THE ENGINEERING SOCIETY.

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CENTRALISED SUPERVISION OF MODERN POWER TRANSMISSION SYSTEMS.

by P. F. GUNNING.

Paper read in The Laboratories of Applied Electricity,
Liverpool University
on Tuesday 18th April 1933.

P Warner / 1964

A.T.M. ENGINEERING SOCIETY.

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PAPER READ on TUESDAY, APRIL 18th, in the
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I N D E X.

INTRODUCTION.

The methods of indication described in this paper are not in themselves entirely new. Systems of selective remote control, or supervisory control as it is called, have been in use in this country and in other parts of the world for several years, but it is only recently that the subject has become of sufficient importance to justify the interest of any but the specialist.

Centralised indication of the dispositions of switches and of meter readings has been adopted by the Central Electricity Board for the British grid; it is thus very appropriate at the present time to consider the facilities offered by the various designs of indicating apparatus available, and to see how important is the part played by signalling and communication in large modern transmission networks. A breif resume of the advantages of interconnected networks, though probably already well known, is included. No apology is needed, however, as without the use of the signalling systems described the operation of such networks would be extremely difficult and the resultant advantages and economies practically impossible to achieve.

As the paper deals with both light and heavy current engineering, Appendix 1 gives short explanations of some of the terms used in each branch. Appendix 2 gives typical examples of voice frequency signalling on supervisory systems.

THE ADVANTAGES OF INTERCONNECTION AND THE NEED FOR CENTRAL SUPERVISION.

Before passing on to more technical matters, the problem of interconnected networks should be examined from an economical point of view. The obvious criticism is that where many isolated generating stations are already in operation, the construction of an interconnecting transmission grid with its associated transformer stations means a considerable increase in capital charges. This of course is perfectly true, but the construction of a grid may also be considered as a rapid means of depreciating and superseding obsolete or inefficient generating plant.

At 31st. March, 1931, the aggregate value of the maximum loads on the Generating Stations of various undertakers in Great Britain was 3,801,342 kW. The combined simultaneous maximum load was, of course, somewhat less than this figure owing to non-coincidence of time and date of the individual maximum load.

The ratio of the aggregate value of the loads to the total capacity of generating plant installed was 100 to 183, indicating a plant capacity of about 83% in excess of the maximum demand.

By the interconnection of the generating stations by means of the Grid, this excess can be reduced to a more rational figure of 20%/25% with corresponding savings in capital expenditure.

The provision of interconnection will also enable the total output required to be divided over the various selected stations with regard to efficiency in operation. The more efficient stations with low working costs will be used to supply the greater part of the energy at high load factors (base load stations), while the balance will be taken from the less efficient, more costly stations, with a resulting overall saving in operating expenses.

The existence of the Grid will also enable the water power resources of the country to be utilised to better advantage, although under existing conditions with cheap coal available, near the load centres, water power in this country is unlikely to assume the same importance as abroad in places where coal is relatively expensive.

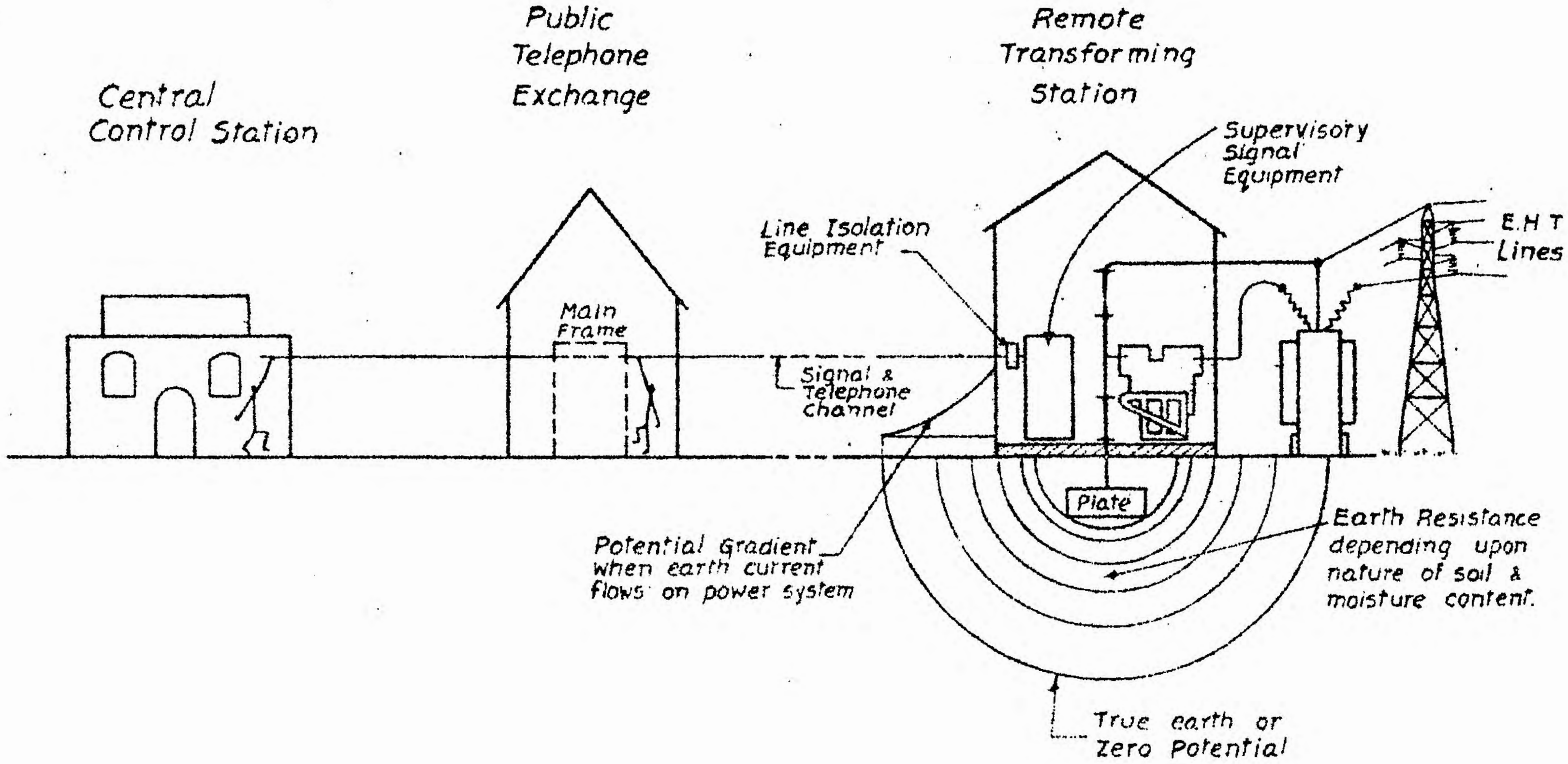
The advantages of interconnected systems are analogous to "grading" in automatic telephony, where a "grid" is used in the form of common trunks to absorb overflows of traffic from several groups of apparatus.

With such possibilities to be considered it is obvious that an interconnected power system cannot be operated successfully without an accurate knowledge of the load conditions obtaining at each station, together with an efficient means of controlling and distributing the outputs of the generating units, and also without means of supervising the switching operations on the system all at some central point. Load despatching, as this function is called in America, can be performed directly by remote control from a central office or, as is the case in the British Grid, by means of communications transmitted to operating room staffs in various parts of the system, or by a combination of both methods. Each method has its own particular application and both are dependent upon rapid and accurate signalling. In this paper, some of the methods available are discussed and classified.

SUPERVISORY SIGNALLING CHANNELS.

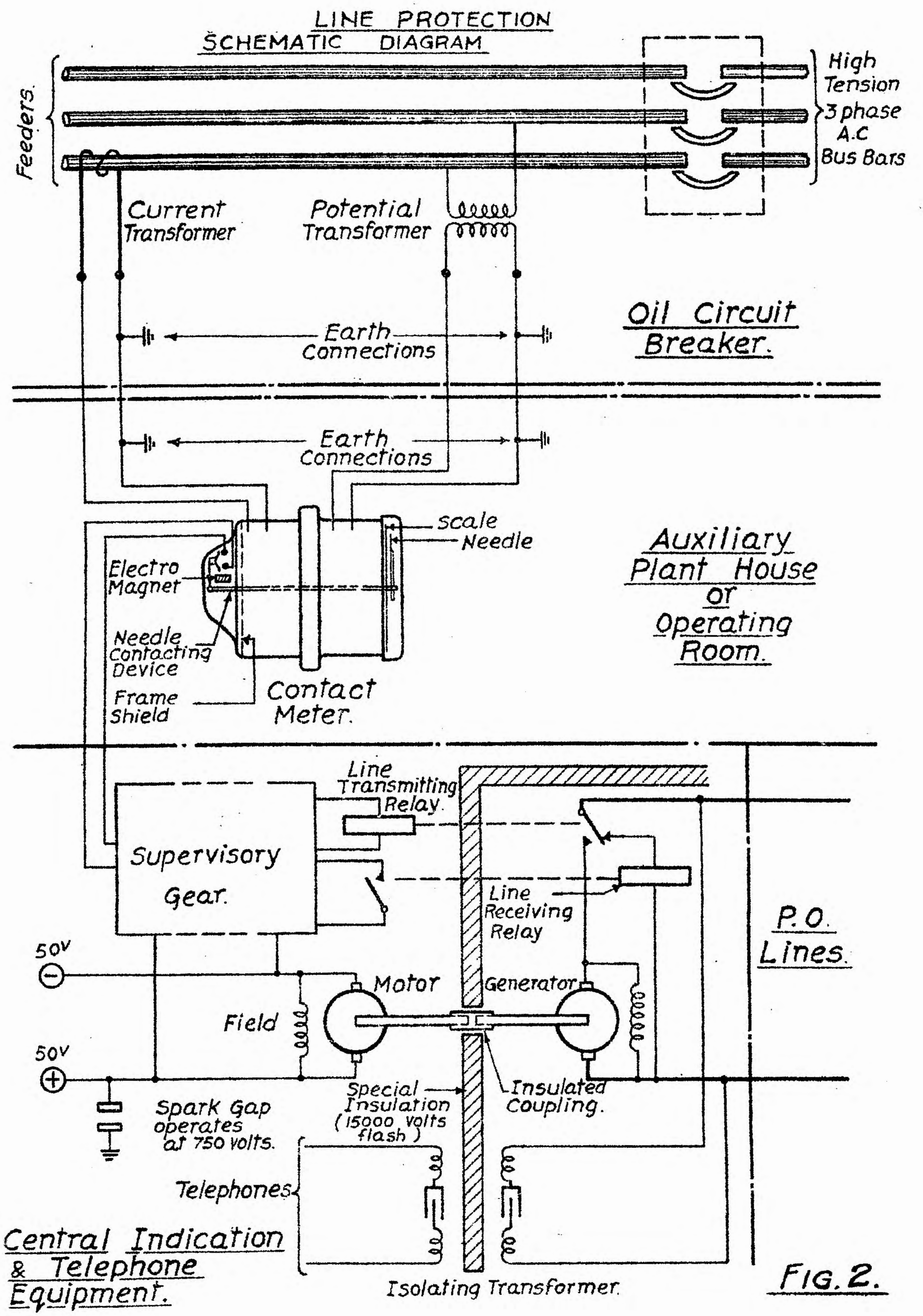
The indicating equipment at the central control room is operated over signal channels which radiate to each station in the section. These signal channels serve the dual purpose of placing before the control engineer a continuous instantaneous record of the varying conditions of the system and at the same time provide him with means of communication or control. The channels may be privately owned or may be single pairs rented from the public telephone authorities. The low rental cost of hired lines is very attractive compared with the high capital and installation cost of privately owned pilot wires.

Again, should the rented channel fail, an alternative can be provided immediately over another route, if necessary. Furthermore, advantage may be taken of repeater-amplified channels to permit satisfactory signalling over long distances. Also, the possibility of using the power transmission wires themselves for signalling purposes by means of carrier currents should not be overlooked. Hitherto, however, the cost of the necessary safe isolation has been prohibitive.



Signal Line Isolation

FIG. 1



LINE PROTECTION
SCHEMATIC DIAGRAM
Feeders.
High Tension 3 phase A.C Bus Bars
Current Transformer
Potential Transformer
Oil Circuit Breaker.
Earth Connections
Earth Connections
Scale
Needle
Electro Magnet
Needle contacting Device
Frame Shield
Contact Meter.
Auxiliary Plant House or Operating Room.
Line Transmitting Relay.
Supervisory Gear.
Line Receiving Relay
P.O. Lines.
50V
50V
Field
Motor
Generator
Special Insulation (15000 volts flash)
Insulated Coupling.
Spark Gap operates at 750 volts.
Telephones
Central Indication & Telephone Equipment.
Isolating Transformer.

FIG. 2.

Before permitting the circuits hired from them to be used for the Grid's central indicating equipment, the Post Office have insisted on elaborate precautions being taken to avoid any possibility whatever of high voltage reaching the communication system. In addition to guarding against any possibility of direct electrical contact between the high voltage and the communication systems, special attention has been directed to protection against their filtration of high voltages due to fall of potential across earth connections, which might take place if by any chance the communication circuits were connected between two points having a high difference of potential set up by a large power earth current flowing through a high earth resistance. Figure 1 shows the conditions on which this theory is based.

When using alternatimg current signalling, a line transformer specially insulated between windings and case is a suitable safeguard. When using direct current signalling, an insulated line signalling battery is used which is connected to the line by specially insulated relays. The insulated line battery sometimes takes the form of a small D.C. generator coupled to a small motor by a special insulated coupling. The line receiving and transmitting relays have specially insulated armatures which engage the signalling contacts. Fig.2.

SOME FACILITIES PROVIDED BY SUPERVISORY EQUIPMENT. FIG.3.

In cases where a large number of different signalling services are provided over a single communication channel, a definite order of priority has to be allotted to each facility and means have to be provided to avoid a loss of any signals whose receipt is temporarily interrupted or suspended. Naturally, different systems merit different orders of priority for the various facilities provided. It is, however, definitely recognised that the indications of circuit breaker positions should have priority over all

FACILITY SCHEMATIC.

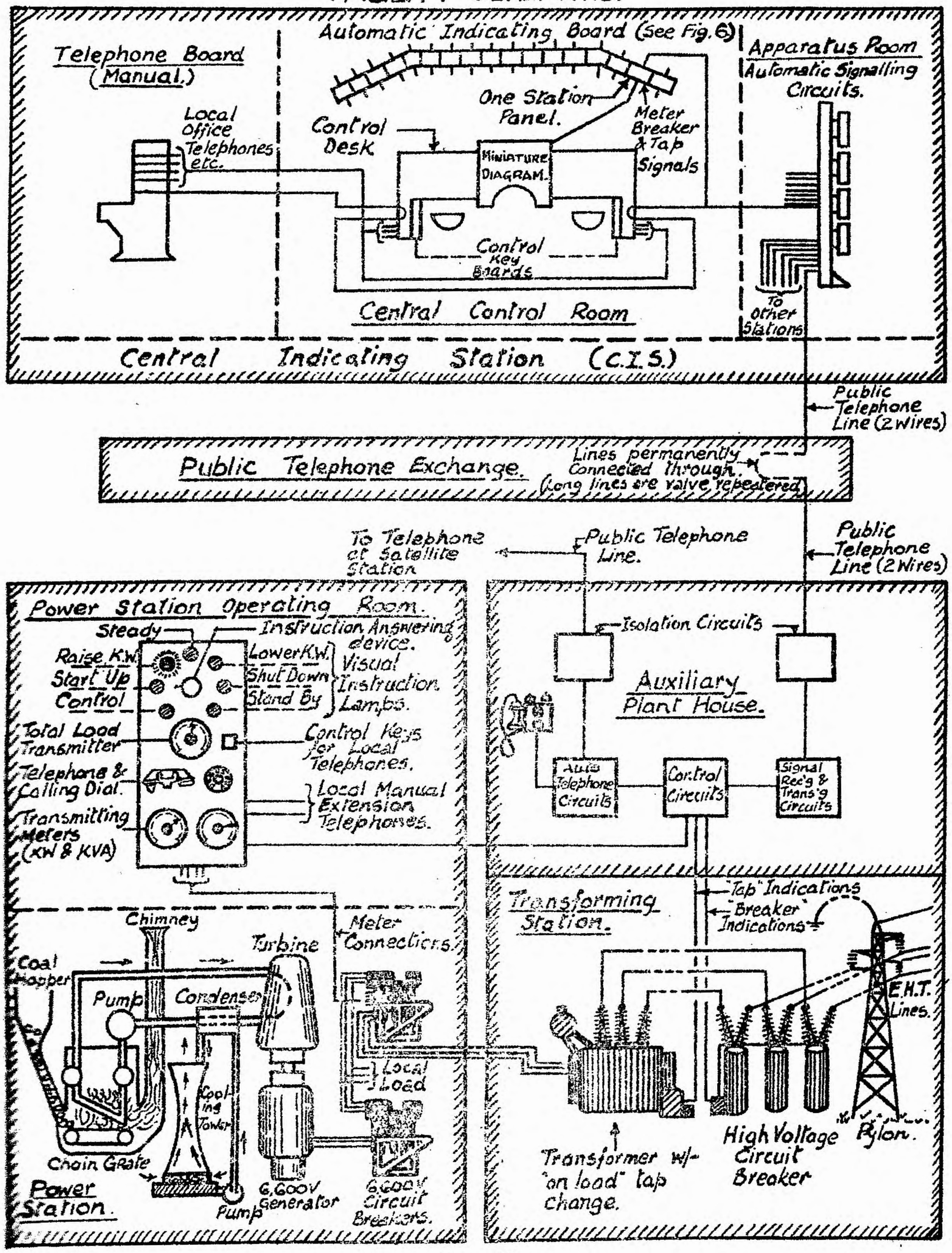


FIG. 3.

other signals. This means that if a circuit breaker should trip in the course of a telephone conversation, the parties will be disconnected for a few seconds while the change in breaker position is recorded. In the same way, other facilities may be given priority the one over the other in the following order.

(1) Indications of positions of circuit breakers.

(2) Telephone communications.

(3) Indications of positions of transformer tap change switches.

(4) Visual instruction signals.

(5) Meter readings.

Each of these facilities is discussed in detail in subsequent sections. All indications are continuous that is to say, changes are recorded immediately they occur. At the same time, visual and audible alarms are received.

The transmission of illuminated stereotyped instructions from a central control office to various operating shifts overcomes trouble from misunderstanding or misconstrued telephone messages, the consequences of which could be very serious.

EQUIPMENT AT CENTRAL CONTROL STATION.

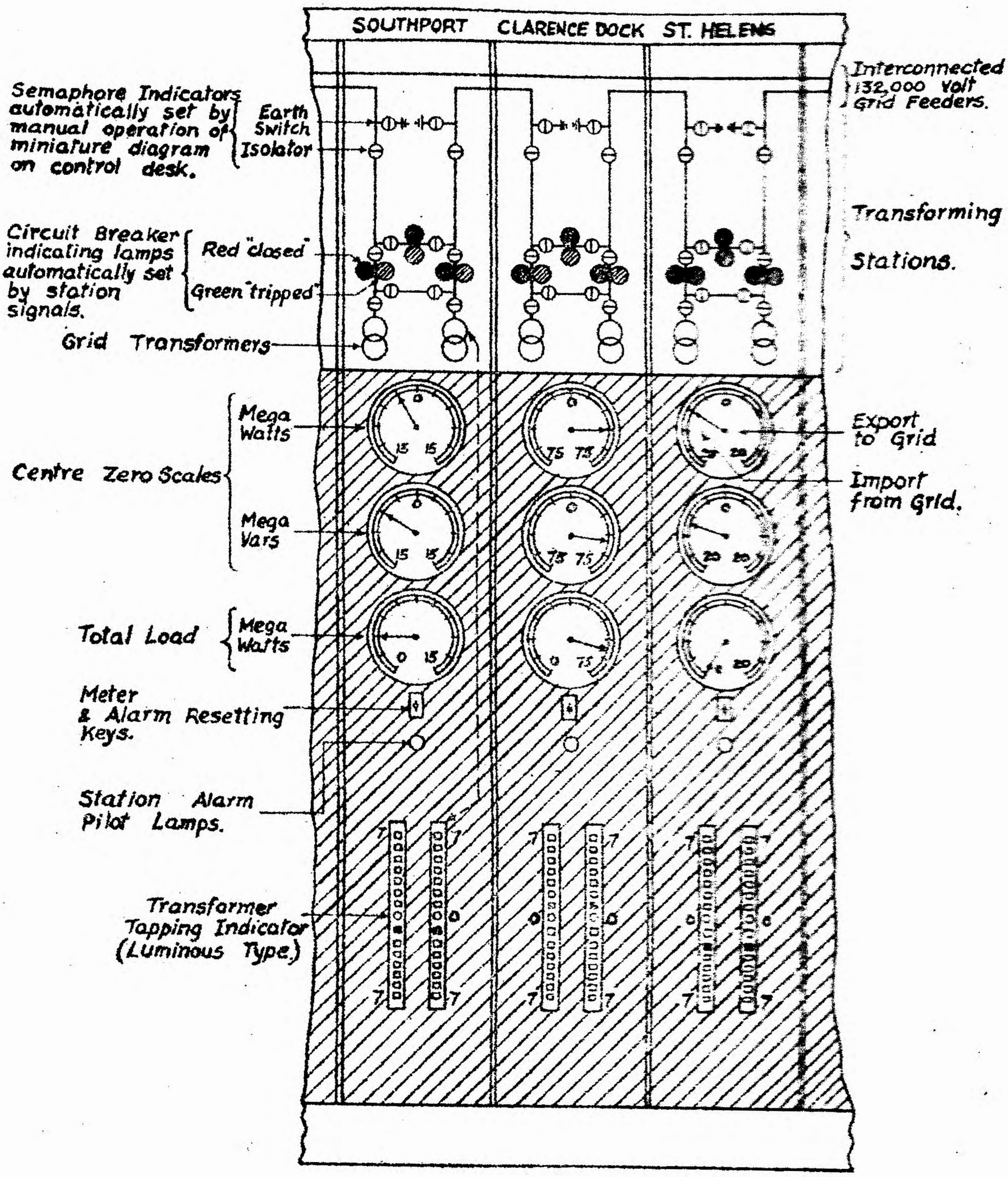
The equipment at the central station varies considerably in different systems. The following items are typical of equipment used on the British Grid.

(1) Automatic indicating board showing the position of the transmission system breakers, isolating, earthing and transformer tap changing switches together with remotely indicated meter readings for each station.

(2) Control engineer's desk.

(3) Manually operated miniature diagram.

(4) Telephone attendant's cabinet.



Typical Automatic Indicating Panels
(Central Electricity Board - North West)

FIG. 4.

Automatic Indicating Boards.

Diagram 4 shows how station information is indicated on the automatic indicating board at the N.W.Grid control room.

Each vertical panel represents one grid station. On the upper portion of the board, painted in contrasting colours on a background of primrose, is a diagram of the complete 132 kV transmission system including indications of each oil circuit breaker, transformer, isolator and earthing switch.

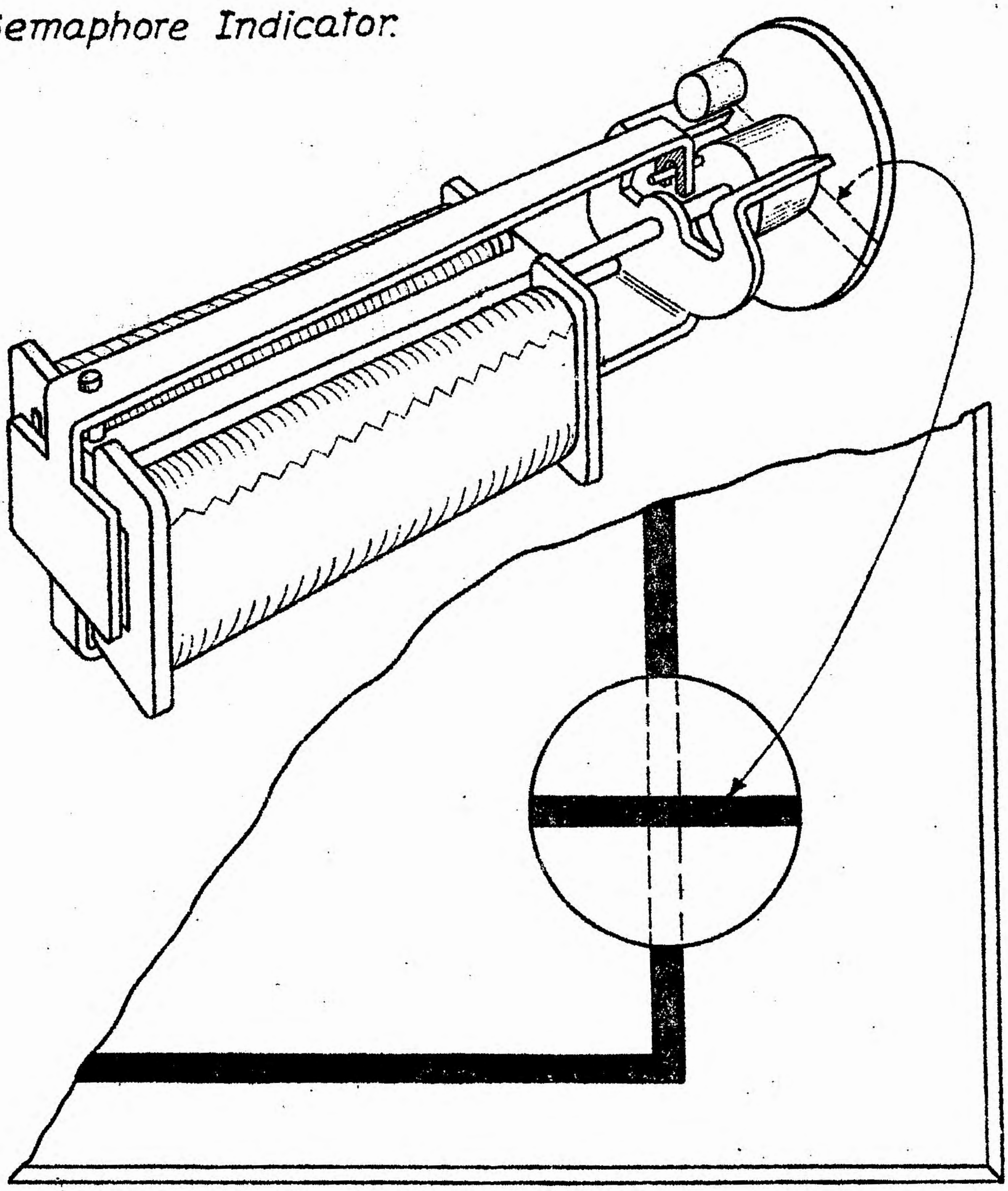
Each oil circuit breaker is represented in the diagram by a separate pair of coloured lamps, one red, the other green. The red lamp glows when the breaker is closed and the green lamp glows when the breaker is open.

Each transformer is represented by a "double circle" convention. The isolator and earthing switches are represented by non-automatic semaphore indicators (Fig.5), let into the face of the board.

Immediately beneath the diagram on each station panel are the meters. There are two instruments for each transforming station to indicate the true power (Megawatts) and reactive kVA (Megavars). Where the transforming station is capable of exporting power the meters have centre zero scales to show the amount of power transferred to or from the system. A third meter is also provided with a side zero scale to show the total load on each generating station. The lower part of each station panel contains luminous transformer tapping indicators, corresponding to the "double circle" transformer conventions appearing in the system diagram on the upper portion of the station panel. Each indicator consists of 15 lamps, one of which glows continuously corresponding to the tap position on which the particular transformer is working. Immediately above the transformer indicators are the station alarm pilot lamps and meter and alarm resetting keys. When a station signals a change in position of a breaker or transformer tapping, the particular station alarm pilot lamp glows on the indicating board, attracting the attention of the control engineer to the station panel on which the change has been indicated. In addition to

FIG. 5.

Semaphore Indicator.



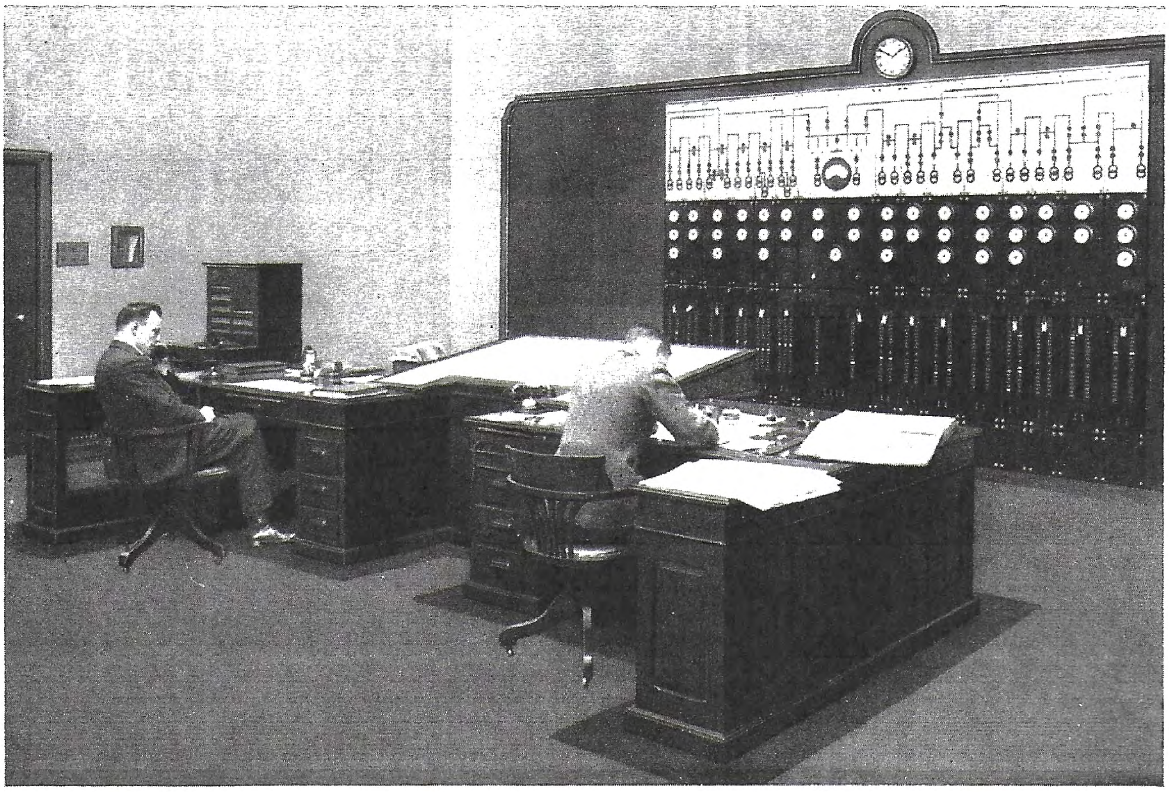


Fig. 6. Control Room, Central Scotland Electricity Scheme.

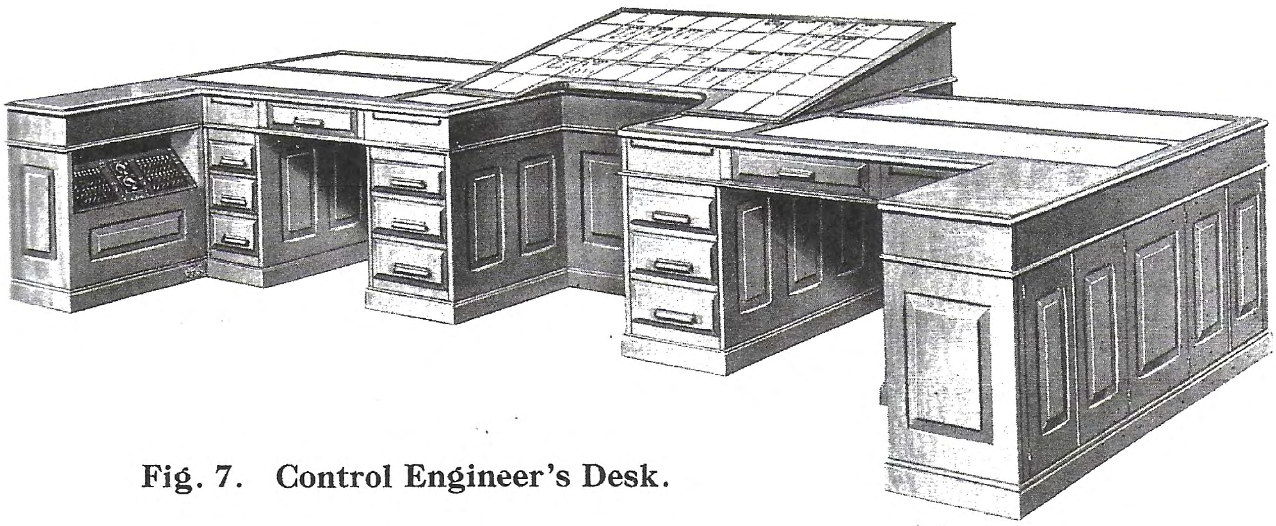


Fig. 7. Control Engineer's Desk.

the pilot lamp there is a common alarm bell which rings in the control room whenever a change occurs. When the station alarm reset key is operated, it causes the alarm bell to stop ringing and the alarm pilot lamp to be extinguished. Operation of the meter key causes the station to transmit signal pulses to set the meters to the latest readings.

Control Engineers Desks.

The control engineers desk provides accommodation for two engineers who have each a separate control key board arranged so as not to interrupt the view of the automatic indicating board. Fig.6.

A manually operated miniature diagram is situated in the centre of the top of the desk.

The control key boards enable the engineers to establish direct telephone conversation with any station, and listen to, or interrupt, any conversation between the manual telephone board and the distant stations.

Each engineer has facilities for transmitting to each generating station any one of seven stereotyped operating instructions, which are displayed and acknowledged in the operating room at the distant station.

A set of lamps, each of which corresponds to a visual instruction, is provided for each generating station. One of the lamps is always glowing, indicating the instruction last transmitted and acknowledged by the distant station.

Meter and alarm resetting keys are provided on the desk and operate in parallel with those on the automatic indicating board.

MANUALLY OPERATED MINIATURE DIAGRAM.

The miniature diagram (3'-6" x 4'-6" approx.) in the top centre of the desk shows the oil circuit breakers, isolating switches, earthing switches and transmission lines throughout the entire grid system. All switch indications

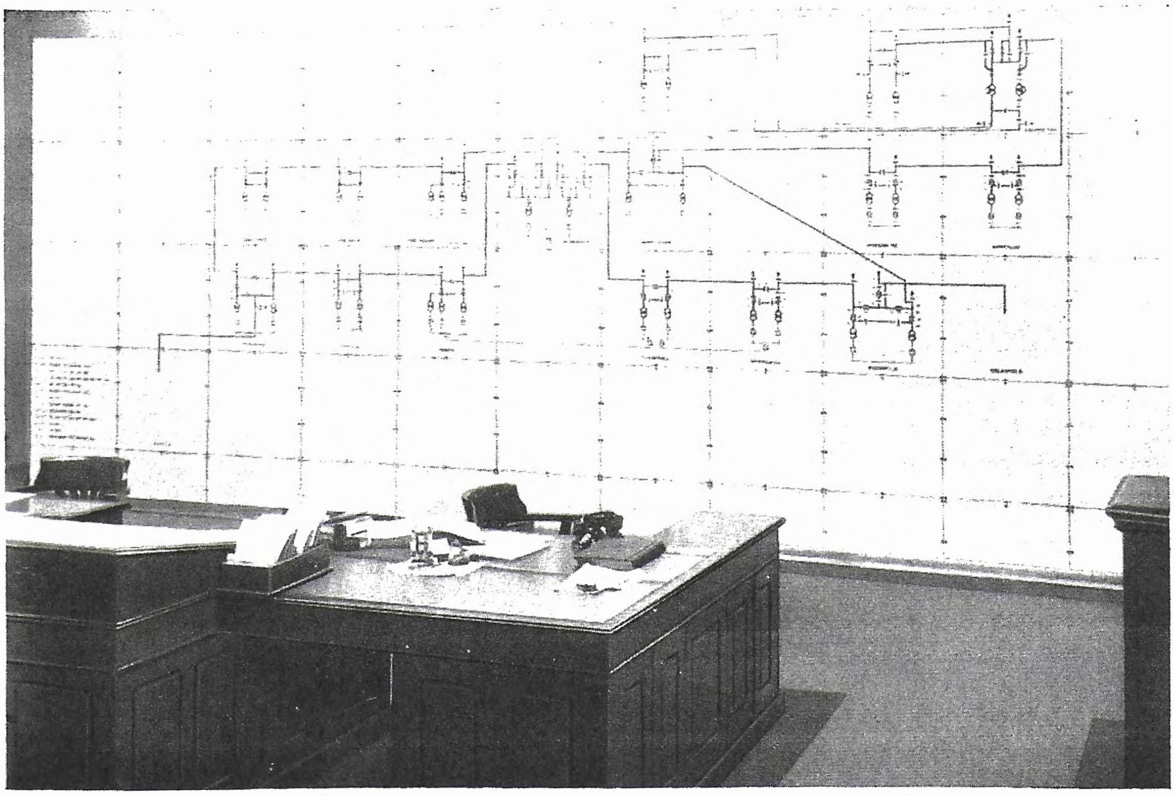


Fig. 8. Wall Diagram, Central Scotland Electricity Scheme.

on the indicating board are represented by small switches fitted with semaphore indicating knobs.

These small switches are hand operated and in the case of oil circuit breakers where automatic indications are received, serve to maintain the alarm until they are reset to correspond with the new conditions.

In the case of isolating and earthing switches, which are not of sufficient importance to be automatically indicated, the small switch indicators in the miniature diagram control the corresponding electromagnetic semaphore indicators on the indicating board. Fig.4.

In one section of the British Grid System, the isolating and earthing semaphore indicators do not appear on the automatic indicating board but on a separate wall diagram. Other semaphore indicators representing the oil circuit breakers, which are automatically indicated by lamps on the indicating board, are also included on the same wall diagram. (Fig.8.)

In another section of the grid the indicating board is part of the control desk and there are no indications of the isolators and earthing switches other than the small switch indications on the miniature diagram. With the consequent reduction in space available, the transformer tapping indications appear as edgewise meter indicators.

Telephone Attendants' Cabinets.

This is a manual telephone board and is for the purpose of extending calls between the control room offices and any of the stations in the area.

AUTOMATIC INDICATION OF SWITCHGEAR

Initiation of Signal Train

Signals are transmitted to the control room to correct the corresponding indications whenever the position of a circuit breaker or transformer tapping is changed. The signal is initiated by a start circuit associated with the particular unit to be indicated.

While there are many types of "change start" circuits, the best are those that have the principle of allocating to each unit an individual "following storage" circuit, which sets itself to correspond with the disposition of the unit being indicated. This feature is not provided in schemes depending upon the transit time of the unit.

When a change occurs, the position signalling contacts in the new position and the "following storage" circuit in the old position energise a common start relay (SR Fig.9). The start relay initiates the signal train and then allows the "following storage" circuit to correct itself so that only one signal train is transmitted.

By the use of latching or permanent magnet relays or rotary selectors, "change start" circuits consume current only during the initiation of signal trains. Continuous current consumption at the remote station in some cases is a serious consideration, especially in the event of failure of the main supply, when the indicating equipment relies on the reserve capacity of the signalling battery.

Examples of various types for breaker signalling:-

(a) Those which use an initiating relay connected in series with the operating supply.
(b) Those in which a series circuit containing the breaker contacts is momentarily disconnected during the operation of the breaker.
(c) Those in which a contact is made momentarily during the operation of the breaker.

Change Start Circuit with "following storage" feature for breakers (Fig.9)

Two individual wires and one common wire are usually connected to the change start circuits from the signalling contacts of each circuit breaker. The two individual leads which are energised singly, one when the breaker is closed, the other when the breaker is open, control the operation and release of a latching relay which in this example constitutes the "following storage" circuit.

Relay SR is energised by the operation of the signalling contacts, and locks up on its second winding. The latching relay does not operate in series with the high resistance of relay SR but waits until the operation of SR provides it with a full negative supply. In operating, relay 1 latches and disconnects its operating supply. The circuit is now ready to respond to the next operation of the breaker.

Change Start Circuit with "following storage" feature for transformer tappings (Fig.9)

A common wire and one wire for each tap are connected between each set of transformer tap signalling contacts and the change start circuits. A latching relay is provided for each transformer tapping. The circuit is similar to the one already described with the exception that as only one wire is provided for each tapping and not two as for a breaker, the latched relay corresponding to the old tapping is unlatched by the operation of the common start relay SR. Where there is a considerable distance between the transformer tap signalling contacts and the auxiliary plant house, in which the signalling equipment is housed, the "change start" circuits are housed in a weatherproof box near the transformers and are connected to the plant house by two wires only.

Transmission of Signal Train (Fig.9)

The signal train transmitted from the transforming station contains sufficient information to check and correct, where necessary, all the breaker and tapping indications at the control room, including that of the particular device responsible for the initiation of the train.

To do this, a pulse per indication is transmitted, the polarity determining whether the corresponding signal lamp should glow. For example, 40 pulses would be required if there were 10 circuit breakers and 2 - "15 tap" transformers (10 + 2 x 15). Pulsing at the rate of 10 pulse indications per second would result in all the station indications being checked and corrected in 4 seconds.

The operation of the start relay SR operates the line impulsing relay IMP which, besides transmitting current to line, energises the signal transmitting switch ST. Switch ST energised, releases relay IMP which releases ST which then steps to the second position. This inter-operation of relay IMP and switch ST continues until all the pulses have been transmitted and switch ST is back on the home or No.1 position.

The polarity of each impulse transmitted is determined by the operation or non-operation of the line reversing relay RV which, connected to a wiper on the signal transmitting switch ST, tests in turn the condition of each "following storage" circuit, which as already described is in a position corresponding to that of its associated breaker or tap signalling contact. In this example the line pulses are normal when the breaker is open or the tap not in use and reversed when the breaker is closed or the tap in use.

At the control room the signal pulses are received on two polarized relays, one operating on normal polarity and the other on reversed polarity pulses. The operation of the polarised relays steps a signal distributor switch SD around its bank, making contact in turn with the various lamp control circuits which are operated in accordance with the polarity of the pulse received on each bank position.

Signal Indicating Circuits and Devices (Fig.9)

A characteristic feature of breaker and tap indicating circuits is that the lamp control relays or signal devices are not dependent upon the control battery to retain the signal last received, so that should the control battery fail, the signals on the indicator board are not lost. This feature is obtained by the use of latching relays, permanent magnet locking relays, or mechanical indicators, which remain in the position to which they were last electrically set by the control battery. The lighting supply for the signal lamps is alternating current suitably stepped down from the mains.

Circuit Breakers (Fig.9)

Connected to the bank position corresponding to the circuit breaker indication is a permanent magnet locking relay ML, the contacts of which control the lighting of the circuit breaker indicating lamps. The locking relay operates on a reversed pulse and remains operated due to the permanent magnet, thereby lighting the "closed" lamp. When the breaker trips, a normal polarity signal pulse neutralises the holding effect of the permanent magnet, thus releasing the relay and causing the "closed" indication to be replaced by the "open" indication.

In some cases, an alternative arrangement is used in which red and green lamps illuminate the same aperture in the panel instead of each appearing individually. This arrangement is useful where space is limited.

Transformer Tapping Switches(Fig.9)

While the indicating circuits for the transformer tap switches can consist of sets of storing relays of the latching or locking type, as in the case of breakers, a rotary selector TS has been chosen in this case as a convenient example.

The tap signal selector TS responds to the normal pulses received on polarised relay OUT (i.e. "tapping not in use" pulses).

The pulse corresponding to the tap in use is of reversed polarity, as already explained, and a locking circuit is provided at the control room to prevent the balance of the pulses operating the selector, which thus remains in position and lights the lamp associated with the tap in use.

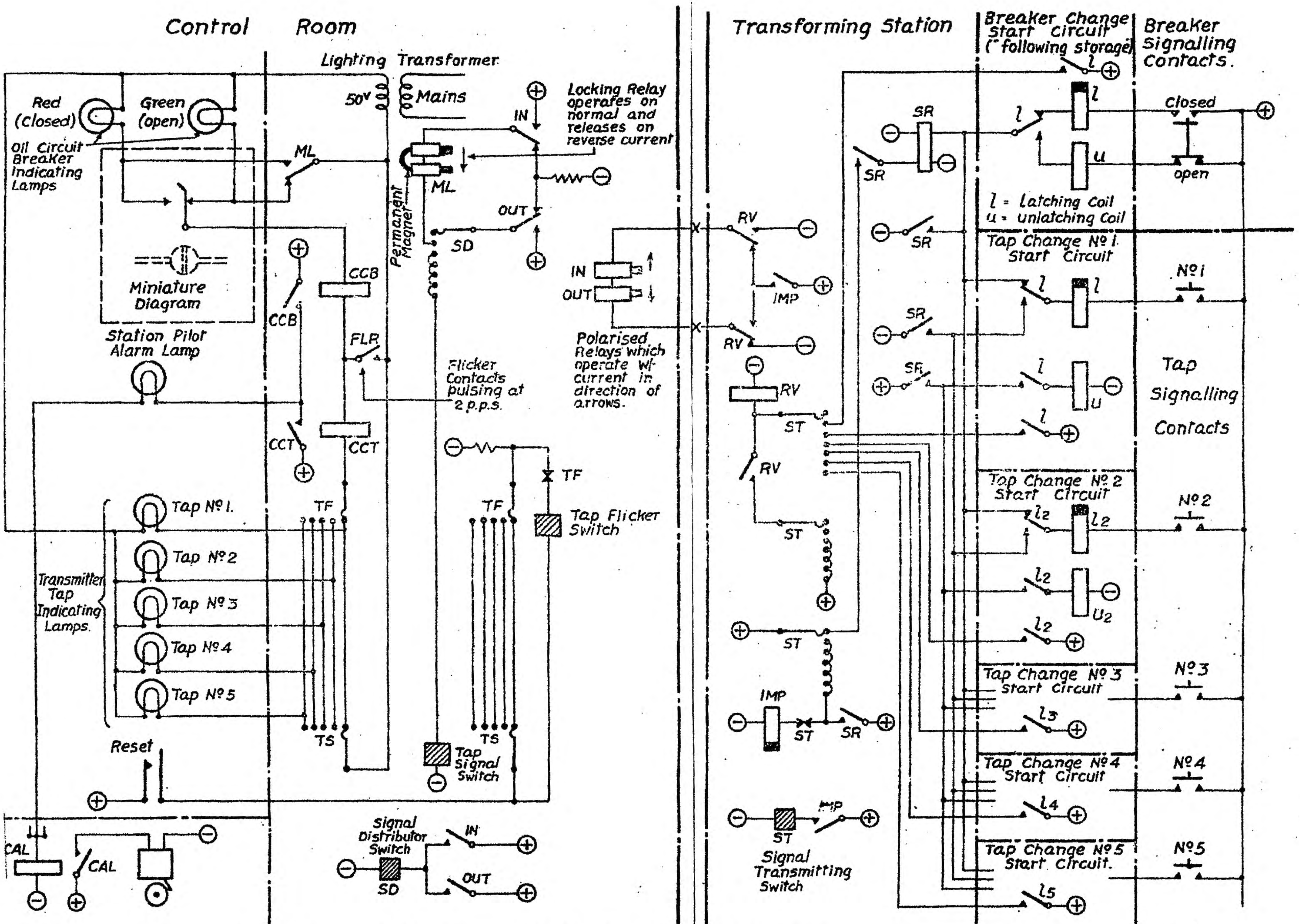


FIG. 9. Automatic Indication of Switch Gear.

Indication Alarm Signals (Fig.9)

In series with the semaphore switch contacts representing the circuit breaker in the miniature diagram is an alarm relay CCB which operates when the switch position does not correspond with the lamp control relay ML as is the case when the breaker change is signalled.

Relay CCB operating, lights the corresponding station pilot alarm lamp in series with a common alarm relay CAL which rings the control room alarm bell.

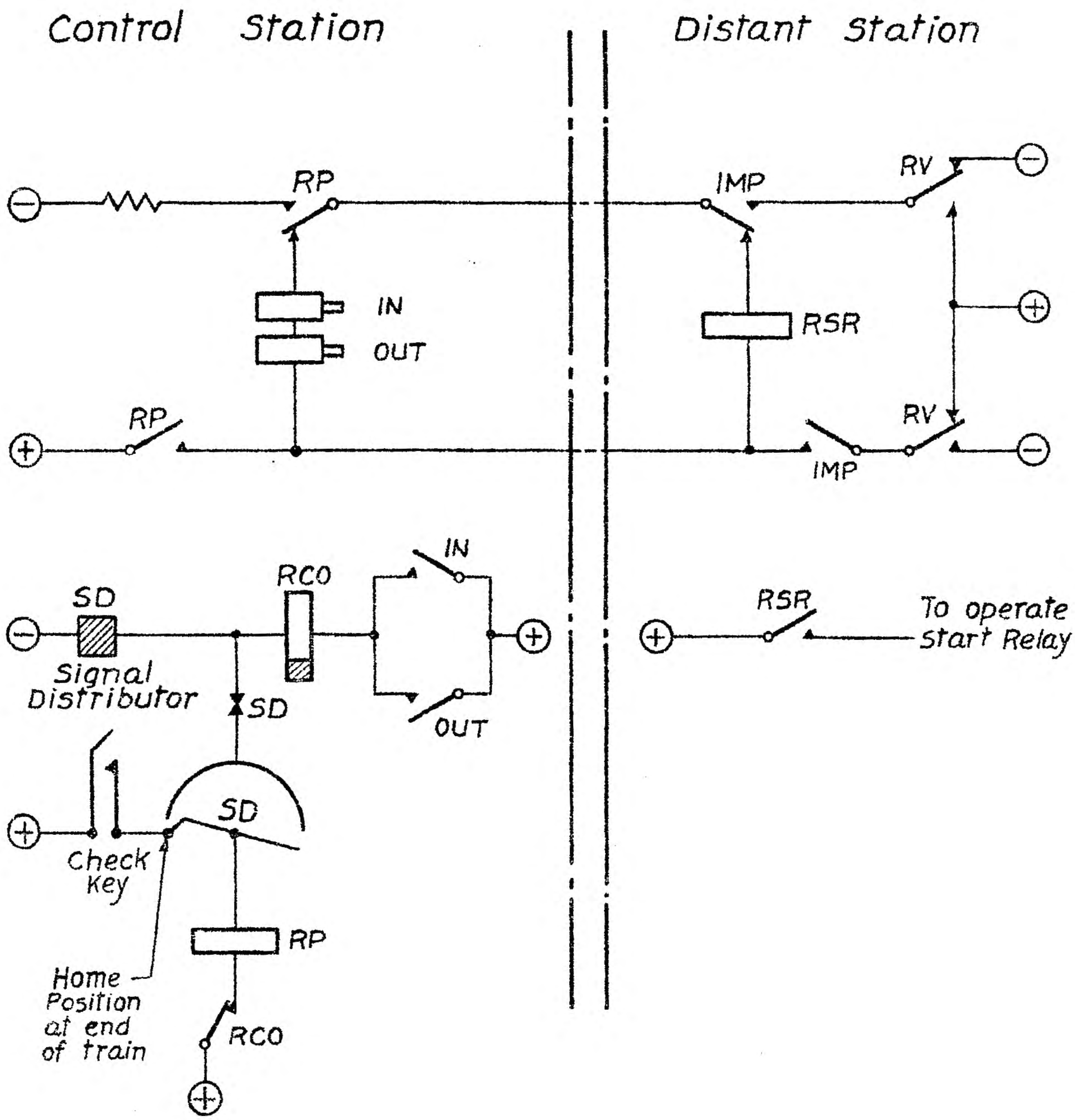
In series with CCB are a pair of "flicker" contacts FLR which cause the breaker indicating lamp associated with the position from which the breaker has just changed to "flicker".

The control engineer, by correcting the position of the semaphore switch on the miniature diagram releases relay CCB which extinguishes the station pilot lamp and cuts off alarm bell and circuit breaker flicker.

For each transformer there is a "tap flicker" selector TF which is normally in a position corresponding to the last tap indication received. When a fresh tap signal is received, causing selector TS to move to a new contact, a circuit is completed for relay CCT in series with the flicker contact FLR. This causes the old indication to flicker and the new indication to glow steadily. Relay CCT lights the appropriate alarm pilot lamp and causes the alarm bell to ring until the reset key is depressed. This causes selector TF to rotate until it corresponds to the new indication in which position relay CCT is released and the visual and audible alarms disconnected.

SIGNAL TRAIN TESTING METHODS (Fig.10)

Due to the possibility of external interference with signal trains, methods have been devised to test whether signals have been received correctly. There are two methods which are widely used.



Signal Train Test Feature.

FIG. 10

(1) Revertive impulsing, where each pulse has to be answered by the receiving station before the next pulse is transmitted.

(2) Impulse counting, which has the advantage of being simple and extremely rapid, as no time is wasted in testing each impulse individually.

From the examples already explained it will be appreciated that the signal distributor switch SD responds to each impulse of the train which contains a fixed number of pulses. Therefore, when the train finishes, the signal distributor SD should always have reached a definite bank position. If SD is not on this position, having lost or gained pulses due to line interference or some other form of disturbance, a repeat signal relay RP operates, transmitting an impulse to the transforming station which re-transmits the signal train. In this way it is impossible for the control room to accept a "marred" signal train, as this testing and re-transmission of signals is repeated until the signal train is received correctly.

REMOTE SELECTION METHODS

In a supervisory control system where a number of points have to be individually controlled over a common channel, some method of selecting these points is necessary.

To ensure absolute reliability, it is essential that the method of remote selection employed embodies a testing feature, which indicates that the remote selection has been correctly made.

There are many ingenious methods of remote selection, the best of which are based on one or other of the following principles :-

(a) Revertive impulsing
(b) Impulse counting

The revertive impulsing method depends upon each impulse transmitted by the control room being answered by a check impulse or condition transmitted by the controlled station. The check impulse is only transmitted when the selector has correctly responded to the preceding selection impulse from the control room.

The impulse counting method depends upon a fixed quantity of impulses being transmitted to the controlled station. The polarity, frequency, intensity, or length of the impulse is altered when the "control point" selector is expected to be on the correct position. The remainder of the impulses then operates a "selection check" selector in place of the "control point" selector, so that the total positions stepped by both selectors equals the number of impulses transmitted. The operating circuit for the selected operation is completed only when the "selection check" and "control point" selectors have been stepped to positions which are complementary.

As an example, on a 25 point selection system where the 18th point is to be selected, the "control point" selector would have to be on position 18 and the "selection check" selector on position 7 before the 18th point could be controlled.

While the "revertive impulsing" method is quicker for a small number of selection points (up to 10), the "impulse counting" method is more simple and saves time on a system with a large number of points.

With the "impulse counting" method, any one of 1000 points can be selected and proved in less than four seconds.

Another method of selection proof is the provision of a self-balancing bridge at the control room. The controlled station answers the selection train with a resistance loop which varies in resistance with the position selected. This method is dependent upon the use of short metallic lines of good insulation.

TRANSMISSION OF STEREOTYPED INSTRUCTIONS

As there is always a risk of misunderstanding telephone communications, the more important operating instructions in frequent use are transmitted on a system somewhat similar to an engine room telegraph.

At the control room there is a set of lamps for each station on the system, and each lamp in a set corresponds to different stereotyped instructions, such as "raise KW", "lower KW", "start up", "shut down", "control", "steady", "stand by", etc. One lamp in each set glows continuously indicating the instruction last answered by the relevant station. This enables the control engineer to see at a glance the instructions to which the stations are working.

The transmission of stereotyped instructions to the operating staff at a distant station is controlled from the engineer's desk.

To send an instruction, the engineer rotates a common instruction dial to a position designated with the instruction he wishes to transmit, and then operates a key allocated to the station required. This causes a train of selection impulses to be transmitted to the station to operate the "control" and "selection check" selectors.(Fig.11).

At the distant station the instruction appears on a visual instruction indicator, accompanied by an audible alarm, and at the same time a signal is transmitted to the control station causing the lamp associated with the new instruction to flicker; this denotes that correct selection has been made. At the control room the condition is now one lamp glowing continuously corresponding to the old instruction and another lamp "flickering" to indicate the latest instruction.

The attendant at the distant station answers the alarm and instruction indication by rotating an answering dial to the illuminated instruction. This action cuts off the bell and extinguishes the indicator and at the same time sends a signal to the control station, which causes the flickering lamp to glow continuously and the other lamp to be extinguished.

A visual and audible alarm warns the control engineer to restore the station sending key and so relase the equipment.

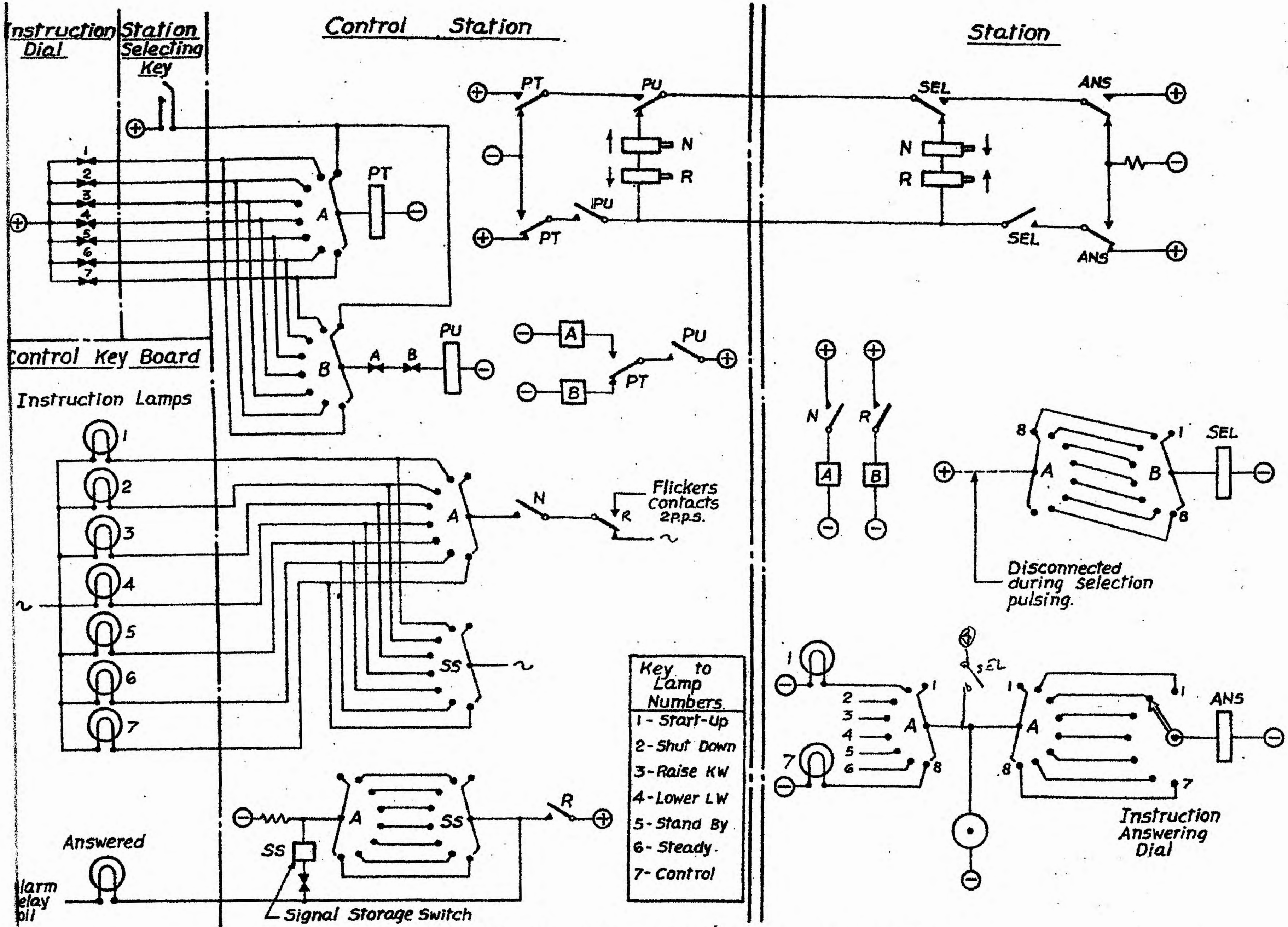


FIG. II. Transmission of the Stereotyped Instructions.

REMOTE INDICATION OF METER READINGS

For some considerable time, much attention and ingenuity has been devoted by engineers to the successful transmission and indication of meter readings over long distances as witnessed by the vast number of patent specification filed in this category.

Remote metering as it is termed can generally be segregated into any of four classes.

(a) Direct quantitative metering, including potentiometer, and the like, translation of complex sources such as KW and KVA.

(b) Start stop synchronous metering.

(c) Variable power factor or frequency metering.

(d) Impulse metering.

(a) Direct metering, as it is most often termed, has great popularity as it provides continuous instantaneous readings with the least amount of metering equipment.

One end of the line is connected to the instrument transformer, shunt, potentiometer, or thermo-couple as the case may be, while the other end is connected to a suitable meter.

The supervisory control lines can be used for direct metering provided the meter current is in simple form, readings of KW and KVA being translated by self-balancing potentiometer equipment. In this case, when the lines are required by the supervisory control equipment, a pulse of twice full scale intensity, opposite polarity or momentary disconnection would lock off the meter and its associated equipment at each end of the line. Using the clearing by disconnection method, the meter would have to be of the "set up" zero type, so as not to register on the residual line current used for maintaining the reading.

While direct metering is used wherever possible, its use is limited to metallically continuous lines of small and constant resistance with a high degree of insulation.

(b) Start stop synchronous methods employ the principle that the interval of time between the start and the stop signals is variable and proportional to the quantity to be metered.

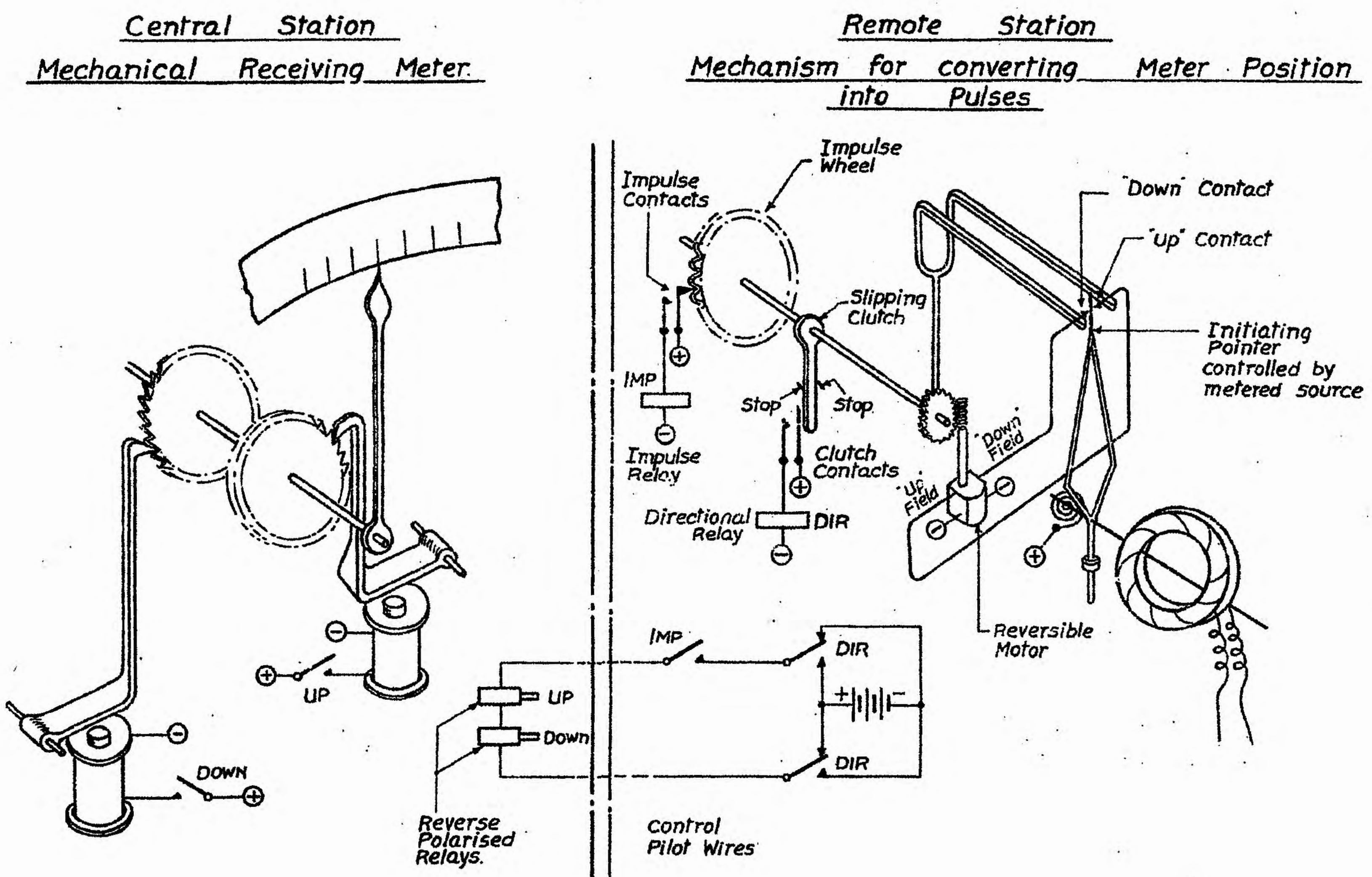
In this method two meters are provided, one at each station. The transmitting meter has two pointers, one continuously indicating the reading, the other actuated by a motor until the pointers coincide in position. The meter at the receiving station has only a motor pointer.

The reading is transmitted with both motor pointers initially in the zero position. When a "start" impulse is transmitted, both pointers move in synchronism.

When the transmitting motor pointer coincides with the "reading" pointer, a "stop" impulse is transmitted cuasing both motor pointers to stop.

This method of metering, while making possible the transmission of simple and complex readings over any type of transmission channel, metallic, voice frequency, or radio, has the inherent disadvantages of remote synchronous equipment and is only suitable for "spot" readings.

(c) This method translates the scale reading into an alternating current, the frequency or power factor of which is varied in proportion to the quantity to be measured, whilst both the frequency and power factor methods have much to commend them where short distances are involved, these methods suffer from the disadvantage that it is difficult to obtain sufficiently sensitive receiving devices for use on long distances.



Impulse Metering for Continuous Fluctuating Readings.

FIG. 12.

(d) Impulse metering translates the scale reading into impulses varying in number in proportion to the reading. As with start stop metering, the advantages of impulse metering are that the accuracy is not affected by transmission channel characteristics, can easily be adapted to operate in conjunction with supervisory control equipment and can be superimposed on channels already in use for other purposes by the use of voice frequency signalling and filters.

Metering by impulses is flexible in that it can be arranged to give "spot" readings of a distant meter or follow its fluctuations. Both methods have their own field of application. In some cases it may be essential that a control engineer should be able to know to what extent a particular load is varying; in others, where little fluctuation is probable, an instantaneous indication or "spot" reading is sufficient. With "spot" readings, the readings for the whole system are transmitted rapidly in succession without individual selection, which is necessary for continuous type metering.

The translation into pulses of the meter reading is effected by means of Midworth apparatus for continuous readings and by a special contact device attached to the meter in the case of "spot" readings.

The Midworth apparatus - Fig. 12 - is used to provide sufficient power to drive the impulse generating device without impairing the sensitivity of the initiating instrument. Fundamentally, Midworth equipment consists of an initiating contact coupled to the meter pointer and riding between two insulated contacts of a second needle which is driven by a motor until the initiating contact rides freely between the two contacts. The direction the motor drives is governed by the particular contact engaged.

The translation into pulses of spot readings is effected by a contacting device or transmitter attached to the rear of the meter. (Fig. 13). The transmitter is a spring contact arm rigidly attached to the meter spindle. This contact arm moves quite freely with the instrument movement, acting like an auxiliary pointer. An

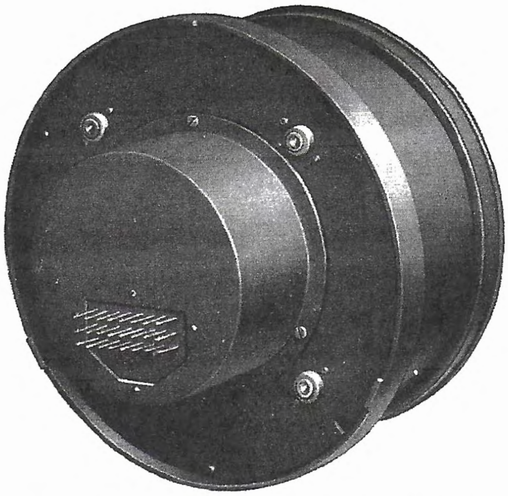


Fig. 13. Instrument fitted with Contact Metering Transmitter.

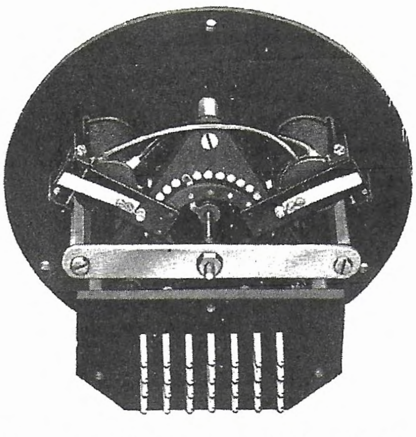


Fig. 14. Internal view of Contact Metering Transmitter.

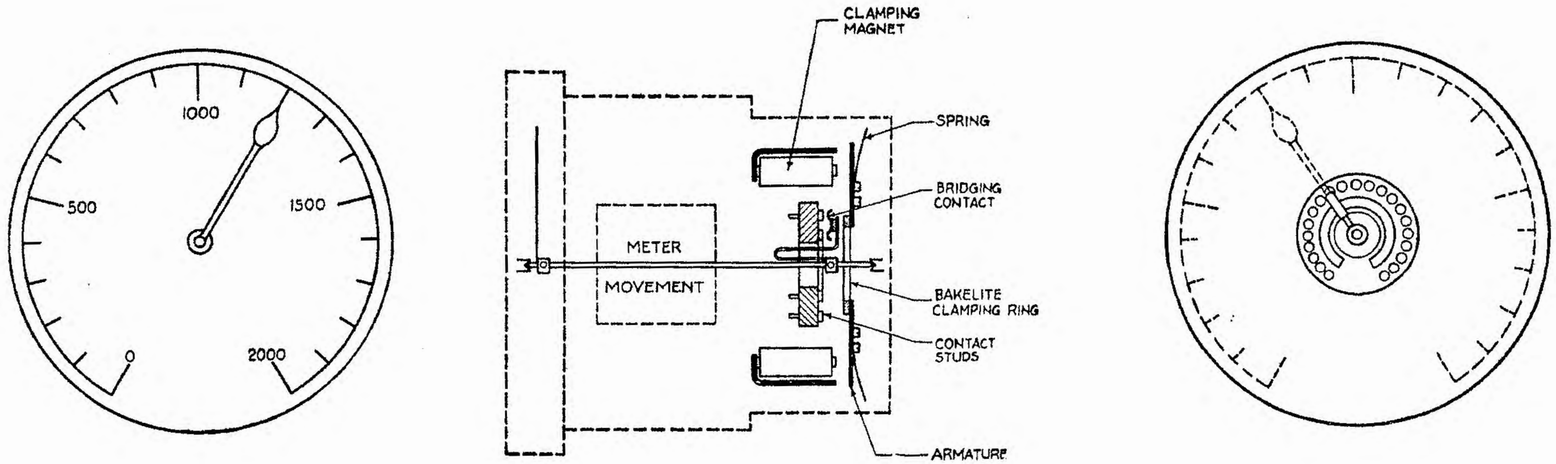


Fig. 15. Schematic of Contact Metering Transmitter.

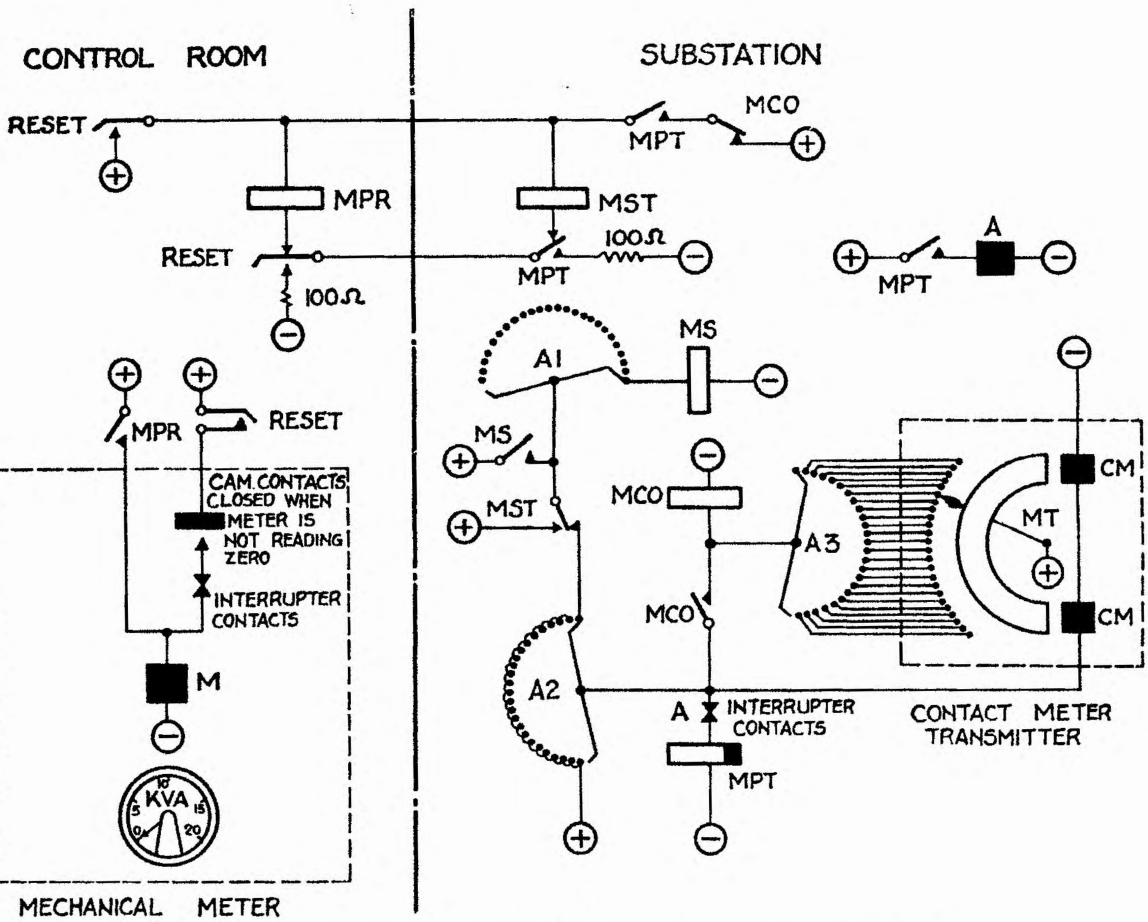
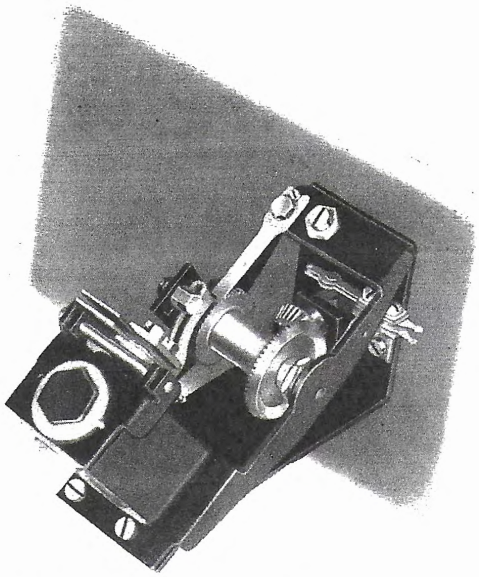
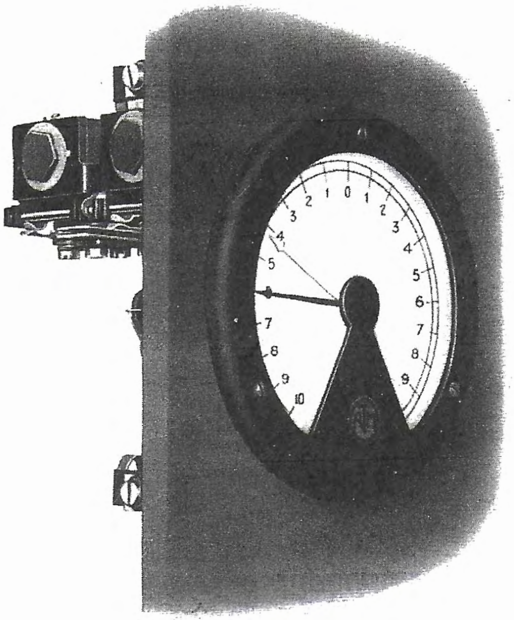


Fig. 16. Diagram of A.T.M. Strowger Contact Metering.



Mechanism of Typical Mechanical Meter.



Mechanical Meter fitted with two pointers.
Fig. 17.

insulated ring of contact studs, each of which is associated with a particular meter reading, is mounted under the contact arm.

When it is desired to transmit the reading, an electro magnet is energised, causing a bakelite ring to clamp the contact arm against the contact corresponding to the reading.(Figs.14&15).

At the same time, a selector commences to step, transmitting for each step an impulse to the control room to drive a ratchet and pawl mechanical meter.

The contact studs on the meter are wired consecutively to the selector so that when the "marked" contact is reached, a relay operates to cut off further pulses. The mechanical meter at the control room is thus left in the position corresponding to the "spot" reading transmitter. (Fig.16 shows the circuit arrangements for spot impulse metering).

The number of contact studs in the contact meter depends upon the degree of accuracy required for the remote reading, e.g. 21 studs give 2½% maximum error on a full scale reading, 41 studs 1¼%, etc.

Where meter readings are naturally associated, for example KW and KVA readings, current and power factor, for a particular machine, or feeder, it is often convenient to record each of these on a single meter equipped with two separate pointers (Fig.17.).

This system is robust, simple and particularly fast; 10 meter readings each with a maximum full scale error or ± 2½% can be transmitted in approximately 12.5 seconds.

TELEPHONES

In central supervisory systems, where the actual operations are initiated at the distant station and not at the control room as in remote control systems, some means of communication is required between the control and distant stations.

The visual instruction system already explained does not cover all contingencies and a telephone system is therefore necessary.

The same channel is used for indication and telephony.

A complete telephone system is illustrated in Fig.18.

It is arranged that all telephones on the system can communicate with each other. Calls between the control engineer and the operating staff at the distant stations take precedence over any other calls, the control desk being equipped with a complete telephone switchboard. A telephone attendant's cabinet is sometimes provided to relieve the control desk during busy periods.

Thermionic repeaters are provided at the control stations for the amplification of speech between the more remote stations.

Selective calling of the satellite station telephones where more than one share the same line is a accomplished by means of different calling frequencies, one per telephone, the telephone bells being "tuned" to respond to their own particular calling frequency.

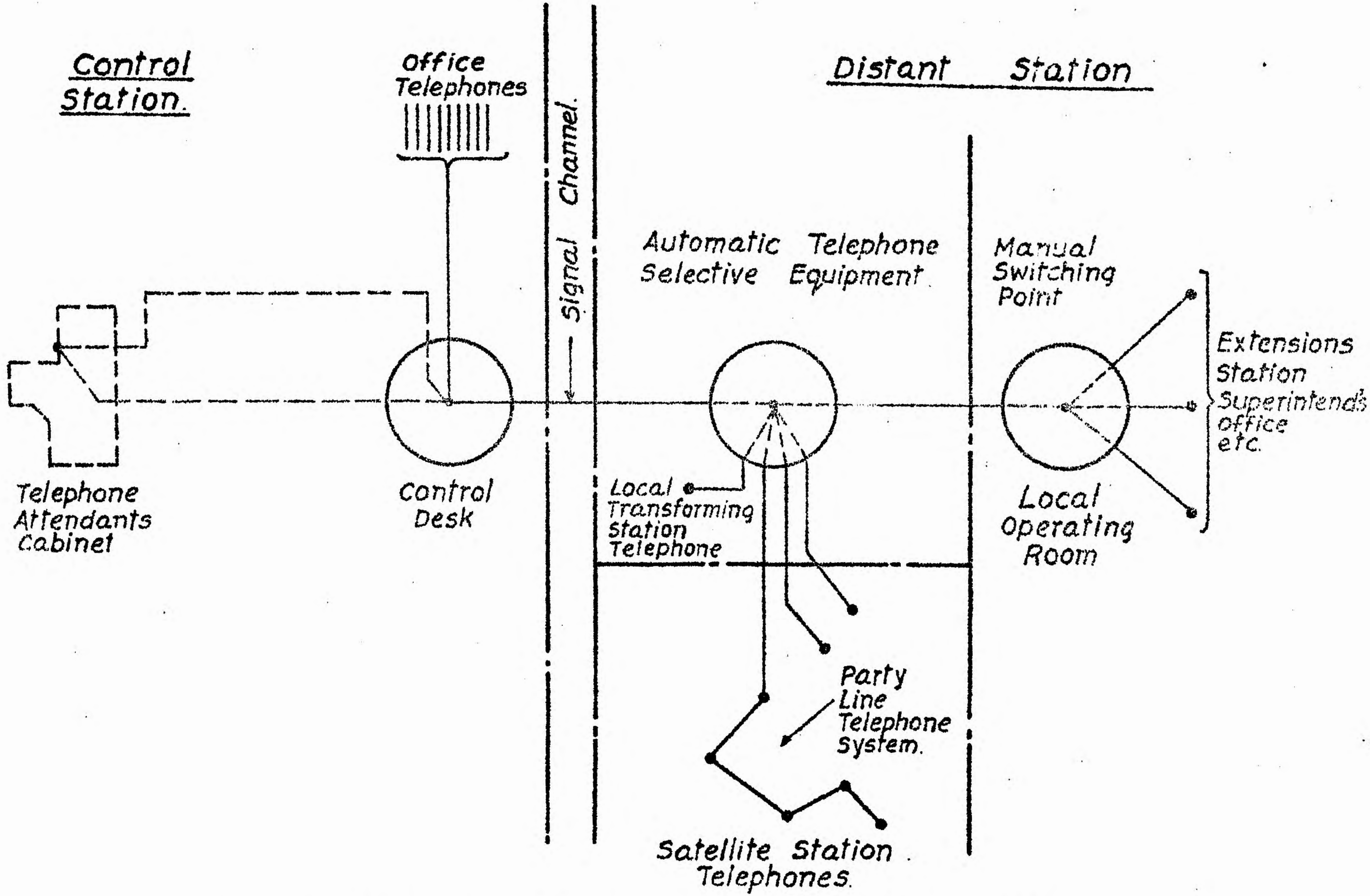


FIG. 18. Diagram of Complete Telephone System.

VOICE FREQUENCY SIGNALLING.

Where the signal lines are not metallically continuous, having been phantomed or having repeaters inserted, signals are transmitted in the form of alternating currents at frequencies within the voice frequency spectrum.

Frequency Range.

Alternating currents at frequencies from 10 to 3500 cycles per second may be used although the voice frequency range 200 to 2500 cycles is more usual, as it permits the use of ordinary telephone channels. The alternating current for signalling is obtained from either small inductor type alternators or thermionic valve oscillators.

Voice Frequency Receivers.

Voice frequency receivers, can be of the tuned relay or tuned thermionic valve type.

The relay receiver is either electrically "tuned" with a resonating circuit or mechanically tuned with a resonating reed or pendulum. The relay receiver can only be used where strong signals are available and therefore is not used as much as the valve receiver.

The valve receiver operates on the "anode bend" principle, in that no anode current flows to operate the relay receiver until the incoming signal makes the grid less negative.

In one method the receiver is arranged to work on varying signal intensities by connecting a neon tube across the tertiary winding of the intervalve transformer. A strong signal which would normally overload the receiver causes the neon tube to flash over, thereby decreasing the impedance of tertiary circuit. This attenuates some of the signal and passes on a constant signal intensity to the receiving valve.

Filters.

These are networks composed of inductances and condensers arranged to pass certain frequencies and to prevent the passage of others.

The use of filters allows signalling at certain frequencies to be carried on simultaneously with speech on the same channel with complete secrecy.

Speech articulation is not seriously depreciated by removing frequencies below 400 and above 2,500 cycles, which frequencies therefore are available for simultaneous signalling without interfering in any way with the conversation.

There are four types of filter, low pass, high pass, band pass and band elimination, the two most frequently used being the low and high pass types.

Choice of Frequencies.

Three frequencies are used: high, medium and low, to be the equivalent of the reversed and normal polarities and line series holding properties of direct current signalling.

At the time of writing, no thermionic receivers have been entirely successful in responding to pure frequencies in the voice.frequency range yet unresponsive to the complex speech frequencies. It is for this reason that the medium and high frequency receivers are normally disconnected from the line and connected only when a low frequency is received; the low frequency (300 cycles approx.) having been removed from the conversation by a 400 cycle high pass filter.

CENTRAL SUPERVISION OF TWO STATIONS ON A COMMON CONTROL CHANNEL.

Economy in control channels can be effected by connecting stations in pairs to single channels, operating the nearer station on direct current signals and the remote station with voice frequency current with little or no alteration to existing circuits. If line conditions necessitate voice frequency working for both stations, a different method of operation is adopted to avoid signal congestion and to preserve signal priority. The two stations have different low frequencies, 300 cycle and 350 cycle, yet the same medium and high frequencies. Selection is performed by transmitting the medium and high pulses in the normal way but with the low frequency peculiar to the station in which selection is to be made.

When a station wants to send a breaker change signal to the central station, it commences to send its low frequency in "on and off" periods of one a second until a pulse of similar frequency, transmitted by the central station during the silent period, is received to cause the station to transmit its breaker change.

The answering pulse transmitted by the central station would be delayed if a signal train was being simultaneously received from the other station. The answering pulse would be transmitted immediately if the line was in use for telephony, the breaker change having priority.

The signal train introductory signals cannot be heard by the conversing parties, as the frequencies 300 and 350 are below the cut off figure, 400 cycles.

EMERGENCY TELEPHONES.

Means are provided for switching the control lines over to local battery magneto telephones on receipt of magneto call from the other end of the line in the event of the indicating equipment or supply failing at either station.

INTER-TRIPPING OF CIRCUIT BREAKERS.

It is often necessary, in fault isolation, for the tripping of a circuit breaker at one end of a transmission line to effect the tripping of the circuit breaker at the other end. This is usually performed by protective relays connected to the power system or by the use of auxiliary pilot wires.

EMERGENCY STAND-BY EQUIPMENT.

At the transforming stations, anode current is obtained from metal rectifiers, automatically changing over to anode converters when the mains fail. All thermionic valves are connected in duplicate, so that in event of cathode failure the duplicate valve comes into service.

The apparatus batteries have sufficient stand-by capacity to cater for the longest anticipated period of mains failure.

At the central station the apparatus battery supplies emergency lighting to the indicating panel and also to the station itself. Two motor alternator generator sets are provided with automatic change-over initiated by frequency, high tension, or motor failure.

An alarm system is used at the central station which gives an audible alarm and indicates the nature of the fault, i.e. mains failure, valve burn-out, fuse, frequency generators, etc.

Equipment failure in the transforming station operates audible and visual alarms in its associated operating room, in which case the attendant can notify the Central Station over the system telephone.

Signal Strengths.

On metallic lines, the D.C. current employed for signalling is approximately 10 milli-amperes at 50 volts, whilst for A.C. signalling over repeatered lines the current is approximately 2 milli-amperes at 2 volts.

Simplicity of Signalling Apparatus.

It will be observed that the apparatus described consists mainly of simple and robust telephone relays and rotary selectors, components that have been thoroughly proved in service in practically all countries of the world. As an additional precaution against the possibility of contact trouble due to dust particles, the contact springs of all relays are duplicated, there being thus virtually two conducting paths in parallel.

CONCLUSION.

An attempt has been made in this paper to give an outline of the facilities provided by central indication and telephone equipment on large interconnected systems and it is hoped will stimulate interest and lead to still further development.

The author desires to express his thanks to the Central Electricity Board for permission to include in the paper the various illustrations of the Strowger equipment installed on the Grid systems, also to Automatic Electric Company Limited, Liverpool, for the facilities afforded to him in the preparation of the paper.

In presenting this review of what has been accomplished, it must be pointed out that the developments described represent the work of a number of engineers with whom the author is privileged to be associated.

APPENDIX I.

GLOSSARY OF TERMS.

Transforming Stations.

The potential at which electrical power is generated is limited by the practical possibility of insulating the generating plant, while the potential at which electrical power is transmitted is increased to reduce one of the principal expenditures of the transmission system, the cost of the line conductors. For these reasons, power is generated at power stations at a potential of 6,600 volts (for example) and is stepped up for transmission by transformers to potentials of the order of 132 kV or 220 kV.

"On Load" Tap Change Gear for Transformers.

Power transformers are often provided with tappings so that the ratio of transformation can be varied from time to time to cater for change in the loading of the system.

On the British Grid System, the limits of ratio variation are usually ± 10% in steps of 1.43% making a total of 15 "tap" positions.

Circuit Breakers.

Oil immersed circuit breakers, capable of rupturing large currents, are used to connect transformers to the transmission lines. Such circuit breakers are normally electrically operated and are arranged to trip automatically in the event of abnormal conditions.

From a signalling point of view they may be regarded as two position devices.

Isolators.

Periodically, transformers and circuit breakers have to be inspected, cleaned, tested or repaired. Before this can be attempted, it is necessary to isolate the transformer or breaker from the rest of the system and an alternative supply arranged. This is usually effected by means ofisolating switches.

In the same category are earthing switches, which are operated to "earth" the transmission lines or any equipment on which men are about to work.

Switches of this type are never called upon to break heavy currents; they are manually operated and do not trip automatically as do circuit breakers, but like the latter they can only occupy one of two positions, i.e. open or closed.

Instrument Transformers.

High voltages and large currents are measured on standard low range instruments (usually 5 amps & 110 volts full scale respectively) by interposing an instrument transformer between the meter and the supply. The transformer also serves to isolate the metering circuits from high voltages.

There are two classes of instrument transformer, one for stepping down the current, the other the voltage. These are called current and potential transformers respectively.

Selector or Rotary Selector.

Consists of an electro-magnetic mechanism, which by means of a ratchet pawl arrangement rotates one or more brushes or wipers over a corresponding number of bank contact levels. The magnet armature, when operated, opens a pair of normally closed contacts, so that by energising the switch magnet through these interrupter contacts, rapid rotation of the switch is obtained. The speed is about 65 steps per second. The switch works on the reverse-drive principle, so that the wipers do not move until the electro-magnet is de-energised. The switch is available up to 8 levels for a 25 contact bank, or 4 levels for a 50 point bank.

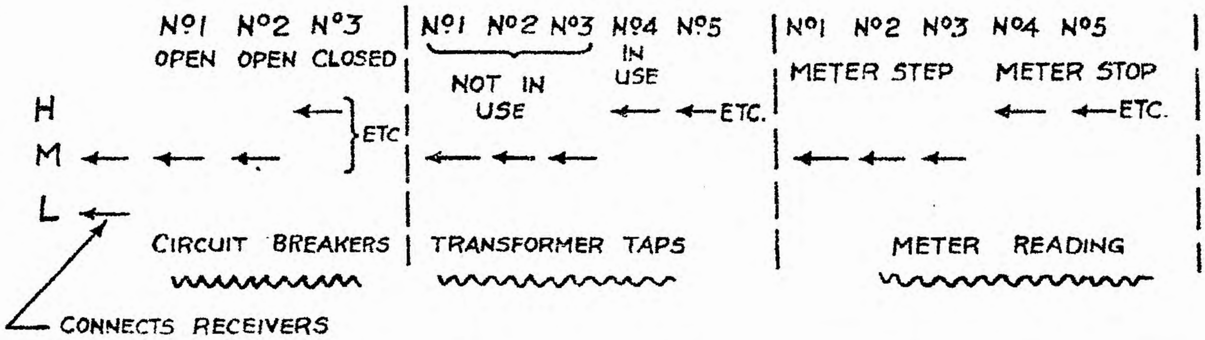
Thermionic repeaters.

Are used to amplify, generally for re-transmission, line attenuated speech or signal frequencies.

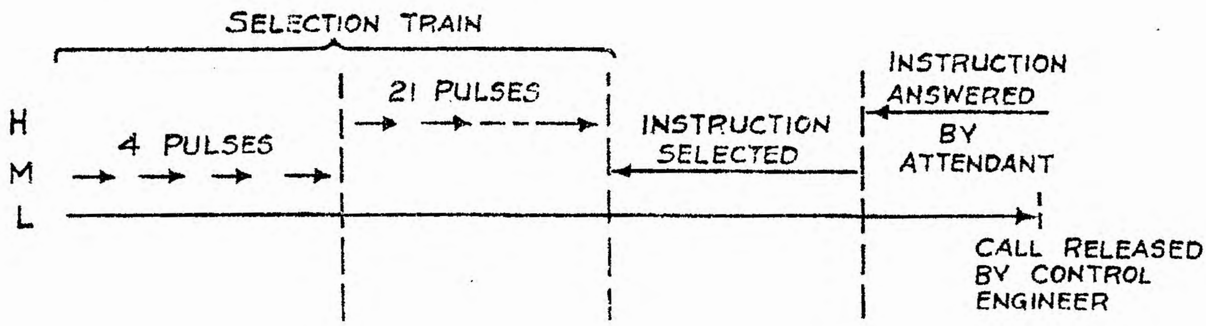
TYPICAL EXAMPLES OF VOICE FREQUENCY SIGNALLING ON SUPERVISORY SYSTEMS

FREQUENCES USED :- LOW (L) 300~ MEDIUM (M) 1250~ HIGH (H) 1500~

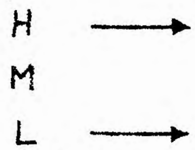
1. *A signal train transmitted to central station to correct circuit breakers, transmitter taps & meter indications.*



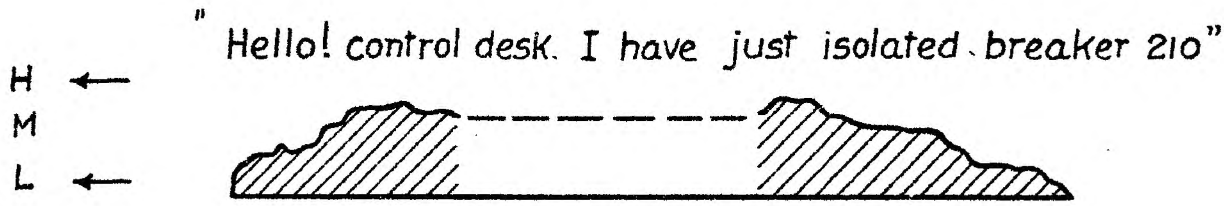
2. *A selection train transmitted from control room selecting a visual instruction indication.*



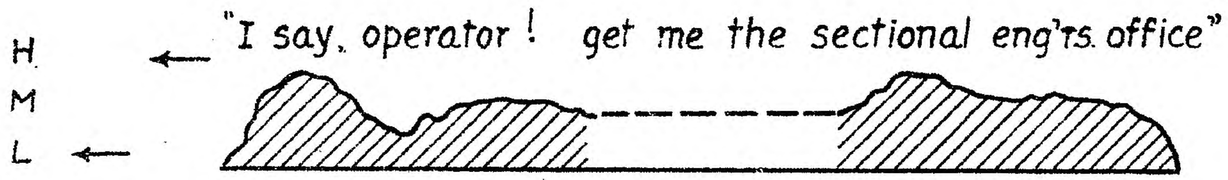
3. *A signal transmitted by control station to initiate signal train from distant station*



4. A telephone call to control desk.

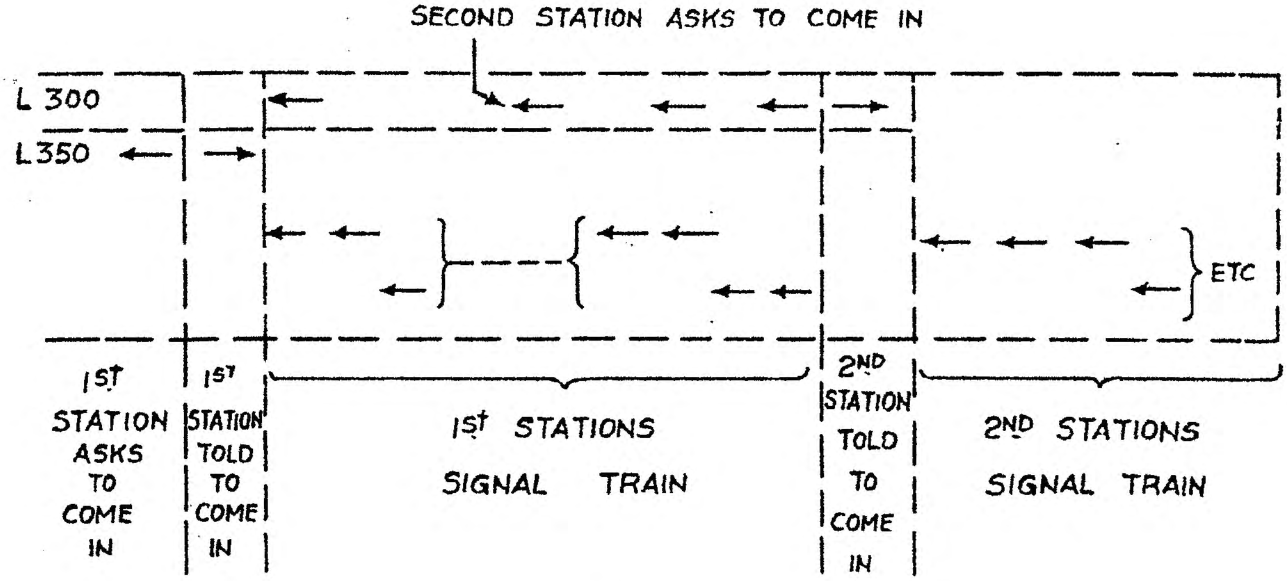


5. A telephone call to manual board

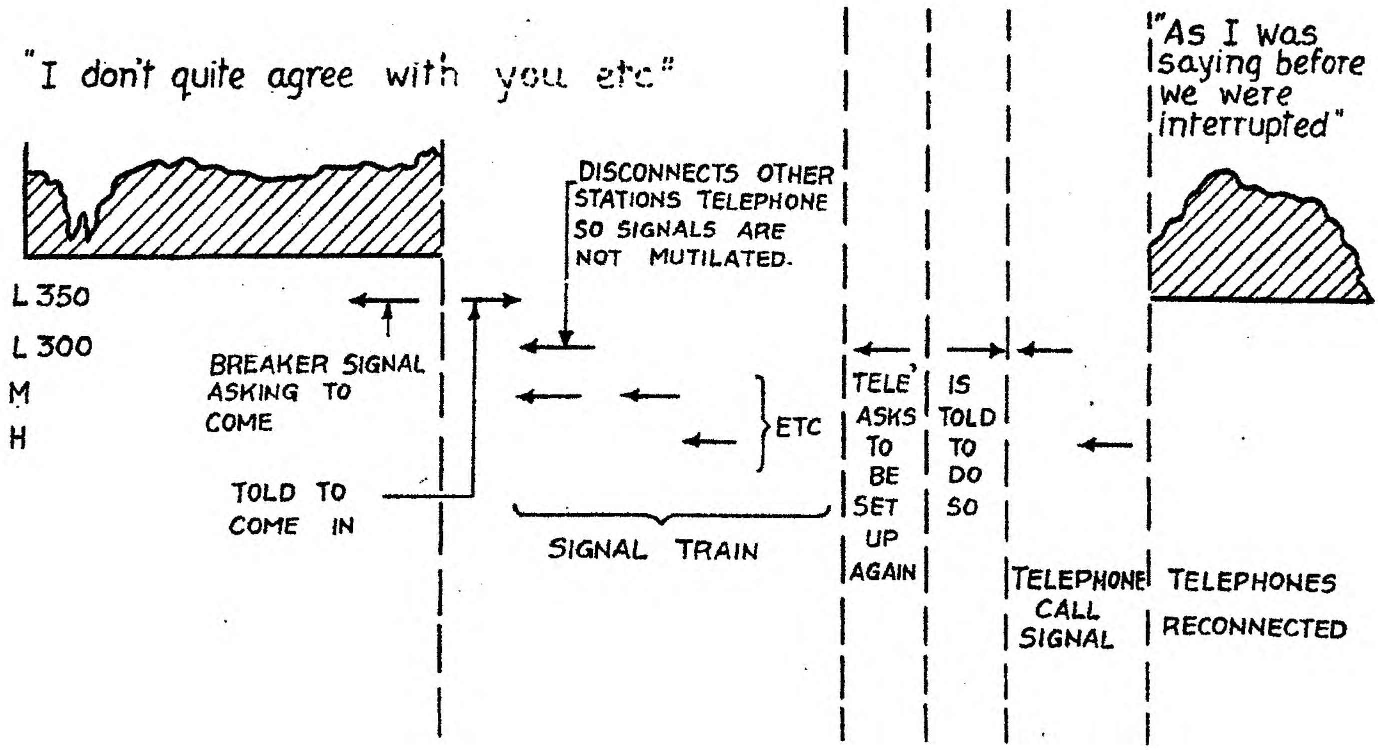


USE OF AN EXTRA LOW FREQUENCY 350 ~ USED WHERE TWO STATIONS SHARE THE SAME LINE

6. *The second station waiting to send signal train while first station is sending a signal train*



7. *A telephone conversation with second station waiting to signal a circuit breaker change*



8. A telephone selection train transmitted to one station from control room interrupted by a priority signal train from the other station.