Westinghouse
Synchronous Converters

INSTRUCTION BOOK

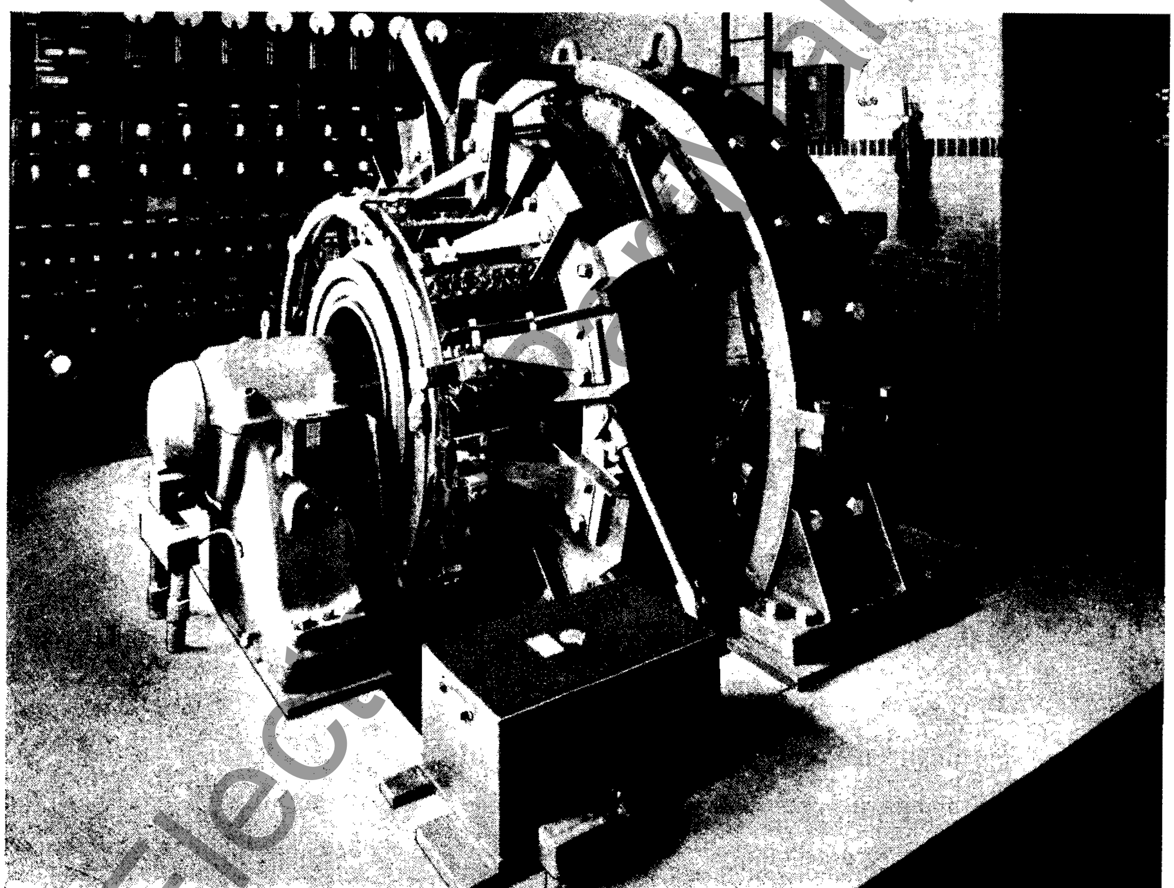

FIG. 1—2000-KW., 600-VOLT, 60-CYCLE, SYNCHRONOUS CONVERTER SHOWING MOTOR OPERATED BRUSH LIFTING MECHANISM

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I. B. 5133-H

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CAUTION

Westinghouse converters will operate satisfactorily under very severe conditions, but the best results from any electrical machine, and particularly from a commutating machine, are obtained only when the apparatus is given careful and intelligent attention.

Keep the converter clean. The finest machines and the most expensive plant may be shut down by accident if they do not have protection and care. The insulation must be kept clean and dry. Oil, dirt, copper and carbon dust in the insulation are as much out of place as grit or sand in a cylinder or bearing.

Before installing or operating a machine, read all of the following instructions carefully, making note of the parts and points to be observed. On account of divergence of construction of the different types, it has been impracticable to arrange all information on any one class of machines in consecutive order.

IMPORTANT NOTICE

MECHANICAL RE-DETERMINATION OF NEUTRAL POSITION

On Fabricated Type D-C. Brush Riggings

At any time, the following mechanical method for determining the factory neutral position, can be applied:

With a convenient constant radius, using the two countersunk holes in the front edge of the frame as centers, scribe two arcs to intersect on the commutator surface between the ends of the bars and the first brush, so that the point of intersection is visible when the brush arm is in place.

If the axial center line of a brush contact surface be made to coincide with the point of arc intersection, the brush will be in the factory neutral position. The position of one brush arm is thus established and the other brush arms can be spaced with reference to it.

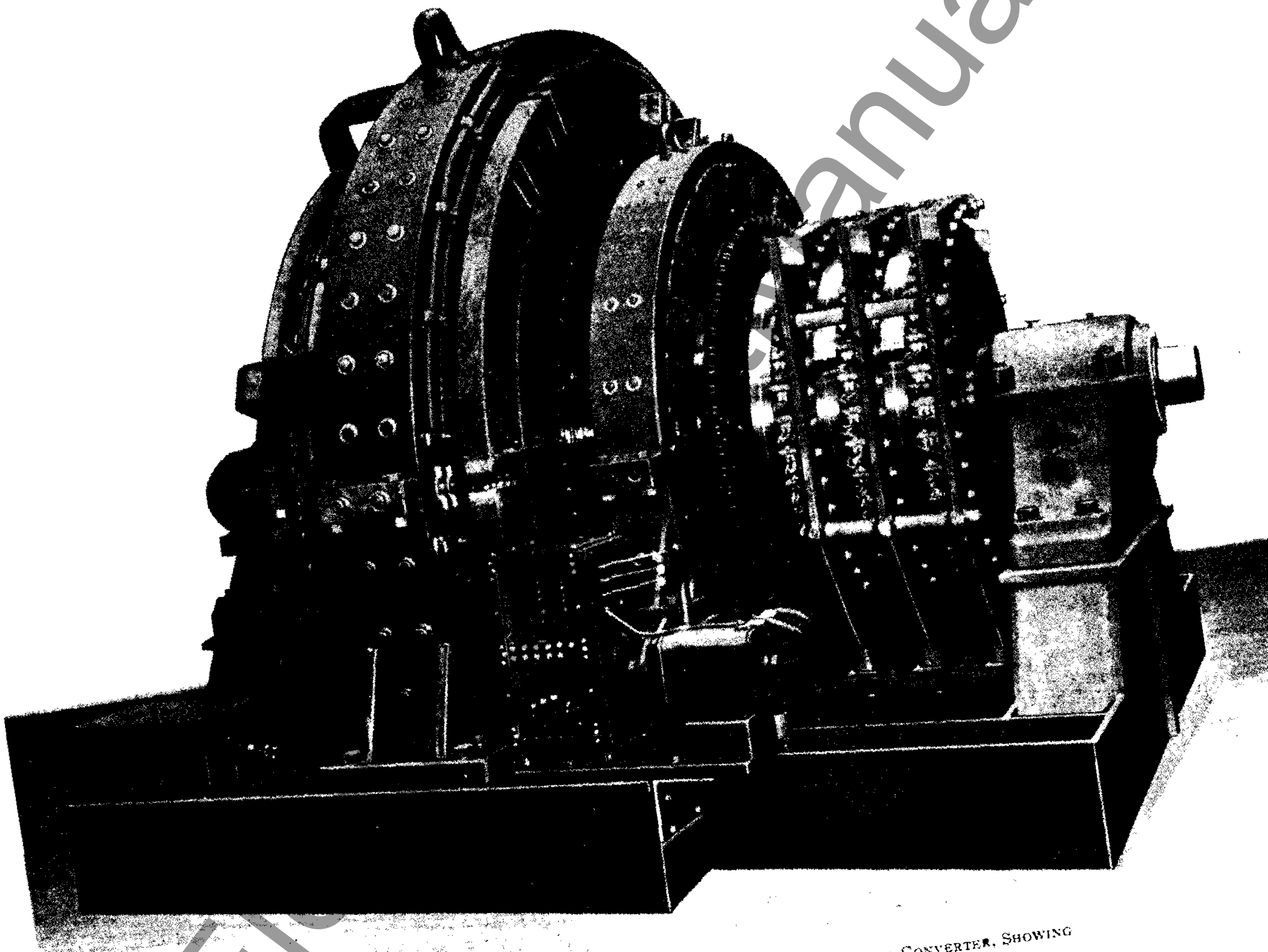


Fig. 2—13000 Ampere, 270 Volt, 6-Phase 60 Cycles, 300 RPM., Booster Converter, Showing Torque Motor and Motor-Operated Brush Lifting Device

Westinghouse

Synchronous Converters

General Information

Types of Construction—From the standpoint of the method of voltage control, Westinghouse synchronous converters may be divided into three classes, as follows:

(1) Plain shunt-wound converters used in railway lighting and industrial power service for which approximately constant voltage is suitable.

(2) Plain compound-wound converters with reactance used in railway and industrial power service for which automatic voltage variation over a relatively small range is required. Converters of this type are built for 25-cycle circuits up to 1500 volts direct-current, and for 60-cycle circuits up to 750 volts. For 1200-volt and 1500-volt, 60-cycle circuits, two 600-volt or 750-volt converters are used in series. Such double units are either constructed with a common bedplate and three pedestals or, as separate units.

(3) Shunt-wound synchronous-booster converters are used for lighting and power service in which a greater variation in voltage is required than can be supplied from converters with reactance control. Converters of this type are usually built for a normal voltage of 270 volts for both 25 and 60-cycle circuits.

From the standpoint of mechanical construction, standard converters may be divided into two classes, as follows:

(1) Self-contained units with frame and bearing pedestals supported from a common bedplate.

(2) Sole-plate units with frame and bearing pedestals supported from four independent sole-plates.

The majority of Westinghouse synchronous converters are self-contained, only a few of the largest converters being built as sole-plate machines.

Three-Wire Synchronous Converters-Any converter or booster converter may be used to furnish direct-current for a three-wire circuit. The neutral point is usually obtained from the middle point of the low tension winding of the transformers or from auto-transformer balancing coils if the converter is used without step-down transformers. The connection for three-wire synchronous converter and transformers is shown in Fig. 39.

Commutating-Pole Synchronous Converters differ from the old non-commutating-pole type only in the addition of commutating-field poles and windings between the main poles, as in the commutating-pole direct-current generator. The purpose of these additional poles and windings is to provide the proper commutating field at all loads with fixed brush position. In non-commutating-pole converters the necessary commutating field is obtained, although not so exactly, by shifting the brushes in the direction of rotation with increasing load until the armature coils, short circuited by the brushes, are in the proper position with respect to the main poles. The main field at any given point (or brush position) is approximately the same at all loads, but since the commutating field should vary in proportion to the load the brushes must be shifted more or less, with change in load, to secure the best commutating conditions. In the commutating-pole converter the varying commutating field is provided with a fixed brush position, by the commutating-pole winding connected in series with the armature and carrying load current.

With commutating-pole converters no convenient means for shifting the brushes is provided and **the brush position, when once correctly fixed, must never be changed.**

On all commutating-pole converters **the polarity of the series commutating-pole winding is the same as the polarity of the main pole ahead in the direction of rotation.**

Synchronous Booster Converters—This type of converter has practically superseded all other types for securing a greater variation in direct-current voltage than is practicable with reactance and variable field excitation in the ordinary form of converter, or with the old form of so-called split pole converter. In construction, the booster converter is the same as a standard converter to which a synchronous alternating-current generator or "booster" has been added. In general, on all of the larger size machines, the booster is of the revolving armature type. On these units, the booster is placed between the converter armature core and the collector rings. On the smaller size units, the booster is sometimes of the revolving field type, in which case it is located outside of the main bearing, with the armature leads carried to the collector ring connections.

The booster field poles are located so that a given booster field excitation produces equal "buck" and "boost" in the converter no-load voltage. Fig. 3 shows a cross-section of a synchronous booster converter and Fig. 4 shows the connections of the converter and booster armature windings.

By varying the excitation of the booster, its armature voltage may be added to, or subtracted from the line voltage and so change the direct-current voltage. This variation is usually done by hand, but may be done automatically. Synchronous booster converters are ordinarily built for Edison three-wire 250 or 270 volt service. The boosters used are ordinarily built to vary this direct-current voltage 30 volts above and below normal, which amounts to around 20 to 25 percent possible voltage variation. When the booster increases the direct-current voltage, it acts as a generator being driven by the converter; when the booster decreases the direct-current voltage, it acts as a motor, driving the converter as a direct-current generator.

In the commutating pole synchronous booster converter, it is necessary to provide both series and auxiliary windings on the commutating poles in order to provide the proper excitation under the varying conditions of output current and voltage. The series commutating field winding has a fixed polarity and provides

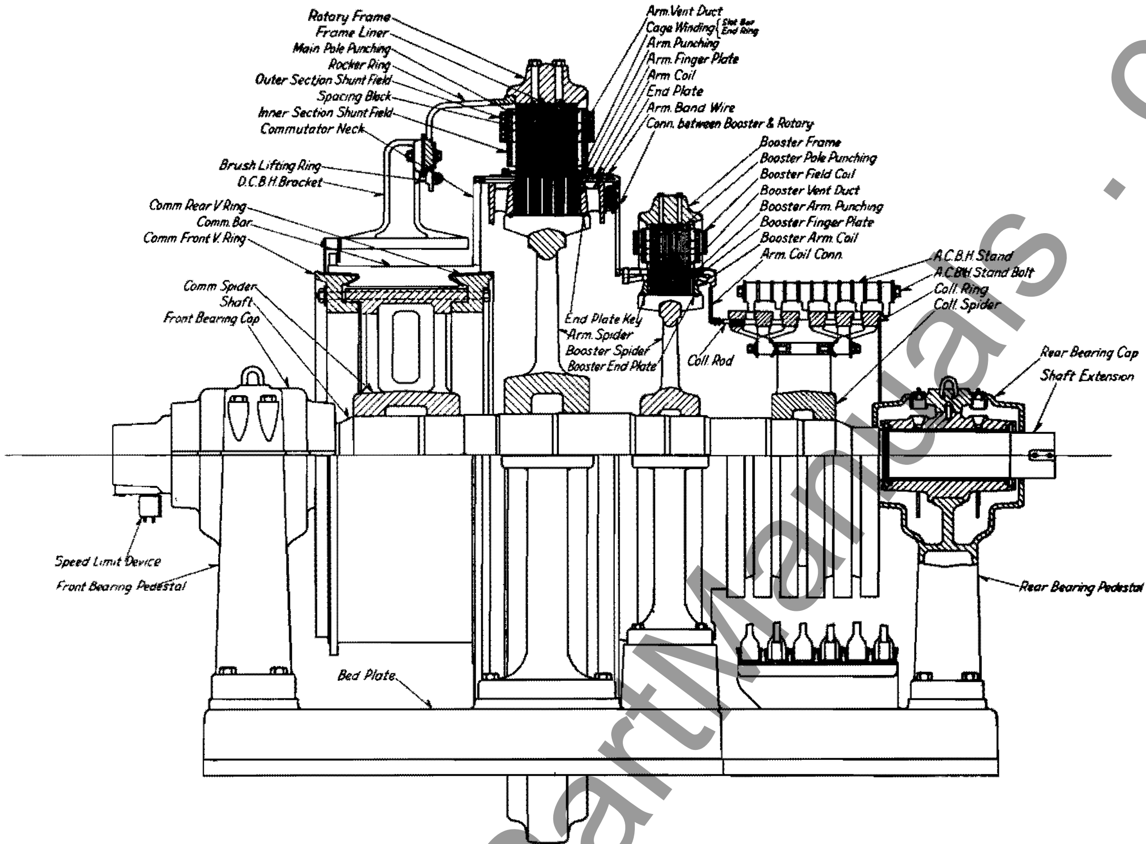


Fig. 3—Cross Section of a Synchronous Booster Converter

commutating pole excitation that is always proportional to the load current. The auxiliary commutating field winding is used to vary the commutating pole field strength to correspond with the variation in armature reaction that takes place in a booster converter when the voltage is being raised or lowered with the booster. Since this auxiliary excitation is proportional to the power generated by the booster in both amount and direction, the rheostats of the booster and the commutating pole auxiliary field windings are mechanically connected. The polarity of the auxiliary commutating pole field winding is so arranged that it assists the series commutating winding when the booster is "bucking", and opposes it when the booster is "boosting".

Automatic Controller or Auxiliary Commutating Pole Field—For any given required condition of "buck" or "boost" voltage on a booster converter, it is necessary to adjust the main converter field as well as the booster field so that the desired voltage conditions are obtained at 100% P.F. Once these adjustments are made a certain amount of commutating pole auxiliary field current is made available for excitation due to mechanical connection of the booster field and commutating pole auxiliary field rheostats. In order that this available excitation of the commutating pole auxiliary field may only flow in the winding in proportion to the load and voltage being taken from the machine, a controller, commonly termed torque motor, as shown in Fig. 5, is used. This torque motor is mounted on the converter bedplate and consists of a shunt wound direct-current motor direct-connected to the arm of a rheostat having a number of contacts. As will be seen from the diagram shown in Fig. 6, the armature element of the torque motor is connected across the line voltage while its field is across the main commutating pole series winding. As torque is a product of current and voltage, the torque motor always functions in direct ratio to the load and voltage on the converter, and thus proportions the available commutating pole auxiliary field current accordingly.

At neutral voltage (no "buck" or no "boost") the booster element is not required, so that the booster and commutating pole auxiliary field rheostats are in their neutral position where no current can flow in either field. As the torque motor is connected permanently in the circuit, torque is being obtained from the torque motor at all times when load is being taken from the converter, even though the converter is operating at neutral voltage. Under this condition the torque motor is idling, but no current is flowing through the commutating pole auxiliary field winding.

The present standard scheme of torque motor control is of the double acting type, the armature of the torque motor turning through an angle of 180° in either direction from the neutral point, and the torque developed by the motor being opposed by a helical spring. This scheme provides for commutation protection to the converter when line disturbances occur that frequently result in inverted operation on the converter.

Adjustment for Automatic Controller for Auxiliary Commutating Pole Field—Every torque motor is adjusted to a standard for both direct and inverted operation before being mounted on the converter. After being mounted on the converter, some final adjustments are usually found to be necessary, due to variations in the circuits. In addition to various taps being made available in the rheostat circuits, it will be seen from the diagram of connections shown in Fig. 6 that an adjustable resistance connected in series with the armature of the torque motor is provided for making these final adjustments in the torque motor itself. The combination of this device, with the commutating pole auxiliary field and booster field reversing rheostats, provides a rugged and positive automatic control that insures satisfactory commutation under all conditions of load and voltage, within the range of the booster.

Care of Torque Motor—One of the essentials to continued creditable operation from any piece of apparatus is its proper maintenance. While our scheme of commutating pole auxiliary field control is both rugged and positive, it cannot be expected to function properly unless given proper maintenance. This maintenance in addition to regular blowing out with compressed air, consists in keeping the contacts of the torque motor rheostat faceplate clean at all times as well as maintaining a proper pressure and brush fit between the contact arm and the faceplate buttons. Note should also frequently be made as to whether the proper amount of torque is being obtained for given load and voltage conditions. For full load and normal voltage, the position of the torque motor arm should be within four or five buttons from the top. This position allows sufficient leeway for the additional torque that will be obtained when the voltage may be increased to full boost.

One-Way Type of Torque Motor Control—Our older scheme of torque motor control, and which is still used occasionally on some of the smaller ratings of booster converters, is shown in Fig. 7. This scheme is essentially the same as our present standard except that the torque motor operates only in one direction. This scheme obviously does not provide for inverted operation protection on the converter, and the commutating pole auxiliary fields are accordingly connected across full line voltage, instead of across half voltage as is necessary on our improved two-way scheme.

Installation

The following instructions apply to all types of synchronous converters except when they are specifically limited to a single type by the context.

General Precautions—Upon receipt of the cases containing the machine or its parts, place them in a dry and sheltered position.

Leave cases unopened and undisturbed until everything is ready for assembling.

It is possible to do more damage by rough handling or careless use of bars or hooks to a machine before or during erection than it would receive in years of regular service. Bear in mind that the armature is liable to damage since its own weight is sufficient to crush the winding, if it is lowered on or swung against a projection.

Care must be exercised in handling and installing synchronous converters.

As moisture is an enemy of the insulation, a converter should not be allowed to stand where it can absorb moisture from the air or any other source.

A blow of any sort upon any part of the winding, or intrusion in the machine of water, pieces of wire, tools, nuts or foreign substances of any kind, by accident or otherwise, may cause a breakdown or burn out, and should be avoided.

It is desirable that all synchronous converters be assembled, installed and placed in operation under the supervision of an experienced engineer. No printed instruction, however complete, can take the place of actual experience.

Unpacking—When a synchronous converter is shipped entirely assembled, all boxing or crating should be removed and the machine is then ready for setting up and drying out. In cool weather, the packing and wrapping should not be removed until the apparatus has been long enough in the room where it is to be installed to come up to the temperature of the air.

If this precaution is neglected the apparatus will sweat and sufficient moisture may condense upon the windings to weaken the insulation, and cause a breakdown.

When a converter is unpacked it should be carefully examined to determine whether any damage was received in transit and if all parts and accessories are present in proper condition and position.

Location of Machines—It is of the greatest importance in laying out a power house or substation that the location of the converters be governed largely by the following considerations:

(1) The machines should not be exposed to moisture from leaky pipes, escaping steam or condensation of atmospheric moisture on overhead glass or a metal roof.

(2) They should not be exposed to the corrosive action of acid fumes or other injurious gases.

(3) They should not be exposed to dirt from coal handling or similar causes.

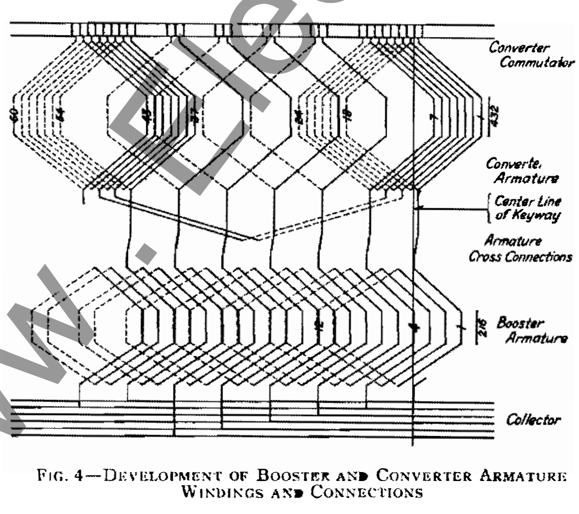


Fig. 4—Development of Booster and Converter Armature Windings and Connections

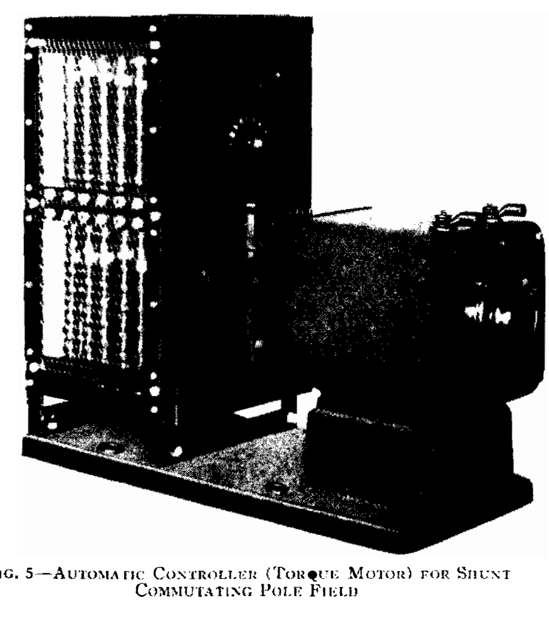


Fig. 5—Automatic Controller (Torque Motor) for Shunt Commutating Pole Field

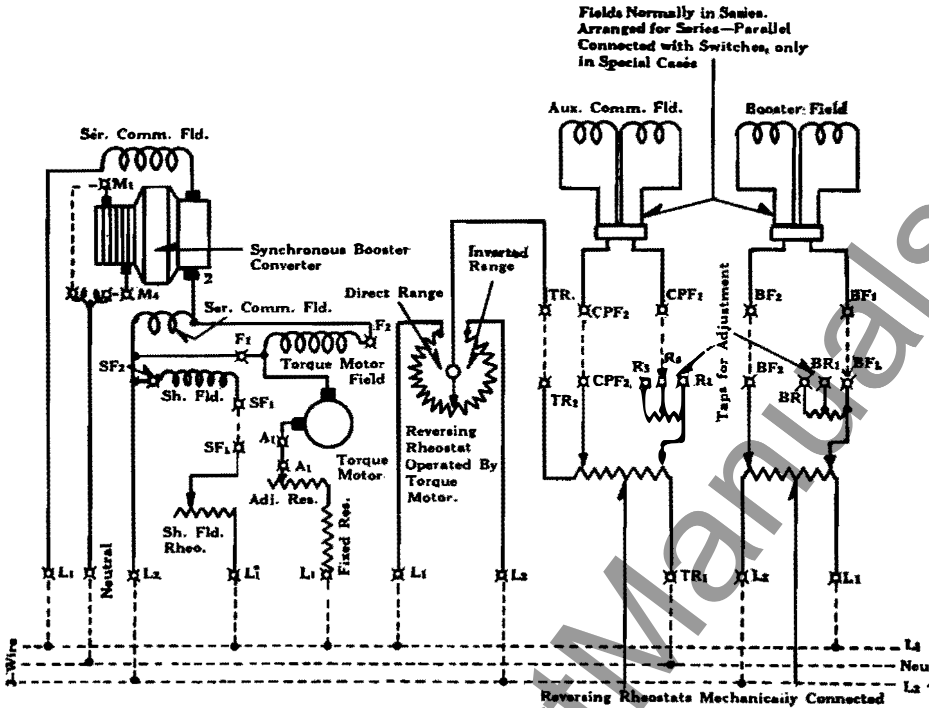


FIG. 6—WIRING DIAGRAM OF STANDARD BOOSTER CONVERTER

Solid lines indicate connections completed within the apparatus. Dotted lines indicate connections to be furnished apart from apparatus.
Note:—Polarity of commutating pole auxiliary field to be same as that of commutating pole series field when booster is lowering D-C. voltage.

(4) Since the total temperature, and consequently the capacity of the machine, depends upon the temperature of the surrounding air, it is evident that the location should be in a room as cool and well ventilated as is consistent with proper protection from dirt and moisture.

(5) The position of the converter should always be such that the commutator and collector rings, which require special attention, are readily accessible for inspection.

(6) The location of machines over a well ventilated pit is essential from the standpoint of accessibility, as well as the benefit obtained from longer life that obviously accompanies a cool operating machine.

Foundations—Wherever possible, solid masonry or concrete piers should be used so as to prevent vibration and minimize the wear on the bearings and brushes.

Be sure that the foundation is carried down to a solid bottom, or is made of sufficient area to prevent sinking or displacement under the load it is expected to support.

A competent engineer who is familiar with local conditions should lay out this part of the work.

Care should be taken that all pits in the concrete are properly drained and ventilated and that passages remaining for piping and wiring are easily accessible and so laid out that the work of installing and connecting up will be simplified in every possible way.

Foundations for sole-plate machines must be of greater strength than foundations for the corresponding self-contained unit.

Erection of Bedplate Type Units—

(1) Set the bedplate on its foundation and level it by wedging. All large converters require foundation bolts, and foundation bolt holes are provided in the bedplate.

In grouting in the bedplate, care should be taken to see that the bedplate or foundation bolts do not come in contact with the structural steel of the building construction.

In cementing the bedplate to the foundation use a mixture of one part of Portland cement and two parts of sand, or half cement and half sand; either will give good results. First mix the cement and sand dry, then add water until a very thin solution is obtained. Construct a dam around the bedplate and pour this solution under it, continuing the process until the cement is flush with the top of the bedplate. "See Power Eng. data letter #13 for reference". The entire operation of mixing and pouring the cement should be carried on without interruption and as rapidly as possible until completed, otherwise the cement first poured under the bedplate may partially set and prevent that poured later from flowing freely to all parts. When the cement has hardened sufficiently, remove the surplus from the outside and smooth up the joint under the bedplate.

(2) Place the lower half of the frame and the bearing pedestals in position on the bedplate. (In the smaller machines the bedplate, frame and pedestals can be handled as a unit.)

(3) Remove the protective coating from the shaft, wipe the journals clean and dry and cover them with a film of oil; see that the bearings are thoroughly cleansed of grit or dust and cover them with a film of oil; lower the rotating part into the bearings, see that the oil rings are in position, put on the upper half bearing and see that all rings are free to move. Fill the bearings with oil to the proper level, put on the bearing caps and screw down the bolts. Do not tighten the bolts until after the armature has been turned over and the operation of the bearings found Satisfactory.

For 3-Wire Machines Series Commutating Field is split as shown. For 2-Wire Machines it may be split or it may all be on Negative side of Armature.

Solid Lines indicate connections completed within the Apparatus. Dotted Lines indicate connections to be furnished apart from Apparatus.

Note:—Polarity of Commutating Pole Auxiliary Field to be same as that of Commutating Pole Series Field when booster is lowering D-C. Voltage. ⌑Indicates Terminals on Apparatus to which Connections from outside points are brought.

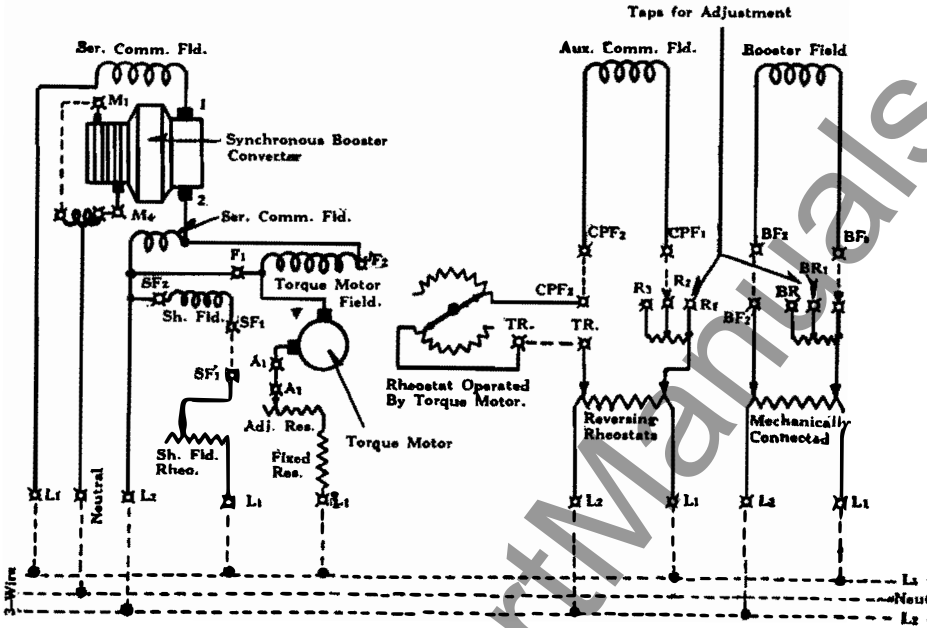


FIG. 7—WIRING DIAGRAM OF SUPERSEDED TYPE BOOSTER CONVERTER CONTROL

When handling the armature always support it by means of rope slings about the shaft, taking care that these do not come in contact with the end connections of the windings or mar that portion of the shaft which normally rests in the bearings. Any roughness at this point would cut the babbitt of the bearings and cause undue heating when the machine is in operation.

Never under any conditions support the weight of the armature from the commutator or collector rings, either by ropes or blocking. In putting the armature into position, be careful not to scratch the bearings or bend the oil rings.

(4) Clean the contact surfaces of the frame and set the upper half of the frame in position and secure it to the lower half by means of bolts and feather keys.

(5) Place the two halves of the direct-current brushholder rocker ring in position. The individual brushholder arms are shipped bolted to the rocker ring, and the individual brushholders are shipped bolted to the arms. **It is not necessary to disassemble these parts** and if they are taken apart the difficulty of obtaining proper brush position is greatly increased.

(6) Connect up the field and alternating-current and direct-current armature leads. Insert the brushes in their holders, grinding them in with sandpaper to as nearly a fullfaced fit as possible before putting any load on the machine. See Fig. 10 and accompanying text regarding method of grinding in brushes. See that the brushes move freely in the holders and are held under an equal and moderate pressure. Connect the machine to the switchboard including the connections of the overspeed device to the direct-current circuit-breaker.

(7) Adjustment of the air gap—In setting up any machine, great care must be exercised to obtain a uniform air gap between the armature core and all pole faces. An inequality in the main pole air gap will cause unbalance in the rotor and heating of the bearings. An inequality in any of the air gaps,—main commutating, or booster,—will adversely affect the commutation.

Erection of Sole-Plate Type Units—The erection of sole-plate type converters differ from the erection of the corresponding self-contained units in the following respects:

(1) The sole-plates should be set in position on the foundations as determined by the foundation bolts. The foundation bolts must be accurately spaced. The approved method of location being to construct a light wood template or frame with the bolt holes carefully bored to dimensions given on the blue print of the converter outline drawing. It is advisable to have these bolts surrounded by iron pipes of proper length and with inside diameter somewhat larger than bolts set in the foundation, with openings in the masonry to allow access to the nuts at their lower ends in case renewals become necessary. The slight flexibility of position permitted by this pipe construction is often of great convenience in the final lining up of the sole-plate.

(2) After levelling, the sole-plates should be finally cemented to the foundation.

(3) After placing the lower half of the frame and rocker ring, the pedestal bearings and armature in position, locate the frame.

(4) Adjustment of the air gap—Adjust the air-gap horizontally by shifting the frame, and vertically by means of the raising screws provided in the frame foot. When the proper adjustment is obtained, insert thin sheet-steel liners of the necessary total thickness between the frame feet and sole-plates. During this operation gauge the gap at different points on

the front and back of the machine by inserting a small metal or wooden wedge in the air-gap and noting the distance to which this wedge enters.

Drying Out Insulation—If the armature or field coils have been exposed to low temperatures during shipment or storage, they should be allowed to come up gradually to room temperature before they are unpacked. If the windings have become damp either in this manner or through exposure to snow or rain, they must be dried out by any of the following methods:

(1) Block the rotor so that it cannot turn, raise the direct-current brushes, short-circuit the shunt field and apply approximately 10 percent of the normal alternating-current voltage to the collector rings. The standard Westinghouse transformers are usually provided with taps, from between which a suitable low voltage may be obtained.

(2) Drive the converter from some external source, such as a separately belted motor, after raising the collector brushes and short circuiting the armature on the direct-current side, using a very weak field excitation. If the converter is shunt wound, low-voltage separate excitation must be employed; if compound wound the armature may be short circuited through the series field coils.

Synchronous converters are very sensitive when operated as series machines and there is danger of generating an excessive current. Consequently this method should be undertaken only by experienced operators.

(3) The field coils may be dried by applying from some separate source of excitation approximately two-thirds of the normal direct-current voltage.

There is always danger of serious injury to the windings when drying out with current since the heat generated in the inner parts is not readily dissipated; furthermore, coils containing moisture are much more susceptible to injury from overheating than when thoroughly dry. The temperature of all accessible parts should be carefully observed during the drying out process and never allowed to exceed 80 degrees Centigrade, total temperature. Several hours or even days may be required for thoroughly drying out large machines.

Insulation Test—It sometimes happens that the insulation of a machine is mechanically injured or exposed to moisture after the test at the Works, but previous to erection. For this reason, insulation tests should be made before the machine is run with load.

The higher the resistance, the better the general condition of the insulating material. The insulating resistance of the field will be much higher in proportion to the e.m.f. of the exciting current than that of the armature and will usually give little or no trouble. Since large armatures have much greater areas of insulation, their insulation resistance will be proportionately lower than that of small machines. Even though the material is in exactly the same condition, the insulation resistance of any machine will be much lower when hot than when cool, especially when the machine is rapidly heated. The only feasible way of increasing the insulation resistance when the machine is complete is by "drying out".

In case a "megger" is not available, insulation resistance measurements may be easily made using a 500-volt direct-current circuit and a 500-volt direct-current voltmeter. The method of measurement is first to read the voltage of the line, then to connect the resistance to be measured in series with the voltmeter and take a second reading.

The measured resistance is then calculated by using the following formula:

$$R = \frac{r\,(V - v)}{v\,(1{,}000{,}000)} \text{ in which}$$

V = voltage of the line.
v = voltage reading with insulation in series with voltmeter.
r = resistance of voltmeter in ohms (generally marked on label inside the instrument cover).
R = resistance of insulation in megohms (1 million ohms).

The method of connecting the apparatus is shown in the diagram Fig. 8.

If a grounded circuit is used in making this measurement, care must be taken to connect the grounded side of the line to the frame of the machine to be measured, and the voltmeter between the windings and the other side of the circuit.

Voltmeters having a resistance of one megohm are now made for this purpose so that, if one of these instruments is used, the calculation is somewhat simplified since $r = 1$ and the above formula becomes

$$R = \frac{V}{v} - 1$$

A safe general rule is that insulation resistance should be approximately 1 megohm for each 10,000 volts applied in testing.

No new machine should have an insulation resistance of less than 1 megohm.

Insulation resistance of machines in service should be checked periodically to determine possible deterioration of the windings.

Breakdown Test—A high voltage or breakdown test is useful in determining the strength of the insulation of the machine. It is made by subjecting the insulation to an e.m.f. greater than it will have to stand in actual service. As this test is in the nature of an overstrain, it must be applied with great caution. Such tests are always made in the factory in line with standard A.I.E.E. ruling. In making such tests, it is well to remember that the insulation is more easily broken down when hot than when cold and that the tests should not be made immediately after the machine is started the first time but after it has run hot for some hours and has a chance to dry out. Tests of this character should not be made when the insulation resistance is low.

Large machines, when tested at high voltage, require a considerable output from the testing transformer, as a heavy charging current may be taken by the machine. The transformer capacity required for testing, varies with the square of the voltage of the test, with the frequency of the circuit, and with the static capacity of the apparatus under test.

A 5-kilowatt transformer has in general sufficient output for testing machines up to 4000 kilowatts at a testing e.m.f. of 6000 volts.

A diagram of connections of the transformer wiring is furnished by the Works in each case and this diagram should be at hand when the transformers are being installed.

The wiring diagram for any particular installation should be obtained from the manufacturer of the switchboard.

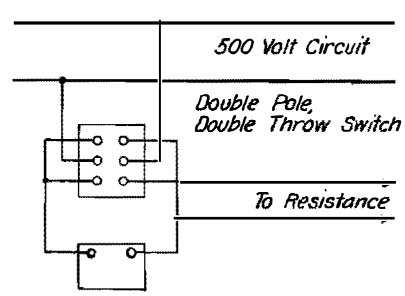


FIG. 8—CONNECTIONS FOR MEASURING INSULATION RESISTANCE

Exceptional precautions must be taken in running wires for high-tension service. As far as possible, all circuits should be out of normal reach and so placed as to minimize any danger from mechanical injury or from contact with other electrical circuits.

All wiring should be exposed and rigidly supported on suitable insulators. Lead covered cables for high potential are to be avoided unless absolutely necessary. When they are used additional precautions must be taken to insure proper insulation.

In laying out the low tension alternating-current wiring and particularly in large 60-cycle installations, care should be taken that the leads of different phases of the converter have the same reactive drop. Differences in reactive drop may be caused by differences in length of cables or in adjacent steel structures, and may cause current unbalance particularly in three-wire converters. Alternating-current leads must not loop parts of the frame as currents will be induced in the frame and starting difficulties are likely to be experienced.

Phase Rotation—In order that the wiring connections between a converter and its supply circuit may be correctly made to obtain a given direction of rotation, it is necessary to know the phase rotation of the converter and the supply circuit. By "phase rotation of the converter" is meant the order in which each ring reaches its maximum voltage of one polarity.

All Westinghouse converters are arranged for clockwise rotation facing the commutator end. With this direction of rotation, the phase rotation is from the outer ring towards the armature core. The sequence of phase rotation is indicated by the inside ring always being M6 on 6 phase converters.

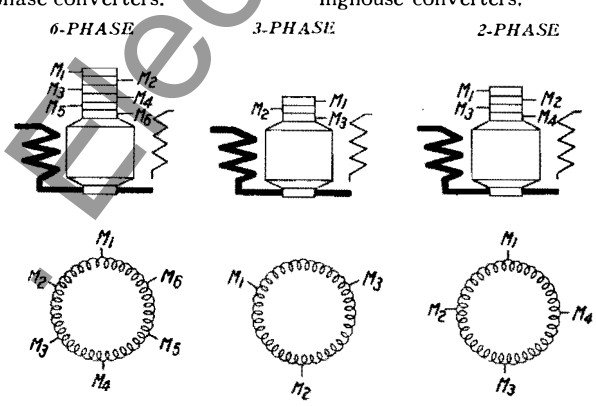
Fig. 9 illustrates the standard nomenclature of the terminals for 2, and 63-phase converters.

The sequence of phase rotation of the supply system can be found by tracing the wiring back to the generating station or else by the use of a phase rotation indicator.

With the sequence of phase rotation of the supply system **known** and indicated by a, b, c, and a corresponding indication on the high tension terminals of the transformer, the sequence of phase rotation will then be indicated on low tension terminals by M1, M2, M3, etc. Therefore, to obtain clockwise rotation on the converter, the connections between the line and transformer and between the transformer and converter should always be made by joining together leads of the same letter. The mechanical arrangement of the leads is no indication whatever of the rotation, this being determined entirely by the letters.

When starting for first time if the armature revolves in the wrong direction, shut down by tripping the oil circuit-breaker and pulling the disconnecting switch and change the alternating-current cable connection. If the converter is two-phase, interchange the two leads of either one of the phases; if it is three-phase interchange any two leads; if six-phase interchange two pairs of leads on the low tension or any two leads on the high tension side of Power Transformer and proceed as before.

Equalizer Leads—In compound-wound converters operated in parallel on the direct-current side, an equalizer lead is required as in compound-wound direct-current generators. With grounded railway circuits, it is desirable to have the equalizer connection made on the negative side of the converter. This is the standard arrangement in Westinghouse converters.



Six Phase Diametrical Connection
M1-M4 First diametrical phase
M2-M5 Second diametrical phase
M3-M6 Third diametrical phase
Six Phase Double Delta Connections
M1-M3-M5 First Delta
M2-M4-M6 Second Delta

M1-M3 First Phase
M2-M4 Second Phase

Fig. 9—Connections Between Winding and Collector Rings for Standard Synchronous Converter.

The relation of the equalizer lead to the other wiring is shown in Fig. 31 for two converters. Note that the equalizer is always connected between the series field and commutating pole field.

The equalizer lead should have small resistance. It is the usual practice to make the equalizer leads one-half the size of the main leads. In installations where long equalizer leads are necessary, a larger equalizer may be advisable in order to maintain a sufficiently low resistance.

It should be remembered that in compound-wound converters the direct-current voltage is determined by many factors that are not present in direct-current generators. (See subsequent text for a discussion of these various factors.) On account of this the series field excitation, as controlled by the equalizer, does not directly nor greatly affect the converter voltage and load.

Series Shunt—A series shunt consists of a low resistance connection across the terminals of the series field, by means of which the compounding effect of the series winding may be regulated by shunting more or less of the armature current past the series coils. It may be in the form of grids, on large machines, or of ribbon resistors on smaller machines. In the latter case it is usually insulated and folded so as to take up but a small amount of space.

Series shunts are usually furnished with all large machines. Provision is made in the wiring of all converters for the convenient addition of a shunt if operating conditions show it to be necessary. When converters are operated in parallel on the d-c. side a shunt across the series field of one machine acts as a shunt across all series fields in parallel.

Main Direct-Current Leads—If the converters are of the same ratings special attention should be made to see that all the cables which lead from the various machines to the bus-bars are of equal resistance. This means that **if the machines are at different distances from the switchboard, different sizes of cable should be used, or resistance inserted in the low resistance leads.**

If the converters differ in design or size, the difference in potential or drop in voltage between the terminals of the machine and the bus-bars to which they are connected should be exactly the same for every converter when each is carrying its proper share of the load. To secure the best results, the total drop between converter terminals and switchboard must not only be the same as equal loads, but the drop in corresponding sections of the connecting cables of the different machines should also be equal; i.e., the drop in the positive lead from any one converter at full load should equal the drop in each of the other positive leads when carrying full load. The same condition should be secured in the negative leads, in the equalizer connections and in the series field windings. It may be necessary in achieving the desired results to alter the length or size of connecting cables, and occasionally additional resistance is required.

Connections for Parallel Operation—

In wiring up converters to be operated in parallel on the direct-current side the following precaution should be observed:

(1) Connect the alternating-current leads to the same value of transformer taps and run the leads from the transformers to corresponding switches and converter terminals as per transformer diagram.

(2) Place the direct-current brushholder arms of the several units on the neutral position, and run the positive, negative and equalizer leads through their respective switches to the positive, negative and equalizer bus-bars of the other converters.

(3) See that the field wires are brought out to the corresponding terminals of the other converters and connected in the same way.

(4) Be sure that the voltmeter lead from the positive terminals goes to the positive voltmeter bus, and the negative to the negative bus.

(5) In case of doubt as to the relation of the phase of the machine and the buses the machine should be "phased out" as described in subsequent text under "phasing out".

Direct-Current Brush Position and Brush Arm Spacing—In **non-commutating pole machines** the correct running position of the brushes is "ahead" of the no load neutral and is found by trial. In **commutating pole machines** the brush position is fixed and the correct adjustment is determined at the Works before shipment.

The relative positions of the ring, which carries the brushholder arms, and the field frame are indicated by a dowel pin. With the dowel pin in place, the rocker ring can be placed only in the correct position.

The brushholder arms are correctly spaced and adjusted, before the machine leaves the Works. This insures the correct brush spacing. The arms, however, may become displaced, due to subsequent disassembly or rough handling, during shipment. In consequence, spacing should be checked to be sure that variations of more than $\frac{1}{32}$'' do not exist between arms, and care taken to see that the arms are parallel to the commutator bars before the machine is put in service. All brushholders should be aligned on the arms, with a clearance between the surface of the commutator and the bottom of the holder of not less than $\frac{1}{16}$'' nor more than $\frac{1}{8}$''.

Location of Neutral Point—The no-load "neutral" point on the commutator is that point at which a minimum voltage is induced between bars when the machine is running without load with only the main pole windings excited.

On the present fabricated type of units, the mechanical method for checking the factory neutral position is as follows:

With a convenient constant radius, using the two countersunk holes in the front edge of the frame as centers, scribe two arcs to intersect on the commutator surface between the ends of the bars and the first brush, so that the point of intersection is visible when the brush arm is in place.

If the axial center line of a brush contact surface be made to coincide with the point of arc intersection, the brush will be in the factory neutral position. The position of one brush arm is thus established and the other brush arms can be spaced with reference to it.

In case it is necessary to check the location of the neutral point one of the following methods should be followed:

On non-commutating pole machines the "neutral" should be found while running the machine as a shunt motor from the direct-current end or by driving the machine by some external power with the shunt field winding excited. Use a low reading voltmeter with .5—1.5 and 15 volts scales preferably. Use two-pointed leads for the meter. Hold the points one commutator bar width apart on the commutator and move them along until the point of minimum voltage is located. This method is not the most accurate, but is usually satisfactory for non-commutating-pole machines.

For commutating-pole-machines there are two methods, either of which, if properly used, is sufficiently accurate.

First—The "Kick Neutral"—This method is based on the fact that when the field circuit of any direct-current machine is opened, an induced voltage is generated in the armature windings. In case the brushes are in the exact neutral position the resultant voltage so generated is zero.

Raise all direct-current brushes. Arrange to separately excite the shunt field from any convenient source of power with a quick-break switch in the circuit. If line voltage is used, a resistance or lamp bank should be used in series with the field circuit to give a small current in the field. A low reading voltmeter should be used for measuring deflections.

Determine the proper commutator bar pitch for the machine. If, for instance, the machine has 36 bars per pole, the throw for a multiple wound armature will be bar 1 to bar 37.

Hold the voltmeter leads on bars 1 and 37, in the neutral zone, and then open and close the field switch and note deflection on the meter.

The deflection, if any, will be only a momentary kick. If deflection takes place it indicates that the bars being registered are not in the neutral position.

Assume for example, that holding the voltmeter terminals on bars 1 and 37 that a deflection of 10 volts to the **left** is registered by voltmeter needle when the quick break switch is closed. The switch should be left closed now until needle settles back to 0. The switch should then be opened and a deflection of 10 volts to the **right** will be obtained, as the induced voltage is in opposite directions when opening and closing the field circuit.

Next move the voltmeter terminals to bars 2 and 38. Suppose now when the field switch is closed a deflection of 10 volts to the **right** is obtained, and after allowing needle to come to rest, and switch if opened, a deflection of 10 volts to the **left** is obtained. This indicates that the correct no load neutral in this case is exactly on the mica between the two pairs of bars tried. The rocker arm should therefore be shifted until the **centre of the direct-current brushes is exactly over this neutral mica position.**

When equal readings cannot be obtained by moving voltmeter leads ahead, or back, on any two pairs of commutator bars, it is necessary to turn the armature slightly until such a condition is obtained.

Second—"Running Neutral"— This method is based on the fact that if the brushes are in the correct no load neutral position no active electromotive force will be generated by the commutating-pole flux when the machine is mechanically driven on open circuit with the commutating windings separately excited.

Beveled brushes should be inserted, one in each arm, and so beveled that the faces of these brushes will be wide enough to bridge one mica segment. The face of the brush must be ground in for good commutator contact and must not be wide enough to make contact with more than two commutator bars with any commutator position. A reversing switch should be connected in the separately excited shunt field circuit and some arrangement made for separately exciting the commutating-pole winding at from two to four percent of its normal current. The commutating-pole circuit should be disconnected from the armature and the armature left open-circuited. Use a low reading voltmeter such as was suggested for the "kick neutral" across arms of opposite polarity. Bring the machine up to approximately normal speed and by exciting the main field, for an instant only, in a direction contrary to normal, demagnetize it entirely, that is, until no deflection shows on the lowest scale of the voltmeter. Any deflection then obtained by exciting the commutating-poles will be due to the commutating-pole flux alone. First excite the commutating-pole windings with about two percent of their normal current and shift the brushes until no deflection is obtained on the lowest scale of the voltmeter. Check the residual magnetism of the main poles from time to time keeping it at as low a value as possible by demagnetization as explained above. After determining the best location for the brushes at this excitation, raise the commutating-pole current to about 4 percent of normal and check results. If no difference is found reverse the current in the commutating-pole and try again, still checking the residual from time to time. In some cases higher currents may be used, but the leakage flux soon becomes large enough to destroy the symmetry of the normal field form and indefinite results will be obtained.

Fig. 10—Grinding Brushes

This method, if used carefully, gives very accurate results. It may be noted that the position of the brushes is at the peak of the commutating-pole field form and as this peak is rather sharp the effect of displacement will be very marked. Since the machine is running, errors due to brush resistance or to a brush resting on mica only, are entirely eliminated, making this method preferable to the "kick method".

Adjustment of Direct-Current Brushes and Brushholders—The direct-current brushes used in synchronous converters are of the graphitic type. This grade of brush is practically free from carbon or hard, gritty material. Among its important characteristics are,—high current carrying capacity, high lubricating quality, low friction coefficient and consequently low friction losses, and low resistance drop.

The absence of abrasive qualities makes this type of brush unsuited for non-undercut commutators, where the mica must be worn down by the brush. The low resistance drop also makes it in some cases unsuited for non-commutating-pole machines which inherently have relatively high voltages induced in the armature coils undergoing commutation, producing large currents in the low resistance brush face.

The following points must be adhered to:—

1. **Location**—The relative spacing of brush arms around the commutator, as determined by the edges of the brushes, must be uniform. The preferable method of checking this point is to stretch a piece of paper tape around the commutator, under the brushes, allowing the ends to over-lap to some extent. Care must be taken that it is smooth and parallel with the edge of the commutator at all points. Make a fine clear mark with a sharp pencil on the tape, exactly at the toe of the brush on each arm resting on the tape. Some marks of identification should also be made, so that after removing the tape from the machine the arms corresponding to the marks may be readily identified. Remove the tape and measure the space between the marks, adjusting the arms until approximately equal spacing results. The difference in spacing should not be more than $\frac{1}{32}$″. Obviously, the brushes must be ground in as indicated in the following paragraph before being spaced.

2. **Grinding in Brushes**—The ends of the carbon brushes should be carefully fitted to the curvature of the commutator. This can be done by putting the brushes in the brushholders and drawing a long strip of sandpaper under each brush while pressing it firmly against the commutator as shown in **Fig. 10**. The sandpaper should cut the brush only on the forward stroke and in the direction of normal rotation. Copper-plated brushes should have the copper plating removed from the brush for a distance of not less than $\frac{1}{4}$″ from commutator in order to prevent the copper sheath from scratching the commutator.

3. **Spring Tension**—The brushholder springs should be adjusted to a uniform tension of from 2 to $2\frac{1}{2}$ pounds per square inch of cross-sectional area of the brush.

Adjustment of D-C. Flash Barriers—The d-c. flash barriers (where used) should be maintained at $\frac{1}{32}$″ from commutator face.

Adjustment of Brush Lifting Device—The brush lifting device is supplied with all commutating-pole synchronous converters which are self-starting from the alternating-current side.

The lifting clip is omitted on one brush on two arms of each polarity, so that these four brushes will remain on the commutator to supply exciting current and to indicate polarity. To avoid sparking these brushes should be kept beveled to $\frac{1}{8}$-inch face. **Under no condition must these brushes be raised from the commutator during starting, as such action might cause insulation failure of the windings.**

When starting from the alternating-current side, the direct-current brushes are to be raised before the starting switch is closed. **The brushes are to be lowered only after the converter is running in synchronism on full voltage.**

When two halves of the rocker ring with the assembled brushholders are in position, see that the dowel locating the commutating position is in place; tighten the rocker ring clamping washers, and test the brush lifting mechanism to see that it has not shifted during shipment or assembly.

For details of brush lifting assembly see Fig. 13.

The lifting clips, as may be seen from the cut, **Fig. 11**, are supplied by the brush manufacturer as an integral part of the brush. The rock-shaft, lifting rod and other parts as shown in Figs. 12 and 13 are shipped assembled on the brushholder brackets and are properly adjusted before the apparatus leaves the factory.

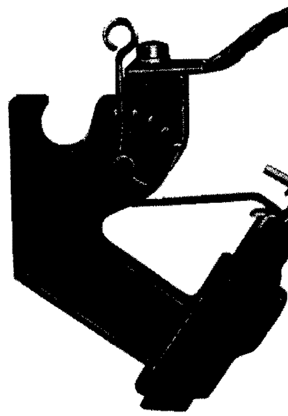


FIG. 11—D-C. BRUSHHOLDER WITH BRUSH AND LIFTING CLIP

Motor-Operated Lifting Device—On remote or automatically controlled converters, the brushes are lifted by motor operated mechanisms. On the larger units, a motor-operated lifting mechanism is recommended to facilitate ease in lifting the brushes in the shortest possible time. These devices are mounted on the bedplate of the converter as close as possible to the direct-current brush rig. See Fig. 1 for arrangement on a railway unit and Fig. 2 for lighting type.

Adjustment of Alternating-Current Brushholder and Brushes—All synchronous converters are now supplied with the block type of brush on the Alternating-current side. The larger size units are equipped with metal graphitic brushes while the smaller size units use electrographitic brushes. The metal graphite brushes are made from finely powdered metal (mainly copper) and graphite, assembled under high pressure. They have very low electrical resistance, which is varied in different grades of brushes, by the quantity of graphite used. The following points must be adhered to:

1—Brushholder Setting—The alternating-current brushholders (See Fig. 15) should be located so that the bottom of the box is never more than 1/8" away from the rings. All holders are adjustable so that follow-up of the holders can be made as the rings wear and become smaller in diameter.

2—Location—Brushes should be so located that the rings are entirely covered by the brush, and so that no part of the brush will overhang the surface of the ring at anytime. This overhang causes a lip to form on the unused portion of the brush and causes rapid brush wear. It may also result in the lip breaking off and causing a short circuit between collector rings.

3—Grinding in Brushes—Metal-graphite brushes are much harder than carbon or graphite brushes. They are machined as nearly as possible to fit the collector ring and then ground in place in the holder by passing sandpaper between brush and ring in the direction of rotation only. When the brushes have been fitted as accurately as possible the machine should be run with less than full load until the brushes are worn down to a good surface. It is advantageous to use more than normal tension, during the wearing-in process.

4—Spring Tension—Metal-graphite brushes should have enough pressure to keep them in good contact with the ring. Under ordinary conditions 2½ to 3 pounds per square inch depending on ring speed will be ample to give good contact. With a 1½ x 1½ inch brush this is equal to a total pressure of 5 to 7 pounds per brush.

Note—For Further Detailed Instructions as to Care and Selection of Brushes on Power Station Apparatus see Instruction Book 5187.

Adjustment of Commutating-Pole Field—The commutating-pole adjustment to give the best commutating conditions is made at the Works and, in general, no reason for changing it after the converter is installed will arise. However, if such reason should arise the proper change in excitation may be determined as follows:

(1) With a low reading voltmeter read the voltage between the brushholder bracket and the commutator at four equi-distant points across the width of the brush (along the circumference of the commutator) when the machine is running at normal load and voltage. These voltages can be most conveniently read by inserting a hardwood or fibre block in an end brushholder having four radial holes correctly spaced in which the voltmeter "point" can be inserted. This is shown in Fig. 14.

Readings should be taken from positions 1 to 4 in the direction of rotation. Take curves under both positive and negative brushes for several brush arms. See Fig. 16.

(2) Changes in commutating-pole strength to secure correct compensation can be made by changing the air gap or by shunting part of the current from the commutating-pole winding. Adjustment by changing the air gap is the more usual method. **In case of over compensation the air gap should be increased and in case of under compensation the air gap should be decreased.**

The measurement of brush curves and the adjustment of the commutating-pole strength should only be undertaken under the supervision of an experienced engineer.

The Speed-Limit Device—As a safeguard against overspeeds, a speed-limit device is attached to one end of the shaft, consisting of a spring closed switch. When the converter reaches a certain speed above normal, a centrifugal governor mechanism operates the switch and opens the circuit-breakers, thus cutting off the converter from its source of supply. A circuit opening switch is regularly supplied with Westinghouse speed-limit devices but a circuit closing switch can be supplied when desired.

To Reset the Switch—It is merely necessary to move the switch arm back to the normal position by hand. This can readily be done at any time whether the machine is running or not and without opening the switch box.

Assembly of Speed-Limit Device—All speed-limit devices are set and tested at the Works. The switch box complete is shipped attached to the pedestal. Bolt up parts in place, fasten the trip case to the shaft, next push in the switch arm; there should be at least 1/8 inch between the switch arm and the trip-case, Fig. 17.

Adjustment of Speed-Limit Device—All standard converters are provided with a test pulley extension on the colector end. When testing for overspeed the synchronous converter can be run

FIG. 12—D-C. BRUSHHOLDERS WITH LIFTING DEVICE AND FLASH GUARDS

as a motor from the direct-current side, or can be belted to a motor on the pulley end. It is important to have complete control of the speed during the test. Use a tachometer or any reliable direct-reading speed indicator, but do not use the ordinary revolving dial indicator.

Then test for overspeed; the switch should trip at about 15 percent above synchronous speed. Bring the speed up slowly and watch for the tripping speed of governor trip lever.

Should it be found necessary to reset the governor proceed as follows:

First determine the tripping speed, and set the governor and switch as shown in Fig. 17. Screw in the adjusting screw even with the governor case, and give the screw about one-half turn inward at each run until it trips at the overspeed. Then tighten the small locking screw on the side of the trip case.

Before starting each test see that the switch arm is in and pull the trip lever several times by hand to see that it works freely.

Inspection—Speed limit devices should be tested and lubricated at regular intervals as a part of the routine inspection to insure that all parts are operative and all circuits complete. **Failure to maintain properly the overspeed device and wiring may result in the loss of a machine.**

Protective Devices

General—In general the satisfactory operation of a synchronous converter depends, to a great extent, upon its proper application and the effectiveness of the indicating and protective devices with which it is provided.

Application—The synchronous converter possesses certain fundamental advantages in efficiency, first cost, weight and space requirements which have led to its almost universal adaption in the conversion of power for most types of railway, industrial and Edison Service.. In applications when the synchronous converter has not been previously used, there are a number of conditions that should be given consideration in order that the converter may not be applied in a field or under operating conditions, that would be detrimental to its satisfactory performance.

Synchronous converters should not be used at the end of a long transmission line or any other location where the alternating-current voltage is subject to sudden and frequent fluctuations, such as surges resulting from faults, switching operations, or quick changes of load. If synchronous condensers are operated in the vicinity of the substation, synchronous converter performance will usually be quite satisfactory, insofar as it is affected by alternating-current system conditions. If the impedance drop of the transmission system is excessive, the operation of synchronous equipment in general will not be satisfactory.

The load characteristics of the direct-current system should be thoroughly analyzed to determine whether or not the load swings are of frequent occurrence and of sufficient magnitude to exceed the momentary commutating capacity of the converter. Frequent heavy load swings, such as occur in certain types of railway and mining service, impose a very heavy cycle of operation on a converter. Proper maintenance and inspection are essential for satisfactory performance of the current collecting elements. The ability of a converter to withstand heavy load swings and short circuits is determined to a great extent by the condition in which the commutating parts are maintained.

As in any synchronous machine, the converter carries load by virtue of its rotor dropping back in its phase position an amount sufficient to pass the necessary load current through the impedance of its internal circuits. On large 60-cycle converters, approximately seven times full load current causes the rotor to drop back enough to pull-out of step or slip a pole, if the load is not removed in a sufficiently short time interval. Obviously, the value of pull-out will decrease as the voltage on the slip rings is decreased by the regulation of the transformers and alternating-current supply line. A synchronous commutator type of machine cannot slip a pole under any considerable percentage of full voltage at the commutator without serious flashing. It is necessary to provide either sufficient minimum short circuit resistance to prevent the current approaching pull out value, or a high speed breaker, to limit the current and relieve the converter of its excessive direct-current load before the rotor can drop back in phase position sufficient to pass excessive alternating-current through its windings.

Sudden interruption of excessive load or short circuit current with an ordinary speed breaker on any synchronous converter is conducive to flashing at the commutator. The net armature reaction in the converter is normally quite

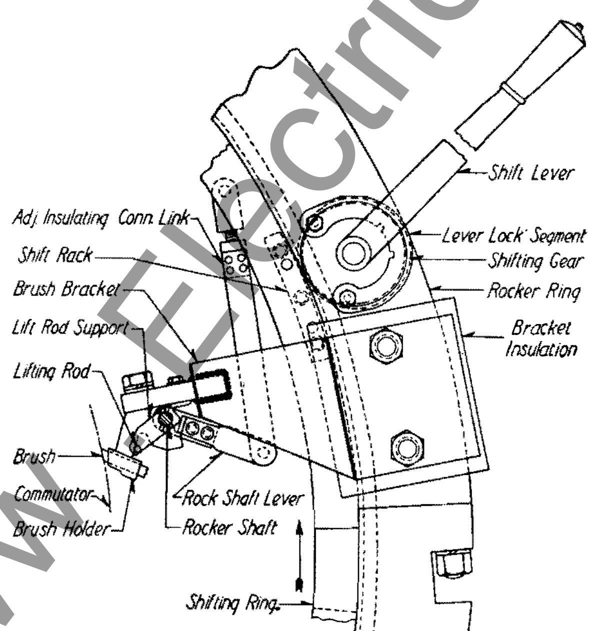


FIG. 13—BRUSH LIFTING DEVICE

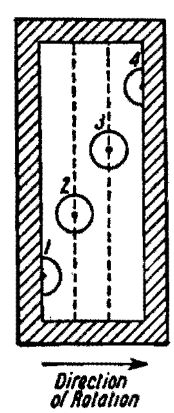


FIG. 14

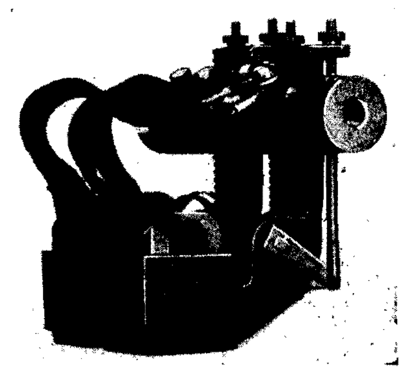


FIG. 15—A-C. BRUSHHOLDER AND BRUSHES

small due to the mutual neutralizing effect of the alternating and direct-currents, and the machine constants affecting commutation are proportioned accordingly. The sudden interruption of a heavy direct-current load, with an ordinary slow speed breaker, is followed by the flow of a correspondingly large alternating-current tending to restore the rotor to its no load phase position. The alternating-current, flowing alone in the windings, produces a large uncompensated armature reaction, with consequent field distortion, excessive short circuit currents under the brushes and high voltage between adjacent commutator bars, that result in heavy sparking or flashing. In most cases of flash over, the converter should be removed from service until the commutator is smoothed, and all brush rigging thoroughly cleaned to remove all carbonized particles.

It has been found that in most 600-volt interurban and street railway service, satisfactorily overall performance of machine can be insured by providing a definite minimum value of short circuit resistance. The maximum short circuit current due to system faults is thus limited to a value which can be safely commutated during the period required for the opening of an ordinary breaker or contactor of normal opening speed. The most common method of providing this resistance is to extend each feeder a sufficient distance from the substation before connecting to the trolley system. In a few cases where the trolley wire in itself possesses sufficient conductivity, it may be desirable to use grid resistance rather than to install a length of feeder copper which would otherwise be unnecessary. It is difficult, if not impossible, to specify a minimum value of resistance which in conjunction with low speed breakers will prove satisfactory on all systems. Any synchronous converter, not provided with high speed breaker protection will flashover on dead short circuit. The minimum resistance of the feeder circuit to the first point connected to the trolley, should be as low as is consistent with overall satisfactory performance under the frequency and severity of short circuits encountered on the particular system under consideration. Final determination of the proper value of resistance will often resolve into a method of "cut and try".

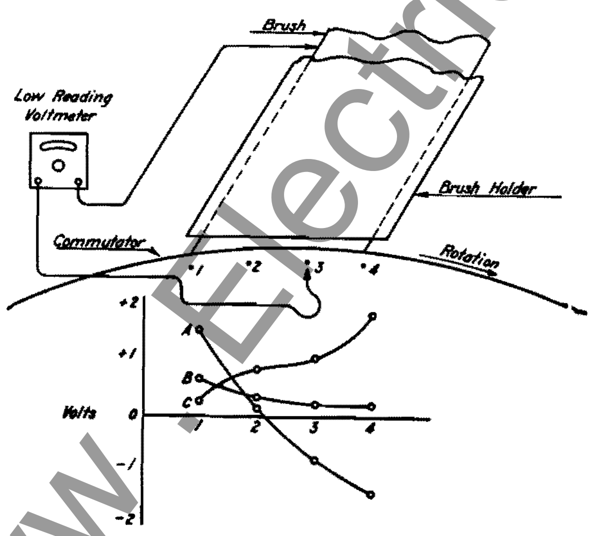
The following are recommended minimum values of positive feeder resistance (not including the negative return circuit) for use with modern high reluctance commutating pole, 60-cycle, 600-volt railway converters. Motor generators and 25-cycle railway converters will perform satisfactorily with the same values.

Converter Capacity in Kw.	Feeder Resistance
300	.080
500	.060
750	.046
1000	.038
1500	.025
2000	.018
3000	.013

In providing the necessary resistance in feeders supplied by synchronous converters, the stability of the transmission line, the switching arrangement and load conditions must be given due consideration. The values as given will limit the current, due to the short circuit at the first feeder tap, to an amount which can be safely **carried** by the machine over the period of operation of a breaker of ordinary speed. However, if this current is totally interrupted by a single operation, the unit will in many cases flash over because of the subsequent lack of any commutating field, to neutralize the excessive alternating-current which continues to flow in the windings.

Properly arranged switching equipments so designed that the converter is relieved of the short circuit current in two steps is very effective in preventing flashing. A suitable time element is introduced in the tripping circuit of the feeder equipment, so that the current is first reduced by the opening of an auxiliary breaker or contactor shunting current limiting resistance. The opening of the feeder breaker then relieves the converter of the reduced current by the isolation of the fault. During the period between the opening of the first and second breaker, a certain amount of direct-current is present to neutralize the effect of the heavy alternating-current flowing in the windings of the converter to restore the armature to its proper phase position.

The presence of connected load on the station bus provides a corrective effect of the same nature and, in multi-feeder stations operating at high load factor may be sufficient. In manually-operated stations where the proper switch sequence cannot be arranged, and where



A Shows Overcompensation
B " Correct Compensation
C " Undercompensation

FIG. 16—ARRANGEMENT FOR DETERMINING PROPER ADJUSTMENT OF COMMUTATING-POLE FIELD

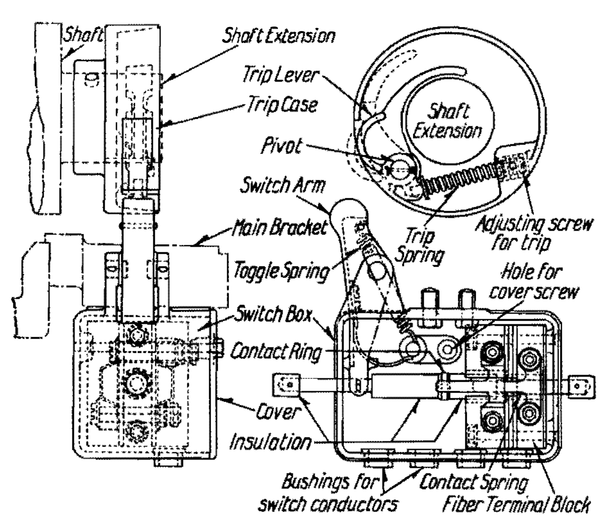


FIG. 17—SPEED LIMIT DEVICE DETAILS
SEE PAGE 31 FOR LIST OF PARTS

the load conditions do not afford sufficient protection, higher values of minimum resistance may have to be used in the feeder circuits to secure satisfactory results.

The recent development of the high speed direct-current breaker offers a means of protection to the synchronous converter from the effects of faults in the direct-current system. The high speed breaker is an air break switch of the contactor type so designed as to open its contacts in a sufficiently short period of time to relieve the unit of its excessive load before the rotor can deliver up its stored energy and drop back in phase position sufficiently to pass excessive alternating-current through its winding, with consequent unbalanced armature reactions and resultant flashing at the commutator.

Protective and Indicating Devices

To secure the most satisfactory results from a synchronous converter it is essential that the converter be properly applied and that the switching equipment be properly designed to protect the unit from such faults and disturbances as occur in service. Proper indicating devices, to enable the operator to have a visual indication of the character of both the alternating and direct-current loads, are essential to the satisfactory operation of the unit.

(Manual Substation)

A-C. Machine Breaker—The alternating-current machine breaker should be of the over current automatic type and adjusted for inverse time or definite time trip, depending on the application. In applications where a high degree of selectivity is desired between the opening of the direct-current feeder breakers and the alternating-current machine breaker, a non-automatic alternating-current breaker equipped with a shunt-trip or direct-trip attachment is necessary. The impulse to trip the breaker is thus secured by the action of sensitive induction type over current relays that have definite minimum and inverse time element characteristics.

In general the setting of alternating-current machine breakers may be relatively high, and is satisfactory to work at any value within the guaranteed momentary capacity of the machine.

The alternating-current breaker and direct-current machine breaker should be electrically interlocked in such a manner that the direct-current circuit-breaker will be opened upon opening of the alternating-current breaker.

The undervoltage release should be adjusted to operate at as high a voltage as is practicable. It is essential, especially for a commutating pole converter, to disconnect the unit from the line when the alternating-current voltage drops an appreciable amount, since the restoration of the normal voltage presents a condition similar to switching the converter from the starting to the running position, with its brushes on the commutator, under which condition a flash may result.

Direct-Current Machine and Feeder Breakers—The direct-current machine breaker should be equipped with an over current tripping mechanism in which a definite minimum time element may be introduced. The feeder breakers should be equipped with a series type instantaneous trip mechanism. Invariably, synchronous converters will satisfactorily commutate very large momentary currents providing the direct-current machine breaker does not open, while they will flash with no greater currents if the breaker is opened. In multiple feeder stations the selective action between opening of the instantaneous type feeder breaker and time delay machine breaker, is of value in that it tends to eliminate flashing due to sudden dropping of heavy loads. During the period between the opening of the feeder and machine breaker, the load current required by the remaining feeders tends to neutralize the excessive alternating-current required to restore the rotor to its normal load position. In normal operation the selective action between opening of machine and feeder breaker may be sufficient to prevent the opening of the machine breaker on faults that are readily isolated by the opening of the feeder breaker. In a single feeder station the time element in conjunction with the machine breaker is of no value as the opening of the feeder breaker ruptures the entire value of machine current.

Overspeed Device — Westinghouse synchronous converters are equipped with a centrifugal overspeed device mounted on an extension of the main shaft. The overspeed device must be interlocked with the alternating-current machine breaker in such a manner as to cause opening of the alternating-current breaker in event the unit is subjected to overspeed. The alternating-current and direct-current machine breakers are so interlocked electrically that the unit is disconnected from both the alternating-current and direct-current system upon functioning of the overspeed device.

Direct-Current Reverse Power Protection—Directional power relay must be provided to prevent motoring from the direct-current end in event of failure of the alternating-current supply voltage or to the bus voltage rising above the machine voltage.

Reverse power protection must be secured by a sensitive type relay capable of withstanding full power flow in the positive direction and of sufficient sensitivity to close its contacts on the flow of a small percentage of reverse power. The relay should be adjusted so as to close its contacts on a value of reverse current sufficient to cause the converter to run idle as a direct-current motor. The operating contacts of the reverse power relay must be interlocked so as to open both alternating-current and direct-current machine breakers in event of a reversal of power flow.

Starting with Brushes on Commutator—With alternating-current self starting commutating pole type of converters it is necessary to raise the direct-current brushes from the commutator to prevent arcing and heavy burning on the brushes and brush gear during the starting period. It is recommended that the brush lifting mechanism be electrically interlocked with the starting equipment so that starting voltage may not be applied to the converter until the brushes have been raised from the commutator.

Closing the Direct-Current Breaker with Brushes Up—To prevent closing of the direct-current breaker before the brushes are lowered on the commutator, after a converter has come up to synchronous speed and full voltage, it is recommended that the brush gear be electrically interlocked with the direct-current-machine breaker to prevent its being closed until the brushes have been lowered upon the commutator. The closing of the direct-current breaker with the brushes raised from the commutator severely overloads the small pilot brushes, which are the only brushes in contact with the commutator during the starting.

Star-Delta Starting

Synchronous converters up to 1500 or 2000 kw. capacity are, in most cases, started from low voltage taps in the secondary windings of machine transformers.

Because of the heavy currents involved the starting and running breakers required for tap starting of large synchronous converters become heavy and expensive. It is more economical in many instances to employ star-delta switching for the larger size units. This scheme provides for connecting the transformer primary windings in star for supplying 58 percent open circuit starting voltage, and switching the connection to delta for full running voltage.

With the star-delta scheme, the star or starting voltage will always be 30 degrees out of phase with the delta or running voltage. It is important that the connections be so arranged that the star voltage will lead rather than lag. Thus, during the lapse of time between the opening of the starting breaker, and the closing of the running breaker, the armature of the machine should drop back in phase position to correspond with that of the line voltage when the running breaker is closed. Without other timing than that inherent to the operation of the breakers, the transition from star to delta is effected very smoothly on many 60-cycle converters. Because of the larger actual time required for the armature to drop back 30 electrical degrees in a 25-cycle converter, it has been found necessary to interpose additional time delay in setting up of the control circuit for closing of the running switch.

Rheostat Position Indication

It frequently happens in converter substations that the switching and control equipment is not in close proximity with the converter rheostats. In such case, correct rheostat settings, for putting machines in service, or taking them out can be most conveniently determined by signal lamps connected to auxiliary contacts on the rheostat faceplate. Position indicators are accordingly recommended for substations where the rheostats are not readily seen by the operator controlling the converter.

Indicating Equipment

Sufficient indicating equipment is required with any converter installation so that operating conditions of the converter can be readily checked.

A direct-current ammeter and voltmeter are essential. Recording instruments, in some cases, are desirable.

Reactive volt ampere meters are recommended as being the most satisfactory means of indicating the magnitude of the phase angle between the supply voltage and current at the slip rings.

The synchronous converter is designed for operation at unity power factor and should be so operated to secure the most satisfactory results.

In applications, such as railway and mining, where the substation load varies rapidly, the field strength should be adjusted so as to secure unity power factor at the average substation load. In stations with low load factor it is recommended the field strength be adjusted to produce unity power factor at a value between three-fourths load and full load.

Automatically Controlled Converter

Protective Equipment—The automatic switching equipment to control and protect a synchronous converter contains rugged sensitive protective relays suitable to protect the converter under any and all operating contingencies that may arise. Automatically controlled converters are protected from:

(1) Reversed, single, or low voltage conditions in the supply voltage.

(2) Unbalanced current due to unbalance on the supply line or due to internal fault in the unit.

(3) Alternating-current overload.

(4) Direct-current short time and sustained overload.

(5) Overheating of machine windings.

(6) Field failure.

(7) Incomplete start.

(8) Starting with brushes on the commutator.

(9) Closing of direct-current breaker before brushes have been lowered to the commutator.

(10) Overheated bearings.

(11) Complete opening of fault current in one step by the opening of the load shifting equipment to insert resistance in the circuit before opening of the feeder breaker.

(12) Flash over. In case of flash over the unit is locked out of service.

(13) Connection to the direct-current bus with the converter polarity reversed. A polarized motor relay operates to check the polarity and to correct it if necessary before the sequence of operation can be completed.

Star-Delta Starting (Automatic)—In automatically controlled converter equipment using the star-delta method of starting a suitable time element is inserted in the switching sequence to secure proper transfer time from opening of the star part to allow the converter to drop back 30 electrical degrees before closing the delta connection.

Automatically controlled booster type converters for use in Edison or Electrolytic work are equipped with voltage and current regulators. The converter voltage is regulated within the current carrying capacity of the unit by the voltage element of the regulating equipment that operates to control the booster element. When the current carried exceeds the machine capacity the current element takes preference and controls the booster field to supply constant current.

Grounding Machine Frame

In no case should the machine be "grounded" by connecting it solidly to the negative lead or terminal. Such connection renders the machine liable to excessive and unnecessary damage in case of flashover or other ground to the frame, as the fault current is limited only by the low resistance of the arc and machine winding.

It is a standard practice with Westinghouse equipment to ground the frame of the unit through a 100-volt shunt trip coil on the emergency breaker in the case of automatically controlled equipment, or through a 120-ohm resistor Style #204832 for manually-operated equipment. In case of flashover to ground the current is limited to a few amperes by the resistance of the coil and the voltage tending to sustain the arc is reduced at once to a low value by the drop across the coil. The result is that the arc to ground is weak and unstable and does little or no damage. The limiting of the ground current to a low value prevents the additional accumulation of conducting gases due to the vaporization of the commutator copper at a point where the arc is established between commutator and ground. The decrease

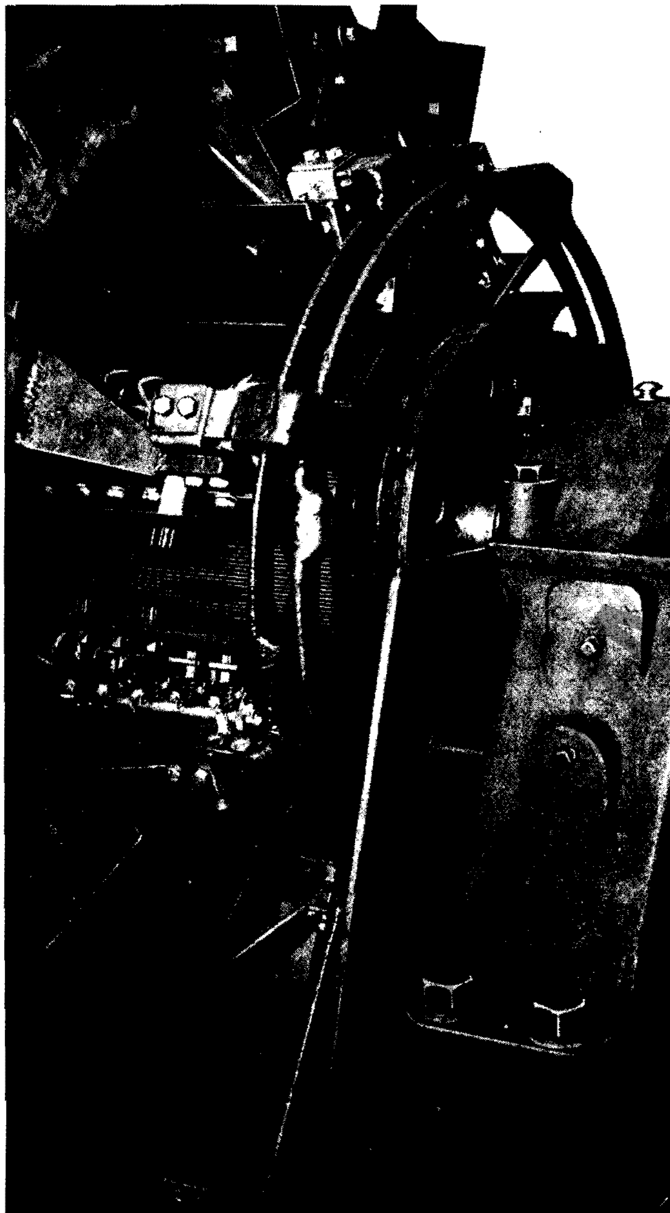


FIG. 18—60 CYCLE RAILWAY CONVERTER SHOWING D-C. BRUSH RIGGING

in vaporization due to the low value of ground current, will in many cases prevent the spreading of the arc, to establish a flash between brush arms.

The trip coil or resistor should preferably be connected to the station ground plate. However, connection to the negative lead is permissible and may be necessary when the rail ground is of exceptionally high resistance as in the case of a dry rock ballast.

In equipments using the type MF flash relay care must be exercised to insure low enough resistance in the ground circuit to permit operation of this series type relay. If connected to the station ground plate, the resistance measured from the frame to negative terminal should fall within the limits of two to four-ohms, for all weather conditions. If the conditions cannot be met the frame should be connected through the relay and a three-ohm resistance, in series, to the negative lead.

Characteristic Data

A-C. and D-C. Voltage Ratio—An important fact to keep in mind in connection with synchronous converters is that the ratio between the alternating-current and the direct-current voltages is fixed. When a change in the direct-current voltage is obtained, therefore, it can only be accomplished by changing the alternating-current voltage, as in the case of "compounding," where the alternating-current supply voltage is varied by combined action of converter fields and reactance; or by the insertion of a booster or an induction regulator in the alternating-current circuit. This characteristic of the synchronous converter makes it quite different from that of the direct-current generator, and thereby accounts for the difficulties that sometimes occur in attempting to obtain suitable load division when operating converters and direct-current generators in parallel. Except in the case of machines specially designed for wide range voltage service, it should be understood that even when an increase in the alternating-current voltage supply is made, the saturation of the converter magnetic circuit, in a normal railway or industrial type converter, limits the over-voltage that can be obtained to approximately 5%. Limitation of reduction of voltage possible by change in the alternating-current supply is fixed by the ability of the converter to remain stable as well as to commutate, but will in most cases be found to be all right as low as 50% of normal voltage if the power factor is kept at 100%.

These ratios **at no load** in converters of average design proportions are as follows:

	Approx. Ratio A-C. to D-C.
Single-Phase, 2 collector rings...	.707
Three-Phase, 3 collector rings...	.612
Two-Phase, 4 collector rings....	.707
Six-Phase, 6 collector rings...... (diametrical)	.707
Six-Phase, 6 collector rings...... (double delta)	.612

At full load these ratios are increased an average of 2 percent due to armature drop, demagnetization, etc.

A-C. and D-C. Current Ratios—On the basis of direct-current amperes being 1.00 the corresponding alternating-current amperes are shown approximately in the following table:

	A-C. Amperes per Ring
Single-phase..................	1.50
Two-phase....................	.75
Three-phase..................	1.00
Six-phase.....................	.50

Effect of Power Factor on Armature Heating—The effective current in the armature of a converter is the **difference** between the alternating-current delivered to the winding and the direct-current taken from it. The heating obtained in the armature of a converter operating at 100% power factor is therefore considerably less than in a corresponding direct-current generator of the same current output, being only about 59% in a three-phase machine and 27% in a six-phase, over what would be obtained as a straight direct-current generator. The loss, or heating, of a converter armature winding is not uniformly distributed among the armature conductors, as it is in a direct-current generator, but is much greater in the conductors near the taps to the collector than in the conductors between taps. At 100% power factor the maximum loss in any tap coil, for a three-phase converter, is 125% of the average loss obtained in a corresponding direct-current generator, and 45% for a six-phase converter. This difference in heating between a three-phase and a six-phase winding explains the reason why six-phase converters have been so universally adopted as the operating standard.

As stated, these percentages are only true for 100% power factor on the converter. The heating in converter armature windings increases rapidly as the power factor is varied from 100%. Thus at 98% power factor the tap coil heating is 33% greater in a three-phase converter and nearly 50% greater in a six-phase, than is obtained when 100% power factor is maintained on the converter.

For this reason converters must not be operated for long periods with heavy loads at power factors other than unity. In converters used on railway service where the load is widely fluctuating some departure from unity power factor is unavoidable. This departure, however, should be made small at the higher loads by proper shunt field adjustment and the converter should be so adjusted that 100% power factor is obtained at loads between 75% load and full load, depending upon the load cycle. Converters used on service where loads remain fairly constant over long periods, should be operated at 100% power factor at all loads. On booster converters, if there is appreciable reactance in the alternating-current circuit, the converter power factor will vary to some extent with varying load and voltage. Adjustment for unity power factor is accordingly necessary on a booster converter if full benefit is to be obtained from the booster element. Otherwise part of the voltage will be used in overcoming the reactive voltage, which is appreciable in its effect, except at unity power factor. On this account, **transformers and circuits for booster converters should have low reactance and the lead reactance must be balanced.**

When temperature tests are made after installation to determine the operating temperatures under the guaranteed conditions, particular care should be taken to have the power factor, at the converter terminals unity, at all tested loads. Failure to observe this point will make the tests of no value as a check against the guaranteed figures since the losses vary so much with variation in the power factor.

Power Factor Measurement — The power factor on a converter should always be referred to in terms of the value existing at the converter sliprings. This required the connecting of both the voltage and current elements of the power factor recording instrument on the low side of the transformer wherever practicable. On the large size heavy current machines the inductive stray field interference obtained on the low tension leads so affects the current transformer to which the meter is connected that the readings are unreliable. It has accordingly become standard practice on the larger sizes of units to connect the voltage element of the meter on the low side of the transformer and the current element on the high side. This arrangement affords a reliable record of the power factor being obtained and is actually a true reading of the converter power factor with the exception of the magnetizing element in the transformer.

Compounding—When reactance in the supply circuit of a converter, the voltage at the collector rings may be varied through a small range by changing the power factor. The phase relation between the current and voltage in the alternating-current supply is changed by varying the excitation of the converter field. In a compound wound converter this change in power factor is automatically accomplished by the combined action of the series field winding and the reactance in the circuit. While the arrangement of field windings is the same as in the compound-wound direct-current generator, the theory and action are entirely different. With lagging wattless currents the voltage across the reactance subtracts from the line voltage and at leading wattless currents it adds to the line voltage. At unity power factor the effect of the reactance voltage is practically negligible. Lagging wattless currents are obtained by making the field excitation **less** than normal, and leading wattless currents, by making the field excitation **more** than normal.

It is apparent that the direct-current voltage regulation of the compound-wound converter depends on many elements internal and external to the converter and that the change in voltage is limited by the inability of the converter to operate at low power factor and heavy load. The range of voltage is more restricted and the results much more difficult to predetermine than in the compound-wound direct-current generator. The voltage range is affected by:

(a) The resistance drop between the point of constant voltage and the converter.

(b) The reactance drop between the same points.

(The values of (a) and (b) apply to that part of the circuit between the synchronous converter collector rings and the point on the supply line at which constant voltage is maintained).

(c) The ratio of armature ampere-turns to shunt field ampere-turns.

(d) The ratio of series field ampere-turns to armature ampere-turns.

(e) The setting of the shunt field rheostat.

(f) The total drop through the converter.

On the average, with constant voltage applied at the high-tension transformer terminals, 15% reactance in the transformers and no shunt on the series field of the converters, approximately constant direct-current voltage can be obtained from no load to full load.

It is possible to obtain units power factor at any desired load with the proper shunt field adjustment, but it is impossible to maintain 100% power factor and at the same time maintain constant voltage. It is usually not practicable to make a converter "over-compound" under the best conditions, and usually a small decrease in voltage with load is preferable.

Effects of Series Field on Fluctuating Loads—When converters carry widely and rapidly fluctuating loads, as in railway service, the series field should be relatively weak so as to avoid sudden changes in voltage. The use of a strong series field tends to hold up the voltage on overloads and thereby increases possibility of flashing. Series field shunts are adjusted at the factory to shunt 50% of the series field current. Heavier series field strength will not usually be found necessary except in cases where parallel operation with existing apparatus may be of paramount importance. A compound wound converter with weak series field approaches a shunt would converter in its voltage characteristic, and is accordingly more stable in operation on rapidly changing loads, and less likely to flash when the machine breaker opens on heavy overloads.

Parallel Operation on the Direct-Current Side of Compound Wound Converters—The problem of load division in parallel operation of converters, as in direct-current generators, is simply the problem of voltage adjustment. In the converter, however, there are many more factors, determining the voltage, as compared with the direct-current generator, and the problem is, therefore, more complicated.

The successful parallel operation of compound-wound converters requires equalizer leads and proper proportions between the resistances of series field windings and connecting leads, as in direct-current generators. In addition, parallel operation of compound-wound converters is affected by the voltage ratio (from high-tension alternating-current to direct-current) by shunt field adjustment, and by the reactance in the alternating-current circuit.

With two converters operating in parallel on the direct-current side, one of which takes less than its proportionate share of the load, the load may be equalized by one or a combination of the following adjustments:

(a) The shunts on the series field windings can be adjusted, decreasing the resistance of the shunt on the overloaded converter, if possible, or increasing the resistance of the shunt on the underloaded converter. It should be borne in mind, however, that changing the ampere-turns in the series field by changing the shunt resistance also changes the resistance of the complete field circuit. This change in resistance must be compensated for by a corresponding change in resistance in another part of the series field circuit so that the resistance of the total circuit remains unchanged. From another standpoint, a shunt on one converter series field may be considered a shunt on both series fields, the effect varying only by reason of the resistance of the leads and buses being added to one shunt circuit and not to the other.

(b) If the relative ampere-turns are correct, but the series field resistances different, the resistance of the leads between the series field and equalizer bus can be changed to compensate for a difference in the series field resistances. The resistance in the series circuit of the converter taking more than its share of the load should be increased. This adjustment varies the resistance of one series field without introducing a third parallel circuit between the equalizer and main bus, and for this reason the adjustment is less complicated than in (a).

(c) The transformer ratio can be changed. This increases the voltage the same amount throughout the range of load and does not change the shape of the voltage characteristic.

(d) The reactance can be increased in the circuit of the lightly loaded converter. This causes an increase in voltage for a given load and is similar in effect to an increase in the number of series field turns.

(e) The relative shunt field currents of the two converters can be changed. The converter having the smaller ratio of series field to armature ampere-turns should have its shunt field current increased. This will increase its no-load voltage and cause it to take a greater share of the load at light loads.

Since there are so many variables affecting load division it is important to make a careful and systematic study of the particular case before making any such changes. Such a study should be conducted as follows:

(a) Adjust the transformer ratio so that at no load and with the shunt field adjusted to give equal power factors all converters have the same no-load direct-current voltage.

(b) The series field should be adjusted by shunts, if possible, so that the ratio of series field ampere-turns to armature ampere-turns is the same.

(c) The resistance of series fields (including shunt) plus the resistance of the leads from the series fields to main bus (positive or negative) should be adjusted so that the resistances are inversely proportional to the rated capacities of the converters.

(d) The reactances should be adjusted, if possible, so that the reactance volts of the various circuits throughout the range of load are equal. If they cannot be made equal, the series ampere-turns should be greater in the converter having the smaller reactance, to afford an approximate compensation.

It is only possible to have exactly proportionate division of load and equal power factor (or percentage of reactive current) **on all converters when all four elements—transformer ratio, series ampere-turns, series field resistance and reactance are properly proportioned.** Such complete similarity in transformers and converters rarely exists, however, satisfactory load division can always be obtained, even if one or two of these elements are not correctly proportioned, providing compensating adjustments are made in the other elements and slight differences in wattless currents are satisfactory.

Parallel Operation of Shunt Wound Converters—The parallel operation of shunt wound converters, which includes booster converters, is comparatively simple, although, if the inherent regulation differs unduly in two machines to be paralleled it may be necessary to insert resistance in either the alternating or direct-current leads of the machine having the higher (more nearly flat) voltage characteristic.

Parallel Operation on Both Alternating-Current and Direct-Current Sides—Conditions sometimes make it convenient to connect several converters to the same low-tension alternating-current bus-bars and the same direct-current bus-bars. With these connections, the alternating-current and direct-current bus-bars close the electrical circuit between any pair of converters and the direct-current load division will be determined by the relative voltages generated by the several converters and by the relative resistances of the different parallel paths. Slightly different voltages in different converters will also cause large circulating currents in the closed electrical circuit which may damage the windings and even burn them out. Different converters rarely have the same voltage ratio and it is very difficult to control the resistances of the various parallel circuits, since the brush-contact drops form a large part of these total resistances. The conditions become worse with converters of different ratings or design proportions. For these reasons **converters must not be operated in parallel on both the alternating-current and direct-current sides.**

General Instructions Starting and Inspecting

Before starting any converter the following routine should be regularly observed:

(1) The alternating-current and direct-current brushes should be examined to see that they move freely in their holders, and where pilot brushes are used, to see that they are all bearing on the commutator.

(2) Examine the interior of the synchronous converter; see that no foreign material is present and that the insulation is intact.

(3) Examine the bearing housings to make sure that there is plenty of oil in the wells and that the rings are free to turn.

(4) See that the speed limit device is in operating condition.

(5) Open all the line knife switches on the switchboard, on the starting panel, and pedestals (if used), and on the converter frame (if used) for both the alternating-current and direct-current circuits. The shunt field switch on the switchboard is to remain closed in the operating position with normal resistance in the shunt field rheostat for alternating-current starting and all out for direct-current starting.

(6) On commutating-pole machines, if they are self-starting from the alternating-current side, raise all of the direct-current brushes, except the pilot brushes.

When the machine has been placed on the line, examine the oil rings to see that they are revolving properly and examine all alternating-current and direct-current brushes to see that they are properly seated on collector or commutator and are not sparking.

Alternating Current Low Tension Self-Starting

NOTE—The D.P.D.T. Field Switch should remain closed in the normal operating position while starting.

When starting booster converters, the booster field rheostat must be in the neutral position, otherwise the voltage induced in the commutating pole auxiliary field may burn out the rheostat.

(1) Raise all D-C. brushes from commutator except the pilot brushes on commutating pole machines.

Under no condition must the pilot brushes be raised from the commutator during starting.

(2) Close the disconnecting switches and the oil circuit-breaker on the high-tension side of the transformer.

(3) Close the double-throw starting switch to the starting position.

The converter should come up to synchronous speed in from 30 to 60 seconds and lock into step, indicating this condition by a steady current on the alternating-current side of the converter and a continuous deflection on the direct-current voltmeter.

(4) If the direct-current voltmeter indicates a reversed polarity, throw the field switch to the reverse position, thus reversing the shunt field and connecting it directly across the armature. The voltmeter pointer will swing back towards zero. When it reaches zero, throw the field switch to the operating position. If the voltage now comes up with the right polarity, proceed as directed in No. 5. If, however, the converter fails to reverse, and the voltage again comes up with the wrong polarity the starting switch should be opened for a moment, thus permitting the converter to slow down somewhat. The starting switch should then be closed again in the starting position, repeating these operations until correct polarity is obtained.

(5) When the machine is up to synchronous speed and the direct-current voltmeter shows correct polarity, throw the starting switch to the running position. The amount of current taken from the line when throwing to full voltage can be made a minimum by slightly over-exciting the field.

(6) Lower the direct-current brushes to the commutator on the commutating-pole machines.

(7) (a) **For Two-Wire Service**—Close the direct-current circuit-breakers. Then close the equalizer, negative and positive switches in the order named.

(b) **For Three-Wire Service**—Close the circuit-breakers in the direct-current circuit, and the neutral, negative equalizer, negative, positive equalizer, and positive switches, in the order named.

(8) Adjust the shunt field to give 100% power factor at the load and voltage being taken from the machine.

Alternating-Current High-Tension Starting (Star-Delta)

NOTE—The D.P.D.T. Field Switch should remain closed in the normal operating position while starting.

Under no condition must the pilot brushes be raised from the commutator during starting.

Be sure that the booster field rheostat is on the neutral position.

The procedure of the first four points in connection with high-tension (star-delta) starting is identical with that of low-tension starting.

When the machine is up to synchronous speed and the direct-current voltmeter shows correct polarity, open the star point oil breaker and close the oil breaker connecting the transformer primaries in delta.

There is a difference in phase position of 30 electrical degrees between the star connection starting voltage and the delta connection running voltage. Therefore, the time required to open the oil breaker connecting the transformer primary windings in star and to close the oil breaker connecting the transformer primary windings in delta should be the same as the time required for the armature to drop back these 30 degrees. See text on protective features recommended for star-delta starting.

Direct-Current Self-Starting—(1) Insert the voltmeter switch key for the direct-current voltmeter. Insert the synchronizing switch key, causing the synchronizing lamps to burn dimly.

(2) Close the negative and series field short-circuiting switch, if any.

(3) Close the direct-current circuit-breaker.

(4) Start the converter by closing the starting switch, cutting out the starting resistance slowly. If machine rotates in wrong direction, shut down by tripping the circuit-breaker and opening the knife switches and reverse either field or armature connections. Check polarity of windings before putting machine in service if any change in connections has been made.

(5) Adjust the speed of the converter to synchronous speed by means of the field rheostat.

(6) Synchronize the machine.

The elementary principle of the method of determining when two alternating-current machines are of the same frequency and are in phase is illustrated in Fig. 19 in which **A** and **B** represent two single-phase machines, the leads of which are connected to the bus-bars by the switches **C**, and through two series of incandescent lamps. It is evident that as the relative positions of the phases of the e.m.f.'s change from that of exact coincidence to that of exact opposition, the flow of current through the lamps varies from a minimum to a maximum. If the e.m.f.'s of the two machines are exactly equal and in phase the current through the lamps will be zero and, as the difference in phase increases, the lamps will light up and will increase in brilliancy until the maximum is reached when the phases are in exact opposition. From this condition they will decrease in brilliancy until completely dark, indicating that the machines are again in phase. The rate of pulsation of the lamps depends upon the difference in frequency; i.e., in the speeds of the machines. In cases of polyphase machines, if the phases are in the correct relation to each other, all the lamps will be bright or dark at the same time. If this is not the case, the leads should be interchanged until this condition is obtained.

In order to determine whether the lamps will be bright or dark for a given connection of transformers when the machines are in phase, remove the main fuses from one machine, or disconnect the machine back of the shunt connection, and throw in the main alternating-current switches with the other machine at full voltage. Since both primaries are now connected through the switches of one machine the lamps will be in the same condition as when the main or paralleling switches are open and both machines are in phase. If the lamps burn brightly and it is desired that they be dark for an indication of synchronism, the connections of one of the primaries or one of the secondaries of the transformers should be reversed. Dark lamps as an indication of synchronism are recommended.

The lamps should be adapted for the highest voltage which they will receive, i.e., double-normal voltage. Fig. 20 shows the connections for a two-phase machine. For three-phase machines the connections are modified to correspond. For six-phase machines the phasing can be most easily done on the high-tension side for which condition one of the above connections will apply.

(7) When the lamps or synchronoscope indicate synchronism close the alternating-circuit switches connecting machine to the line.

(8) Close the positive switch and open the starting switch.

(9) Open series field short-circuiting switch, if any.

(10) Close the equalizer switch, if any.

(11) Adjust shunt field to correct setting for 100% power factor at the load and voltage to be taken from the converter.

Induction Motor Starting (without Current in the Converter Armature)—

(1) Close the oil circuit-breaker on the high-tension side of the transformers.

(2) Insert the voltmeter switch key for the direct-current voltmeter. Insert the synchronizing switch key, causing the synchronizing lamps to burn dimly.

(3) Start the converter by closing the switch which controls the starting motor.

(4) Build up the direct-current voltage to approximately the line voltage by adjusting the field rheostat.

(5) Slow down the converter to synchronous speed by closing the switch to the synchronizing resistance. If the speed becomes too low, open the switch and close it again in a short time.

(6) Synchronize machine as described under Direct-Current Starting.

(7) When the lamps or synchronoscope indicates synchronism, close the alternating-current switches connecting the machine to the line.

(8) Open the switches controlling the starting motor and the synchronizing resistance.

(9) Adjust shunt field to correct setting for unity power factor.

Induction Motor Starting (with the starting motor windings in series with the converter armature windings)—

(1) Close the oil circuit-breaker on the high-tension side of the transformer.

(2) Close the smaller low-tension switch in the starting motor circuit thus energizing starting motor and converter windings in series.

The converter should come up to speed and lock into step as with alternating-current self-starting.

The polarity of the direct-current voltage will always be correct.

(3) Close the larger low-tension switch short-circuiting the starting motor winding and open the switch in the starting motor winding.

The brushes are not raised when this method of starting is used due to the small current flowing in the converter armature during starting.

(4) Proceed as with alternating-current self-starting.

Starting a Synchronous Converter, to Run in Parallel with Another—

(1) In starting a second converter to be run in parallel with another, follow the same procedure as in starting a single converter.

(2) In adjusting the direct-current voltage on the machine being put in service, it is best to under-excite the field slightly to keep the voltage low enough so that the machine does not grasp too much load as soon as it is closed in on the line.

Bearings—When first starting a machine particular attention must be given the bearings to see that they are well supplied with lubricant. The oil rings should revolve freely and carry oil to the tops of the journals. The bearings of all Westinghouse machines are liberal in size, and with proper care will not give trouble. They may, however, be made to overheat by any of the following causes:

(1). Insufficient lubrication which may be owing to—

(a) Poor lubricant.

(b) Insufficient quantity.

(c) Failure of oil rings to revolve.

(2). Poor alignment or leveling causing excessive end thrust or binding.

(3). Rough bearing surface which may be caused by careless handling, or the presence of dirt or gritty substances in the oil or grease.

(4). Bent shaft.

A bearing is usually safe if it operates at a constant temperature below the boiling point of water, 212 degrees Fahrenheit (100 degrees Centigrade). The rapid rise of temperature toward this limit, however, is a danger signal calling for prompt attention. A bearing will be below this temperature, and may be safe even when hot enough to burn the hand held continuously against the outside a few seconds. It will seldom be necessary to do more than to supply a hot bearing with an abundance of fresh clean lubricant, making certain that the oil reaches the bearing surface. If this is not effective, pour a heavy lubricant directly onto the journal. Keep the rotating part in motion enough to prevent the bearing from becoming set or "frozen."

In normal service the old oil should be withdrawn from bearings occasionally and fresh oil substituted, running enough of the fresh oil through the bearings to wash out all sediment. The old oil as well as that used for rinsing can be run through a filter and used again. A good oil filter is a necessity in every plant where much machinery is in use. The frequency with which the bearings must be refilled depends so much on local conditions, such as the severity and contin-

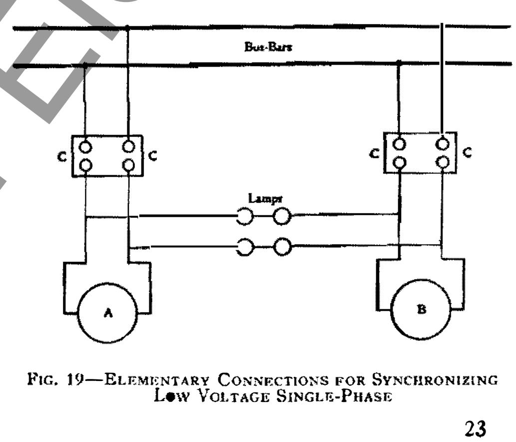


Fig. 19—Elementary Connections for Synchronizing Low Voltage Single-Phase

uity of the service, the room temperature, the state of cleanliness, etc., that no definite instructions can be given. Until local conditions show another interval to be more suitable, bearings should be refilled every six months.

Oil—Only the very best grade of dynamo oil should be used. In the long run it always proves a false economy to use cheap oil. If the oil is to be used a second time it should be filtered and if warm allowed to cool before the bearings are refilled. Even new oil should be examined carefully and filtered or rejected if it is found to be gritty.

Shutting Down a Single Converter—

(1) Open the direct-current breakers, thus taking the load off the machine. If the converter to be shut down is in parallel with others, shift as much load from it as possible by operating the field rheostats before opening the direct-current-breakers. On booster converters this is done with the booster field rheostat.

(2) Open the direct-current switches.

(3) Open the alternating-current breakers.

(4) Open the alternating-current switches.

(5) Leave the main field rheostat in normal running position, but set booster field rheostat on neutral.

(6) See that the synchronizing switch keys, if any, are pulled out.

Emergency Instructions—

(1) When converters flash over, or the breakers come out from excessive current, it is always wise to note the direct-current voltmeter before throwing in on the line again, as these troubles very frequently cause a reversal of polarity in the fields, making them build up in the opposite direction.

(2) When the alternating-current power goes off for any reason, shut down the converter at once, opening all switches.

(3) When the alternating-current breakers come out, open the direct-current breaker (if not tripped out automatically) and the switches and then proceed to start as in first starting.

(4) When a converter flashes over and is thrown out of circuit, it is best if possible to shut down for a moment and examine the commutator, collector, and brushes and clean up any burrs which may have been caused. If this is not possible, the commutator can be cleaned after the converter has been put in service, by exercising great care.

Caution

Leave all switches open when machine is not operating.

When the shunt field circuit of a converter is excited, never open it quickly unless a path for the inductive discharge is provided. The circuit can be opened slowly, if desired, the arc at the opening serving to reduce the field current gradually. Do not permit any part of the body to bridge this opening, or a serious shock will be received; it is best to use one hand only, keeping all other parts of the body clear of the circuit.

Always follow a fixed regular order in closing and opening switches, unless there are special reasons for departing from this order. A routine method will aid in avoiding mistakes. Close switches carefully, keeping firm hold of the handle until completely closed.

Keep small pieces of iron and bolts and tools away from the frame. Any such fragments attracted to the pole of a field magnet may jam between the armature and pole and cause serious damage.

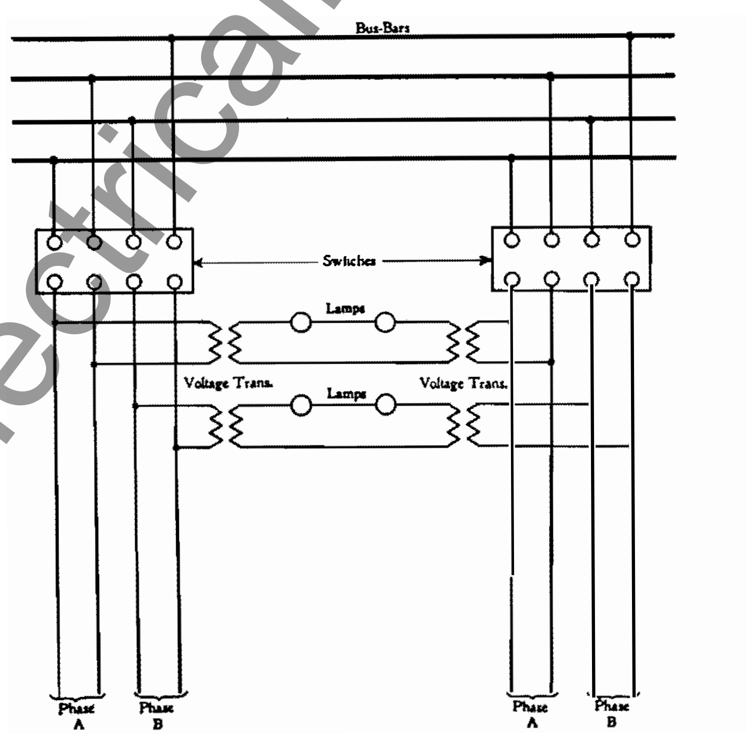


Fig. 20—Connections for Synchronizing Two-Phase Machine

MAINTENANCE

General

1. The machine should be well blown out with clean dry air at least once a week. An air pressure of from 60 to 70 lbs. min. is recommended. This blowing out should be done when the machine is at rest. The air stream should be directed in through the spokes of the spiders on the rotating element, and through the spaces between the windings on both ends of the machine. The machines should be carefully wiped off after such a blowing-out, and special care should be taken to see that all dirt and brush deposit particles are removed from the current collecting parts, especially the risers.

2. Insulation resistance of the windings should be measured frequently, at least, once every three months. The readings obtained should not be allowed to get below the values recommended by Standard A.I.E.E. ruling. This ruling is as follows:

$$\frac{\text{Machine terminal voltage}}{\text{KW rating of machine}} + 1000 = \text{megohms}$$

When insulation readings below results obtained by this formula are shown to exist on any machine, the machine should be taken out of service and cleaned until the value comes up to this standard. Cleaning by the use of carbon tetrachloride, wiping, and brushing is recommended at periods of measuring the insulation resistance.

3. A direct-current brush pressure should be maintained at a uniform value on all brushes of from 2 to 2½ lbs. per sq. in. of cross sectional area of the brush.

4. An alternating-current brush pressure should be maintained at uniform value on all brushes of from 2½ to 3 lbs. per sq. in. of cross sectional area of the brush.

5. All of the direct-current brushes should be gone over once a week to make sure that all brushes move freely in their holders. Shunts on the direct-current brushes should always be kept in well-rounded shape and never mashed down, otherwise proper brush contact on the commutator will not be obtained.

6. All alternating-current brushes should be gone over at least once a week, and each brush removed from its holder and the brushes wiped off clean with a piece of cloth. The alternating-current brush rigging should be blown out thoroughly before re-setting the alternating-current brushes in their holders, for in this manner only can the dust that accumulates in the brushholder boxes be blown away. Check weekly for at least .006 inch clearance on each side of each brush. Shunts on A-C. brushes should always be kept in well-rounded shape, the same as recommended in connection with the D-C. brushes.

7. Do not mix brush grades on any given machine. Obtaining experimental brush data by equipping one D-C. brush arm, or one collector ring with a particular grade of brush is apt to be quite misleading, due to the effect of the other brushes on the adjacent arms. By mixing brush grades on any given arm, unequal current distribution is inevitable.

8. All A-C. and D-C. brushholders should be kept as near as possible to within about ⅛″ of the commutator and collector rings. As wear on the commutator and collector make it necessary, follow them up by moving the brushholders down to keep this recommended clearance.

9. Always keep the D-C. brushholder bracket arms spaced to within $\frac{1}{32}$″ and always keep the brushholders on each individual arm in alignment.

10. When machines are equipped with flash-guards or barriers, always keep the barriers clean and set to within approximately $\frac{1}{32}$″ of the commutator. When carbonization occurs on the barriers as a result of flashing, a conducting path to ground will often be found to exist. Such barriers damaged by carbonization should, therefore, always be removed from the machine, properly cleaned off, if possible, and if not possible to repair, replaced by a new barrier.

11. Keep the commutator and collector smooth. Some scoring of the current collecting parts is inevitable, and therefore, grinding about once a year is a good insurance for best operation. Keep the

mica well undercut and the bars properly chamfered. Keep the undercutting well cleaned out. Whenever commutator flashing has been experienced, the commutator should always be smoothed up with at least hand-stoning, and polished off with sandpaper. If the operation is of a severe nature, the commutator should be ground with a regular grinding outfit.

12. When commutators are ground, this should always be done at 100% of normal speed. Stationary stone for grinding is preferable to a rotating stone. If the commutator bolts are to be tried for tightness, this should only be done in accordance with instructions from the East Pittsburgh Engineering Department. If any tightening on the bolts is obtained, the process of alternate heating and tightening every 3 or 4 days should be repeated until the commutator bolts cannot be tightened further. When a commutator has been tightened, and after no further tightening can be obtained, it should always be given at least two weeks running under normal service conditions before grinding. During grinding, the copper dust should be collected in some form of a vacuum container in order to prevent the dust being thrown off into other machines or other apparatus around the station.

13. Always connect to the proper transformer tap to give normal D-C. operating voltage at full load, and then set the field rheostat to give 100% P.F. (reactive KVA zero over the required operating load range).

14. When motor-operated lifting mechanisms are used, they should be tried frequently to make sure that they are functioning properly. When brush lifting devices, either motor or hand-operated, are used, notice should be taken to see that all the D-C. brushes lift clear of the commutator when in the "up" position, and that all brushes go down on the commutator when in the running position.

15. Check the field rheostats at least once a year for open or short-circuited tubes, and always keep the buttons on the face plate clean so that positive contact (no arcing) is obtained with the rheostat arm.

16. Keep the commutating pole auxiliary field control equipment on synchronous booster converters in operating condition. Frequent sandpapering of the buttons on the face plate of the torque motor arm rheostat is necessary to insure freedom of movement of the arm.

17. Check the speed limit device for maintenance of its proper calibration, at least twice a year, and more frequently if the apparatus is subjected to unusual dirt or oily vapor conditions. The speed limit device should always be checked after occurrence of any unusual operating disturbances; when the machine has been out of service for repairs, or has been standing idle for any appreciable length of time.

18. The oil supply of the bearing should always be kept adequate. Examination of oil rings should be made each time a machine is put in service to make sure they are functioning properly. The bearing caps should be removed and bearings examined at least twice a year. If any indication exists showing wiping or pitting, the bearing should be scraped.

19. Keep the oil in the bearings clean. Oil should be entirely drained from the bearings and new clean oil inserted once a year. During hot summer weather, if the temperature of the oil exceeds 70°C., it should be changed more frequently, as carbonization of the oil is likely at these high temperatures

Some commutator wear and collector ring wear must be expected on all converters. A liberal wearing depth in current collecting parts is provided to allow for this wear. If proper maintenance is given the apparatus, as outlined above, a reasonable life will be obtained.

Commutator Seasoning and Grinding—The satisfactory operation of a synchronous converter is as dependent on the condition of the commutator as on any other one item. It is a well recognized fact that a commutator only becomes thoroughly "seasoned", (the insulation baked out and all parts in their final set position) after operating for a considerable time. Owing to lack of facilities for current loading at the Works, it is not feasible, in all cases, to get the commutators finally seasoned before shipment. It should be understood that a certain amount of commutator seasoning will take place during the first year after the converter is put into service, particularly if the commutator is of large size.

That the commutator needs attention will usually be indicated by its becoming rough due to a general unevenness, high or low bars, flat sections or eccentricity. If these conditions are not corrected they will result in poor commutation, overheating of the commutator, a rapid deterioration of the brushes, clips and shunts, and greatly limit the machine's ability to satisfactorily handle overloads.

If the commutator is in very bad condition, it may be necessary to use a turning tool, but for ordinary cases a grinding tool, Fig. 21, is preferable and is recommended. Commutators should always be ground at 100% normal speed. Turning requires a much lower speed; it should not be higher than 300 to 400 feet per minute. Before grinding a commutator, the machine should have been in service a sufficient length of time to bring the temperature of the commutator up to a constant value of at least 50°C . rise above the surrounding air. Mach ine should then be shut down and the bolts holding commutator "V" ring, shown in Fig. 22, tried for tightness in accordance with instructions from the East Pittsburgh Works Engineering Dept' If any tightening on the bolt is obtained, the process of alternate heating and tightening should be repeated until the commutator bolts cannot be tightened further. The tightening of the commutator is all done with click wrenches. These click wrenches give a click indication when the pull for which they are set is exceeded. Our District Service Depts. all carry these click wrenches as part of their standard equipment, for use in tightening commutators.

Commutators of the so-called 3V construction (see Fig. 23) have now been superseded by the 2V type of construction shown above in Fig. 22. Reference to this 3V type of construction should therefore be understood to pertain only to apparatus now in service.

In tightening commutators having the 3V construction (Fig. 23) the outside

Fig. 21—Grinding Device for Truing Commutators

(Aux. V) bolts should always be backed off slightly, say ½ turn, before attempting to tighten the bolts of the main V. After machine is given its final tightening, it should be run for at least 12 hours to reach a constant temperature on commutator of at least 50°C. rise before grinding.

After commutators have been made properly tight they should then be ground or turned to a true surface. Before grinding, the brushes should be lifted off the commutator, as the copper and stone dust will rapidly wear them off. The dust will also become imbedded in the brush contact surface and later damage the commutator or cause poor commutation. The armature winding should also be **thoroughly** protected during this operation to prevent an accumulation of dirt and metal chips, which may result in an insulation failure when the machine is again put in service. This protection can usually be best obtained by using a circular shield of fullerboard, or similar material, around the commutator at the end next to the armature. This shield can be easily supported from the brushholder arms and should extend from the commutator surface to an inch or two above the surface of the armature. Another method is to shellac circular segments of heavy paper to the commutator necks, making an air-tight shield that revolves with the armature. A shield of some kind should also be put at the front end of the commutator around the shaft, so as to prohibit any dust or chips from being drawn back under the commutator and into the windings.

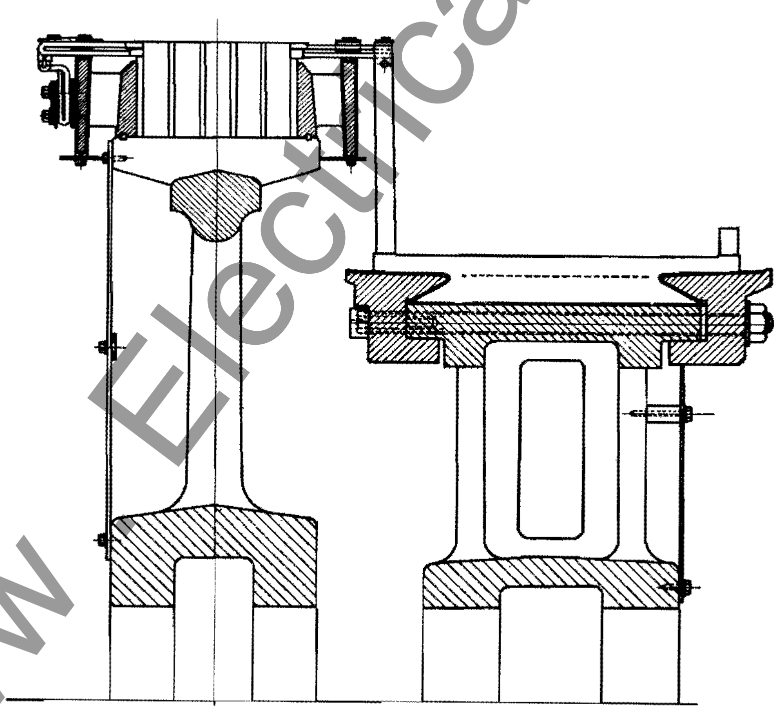


Fig. 22—Section of Commutator Showing Latest Type of Through Bolt Construction

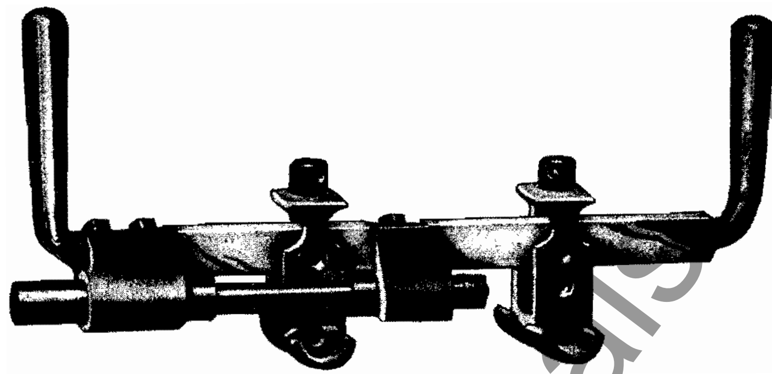


Fig. 24—Motor Operated Slotting Tool

A vacuum dust collecting outfit is now being used quite generally by our Service Engineers when commutators are being ground. This outfit works on the same principle as the ordinary household vacuum sweeper. The nozzle is of special shape so that it fits close up against the grinding stone and collects the discharge dust as it leaves the stone. A flexible hose permits the nozzle to follow the stone back and forth across the commutator. It has been found that with this arrangement from 85 to 90% of the dust is collected that otherwise used to be thrown off into the room and into the machine.

After grinding a commutator the machine should always be thoroughly cleaned by blowing out with **dry** compressed air or by wiping out with rags before replacing it in service, or by both.

Emery cloth or paper should never be used on account of the continued abrasive action of the emery which becomes embedded in the copper bars and brushes.

In cases where it is desired to obtain a high temperature on the commutator for seasoning, this can be conveniently accomplished by removing the direct-current brushes from their holders and replacing them by maple block brushes. By imposing a high tension on these wooden brushes and running the machine at its normal rated speed the desired temperature for seasoning will usually be found to be easily obtained. It may also be heated by external sources, but due to the inability to heat uniformly in this way, the former method will ordinarily be found to be preferable.

Undercutting Commutator Mica—All standard commutators have the mica between bars undercut $\frac{1}{16}$-inch. After grinding or turning a commutator, the undercutting should be cleaned out and the edges of the bars scraped to remove burrs. **It is particularly important that the edges of the bars be well rounded.** Failure to do this has caused machines to buck on sudden changes in load or when the circuit-breaker opens.

If it is necessary to re-undercut the mica due to grinding or turning the commutator or due to wear after long operation, this may be done with a hack saw blade held between suitable guides or, more conveniently and accurately with motor-driven circular saws.

Care of Commutators—The ideal appearance of a commutator surface is a polished dark brown or chocolate color. Such a commutator needs no attention other than to be kept clean. Use of oil, grease, vaseline, or so-called commutator compounds will gum up the commutator causing a deposit of carbon and metal dust on the surface and particularly in the undercutting that may cause "burning" and "flashing".

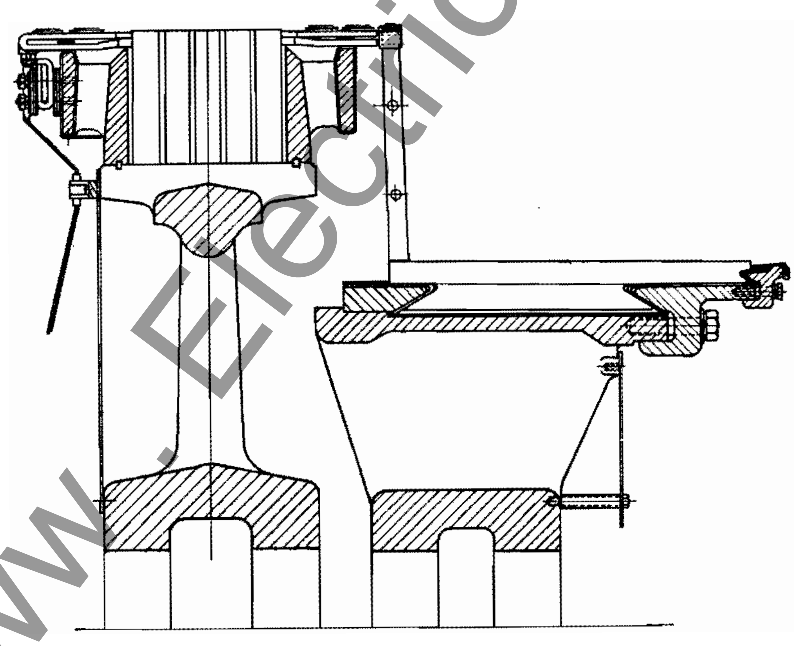


Fig. 23—Section of Commutator Showing 3V Type of Construction

Sparking at Direct-Current Brushes—Some sparking under the brushes on modern high-speed commutating apparatus should not be construed as discreditable performance. The personal element involved in the interpretation of satisfactory commutation makes the subject a difficult one for reaching agreement in many cases. An effort to arrive at some common basis of reasonable commutation requirements has accordingly been made in the 1925 Standards of the American Institute of Electrical Engineers. Under paragraph 5—254, successful commutation is defined as follows: "Successful commutation is attained if neither the brushes nor the commutator are burned or injured in an acceptance test or in normal service to the extent that abnormal maintenance is required. **The presence of some visible sparking is not necessarily evidence of unsuccessful commutation."**

Sparking may either be due to mechanical causes or electrical causes.

The usual causes of sparking from mechanical faults are:

(1) Rough commutator, due to high bars, high mica (if commutator is not undercut,) flat spots, or rough edges of undercutting.

(2) Vibration, originating in brush rig.

(3) Unequal spacing of brushholder bracket arms.

(4) Incorrect setting of direct-current brushholders too far away from commutator, or misalignment of the holders on the bracket arm.

(5) Incorrect brush tension.

(6) Brushes sticking in holders.

If the sparking is due to electrical causes, it will be seen to vary appreciably with load changes on the machine. The more common electrical causes of sparking met with in operation are:

(1) Brushes on all arms or on part of the arms incorrectly set with respect to neutral points.

(2) Brushes of wrong composition or resistance.

(3) Incorrect adjustment of commutating-pole winding.

(4) Non-uniformity of main or commutating-pole air gaps.

(5) Hunting—In this case sparking will be periodic, corresponding to frequency of oscillation of armature.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature.

If sparking occurs that cannot be accounted for by overloads or other service conditions, wrong adjustments, or mechanical defects, an experienced engineer should be consulted to determine the cause and remedy.

"Bucking" or "Flashing" between arms of opposite polarity is caused by excessive voltage generated in the coils short-circuited by the brush or between adjacent commutator bars, or abnormally low surface resistance on the commutator between adjacent brush arms. Any condition tending to produce poor commutation increases the likelihood of "bucking". Bucking is usually caused by the following:

(1) Rough or dirty commutator.

(2) A drop of water on the commutator, from the roof, leaky steam pipes or other source.

(3) Sudden change of alternating-current voltage due to disturbances on the high tension distributing system, induced by lightning, switching, short-circuits, etc.

(4) Excessive overloads or short-circuits on the direct-current side.

(5) Frame or bedplate grounding. It is necessary that the resistance from the machine frame to the station ground should be of such a nature that the current incident to an arc from the commutator to one of the grounded circuits should not be of a sufficiently appreciable value to cause damage. See grounding machine frame under "Application and Protection" heading.

"Bucking" or "Flashing" Remedies—If flashing continues after the first two possible causes have been eliminated the trouble will usually be due to causes external to the machine. If alternating-current line troubles are in evidence the converter can usually be protected as indicated under the heading "Adjustment of Protective Devices". If this does not remedy the trouble the high tension line disturbances must be eliminated or reduced to a minimum.

Flashing can in most cases, especially on railway converters, be traced to excessive overloads usually caused by short-circuits. The only way to correct this is to protect the converter from these short-circuits. This can often be accomplished by increasing the resistance in the feeders. A readjustment of machine and feeder breakers will very often improve results. Experience has shown that the majority of flashing troubles on converters **are due to external local conditions** which must be corrected before the flashing trouble will be eliminated.

Collector—Care should be taken to insure the true running of the rings. If only slightly roughened, the rings can be trued up with sandstone and sandpaper.

It is particularly important to maintain the trueness of the collector rings when using the metal-graphite type of alternating-current brush as any sparking will cause rapid wear of the brushes.

Sparking at Alternating-Current Brushes—Sparking, when it occurs in regular operation, is in general caused by imperfect contact between brush and slip ring. This may be due to:—

(1) The introduction of dirt or particles broken from the edge of the brush between the brush and the ring.

(2) Lack of free movement of the brush in the holder either because of too

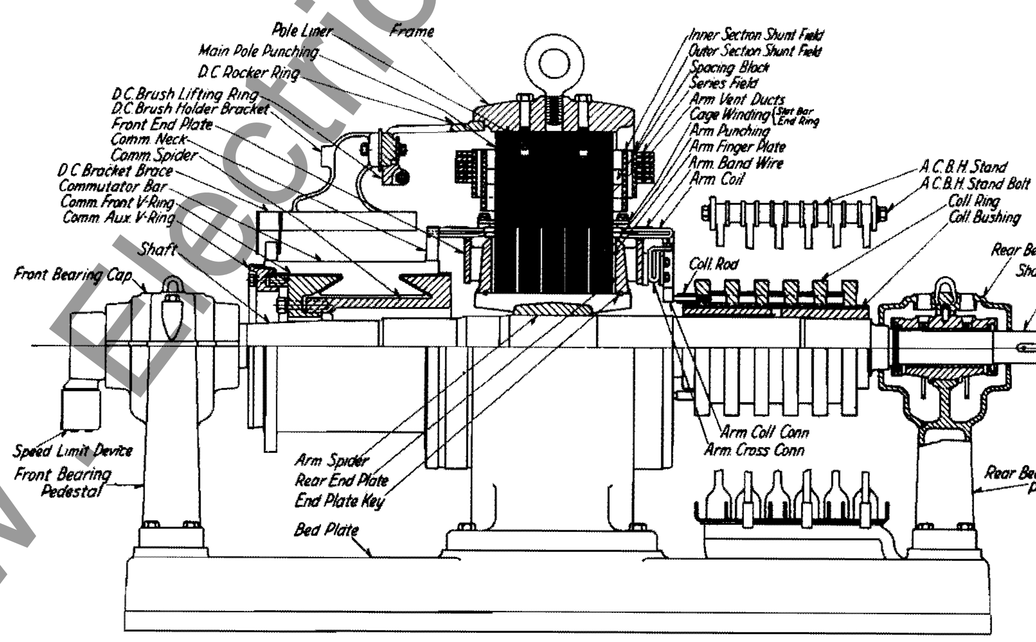


FIG. 25—CROSS SECTION OF A SMALL CAPACITY SYNCHRONOUS CONVERTER

tight fit, or cramping due to too loose fit. Brushes may stick in the holders because of the collection of copper dust between the brush and the holder. This dust may conduct sufficient current to fuse the dust to the brush and the brush to the holder.

(3) Incorrect brush spring pressure.

(4) Rough or untrue collector rings which cause momentary separation between the brush and the ring.

(5) Vibration of collector rings, brushes or brush supports which also causes a momentary separation.

(6) Incorrect setting of brushes on the rings.

(7) Incorrect setting of the brush-holders.

(8) Excessive current density due to overloads. The mechanical contact is never perfect and high current density will cause sparking with brush fits which would be accurate enough for normal densities.

Lubrication of Collector Rings—If the proper grade of alternating-current brush is used on a converter, there is sufficient graphite in the metal-graphite brushes so that no lubrication of the rings should be necessary.

Repairs

Ordering of Renewal Parts—Renewal parts of any standard Westinghouse converter may be secured. To avoid misunderstanding always give the serial number and S. O. number if available, of the stationary or of the rotating part of the machine, as the case may be. The numbers will be found stamped on the nameplate or on the end of the shaft. When material for coils is ordered, it should also be stated whether or not insulation for the winding is also desired. Specify renewal parts as far as possible by name as per Figs. 3 and 25.

Rebabbitting Bearings—The old babbitt should first be melted out and a suitable mandrel prepared. Split bearings should be babbitted one-half at a time, and the mandrel should consist of a half-cylinder with shoulders running along its length on which the sides of the bearings may rest, so as to form a close fit when the bearing housing is in position for babbitting. Pieces of felt should be placed between the ends to prevent the babbitt from running into the oil well in the spaces back of the bearing shell. Use only the best babbitt metal. The melted babbitt should be poured in the gate until it begins to overflow, and a few moments should elapse before it is removed from the mandrel, in order that the bearing may become quite hard. The bearing housing should then be bored or reamed to the proper size, the holes for inspecting the working of the oil rings drilled, and the oil ring slots melted or cut to the proper depth. The finishing can be done with a file. If the mandrel is a smooth half-cylinder the oil grooves should be chipped out. The grooves may be cast by properly designing the mandrel.

Repairs to Insulation—If a defect develops in the outside of a field or armature coil, it can sometimes be repaired by carefully raising the injured wire or wires and applying fresh insulation. More extensive repairs should not be attempted by inexperienced or unskilled workmen.

Sectional Bands—Large converter armatures are provided with sectional bands instead of the more familiar continuous bands, greatly facilitating the repair of large armatures.

Figs. 26 and 27 show the tool used in connecting and disconnecting sectional bands.

To make the final connection between the free ends, after the different sections have been keyed together into an open hoop and are in position on the armature, place the tool as shown in Fig. 26, the two jaws gripping the projecting ends of the fixed pieces let into the ends of each section for this purpose. With the tool in the position shown in Fig. 26, bring down the handle to the position of Fig. 27, forcing the movable jaw forward along the beam and interweaving the loops on the section ends. Insert the steel pin A in the holes through the movable jaw and beam, and with the tool clamped in this way, remove the handle and advance it to the next hole in the beam. This operation is repeated until the ends of the band are interlocked sufficiently to permit the steel key piece B to be inserted (see Fig. 26). All that remains is to remove the tool and paint or shellac the joint.

To remove the band, reverse the preceding process. Relieve the tension on the joint by tightening the band with the tool and then drive out the key piece.

Caution

In soldering connections use an acid that will not act on the insulation or the copper; an alcoholic solution of resin is a suitable soldering flux.

In soldering commutator connections do not allow bits of solder to drop down where they may short-circuit commutator bars.

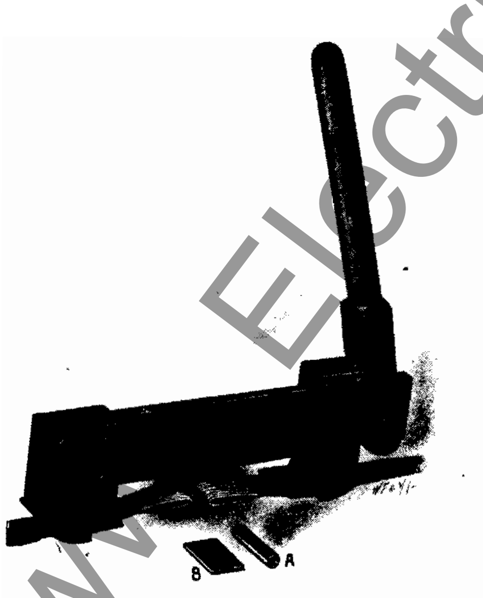


Fig. 26—Banding Tool—Open

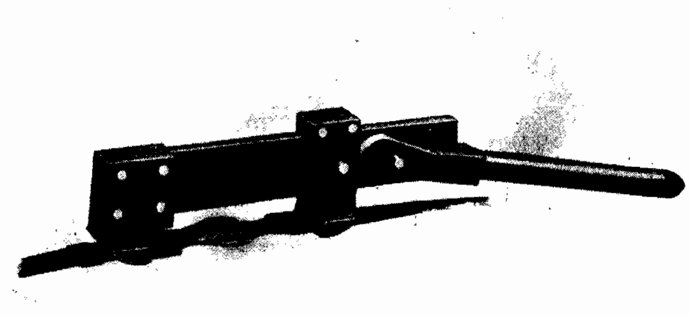


Fig. 27—Banding Tool—Closed

RENEWAL PARTS

Repairing

Repair work can be most satisfactorily accomplished at our Works, or nearest Service Shop. However, interchangeable renewal parts can be furnished, as listed below, to customers, who are equipped for doing repair work.

Recommended List of Renewal Parts

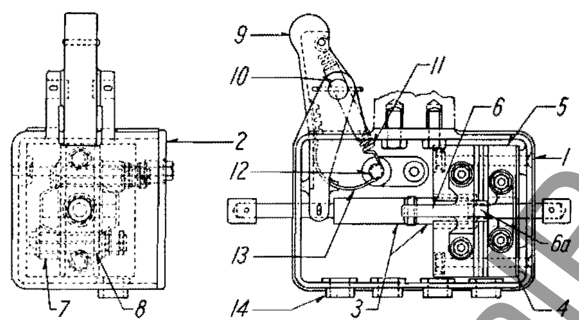
The following is a list of the renewal parts and the minimum quantities of each that should be carried in stock. These are the parts most subject to wear in ordinary operation and to damage or breakage due to possible abnormal conditions. The maintenance of such stock will minimize service interruptions caused by breakdowns.

Synchronous Converter

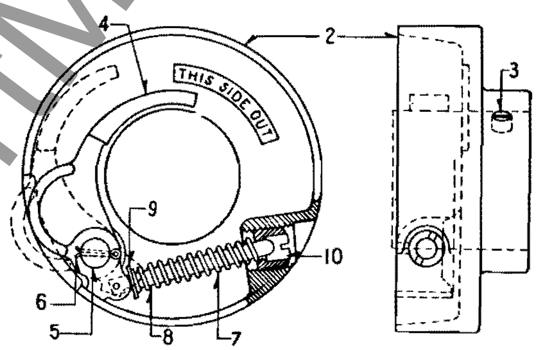
Name of Part	No. Per Unit	Recommended For Stock	
Total number of units up to and including		1	5
Rotary Parts			
Armature coil—(1 Set)	1	1/3	1
Necessary rewinding material for above	1 set	1 set	2 sets
Main field coil	**	1**	1**
A-C. brush—(1 Set)	1	1	2
A-C. brushholder—(1 Set)	1	1/6	1/3
D-C. brush—(1 Set)	1	1	2
D-C. brushholder—(1 Set)	1	1/4	1/2
Bearing	2	1	2
Oil ring	4	2	4
Booster Parts			
Armature coil (1 Set)	1	1/3	1
Necessary rewinding material for above	1 set	1 set	2 sets
Main field coil	*	1	1

*Number per unit varies with type of machine

**On fabricated machines, include pole also.



Mechanical Speed-Limit Switch



Governor

Mechanical Speed-Limit Switch

Ref. No.	Name of Parts	No. Per Unit	Recommended for Stock	
	Total number of units up to and including		2	5
1	Switch box	1	0	0
2	Switch box cover	1	0	0
3	Contact plunger	1	0	0
4	Micarta insulating plate	1	1	1
5	Fibre switch base	1	1	1
6	Contact spring (Large)	2	1	2
6-a	Contact spring (Small)	2	1	2
7	Micarta insulating tube	2	1	1
8	Micarta insulating tube	2	1	1
9	Switch lever	1	0	0
10	Hinge pin for switch lever	1	0	1
11	Spring for switch lever	1	1	1
12	Spring post	1	0	0
13	Flat spring for switch lever	1	1	1
14	Insulating bushing	2	1	2

Governor for Mechanical Speed-Limit Switch

Ref. No.	Name of Part	No. Per Unit	Recommended for Stock	
	Total number of units up to and including		2	5
2	Governor case	1	0	0
3	Headless set screw	2	0	0
4	Governor lever. . (Brass)	1	0	0
5	Steel Shaft	1	0	0
7	Operating spring	1	1	1
8	Guide	1	0	0
9	Steel washer	1	0	0
10	Headless set screw	1	0	0

Ordering Instruction

Give the complete name plate reading and name the part. State whether shipment is desired by express, freight or by parcel post. Send all orders or correspondence to the nearest Sales Office of the company.

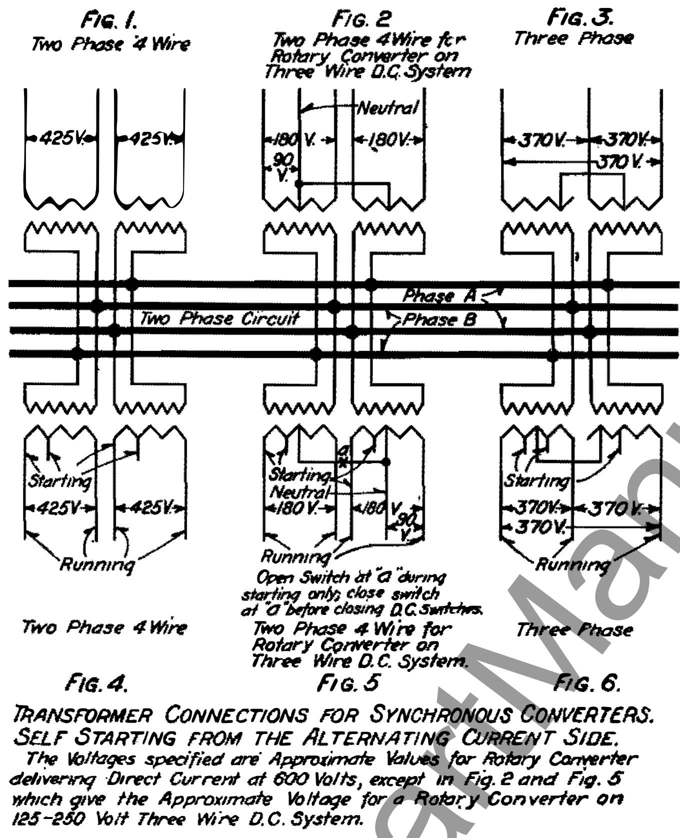


Fig. 28—Transformer Connections

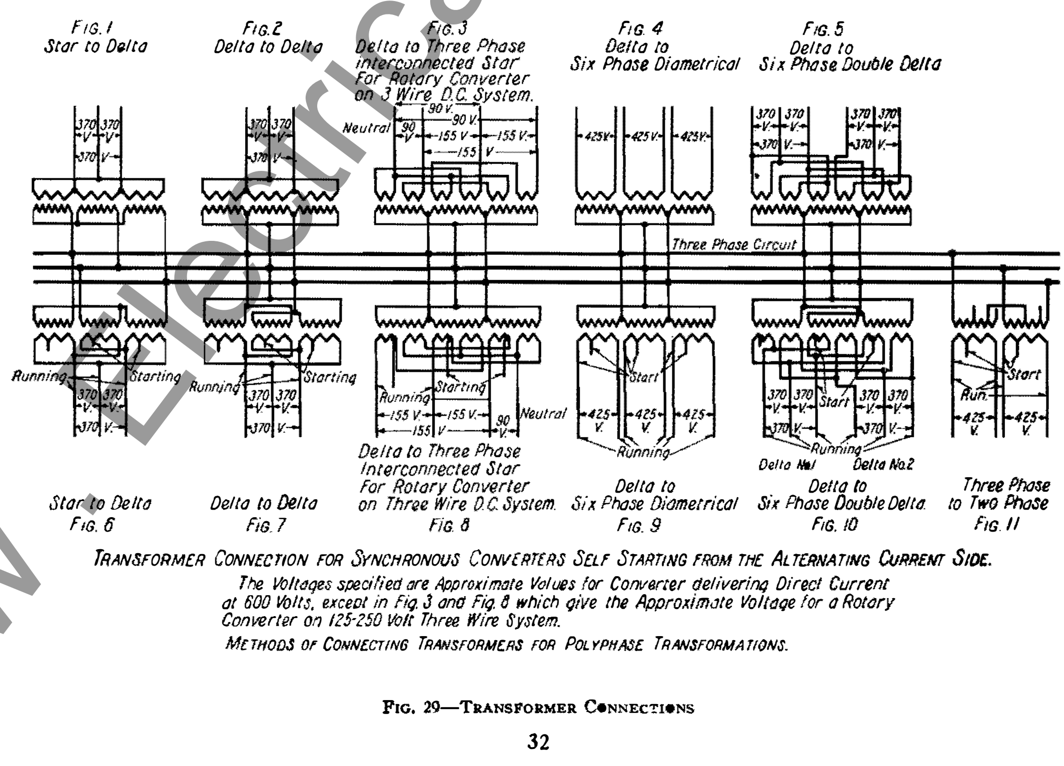


Fig. 29—Transformer Connections

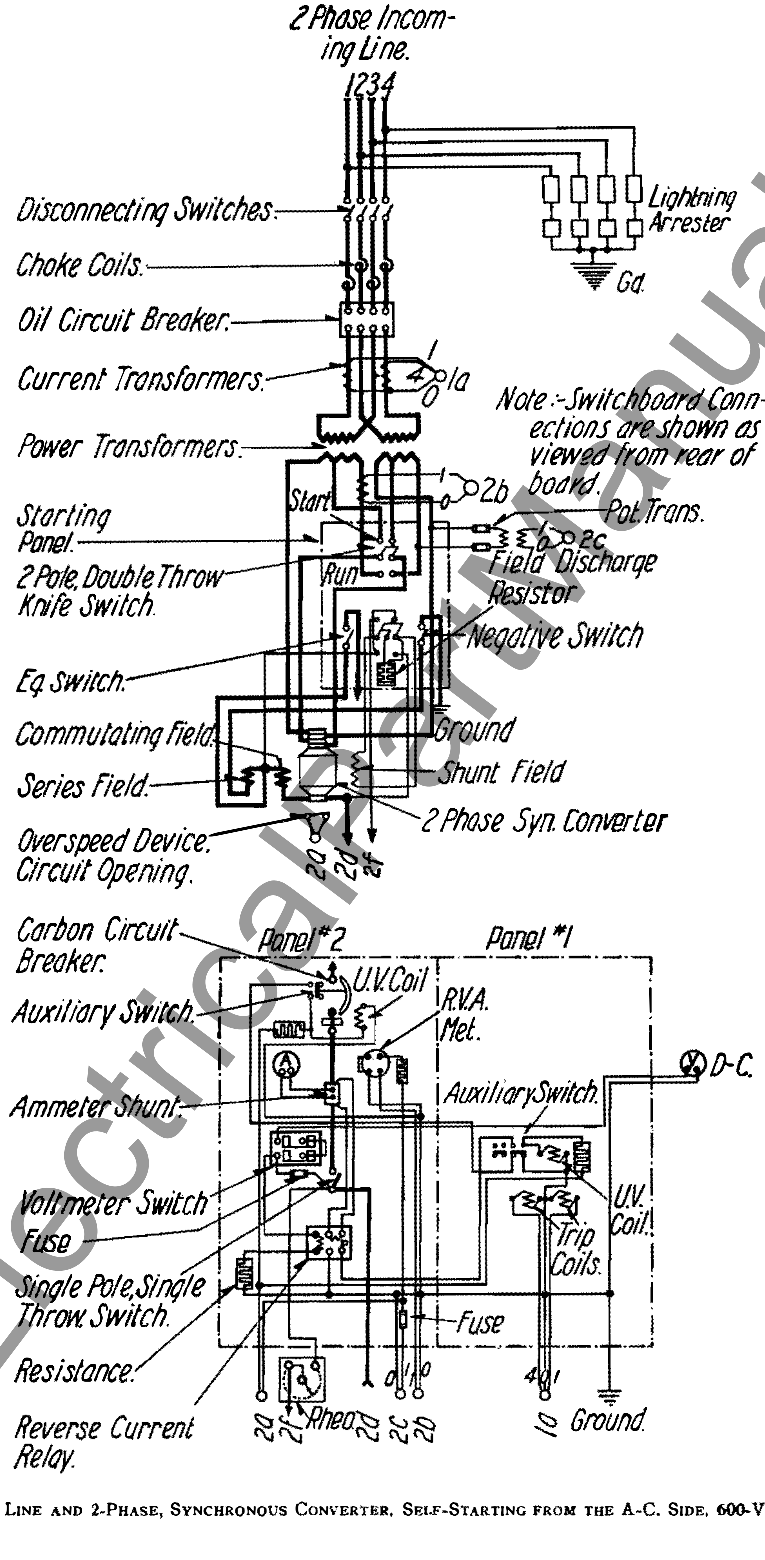


Fig. 30—2-Phase, Incoming Line and 2-Phase, Synchronous Converter, Self-Starting from the A-C. Side, 600-Volt, D-C. Railway Seraice

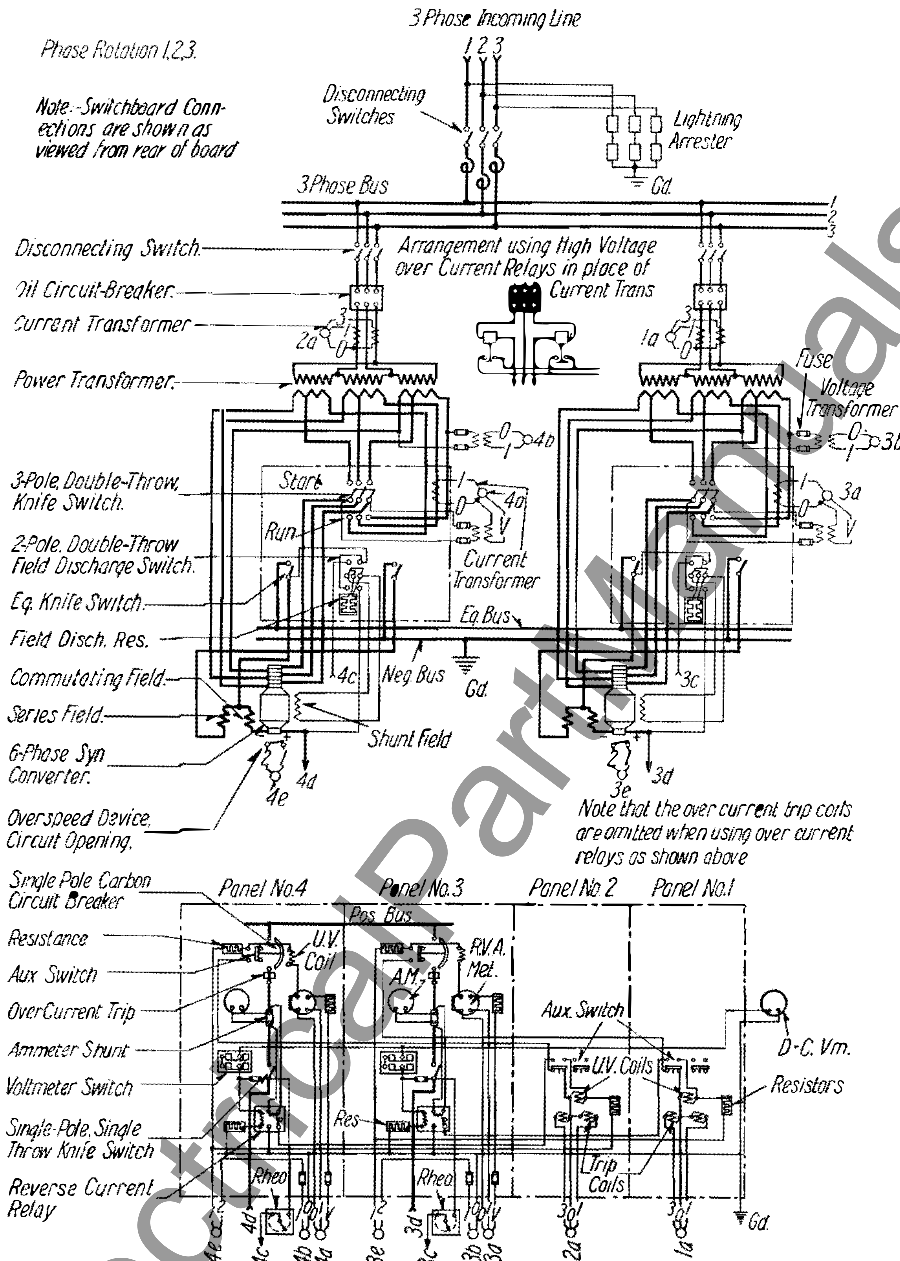


FIG. 31—3-PHASE UNGROUNDED NEUTRAL INCOMING LINE, STEP DOWN TRANSFORMERS AND 6-PHASE, SYNCHRONOUS CONVERTERS, SELF-STARTING FROM THE A-C. SIDE, OPERATING IN PARALLEL, 600-VOLT, D-C. RAILWAY SERVICE, REMOTE MECHANICALLY CONTROLLED OIL CIRCUIT-BREAKERS

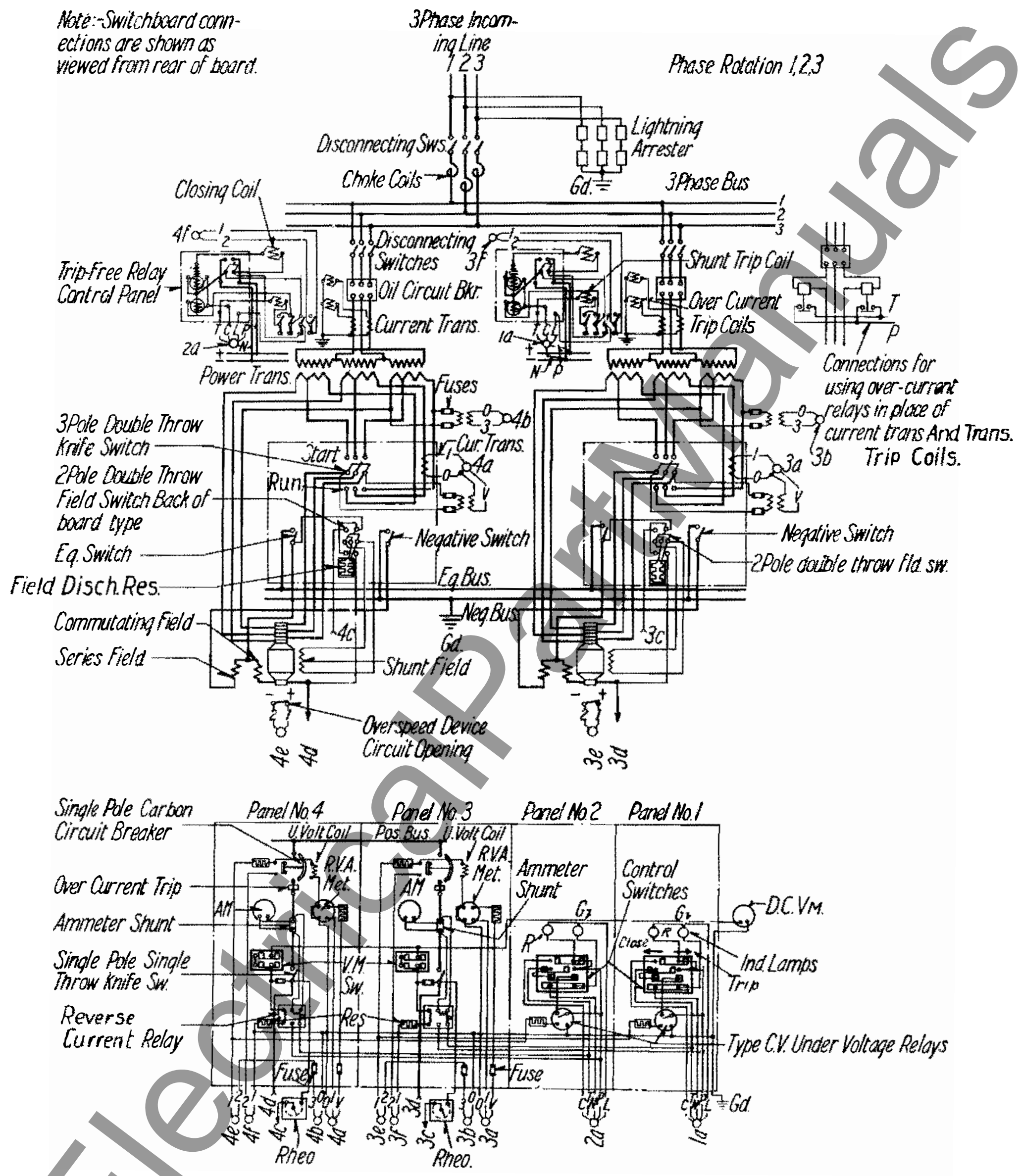


FIG. 32—3-PHASE INCOMING LINE AND 6-PHASE SYNCHRONOUS CONVERTERS, SELF-STARTING FROM THE A-C. SIDE, 600-VOLT D-C. RAILWAY SERVICE ELECTRICALLY OPERATED OIL CIRCUIT-BREAKERS

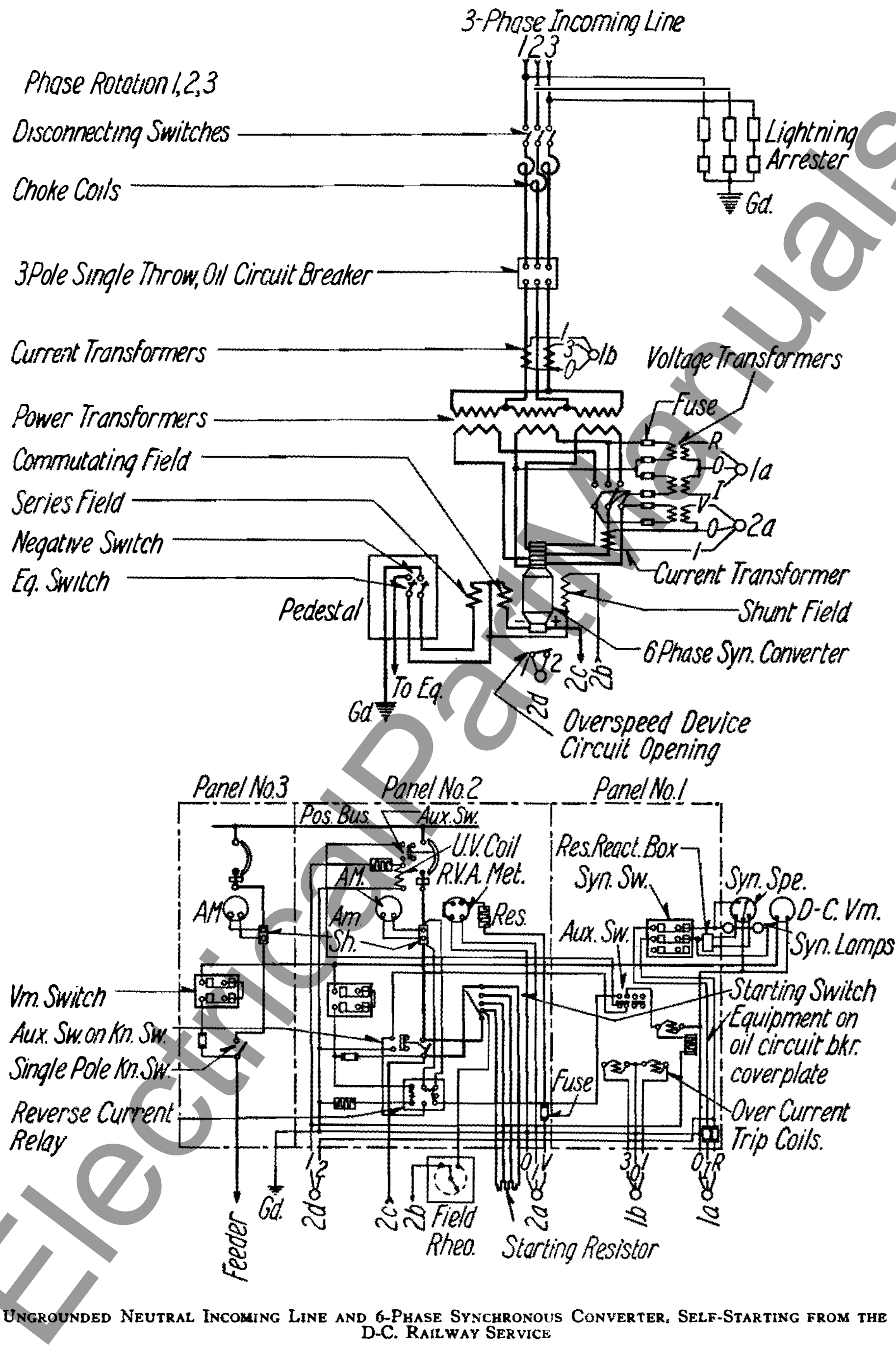


Fig. 33—3-Phase, Ungrounded Neutral Incoming Line and 6-Phase Synchronous Converter, Self-Starting from the D-C. Side, 600-Volt D-C. Railway Service

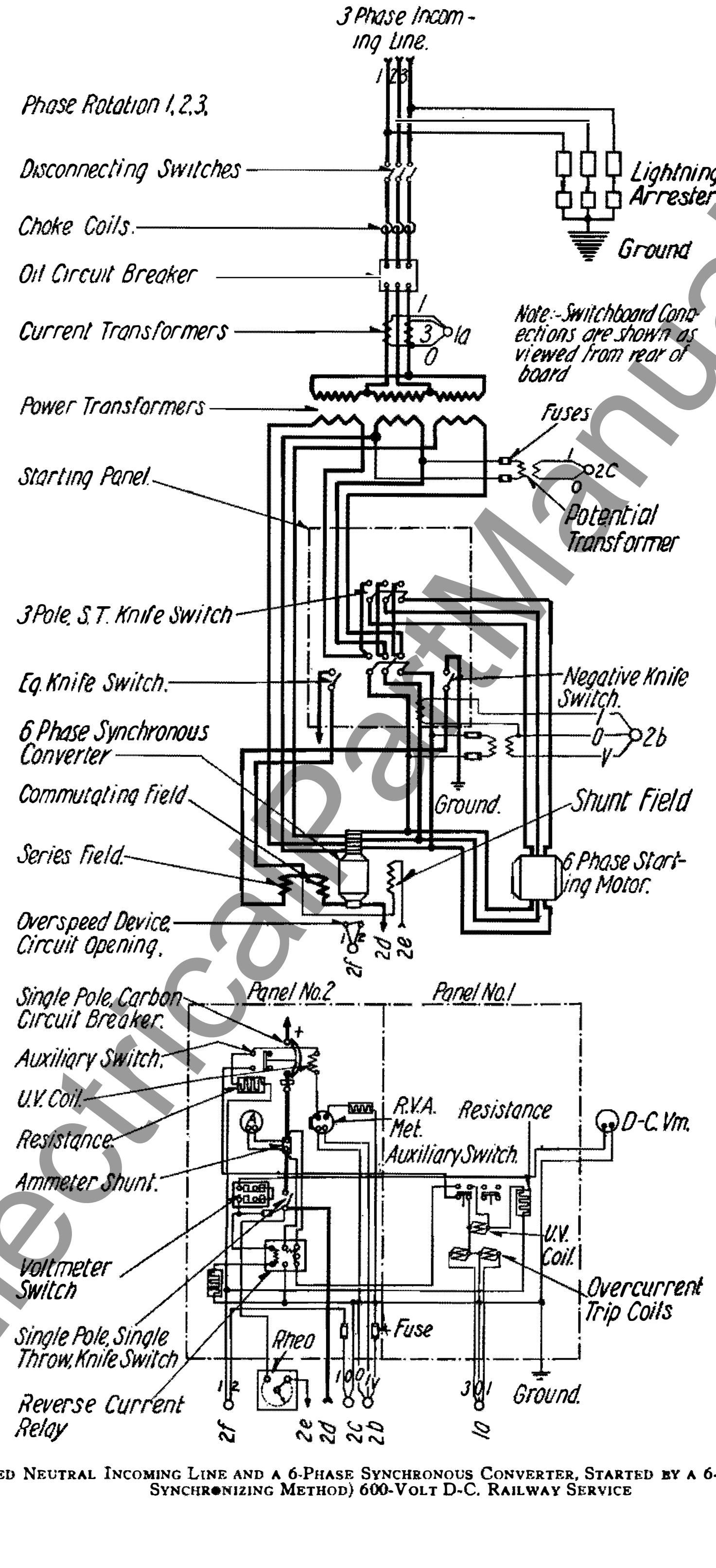


FIG. 34—3-PHASE UNGROUNDED NEUTRAL INCOMING LINE AND A 6-PHASE SYNCHRONOUS CONVERTER, STARTED BY A 6-PHASE STARTING MOTOR (SELF SYNCHRONIZING METHOD) 600-VOLT D-C. RAILWAY SERVICE

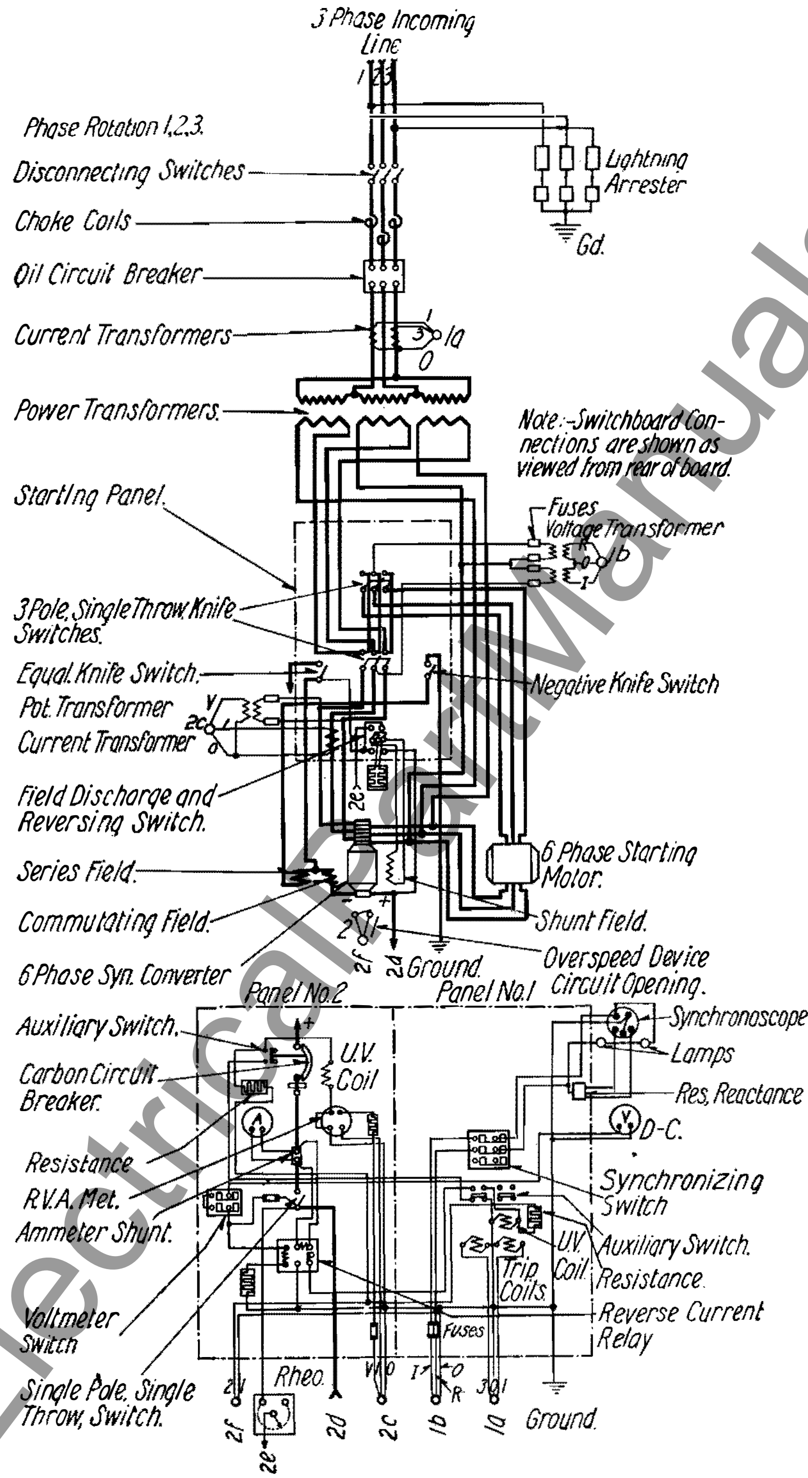


FIG. 35—3-PHASE UNGROUNDED NEUTRAL INCOMING LINE AND A 6-PHASE, SYNCHRONOUS CONVERTER, STARTED BY A 6-PHASE STARTING MOTOR 600-VOLT, D-C. RAILWAY SERVICE

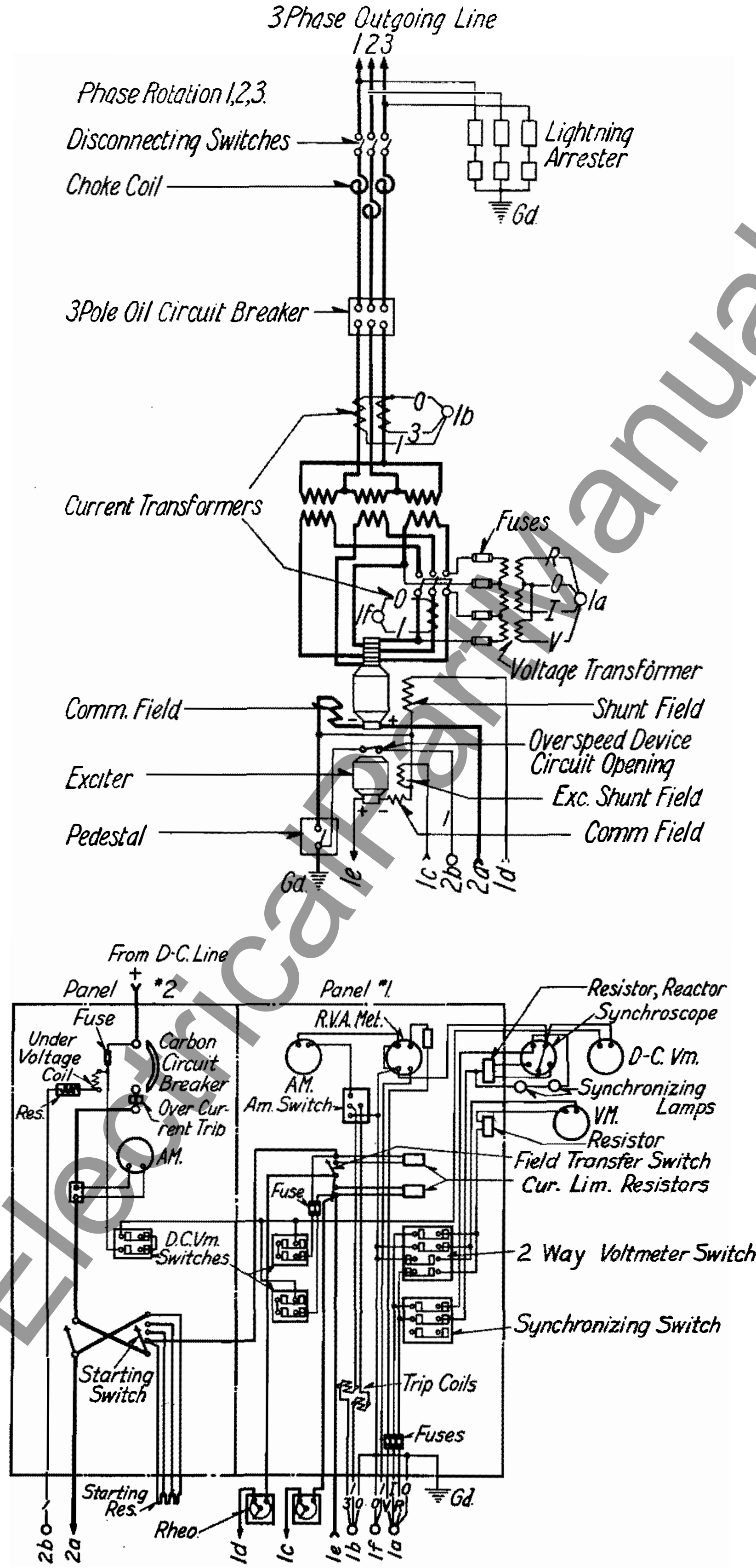


FIG. 36—600-VOLT, D-C. LINE AND 6-PHASE INVERTED SYNCHRONOUS CONVERTER, SELF-STARTING FROM THE D-C. SIDE, SUPPLYING A 3-PHASE UNGROUNDED NEUTRAL OUTGOING LINE

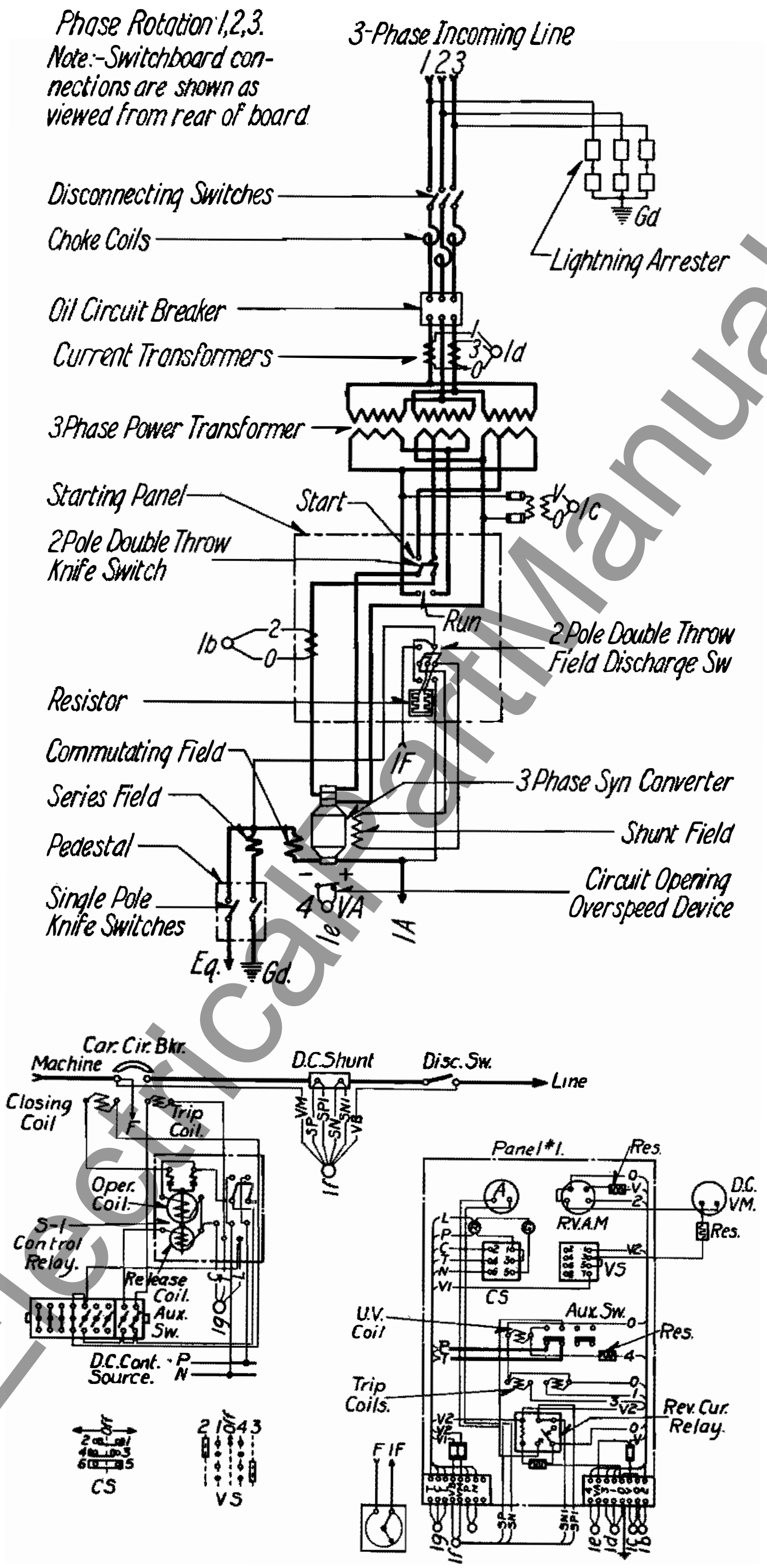


Fig. 37—3-Phase, Ungrounded Neutral Incoming Line and a 3-Phase Synchronous Converter, Self Starting from the A-C. Side, 1200 to 1500 Volt, D-C. Railway Service

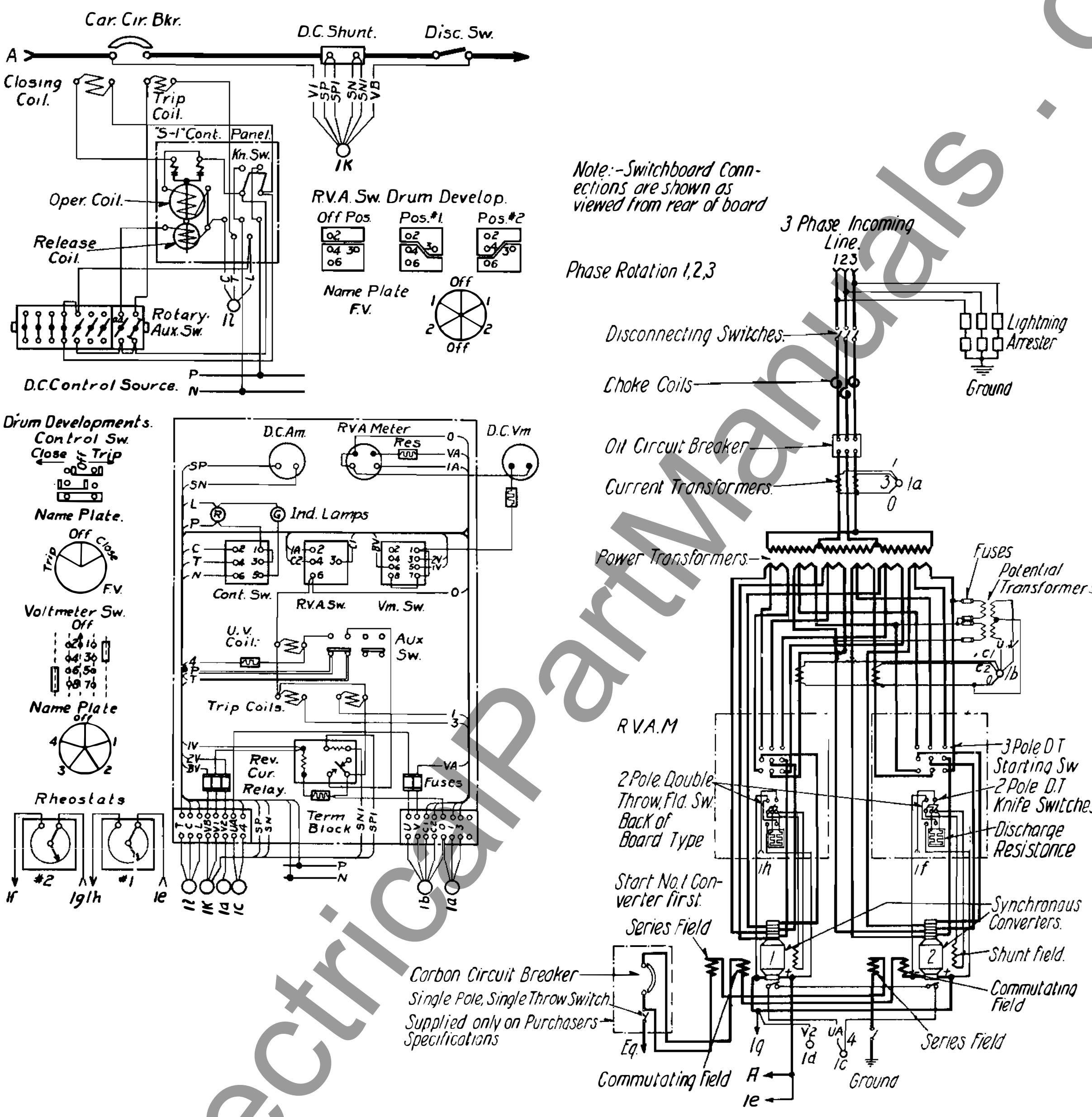


FIG. 38—3-PHASE, UNGROUNDED NEUTRAL INCOMING LINE, AND TWO 6-PHASE SYNCHRONOUS CONVERTERS, SELF-STARTING FROM THE A-C. SIDE, OPERATING IN SERIES, 1200 TO 1500-VOLT, D-C. RAILWAY SERVICE

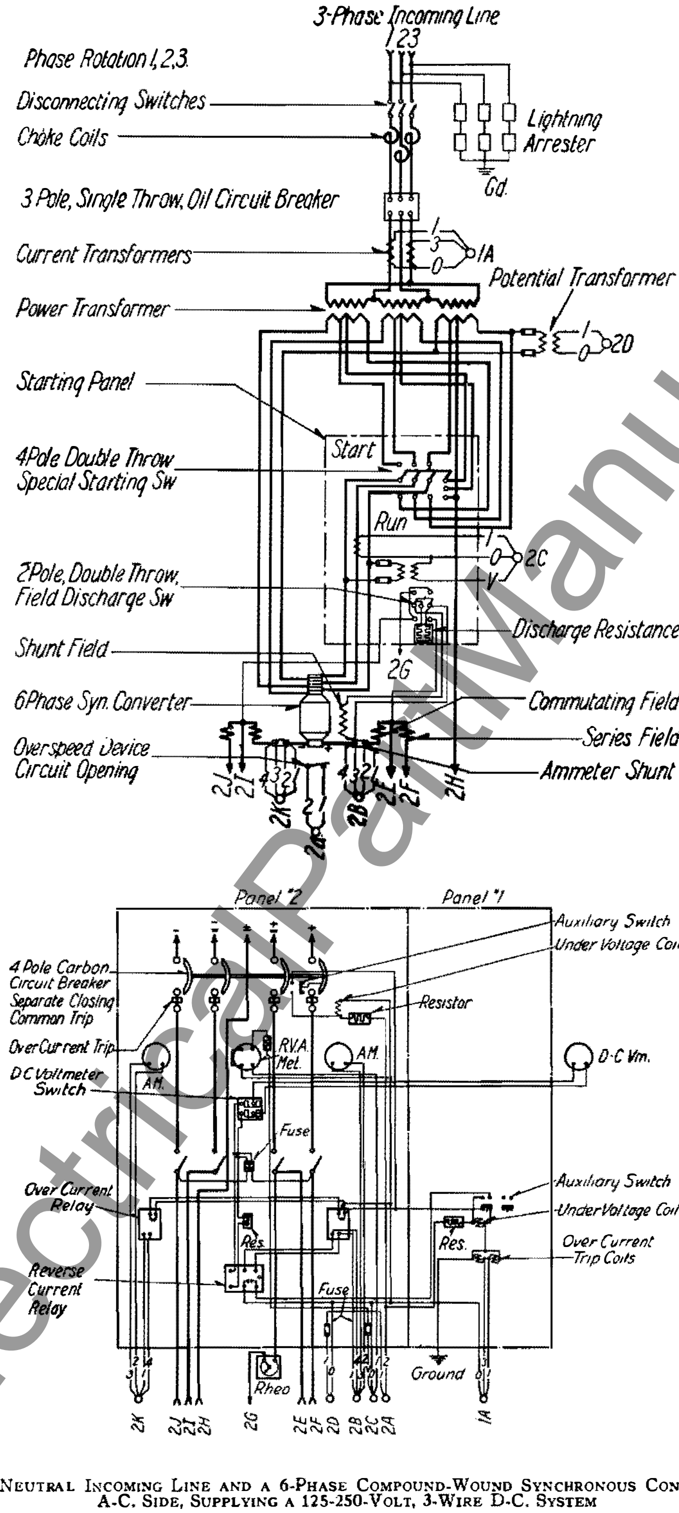


FIG. 39—3-PHASE UNGROUNDED NEUTRAL INCOMING LINE AND A 6-PHASE COMPOUND-WOUND SYNCHRONOUS CONVERTER, SELF-STARTING FROM THE A-C. SIDE, SUPPLYING A 125-250-VOLT, 3-WIRE D-C. SYSTEM

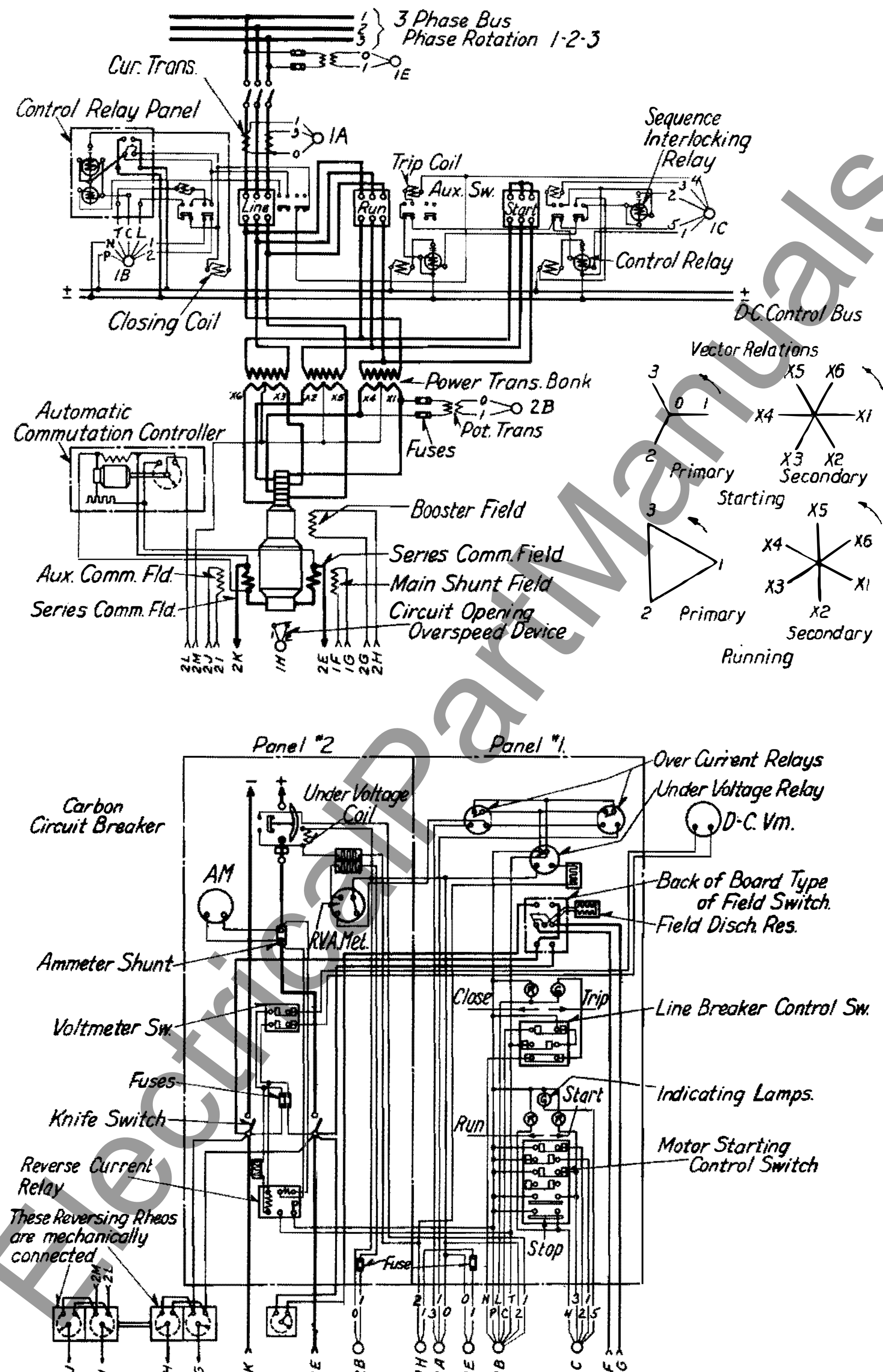


Fig. 40—3-Phase Ungrounded Neutral Bus and a 6-Phase Shunt Wound Synchronous Booster Converter, Self-Starting from the A-C. Side (H.T. or Star Delta Method) Supplying a 270-Volt, 2-Wire, D-C. System

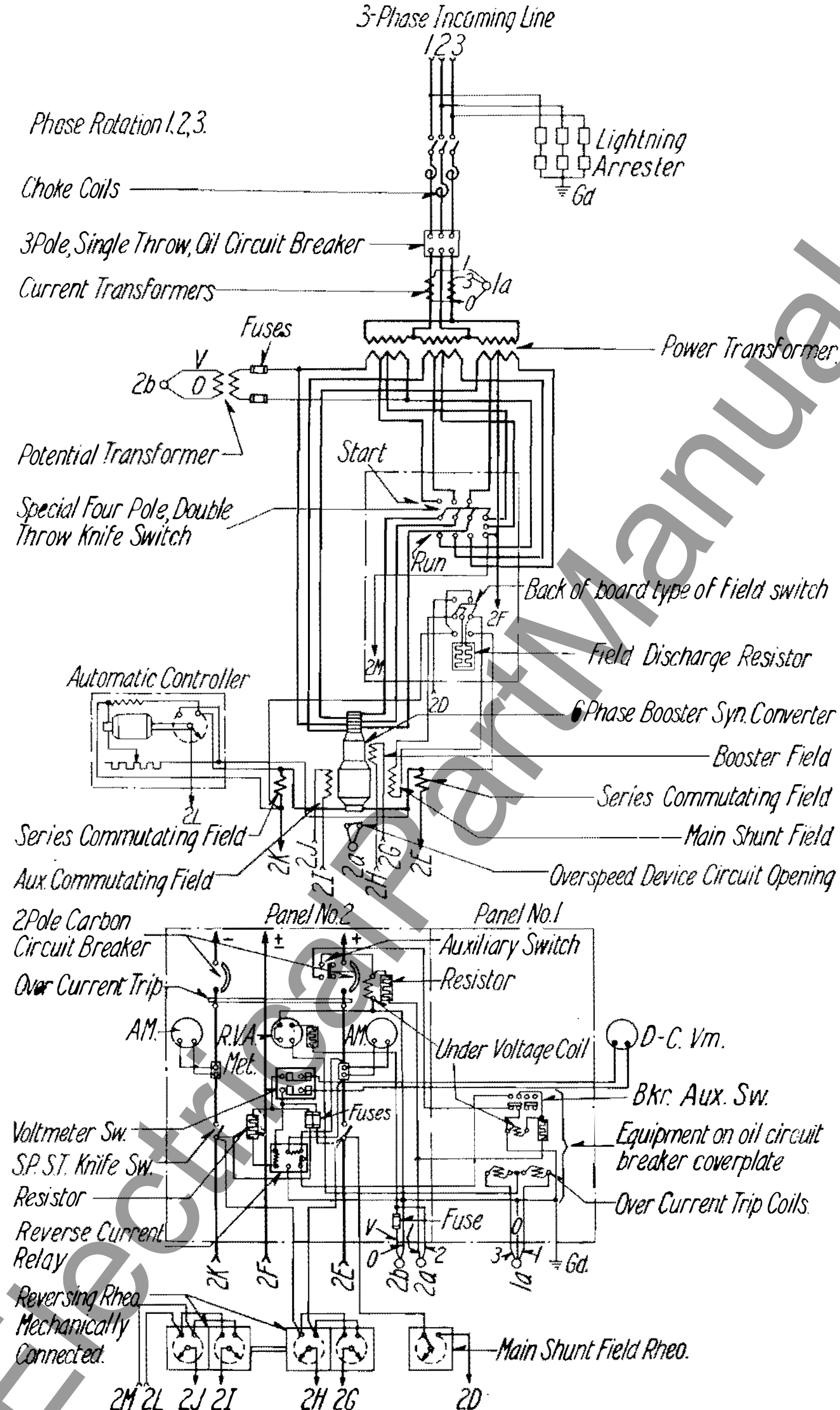


FIG. 41—3-PHASE UNGROUNDED NEUTRAL, INCOMING LINE AND A 6-PHASE, SHUNT WOUND SYNCHRONOUS BOOSTER CONVERTER, SELF-STARTING FROM THE A-C. SIDE (LT. METHOD) SUPPLYING A 135-270 VOLT, 3-WIRE D-C. SYSTEM