A Ten-Point Tandem Supervisory Control System.

WITH the rapid growth of electrical distribution systems and other public services such as water supply, sewerage, etc., the need of some form of centralised control is becoming increasingly important. In this connection a great deal of development work has been carried out and wide publicity has been given to the very comprehensive supervisory control schemes which have been designed for large distribution networks. There are, however, many other instances where remote control can be employed with advantage if the cost of available schemes bears an economic relation to the earning capacity of the plant.

In this article it is proposed to describe a simple, inexpensive and yet flexible method of remote supervisory control, the special application chosen for descriptive purposes being the control of equipment on an A.C. rural distribution system.

Such a network will usually consist of one or more ring mains operating at 11,000 volts or 33,000 volts, and at comparatively frequent intervals kiosks or pole-mounted tapping points will be provided where power is transformed from the E.H.T. supply to feed in to the 400-volt 4-wire network.

One of the chief difficulties in operating such a system is the maintenance of normal voltage at consumers' terminals within the limits laid down by the Board of Trade. Another difficulty is the rapid re-arrangement of circuits to restore power after line trouble or any other disturbance which may have caused a failure of supply.

To maintain normal voltage at the consumers' terminals it is in most cases not possible to vary the ring main pressure with the rise and fall of load and it becomes necessary to fit each of the distribution transformers with on-load tap-changing gear or to instal induction regulators in the kiosks. From the above it will be seen that some form of remote control is very advisable and the system to be described is admirably adapted for use in such a case.

As is indicated by the title this is a tandem system, the pilot wires, which are four in number and common to all sub-stations, being looped into each point in any convenient manner and terminated at the control station. Thus when a new sub-station is installed it is only necessary to extend the pilots from the nearest existing point.

The maximum number of operations which can be performed is ten, which number it is considered will adequately meet the requirements of even the larger type of kiosk installation. For example, the following facilities might be provided, leaving one spare:

(1) Raise the transformer ratio.
(2) Lower ,, ,, ,,
(3) Indicate ,, ,,
(4) Indicate the system voltage.
(5) Close No. 1 Circuit Breaker.
(6) Trip ,, ,, ,,
(7) Close No. 2 ,, ,,
(8) Trip ,, ,, ,,
(9) Telephone Call.

The number of stations which can be worked in tandem on one pilot cable is theoretically almost unlimited, but practical considerations usually limit the total to approximately thirty.

Method of Operation.

To each sub-station a number is allocated, consisting of two or three digits according to the size of the system. Each operation to be carried out at these stations is also numbered, but by a single digit only, the same number being employed as far as possible for equivalent operations at all stations.

At the point of control a dial of the automatic telephone type is provided, by means of which, after a start key has been operated, a station number may be dialled in the usual manner. This action causes impulses to be sent out over two pilot wires to all stations, where they are received by step-by-step selectors, each impulse advancing the selectors by one step. Thus, on completion of a train of impulses all selectors will be resting in the same position.

By the setting of straps on a terminal panel each station is made responsive only to its allotted number which, when received, prepares a local circuit condition enabling the selector at that station to respond to further impulses. The receipt of the first dialled impulses at all stations other than that of which they constitute the pre-arranged number causes those stations to be locked out. Further, the receipt of the digits at the selected station is confirmed to the control point by a signal which is sent back and illuminates a check-back lamp on the control panel. For this back-indication a separate lamp is provided for each station so that if, due to faulty dialling or interference on the pilot wires, the wrong station is selected, the operator is warned by the illumination of the corresponding lamp. It would then be necessary to release the line and dial again before proceeding.

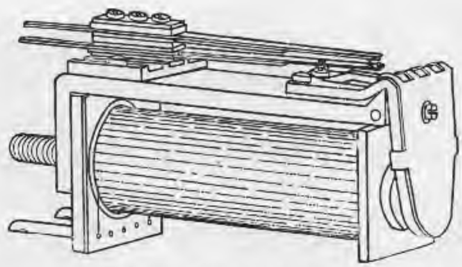

Fig. 1. Standard relay.

Having selected the station and received the correct check-back indication the operator will dial the number allocated to the particular operation it is desired to perform at that station. A further train of impulses will thus be sent out to the line, but, as already mentioned, these impulses will be effective at the selected station only, where the selector will now be advanced to a position corresponding to the desired operation. When this is completed a check-back signal is again sent to the control station to indicate that the equipment is prepared correctly. This indication is also given by a lamp, associated with the selected operation.

Thus if it were desired to ascertain the position of the transformer tap-changing switch the allotted number, say 5, would be dialled and, after the correct selection had been effected, the corresponding lamp on the control panel would light. But if for any reason the point associated with, say, the raising of the tap-changing switch had been selected, a separate lamp indicating preparation of the equipment for this purpose would warn the operator to release and dial again.

The second check-back signal having been received correctly, the desired operation is carried out by depressing an "operate" key which controls the functioning of a contactor associated with the point on which the sub-station selector is standing. In the typical case referred to above this contactor causes a device connected to the tap-changing switch to send back a signal to the control station, where one of a strip of lamps is illuminated to indicate the point on which the tap-changing switch is resting. On the release of the "operate" key the contactor releases and the indication stops.

The whole system can then be returned to normal by restoring the start key.

It will be noted that a dial has been specified as necessary for sending out the impulses required for selecting firstly the station and subsequently the operation to be carried out. If desired this piece of apparatus at the control point may be replaced by a set of telephone type keys, in which case a separate key would be provided for each operation at each station on the system. Instead of dialling the numbers a station and operation would then be selected by depressing the appropriate key, an auxiliary equipment being provided to generate and control the impulses sent to the line. While to some extent this arrangement simplifies the procedure it adds to the complexity of the system and increases the cost by an amount which, in many cases, may not be justified.

Apparatus.

The control station equipment comprises :

(*a*) A control panel.

(*b*) Relay and selector equipment.

(*c*) A 50-volt storage battery.

(*d*) Telephone instrument when required.

The control panel (*a*) in its simplest form consists of the wood front of a cabinet containing the relay and selector equipment (*b*), and carries the start and operate keys, the dial,

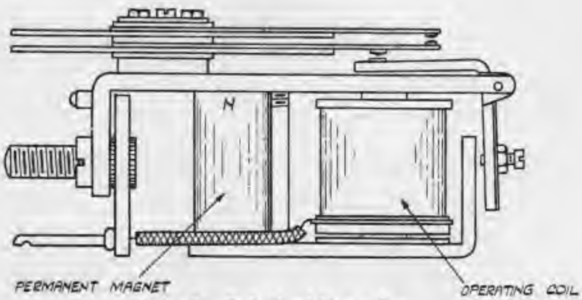

Fig. 2. Polarised line relay.

two strips of check-back lamps (one for station check-back, one for operation check-back), and when required a further strip of lamps for tap-changing switch indication. There may also be mounted on this panel a chart showing the numbers allotted to the various sub-stations and operations.

The cabinet in which the relay and selector equipment is mounted is of convenient size, measuring approximately 17-in. × 24-in. × 7-in. In design the whole of the apparatus it contains is similar to that used in public automatic telephone systems, the principal types of relays being as shown in Figs. 1 and 2. Contacts on all springs of these relays are of platinum and are duplicated to ensure freedom from faults commonly caused by dust and the presence of foreign matter. In order to give them a slow-to-release characteristic some of the relays are also provided with copper sleeves surrounding their cores.

The selector (Figs. 3 and 4) is a reverse drive rotary step-by-step switch. When the coils A are energised the armature B is attracted and pivots about the knife edge C against the pull of the helical springs H attached to the frame D. An extension of the armature carries a flat spring E to the extremity of which is connected the pawl F engaging the ratchet G. A further extension T of the armature breaks the contacts V when the armature is operated.

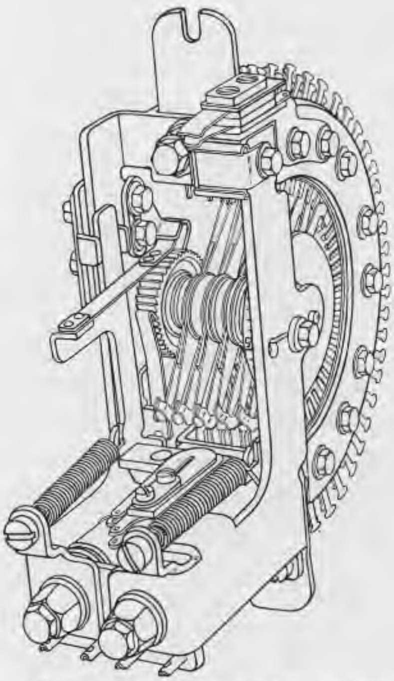

Fig. 3. Control station rotary selector.

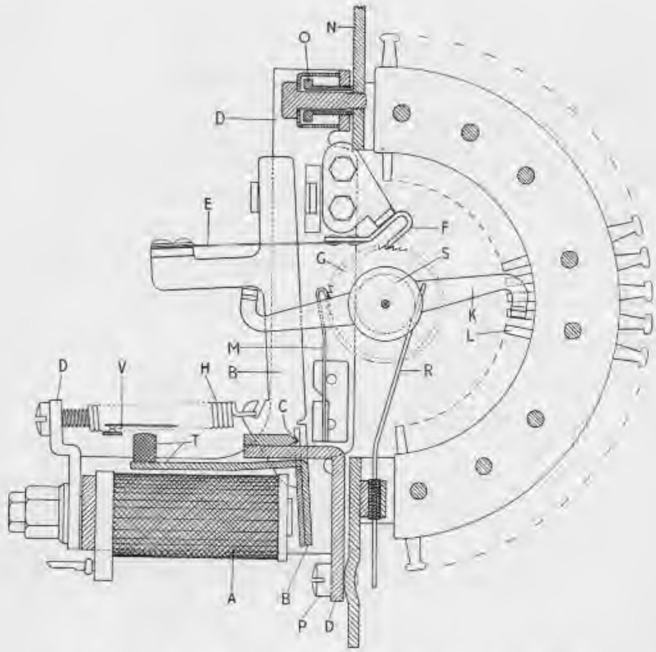

Fig. 4. Control station selector—mechanical details.

When the armature is attracted the pawl is carried into the next tooth of the ratchet, after which, when the coils are de-energised, the helical springs restore the armature to normal, thereby pulling the ratchet wheel one step forward. In this position it is held by the restraining pawl M. After each step a set of wipers K, clamped to the spindle of the ratchet wheel, is brought to rest centrally on a set of contacts L. Current is fed to the wipers by means of wire brushes R running in grooved discs S to which the wipers are secured. The banks or arcs of insulated contacts are mounted on the frame N which is carried by the main framework of the cabinet, while the frame D carrying the selector mechanism is attached to the bank framework by the gland screw O and screw P. The mechanism is easily detachable and can be accurately positioned relative to the bank contacts by means of the gland screw. All mechanisms are interchangeable.

With regard to the 50-volt supply (*c*) it is recommended that a separate storage battery be provided. Existing D.C. supplies might be used but it is considered advisable to keep the system independent of these, as it is at times when such supplies have failed that the equipment is particularly required. This 50-volt battery may be trickle-charged and of low capacity, say 10 ampere hours.

When provision is made for telephone communication between any or all of the sub-stations and the control operator, a telephone instrument (*d*) is included, working over the same pilot wires to all points.

The equipment provided at each sub-station consists of :—

(*e*) Relay and selector equipment.
(*f*) Such auxiliary contacts on the switchgear as may be required.
(*g*) A D.C. supply.
(*h*) Telephone instrument when required.

The relay and selector equipment (*e*) is mounted in a wood case 15-in. × 20-in. × 7-in. and includes the numbering panel complete with an arrangement of straps by which means each station is made responsive only to its allotted number. The relays are of the types already described but the selector is as shown in Fig. 5. This switch, which is also of a design used in automatic telephony, consists of an arc of 11 contacts swept by a set of wipers clamped to a shaft carrying a ratchet wheel which is engaged by the operating pawl. The operating pawl is pivoted on the extremity of the armature which is pulled forward under the control of the drive magnet against the tension of its return spring. The restraining pawl is kept in engagement with the ratchet wheel by a spring and is pulled out of engagement by energising the release magnet. A spiral spring housed within the hollow ratchet wheel, and having one extremity clamped to the ratchet and the other to the frame, is wound up as the wipers are advanced step-by-step over the arc of contacts. When the restraining pawl is withdrawn from the ratchet this spring returns the wipers to their normal position.

The auxiliary contacts (*f*) required on the switchgear are :—

> For each circuit breaker : One pair of contacts made when the breaker is open, and one pair made when closed.
>
> For each tap-changing switch : An auxiliary tapping switch geared mechanically to the tap-changing switch and making a separate contact for each position.

Depending on the size of switchgear to be controlled it may be necessary also to provide auxiliary contactors to step up from the voltages and currents carried by the contacts

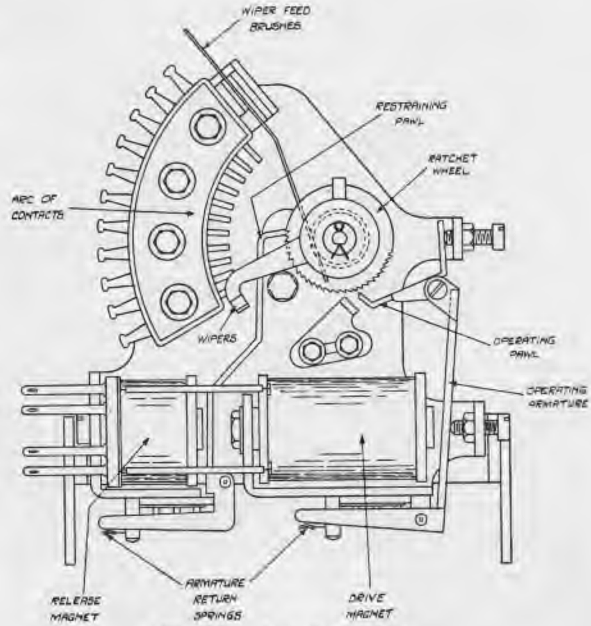

Fig. 5. Sub-station selector.

of the supervisory gear to those necessary for the operation of the switchgear. The contactors of the supervisory equipment, which form the link between the comparatively light telephone type apparatus and the switchgear, are capable of carrying and breaking 1 amp. at 230 volts.

The D.C. supply (*g*) required at each substation, preferably one of 24 volts, may conveniently be taken from the tripping battery, if available. If not, a trickle-charged storage battery may be used, or a rectifier and smoothing unit working from the A.C. mains.

The type of telephone instrument (*h*) recommended for the sub-station is made in a single unit containing the whole of the apparatus together with speaking batteries.

Circuit Operation.

The simplified circuit diagram in Fig. 6 shows the principal details of the equipment necessary at the control station and one substation for carrying out the following operations :—

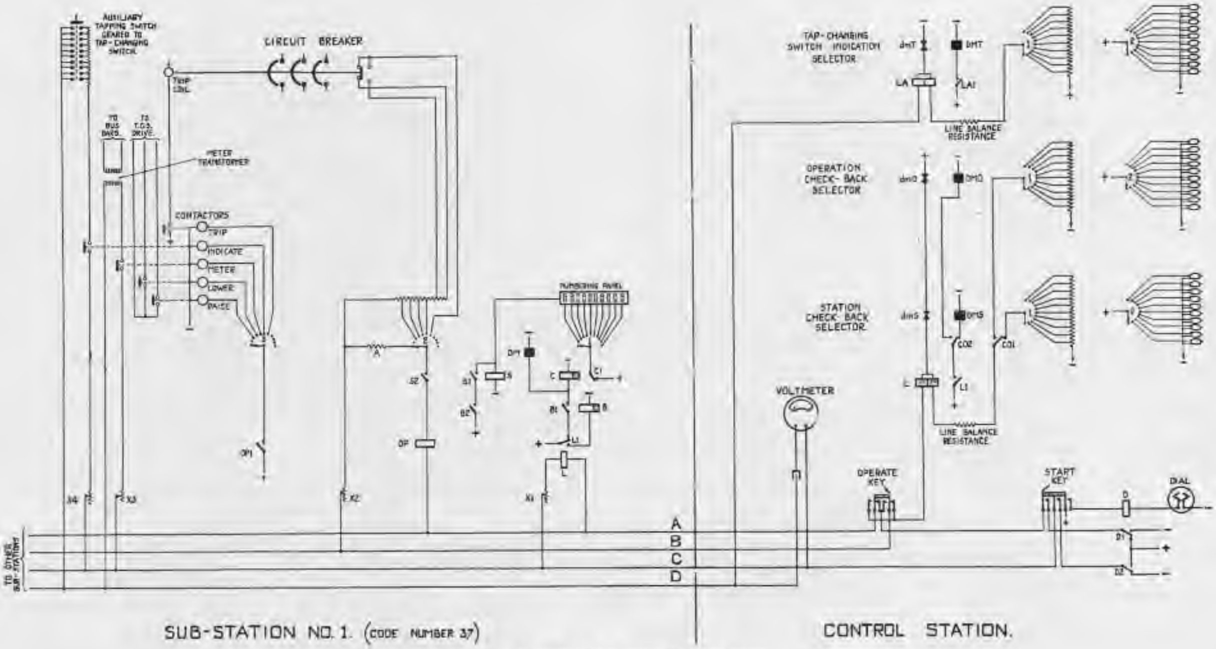

Fig. 6. Simplified circuit diagram.

(1) Raising and lowering the tap-changing switch.
(2) Reading the low tension bus bar voltage.
(3) Indicating the position of the tap-changing switch.
(4) Tripping the circuit breaker and indicating its position.

It will be assumed that the number allotted for selecting the sub-station shown is 37 and that the common digit 2 covers selection of the operation necessary to raise the tap-changing switch at any station on the system.

When the start key at the control station is operated one contact of the key connects positive battery via the dial contacts to relay D. Operated contacts D1 and D2 connect positive and negative battery via the operated contacts of the start key and normal contacts of the operate key to lines C and A respectively.

At each sub-station a polarised relay L is bridged across these lines in series with a variable resistance X1 which is set at each station to allow equal currents to flow in all L relays. The polarity of the L relays is such that they operate with negative battery on the A line and positive on the C.

Operated contacts L1 at the sub-station connect positive to relay B which operates. Having its core surrounded by a copper sleeve relay B is of the slow-release type and will remain operated for some 200 milliseconds after current is cut off.

The station number 37 will now be dialled. With the finger first inserted in the hole numbered 3 the dial will be pulled round to the stop and released, whereupon the finger plate will run back to normal and cause the dial springs to be opened and closed three times. Thus relay D will release and re-operate three times. On each release of D, contacts D1 and D2 reverse the direction of current in lines A and C, and consequently in the polarised relay L at the sub-station, which also releases three times.

On each release normal contacts L1 complete a circuit from positive through operated contacts B1 to relay C and to DM which is the operating coil of the selector. Each time DM is operated the wipers of the selector will be advanced one step.

As each impulse transmitted by the dial consists of a period during which the dial contacts are closed for 33 milliseconds and open for 66 milliseconds, relay B remains operated over the open periods, and relay C, which is also slow to release, holds over the closed periods.

At the end of the train of impulses the selector will be resting in position 3 and after a short pause relay C will release. While the selector was being stepped round, operated contacts C1 had removed positive battery from wiper 1, but this is now restored.

To make this station respond to its allotted number (37), the third strap on the numbering panel is permanently removed. At all other stations, where this strap still remains, an auxiliary circuit is completed to restore the selectors to normal and to render them inoperative to further impulses received. Only that station having 3 as the first digit of its distinctive number is therefore prepared to continue selection.

The digit 7 is now dialled, the impulses being received at all stations but effective only at that where the selector wipers are resting in position three. By this second train of impulses the wipers are advanced to position ten. When relay C releases at the end of impulsing the positive battery from wiper 1 is extended to operate relay S which locks via contacts S1 and operated contacts B2. Additional contacts (not shown) on relay S now complete the circuit of the release magnet which operates and so returns the selector to normal.

To summarise the above the selectors at all stations are at normal, but at the selected station relay S is locked in its operated position.

The following circuit can now be traced. Negative battery at the control station, operated contacts D1, operated contacts of the start key, normal contacts of the operate key, line A to the selected sub-station, polarised relay OP, operated contacts S2, wiper 2 of the selector, home bank contact, resistance A, variable resistance X2, line B to the control station, normal contacts of the operate key, one winding of relay L, interrupter springs dmS and dmO to positive battery.

The resistance A is different in value at each sub-station and, as the variable resistance X2 is set to compensate for the different lengths of line to each station, a current will now flow in one winding of relay L at the control station which will be determined in value by the particular station selected. Thus if No. 1 sub-station were selected a current of 10 milliamperes might be flowing, while in the case of No. 2 the value might be 20 milliamperes, and so on increasing by 10 milliamps. for each station on the system. The minimum current, i.e., 10 milliamps., is sufficient to operate the relay.

In the present example it will be assumed that the first sub-station has been selected by dialling number 37 and that the value of the fixed resistance A is so proportioned as to give a current of 10 milliamps. in relay L at the control station. Operated contacts L1 connect positive battery via normal contacts CO2 to operate the driving magnet DMS of the station check-back selector. This causes the interrupter springs dmS to open and relay L is released. Contacts L1 open the circuit of DMS, allowing the selector to step to its first position, and close contacts dmS. Wiper 1 now being on the first bank contact the following circuit can be traced. Positive, normal contacts dmO and dmS, second coil of relay L, line balance resistance, normal contacts CO1, wiper 1, bank contact, resistance to negative.

The line balance resistance is equal in value to the resistance of the line to any sub-station plus the setting of the variable resistance at that station plus the resistance of relay OP. The resistances connected between the bank contacts of the control station selectors are such that when a selector is resting on its first position the resistance from the wiper to negative is equal to the value of the resistance A at the first sub-station. Similarly when in the second position the resistance brought into circuit by the bank contacts is equal to A at the second station, and so on.

As station No. 1 (code number 37) has been selected a current of 10 milliamps. is flowing in the first coil of relay L, and as the selector is resting on its first position 10 milliamps. will be flowing in the second coil. Since relay L is differentially wound there will be no resultant flux and the relay will not re-operate. It will be seen that this action is independent of supply voltage.

Should the code number of, say, No. 5 sub-station have been dialled, the station check-back selector on reaching the first position would cause 10 milliamps. to flow in the second coil, but there would be 50 milliamps. flowing in the first. The resultant flux being equal to that produced by 40 milliamps. in one coil, relay L would re-operate and step the selector to the second position, and so on until on reaching the fifth position the currents in the two coils would be equal at 50 milliamps. Relay L would then cease to operate.

When the selector thus comes to rest in the position corresponding to the number of the station dialled, positive battery is extended from wiper 2 to light the particular lamp associated with that position. In the original example this check-back lamp would be the first of the group, indicating correct selection of sub-station No. 1.

Selection of the operation to be carried out, i.e., raising the tap-changing switch by one step, is now made by dialling the pre-arranged number, which in this case is 2. Impulses are sent to the line as before, but as the selectors still remain locked out at all stations except that previously selected and checked back, they are effective at No. 1 station only, where the operation of relay L steps the selector to its second position. The circuit through wiper 2 and resistance A is opened and replaced by a circuit through wiper 2 and the first of a set of resistances connected between the bank contacts. This destroys the balance between the two coils of relay L at the control station and causes it to re-operate.

At this stage a subsidiary circuit (not shown) associated with relay L at the control station operates contacts CO1 and CO2, thus connecting the operation check-back selector. From contacts L1 positive battery is now extended via operated contacts CO2 to the driving magnet DMO of this second check-back selector. In exactly the same manner as already described the switch continues to step until a balance is obtained between the two coils of relay L. In the example given the balance is found when wiper 1 reaches the first bank contact, and the selector comes to rest. Wiper 2 completes the corresponding lamp circuit to indicate that the selector at the sub-station has been correctly positioned for the operation of raising the tap-changing switch.

Upon receipt of the check-back signal the operate key is depressed, so reversing the direction of current flowing in lines A and B and through relay OP at the sub-station. Relay OP, which is polarised in such a direction that it does not operate until the key is depressed, connects positive battery from contacts OP1 via wiper 3 of the selector to energise the coil of the "raise" contactor which moves the tap-changing switch one step higher.

The same sequence of operations applies for lowering the tap-changing switch, except that the last digit dialled is 3.

Other numbers are allocated to the various facilities which the system offers and in each instance the two check-back signals are received before the operation is carried out. When it is desired to ascertain the voltage at the sub-station the selector is stepped to its fourth position. Upon operation the associated contactor connects the secondary of a step-down transformer, whose primary is placed across the station bus bars, to the lines C and D through the line compensating resistance X3. A reading is then obtained from the meter at the control station.

The position of the tap-changing switch is indicated by means of an auxiliary tapping switch geared to it and having a set of resistances wired between the position contacts. When the indication contactor is operated a definite resistance is connected across lines C and D, depending on the position of the switch. A current of definite value consequently flows through one winding of relay LA at the control station, which functions in a similar manner to relay L to drive round the switch indication selector until a balance is found. When the selector comes to rest the position of the tap-changing switch is shown by the corresponding lamp.

The operation of reading the position of a circuit breaker and tripping it is again similar to that described but in this case the resistances controlling the current in the line are connected directly to a contact of bank 2 at the sub-station. Either one or two resistances are in circuit, according to the position of the circuit breaker, so that one or other of two lamps associated with the operation check-back selector will indicate at the control station whether the position is "open" or "closed" respectively.

After any operation has been carried out the whole of the equipment is returned to normal by restoring the start key.

Conclusion.

Although the example taken and described is that of a typical A.C. distribution network it is obvious that the possible applications of the system are numerous. As a relatively simple and inexpensive means of concentrating the control of equipment at one point it is suitable for use in conjunction with semi-automatic converting sub-stations, synchronous condenser equipments, mercury arc rectifier stations, induction regulator plant, hydraulic and sewage-pumping stations, hydro-electric power stations and many other types of equipment.