is approximately 1.25 per cent. at unity power factor.

An idea of the size of these transformers and the immense quantity of material required is given by the following approximate dimensions: Floor space occupied is approximately 9¼ ft. by 5¼ ft., with a height from the floor to the top of the leads of about 17 ft. Each unit complete with oil weighs 28 tons. The windings in each transformer require approximately four miles of copper strip, built up into the usual flat coil structure having one turn per layer. The fact that transformers of this character can be built in quantities indicates the enormous facilities and resources of the manufacturer.


Transformer Removed from Case

All of the coils in these transformers are impregnated under vacuum with an oil-proof insulating compound, making, in connection with a good mechanical construction, a very substantial structure. The leads used in these transformers are the regular oil-filled type, of good proportions, providing a wide margin of safety.

TRANSMISSION SYSTEM OF THE SOUTHERN POWER COMPANY

By John Liston

The cotton mills of the Piedmont district take about 80 per cent. of the entire output of the Southern Power Company's generating stations, the balance being utilized in various other industries and for lighting. The scattered location of the numerous mills in North and South Carolina rendered the problem of economical transmission unusually complicated, and it was necessary to provide several main transmission lines with a number of branch circuits and taps to the mills; so that the present transmission system, as indicated in Fig. 1, involves a network of 11,000 volt, 44,000 volt and 100,000 volt, three-phase, 60 cycle circuits, which have an aggregate pole and tower length of 639 miles, with a single circuit total of 983 miles.

The present lines extend north from the Rocky Creek power station for a distance of more than 100 miles, while their range east and west is approximately 165 miles.

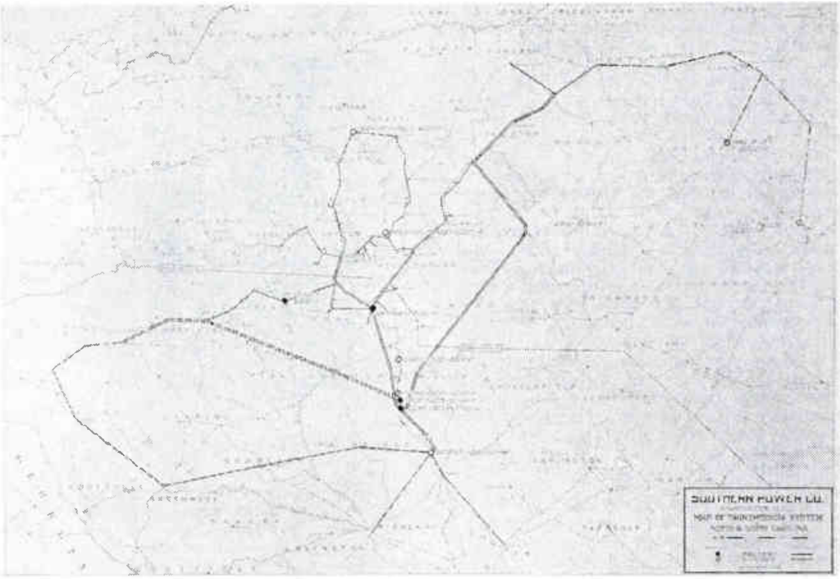


Fig. 1. Map of Transmission System Showing Existing and Projected Lines

When the new power stations and the projected lines are completed the total mileage of the transmission system will be more than double that of the existing lines.

The main generating stations at present constructed are arranged for parallel operation and are tied together by means of a trunk line with three circuits, two circuits on twin towers and one on poles running from the Great Falls and Rocky Creek stations to

Catawba. The general transmission system is not, however, operated as a trunk line, but the various sections are interconnected through four main switching stations, and 57 local transformer sub-stations. These insure uninterrupted service in case a generating station is either overloaded or shut down. If trouble occurs on any one of the lines, the particular section affected can be readily cut out and the balance of the line fed through the switching stations at either end.

The entire system is patrolled each week, fourteen men being employed in this work. They keep the right of way clear and do all ordinary repair work; under normal conditions each man patrols a limited territory, but in case of serious trouble an effective communication system enables them to be readily assembled within a short time after the discovery of the trouble.

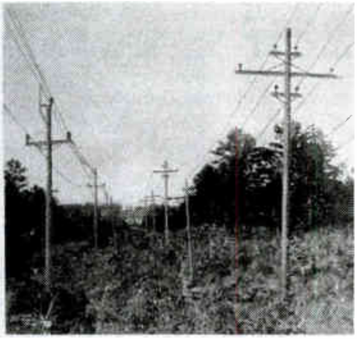


Fig. 2. Single and Twin Circuit Poles

At present the total transformer capacity of the local sub-stations on the 11,000 volt lines is 7000 kw., and on the 44,000 volt lines 55,350 kw. In the 17 stations on the 11,000 volt lines the secondaries of the transformers are arranged for 550 volts. On the 44,000 volt lines there are 22 stations having transformers with 2300 volt secondaries, and 8 stations having transformers with 550 volt secondaries. Nine stations are already provided for the 100,000 volt lines, and these all have transformers with 2300 volt secondaries. In addition to these, two stations on the 100,000 volt line will have transformers for stepping down to 44,000 volts, for tying in with the 44,000 volt system in case of breakdown.

At present a total of 130,000 kw. in 100,000 volt transformers has been installed. In all sub-stations on the 100,000 volt lines three single-phase transformers will be used, and in no station will the capacity of the transformers be less than 1000 kw.

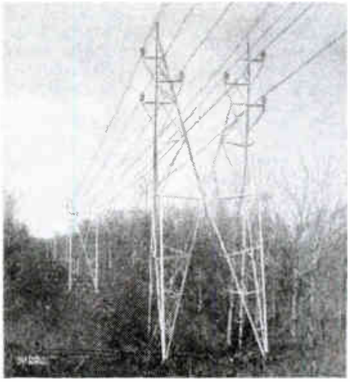


Fig. 3. Twin Circuit "Aermotor" Towers Carrying 44,000 Volt Conductors

The main switching stations referred to above have operators, but most of the local transformer sub-stations do not require the services of special attendants.

At present the transformer connections throughout the system are delta-delta, from generating station through sub-stations to the mills. When the 100,000 volt system is put in operation, the transformer connections at the generating station will be changed to delta-Y, and those at the junctions with the 44,000 volt line to Y-delta.

A reference to Fig. 1 and the following tabulation will give an idea of the extent of territory covered by the existing lines, and will indicate the problems which confronted the engineers of the Company when planning the routes to be followed, so as to obtain economical current distribution and, at the same time, secure immunity from serious interruption of the service; this latter feature being further complicated by the frequent local lightning storms which are characteristic of the region served.

For the various transmission lines five distinct types of poles and towers have been used. The two forms of wooden poles shown in Fig. 2 were used for the original Catawba transmission line—they are either cypress, juniper or chestnut (chestnut being finally selected as the most suitable available wood), and the cross arms are all of hard pine creosoted. The twin circuit pole shown on the right hand of Fig. 2 is used for 11,000 volt circuits, while the single circuit poles at the left now carry 44,000 volt conductors; and will also be used for a short 100,000 volt line.

The bulk of the 44,000 volt lines are now carried on twin circuit structural steel "Aermotor" towers similar to that shown in Fig. 3, while for the intended 100,000 volt lines a 3-arm steel twin circuit "Milliken" tower (see Fig. 4) has been provided. These towers are practically duplicates of those used in the Schaghticoke-Schenectady line of the Schenectady Power Company, which were fully described in the May, 1909, REVIEW.

For running tap lines to mills and carrying the conductors across railroad tracks and through cities, a type of pole similar to that used for the Chicago Drainage Power Transmission system (see Fig. 5) has been adopted. These are twin circuit 2-arm poles built of structural steel, and are used intermittently in the different transmission lines, their height varying from 45 to 80 feet, the 80 foot poles weighing 9000 pounds each. These poles, as well as all the "Aermotor" type, have their bases weighted with concrete.

The "Milliken" towers are mounted on metal stubs sunk 6 feet in the ground. Where the angle of the line is over 15 degrees, however, these stubs are weighted with rock and concrete, and where an angle of over 30 degrees occurs, two and sometimes three towers are used for making the turn. The weight of the standard "Milliken" tower is 3080 pounds, and its height from ground line to peak 31 feet. The towers are spaced

EXISTING TRANSMISSION LINES OF THE SOUTHERN POWER COMPANY

		Poles	Distance in Miles	No. of Circuits	Total Mileage Single Circuit
		44,000 Volt Lines in Operation			
Rocky Creek	—Gt. Falls	Aermotor	2	2	4
Great Falls	—Gastonia	"	63	2	126
Great Falls	—Gastonia	Wooden	4	2	8
Great Falls	—Catawba	"	36	1	36
Clover	—99 Islands	"	18	1	18
Gastonia	—Kings Mt.	"	13	1	13
Bessemer City	—Shelby	"	20	1	20
Gastonia	—Newton	"	32	1	32
Gastonia	—Statesville	"	59	1	59
Catawba	—Charlotte	"	18	2	36
Charlotte	—Spurries	"	12	1	12
Charlotte	—Concord	"	18	2	36
Concord	—Salisbury	"	24	1	24
Taps of various mills			10	1	10
		100,000 Volt Lines now Operating at 44000 Volts			
Great Falls	—Monroe	Milliken	37	2	74
Great Falls	—Chester	"	22	2	44
Chester	—Greenville	"	74	2	148
Monroe	—Greensboro	"	105	2	210
High Point	—Winston—Salem	Wooden	17	1	17
		*** 11,000 Volt Lines Total**			
		Wooden	56	1	56

* 7 Miles Double Circuit.

to average 8 to a mile and a strain tower weighing 4250 pounds is used every mile. For particularly long spans a special heavy tower weighing 6000 pounds is used. The circuits are transposed every 30 miles. The magnitude of the operations carried on by the Southern Power Company will be indicated by the fact that there are 2157 of these "Milliken" towers already erected, having a total weight of almost 3700 tons.

The "Aermotor" towers vary in height from 35 to 50 feet, and the circuits are transposed every 10 miles. All steel towers were assembled on the ground and erected by means of gin poles.

Both copper and aluminum conductors have been used in the construction of the line. On the 44,000 volt, 2-circuit trunk lines, from Great Falls to Catawba, a No. 000 6-wire stranded copper cable weighing 8 tons per mile of two circuits and provided with a hemp core, has been used.

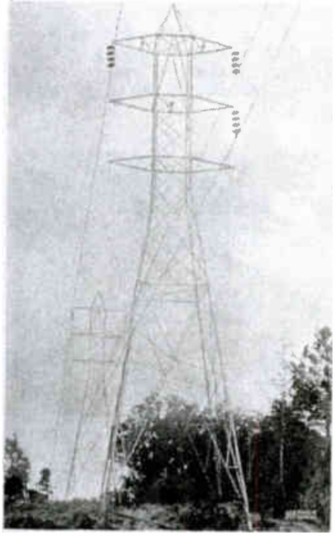


Fig. 4. 100,000 Volt "Milliken" Towers with one Circuit Strung

On the 18 mile line between Catawba and Charlotte the two single circuit 44,000 volt wooden pole lines carry an aluminum cable weighing 1029 pounds per mile. This cable is 6-strand with a cross section of 208,000 cir. mils.

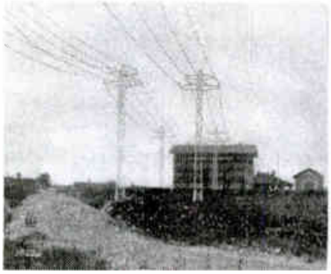


Fig. 5. 44,000 Volt Lines entering the Gastonia Substation

For the 140 miles of 100,000 volt line from Great Falls to Greensboro a No. 00 7-strand copper cable weighing 2144 pounds per 2-circuit mile has been used.

All conductors except those on the 100,000 volt lines are carried on triple petticoated pin insulators. The center stud provided with these insulators is of special design, and is the invention of Mr. W. S. Lee, Vice President and General Manager of the Company; it permits the rapid replacement of insulators in case of breakage.

On the 100,000 volt lines multiple disk insulators are used—four disks being used to suspend each conductor from standard towers, and ten disks to each conductor on strain towers.

The length of span required on the different lines varies with the topographical conditions; the standard distance for the wooden pole lines is 150 feet, the "Aermotor" towers being normally spaced 500 feet apart with a sag of 5 feet 8 inches. The minimum distance between towers is 300 feet, and the maximum 720 feet, this latter span occurring where the line crosses Fishing Creek.

The "Milliken" towers have a standard span of 600 feet; the sag at a temperature of 50 degrees F. being 11 feet. At a point where the line crosses the Catawba river just above the Great Falls station the distance between the towers is 1300 feet. The lines are strung at an average tension of approximately 1537 pounds per conductor and a single guard wire of $\frac{3}{8}''$ stranded Siemens-Martin steel is carried along on the peaks of the towers. This guard wire weighs 316 pounds per mile, and has a breaking strength of 9,000 pounds. A similar guard wire of $\frac{5}{16}''$ steel is used on the wooden pole lines, and the "Aermotor" towers are provided with two.

Fig. 6. Bessemer City Transformer Substation Built to Accommodate Multigap Lightning Arresters

The sub-stations have the usual equipment of transformers, oil switches, switchboards, etc., and either multi-gap or electrolytic lightning arresters. Disconnecting switches are also provided outside each station.

The interior of a typical sub-station is shown in Figs. 8 and 9, all the apparatus in view being of General Electric manufacture.

Reference has already been made to the lightning storms which are of frequent occurrence in the territory through which the transmission lines run, and every sub-station is, therefore, provided with a lightning arrester outfit. The experience of the Company in testing out various types of lightning arresters has resulted in the final adoption of the electrolytic aluminum cell type for all future installations, and there are already installed 22 sets of this type.

The illustration, Fig. 7, shows a set of General Electric electrolytic lightning arresters installed outside sub-station and the conductors entering the building through heavy plate glass windows, and also indicates one of the economics which the adoption of this type of arrester has made possible. When the multi-gap form of lightning arrester was first used, a high wall was provided on one side of the sub-station in order to provide sufficient space to suitably install them, the type of building used being shown in Fig. 6. It was later found advisable to discontinue this form of construction and erect a separate building in the form of a tower similar to that shown in the left hand of Fig. 7, in which the multi-gap arresters were installed. In view of the great number of sub-stations on the system, it is obvious that, with the adoption of the electrolytic type of lightning arrester, which can be installed out of doors, a very considerable item in the construction expense of sub-station buildings has been eliminated.

The completion of the 100,000 volt lines and the construction of the new 100,000 h.p. hydro-electric plant at Wateree on which work has already been commenced will, at an early date, add appreciably to the range and volume of the greatest transmission system in the South, which is already one of the most extensive, in respect to aggregate mileage, in the world.

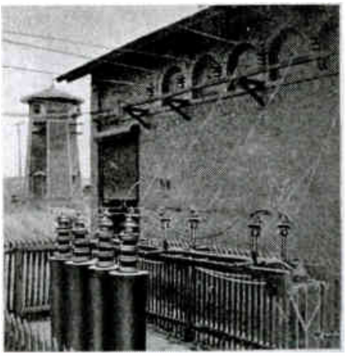


Fig. 7. Highland Park Substation, Charlotte, N. C., Showing Old Lightning Arrester Tower on left, G.E. Aluminum Cell Lightning Arrester and Horn Gaps in Foreground

While the transmission line construction work has been characterized by few departures from standard practice, a comparison of the original 11,000 volt Catawba pole line with the 100,000 volt tower system, now nearing completion, gives a graphic illustration of the general advancement which has been made in transmission line construction during the few years which have elapsed since the Southern Power Company was organized.

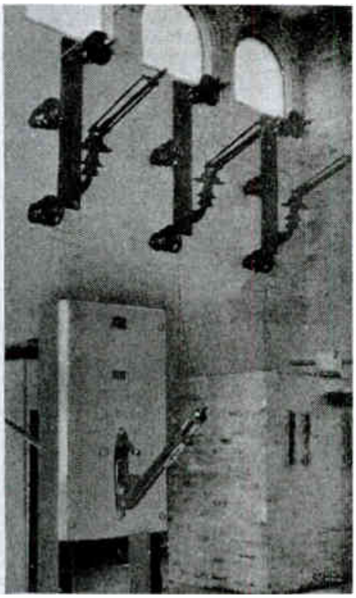


Fig. 8. Interior of Kannapolis Substation Showing Conductors entering through heavy glass plates G.E. K-6 Oil Switch and T.P. Fuses

The success with which this Company has met the requirements of the cotton mills and other industries of North and South Carolina is indicated by the readiness with which mill operators have adopted electric drive and the very noticeable increase in the industrial activity of those sections of the Piedmont cotton belt where the transmission lines of the Southern Power Company have been run.

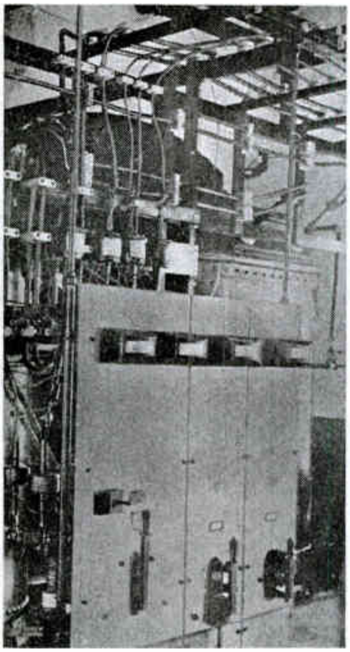


Fig. 9. Interior of Kannapolis Substation Showing G.E. Transformers, Switches, Panels, etc.

GAS-ELECTRIC MOTOR CAR—SELF CONTAINED TYPE

By A. W. Jones

The immediate and gratifying success of the larger type of gas-electric motor car manufactured by the General Electric Company for steam railroads, and the successful application of this form of drive on trucks and passenger vehicles operated on streets without rails, has naturally suggested the use of the gas-electric drive for cars of medium size for which there has already been manifested a marked demand. This demand will increase and new uses will be found for this type of equipment when its reliability and ease of operation become better known.

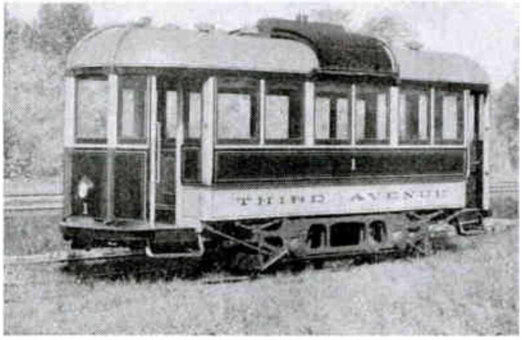


Fig. 1. Third Avenue Gas-Electric Car

The General Electric Company has just completed the first car of this type, which has been placed in commercial service with excellent results. The car is shown in Figs. 1 and 2. The car body and trucks are especially designed for strength and lightness, and the equipment, briefly described, consists of a direct coupled gas engine and generator with exciter on the same shaft, all completely enclosed and mounted between the axles of the truck and below the car floor. This arrangement permits low and convenient platforms, and leaves the interior of the car entirely unobstructed. The car is heated in cold weather by hot water pipes under the seats, through which the circulating water is passed. A railway motor, of the standard type, is mounted on each axle, and the current for these motors is transmitted from the generator through a controller at either end of the car designed to vary the resistance in the shunt field of the generator and place the motors progressively in series and parallel. The car is illuminated by tungsten incandescent electric lights, deriving their current from the exciter circuit.

The operation is like that of an ordinary electric trolley car, and, due to the characteristics of the gas engine and generator, there is less liability of abusing or overloading the apparatus by improper use of the controller. The car is reversed by a reversing handle on the controller, without affecting the gas engine, and can be equally well operated in either direction, a controller being provided on each platform.

The Gas Engine

The gas engine is of the 4-cylinder, 4-cycle type, the cylinders being 5¾ in. diameter by 5 in. stroke, and cast *en bloc* (Fig. 3). The inlet and exhaust valves are of large size, located on opposite sides and actuated by separate cam shafts. The crank shaft is of high grade steel, hand forged, and oil treated. Fig. 3 shows a side view of the engine and generator. The crank shaft is supported by three babbitt lined bearings. Both the crank shaft and the bearings have been made of extra large size, and much greater strength and bearing surface are provided than would ordinarily be used on an engine of this size. The crank case is arranged so as to provide a constant level system of splash lubrication for the engine, oil being kept in circulation and the level maintained by a centrifugal pump with adjustable overflow.

The pistons are of the trunk type and made of the same material as the cylinders. They are provided with four cast iron snap rings. The wrist pins are of steel, hardened and ground, and are fastened in the connecting rod in a special manner.

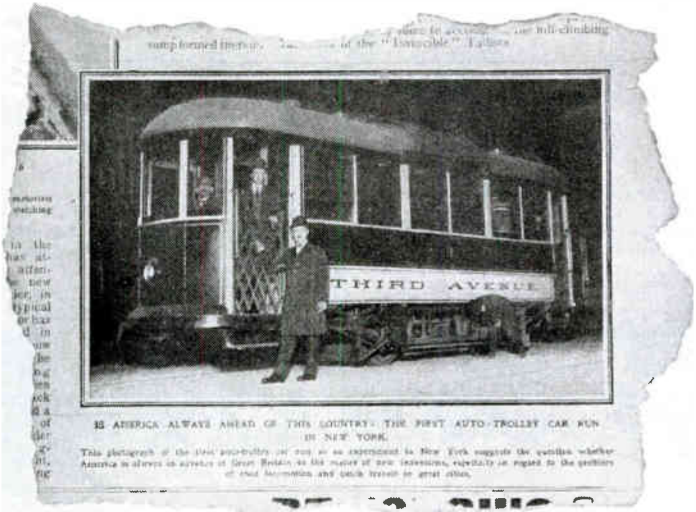
The connecting rod is of drop forged machinery steel, and oil treated. The cylinders are water jacketed, circulation being secured on the thermo siphon principle, the circulating water being cooled by a radiator located on the roof of the car, which can be seen in Fig. 1. This radiator has a cooling surface of approximately 900 square feet, and a capacity, including water jackets and piping, of about 65 gallons.

A centrifugal type of governor gear driven from the inlet cam shaft is furnished, which acts directly on a balanced valve controlling the quantity of the mixture admitted to the cylinders, and maintains the speed of the engine and generator with small variations at about 800 r.p.m. Ignition is provided by a gear-driven Bosch low tension magneto and magnetic plugs.

The entire engine is so designed that when it is assembled, together with the governor, magneto and spark plugs, it is completely enclosed thus being protected against dust, dirt and water. This construction is clearly shown in Fig. 3.

The carburetor is of the Venturi type, with float feed, the gasolene being admitted by gravity from the gasolene tanks located under the car seats. Two of these tanks are provided, each of 35 gallons capacity.

The engine exhausts into a muffler, the exhaust gases thence being carried to the roof of the car, thus avoiding all odor of burned gases and eliminating noise.



IS AMERICA ALWAYS AHEAD OF THIS COUNTRY? THE FIRST AUTO-TROLLEY CAR RUN IN NEW YORK.

From *Illustrated London News.* Fig. 2

Generator and Exciters

The generator and exciter, Figs. 4 and 5, are direct coupled to the gas-engine and are completely enclosed. The armatures of these two machines are assembled on the shaft so that the commutators are adjacent. This arrangement permits of using but one inspection cover for both machines. The generator is shunt wound, and the exciter, in addition to the shunt winding, has a series field.

Motors

Two standard GE-60 250 volt railway motors are used. Each motor will develop 22 h.p., the output being based on standard rating.

The magnet frame is made of two castings bolted together, the suspension side bolts are hinged, and the lower frame is arranged to swing down so as to permit of inspection of fields and armature. The axle and armature bearings are of bronze, lined with babbitt, and are designed for use with oil and waste lubrication.

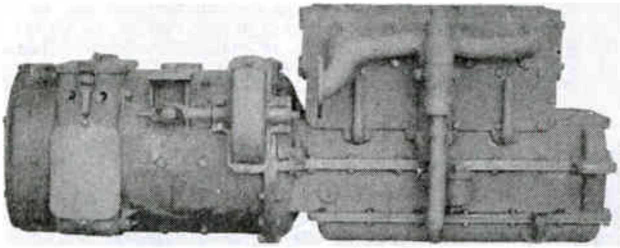


Fig. 3. 35/40 H.P. Gas Motor Direct Connected to 15 Kw. 250 Volt Generator

The pinions and gears are of steel, and entirely protected by a gear casing. The number of teeth in the gear and pinion, that is to say, the gear ratio, may be varied to suit different conditions of service.

Fig. 4. Generator and Exciter Armatures Mounted on Same Shaft

Controllers

Two controllers (Type P-15-A) are furnished, one for each end of the car. These controllers are provided with the usual reversing cylinder, fingers, and connections for placing the motors progressively in series and parallel. Magnetic blow out coils for main contacts, and cut-out switches for the motor circuits are also provided. In addition there are provided fourteen steps introducing resistances in the generator shunt field for varying the voltage impressed upon the motors, thus securing a smooth and even rate of acceleration.

A separate reversing handle is provided, so designed that the controller is locked in the off position when the reverse handle is removed.

Truck

The truck is of a special light construction of riveted plate frame, and is supported on the journal boxes by helical springs.

The car body is carried on the truck by means of helical springs, in addition to four half elliptic springs which prevent excessive longitudinal rocking of the car body. The truck is 7 ft. 0 in. wheel base with 31 in. wheels.

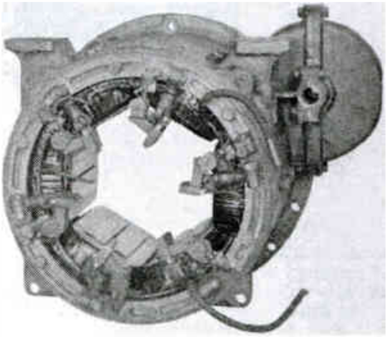


Fig. 5. Generator Field

The generating unit is swung centrally in the truck and bolted directly to cross ties which are riveted to the side frames.

The motors are outside hung on the truck, with the suspension side supported on the main truck frame. An extension shaft is brought out from the engine to the end of the car for purpose of cranking.

Car Body

The car body, which is clearly shown in Fig. 1, is designed with especial reference to strength and lightness. The platforms are semi-vestibuled.

The roof has no monitor, it being dome shaped and provided with suction ventilators. The radiator is placed on the roof over the center of the car, and is connected to the water jackets of the cylinders by pipes enclosed within the center posts of the car. The seats are longitudinal, finished in rattan, and have a capacity of 26 passengers. Trap doors are provided on the bottom of the car floor, giving ready access to engine, generator and motors. The controllers, hand brakes, auxiliary switches, etc., are carried on the platforms. The accompanying table gives principal dimensions:

DIMENSIONS

Length over bumpers	28 ft. 0 in.
Length of car body (inside)	19 ft. 0 in.
Length of each platform	4 ft. 0 in.
Width over body	7 ft. 4 in.
Width over radiator	8 ft. 0 in.
Height from rail to top of roof	11 ft. 1 in.
Height from rail to top of radiator	12 ft. 4 in.

An obvious usefulness for this type of car on trolley systems lies in its adaptation to "owl" trips, thus permitting the power station to be entirely shut down, say, between midnight and morning, when otherwise one generating unit would have to be kept in operation.

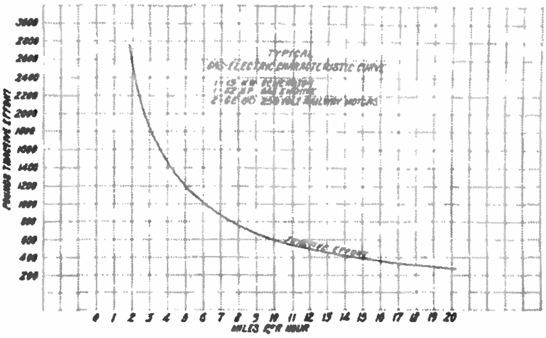


Fig. 6. Performance Curve of Gas-Electric Car

The type of car body which may be used with this equipment is, of course,

TABLE OF SCHEDULE SPEEDS IN FREQUENT STOP SERVICE AND ON GRADES

AVERAGE LENGTH OF RUNS IN MILES

Per Cent. Grade	Duration of Stops 5 Secs.					Duration of Stops 30 Secs.							Free Running Speed
	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	2.0	4.0	
0.	6.7	9.0	10.5	11.5	12.4	11.3	11.9	12.4	12.0	13.1	15.0	17.4	23.0
.25	6.5	8.5	9.8	10.7	11.5	10.5	11.0	11.4	11.9	12.3	14.4	15.6	20.0
.50	6.3	8.1	9.2	9.9	10.6	9.7	10.1	10.5	10.9	11.3	12.9	13.9	17.0
.75	6.1	7.6	8.6	9.2	9.7	9.0	9.1	9.7	10.0	10.3	11.5	12.3	14.5
1.00	5.9	7.2	8.0	8.5	8.9	8.3	8.7	8.9	9.1	9.3	10.3	10.8	13.0
1.25	5.7	6.8	7.6	7.9	8.2	7.8	8.1	8.3	8.5	8.7	9.5	9.9	11.5
1.50	5.5	6.5	7.2	7.4	7.6	7.3	7.5	7.7	7.9	8.0	8.7	9.1	10.0
1.75	5.3	6.2	6.8	7.0	7.2	6.8	7.0	7.2	7.3	7.4	7.9	8.3	9.0
2.00	5.2	5.9	6.4	6.6	6.8	6.4	6.5	6.6	6.7	6.8	7.2	7.4	8.5

not restricted to that shown in the illustrations and described above. Many other designs suggest themselves. A baggage space can be provided. An open type of car with transverse seats will be useful in warm climates. A flat car with plain roof to support radiator, and open ends and sides will be found very convenient in construction work for carrying men and tools.

STANDARDIZATION RULES OF THE A.I.E.E.*

By Dr. C. P. Steinmetz

The subject on which I desire to speak is the Standardization Rules of the American Institute of Electrical Engineers. My reason for selecting this subject is that, in my experience, these standardization rules are not as well known to many engineers as their importance makes it desirable. In my opinion, the Standardization Rules represent the most important work the American Institute of Electrical Engineers has ever undertaken, and constitute one of the most important documents in the literature of the electrical engineering industry, for I believe that the rapid and successful advance of the electrical industry of the United States is to no small extent due to their existence.

At present few of us realize the conditions which existed before these rules were drawn up and generally adopted. These rules have made it possible to build good apparatus and sell good apparatus, which procedure was not always possible before that time. The standard set by the rules is high, but not too high. It can easily be attained, and yet it is sufficiently high to be safe, though no more. Since their adoption, the rating of any piece of electrical apparatus whatever means something definite, and means the same thing within the limits of the relative conscientiousness of the different manufacturers, no matter from what manufacturer it may be bought; and these limits are very narrow, because the tests are specified and may be easily made to check up the required performance, thus making it impossible to deviate much from the standard without having it noticed. Now that has not always been the case. On the contrary, in the early days, a small manufacturer would make high guarantees regarding the efficiency and performance of his apparatus, which an engineer, knowing all about the apparatus, could not make. It will be realized that it was a very severe handicap to the advance of the electrical industry that those engineers who knew as much about the apparatus as was known at that time, were not able to build as good apparatus as possible because it could not be sold in competition with inferior apparatus which was guaranteed to have higher efficiencies. For instance, in those times core loss was a quantity not generally known. Quite commonly small manufacturers guaranteed efficiencies without figuring the core loss. It can be realized that a larger manufacturing company, having engineers who understood and could calculate this, might have built apparatus with much lower core loss and much higher efficiency, and still could not guarantee as high an efficiency as the manufacturer who did not take it into consideration. They knew of losses which others did not and which others therefore did not consider. At that time the commutator losses had just begun to be found out, but often the manufacturer did not dare include them in the losses because nobody else did, although they amounted to several per cent. It was a very unfortunate condition of affairs which made it necessary for those designing engineers who knew of the losses in the apparatus to count them in, while the engineers who were ignorant of their existence were able to sell inferior apparatus under higher guarantees; for the happy custom used to count only those losses which were specified, and of course the less specified the less the losses appeared. That condition of affairs has passed, and now the higher class of producers find it desirable to have everything known; to have tests of the performance and calculation of efficiency made, and the customer to know what the efficiency is, because they can gain by it. The same advantages accrue to the customer. He was formerly helpless when in the market to buy electrical apparatus, as one manufacturer guaranteed his apparatus at 92 per cent. efficiency while another and smaller.

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* Lecture before Schenectady Section A.I E. E., Nov. 2, 1909

manufacturer was willing to sell him the same kind of apparatus cheaper and guaranteed at 95 per cent. efficiency. What could the customer know and do? That condition is not possible now, for the manufacturer could not guarantee efficiencies not in existence—he would be found out. In 1892, when I wrote a paper on hysteresis losses, I remember that one engineer even claimed there was no such thing. It could not be, because the efficiency was known. There could not be such a loss, because it would have shown up in the efficiency and it would have been noticed. All that has now become generally known and understood, and this fact is to a very large extent due to the educational work done by these standardization rules.

The benefit resulting from these rules extends throughout the entire field of electrical work. In those early days, it must be realized that it was not generally accepted and recognized that the efficiency could be got by adding the losses. Commonly the engineers or customers rejected an efficiency test made in this manner. The recognition of the correctness of the method of measuring efficiency by adding the losses has from the first been brought out in those Standardization Rules. I recall an instance where some big machines were built and the question was, how to measure their efficiency. The input and output could not be measured very well on a 400 kw. machine, which, in those days, was a monstrous machine. It was agreed that the core loss was one of the losses which was to be added. The customer insisted that it be taken at no load and full load excitation. The machine was one of those early high frequency alternators, and when run light at full load excitation gave 40 or 50 per cent. higher voltage and two or three times the actual core loss obtained at full load. It took a long time to satisfy the customer that the addition of the losses gave the correct efficiency. Ultimately, however, the machines were accepted. When these machines went to England and were turned over to the customer, he would not accept them without further test; so they were coupled together, one being used as a motor and the other as a generator, and a whole series of tests were made, measuring the power input and output, and the input at all possible displacements, etc., to satisfy him that the efficiency was right. He finally accepted those tests, although I do not believe they meant anything; but he got what he wanted.

We know now what the efficiency is, what the losses are, and how the efficiency should be determined. Some consulting engineers had the habit of drawing up the most wonderful specifications, often 65 pages or more, specifying everything covering the armature, conductors and many other things. This was entirely improper, because that was no business of the customer—what he looks for is the performance. Even prominent consulting engineers frequently specified things of decided disadvantage and made it impossible to get the best machines for their purpose; for, while desiring to get the best apparatus, they made the mistake of specifying things which would be a disadvantage, as they were not familiar with the state of the art at that time. The early days of the industry are full of such instances.

Even though an agreement was reached, nothing definite was understood—it meant a different thing to different people. Speaking of the regulation of a machine: what did it mean? The Westinghouse Company understood something entirely different when guaranteeing regulation from what the Stanley Company or General Electric Company did. The one understood the percentage rise of excitation from no load to full load, and the other, the percentage increase of voltage at full load excitation when full load is thrown off. Such disagreements naturally made matters very difficult for a customer desiring to get apparatus, for the regulation would be guaranteed by one manufacturer as 8 per cent. and by another as 12 per cent. Twelve per cent. might have been a better regulation than 8 per cent. because the latter might mean that if load is thrown off at full load, the voltage will not rise more than 8 per cent., and the other, if a change is made from no load to full load, a full excitation of 12 per cent. increase was necessary.

Before people could understand each other and before customers could compare intelligently the offerings of different manufacturers, it became necessary to have some definite meaning for the different terms. People might use the same term and mean very different things.

The radical advance in the industry became possible only when all these childrens' diseases —the competition of manufacturers of inferior apparatus guaranteeing superior results by reason of lack of knowledge, etc.,—became eliminated, and all manufacturers and customers could meet on a common footing, employing the same terms and having to come up to the same performance. So in those early days the question of standardization was really of the greatest importance to customers, operating engineers, and to the manufacturers; and it was natural that the question of establishing standard rules should be brought before the Institute. That this was done is due to Mr. S. D. Greene, who is still a member of the organization. Mr. Greene read a paper before the American Institute of Electrical Engineers, drawing attention to the necessity of deciding what represented the best standards, the best practice, and the best definitions in the field of electrical engineering, as far as the prominent engineers could agree on the subject. As a result, the motion was made and finally carried to establish such standardization rules, and a committee was appointed to draw them up. Naturally, there was considerable discussion as to whether such rules would not handicap the development of the industry; they might hinder it, because of limitations, or they might sap inventive activity by establishing standards. Experience has shown that this has not been so. The rules have been very helpful in assisting development, have made unnecessary an enormous amount of waste effort, have combated foolish ideas by educating people to understand the meaning of terms, and have cleared up mistakes of understanding and made it possible for the results of the work to be recognized. If machinery and apparatus is superior it can be shown, which advantage was not always possible before. It is amusing now to remember some of those discussions. For instance, a motion was made that engineers connected with manufacturing companies should not be included in this Standardization Committee because of the fear that they might make the standard of the rules so low that it would be easy to build apparatus. As a matter of fact, most of the work on the rules as they stand has been done by Mr. C. F. Scott, of the Westinghouse Company, and by myself, both representing manufacturing companies which have always insisted on strictness and rigidity, and on making the requirements as high as could well be made, firmly resisting any attempt to reduce them. This is natural, because it can easily be seen that the manufacturer has no objection to building better machinery—it is really an advantage, because the better machinery will give a better record and not as much trouble; while if a cheap and poor machine is built the manufacturer gets the blame for it, and justly.

The standardization rules are of great advantage to the producer, to the designing engineer, and to the customer. They were started by a committee appointed by the A.I.E.E. and since then a committee for this work has been appointed every year. Every few years it becomes necessary to bring the rules up to standard and to add whatever new features have been developed in new industries that require attention.

Standardization rules have been drawn up and an attempt made to follow them in other countries, but in no country, as far as I know, have they been so generally accepted and so helpful to the industry as here in the United States. To a very large extent this is due to the close co-operation of the manufacturers, operating engineers, and theoretical men here; but in other countries the tendency is to delegate it to the theoretical men, who draw up rules from mere theoretical knowledge, which no manufacturer or customer can follow or cares to follow, and therefore such standardization rules have occasionally been handicaps.

It is natural that manufacturers' engineers should have done most of the work in drawing up the rules, because the engineer who designs the machine, and afterwards follows it in test and is held responsible by the Commercial Department for its successful operation, naturally knows the ins and outs of the machine better than can anyone else. He therefore knows better to what extent strict specifications should be made in order to get the best machine; and for him it is an advantage to see that specifications are high enough, so that he may not be held responsible for troubles that develop in his production outside.

The reason that the Standardization Rules have been so successful is that, from the beginning, the principle has been very rigidly maintained that the performance should be specified and not the design data. For instance, in an armature winding, it is proper to specify the temperature, but it would be improper to specify current density. Any specifications or standards of design data are a handicap to the development of the industry; but the standardization of performance has put a premium on designs which will make it possible to produce the same performance with a less amount of material and smaller apparatus, thus making the apparatus cheaper to manufacture.

Another mistake which has been carefully avoided, and which has been made especially by our European friends, is the attempt to specify size, speeds, etc. Such specifications tend to stop the advance of the art.

As I have already stated, the result has been accomplished by the co-operation of all representatives of the electrical industries in the country, and therefore the rules have not met with much difficulty in finding general acceptance.

We now come to a more specific discussion of some of the leading features of the Standardization Rules:—

Classification of Apparatus. Classifying apparatus as motors and generators was entirely unsuitable. If it is desired to classify and draw up rules for measuring efficiency and specify what performance should be expected from motors, it is evident that synchronous motors, direct current shunt motors, induction motors and railway motors cannot be put in the same group. They are entirely different types of apparatus. Neither can synchronous generators, direct current commutating generators, and induction generators be put in the same group. Again, a direct current generator and direct current motor are practically the same machine. A direct current motor can be run as a generator, and inversely, a direct current generator can be run as a motor. A synchronous motor and an alternating current generator are the same class and type of machine, and the specifications for the performance of each would be the same. There may be some quantitative differences of a minor nature, as for instance, if a synchronous machine is designed to operate only as a motor, a higher armature reactance is chosen than if the machine is designed to operate only as a generator. We also have compound motors and shunt generators, and a definite line cannot be drawn between generators and motors; but there is a distinct dividing line between commutating machines and synchronous machines and between induction motors and synchronous motors. In many cases machines are installed where it is impossible to say whether they are generators or motors. To-day they may be running as synchronous motors and tomorrow as generators. It is common in steam stations or water power plants to install synchronous motors to receive power from the transmission line and drive other apparatus, such as commutating machines for railway work, etc. During a period of low water it may not be possible to get power enough from the water and the synchronous motor has to be started as an alternating current generator. That is a very common thing. It became necessary to find a classification of electrical apparatus based on its nature, structure, and construction, and not on the particular use to which it happens to be put.

As an illustration of the confusion which existed in nomenclature of electrical apparatus before these rules were generally accepted, I mention the converter and transformer. It just happened that when the Westinghouse Company started to build alternating current transformers they called them converters. When the Thomson-Houston Company, the predecessor of the General Electric Company, started to build transformers, they called them transformers; so the same type of apparatus went by the name of converter in the Westinghouse Company and transformer in the the General Electric Company. A synchronous converter was developed by the Westinghouse Company which they called a rotary transformer, because the stationary apparatus was called a converter; and the General Electric Company, which had used the name transformer for stationary apparatus, naturally called the other a rotary converter. This is one illustration of the different definitions which were applied to the same things. The Standardization Rules adopted what appeared to be the best practice, and in this case adopted the name transformer because it had come into general use by other people. Rules were drawn up to establish as definitions those terms which appeared to the committee as representing the best practice and were most generally accepted. Then we find definitions of quantities like load factor, saturation factor, pulsation, etc., which had to be standardized so as to mean something definite.

With the advance of the art, this work has been expanded and new chapters inserted. The procedure which has been followed is never to standardize anything until best practice has already crystalized upon some definite form, and not to create definitions, but accept those definitions toward which good practice tends and which therefore can easily be accepted. It is no longer the definition of a competitive company, but a definition of the Institute, an impartial body. A company may hesitate to change the name of its apparatus and adopt the name used by a competitor, but there can be no hesitation to adopt the name given to it by the general body of the Institute; and this tends to uniformity, which is not only desirable but absolutely necessary.

Then comes the second part of the rules, covering specifications of performance of apparatus, and tests; that is, how the apparatus should perform and how this performance should be determined by test. It can be readily appreciated that one of the most important considerations is efficiency—the definition and determination of efficiency—and one of the most important features of the work done by the rules is the establishment of a method of measuring efficiency by adding the losses, making that method safe by carefully scrutinizing the losses and showing how they should be measured. These efficiency specifications and the method of making tests are well worth careful study, because they are really the general standard for testing electrical apparatus.

In the matter of insulation, which is an important one, attention is directed to the importance of high voltage tests and the relative unimportance of measuring the ohmic resistance of insulation. The ohmic resistance of the insulation is increased by baking, and in this way one could get 50 megohms or more; but this is liable to weaken the dielectric strength of the insulation. Tests of ohmic resistance are desirable as merely showing that there is no great leakage but they do not show how the insulation will perform, which performance is given by the dielectric test. A standard of one minute has been established for tests for dielectric strength. It is unsafe and objectionable to extend the time of test much longer, because of harm to the insulation. High voltage tests must be made at voltages very much higher than those to which the insulation will be normally subjected, and such high voltage puts a strain on the insulation which deteriorates it. Therefore, the test should not be continued longer than necessary to make sure that the voltage is there, and one minute is sufficiently long for this purpose. With some kinds of apparatus, however, a half hour is specified. With some apparatus half an hour is not so bad, although a minute is better. Naturally when saying a minute is better, the same test is intended to be applied. One minute at 25,000 volts is preferable to half an hour at 10,000 volts. The shorter the time the voltage is kept on, with correspondingly higher voltage used to get the same severity, the less will be the deterioration of the insulation. Apparatus must be tested with at least twice its rated voltage—twice the rated voltage of the circuit to which the apparatus is to be connected—except, of course, on machines for very low voltage, on which tests are made at a voltage much higher in proportion. There would be no sense in testing a 100 volt machine at 200 volts; but when you come to 10,000 volt apparatus, the test which experience has shown is sufficiently high, but not too high, is 20,000 volts, which really means four times the normal voltage strain. The reason that this is necessary is because of the abnormal conditions of operation which may occur. On a high voltage system, if one side of the winding becomes grounded, the whole rated potential is exerted between the winding and the iron; and in normal operation, during conditions which we must expect frequently, voltages occur which last but for a small fraction of a second that are as high as the testing voltages of the apparatus. No insulating material can stand higher voltages momentarily than continuously. It would not be safe to lower the testing voltage. Once it was done. It was very difficult to test alternators at double voltages. At that time a 20,000 volt alternator could be built that could be tested at 30,000 volts, but which would not stand 40,000 volts. Since the engineers agreed that it would be desirable to have such alternators, they asked the Standardization Committee to lower the specification for high voltage apparatus to 1½ times the rated voltage. All kinds of breakdowns followed the introduction of this practice, and we came back to the double voltage, and experience has shown that the double voltage is not too high and not too severe a test.

Then going further, overload capacities is another point. Very great difficulty existed formerly in comparing our apparatus with foreign makes, and it has often been noticed how superior the continental companies are in their designs; how much smaller and cheaper their smaller motors are; but they do not follow the Institute rules, and a 5 h.p. motor may mean a very different thing with them from what it does with us. It may mean a motor which can give power at but 5 h.p., or it may mean a motor which can continuously carry power averaging 5 h.p.; sometimes going below that figure. The tendency here in America has been to rate the apparatus at the average output which it can give. Without any guidance of standardization rules, the tendency has been very often to rate apparatus at the maximum which it can perform. Naturally, where these two classes of apparatus are compared, the one appears very much larger and more expensive than the other. The uniform rating which has been established as a minimum is 25 per cent. overload for two hours, and for motors or apparatus which may go out of service by reason of excessive overload, 50 per cent. overload for one minute. One minute means that it shall be able to carry 50 per cent. overload at least, without stopping, falling out of step, or doing anything to interrupt operations.

Now as to temperature rise: The uniform rating of 50° C. rise by resistance and 40° C by thermometer has been established for all apparatus, with a few exceptions. Commutators and brushes are allowed 5° C. more. In looking over these specifications we must naturally realize that they do not attempt to represent best practice, but the maximum safe value. It does not mean best practice to specify 50° C.; very commonly 40° C. is called for. In drawing up general specifications, it is not safe to permit a rise of more than 50° C.

I have spoken of Standardization Rules, but really, as they stand at present, they constitute a list of all electrical apparatus, and very few, if any, kinds of apparatus which is used or contemplated in any electric light or power system, are not mentioned, described and classified in those rules sufficiently for an engineer to be able to handle them and know what to do with them, and specify their performance. In this respect they are more complete than any text book of electrical engineering I know of, for during the last twelve years so many people have worked on them, studied them, and discussed them, that they have really become a very complete compendium or dictionary of electrical apparatus in the matter of its performance and test.

ROSENBERG GENERATORS*

By J. L. Hall

In supplying power for projectors some means must be provided whereby a drooping characteristic is obtained at the lamp terminals; ordinarily this is accomplished by inserting a resistance in series with the arc. Upon the steepness of the characteristic, or rate of change of potential at the lamp terminals, with reference to the current, depends the regulation of the current. With rheostatic regulation the higher the potential of the line from which the projector is operated, the steeper the characteristic and the closer the regulation, as shown by curves in Fig. 2.

In operating large projectors such as the 60-inch size, taking an amount of current relatively high, it is impossible to obtain a characteristic too steep; in fact, as near actual constant current conditions as possible is desirable. To meet this latter condition, as well as to save the energy ordinarily wasted in rheostatic regulation, the Rosenberg type of generator seems to be the solution of the problem. This type of generator (the Rosenberg American patent rights having been purchased by the General Electric Company), has been described in the Review (December, 1907) and various other technical magazines and little can be added to the mass of literature already published.

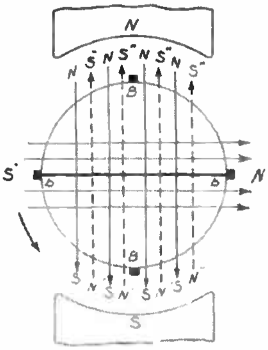

Fig. 1

As constructed at the present time it resembles, to a certain extent, an ordinary bipolar generator, but differs from it by having four sets of brushes. Two of the four sets of

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* Reprinted from the *Journal of the United States Artillery*

brushes are located in the same position on the commutator as in the ordinary generator, and are connected together, or short circuited, by a heavy copper conductor, and are called the "short circuit" brushes. The remaining two sets of brushes, called the "service" brushes, are located midway of, or 90° from the short circuit brushes.

From the field excitation is derived the primary flux, which induces a current in the armature flowing through the short circuit brush circuit, as would be the case in an ordinary generator short circuited. The short circuit current sets up a secondary flux at right angles to the primary flux, the path of which is through the armature and pole shoes. This secondary flux induces a current in the service brush circuit, which in turn induces a tertiary flux at right angles to the secondary and 180° from the primary flux, and having a tendency to neutralize the latter.

The flux distribution is diagrammatically shown in Fig. 1, and the relation between service and short circuit amperes at different generator voltages is shown in Fig. 3. The curve sheet also shows the load amperes taken by the motor driving the Rosenberg generator. This generator was shunt separately excited, and it will be noted that the curve showing the current in the short circuit brush circuit would extend beyond the limits of the curve sheet if completed. The operation may perhaps be better understood by outlining the conditions at no load and the actual short circuit of the generator with shunt separate excitation.

At no load the tertiary flux is at zero, as no current is being taken from the generator, and the excitation due to the primary flux will be at the maximum. Under these conditions the current in the short circuited brush circuit will be the maximum, but the secondary flux induced by it has little effect on the primary flux.

If the generator be short circuited, which can be done with impunity, the tertiary flux is at its maximum, being induced by the service current, and its magnitude is such as to practically neutralize the primary flux, and the potential at the service brushes will be zero. As the effect of the primary flux is practically neutralized, the current in the short circuited brush circuit will fall to zero.

This type of generator may be wound either for series self excitation or for separate shunt excitation.

For series self excitation the field cores are purposely made very small in cross section in order that saturation may be reached quickly, after which the primary flux increases less rapidly than the tertiary. In Fig. 4 the shape of the characteristic of the series wound generator illustrates this feature.

At no load the potential is that due to the residual magnetism only. As the load comes on, the potential rises until saturation is reached, after which, the tertiary flux increasing more rapidly than the primary, the curve begins to droop; but as the current is still rising in the service brush circuit, and consequently the excitation, there will still be some increase of primary flux. It is for this reason that the volt-ampere curve is less steep than if the primary flux were derived from a constant excitation.

The poles are laminated and purposely made massive and are cut away at a point corresponding to the location of the service brushes to provide a weak field for good commutation.

The highest no load voltage obtainable is by the use of cast iron for the magnet frame. This, in an ordinary generator, would result in an increase in weight, but in the Rosenberg generator the cross section of the iron need be no heavier than consistent with actual mechanical strength, as the pole cores are small.

For a shunt separate excitation the cross section of the field cores is designed for the proper density of the primary flux, and the field is excited from a constant potential source. For projector use it appears that this is the better practice and a comparison of the curves shown in Fig. 4 will illustrate the point in question.

As already explained, in the series self excited generator, while the primary flux is limited to a certain extent by a reduction of the cross section of the field core, there is still a rising field and the droop in the characteristic is not as steep as it would be if the primary flux were derived from a constant excitation. The current in the short circuit brushes, however, does not reach so great a magnitude.

In the shunt separately excited generator, the droop in the characteristic is more steep and the origin of the curve much higher. The disadvantage of this form of excitation is the high current in the short circuit brushes at no load. This high short circuit current at no load causes abnormal sparking at the short circuit brushes, and would be a serious matter were it not possible to easily limit it at no load by the use of a simple automatic switch which reduces the excitation and consequently the primary flux. The main switch could also be so designed as to short circuit the generator when opening the load circuit, which would entirely take care of the sparking were it not for the period between closing the switch and the actual starting of the lamp, or the short time necessary for the carbons to feed together. A reference to the motor current curve in Fig. 3 will also show that economy is a second reason for short circuiting the generator when removing the load, as the generator requires the minimum amount of energy to drive it when actually short circuited.

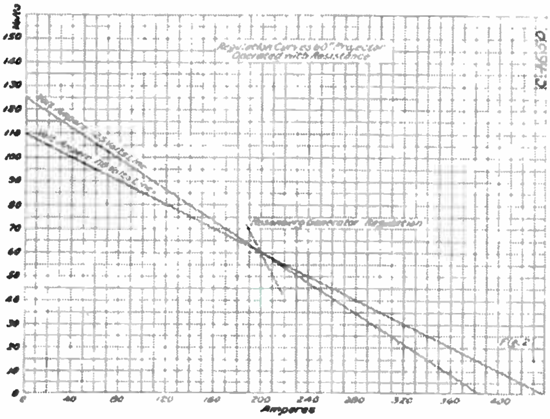


Fig. 2

This feature, the ability to short circuit the generator with safety, and without serious increase in current, makes the Rosenberg type of generator of special value in Coast Artillery service.

It is possible to occult the light by feeding the carbons together until they arc in contact, when the current flowing will keep the crater hot ready for starting at a moment's notice without actually developing a crater, as there will be no arc.

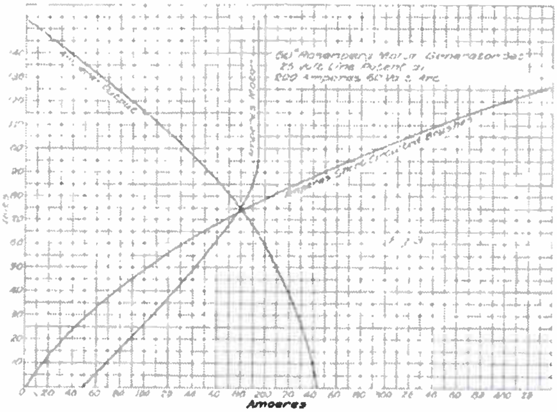


Fig. 3

Furthermore, it removes the necessity for any protective devices in the lamp circuit, as the current can increase but a small amount above the normal, and the load on the generating plant is decreased rather than increased by a short circuit on the Rosenberg generator.

It is also on account of the small increase in current at short circuit above the normal that the shunt separately excited generator is preferable.

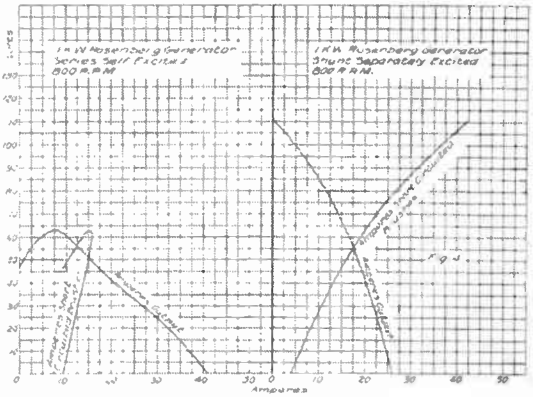


Fig. 4

In order to compare the degree of regulation obtainable with the Rosenberg generator with that obtained by rheostatic regulation, a section of the Rosenberg curve taken from Fig. 3 is plotted in Fig. 2 in dotted lines.

The curves shown in Fig. 5 illustrate the performance of this type of generator with a varying speed.

The left hand curve was taken from a 1 kw. generator series self excited, and the speed varied between 800 and 2100 r.p.m. It will be noted that the output current increases considerably, but not nearly as much as would be the case in an ordinary generator.

The right-hand curve was taken from the same machine, shunt separately excited, and here we find nearly constant current conditions with the speed varied between the same limits.

An analysis of all the curves shown indicates that for projector use the Rosenberg generator wound for separate shunt excitation provides the highest degree of regulation combined with stability.

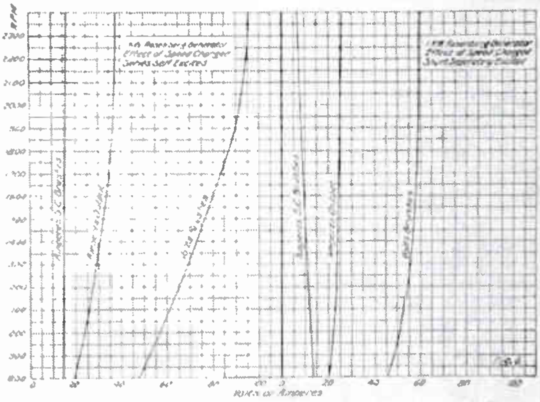


Fig. 5

TRANSMISSION LINE CALCULATIONS

PART IV

BY MILTON W. FRANKLIN

LINE CAPACITY

In any given system of electrical conductors a potential difference between two of them corresponds to the presence of a quantity of electricity on each, the one being positive and the other negative. With the same charges, the P.D. may be varied by varying the geometrical arrangement and magnitudes and also by introducing various dielectrics.

The constant connecting the charge and the resulting potential is called the Capacity of the System and this may be calculated in the cases of a few sample geometric forms.

Capacity of an Isolated Thin Cylinder

Let L_2L_1 (Fig. 10) be a thin cylinder.

Let Q be the electrostatic charge per cm. of L_2L_1.

Let Qdy be the charge on element dy at p.

Let ϕ be $\tan^{-1} \frac{y}{r}$

Then the distance $P\ p = r \sec \phi$,
and if dF_1 be the force exerted by Qdy on unit charge at P

$$dF_1 = \frac{Qdy}{(r \sec)^2} = \frac{Qdy}{r^2} \cos^2\phi \qquad (1)$$

The component of dF_1 perpendicular to L_2L_1 will

$$\text{be } dF_1 \cos\phi = \frac{Q}{r^2} \cos^3 \phi \, dy = dF \qquad (2)$$

and

$$F = \frac{Q}{r^2} \int_{L_1}^{L_2} \cos^3 \phi \, dy \qquad (3)$$

but

$$\cos \phi = \frac{r}{\sqrt{r^2 + y^2}}$$

whence:

$$F = Qr \int_{L_1}^{L_2} \frac{dy}{(\sqrt{r^2+y^2})^3} \qquad (4)$$

$$= Qr \left[\frac{y}{r^2\sqrt{y^2+r^2}} \right]_{L_1}^{L_2} \qquad (5)$$

In the case of a transmission line the length may be regarded as infinite, and the values of L_2 and L_1 in (4) may be represented by $+\infty$ and $-\infty$ respectively, thus:

$$F = \frac{Q}{r} \left[\frac{\pm 1}{\sqrt{\frac{r^2}{y^2} + 1}} \right]_{-\infty}^{\infty} = \frac{2Q}{r} \qquad (6)$$

The potential at a point in the vicinity of a charged cylinder is defined as the work necessary to bring a unit charge to this point from a point at which the force due to the charged thin cylinder vanishes. From (6) it will be seen that $F = 0$ when $r = \infty$, *i.e.*, the force vanishes at ∞.

The potential at point P may now be defined as the work done in bringing a unit charge from infinity to P.

Work = force × distance, whence,

$$dW_r = Fdr \qquad (7)$$

from (6),

$$W_r = \int_r^{\infty} \frac{2Q}{r} dr.$$

$$= 2\,Q \left[\ln r \right]_r^{\infty} = 2\,Q\,(\ln \infty - \ln r)$$

$$= C - 2\,Q \ln r \qquad (8)$$

C is an infinitely great constant and (8) shows that the potential at P cannot be determined from the conditions given alone.

The potential at the surface of the thin cylinder, whose radius may be taken as ρ, will be given by:

$$W_\rho = C - 2Q \ln \rho \qquad (9)$$

From (8) and (9) the *difference in potential* may be calculated thus:

$$W_\rho - W_r = 2Q\,(\ln r - \ln \rho) = 2Q \ln \frac{r}{\rho} = V \qquad (10)$$

V is the potential difference between the surface of the conductor of radius ρ and the point P distant r from the center of the conductor, the potential at P being due solely to the charge on the conductor $rad^{-1}\,\rho$. If there exist other charges in the vicinity the potential at P will be

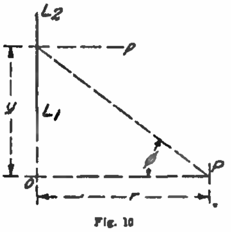


Fig. 10

$$V = \sum (2\,Q \ln X + C) \qquad (11)$$

where Q represents the charges.

X represents the distances of P from the various charges.

C is an infinitely large constant.

The potential difference between two parallel cylinders (Fig. 11) equally and oppositely charged may be calculated as follows:

Let V_1 be the potential at P due to B_1

Let V_2 be the potential at P due to B_2

From (9)

$$V_1 = C - 2\,Q\ln X$$
$$V_2 = -C + 2\,Q\ln(d-X)$$

From (11)

$$V = 2\,Q\ln\left(\frac{d-X}{X}\right) \qquad (12)$$

when P is at the surface of B_1

$$V_1 = 2Q\ln\left(\frac{d-r}{r}\right) \qquad (13)$$

similarly at B_2

$$V_2 = 2\,Q\ln\left(\frac{d-(d-r)}{d-r}\right) = 2\,Q\ln\frac{r}{d-r} \qquad (14)$$

the potential difference between the surfaces of B_1 and B_2 is (13) − (14) thus

$$V = 2\,Q\left(\ln\frac{d-r}{r} - \ln\frac{r}{d-r}\right)$$
$$= 2\,Q\ln\left(\frac{d-r}{r}\right)^2$$
$$= 4\,Q\ln\left(\frac{d-r}{r}\right) \qquad (15)$$

Capacity is defined as the ratio $\frac{Q}{V}$ whence from (15)

$$C = \frac{Q}{4\,Q\ln\left(\frac{d-r}{r}\right)} = \frac{1}{4\ln\left(\frac{d-r}{r}\right)} \qquad (16)$$

where C is the capacity per unit length
d is the distance between conductor centers
r is the radius of each conductor

and Q is the charge per cm. length of two parallel conductors, in a medium whose specific inductive capacity is unity. In actual calculations an imaginary line is devised and the capacity of the wire with respect to this line is called the capacity of the wire.

The capacity of either wire with respect to an imaginary line situated in the vicinity may be found from (12)(13): *e.g.* the capacity of B_1 with respect to the line bisecting the plane of centers of B_1B_2 is calculated as follows:

$$\text{From (13) } V_1 = 2\,Q\ln\left(\frac{d-r}{r}\right)$$

$$\text{From (12) } V_P = 2\,Q\ln\left(\frac{d-\frac{1}{2}d}{\frac{1}{2}d}\right) = 2\,Q\ln 1 = 0 \qquad (17)$$

$$\text{From (15) } V = 2\,Q\ln\left(\frac{d-r}{r}\right) = P.D. \text{ between}$$

B_1 and P

$$\text{From (16) } C = \frac{1}{2\ln\left(\frac{d-r}{r}\right)} \qquad (18)$$

Equation (17) shows that the above imaginary line is of zero potential; for this reason the line is called the neutral line and also for this reason it is situated parallel to and midway between the line wires and is the imaginary line selected, in the case of a single-phase, two-wire line.

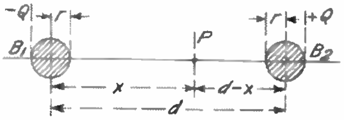


Fig. 11

Equation (18) shows that the capacity of a single wire and the central line is two times that of the two wires considered as a condenser.

The significance of this is evident from the relation

$$V = \frac{Q}{C} \qquad (19)$$

which shows that the potential difference varies inversely as the capacity, and therefore the potential difference between B_1 and the neutral line, being one half that between B_1 and B_2, the capacity between B_1 and the neutral line will be two times that between B_1 and B_2.

The values given in (16) and (18) are for absolute units, *i.e.*, capacity in farads, per centimeter for an interaxial distance given in centimeters and natural logarithms. Reducing to units of 1000 feet and to common logarithms the expressions (16) and (18) reduce respectively to

$$C = \frac{3.677 \times (10)^{-9}}{\log\left(\frac{d-r}{r}\right)} \qquad (20)$$

farads per 1000 feet of 2 parallel wires, and

$$C = \frac{7.354 \times (10)^{-9}}{\log\left(\frac{d-r}{r}\right)} \qquad (21)$$

farads per 1000 feet of one wire and neutral line.

A three-phase three-wire transmission line spaced at the corners of an equilateral triangle behaves as regards capacity precisely as though the neutral line were situated at the center of the triangle. This has been proven experimentally by Perrine & Baum.

For three parallel wires equally spaced, in a plane, the neutral or zero potential line moves harmonically between the positions midway between the other lines and the center line.

Tables (12) (26) give the capacities for solid and stranded conductors respectively.

(To be Continued)

EXHAUST FAN BLOWERS FOR RESIDENCE FURNACES

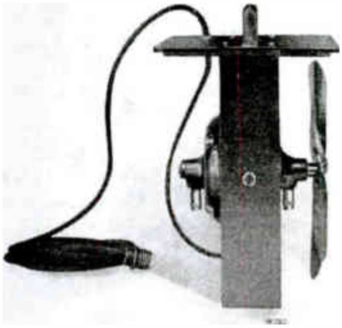
By R. E. Barker

Small Motor Department, General Electric Company

The ordinary hot-air furnace is used very widely for heating residences and usually performs an economical and satisfactory service. There are, however, cases where the natural air currents from the furnace do not properly heat all parts of the house. In nearly every installation some rooms may be found which cannot be comfortably warmed, although excessive quantities of fuel are burned. The length of feed pipes, direction and force of the wind outside, etc., all have their effect in impairing the heating afforded by the furnace. The exhaust fan blower is offered by the General Electric Company as an easy means of relieving such conditions. It often proves to be a very effective remedy.

The device is well shown in the illustration and consists of a moderate speed motor driving a six blade fan in a supporting frame. The apparatus is supplied with an attaching cord and plug, and thus connections to the ordinary lighting circuit may be made with ease. No special wiring is required, as the motor takes no more power than one sixteen candle-power incandescent lamp.

The above mechanism will undoubtedly improve the heating effect of the average hot-air furnace, and as its cost of operation is very low it will show a considerable saving in fuel consumed. Instead of piling on extra coal when the weather becomes severe, the extra heat required may be moved through the piping system by the action of the furnace blower without any appreciable increase in the fuel burned. The heat which under usual conditions remains in the cellar is taken up by the air forced through the pipes by the fan and is sent to the rooms above before the heat is lost.



Fan Blower for Residence Furnace

These motors are furnished for the following circuits:

ALTERNATING CURRENT—SINGLE-PHASE

Size	Cycles	Volts
12 in.	60	110
12 in.	60	220
12 in.	40	120
12 in.	40	220
DIRECT CURRENT—SERIES WOUND		
12 in.	1100	110
12 in.	1100	220

The outfit should be installed in the cold air box or duct near its junction with the furnace. To receive the motor, an opening $14\frac{3}{8}$ in. by $8\frac{5}{8}$ in. should be cut in the top of the box. This hole should be fitted with a hinged door or lid, with the hinges set back to allow the iron cover of the outfit to rest on the box when placed in the operating position. In mild weather, when the motor is not required, it may be easily removed and the opening closed by the hinged cover. The handle on the top of the motor support provides a ready means of moving the apparatus when necessary.

Among the several good features possessed by this blower, the following may be mentioned:

Simplicity of construction.
Ease of installation.
Quietness of operation.
Low cost of operation.
Saving of fuel.
No special wiring required.
Moderate first cost.

This outfit in its complete and special form is the result of a practical test of the application herein described. This statement may be somewhat reassuring to a prospective buyer to whom the theory appeals but who is doubtful of the results to be obtained in actual practice. There is nothing experimental either in the outfit itself or in the manner of its use.

CHARGING CURRENT PER 1000 VOLTS

TABLE XXVI

THREE-PHASE

25 CYCLES

Divide Values in this Table by 100

Amperes each Conductor per 1000 Volts for 1000 Feet of Line

STRANDED CONDUCTORS

Interaxial Distance, Inches	CIRCULAR MILS—SIZE OF CONDUCTOR—B.&S. GAUGE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.4220	.3286	.2763	.2317	.1976	.1690	.1566	.1302	.1160	.1030	.0947	.0871	.0811	.0767
2	.1132	.1070	.1023	.0970	.0917	.0860	.0817	.0762	.0717	.0679	.0639	.0605	.0579	.0562
3	.0833	.0806	.0777	.0748	.0717	.0684	.0659	.0622	.0594	.0568	.0541	.0516	.0497	.0477
4	.0708	0686	.0668	.0646	.0624	.0601	.0581	.0554	.0531	.0510	.0488	.0466	.0454	.0438
5	.0635	.0619	.0604	.0586	.0568	.0550	.0534	.0510	.0492	.0474	.0455	.0438	.0426	.0410
6	.0588	.0574	.0561	.0546	.0531	.0519	.0500	.0480	.0463	.0448	.0430	.0419	.0405	.0392
9	.0504	.0494	.0485	.0474	.0463	.0450	.0440	.0425	.0411	.0400	.0385	.0374	.0365	.0354
12	.0469	.0460	.0443	.0434	.0425	.0414	.0405	.0392	.0381	.0371	.0360	.0350	.0341	.0332
18	.0406	.0401	.0396	.0388	.0381	.0373	.0365	.0356	.0346	.0338	.0328	.0320	.0313	.0305
24	.0380	.0373	.0369	.0362	.0356	.0349	.0342	.0333	.0325	.0317	.0309	.0301	.0295	.0288
30	.0360	.0354	.0349	.0344	.0338	.0331	.0326	.0317	.0310	.0303	.0296	.0289	.0283	.0277
36	.0348	.0340	.0335	.0330	.0325	.0319	.0313	.0306	.0299	.0293	.0285	.0279	.0274	.0268
42	.0332	.0328	.0324	.0320	.0314	.0309	.0304	.0297	.0290	.0284	.0278	.0271	.0266	.0261
48	.0323	.0319	.0316	.0311	.0306	.0301	.0296	.0289	.0283	.0277	.0271	.0265	.0260	.0256
54	.0316	.0311	.0306	.0304	.0299	.0294	.0289	.0283	.0277	.0271	.0266	.0260	.0256	.0250
60	.0309	.0305	.0301	.0297	.0293	.0288	.0283	.0277	.0272	.0266	.0260	.0255	.0251	.0246
72	.0298	.0294	.0290	.0287	.0283	.0278	.0274	.0269	.0263	.0259	.0253	.0248	.0244	.0239
84	.0289	.0285	.0282	.0279	.0275	.0271	.0267	.0261	.0257	.0252	.0247	.0242	.0238	.0233
96	.0281	.0279	.0276	.0272	.0269	.0264	.0261	.0256	.0251	.0247	.0241	.0237	.0233	.0229
108	.0276	.0273	.0270	.0267	.0263	.0259	.0256	.0251	.0246	.0242	.0237	.0233	.0229	.0225
120	.0270	.0268	.0265	.0262	.0259	.0255	.0251	.0247	.0242	.0238	.0233	.0229	.0225	.0221
132	.0266	.0263	.0261	.0258	.0254	.0251	.0248	.0243	.0239	.0234	.0230	.0226	.0221	.0218
144	.0262	.0260	.0257	.0254	.0251	.0247	.0244	.0239	.0236	.0231	.0227	.0223	.0219	.0216
156	.0259	.0256	.0254	.0250	.0248	.0244	.0241	.0237	.0232	.0229	.0224	.0220	.0217	.0213
168	.0255	.0253	.0251	.0248	.0245	.0241	.0238	.0234	.0230	.0226	.0222	.0218	.0215	.0211
180	.0252	.0250	.0248	.0245	.0242	.0239	.0236	.0231	.0227	.0224	.0220	.0216	.0213	.0209

CHARGING CURRENT PER 1000 VOLTS

TABLE XXVII

THREE-PHASE

Amperes each Conductor per 1000 Volts for 1000 Feet of Line

Divide Values in this Table by 100

60 CYCLES

STRANDED CONDUCTORS

Interaxial Distance, Inches	CIRCULAR MILS—SIZE OF CONDUCTOR—B.&S. GAUGE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	1.0130	.7881	.6610	.5561	.4750	.4060	.3690	.3123	.2782	.2521	.2273	.2090	.1947	.1816
2	.2718	.2570	.2457	.2326	.2200	.2065	.1960	.1830	.1720	.1630	.1533	.1460	.1390	.1325
3	.2000	.1936	.1864	.1794	.1720	.1642	.1582	.1494	.1426	.1363	.1298	.1242	.1194	.1146
4	.1698	.1646	.1603	.1550	.1498	.1442	.1394	.1328	.1274	.1224	.1172	.1123	.1090	.1050
5	.1525	.1485	.1450	.1407	.1364	.1320	.1280	.1224	.1180	.1137	.1092	.1052	.1020	.0985
6	.1412	.1377	.1346	.1312	.1273	.1245	.1198	.1150	.1110	.1073	.1032	.0997	.0971	.0939
9	.1211	.1184	.1163	.1137	.1110	.1080	.1054	.1019	.0987	.0958	.0926	.0897	.0876	.0850
12	.1101	.1080	.1063	.1041	.1016	.0993	.0972	.0941	.0915	.0890	.0863	.0838	.0819	.0797
18	.0980	.0962	.0950	.0932	.0915	.0896	.0875	.0852	.0830	.0810	.0787	.0767	.0750	.0732
24	.0910	.0895	.0884	.0870	.0854	.0836	.0821	.0798	.0780	.0762	.0741	.0723	.0708	.0692
30	.0862	.0850	.0826	.0822	.0810	.0795	.0781	.0762	.0744	.0727	.0709	.0693	.0680	.0664
36	.0826	.0815	.0804	.0793	.0780	.0764	.0752	.0734	.0717	.0702	.0685	.0670	.0657	.0643
42	.0797	.0787	.0778	.0767	.0764	.0740	.0730	.0712	.0696	.0682	.0665	.0652	.0639	.0626
48	.0775	.0766	.0756	.0746	.0734	.0721	.0709	.0694	.0680	.0666	.0650	.0636	.0625	.0614
54	.0758	.0747	.0739	.0728	.0717	.0706	.0694	.0680	.0664	.0652	.0637	.0624	.0612	.0600
60	.0741	.0732	.0723	.0713	.0703	.0691	.0680	.0666	.0652	.0640	.0625	.0612	.0602	.0590
72	.0714	.0706	.0697	.0688	.0680	.0668	.0658	.0645	.0632	.0621	.0607	.0596	.0586	.0574
84	.0693	.0685	.0678	.0670	.0660	.0650	.0640	.0627	.0616	.0605	.0592	.0581	.0571	.0560
96	.0675	.0669	.0662	.0654	.0645	.0635	.0626	.0614	.0602	.0592	.0580	.0568	.0559	.0549
108	.0662	.0654	.0648	.0640	.0632	.0622	.0614	.0602	.0591	.0581	.0566	.0559	.0549	.0540
120	.0649	.0642	.0636	.0626	.0621	.0611	.0603	.0592	.0581	.0571	.0560	.0549	.0540	.0530
132	.0639	.0632	.0626	.0619	.0611	.0602	.0594	.0583	.0572	.0562	.0551	.0542	.0530	.0524
144	.0629	.0623	.0616	.0610	.0602	.0593	.0586	.0574	.0564	.0556	.0544	.0535	.0526	.0518
156	.0621	.0614	.0609	.0601	.0595	.0586	.0578	.0568	.0558	.0549	.0538	.0529	.0520	.0512
168	.0613	.0607	.0601	.0594	.0587	.0579	.0572	.0561	.0552	.0542	.0532	.0523	.0516	.0507
180	.0606	0600	.0595	.0588	.0581	.0573	.0566	.0555	.0546	.0537	.0527	.0518	.0510	.0502

CHARGING CURRENT

TABLE XXVIII

THREE-PHASE

Divide Values in this Table by 100

Amperes each Conductor per 1000 Volts for 1000 Feet of Line

100 CYCLES

STRANDED CONDUCTORS

Interaxial Distance, Inches	CIRCULAR MILS—SIZE OF CONDUCTOR—B.&S. GAUGE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	1.688	1.314	1.102	.927	.792	.677	.603	.531	.464	.420	.379	.349	.326	.303
2	.453	.428	.410	.388	.357	.344	.327	.305	.287	.271	.266	.242	.232	.221
3	.333	.322	.311	.299	.287	.274	.263	.249	.237	.227	.216	.207	.199	.191
4	.283	.274	.267	.258	.260	.240	.232	.221	.212	.204	.195	.187	.181	.175
5	.254	.248	.242	.238	.227	.220	.213	.204	.197	.190	.182	.176	.170	.164
6	.236	.229	.224	.219	.212	.206	.200	.192	.185	.179	.172	.166	.162	.157
9	.202	.197	.194	.189	.185	.180	.176	.170	.164	.160	.154	.150	.146	.142
12	.184	.180	.177	.173	.170	.165	.162	.157	.152	.148	.144	.149	.137	.132
18	.163	.166	.158	.155	.152	.149	.149	.142	.136	.135	.131	.128	.126	.122
24	.152	.149	.147	.145	.142	.139	.137	.133	.130	.127	.123	.120	.118	.115
30	.144	.142	.140	.137	.135	.133	.130	.127	.124	.121	.118	.115	.113	.111
36	.138	.136	.134	.132	.130	.128	.125	.122	.120	.117	.114	.112	.109	.107
42	.133	.131	.130	.128	.126	.124	.122	.119	.116	.114	.111	.109	.106	.104
48	.129	.128	.126	.124	.122	.120	.118	.116	.113	.111	.108	.106	.104	.102
54	.126	.124	.123	.121	.120	.118	.116	.113	.111	.109	.106	.104	.102	.100
60	.122	.122	.121	.119	.117	.115	.112	.111	.109	.107	.104	.102	.100	.0984
72	.119	.119	.116	.116	.112	.111	.110	.108	.105	.103	.101	.0990	.0974	.0956
84	.115	.114	.113	.112	.110	.108	.107	.105	.102	.101	.0986	.0968	.0950	.0933
96	.113	.111	.110	.109	.107	.106	.104	.102	.100	.0986	.0966	.0947	.0931	.0914
108	.110	.109	.108	.107	.103	.104	.102	.100	.0985	.0968	.0947	.0930	.0914	.0899
120	.108	.107	.106	.105	.102	.102	.100	.0986	.0968	.0951	.0933	.0914	.0900	.0884
132	.106	.105	.104	.103	.102	.100	.0990	.0971	.0954	.0938	.0919	.0903	.0884	.0872
144	.105	.104	.102	.102	.100	.0989	.0976	.0957	.0940	.0925	.0906	.0892	.0877	.0863
156	.104	.102	.101	.100	.0991	.0976	.0963	.0949	.0930	.0915	.0896	.0881	.0868	.0853
168	.102	.101	.100	.0991	.0978	.0966	.0952	.0935	.0920	.0904	.0887	.0871	.0859	.0845
180	.101	.100	.0991	.0980	.0968	.0954	.0942	.0925	.0910	.0893	.0878	.0862	.0850	.0836