ELEMENTS OF ELECTRICAL ENGINEERING.—XVIII.

CURRENT REORGANIZERS.

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Continued from Supplement No. 1689, page 310.

It sometimes happens that the particular needs of some customer cannot be satisfied from the existing or common system of mains that convey the current. The supply may be of direct current, and the demand be for alternating; or the supply be alternating, and for some use the direct sort be imperative; even if already

Fig. 83.—Dynamotor for Exchanging Direct-Current Voltages.

direct, it may be of improper voltage. Various other disagreements may readily be imagined. Of course the "system" of supply is adopted which will best satisfy the largest number of users, and then for the special needs of others accessory apparatus must be installed on the customers' premises that will make the desired alterations. Even in the case of a central station, especially if it be one receiving or delivering electrical energy over long distances, such auxiliary apparatus would commonly be found—its functions rather puzzling to a novice, yet contributing in a high degree to the practicability or economy of the operation of the entire plant.

The name "reorganizers" has been suggested for this class of apparatus—most of it involving some rotating parts—but the reader will better understand just what is meant after reading the article. The real definition can then perhaps be better imagined than expressed.

The most common cases encountered are those in which (1) the supply is of direct current, but the voltage is either too high or too low; (2) the supply is of direct current, but alternating currents of one, two, or three phases, and of appropriate voltage, are desired; (3) the converse of case (2) may more often be met; (4) alternating currents of one voltage and number of phases are to be exchanged for another voltage and number of phases, but of the same frequency; (5) the same case as (4) but with a change in frequency also imposed.

It is to be expected that some of these changes may be accomplished in more than one way, yet each of these has peculiar qualifications or limitations, and it will be appropriate to compare their utility. Definite names have been applied to most of these devices—more or less suggestive or familiar to the reader. These are, in the order of the above list, (1) dynamotors, motor-generators, boosters, converters, or inverted converters, "Scott" connected transformers, and frequency changers. The simple transformer for changing from one alternating voltage to another need not here be considered, for that topic formed the subject matter of Chapter XVII.

Instances under the first of these conditions are met when the regular supply is from the original low tension, or "Edison" system, of 110 or 220 volts, such as is found in the congested portions of almost all large cities, and a voltage of from 2 to 10 volts is desired for electroplating purposes, or of 25 volts for charging storage batteries in a telephone exchange, or 70 to 140 volts for operating telegraph circuits. The simplest sort of machine to make the necessary transformation is illustrated in Fig. 83. In this is seen a single field magnet and armature, two commutators with their respective brushes, but no pulley. One commutator is larger than the other, therefore suggestive of larger current carrying capacity. Though not discernible, the armature winding is really double, one consisting of relatively fine wire, and attached in the regular manner to the right-hand commutator, and the other of coarser wire, and attached to the other commutator. Naturally, some skill is required to put these two windings smoothly in place, yet well insulated from each other. The field winding is of sufficiently high resistance to be connected in shunt

fashion to the same source of supply as the finer of the armature windings. In use, this fine wire part of the machine is merely a shunt motor, but as the armature rotates, it complies with all the conditions for generating an electromotive force in the coarse wire; the electromotive force in this latter will bear the same ratio to the supply as that of the number of turns in the two windings. It is therefore a matter of apportioning the number of turns to fit the needs of each individual case. In consequence of the larger current allowable from the coarse wire, its commutator must be of larger dimensions than the other. Such a machine has, inherently, only one economical voltage of supply, for this is at once involved in the initial winding. It is seen to resemble the ordinary alternating current transformer, in which a definite ratio of transformation is involved with every particular winding. Still further resembling the latter, the "dynamotor" is equally helpless to change that ratio by any change in the speed. In the alternating current case, the speed of the generator, and therefore the frequency of the alternations, might be changed; but the secondary electromotive force would still bear the same ratio to the primary. If, to give a higher motor speed, the field of the dynamotor be weakened, this increase could not raise the dynamo voltage; for, in consequence of the field magnet being common to both windings, the increase in speed of conductors would be just offset by the lesser magnetism. With no means of adjusting the voltage of the dynamo part

Fig. 84.—Motor-Generator, or Dynamotor With Independent Windings.

to the nicety often demanded by the user, these machines have largely been replaced by a variation of the scheme, in which the armatures are separate and each revolves under the influence of a field magnet of its own. A great variety of such constructions is

to be operated from a single large generator. If such a generator supplies 220 volts, and it is desired to use 110-volt lamps, the double wound machine is connected across this circuit, and a third wire, to serve as the neutral, is led from the conductor joining the two commutators. The field winding is in shunt across the 220-volt mains. In case of a balanced load, the dynamotor runs idly, for its two 110-volt armature

Fig. 86.—Elementary Three-Phase Rotary Converter or Double Current Generator.

windings in series set up a suitable counter electromotive force, and very little energy is wasted. If more load comes on one side of the system than on the other, the lighter side immediately draws about half the excess through one of the armature windings, making a motor of this part, and generates the other half needed in the other, or dynamo, portion of the machine. Since this double-wound machine needs to care for the unbalanced portion only of the load, it can be relatively small, and placed somewhat independent of the location of the main generator. In consequence of the particular functions fulfilled, this sort of dynamotor is often called a "balancer" or "equalizer."

A machine with independent windings closely imitating the one just described, but offering all desired control, is given in Fig. 84. Wide range of voltage is possible, for with a rheostat in the shunt field winding of the generator, the variation from normal to a minimum is made, while with a rheostat in the motor field, the speed may be increased, and values higher than normal secured. The act of putting two distinct armatures on the same shaft gives the same electrical conditions as if the generator were an entirely independent machine driven by means of a belt from some separate motor. The combination shown makes a very compact and noiseless arrangement. In case, too, of injury to one of the windings, repairs are

Fig. 85.—Booster Set of Large Size for Storage Battery.

made, and recognized under the name, "motor-generators."

A special use of the dynamotor is that in which both windings are alike, and their circuits connected in series across the mains of a double voltage generator. This is a device to enable a three-wire system

more readily effected than when the two are on the same structure.

A highly specialized form of the motor-generator is known as a "booster-set." In this, the generator may be wound for low voltages, but still higher than for plating purposes, and for large currents. The arma-

ture would be inserted directly in series with a railway feeder, in order to hold up the voltage at the distant end, or in a storage battery circuit, to assist the main generators during the charge, and, during the "peak" of the load, to help the batteries to discharge. The field windings of such generators are often various, and, dependent upon the conditions imposed, may be series, shunt, compound, differential, or even with triple windings. Some of the most beautiful refinements in dynamo design have been developed in the highly successful adaptation of booster control

Fig. 87.—Section Through Rotary Converter, as Designed for Railway Service.

for storage battery operation. Especially in heavy railway service, where the demands for current may be sudden and severe, and quite out of direct reach of the generators alone, the booster will automatically transfer the fluctuations to the battery, and allow the generators to operate under fairly constant loads and with maximum economy. An idea of the size and appearance of such a set is given in Fig. 85. Of the two machines the one on the left is the generator; it has eight poles, and the armature output is 160 kilowatts at from 55 to 110 volts, meaning a current 1,450 amperes. The number of cables leading from the brush holders and the series coil is suggestive of large current capacity. The motor has six poles, is of 230 horse-power, and is supplied at the standard railway potential of 550 volts. The speed is 450 revolutions per minute. Of course, such a piece of apparatus wastes some energy—far more must be put into the motor than is secured in return out of the generator, but a working efficiency of 75 per cent to 80 per cent is readily secured. This represents, however, only a fraction of the entire output of a station, and the losses are fully offset by various economies in other directions. In such a set, the relative number of amperes in the two circuits is graphically shown by the small twin cables on the motor, and the large quadruple ones on the generator.

By making the motor portion of such a set adapted for running on alternating currents, it is seen that still further opportunities are open to its use. In case alternating current was at high voltage, the set would regularly have three or four bearings for the shaft, and the latter in two portions connected through an insulating coupling. Whether with or without this insulating feature, the applications of such motor-generator sets are very large, ranging from those adapted for small experimental purposes to the running of really large generators in central stations.

Fig. 88.—Three-Phase Rotary Converter for Large Currents, for Electrolytic Refining.

Very often the motor shaft is extended in both directions and independent direct current machines driven. For such, the alternating currents, in two or three phases, would be transmitted from some remote source of supply, but at such voltage as to be dangerous and otherwise unfitted for distribution to customers. If

direct current, on the three-wire system, was to be supplied, the two direct current generators of the set would be joined in series to supply that network of conductors, and the power to drive them delivered to the motor. The motor itself might be of the induction type, and self-starting; but a higher efficiency, and closer regulation of speed and voltage are secured through the use of those of the synchronous type.

In alternating current generating stations it is common to have the engines or water wheels of appropriate sizes to drive the main machines only. Direct current is, of course, imperative for energizing the field magnets of the generators, and this is conveniently obtained from a suitably small machine driven from an alternating current motor. The combination is commonly denoted as a motor driven "exciter." For making a start from a condition of complete shutdown, such a set would be helpless; consequently to tide a station over such a period, reliance would need temporarily to be placed in a small independently driven dynamo or in a storage battery.

One arrangement of the motor-generator set has found considerable adoption in connection with street lighting. When the transmission is by three-phase alternating currents, yet direct currents are preferred for the arc lamps, synchronous motors are usually coupled, at their two ends, to two large arc dynamos, often of the most modern Brush 4-pole type, and thus make double sets for changing from constant potential, three-phase alternating to those of direct constant current sort. From each of these arc machines 100 to 125 lamps in series would be operated. At Buffalo, Niagara power, brought for a distance of twenty-six miles, is used to drive the motors; but the flexibility and convenience of this motor method is often utilized for transmissions quite within some one station. A notable illustration of this procedure is at the South Boston station of the Edison Illuminating Company.

Fig. 89.—Two-Phase to Three-Phase Transformation or Vice Versa.

In this eighteen such sets are arranged in the same room as the main generators; each of the synchronous motors is of 200 horse-power, and drives two 106-light 6.5-ampere dynamos. Although the transmission is for a distance not over 100 feet, all belting, with its accompanying losses and waste of space, is saved, and an additional valuable gain is that any one set is not associated with some one particular engine.

"rotary converter." Abridged names are "rotary" and "converter." Schuckert & Co. exhibited the first one at the electrical exhibition in Frankfort, in Germany, in 1891. An ordinary multi-polar direct current shunt wound generator has been fitted with collector rings,

Fig. 90.—Connections and Circuits of Mercury Arc Rectifier.

and these were attached at suitable symmetrically located points of the same winding as that to which the commutator was still connected. Treated as an alternating current generator, all the conditions for three phases were provided, as diagrammatically represented in Fig. 58, of Chapter XIV. Ignoring these connections, it was, of course, possible to use the machine for direct currents, either as motor or generator. With field excited with direct current, the armature could deliver three-phase alternating currents; or half the output could be direct and the other half alternating. Further, if alternating currents were supplied in proper manner to the armature, the machine became a synchronous motor. The most interesting feature was then found that direct currents were obtainable from the commutator, just as if the armature was driven by an engine. That is, alternating currents could be delivered to the rings and direct current taken from the commutator. Of course, the same current that was put in at one place came out at the other; but the commutator directed or "rectified" the separate impulses into as truly a direct current as attainable from any machine. The converse was also found true—that the machine could receive direct currents at its commutator, and deliver alternating from the rings.

Great interest immediately attached to this discovery, and not many years elapsed before such machines were found installed in substations at distant points on railway lines. The current was transmitted from the central power house by means of high voltages, then transformed to suitably low potentials, and delivered to the rings of the converters, whence direct currents were led to the trolley wires.

A graphical representation of the arrangement of parts, and the location of the wires for a three-phase converter, is given in Fig. 86. The rings are at one end of the machine, with taps to three equidistant points of armature winding, while the commutator is conveniently at the other end. A pulley is here shown, but its place would ordinarily be taken by an induction motor, used for starting just as that shown in Fig. 68, of Chapter XV; or, in case the machine was in a central station, and used for changing direct current into alternating, a separate exciter could be substituted, and give better control over the field than when the energy comes from the main armature. For it has been found that under such running of an "inverted" converter, an extra heavy load—and surely a short circuit on the transmission line—will admit such a lagging current in the armature as to weaken the field magnets, and dangerously accelerate the speed. If the field magnet of the separate exciter is normally worked at a very low degree of magnetization, even a slight increase in speed will so raise the electromotive force as at once to correct the tendency toward the weakening of the main magnets, and therefore the speed will be held closely at its proper value.

It may be of interest to learn just what relation exists between the direct and alternating electromotive forces; that is, to find what number of volts acting at one end of the machine will produce a given number at the other. Reference to the diagrams shown in Chapter XIV will be helpful. If every one of the

From whatever source the alternating current may come, any one of the motors is equally in condition to run.

The first sort of machine to change alternating currents to direct, and *vice versa*, and one still popular for railway and some other service, is now called the

loops in the ring winding in Fig. 59 be imagined as attached to a commutator segment, the direct current conditions will be filled. The four taps to the collector rings will provide for two-phase alternating currents. Imagining now the direct voltage, as measured across the brushes, to be called 1, then the alternating, measured across either of the opposite points, will be, as explained in the text, 0.707; draw then a diameter through A_1 and A_2 to represent this effective value. That is, if the machine be used as a double current generator, a certain direct voltage would be impressed on one circuit, while alternating ones, 0.707 as great, would be acting on each of the two-phase circuits. Consequently, except for such losses as may be due to the resistance and reactance of the armature, if 550 volts direct is desired, 550×0.707 , or 389 volts, alternating, must be impressed. This would ordinarily be afforded through the medium of special transformers. To ascertain what the value for the case of three phases would be, draw, in Fig. 58, a diameter through the point A ; this will, as before, represent points between which the alternating voltage is 0.707 of the direct. Draw a line connecting A with either B or C ; by measurement or calculation this length, representing the voltage in the three-phase circuits, will be found to be 0.612 of the direct. Then for a direct voltage of 550, 337 volts alternating must be impressed on each of the three ring circuits.

The particular ratios, just deduced, are seen to be dependent upon the armature connections, and no reference has been made to any particular strength of field. This is an important point, and indicates at once that control of the terminal voltage cannot be sought in the ordinary direct current manner. Slight adjustments of field strength are possible, and compound windings have met with favor in railway work; but the most satisfactory and complete means are found in introducing variable reactance coils into the alternating current circuits, between transformers and rings. This, of course, results in varying the number of impressed volts, and the direct current voltage will follow in the computed ratio.

Two-phase converters have four rings, therefore they are capable of passing more current than the three-phase, with its three rings. Sometimes a double three-phase winding is used, and somewhat improperly called six-phase; still more current can be passed by such a winding than even the one with four rings. With a certain direct current rating, the same winding will get no hotter, when used as a three-phase converter, though carrying 1.32 times as much current, or with two phases, 1.62, and with six phases, 1.92. For the amount of current they convey, the rotary converters, therefore, need not be so large as the generators from which the energy originally comes. Most converters operate on 25-cycle circuits, and the number of poles and speed to give this frequency are quite within easy engineering practice. For 60 cycles, however, requiring more poles and higher speeds, the conditions are not at all favorable; in addition to the expected mechanical drawbacks, there is increased difficulty in producing sparkless commutation.

Sometimes irregularities in the supply circuits, or periodic fluctuations in the load, especially when a number of converters are operated in parallel, set up surges in the speed of armature, even to the extent of causing the machines to break step with the necessary condition of synchronism, and suddenly stop. To prevent this accident, heavy copper grids are placed around the pole tips, or are imbedded in their faces; by this provision, any fluctuations will induce such large local currents as at once to serve as effective dampers.

In Fig. 87 is given a partial half-section through a standard three-phase converter for railway service, and in Fig. 88 the outside appearance of a special one for passing very large currents for electrolytic refining.

Since two-phase apparatus has a slightly higher current capacity than the same weight of materials arranged for three phases, and the former has some good qualifications for local distribution not found in the other, the two-phase sort is often installed; yet for purposes of long-distance transmission, the advantage lies with three phases, for only three-fourths as much copper is required for the line wires, and one row of insulators is saved. Means for exchanging the number of phases has therefore been sought. Of course a motor-generator set would accomplish the result, but in too expensive a manner. The problem was ingeniously solved by Mr. Scott, chief electrical engineer of the Westinghouse Company, by the use of special transformers. These must be made in pairs, with the two-phase windings alike; but one of the windings for the three phases has a tap brought out in the center, while the other winding has only 0.866 as many turns as the first. A representation of the circuits and their geometrical combination is given in Fig. 90. A and B are the two-phase portions, and have the same number of turns; it is to be remembered that one of these windings receives its impulse one-quarter period later than the other. In one transformer the

coils a and b , with the tap in the center, give the terminals 1 and 2, while the coil c in the other transformer, joined to this middle point, gives terminal 3. Since the device can be used either way, to change two to three, or three to two phases, either set of coils may be primary or secondary. In the geometrical diagram, the phase A is to be regarded as acting on its other winding a and b , while the phase B acts on winding c , erected as a perpendicular at the middle of $a-b$; the instantaneous sum of a or b and c is just equal to a plus b ; therefore the electromotive forces between points 1, 2, and 3 are equal and follow a genuine three-phase order. The numbers given in the diagram are not to be taken as actual, but proportional to the real ones, for an illustrative case of exchange between 50 volts, two-phase, and 100 volts, three-phase. Since the power transmission usually involves the use of some sort of transformers, this change in the number of phases is accomplished at the same time, without any extra expense whatever.

When an actual change in the frequency of the alternations is imperative, as when the transmission is at 25 cycles and the proper operation demands 50 or 60, the current must really be re-generated; a motor-generator set is unavoidable, usually consisting of a synchronous motor with a given number of poles directly coupled to a generator with a suitably increased number of poles. Such a set is of course expensive, and has led to the adoption of the higher frequency for the initial generating plant, while many reasons of economy and regulation would argue for a lower rate.

Considerable interest now attaches to the newly discovered means for obtaining a direct current from a single-phase alternating circuit, by means of the curious selective conductivity of mercury vapor. That is, a current will quite readily pass in one direction

PNEUMATIC TOGGLE-JOINT RIVETER, WITH AUTOMATIC ADJUSTMENT FOR THICKNESS OF WORK.

and scarcely at all in the other. This condition can be obtained only in case the electrodes are of different materials. Reference to Fig. 89 will give an idea of the circuits. A glass bulb Y , ten inches or more in length, from which the air has been exhausted, contains a few ounces of liquid mercury in contact with a bottom electrode B , called the cathode. A and A' are other electrodes, terminating in graphite, and called anodes. These latter are connected to the source of alternating currents. From the bottom electrode connection is made, if batteries are to be charged, to the positive pole. Adjustable reactive coils, for purposes of regulation, are inserted at F and E . With no vapor in the tube no current can pass in any direction. By means of an auxiliary anode C current can flow through an ohmic resistance R and some liquid mercury in a narrow channel, thereby filling the bulb with vapor and breaking this starting circuit. At one instant current will follow a path from H in the direction shown by the simple arrows, through A , B , the batteries J , D , E , and to the transformer terminal G . At the next instant the path will be that shown by the arrows within circles, but still in the same direction through the batteries. Current will not pass from A to A' , or A' to A , for both these terminals are of the same material.

The current through J is unidirectional, and entirely suitable for battery charging purposes, or for operating arc lamps that demand direct currents; but the flow is pulsating, therefore not best fitted for running motors. As expected, the vapor has some resistance even in the direction that the current flows, and a constant drop of about 14 volts is suffered. A standard size of apparatus operates on a 110-volt 60-cycle alter-

nating circuit, and can supply 16 to 45 volts and up to 25 amperes direct current. Efficiency is about 75 per cent. The life of the bulbs ranges between 600 and 1,000 hours of use. In warm places it may often be necessary to run a fan motor to provide for the effective condensation of the vapor on the walls of the glass.

For general experimental purposes, it is likely that a motor-generator set would allow greater flexibility of control, and not represent a much higher first cost than mercury "arc" with its considerable accessories. For steady loads, as for battery charging, or for series arc lamps, an extensive adoption is predicted.

Chapter XIX will explain the construction and connections of instruments for measuring direct currents.

SOME LATE IMPROVEMENTS IN COMPRESSIVE RIVETERS.*

By CHESTER B. ALBREE.

THE comparative advantages of the various forms of compressive riveters—hydraulic, hydro-pneumatic, direct pneumatic, and pneumatic toggle-joint—have been considerably discussed and are fairly well understood. Each of them has certain advantages not possessed by the other. In this paper is described a new riveter in which some of the advantages of the various forms are combined, together with some additional improvements not hitherto attained. This riveter has the action of the toggle-joint type, with its increasing pressure toward the end of the stroke, where pressure is most needed in heading the rivet. It also has the valuable feature of the plain hydraulic machine in not requiring adjustment of the riveting jaws for work of different thicknesses. The machine is self-adjusting in this respect, and always gives the same terminal pressure, even though the thickness riveted may vary from one stroke to another.

In the cut is shown the perfected form. The piston in the air cylinder is connected to the plunger by a toggle mechanism of the usual construction. The pressure from the toggle is transmitted to the top of the ram and also through a pipe to the adjusting cylinder. The ram being small in area and free to move, advances rapidly and continues until the rivet die on its extension strikes the projecting rivet. As the plunger continues, the pressure in the cylinder is limited by the pressure due to the spring in the adjusting cylinder, there being free communication to it through port M and the pipe shown. This pressure is only 20 pounds per square inch, insufficient to upset the rivet beneath the ram. Hence the liquid will now displace the piston in the adjusting cylinder, the ram remaining stationary.

Referring to the cut, it will be noted that the extension of the plunger, when fully up, still projects into the smaller area of the ram cylinder; and that cup leathers are used to pack it. In the interior of this extension is a valve of the poppet type, but having a stem carrying on its end a small piston. This valve is normally held open by a spring. So long as the pressure above and below this small piston is the same, the spring holds the valve open, but when the pressure below is greater than above the piston will move up, closing the poppet valve. This occurs only when the port M leading into the space below the small piston is closed, due to its passing from the large diameter bore to the smaller ram bore. When closed, the toggle pressure acts on the liquid below the plunger extension, raising the pressure sufficiently to move the small piston and connected valve, and later exerting very high pressure on the poppet valve, shutting it perfectly tight.

During the downward motion of the ram the liquid beneath it is forced into the opposite end of the adjusting cylinder, against the spring pressure. It is obvious that the ram may move its whole adjusting stroke, or not at all, up to the time when port M is closed by entering the smaller diameter of the cylinder; after which the further travel of the ram is that of the plunger, until the ram meets opposition greater than the pressure of the toggle, when it will stop. This arrangement, therefore, automatically adjusts the point of maximum pressure to suit the work. On the return stroke we have the direct pressure beneath the ram, as well as the suction of the plunger, to raise the ram to its original position.

Leakage of the liquid is made up from a small storage, or compensating, cylinder, full of liquid, having a piston with a spring behind it, connected to the larger bore of the plunger by a pipe, having a check valve in it. Whenever there is pressure in the plunger cylinder, the check valve remains closed; but when the toggle is fully back, and the piston in the adjusting cylinder is against its cylinder head, so that no pressure due to its spring is exerted on the liquid, any loss of liquid will tend to create a vacuum in the plunger cylinder, and then the check valve will open, and oil flow out of the compensating cylinder, under the pressure of the spring acting in its piston, to replace that which is lost.

* Abstracted from a paper read before the Engineers' Society of Western Pennsylvania.