TECHNICAL INSTRUCTION
T.14

Power Supply Installations
General

First issue May 1967

PREFACE

This Instruction is complementary to others dealing with power-supply arrangements at individual transmitting stations. It provides details of various items of equipment in common use. Certain underlying principles are outlined. They relate to BBC practice and are intended only as introductions to the particular subjects.

AMENDMENT RECORD

Amendment Sheet No.	*Initials*	*Date*	*Amendment Sheet No.*	*Initials*	*Date*
T.14—1	✓	✓			
T.14—2	JWW	3/6/71			
T.14—3					
T.14—4					
T.14—5					
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To locate information on other equipment, consult the current List of Technical Publications.

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ACKNOWLEDGEMENT

The British Broadcasting Corporation is indebted to the following organisations for permission to copy or adapt illustrations from their publications for use in Part 3 of this Instruction.

The General Electric Company Limited, for Figs. 2.3 and 2.4.

Allen West and Company Limited, for Fig. 4.3.

Associated Electrical Industries Limited, for Figs. 3.2 and 4.7.

The English Electric Company Limited, for Figs. 5.3—5.8, 6.3 and 7.1.

Johnson and Phillips Limited, for Figs. 6.1 and 6.2, taken from the *J. & P. Switchgear Book*.

NEW DRAWING SYMBOLS

Certain new drawing symbols used in this Instruction have been introduced to conform to British Standard 3939.

SECTION 1

SEMI-AUTOMATIC CONTROL SYSTEM FOR TWO AND THREE DIESEL-ALTERNATOR SETS

1.1 Introduction

These installations provide standby power supplies at certain transmitting stations. Some installations comprise two Diesel-alternators and others three. The ratings of the individual engines and alternators in any one installation are the same.

The engines are started semi-automatically, each engine-starting sequence being initiated by pressing an associated *Start* button. Means are provided for paralleling the outputs of the alternators, and their combined output can be fed to the Station's main 415-volt switchboard. *The alternators cannot be synchronised with the incoming mains supply.*

For each Diesel-alternator there is a starter panel, a battery and a battery-charger. A combined switchboard is provided and it comprises a panel associated with each alternator, a panel controlling the combined output, and a synchronising panel. This associated equipment is the same at each Station.

In the event of serious faults the engines concerned are automatically shut down and an alarm (visual and aural) is given.

1.2 Equipment Details

1.2.1 Engines

Certain installations have two engines and others have three, which are identical in any one installation.

Fig. 1.1 gives the typical circuit arrangement for control of a single engine, and includes details of the shared alarm facilities.

The engines are water-cooled with the aid of their own engine-driven water pumps. Water and lubricating oil are fed to each engine through an individual radiator. Air from outside the building is drawn, via manually- controlled louvres, through the radiator by means of a thermostatically-controlled electric fan. Thermostatically-controlled heaters are fitted in (a) the engine sump, (b) the engine water system, and (c) the radiator water system.

The installation has a common electrically-driven lubricating-oil priming pump. Before priming an engine it is essential to ensure that the suction and delivery valves on the other engines are closed, to prevent possibility of the pump transferring oil from one sump to another. Alternatively use can be made of the hand-priming pump fitted to each engine, and then it is unnecessary to close the suction and delivery valves on the other engines.

Fuel is drawn from a daily-service tank in the Diesel hall. The tank can be replenished from a remote storage tank by use of either an electrically-driven fuel-transfer pump or a semi-rotary hand pump.

1.2.2 Alternators and Exciters

The alternators are a conventional design giving a 415-volt three-phase and neutral output. The exciter is a cross-field type having two separate field-windings. Current flowing in the field windings is controlled by an automatic voltage regulator (a.v.r.) which in turn is controlled by the output voltage of the associated alternator. Varying the exciter-output voltage varies the excitation current flowing in the alternator field winding and hence maintains the alternator-output voltage at a constant value.

Details of the a.v.r. are given in a handbook issued by the Electric Construction Company Limited and entitled:

Automatic Voltage Regulator B.1864/P Series

1.2.3 Batteries and Battery-chargers

Each engine-starting motor is powered individually by a nickel-iron alkaline battery, used also to operate equipment in the associated engine control panel.

The battery has 18 cells (nominally 24 volts) with a total capacity of 190 ampere-hours at the 2-hour rate. Connected across it is a constant-voltage charger adjusted to maintain a voltage about 1·5 volts in excess of nominal battery voltage. That gives a charging current of approximately one ampere, except while the battery is recovering from discharge. Adjacent to the box which houses the battery is a switch for isolating the starter motor from the supply; see Fig. 1.1.

One of these battery-and-charger combinations has the additional duty of providing the 24-volt supply needed for the alternator control board. This feed is taken from terminals on the appropriate engine control panel, as indicated in Fig. 1.1.

1.2.4 Engine Starter Panel

This panel contains all the control relays for one engine, and it has the circuit arrangement shown in Fig. 1.1. Mounted on the front door of the panel are:

- (a) A switch, known as *Isolator No. 2*, to break the 24-volt supply to the panel, the starting-motor contactor and a circuit in connection with an excess water-temperature thermostat.
- (b) A voltmeter across internal 24-volt busbars.
- (c) A *Priming Switch* which, when closed, prevents initiation of engine-starting sequence in addition to energising a contactor for the purpose of powering the lubricating-oil priming-pump motor.
- (d) A fault warning-lamp and a switch to enable an audible alarm to be muted.
- (e) A *Reset* button for restoring fault-indicating circuits to normal subsequent to their operation.
- (f) Fuses in various circuits.

The handle securing the door of the panel incorporates *Isolator No. 1* which breaks the circuits incoming to the panel, except the excess water-temperature alarm, before the door can be opened.

1.2.5 Alternator Control Board

One section of the board contains equipment to control the combined output of the alternators. The other two (or three) sections of the board are associated one with each engine. The general arrangement of the board is illustrated in Fig. 1.2 by circuit details for one alternator panel (No. 2) and the two panels common to the alternators as a group.

In the combined-output section are:

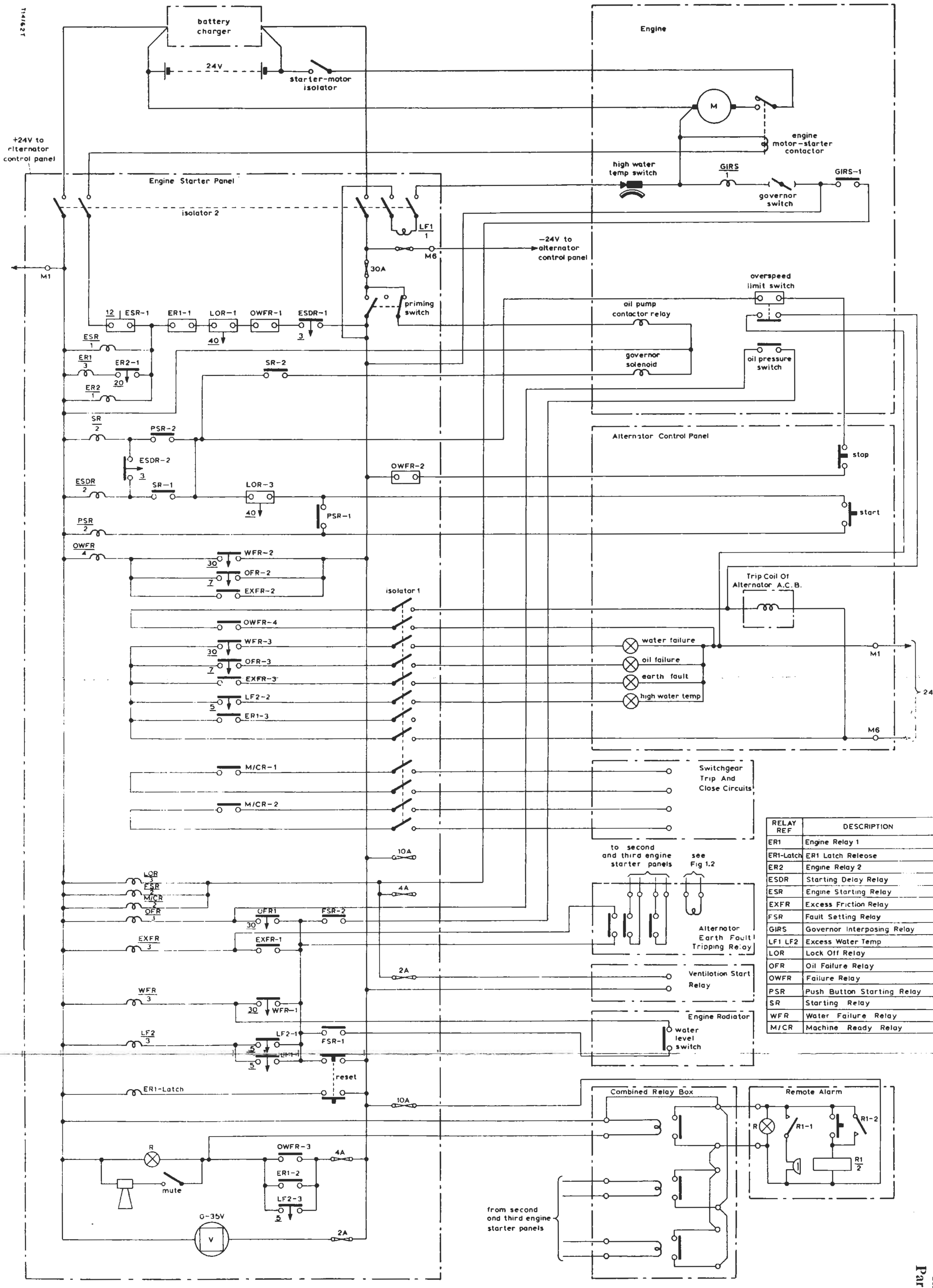
- (a) A 400-ampere air circuit-breaker controlling the combined output from the alternators. This breaker is fitted with over-current coils and mechanically interlocked to a 24-volt contactor so that it cannot be closed unless the 24-volt supply is present at the panel.
- (b) A *Raise/Lower* governor switch for simultaneously adjusting the speed of all the engines.
- (c) An earth-fault relay and a tripping relay. These operate sequentially to shut down all alternators by energising a relay (EXFR in Fig. 1.1) in each of the engine starter panels.
- (d) A four-pole turn-switch in a 415-volt, three-phase and neutral circuit depending on the combined output. Through an external change-over contactor the feed provided by this circuit is connected to an engine auxiliaries distribution fuse-board in the event of mains failure.
- (e) An ammeter and a kilowatt-hour meter.

Each section associated with a particular alternator contains the following equipment:

- (a) A 200-ampere air circuit-breaker, fitted with over-current coils and a shunt-trip coil.
- (b) *Start* and *Stop* buttons to control the engine.
- (c) A *Hand/Auto* switch for selecting either manual or automatic control of the alternator-output voltage.
- (d) A *Raise/Lower* governor switch to vary the engine speed; this is used when the alternators are being synchronised.
- (e) A five-pole turn-switch with *Off* and *Synchronise* positions. This switch incorporates a lock in its handle. The key must be turned, and thus trapped, in the lock before the switch can be turned from *Off* to *Synchronise*. Removal of the key is conditional on the switch being at *Off*.
- (f) Four fault-indication lamps.
- (g) A ammeter, a power-factor meter and a kilowatt meter. The ammeter measures the current in the exciter control-field.

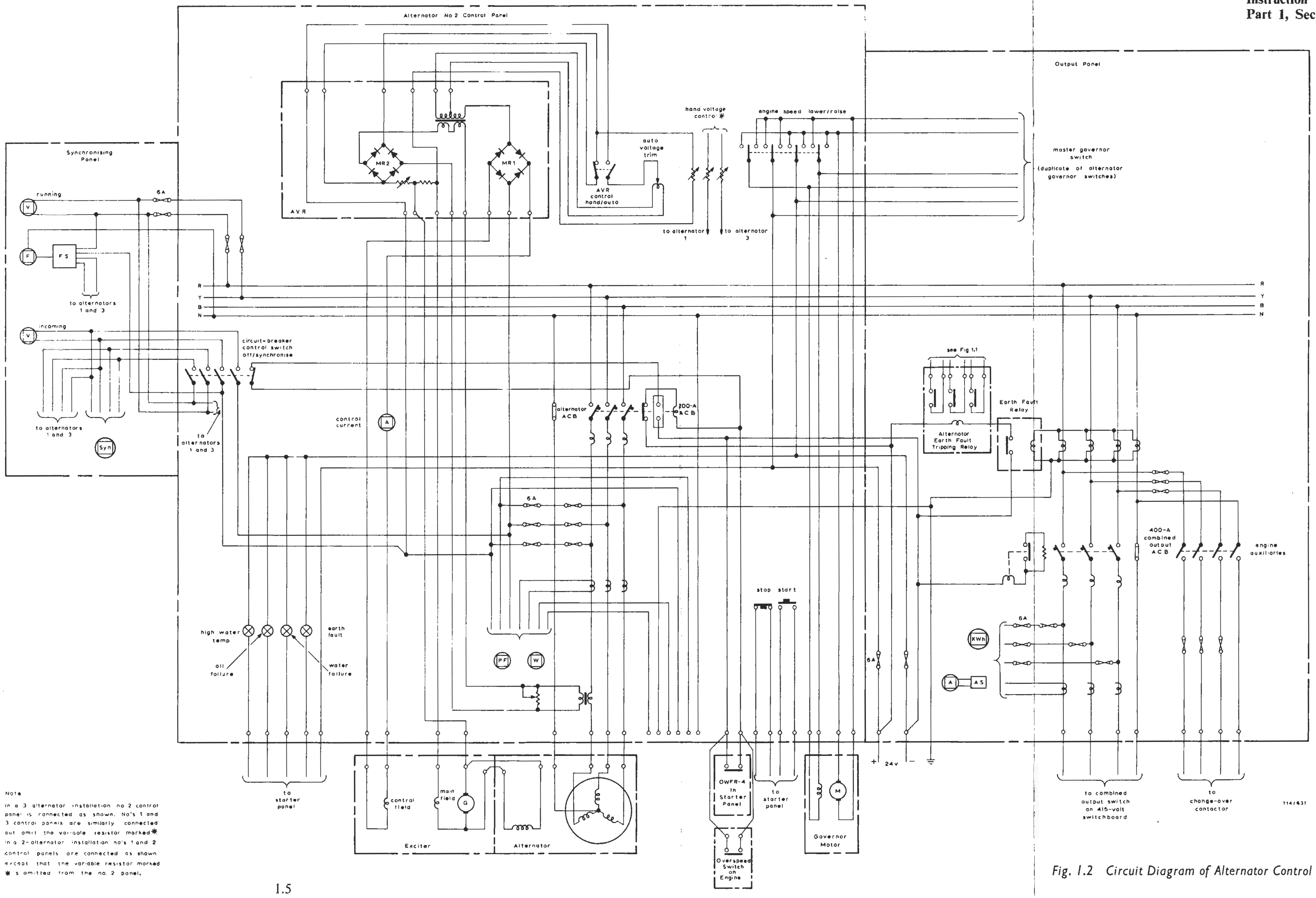
A three-engine installation has three variable resistors, ganged together, on the No. 2 alternator panel. In a two-engine installation there are two ganged variable resistors on the No. 1 alternator panel. Each resistor is connected in series with the main field of an associated exciter when the appropriate *Hand/Auto* switch is set to *Hand*; thus it is effective for the purpose of controlling the output voltage of the associated alternator. The output voltages of more than one alternator can be adjusted simultaneously if the appropriate *Hand/Auto* switches are put to *Hand*.

In the *Auto* position of the switch the alternator-output voltage is indirectly controlled by an a.v.r. arranged to vary the control-field current, and hence the excitation current. The range of regulation can



RELAY REF	DESCRIPTION
ER1	Engine Relay 1
ER1-Latch	ER1 Latch Release
ER2	Engine Relay 2
ESDR	Starting Delay Relay
ESR	Engine Starting Relay
EXFR	Excess Friction Relay
FSR	Fault Setting Relay
GIRS	Governor Interposing Relay
LF1 LF2	Excess Water Temp
LOR	Lock Off Relay
OFR	Oil Failure Relay
OWFR	Failure Relay
PSR	Push Button Starting Relay
SR	Starting Relay
WFR	Water Failure Relay
M/CR	Machine Ready Relay

Fig. 1.1. Circuit Diagram of Engine Control Equipment



Note

In a 3 alternator installation no 2 control panel is connected as shown. No's 1 and 3 control panels are similarly connected but omit the variable resistor marked *. In a 2-alternator installation no's 1 and 2 control panels are connected as shown except that the variable resistor marked * is omitted from the no. 2 panel.

Fig. 1.2 Circuit Diagram of Alternator Control Panels be determined, from the front panel, by pre-setting adjustment of an auto-transformer.

The switch mentioned in (e) is used to prevent inadvertent paralleling of alternator outputs. Unless this switch is in the *Synchronise* position it is not possible to close the alternator circuit-breaker. Once the breaker has been closed, the switch must be put to *Off* in order that the key can be returned to the key-rest switch on the synchronising panel. One key only is provided for the two (or three) switches and, as already mentioned, they cannot be moved to *Synchronise* until the key is in the lock.

A hinged synchronising panel is fitted to one side of the alternator control board. On this panel are a synchroscope, a frequency meter and two voltmeters. By use of a selector switch the frequency meter can be connected to indicate the frequency of the supply on the control-board busbars and the frequencies of the individual alternator outputs. One voltmeter, labelled *Busbar Voltage*, indicates the voltage between red and yellow phases of the busbars. The other voltmeter (*Incoming Voltage*) indicates the voltage between red and yellow phases at the output of any alternator whose *Off/Synchronise* switch is at *Synchronise*. Only one of these switches can be in that position at any one time.

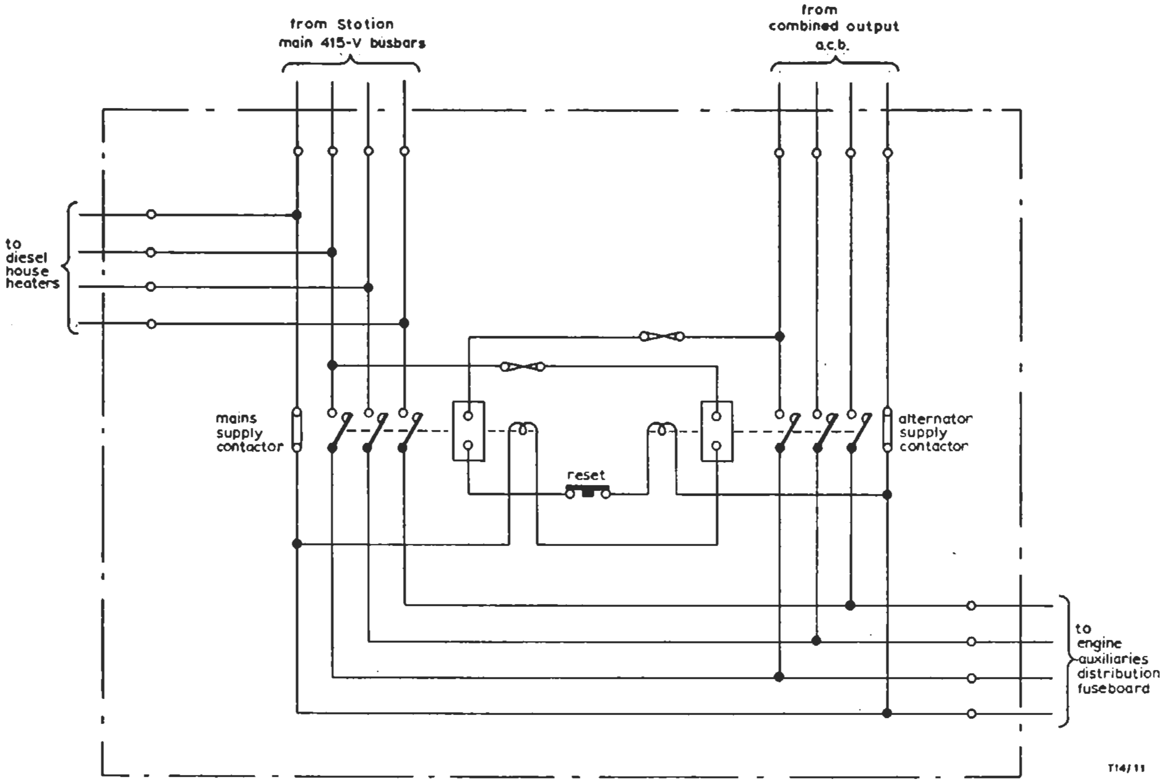


Fig. 1.3 Circuit Diagram of Change-over Contactor Cubicle

1.2.6 Change-over Contactor Cubicle

Inside this cubicle are two three-pole contactors. They are mechanically interlocked so that only one can be closed at one time. Two 415-volt three-phase and neutral inputs to the cubicle are obtained from the incoming mains supply and the combined output of the alternators. The change-over contactor feeds an engine auxiliaries distribution fuseboard. Heaters in the Diesel Hall are fed directly from the mains input and the supply is not maintained in the event of a mains failure. The contactor-circuit arrangement is given in Fig. 1.3.

If a mains failure occurs, the operating coil of the mains-supply contactor is de-energised. When the alternators are providing an output, the operating coil of alternator supply-contactor is energised and the contactor closes. When the mains supply is restored it is necessary to press a *Reset* button on the panel in order to restore the contactors to their normal positions, in which the engine auxiliaries distribution board is fed from the incoming mains supply.

1.2.7 Engine Auxiliaries Distribution Fuseboard

This eight-way three-phase and neutral fuseboard is used to distribute the following supplies:

(a) 240-volt single-phase and neutral to the battery chargers.
(b) 240-volt single-phase and neutral to the lubricating-oil and water heaters on each engine.
(c) 415-volt three-phase and neutral to radiator-fan motors.
(d) 415-volt three-phase and neutral to a fuel transfer-pump motor.
(e) 240-volt single-phase and neutral to a Diesel Hall lighting circuit.
(f) 240-volt single-phase and neutral for a ring-main supply to socket outlets in the Diesel Hall.

1.3 Engine Starting and Stopping Sequences

This itemised description applies to Fig. 1.1.

(*a*) *To Start the Engine*

1. Press the *Start* button.
2. PSR, energised via LOR-3, the over-speed limit switch, the *Stop* button and OWFR-2, locks on through PSR-1.
   PSR-2 completes the circuit to energise SR.
3. SR-1 completes the circuit to energise ESDR. ESDR locks on, after 3 seconds, through ESDR-2.
   SR-2 completes the energising circuit to the governor solenoid, 3 seconds after ESDR is energised. ESDR-1 completes the circuit to energise the starting-motor contactor, ESR and ER2.
   ESR-1 begins a timing-out period of 12 seconds. The motor starts and runs up to speed.
4. When the engine reaches 80 per cent of full speed the governor switch closes and completes the circuit to energise GIRS. GIRS-1 completes the circuit to energise LOR, FSR and M/CR.
   LOR-1 further isolates the starter circuit and causes ER2 to be de-energised.
   LOR-3 causes PSR to de-energise.
   FSR-1 and FSR-2 prepare the water-level and lubricating-oil-pressure trip circuits respectively.
5. ESR-1 ends a 12-seconds delayed opening by breaking the circuit to the starting-motor contactor. Thus the engine-starting attempt is limited to a period normally more than adequate for completion of preceding operations; see 1.4.1.

(*b*) *To Stop the Engine*

1. Press the *Stop* button.
2. The governor solenoid is de-energised and causes the fuel supply to the engine to be cut off at the fuel pump.
   ESDR, FSR, GIRS, LOR and SR are de-energised.

Note: The engine cannot be restarted until 40 seconds after LOR has been de-energised. This delay ensures that the engine has come to rest.

1.4 Engine Faults

Audible and lamp alarms are arranged to draw attention to various faults that may occur either during the starting sequence or while the engine is running. In certain circumstances the engine is shut down. Some typical fault sequences are detailed below, with reference to Fig. 1.1.

1.4.1 Starting Faults

If the engine fails to fire within 12 seconds:

1. ESR-1 opens to break the circuit to the engine starting-motor contactor.
2. After a further 8 seconds, ER2-1 closes to energise ER1, which mechanically latches on.
3. ER1-1 latches open to further isolate the starting-motor contactor and to de-energise ER2 and ESR.
   ER1-2 latches closed to complete the circuit of the audible and lamp alarms.
   ER1-3 latches closed to complete the circuit to give a remote buzzer-and-lamp alarm.

1.4.2 Running Faults

In operation 4 of the starting sequence, FSR is energised to prepare the fault circuits. These are concerned with water level, lubricating oil pressure and water temperature.

(*a*) *Water Level*

If the water falls below a predetermined level a water-level switch closes and:

1. WFR is energised and, after 5 seconds, locks on through WFR-1.
   WFR-2 completes the circuit to energise

OWFR.

2. OWFR-1 interrupts the starting-motor contactor circuit.
   OWFR-2 causes SR, ESDR and the governor solenoid to be de-energised.
   The engine is shut down.
   OWFR-3 completes the circuit for the lamp and audible alarm.
   OWFR-4 completes the trip coil circuit to the circuit-breaker controlling the alternator output
3. WFR-3 completes the circuit to give the remote alarm.

(*b*) *Lubricating-oil Pressure*

If the lubricating-oil pressure falls below 25 lb/sq in., a pressure-operated switch closes and:

1. OFR is energised and locks on, after 5 seconds, through OFR-1. OFR-2 completes the circuit to energise OWFR.
2. The engine is shut down due to the action of OWFR; see item 2 under heading (a).
   After 7 seconds, OFR-2 completes the circuit to a lamp (*Oil Failure*) on the alternator control board.

(*c*) *Water Temperature*

Water temperature in excess of 87 degrees C (190 degrees F) causes energising of LF1 and:

1. LF1-1 completes the circuit to energise LF2 which locks on, after 5 seconds, through LF2-1.
2. LF2-3 completes the circuit to light a lamp and give an audible alarm.
   LF2-2 completes the circuit to light a *High Water Temperature* lamp on the alternator control panel.

After an engine has been shut down due to a fault condition, a *Reset* button must be used before it is possible to re-start. By pressing this button:

1. The latch-release relay is energised and releases the latched relay ER1.
2. The particular relay that was energised by the fault condition is de-energised and in turn de-energises OWFR.

1.5 Time Delay Relays

Certain of the relays in Fig. 1.1 incorporate adjustable time delays. These delays are achieved by means of oil-dashpots and are set up on installation. The relays and the reasons for their delays are as follows.

ESR (Engine Starting Relay)

Normally closed; 12-second delay in opening. The engine should have fired and run up to full speed within 12 seconds. ESR-1 breaks the circuit of the starting-motor contactor to prevent the battery from being discharged if the engine has not fired.

ER2 (Engine Relay 2)

Normally open; 20 seconds delay in closing. ER2-1 completes the energising circuit of ER1 which further isolates the starting motor-contactor if the engine does not fire.

ESDR (Starting Delay Relay)

Normally open; 3 seconds delay in closing. ESDR-1 completes the starting-motor contactor circuit. The delay is necessary to allow the governor solenoid to fully open the fuel supply to the engine.

LOR (Lock Off Relay)

Normally closed; 40 seconds delay in re-closing. LOR-1 breaks the starting-motor contactor circuit and gives a delay before the starting motor can be energised for a second time. LOR-3 breaks the start push-button switch circuit. This gives the engine an interval in which to stop rotating.

WFR (Water Failure Relay)

Normally open; 5 seconds delay in closing. This delay ensures that the alarm does not operate on any transient effect.

OFR (Oil Failure Relay)

Normally open; 5 seconds delay in closing. This delay ensures that the alarm does not operate on any transient effect.

1.6 Operating Procedures

Typical operating procedures given below may vary in detail from Station to Station and should always be read in conjunction with Station Local Instructions.

1.6.1 Routine Daily Procedure

At regular intervals the engine should be primed to ensure that, in the event of a mains failure, it can be started without delay. The following procedure applies to each engine:

1. Open the *Delivery* and *Suction* valves on the engine and make sure that the valves on the other engine(s) are closed.
2. Turn the *Priming* switch on the starter panel to the *Priming* position and check the oil pressure-gauge reading.
3. Bar the engine flywheel round once.

4. Put the *Priming* switch to *Off* and close the *Delivery* and *Suction* valves.
5. Ensure that the *Hand/Auto* switch is at *Auto*, the synchronising switch is at *Off* and the hand voltage-control is turned fully clockwise.

Note: On no account must more than one priming switch be closed at the same time. Otherwise there is a paralleling of batteries through the priming switches.

1.6.2 Starting and Synchronising Procedure

A simplified diagram of the synchronising circuit is given in Fig. 1. 4.

First Machine

1. Press the *Start* button and wait until the engine reaches full speed.
2. Adjust the *Raise/Lower* switch to give a frequency of 50 Hz.
3. Put the *Off/Synchronise* switch to *Synchronise* and close the alternator circuit-breaker.
4. Return the *Off/Synchronise* switch to *Off*.

Second Machine

Carry out operations 1 and 2 as already detailed. Then:

5. Remove the key from the *Off/Synchronise* switch of the first machine. Insert the key into the *Off/Synchronise* switch of the second machine.
6. Turn the *Off/Synchronise* switch to *Synchronise*.
7. Adjust the *Raise/Lower* switch until the synchroscope pointer is rotating slowly in the clockwise direction.
8. When the pointer is about to coincide with the 12 o'clock position, close the alternator circuit-breaker.

If a third machine is installed, proceed as for the second machine.

1.6.3 Normal Loading

In the event of a mains failure:

1. Trip the circuit-breakers controlling the incoming mains supplies.
2. Lock the circuit-breakers in the *Off* position by removing the Castell keys from their locks.
3. On the 415-volt distribution board, open all switches which control non-essential supplies; see Local Instructions.
4. Use the Castell keys from the circuit-breakers to release a Castell key from a key-exchange box. By this action the keys from the incoming-mains breakers become trapped.

Note: The key-exchange box is usually on the wall near the switchboard.

5. Use the released Castell key to free the Diesel-supplies switch on the main 415-volt switchboard.
6. Close the Diesel-supply switch.
7. Start and synchronise the alternators as previously described.
8. Close the combined output circuit-breaker (on the output panel of the alternator control board).
9. At the 415-volt switchboard, close the switches appropriate to powering of equipment which has been specified, by Local Instruction, for maintained operation.
10. Equalise the loading of the alternators by suitably adjusting their individual *Raise/Lower* switches.
11. Adjust the master *Raise/Lower* switch (on the output panel) to obtain an output frequency of 50 Hz.

1.6.4 Automatic Voltage Regulation

If it is suspected that an a.v.r. is faulty while the alternators are on load, the output of the affected alternator can be regulated by hand after:

1. Turning the hand voltage-control counter-clockwise to reduce the control current to approximately 0·4 amperes; this is indicated by a red line on the meter scale.
2. Putting the *Hand/Auto* switch to *Hand* and adjusting the hand voltage-control until the power factors of the alternators are similar.

To revert to *Auto* control the above procedure is reversed.

1.6.5 Reverting to Mains Supply

1. Remove the entire load from the 415-volt busbars.
2. Open the Diesel-supply switch and remove the Castell key.
3. Obtain the Castell keys for the incoming mains circuit-breakers by releasing them from the key-exchange box.
4. Close the incoming mains circuit-breakers.
5. Re-make the load to the 415-volt busbars.
6. Close down each Diesel engine; see following description.

1.6.6 Engine Close-down

The procedure to close down the installation is:

1. Trip the combined output circuit-breaker.
2. Trip each alternator circuit-breaker.

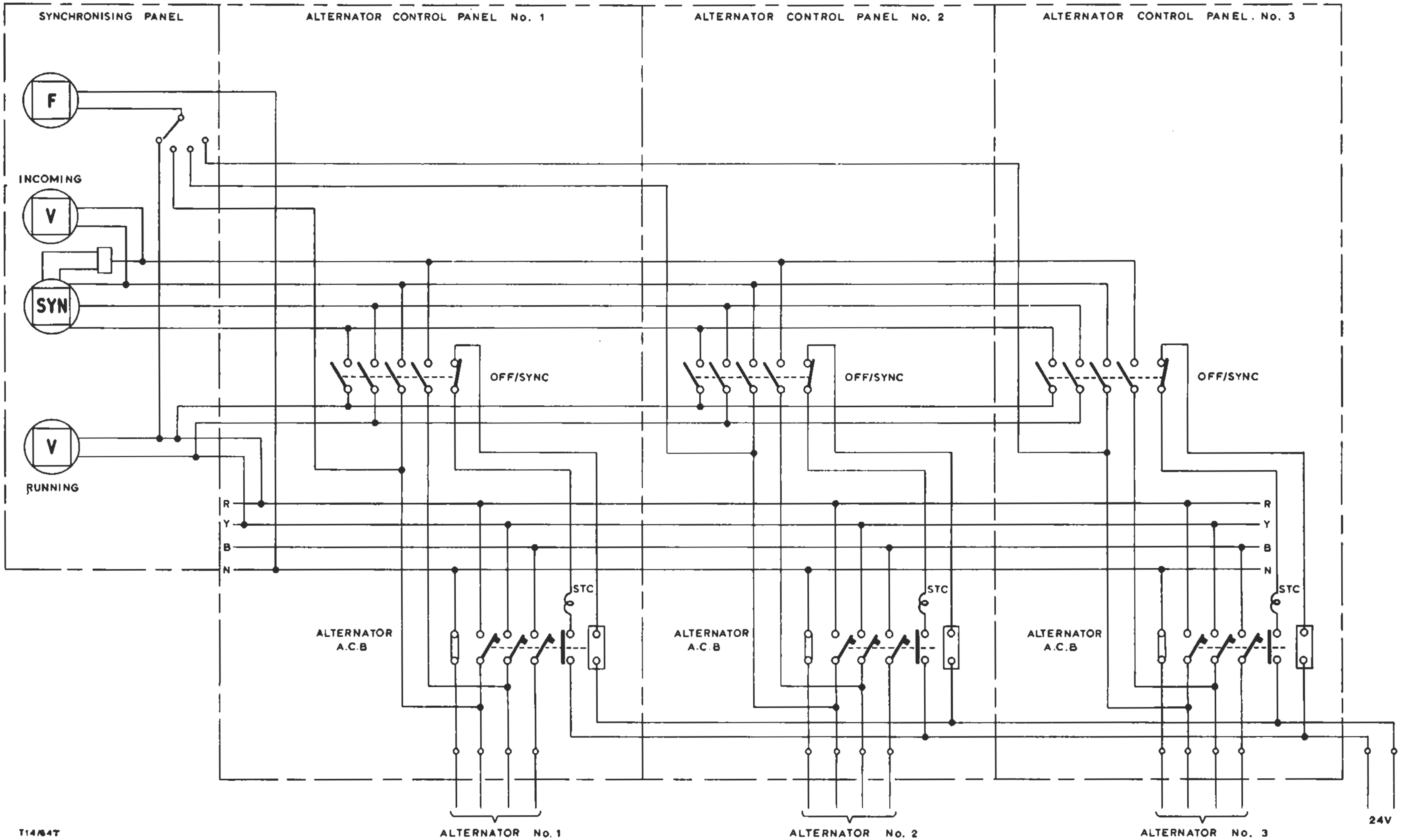


Fig. 1.4 Simplified Diagram of Synchronising Circuits

3. Stop each engine by pressing the associated *Stop* button.

1.6.7 Routine Testing

As a standard ancillary feature there is an arrangement for undertaking on-load testing of alternators while the Station is operating normally from the incoming mains supply. Usually the test load is one half of the Band-II installation. The transmitters chosen to act as a test load are fed via a change-over switch on the main 415-volt distribution board, so that they can be powered from either the main busbars or the Diesel-alternators.

The following procedure applies to single-machine testing. It must be strictly adhered to because *the change-over switch is an off-load type which must in no circumstances be operated while it is carrying a load current.*

1. Start the engine.
2. Close the combined output circuit-breaker.
3. Close down the transmitters which are to be used as the test load.
4. Open the switch controlling the supplies to these transmitters.
5. Put the change-over switch to the *Diesel* position.
6. Close the switch controlling the supplies to the transmitters.
7. Re-power the transmitters.

To revert to the mains supply:

1. Close down the transmitters forming the test load.
2. Open the switch controlling the supply to these transmitters.
3. Put the change-over switch to the *Mains* position.
4. Close the switch feeding the supply to the transmitters.
5. Re-power the transmitters.
6. Close down the Diesel engine.

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SECTION 2

AUTOMATIC CONTROL AND PROTECTION EQUIPMENT MARK II, MARK III AND MARK IIIA

2.1 Introduction

This Section describes a system of standby Diesel-alternator control installed at a number of transmitting stations. The Automatic Control and Protection Equipment Mark II is the original practical realisation of the system; the Mark-III and Mark-IIIA versions are successive developments of the Mark-II equipment.

The function of the Equipment is to monitor a mains supply and respond to supply failure by starting the engine and connecting the alternator output to circuits for which standby facilities are required. While the engine is running, the Equipment monitors engine-protection devices. When any of these devices detects a fault, the Equipment indicates the fault condition and can shut down the engine. When the mains supply is re-established, the Equipment closes down the standby plant and restores the power circuits to normal.

The Mark-II Equipment is fully described and details of changes incorporated by the later versions are given subsequently.

2.2 Normal Working Conditions

A simplified diagram of a typical installation is given in Fig. 2.1.

The total load of the Station is normally supplied from the mains, and the standby plant is idle. All loads covered by the standby facility are connected to maintained busbars, supplied from the mains via a contactor. This contactor is mechanically and electrically interlocked with a similar contactor for switching the alternator supply to the maintained busbars. The interlocks ensure that the mains and alternator cannot be connected together.

The Mark-II circuit given in Fig. 2.2 shows the state of the Equipment with all isolators open. With the mains healthy and the Equipment prepared for automatic operation, the following conditions apply to this circuit:

(a) Auxiliary switch FS-1 is closed because incoming-mains isolator FS1 is closed.

(b) The cubicle-isolator, control-circuit isolator and battery-isolator are closed.

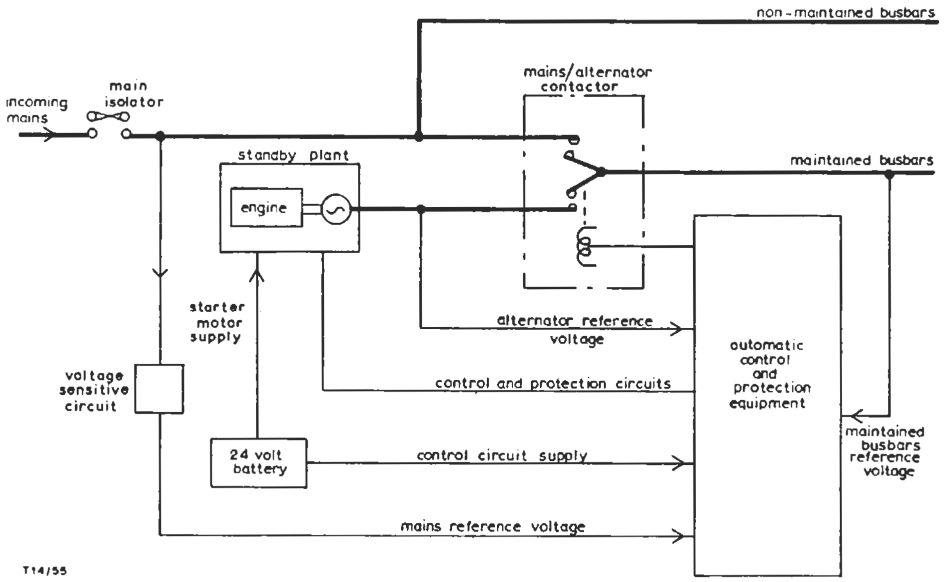

Fig. 2.1 Simplified Schematic of Typical Standby Installation

(c) *Auto/Manual* selector switch (AMSS) is set to *Auto*.

(d) Mains-reference voltage is present.

(e) Mains failure test-switch (MFTS) is closed; hence mains failure relay (MFR) is energised. MFR-1 and MFR-4 are closed. MFR-2 and MFR-3 are open.

(f) Alternator contactor (AC) is not energised.
Mains contactor (MC) and its auxiliary relay (MAC) are energised via MFR-1, MC-2 and AC-1.
MC-1 is open. MAC-1 and MAC-2 are closed.

(g) Maintained-busbars reference voltage is present.

(h) Maintained-busbars relay (MTR) is energised.
MTR-1 is open. MTR-2 is closed.

(j) Control relays CR2 and CR3 are energised via MTR-2 and LORB-1, and MRF-4 and LORB-1, respectively.
CR2-1 and CR3-1 are open.

2.3 Circuit Operation

The operating sequence of the system shown in Fig. 2.2 is given here in tabular form and numbered for ease of reference. Explanations of time delays affecting some operations, and descriptions of additional facilities, are given after the sequence table.

2.3.1 Change-over from Mains to Standby Supply

On failure of the incoming mains supply the mains-reference voltage and the maintained-busbars reference voltage are lost; derivation of the mains-reference voltage is dealt with in 2.4.2.

The sequence which brings the standby supply into use is:

1\. (a) MFR releases. MFR-1 opens to de-energise MC and MAC. MTR releases.

(b) MTR-1 and MFR-2 close to energise CR1 via LORB-1 and FS-1.
CR1-1 and CR1-2 begin to time out their closing time, preset up to ten seconds.

(c) MFR-3 closes and MTR-2 opens; CR2 remains energised.

(d) MFR-4 opens to de-energise CR3. CR3-1 closes to prepare AC-coil circuit.

(e) MC releases, MC-1 closes to prepare AC-coil circuit.

2\. (a) After a delay of 0·5 second, MAC releases and its two contacts open; see 2.3.4.

(b) CR1 contacts complete their closing times; see 2.3.4.
CR1-1 closes to prepare AC-coil circuit.
CR1-2 closes to energise SR1 and SR2, via LORB-1, CSRB-2, STR2-3 and AMSS.

3\. (a) SR2-1 begins to time out a predetermined closing time, adjustable from 0 to 30 seconds; see 2.3.4.

(b) SR1-1 closes to energise SMC; SMC-1 closes to energise the engine starter-motor.

If the engine starts successfully:

4\. (a) CS closes at 80 per cent of full speed, to energise CSRA and CSRB.
CSRA-1 begins a delayed-closing operation.

(b) CSRB-2 opens to de-energise SR1 and SR2. SR1-1 opens to de-energise SMC and hence de-energise the starter-motor.

(c) CSRB-1 closes to energise AC from the alternator-reference voltage, via LORA-3, CR3-1, PB1, CR1-1 and MC-1. AC closes, and its main contacts connect the alternator output to the maintained busbars.
AC-1 opens in MC operating-coil circuit.
AC-2 closes to hold in AC. (At this point the engine-cooling equipment operates; see 2.6).

(d) CSRB-3 closes to prepare STR1 (stop) circuit.

At this stage the maintained-busbar reference voltage is re-established from the alternator output, and:

5\. MTR is re-energised.
MTR-2 closes to maintain CR2 circuit.
MTR-1 opens to de-energise CR1.
CR1-1 opens in AC circuit (AC is held in by AC-2).
CR1-2 opens.

6\. CSRA-1 completes its preset closing time, begun in operation 4(a), and closes to prepare the engine-fault protection circuits: see 2.3.3 and 2.3.4.

This ends the change-over sequence.

2.3.2 Change-over from Standby Supply to Mains

Re-connection of the maintained busbars to the mains supply, as well as engine close-down, occurs automatically provided the *Auto/Manual Restoration* switch is in the *Auto* position; see Fig. 2.2.

When the mains supply is re-established, the mains-reference voltage is restored and:

7. MFR is energised.
   MFR-1 closes to prepare MC circuit.
   MFR-2 opens to prevent CR1 from being re-energised.
   MFR-3 opens to prepare for release of CR2.
   MFR-4 closes to energise CR3 via LORB-1.
8. CR3-1 begins its opening time of 30 seconds; see 2.3.4.
   At the end of the delay period, during which the re-established mains supply is being monitored, CR3-1 opens to de-energise AC.
   AC-1 closes to prepare MC circuit.
   AC main contacts open to disconnect the maintained busbars from the alternator output, consequently the maintained-busbars reference voltage is lost and:
9. MTR is de-energised.
   MTR-1 closes in CR1 circuit.
   MTR-2 opens to de-energise CR2.
10. After a pre-set delay, CR2-1 closes to energise MC and MAC via MFR-1 and AC-1; see 2.3.4.
    MC-1 opens in AC circuit.
    MC-2 and MAC-1 close to hold in MC and MAC.
    MC main contacts close to restore mains supply to the maintained busbars, so restoring the maintained-busbars reference voltage.
    MTR is re-energised.
    MTR-1 opens in CR1 circuit.
    MTR-2 closes to energise CR2.
    CR2-1 opens in MC circuit.
    MAC-2 closes to energise STR1 via *Auto/Manual* switch and CSRB-3.
11. STR1-1 closes to energise STR2.
    STR2-1 closes to energise FPS, which operates to cut off the fuel supply in order to stop the engine.
    STR2-3 opens in SR1 circuit to ensure that re-starting is impossible during run-down period.

As the engine speed decreases:

12. CS opens, at about 80 per cent of full speed, to de-energise CSRA and CSRB.
    CSRA-1 opens to disable engine-protection circuits.
    CSRB-1 opens in AC circuit.
    CSRB-2 closes to prepare starting circuit for subsequent operation.
    CSRB-3 opens to de-energise STR1.
13. After a preset delay (see 2.3.4):
    STR-1 opens to de-energise STR2.
    STR2-1 opens to de-energise FPS and re-open fuel line to engine.
    STR-3 closes to prepare starting circuit for subsequent operation.

This ends the return of the system to the original state, with the mains supply connected to the maintained busbars.

2.3.3 Engine Protection Circuits

These circuits become effective at stage 6 of the preceding automatic sequence. Operation of their relays depends on the action of various devices suitably positioned on the engine and its auxiliary equipment. Some of the types used in the system under consideration are described in Section 3, and all have a set of contacts which close for the associated fault condition; for simplicity the contacts are represented as switches in Fig. 2.2. The system has protection circuits for (a) low oil-pressure, OFS, (b) low water-level, or alternatively low water-pressure, WFS, (c) loss of radiator air-flow, FFS, and (d) high water-temperature, TAS. Also available is a spare circuit in connection with relay SFR.

Independently each of the five circuits can be arranged for either executive or non-executive operation according to the setting of a change-over link. With the link in the *Executive* position, the fault condition causes engine shut-down and its nature is signalled by lighting of the appropriate lamp. In the *Non-executive* position there is visual indication only, and an audible alarm provided use has been made of an optional facility for that purpose.

Apart from the circuits already mentioned there is one (FSR) permanently connected for executive action if the engine fails to start within a reasonable period; see 2.3.4.

All six relays are designed to latch-in mechanically when their coils are energised, and their resetting involves energising of associated release-coils.

The working of the five circuits previously itemised is adequately explained by reference to any one fault condition. For example:

14. If the oil-pressure fails, OFS closes to energise OFR.
    OFR-1 closes to complete the indicator-lamp circuit.

If the link is in the *Executive* position:

15. (a) OFR-2 closes to energise latching relays LORA and LORB.
    LORA-1 closes to energise STR1 via CSRB-3.
    STR1 operates to stop engine, as from

LOCATION GUIDE FOR FIG. 2.2

Component		*Location*				
			Contacts‡			
Code	*Designation*	*Comp.*	1	2	3	4
AC†	Alternator contactor	N7	J2	J7	*	L7
AMRS	Auto/Manual restoration switch	G8	—	—	—	—
AMSS	Auto/Manual selector switch	T5	—	—	—	—
—†	Battery isolator	F12	—	—	—	—
CCS	Control circuit isolator	F11	—	—	—	—
CR1	Control relay No. 1	Y1	J8	U3	—	—
CR2	Control relay No. 2	Y2	H2	—	—	—
CR3	Control relay No. 3	Y3	G7	—	—	—
CS†	Centrifugal switch	U7	—	—	—	—
CSRA	Centrifugal-switch relay A	Y7	Q11	—	—	—
CSRB	Centrifugal-switch relay B	Y8	F7	Q4	W6	—
—	Cubicle isolator	D11	—	—	—	—
ELOBS	Engine lock-out alarm-cancellation switch	U18	—	—	—	—
FFS†	Fan-fail switch	U13	—	—	—	—
FFR	Fan-fail relay	Y13	N17	Q17	—	—
FPS†	Fuel-pump solenoid	L14	—	—	—	—
FS-1†	Main-isolator auxiliary switch	W1	—	—	—	—
FSR	Fail-to-start relay	Y9	N15	Q14	—	—
LORA	Lock-out relay A	Y15	Q7	N15	E7	—
LORB	Lock-out relay B	Y16	P1	—	—	—
MAC	Mains-contactor auxiliary relay	M3	H3	U5	—	—
MC†	Mains contactor	L2	K7	H2	*	M1
MFR	Mains failure relay	J1	F2	S1	S2	S3
MFTS	Mains failure test switch	F1	—	—	—	—
MTR	Maintained busbar relay	L10	Q1	S1	—	—
OFR	Oil-fail relay	Y11	N16	Q15	—	—
OFS†	Oil-fail switch	U11	—	—	—	—
PB1	Restore to mains	H7	—	—	—	—
PB2	Engine start	U4	—	—	—	—
PB3	Engine stop	U6	—	—	—	—
PB4	Fault reset	U9	—	—	—	—
REL2†	Engine cooling relay	Y7	F13	F15	—	—
SFR	Spare fault-relay	Y14	N18	Q18	—	—
SMC†	Starter-motor contactor	L14	G11	—	—	—
STR1	Stop relay No. 1	Y6	Q8	—	—	—
STR2	Stop relay No. 2	Y8	N14	U6	S4	—
—†	Engine starter-motor	H11	—	—	—	—
SR1	Start relay No. 1	Y3	N14	*	—	—
SR2	Start relay No. 2	Y4	Q9	—	—	—
TAR	Temperature alarm relay	Y12	N17	Q16	—	—
TAS†	Temperature alarm switch	U12	—	—	—	—
WFR	Water-fail relay	Y10	N16	Q14	—	—
WFS†	Water-fail switch	U10	—	—	—	—

† Components not in cubicle
‡ If applicable
* Spare contacts not shown in diagram

Facing Fig. 2.2

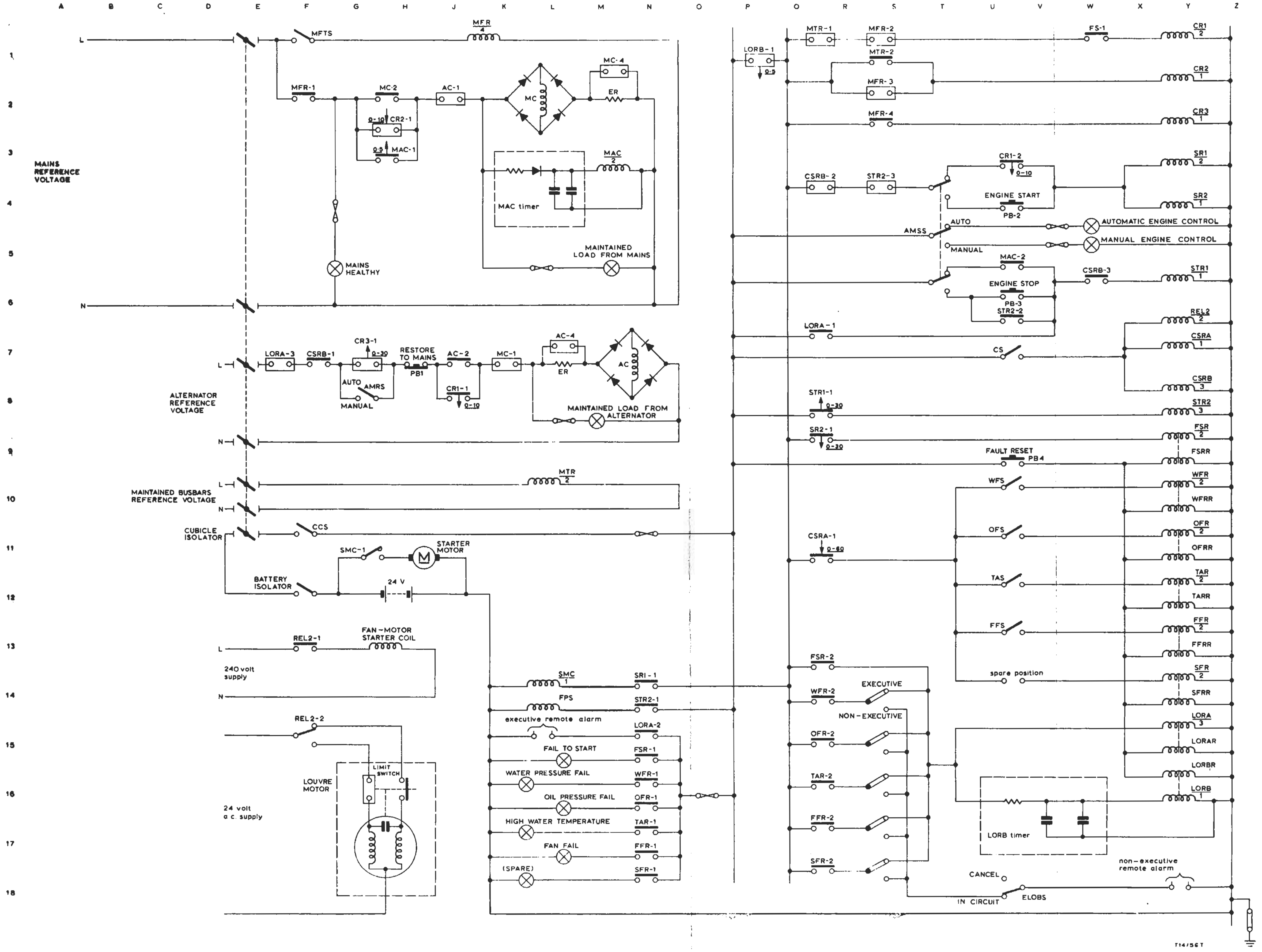

Fig. 2.2 Circuit Diagram of Mark-II Equipment

operation 11.
LORA-2 closes to complete remote-alarm circuit.
LORA-3 opens to de-energise AC.
(b) After a delay of 0·5 second (see 2.3.4):
LORB-1 opens to isolate start and protection circuits from 24-volt supply.

Alternatively with the link in the *Non-executive* position, action is limited to OFR-2 closing to complete the supply to an audible alarm, where fitted.

After a shut-down the fault-indication lamp remains lit and the engine is incapable of restarting until PB4 has been pressed to energise the latching-relays release coils. Consequently the 24-volt supply is restored, through LORB-1, to the start circuits.

2.3.4 Time Delays

The following summary deals with delays affecting operations in the automatic sequences, and gives the reasons for their introduction.

Operation 2(a): MAC-1; opening delay of 0·5 second

Prevents continuance of the sequence when mains-voltage fluctuation is only momentary. If the mains supply recovers before this contact opens, the system reverts to normal.

Operation 2(b): CR1-1 and CR1-2; closing delay up to 10 seconds by adjustment operative on both contacts simultaneously

Provides a definite period during which supplies to transmitter control circuits are off. The chosen delay is made sufficient to allow these circuits to assume normal off states before they are re-powered.

The mains-supply monitoring is effective during this interval. If the mains supply returns before the end of the delay period, the system reverts to normal as follows:

MFR is re-energised.
MFR-2 opens to de-energise CR1, and thus interrupt CR1-1 and CR1-2 closing times.
MFR-1 closes to prepare MC closing circuit.
MFR-3 opens to de-energise CR2 (MTR-2 is still open).
CR2 releases. CR2-1 begins to time out its re-closing delay (pre-set adjustable; see later reference to operation 10).
CR2-1 ends its time-out period by closing to energise MC and MAC.
MC connects mains supply to maintained busbars, and control system reverts to normal.

Operation 3: SR2-1; closing delay adjustable up to 30 seconds

When the engine starts successfully, the starter-motor is de-energised at operation 4(b). If the engine fails to start within a period determined by the SR2-1 delay setting, FSR is energised to lock out the start circuits and break the starter-motor supply.

Operation 6: CSRA-1; closing delay adjustable up to 30 seconds

Ensures that the engine protection circuits are made operationally effective after the engine has been allowed sufficient time to attain the normal running condition. The delay is adjusted on installation.

Operation 8: CR3-1; opening delay of 30 seconds

Defers disconnection of the standby supply subsequent to re-establishment of the mains supply. This pause is a precaution allowing for the possibility that the mains supply may reappear for a comparatively short period.

Operation 10: CR2-1; re-closing delay of 10 seconds

As for operation 2(b), but in this instance applying to transfer from standby supply to the mains supply. The delay also ensures an adequate off-period for the transmitter control circuits in the event of an incomplete change-over due to short-term mains failure.

Operation 13: STR1-1; re-opening delay adjustable up to 30 seconds

Ensures that the engine has time to come to rest before STR2 is de-energised. When STR2 releases, one of its contacts opens to de-energise FPS, and so restore the fuel supply to the engine, as another closes to prepare the starting circuit for eventual operation. During the delay period the engine-start circuits are isolated to prevent starter-motor energising while the engine is running down.

Operation 15(b): LORB-1; opening delay of 0·5 second

Ensures that the latching mechanism of LORB has time to engage before the operating supply is interrupted.

2.3.5 Additional Facilities

These facilities are described with reference to Fig. 2.2.

FS-1 is an auxiliary contact on the incoming-mains isolator. When the isolator is set to *Off*, an automatic sequence is initiated by the loss of mains-reference voltage. Because FS-1 is open, however, the sequence is halted at operation 3 and the engine-start stage is not reached. Thus there is no need for special measures to immobilise the control system when the Station has to be completely isolated for maintenance, or in an emergency.

Non-automatic control of the engine is available by use of push-buttons provided the *Auto/Manual* switch AMSS is at *Manual*. The *Start* button PB2, which must be held in until the engine picks up, is equivalent to contact CR1-2 which closes at operation 2(b) of the automatic sequence. Operating the *Stop* button PB3 has the effect obtained by closing of contact MAC-2 in operation 10, namely energising of STR1. Across PB3 is contact SR2-2 which obviates the need to hold this button in until the engine has stopped. During a hand-controlled engine run the power-switching equipment is not operative unless a mains failure has occurred.

Switch AMRS and push-button PB1 allow for the arrest and resumption, at operation 8, of the automatic sequence for returning to mains supply. By setting AMRS to *Manual*, contact CR3-1 is over-ridden and incapable of de-energising contactor AC. For that purpose PB1 is operated when completion of the sequence is desired.

2.4 Mark-II Equipment Details

The cubicle containing most of the system's equipment is known as the Control and Protection Cubicle, Mark II; the list facing Fig. 2.2 indicates items housed in the cubicle. The bulk of the remaining equipment is generally accommodated in the switchboard employed for primary distribution to areas requiring the standby facility. External items for equivalent purposes differ slightly in detail because various makes of switchboard and running plant are used.

2.4.1 Control and Protection Cubicle, Mark II

This cubicle is designed to make all equipment accessible from the front, which is shown in Fig. 2.3.

The top section of the cubicle has a front panel carrying the control switches and indication lamps. After its securing screws have been released, the panel can be drawn forward to allow interior inspection. The lower section has a glazed door which is mechanically interlocked with the *Cubicle Isolator* in order to prevent opening unless the switch is at *Off*. This setting of the switch removes the supply from the mains contactor coil and therefore, *before the isolator is opened, care should be taken to ensure that no essential load is connected to the maintained busbars*. A warning label to this effect is fixed to the cubicle door.

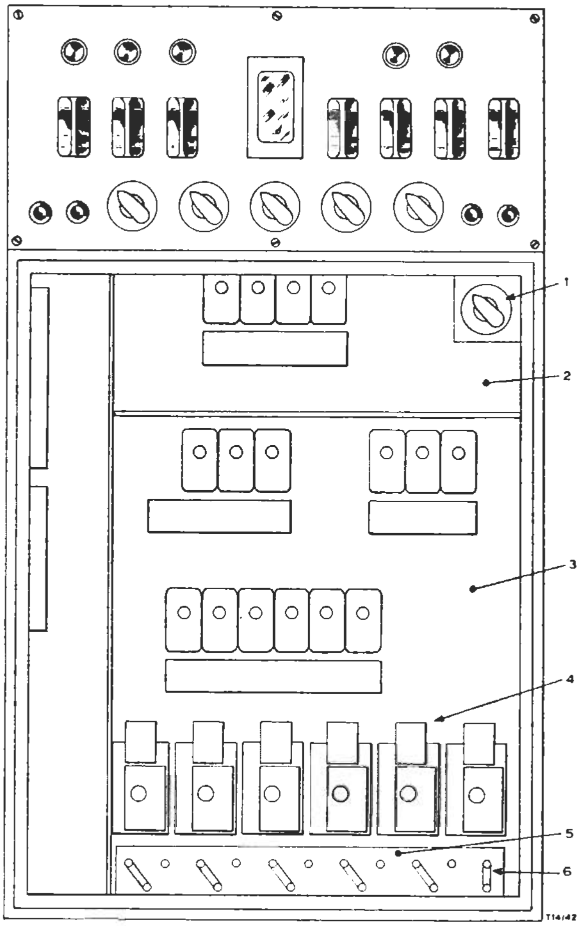

Fig. 2.3 Front Layout of Mark-II Cubicle

1. *Cubicle Isolator*
2. *A.C. Section*
3. *D.C. Section*
4. *Time Delay Relays*
5. *Executive/Non-executive Links*
6. *Earth Link*

The a.c.-operated relays, placed in a row at the top of the lower section, are separated from the d.c.-operated relays by a horizontal barrier of insulating material. The majority of these relays are selected from a standard range of plug-in units. Two of this pattern (MAC and LORB) are associated with plug-in fixed-delay units. The delays are obtained by combinations of series resistor and shunt capacitor, but the timer circuit for relay MAC has an added series-connected diode because the operating supply is 240 volts a.c.; see Fig. 2.2.

The non-detachable relays are those with adjustable time-delays. For these the contact operation is held off by a clockwork-escapement mechanism which is set in motion by operation of the armature. The delay periods are determined on installation.

2.4.2 Switchboard Equipment

This equipment includes contactors AC and MC, which are built on a common panel and mechanically coupled as explained in 2.1. Owing to the use of various makes of switchboard the complement of other apparatus in connection with the standby facility is not always the same and equivalent items differ to some extent in practical detail. The switchboard described in Section 1 of Part 4 has an arrangement embodying features associated with the control and protection system.

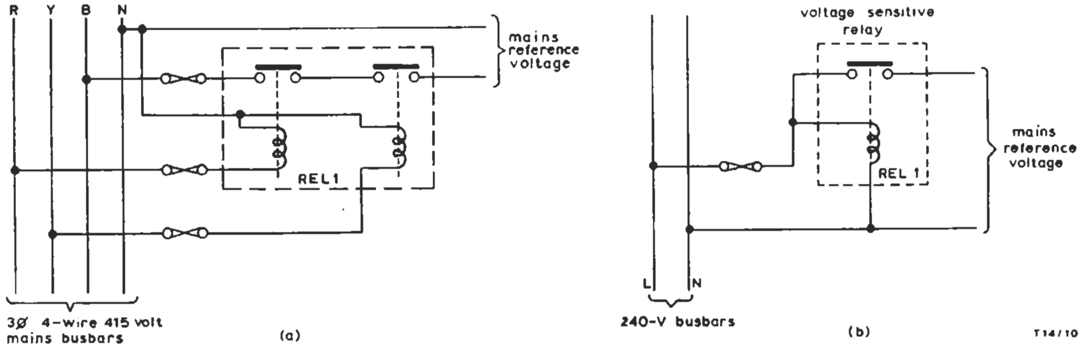

Fig. 2.4 Methods of Deriving Mains-reference Voltage

Fig. 2.4 shows the methods of obtaining the mains-reference voltage from 3-phase and single-phase circuits. Both arrangements meet the essential condition that loss of the reference voltage occurs for partial, as well as total, failure of the mains supply to the maintained busbars.

2.5 Mark-III and Mark-IIIA Equipment

These developments from the Mark-II version differ from each other only in the physical positioning of minor components such as indicator lamps. The circuit diagram is given in Fig. 2.5.

2.5.1 Circuit Operation

The circuit of Fig. 2.5 incorporates a number of changes relative to that of Fig. 2.2, but its automatic operation is as for the Mark-II equipment. There is, however, a slight control-circuit modification allowing for maintenance work without resorting to complete isolation of the Station. For that purpose the power circuits include a bus-section isolator operating on the supply to the mains contactor. Ganged to the isolator is an auxiliary switch S1-1, which is connected in series with FS-1; see Fig. 2.5. When the bus-section switch is opened, S1-1 opens to inhibit automatic engine-starting as FS-1 does when the Station is completely isolated; see 2.3.5.

2.5.2 Control and Protection Cubicles Mark III and Mark IIIA

Constructionally these cubicles are generally similar to the Mark-II type described with reference to Fig. 2.3. They differ from that version chiefly in circuit modification to obviate disturbance of the related mains distribution arrangement when the isolator and door have to be opened. For this purpose (a) the cubicle isolator has four additional poles, and (b) the mains-failure relay (MFR) and *Mains Failure Test Switch* (MFTS) are excluded from the cubicle; they are placed in the Station main switchboard.

Further, the relays having adjustable time-delays employ pneumatic bellows instead of clockwork-escapement mechanisms. Each relay has a lamp in parallel with the operating coil. In the Mark-III cubicle the lamps are on separate panels near the individual relays, whereas in the Mark-IIIA they are grouped on a front panel at one side of the door.

LOCATION GUIDE FOR FIG. 2.5

Component		*Location*				
			Contacts‡			
Code	*Designation*	*Comp.*	1	2	3	4
AC†	Alternator contactor	N7	C3	J7	*	L7
AMRS	Auto/Manual restoration switch	G8	—	—	—	—
AMSS	Auto/Manual selector switch	T5	—	—	—	—
—†	Battery isolator	F12	—	—	—	—
CCS	Control circuit isolator	F11	—	—	—	—
CR1	Control relay No. 1	Y1	J8	U3	—	—
CR2	Control relay No. 2	Y2	K2	—	—	—
CR3	Control relay No. 3	Y3	G7	—	—	—
CS†	Centrifugal switch	U7	—	—	—	—
CSRA	Centrifugal-switch relay A	Y7	Q11	—	—	—
CSRB	Centrifugal-switch relay B	Y8	F7	Q4	W6	—
—	Cubicle isolator	D11	—	—	—	—
ELOBS	Engine lock-out alarm-cancellation switch	U18	—	—	—	—
FFS†	Fan-fail switch	U13	—	—	—	—
FFR	Fan-fail relay	Y13	N17	Q17	—	—
FPS†	Fuel-pump solenoid	L14	—	—	—	—
FS-1†	Main-isolator auxiliary switch	W1	—	—	—	—
FSR	Fail-to-start relay	Y9	N15	Q14	—	—
LORA	Lock-out relay A	Y15	Q7	N15	E7	—
LORB	Lock-out relay B	Y16	P1	—	—	—
MAC	Mains-contactor auxiliary relay	H3	K1	U5	—	—
MC†	Mains contactor	C4	K7	G2	*	B6
MFR	Mains failure relay	A3	B1	S1	S2	S3
MFTS	Mains failure test switch	A1	—	—	—	—
MTR	Maintained busbar relay	L10	Q1	S1	—	—
OFR	Oil-fail relay	Y11	N16	Q15	—	—
OFS†	Oil-fail switch	U11	—	—	—	—
PB1	Restore to mains	H7	—	—	—	—
PB2	Engine start	U4	—	—	—	—
PB3	Engine stop	U6	—	—	—	—
PB4	Fault reset	U9	—	—	—	—
REL2†	Engine cooling relay	Y7	F13	F15	—	—
S1-1†	Bus-section auxiliary switch	U1	—	—	—	—
SFR	Spare fault-relay	Y14	N18	Q18	—	—
SMC†	Starter-motor contactor	L14	G11	—	—	—
STR1	Stop relay No. 1	Y6	Q8	—	—	—
STR2	Stop relay No. 2	Y8	N14	U6	S4	—
—†	Engine starter-motor	H11	—	—	—	—
SR1	Start relay No. 1	Y3	N14	*	—	—
SR2	Start relay No. 2	Y4	Q9	—	—	—
TAR	Temperature alarm relay	Y12	N17	Q16	—	—
TAS†	Temperature alarm switch	U12	—	—	—	—
WFR	Water-fail relay	Y10	N16	Q14	—	—
WFS†	Water-fail switch	U10	—	—	—	—

† Components not in cubicle
‡ If applicable
* Spare contacts not shown in diagram

Facing Fig. 2.5

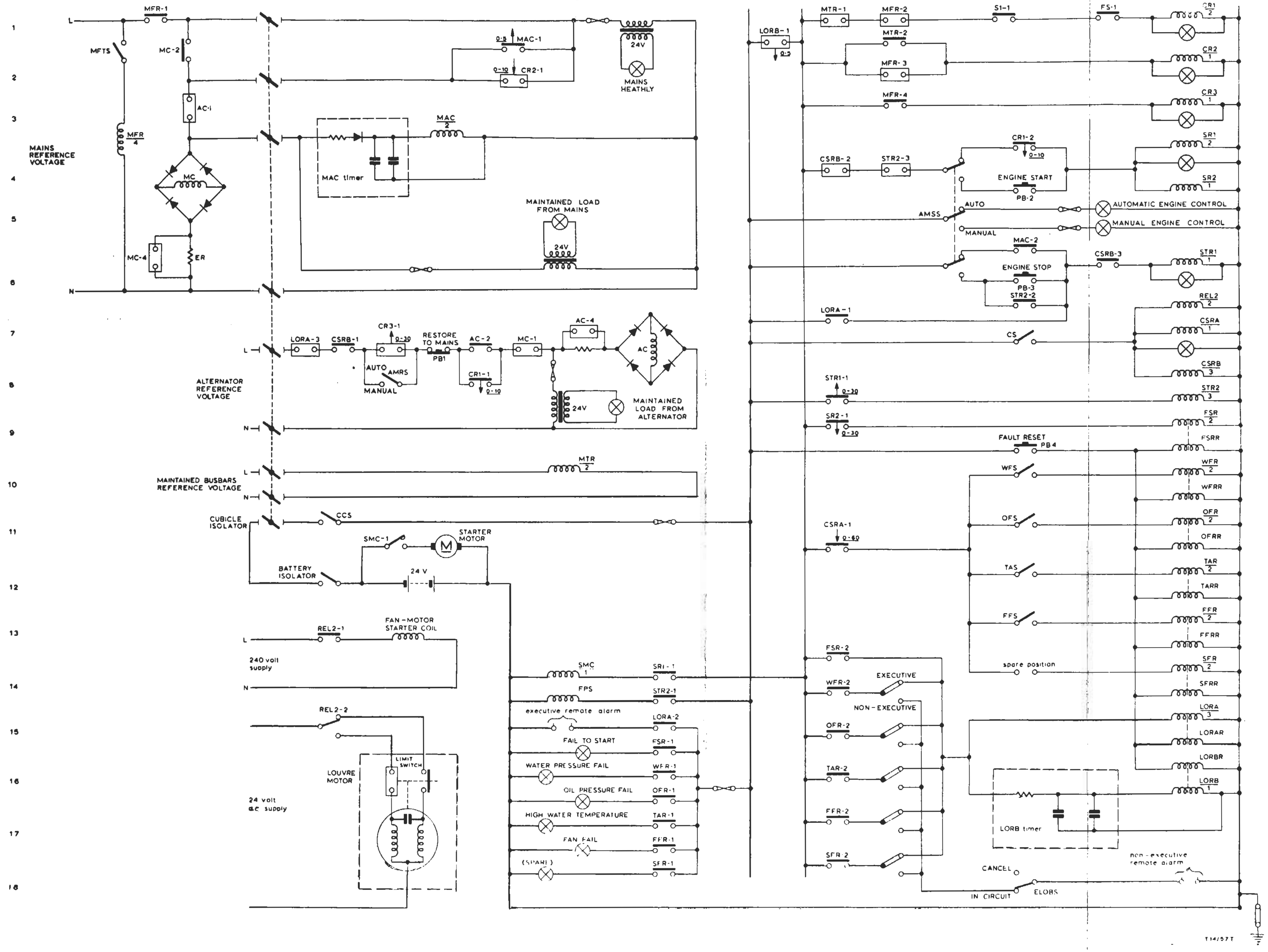

Fig. 2.5 Circuit of Mark-III Equipment

2.6 Engine Cooling

Engine-cooling water is circulated through a remotely-mounted radiator complete with a fan driven by a single-phase motor. The radiator and fan are fitted in a duct which has louvred inlet and outlet apertures, both opening to atmosphere outside the engine room, in addition to an aperture opening into the engine room.

At some sites one set of louvres is motor-driven and the other set takes the form of gravity-return flaps which are forced open by the passage of air. At others both sets of louvres are driven by flexible cable from a common motor. The motor is a 24-volt, single-phase type fed from a 240/24-volt transformer.

Operation of the fan motor and the louvre motor is part of the automatic sequence. The action, referring to operation (4a) under heading 2.3.1, is as follows:

When CS closes, REL 2 is energised.
REL2-1 closes in coil circuit of fan-motor starter.
REL2-2 changes over to prepare louvre-motor circuit for an opening operation.
AC closes, in operation 4(c), completing supplies to both motors.

Some sites have slightly different arrangements for control of the radiator fan. One instance is the use of a separate wall-mounted Fan Control Unit working in conjunction with extra thermostats and connected into the standard system. The details are shown in Fig. 2.6.

As the basis of operational description it is assumed that the engine has been at rest long enough for its cooling water to be at, or near, room temperature when an automatic start occurs; see 2.3. At operation 4(a), CS closes but normally-open contacts RC-2 and RC-3 prevent that having any effect on the cooling control circuit. The cooling-water temperature of the running engine continues to rise until, at about 175 degrees F (80 degrees C), Th2 closes. No action occurs until, at 185 degrees F (85 degrees C), Th1 also closes and then:

RC operates via Th1 and Th2.
RC-1 closes to bypass Th1.
RC-2 and RC-3 close to complete REL2 operating circuit.
REL2-1 closes to complete fan-motor starter circuit.
REL2-2 changes over to open air-inlet louvres.

The passage of air through the radiator causes the water temperature to fall. At 185 degrees F, Th1 opens but the bypassing contact (RC-1) keeps

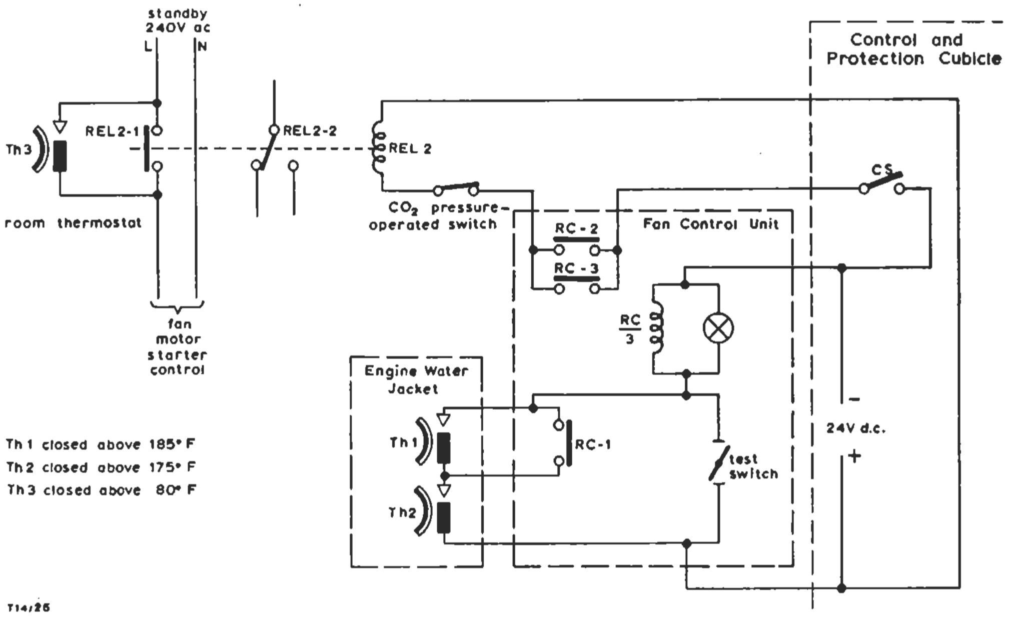

Fig. 2.6 Engine Cooling Circuit with Fan Control Unit and Room Thermostat

the fan running. When the water temperature falls below 175 degrees F, Th2 opens to stop the fan and therefore the louvres close. This cycle is repeated as long as the engine continues to run.

Th3 is to prevent excessive rise of engine-room air temperature, otherwise possible when an engine is so lightly loaded that the water temperature fails to reach 185 degrees F. If the air temperature rises to 80 degrees F (27 degrees C) this thermostat starts the fan motor by short-circuiting REL2-1. Because REL2 is unoperated the air-intake louvres remain closed, and consequently there is a rapid extraction of air through the engine-room aperture in the duct.

With fan control as described, the Fan Fail Switch (FFS) is either not fitted or made inoperative. Protection against engine over-heating remains with TAS.

There are installations using the Fan Control Unit without thermostats. In these it is usual to leave the *Test* switch at *On* to make REL2 operate as soon as the alternator supply is available.

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SECTION 3

ENGINE PROTECTION DEVICES

3.1 Introduction

Most Diesel-generator installations incorporate arrangements whereby the presence of faulty running conditions can be detected. These arrangements generally include means of indicating the presence of a fault and, especially with unattended plant, are often connected with automatic control equipment to shut down the plant.

This Section details some of the fault conditions which can arise, and describes a number of devices or arrangements used to detect them.

3.2 Incorrect Running Speed

The correct electrical output of a standby installation is dependent upon the engine speed being within a few per-cent of a fixed value for which the generator is designed. This speed is usually maintained by some form of governor which controls the fuel supply to the engine.

Devices used to detect incorrect engine speed are often known as Centrifugal Switches, although many are not operated by centrifugal action. In addition to their engine protection duty, these switches can be used to control switchgear in the standby engine circuits and thus prevent distribution of abnormal supplies. The equipment described in Section 2 exemplifies the control obtainable by means of a centrifugal switch.

3.2.1 Speed Switch

This switch has a hollow metal rotor which is driven by the engine. A permanent magnet inside the rotor is dragged round as the rotor spins and takes up an angular position which depends upon engine speed. Adjustable cams are attached to the same shaft as the magnet and are set to operate micro-switches at required engine speeds. Further details can be found in a manufacturer's handbook: Speed Switch (Installation and Maintenance Instructions). Publication TH 45; S. Smith and Sons (England) Ltd.

3.2.2 Tachometer Generator and Relay

The tachometer generator is a small alternator with a wound stator and a permanent-magnet rotor. It is driven from the engine and gives an output voltage proportional to the speed of rotation. This output is connected to a relay circuit which can be adjusted to operate at the desired engine speed. In some instances the output is applied also to a speed-indicating meter.

3.3 Lubricating-oil System Failure

The majority of engines have a pressurised lubricating-oil system, failure of which can be detected by a pressure-sensitive switch. Typically this has a bellows which actuates a micro-switch and is connected by a flexible tube to the pressurised system.

3.4 Cooling Water Failure

The presence of an adequate supply of cooling water can be detected either by a pressure-sensitive switch (forced-circulation systems only) or by a level-sensitive device. The pressure-sensitive switch can be similar to that mentioned in 3.3. Some water-level detectors are simply conventional float-switches placed in the header-tank of the water system. A more complex arrangement is described in the next sub-section.

3.4.1 Two-electrode Water-level Detector

Fig. 3.1 shows the circuit in connection with two electrodes positioned high in the water system and at slightly different levels. For explanatory purposes, suppose the water system is being filled. Current flow begins when the water provides a path as it reaches electrode E1, but it is limited by the variable resistor to a value less than that needed to pull the relay in. When electrode E2 becomes immersed the additional path through the water increases the current sufficiently to operate the relay. Subsequently the relay can remain operated if the water falls to any level intermediate to the two electrodes, but is released if the level drops below electrode E1. Correct working necessitates a variable-resistor adjustment such that the current via E1 alone is insufficient to pull the relay in, but is enough to hold it in.

This method of detection is sometimes employed

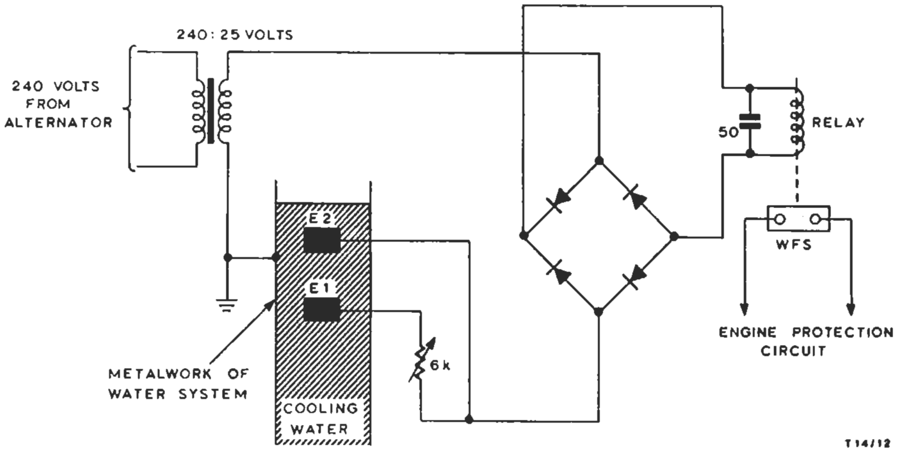

Fig. 3.1 Water-Level Detector Circuit

with the equipment described in Section 2, one contact of the relay being used as a *Water Fail Switch* connected into the control system; see WFS in Fig. 2.2.

3.5 Excess Temperature

Abnormally high temperature can be detected by using one of the many types of conventional thermostats placed in a suitable position. The most common requirement is to detect an excessive rise in temperature of the engine-cooling water.

3.5.1 Volatile-liquid Temperature-Sensing Unit

This unit comprises a sensing-bulb immersed in the cooling water, and connected to a bellows element via capillary tube. These items contain a volatile liquid which causes the bellows to expand when the water temperature rises. The movement of the bellows is restricted by a compression spring which can be adjusted to allow the bellows to actuate a micro-switch at the desired temperature.

3.6 Radiator Air-flow Failure

The cooling-water of some engines is circulated through a remotely-mounted radiator with which is associated an electrically-driven fan. Correct operation of the fan can be detected by use of a centrifugal switch attached to the driving shaft. Where the radiator and fan are mounted in a duct, an Air Flow Switch can be used.

3.6.1 Delta (Type M) Air Flow Switch

This unit has a cast-aluminium body in which is a moveable vane coupled to a mercury switch. The body is bolted over a hole (2in. diameter) in a vertical face of the air duct, so that variations of pressure within the duct act on one side of the vane. The other side of the vane is maintained at atmospheric pressure, by suitably-placed holes in the body. The switch is a two-state device in which the position of the vane, and hence the mercury switch, is determined by the applied pressures.

SECTION 4

SYNCHRONISING OF ALTERNATORS

4.1 General

If two or more alternators are to be run in parallel it is essential that three conditions be fulfilled:

(a) the output voltage of each of the alternators must be the same,
(b) the frequency of the output voltage of each of the alternators must be the same,
(c) the output voltages must be in phase.

When these conditions are met the alternators are said to be running in synchronism and can be connected in parallel without any danger. Alternators that have been synchronised and connected in parallel remain, under normal conditions of loading, in synchronism.

It is extremely dangerous to attempt to connect alternators in parallel without first ensuring that they are synchronised. To do so might cause heavy current to flow from one machine to another and cause severe damage.

In dealing with three-phase alternators it is necessary to synchronise only one of the phases. This is sufficient because the relative positions of the phases are fixed.

The relative frequency and phase relationships between two alternators are indicated by an instrument called a synchroscope.

4.2 Rotary Synchroscope

The most common type of synchroscope is a moving-iron instrument with a basic construction as in Fig. 4.1. Note that in further explanation the words *running* and *incoming* are used in the accepted qualifying sense, the first normally applying to an alternator already connected to busbars, and the second denoting an alternator which is to be connected to those busbars. In any event the running alternator is the reference source with which the incoming alternator is compared.

The synchroscope has two small coils connected via a reactive network to the running-alternator output. The values of the reactive-network components, L, C and R, are chosen so that the voltages applied to the small coils are in quadrature. The effect of this is to produce a rotating magnetic field. The rotor is formed of two iron cylinders fixed to a spindle which is supported at both ends.

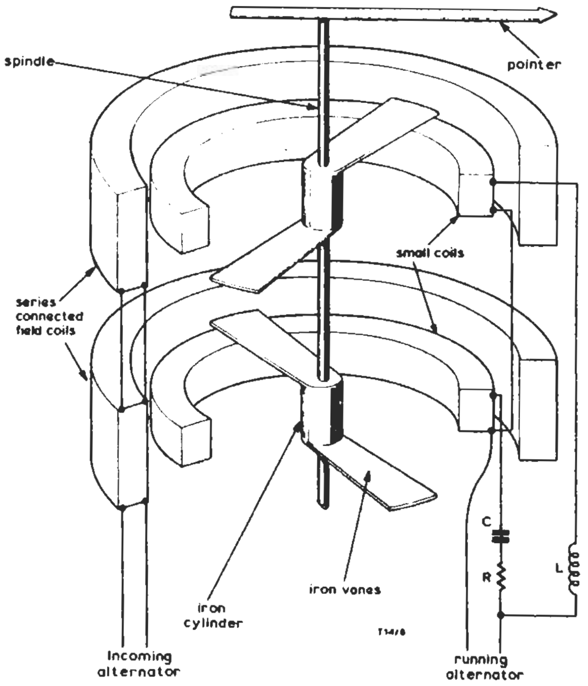

Fig. 4.1 Cut-away View of Typical Rotary Synchroscope Assembly

The iron vanes attached to the upper and lower cylinders are at right angles to each other. The small coils are surrounded by series-connected field coils which are connected to the output of the incoming alternator.

The connections to the coils and the position of a pointer are so arranged that when the running alternator and the incoming alternator are producing in-phase voltages the synchroscope pointer is stationary in the vertical (12 o'clock) position.

If the output frequency of the incoming alternator is higher than that of the running alternator, the pointer rotates in a clockwise direction at a speed equal to the difference in speed between the two machines. If lower, the pointer rotates in a counter-clockwise direction. If the two alternators are running at exactly the same speed but are not in phase, the pointer is stationary at some position other than 12 o'clock.

4.3 Synchronising Conditions

Before alternators are paralleled it is essential to provide the conditions listed under 4.1.

Condition (a) is obtained by adjustment of alternator excitation. The induced e.m.f. is higher than the terminal voltage by an amount which depends upon the voltage drop due to the reactive current flowing through the synchronous impedance of the armature. Therefore before alternators are connected in parallel the excitation of each must be adjusted until their terminal voltages are equal.

Conditions (b) and (c) are interdependent and are controlled by alternator-speed adjustment. This adjustment must be carried out with the aid of the synchroscope before the parallel connections are made. The speed at which an alternator is driven is regulated by the rate at which fuel is supplied to the Diesel-engine.

Normally a Diesel-alternator installation is equipped with only one synchroscope. A suitable switch is provided to enable the synchroscope to be connected to the outputs of any two alternators.

It is difficult to adjust the speed of the incoming alternator so accurately that the synchroscope pointer remains stationary at the 12 o'clock position. In practice the speed is usually adjusted until the pointer is moving very slowly in the clockwise direction, and thus it is fairly easy to parallel the alternators as the pointer is about to pass through the 12 o'clock position.

If the running alternator is supplying power to a load it is preferable to arrange that the incoming alternator runs at a slightly higher speed before the outputs are paralleled. This ensures that the incoming alternator immediately supplies some power to the load and draws into step with the running alternator. If the incoming alternator runs slowly it imposes a load upon the running alternator when they are connected in parallel.

4.4 Parallel Running

When alternators are running in parallel their individual loading can be varied by adjusting the fuel-flow rates to the engines. Thus immediately after one alternator has been paralleled with another already in service it can be made to take a share of the load by increasing the fuel feed to its engine. At the same time the fuel supply of the engine brought into use first can be reduced. Ordinarily, assuming the machines are similarly rated, these adjustments continue until the alternators are sharing the load equally.

The frequency of the generated supply can be adjusted only by increasing or decreasing the speed of all the engines. Slight variations in terminal voltage of an alternator, or individual engine speed, are self-cancelling because a current is caused to flow between the two machines if the terminal voltage tends not to be the same. The phase of this current is such that the machine tending to run faster experiences a decelerating torque while at the same time the machine tending to run slowly is accelerated.

Variation of the excitation control on one alternator causes a variation of the reactive current supplied by that alternator. If the two machines are not excited equally, then the induced voltage in each machine tends not to be the same. This, too, is a self-cancelling effect because the phase of the current which flows due to the unequal induced voltages is such that the over-excited machine experiences demagnetising armature-reaction while the under-excited machine experiences a magnetising armature-reaction. The induced e.m.f. of the over-excited machine is therefore reduced and the e.m.f. of the under-excited machine is increased. this is, however, an undesirable condition because a current flowing between the two alternators has a large reactive component.

It is important to realise that altering the fuel flow to an alternator set varies the kilowatt load only, whereas varying the excitation alters the kilovolt-ampere load.

When one of a number of paralleled alternators is to be disconnected from common busbars, the load must first be removed from the alternator before the paralleling switches can be safely opened. This is done by reducing the fuel input to the engine to shed the kilowatt load, and then reducing the excitation until the alternator is supplying no reactive load. The paralleling switches can then be opened without danger, and then the engine can be stopped.

PART 2: AUTOMATIC VOLTAGE REGULATORS

SECTION 1

GENERAL PRINCIPLES

1.1 Definition

This Section is limited to a consideration of the principles of a.c. voltage regulators of the variable-ratio transformer and moving-coil types. No attempt has been made to describe regulators which have regulating units comprising electronic valves or semiconductor devices, or regulators used to control the excitation of alternators.

1.2 Glossary

Voltage Regulator	A device for varying, at will, the voltage of a circuit or for automatically maintaining it at or near a prescribed value.

The above definition of a voltage regulator appears in British Standard* 205: 1943. At the time of writing no other definitions concerning voltage regulators, apart from that for a Booster Transformer, appear in any British Standard. The following terms used in this Instruction have been defined in the light of current BBC practice.

Booster Transformer	A transformer the secondary winding of which is in series with a circuit in which it adds (or opposes) its voltage to that provided by another source.
Continuous Control	A system in which the magnitude of Error Signals developed by a Measuring Unit is dependent upon the magnitude of the error causing them.
Control Unit	A part of a Voltage Regulator acted upon by a signal from the Measuring Unit and used to control the Regulating Unit.
Dead Zone	In a Discontinuous Control system, the limits between which no Error Signals are developed.
Discontinuous Control	A system in which the magnitude of Error Signals developed by a Measuring Unit is independent of the magnitude of the error causing them.
Error Signal	A signal developed by a Measuring Unit when the output voltage of a Voltage Regulator varies from the prescribed value.
Measuring Unit	A part of a Voltage Regulator used to detect changes in output voltage of the Voltage Regulator.
Regulating Unit	A part of a Voltage Regulator acted upon by the Control Unit and used to vary the output voltage of the Voltage Regulator.

1.3 Purpose

To ensure optimum working conditions, the voltage of supplies to equipment must often be maintained within a constant range of values. Automatic voltage regulators (a.v.r.'s) are used to regulate the supplies to chosen groups of equipment.

1.4 Principle

Essentially any a.v.r. comprises a measuring unit, a control unit and a regulating unit. The purpose of the measuring unit is to detect any change in the output voltage and to produce an error signal. The error signal is fed to the control unit, which actuates the regulating unit. The regulating unit makes the alteration required to restore the output voltage of the regulator to the prescribed value. In many

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* B.S. 205:1943: Glossary of Terms used in Electrical Engineering.

instances the three units cannot readily be distinguished, one circuit comprising the measuring unit and part of the control unit, and another the regulating unit and the remainder of the control unit.

1.5 Classification

Measuring units and control units can operate either discontinuously or continuously. A measuring unit that is discontinuous in operation produces an error signal whenever the measured voltage goes outside preset limits. The error signal is constant in magnitude and disappears when the voltage is again within limits. The limit range within which there is no error signal is known as the dead zone.

A measuring unit that is continuous in operation produces a signal proportional in magnitude to the error in the voltage measured. This type of unit has, theoretically, no dead zone.

A control unit classed as discontinuous actuates the regulating unit so that the output voltage is corrected at a constant rate. When the signal from the measuring unit stops, the regulating unit remains in its new position. A continuous control unit makes the regulating unit correct the error at a rate proportional to the magnitude of the signal from the measuring unit. Continuous control units can be operated only by continuous measuring units, whereas discontinuous control units can be operated by either kind of measuring unit although they are normally associated with the discontinuous type.

1.6 Specification

In the choice of an a.v.r. for any given purpose, a number of factors are taken into account. Among the most important are:

(a) Input voltage.
(b) Output voltage.
(c) Operating frequency.
(d) Maximum load required.

These factors are explained below and figures from the specification of a typical single-phase a.v.r. are used as examples.

(a) Supply Authorities are required to maintain the voltage supplied to a consumer to within ±6 per cent of the nominal value, usually 240 volts. Nevertheless excursions beyond this range may occur and a regulator is normally required to accept a variation in input voltage of 20 per cent.
(b) Normally the output voltage is held at 240 volts ±1 per cent.
(c) The supply frequency is 50 Hz. The regulator operates at this frequency and should not be affected by small changes in frequency.
(d) Regulators are rated in kVA.

1.7 Special Requirements of Three-phase Systems

Two methods of regulating three-phase voltages are in use. One method is to use three separate single-phase a.v.r.'s, usually star-connected to the three phases. Provided that the three regulators are identical, this method gives an accurate control of voltage and does not depend upon the load being balanced.

The other method is to use a regulator which has one measuring unit, one control unit and three regulating units. The measuring unit is connected either across two phases or across one phase and neutral. This method is satisfactory provided that the load is reasonably balanced.

1.8 Types of Units

1.8.1 Measuring Units

Discontinuous measuring units are usually either contact-making voltmeters such as those made by Austinlite Ltd., or voltage-sensitive relays such as the Ferranti Astatic Voltage Relay used on Ferranti moving-coil regulators. Measuring units using electronic circuits are becoming more common and an example, described in Section 3, is the Brentford MVR2 unit; this is a continuous measuring unit which is used with a discontinuous control unit.

1.8.2 Control Units

Control units are seldom separately identifiable items. All control units, however, use an electric motor to drive the regulating unit, usually via an endless chain-drive arrangement. Limit switches must be incorporated in the motor circuit in order to prevent damage by movement beyond the two extremes of correction.

1.8.3 Regulating Units

Two types of regulating unit are in common use, one a variable-ratio auto-transformer and the other a moving-coil type. The variable-ratio type is found in various forms, depending on the maker. A simple arrangement is shown in Fig. 1.1(a). The transformer has a brush assembly which bears against a bared track on its winding. To keep the physical size of the auto-transformer to a minimum,

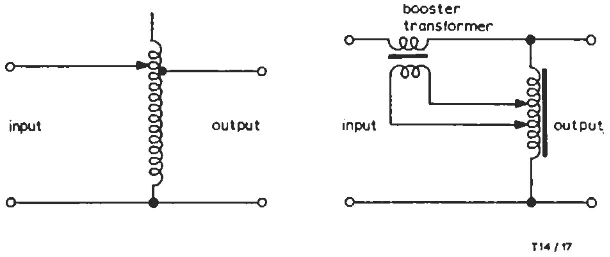


Fig. 1.1 Auto-transformer Regulating Unit
(a) Simple Arrangement
(b) Unit with Booster Transformer

use is often made of a booster transformer; see Fig. 1.1(b). With this arrangement the auto-transformer is fitted with two brushes. When the brushes are directly opposite each other no voltage is applied to the booster transformer primary and the regulator output voltage is the same as the input. When the brushes are at opposite ends of the winding, the voltage applied to the booster transformer either fully aids or fully opposes the input voltage. The ratio of the booster transformer is chosen so that the regulator corrects for a specified range of input voltage.

The moving-coil type of regulating unit is shown in Fig. 1.2. The output is taken from fixed tappings on two coils which are connected, in series opposition, to form an auto-transformer. A third coil, short-circuited upon itself, is arranged so that it can be moved along the length of the fixed coils. The effect of the moving coil is to vary the impedance of the fixed coils depending upon its position. As the impedance of the fixed coils varies so does the voltage developed across them. A suitable arrangement of the coils can enable the output voltage to be varied from zero to any desired value in a completely smooth manner. This type of regulating unit has been extensively described in electrical journals and further details can be obtained from makers' information.

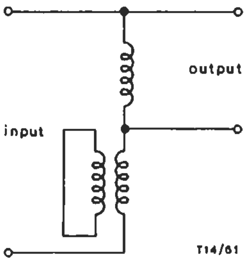


Fig. 1.2 Moving-coil Regulating Unit

1.9 11-kV/415-volt Regulating Transformers

In the past, where equipment required regulated supplies, it was the usual practice to provide each individual group of apparatus with a separate a.v.r. At many modern transmitting stations however it is more economical to regulate each incoming 11-kV three-phase feed and supply the entire station load from a regulated source.

To meet this requirement there have been developed automatic voltage regulators which take an input, within a specified range, at 11-kV and provide a 415-volt three-phase and neutral output of ±1 per cent variation. A block diagram of such a regulator is shown in Fig. 1.3.

A typical installation comprises four physically separate units:

(a) A conventional oil-filled 11-kV/415-volt 1000-kVA transformer.

(b) A 750-kVA three-phase oil-filled booster transformer.

(c) A three-phase oil-filled regulating unit of the variable-ratio auto-transformer type.

(d) A voltage-sensitive-relay measuring unit and a simple control unit. These two items are usually mounted in a steel cabinet inside the transmitter building.

The component parts of a widely used regulating transformer are described in Section 3 of this Instruction.

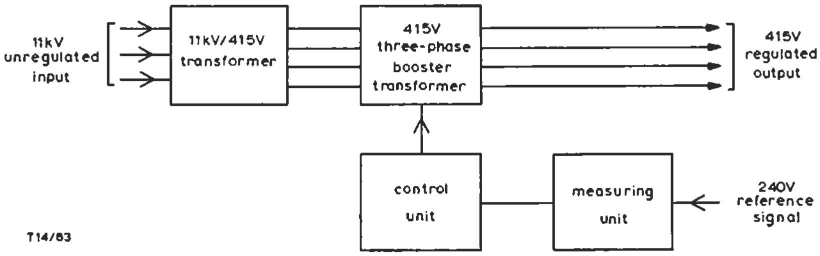


Fig. 1.3 Simplified Diagram of 11-kv/415-volt Regulating Transformer

SECTION 2

BERCO REGULATING EQUIPMENT

2.1 Introduction

This equipment is made by the British Electrical Resistance Company. Similar types of regulators are made by an associate, the British Power Transformer Company. The following descriptions apply to regulators of either make.

The regulators are of discontinuous type, using a contact-making voltmeter measuring unit and a variable-ratio auto-transformer regulating unit. Some models use a booster transformer in conjunction with the regulating unit. Single- and three-phase regulators of various ratings are in use, some air-cooled and others oil-cooled. The regulating units are all of a similar basic design. Three-phase regulators use three identical units driven by a single motor.

Further details are given in the maker's booklet, *Installation and Maintenance of Automatic Voltage Regulators*.

2.2 Measuring Unit

This unit, made by Austinlite Ltd., is a d.c. suppressed-zero moving-coil contact-making voltmeter. The coil is fed via a bridge rectifier from the output of the regulating unit.

If the output voltage of the regulator rises and falls by more than a preset amount, a contact on the voltmeter pointer makes with fixed *high* and *low* contacts. This completes the circuit of a motor which adjusts the regulating unit to bring the output voltage back within the dead zone. The fixed contacts can be set to give the dead zone required, usually within ±1 per cent of the nominal output voltage.

2.3 Control Units

Two types of control unit are in use, the more common being known as *Type A*. A second type was made to a BBC specification which required the provision of push-button control of the output voltage.

The control unit and the regulating unit are mounted on a steel panel. On air-cooled regulators, the panel is adjacent to the regulating unit. The auto-transformer and the drive motor are both mounted on the same frame. On oil-cooled regulators, the control unit is in a steel box on the outside of the regulator tank. The motor and the drive mechanism are immersed in the oil.

2.3.1 Type-A Control Unit

The Type-A control unit is used with the standard range of regulators. There are two versions of this unit. The earlier one, shown in Fig. 2.1, was used with regulators having serial numbers up to 65850. Fig. 2.2 shows the slightly different circuit of the unit subsequently used. The explanation which follows can be read in conjunction with either diagram.

The output of the regulator is applied to the control unit across terminals A0 and A1. When this voltage is present, relay SR is energised, SR-1 being open and SR-2 closed.

If the regulator output voltage is normal, the coil of contact-making voltmeter VR is balanced in a central position, the High and Low contacts being both open. The *lower* and *raise* relays LR and RR are de-energised.

If the regulator output voltage falls:

1. The current through VR falls and its moving contact makes with the fixed Low contact. The a.c. supply to rectifier MR2 is completed via LR-2, SR-2 and the VR Low contact.
2. Relay RR is energised.
   RR-1 opens to further reduce the current through VR and prevent possible contact chatter.
   RR-2 opens to prevent relay LR from being energised.
   RR-3 closes to make the supply to the motor which drives the regulating unit.
3. The motor rotates and the brush mechanism is adjusted so that the regulator output voltage is increased to the correct value.
4. When the voltage is within limits, the VR Low contact opens. RR is de-energised, and RR-3 opening breaks the motor supply.

If the regulator output voltage rises, a corresponding sequence takes place on the High side. Relay LR takes the place of relay RR, and the sequence is completed when LR-3 reopens and switches off the motor supply.

If VR energising circuit fails, relay SR is de-energised. SR-1 closes, simulating a high output

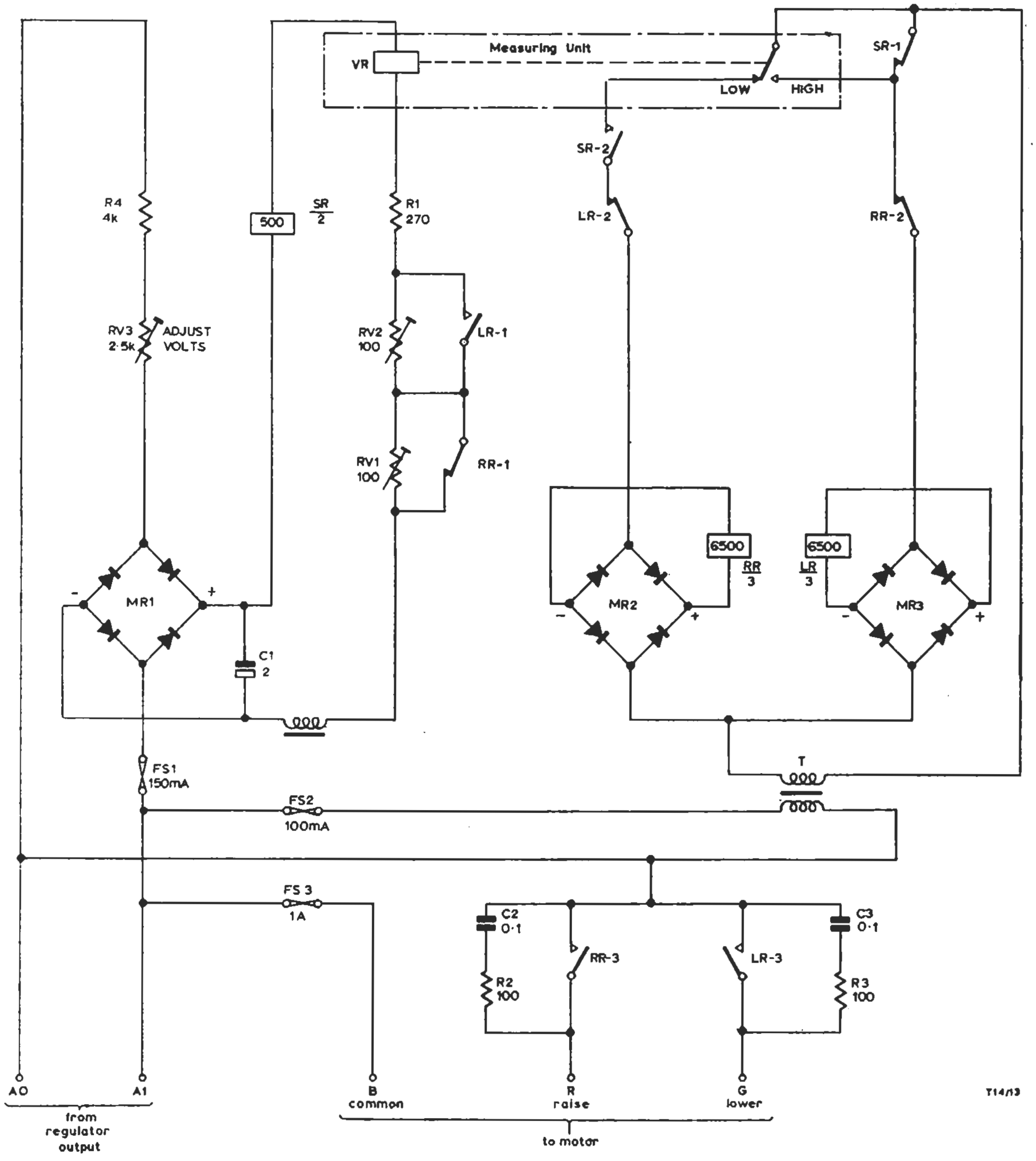


Fig. 2.1 Type-A Control Unit (Regulators with Serial Numbers up to 65850)

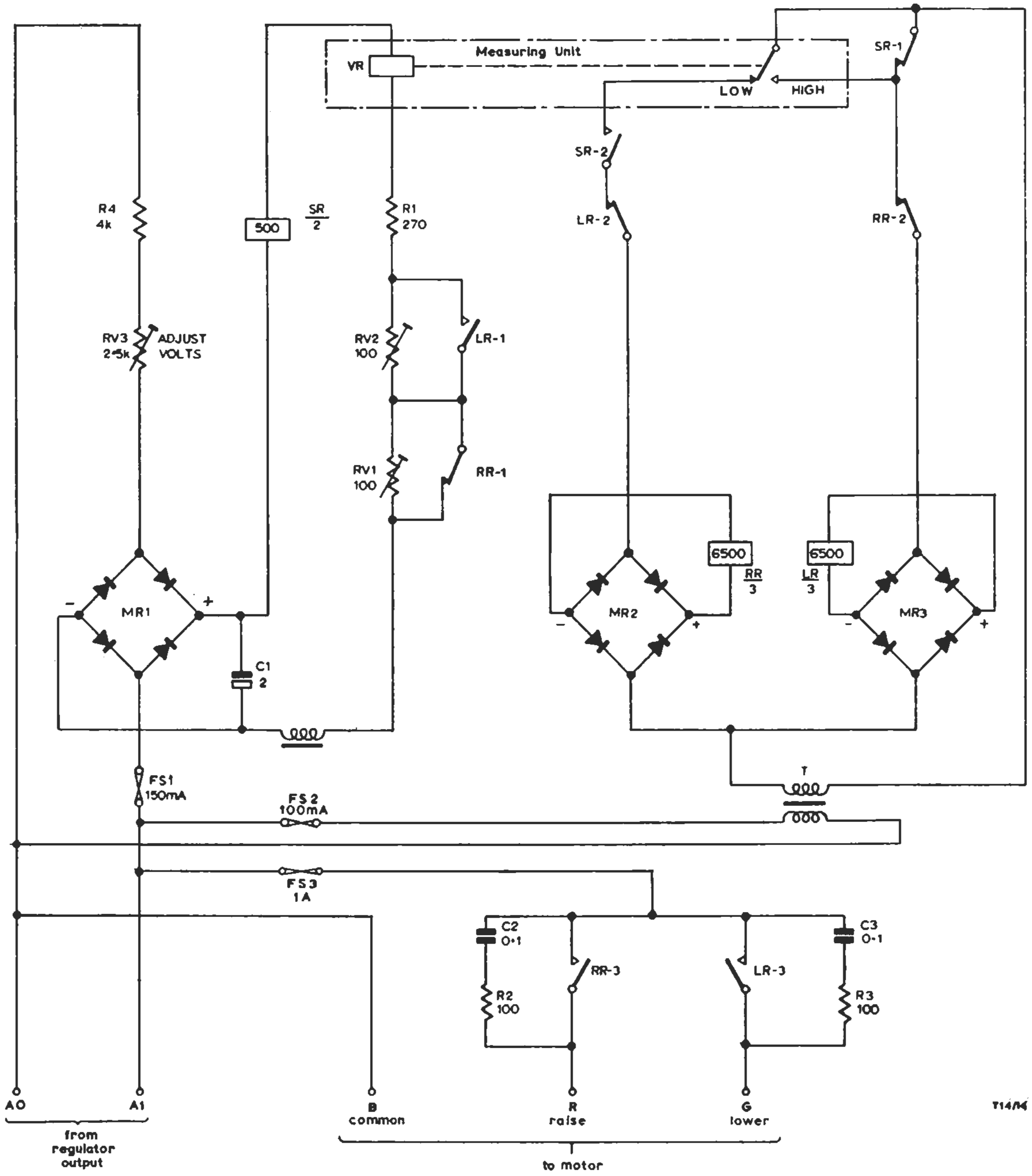


Fig. 2.2 Type-A Control Unit (Regulators with Serial Numbers from 65851)

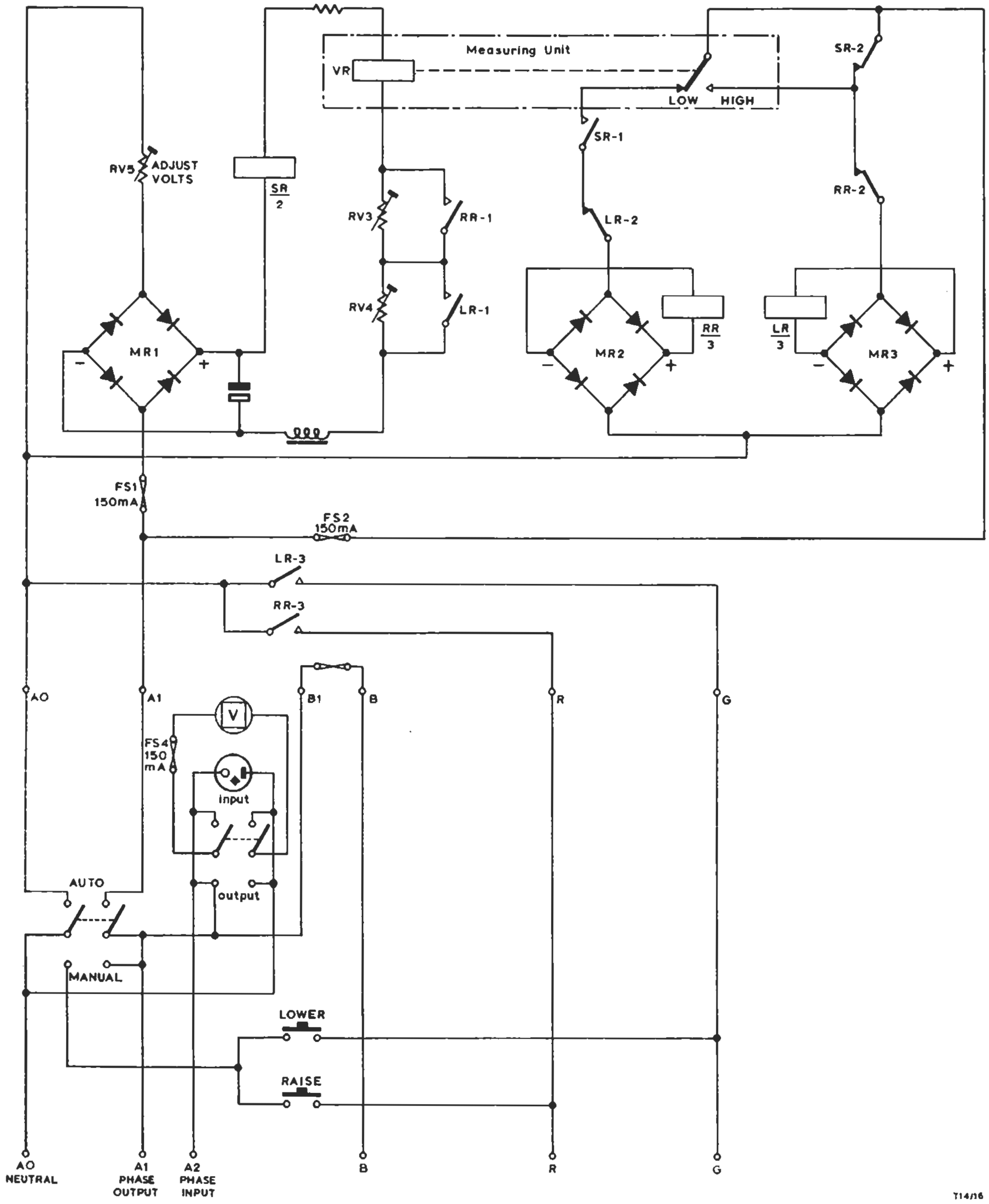


Fig. 2.3 BBC-specified Control Unit

voltage, and SR-2 opens to prevent relay RR being energised. This ensures that the regulator output voltage is reduced to a minimum.

The regulated output voltage can be set to the required value by RV3, the *Adjust Volts* control, which varies the voltage of balance of VR. Controls RV1 and RV2 are preset by the maker and should not need adjusting.

2.3.2 BBC-specified Control Unit

Fig. 2.3 is the circuit of the control unit designed for the BBC. It is the same in operation as the unit described in 2.3.1, but with the extra facility of push-button control of the output voltage.

When the *Auto/Manual* switch is at *Auto*, the output voltage of the regulator is applied directly to the control unit in the usual way. When the switch is at *Manual* the output voltage is applied to the driving motor via one of the two push-button switches marked *Raise* and *Lower*. A voltmeter with selector-switch is fitted to allow the input and output voltages of the regulator to be measured.

2.4 Regulating Unit

The regulating-unit transformer has a core of conventional construction and rectangular cross-section. Clamped to the core, but insulated from it, are two vitreous-enamelled steel sections. A single layer of insulated copper wire is wound over these sections, part of the insulation being removed from the outer surface of the winding to allow a carbon brush to make contact.

The brush can be driven along the whole length of the winding by a single-phase motor and an endless-chain drive. The material from which the brush is made is chosen for its low contact-resistance and self-lubricating properties. The brush is made physically large to keep current density at a minimum, but because of the large size, turns on the winding under the brush are short-circuited. The heat thus generated is, however, conducted away by the steel sections clamped over the core, and an excessive temperature-rise is avoided. To keep transformer size as small as possible, single-phase regulators sometimes have two transformers connected in parallel.

Certain models have two brushes which bear on tracks on opposite sides of the winding. When these brushes are positioned directly opposite each other, they are midway along their tracks. The two brushes are driven by the same chain and are arranged to move in opposite directions.

The brush mechanism is driven by a split-phase capacitor motor with a solenoid-operated brake. When the motor is energised, this brake releases. The circuit of the motor and regulating unit is shown in Fig. 2.4. Upper and lower limit-switches are arranged to break the motor supply if excessive correction is attempted.

Provision is made on all regulators for some form of emergency hand control of output voltage. This is usually effected by means of a handle which, when pressed to release a clutch, can be used to alter the position of the brush mechanism.

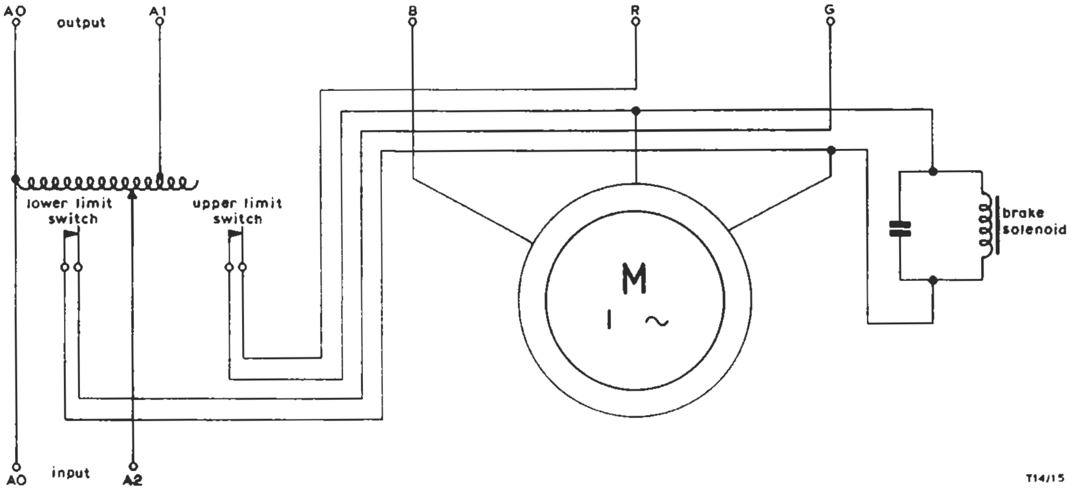


Fig. 2.4 Regulating Unit Drive-motor Circuit

SECTION 3

BRENTFORD REGULATING EQUIPMENT

3.1 Introduction

This equipment is made by Brentford Electric Ltd. The regulating units are usually variable-ratio auto-transformers; in some instances booster transformers are used also. Single and three-phase regulators of various ratings are in service, some being air- and others oil-cooled. Three-phase regulators commonly have three identical regulating units which may be driven either by a single control unit or by three separate units. Similarly there may be one or three associated measuring units. Each measuring unit is normally connected between one phase and neutral of the regulated supply. There are several types of measuring unit commonly in use and some typical ones are described in this Instruction.

3.2 Measuring Units

3.2.1 Cone-pivot Relay

The cone-pivot relay is a discontinuous measuring unit. It derives its name from the method of construction. Various electrical features mentioned in following description are to be seen in control-unit circuit diagrams (Figs. 3.3 and 3.4) referred to under heading 3.3.

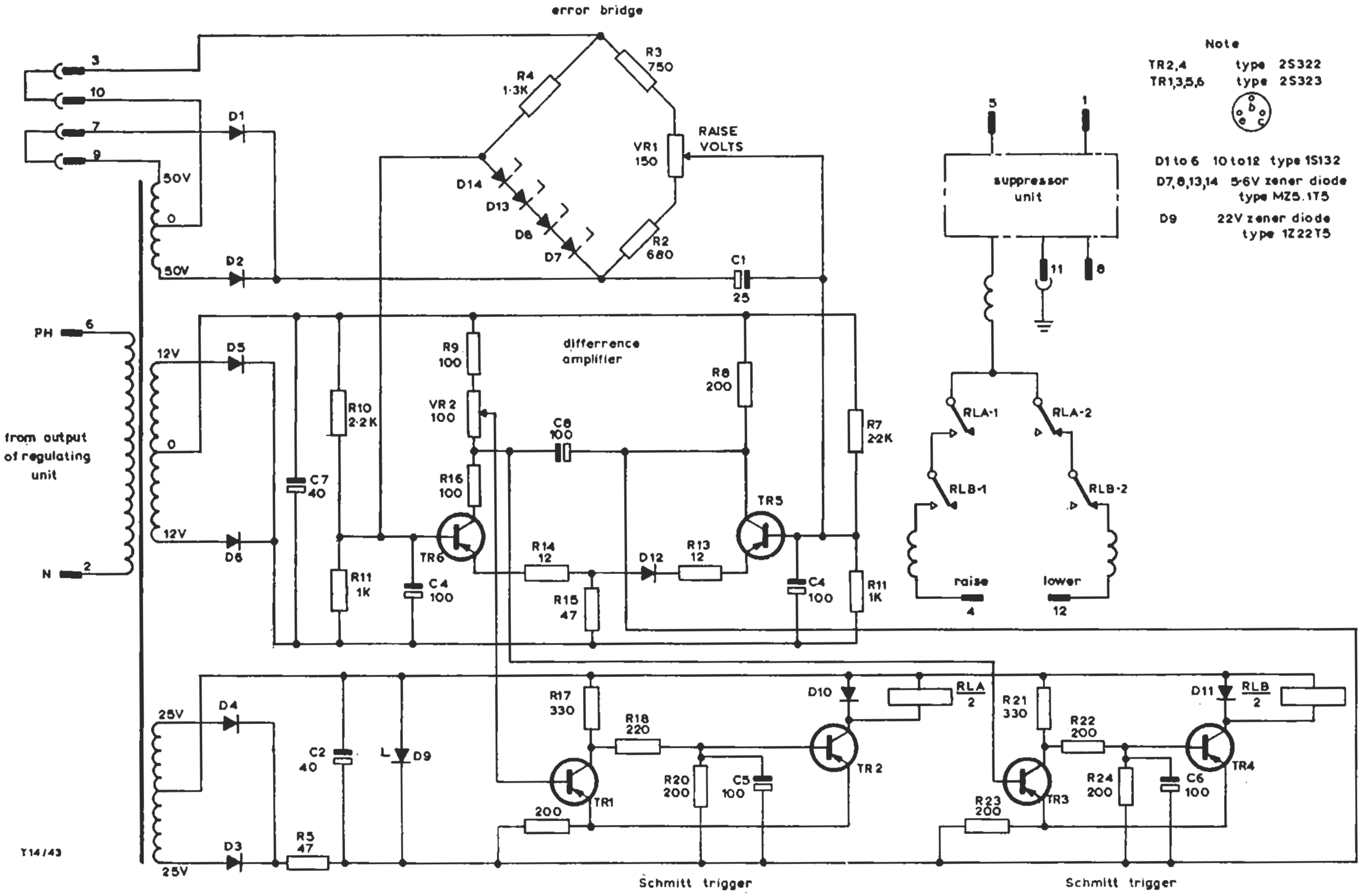
The relay consists of a solenoid, mounted horizontally on a control panel, and a plunger arranged to move in and out of the coil. The plunger is attached by a shaped beam to a swivel connection near the upper end of a vertical beam, which is balanced on cone-shaped pivots. On opposite sides of the beam are two contacts which move between fixed contacts connected to control motor windings. The beam is fitted with a clamping screw, for use when the relay is being transported, and a damping device in the form of a vane in an oil dashpot. The contacts (in series with the bias coil and the raise/lower motor-supply contacts in Fig. 3.4) are closed under working conditions. These contacts prevent the motor-operating current from passing through the relay pivots.

The voltage-control coil has a cam-operated device for adjusting the reluctance of its magnetic path. The device incorporates a strip of magnetic material lying outside the solenoid and parallel to its axis. The right-hand end is pivoted and the left-hand end is bent downwards through 90 degrees, outside the solenoid end-cheek, to point at the solenoid plunger. The cam is mounted with its edge bearing against the underside of the centre of the strip. By rotating the cam, the strip can be raised and lowered to vary the gap between the end of the strip and the plunger. The cam has a knob and dial plate, calibrated 0—25, the limits corresponding to minimum and maximum gap.

The magnetic pull on the plunger depends on the width of the gap, increase of which necessitates an increase of voltage across the coil to move the plunger to a given position. Thus, under operating conditions, an adjustment of the cam setting is compensated by a change in output voltage. This arrangement provides a fine control for determining the voltage to which the output is regulated. A coarse control is provided by a resistor (R in Fig. 3.4) in series with the coil.

The bias coils are wound on an iron core, mounted with its axis perpendicular to the face of the insulating panel. The coil is placed at a position where the core projects centrally between the prongs of a U-shaped armature attached to the right-hand side of the beam. These prongs lie horizontally one above the other. Set-screws are provided for limiting the extent of their travel, and thus the travel of the beam. The purpose of the bias coil is to increase the hold-on force when the control equipment is in process of correcting the output voltage. This ensures that the motor supply is maintained until the correction has been fully carried out, since without the coil this supply would be interrupted as the output voltage neared the predetermined value. Thus, the motor-supply contacts operate positively and arcing due to contact bounce is reduced.

With the regulator out of service, the tension spring attached to the linking arm holds the beam in the position at which the *raise* contacts are made. When the supply is switched to the regulator, the motor circuit is not in the operative state until the second pair of contacts, in series with the bias coil, also make. This occurs as the plunger moves into the solenoid but, if the output voltage is reasonably near the correct value, the excursion of the plunger is sufficient for an almost immediate breaking of the



Note
TR2,4 type 2S322
TR1,3,5,6 type 2S323

D1 to 6 10 to 12 type 1S132
D7,8,13,14 5·6V zener diode type MZ5.1T5
D9 22V zener diode type 1Z22T5

Fig. 3.1 Circuit of MVR2 Relay

motor supply at the *raise* contact. The beam then assumes the mid-position, where both motor-supply contacts are broken. If the output voltage varies, the plunger moves in or out of the solenoid as the voltage rises or falls and, providing the change is sufficient, causes the appropriate motor-supply contacts to make. When the output voltage again reaches the correct value, the motor supply is interrupted and the beam returns to its mid-position.

3.2.2 MVR2 Relay

(*a*) *General Description*

The MVR2 relay is a continuous measuring unit which is used in conjunction with a discontinuous control unit. It employs a transistor circuit to sense changes in voltage and to energise relays which give *raise* or *lower* signals to the control unit. A circuit diagram is given in Fig. 3.1.

A voltage proportional to the regulator output voltage is applied to an error bridge incorporating zener diodes. The bridge is normally balanced, but a variation from the nominal output voltage produces unbalance, resulting in an error signal which is amplified and applied to two Schmitt trigger circuits. The trigger circuits operate relays RLA and RLB which pass the appropriate *raise* or *lower* signal to the control unit.

(*b*) *Circuit Description*

The error bridge in the MVR2 relay is shown at the top of Fig. 3.1. The input to the bridge is the voltage which is developed across the 50-0-50 winding of the transformer and rectified by diodes D1 and D2. This d.c. voltage varies in sympathy with the regulator output voltage.

The action of the error bridge is comparable with that of a normal Wheatstone bridge. With a constant voltage applied to the input the bridge can be balanced by means of VR1 so that there is no output. If the input voltage to the bridge varies, the resistance of the zener-diode chain alters and an output voltage is developed.

When the regulator output voltage falls below the nominal 240 volts, the input to the bridge decreases and the output from the bridge increases. This action is shown in Table 3.1.

The output of the error bridge is applied to a difference amplifier comprising two transistors, TR5 and TR6, arranged as an emitter-coupled or 'long-tailed' pair. The output of this amplifier is proportional to the difference in potential between the transistor bases.

TR5 collector is connected to the common positive lead of the Schmitt trigger circuits, TR1/TR2 and TR3/TR4. (A Schmitt trigger is a bistable circuit in which the state assumed depends on the d.c. potential at the input, e.g., the base of TR1 in the circuit TR1/TR2.) It is arranged that TR1 is normally non-conducting and TR2 conducting, relay RLA being then energised. A negative change of potential at TR1 base causes TR1 to conduct, so TR2 stops conducting and RLA is de-energised. The trigger circuit TR3/TR4 is similar in action, but TR3 is normally conducting, TR4 non-conducting and relay RLB de-energised.

TABLE 3.1: ERROR BRIDGE VOLTAGES

Voltage across:	*Regulator Output Voltage*	
	Normal	*1 per cent low*
Bridge input	50	49·5
Zener diodes	20	20
R4	30	29·5
R2 & part VR1	20	19·8
R3 & part VR1	30	29·7
Bridge output	0	0·2*

*29·7—29·5=0·2.

Variations in potential between the collectors of TR5 and TR6 cause the potentials applied to the bases of TR1 and TR3 to vary.

When the output of the error bridge increases, the base of TR5 becomes more positive than the base of TR6. TR5 then conducts less and TR6 conducts more. The potential at the junction of R16 and VR2, which is more negative than at the collector of TR5, goes in a positive direction and the potential at the collector of TR6 goes in a negative direction. But, because the collector of TR6 was initially more negative than the collector of TR5, the input to the Schmitt trigger decreases. TR1 is not conducting and is not affected. TR3 was conducting and is rapidly switched to the non-conducting state. TR4 therefore conducts, energising RLB and causing a *raise* signal to be given to the control unit.

By similar reasoning it can be shown that if the regulator output voltage increases instead of decreasing, both relays are de-energised to give a *lower* signal to the control unit.

If the error bridge circuit fails, resulting in a loss of signals to the amplifier, a *lower* signal is given to the control unit because in practice VR1 slider is set to +1 volt with respect to the junction of R4 and D14. If the bridge were balanced so that in normal circumstances the output was zero, no indication would be available if the error bridge became faulty and gave no output at all.

(*c*) *Construction*

The MVR2 relay is made as a plug-in unit with most of the components on a printed-wiring board. Relays RLA and RLB are an hermetically-sealed type and are permanently wired in. The circuits switched by the relay contacts are fitted with suppressors.

(*d*) *Adjustment*

The MVR2 relay (Fig. 3.1) and the associated control unit (Section 3.3.2 and Fig. 3.5) should be adjusted at the same time.

The setting of R2 on the control unit should be such that the regulating-unit output can rise only to 245 volts before it is automatically reduced to some value below the input voltage. To check this, turn the *Raise Volts* control, VR1 on the MVR2 relay, fully clockwise. If R2 needs adjustment:

1. Open switch S1 on the control unit.
2. Adjust R2.
3. Reclose S1.

When R2 is correctly set, adjust VR1 to obtain an output voltage of 240.

VR2 on the MVR2 relay determines the difference-amplifier gain and enables the dead zone to be correctly set. VR2 is adjusted by the maker to give control of the 240-volt output voltage to within ±1 per cent.

3.2.3 *AVC3 Relay*

The AVC3 relay is a voltage-sensitive measuring unit of the discontinuous type. It can be set to operate for voltage differences of ±½ per cent from the mean value. Normally the setting is for a tolerance of ±1 per cent.

Fig. 3.2 is a simplified illustration diagram of the relay. An exact physical layout is not shown because certain parts have either been omitted or positioned to aid clarity.

A solenoid (a) has an iron core (b) which is supported at either end by leaf springs (c). The springs ensure that the core can move vertically but not horizontally. The lower end of the core has a contact (d) which moves between contacts (e) and (f). Normally contact (d) is midway between (e) and (f) and the weight of the core is partially supported by spring (g).

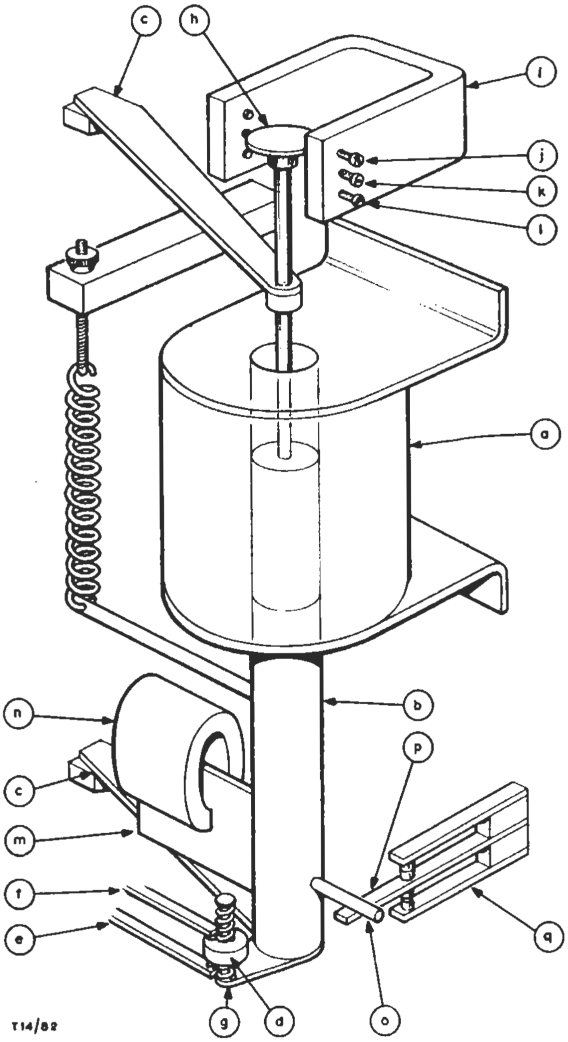


Fig. 3.2 Simplified Illustration of the AVC3 Measuring Unit

If the voltage applied to the solenoid falls the core moves down and contact (d) makes with contact (e). Conversely if the voltage rises the core is attracted further into the solenoid and (d) makes with (f). To ensure a positive make and break action an iron disc (h) moves in the field of a permanent magnet (i) which has three pairs of poles, (j), (k) and (l). The poles are formed by six screws. When contact (d) is in its mid-position the iron disc is held between the middle pair of poles (k). When the voltage is low the disc is held between the lower pair of poles (l) and when the voltage is high the disc is held between the upper pair of poles (j). Momentary fluctuations in the movement of the core are damped by the movement of a copper vane (m) which is fixed to the core and moves between the poles of a permanent magnet (n).

To counteract possible variations in the resistance of the solenoid with temperature changes, a low-temperature-coefficient resistor, with a high value compared to the solenoid resistance, is connected in series with the solenoid. Part of this external resistance is made variable so that the voltage at which the relay balances can be adjusted.

If the incoming voltage were abnormally low the associated control unit would drive the regulating unit to its maximum output position. To prevent this happening a peg (o) is attached to the core so that if the core falls beyond a predetermined distance peg (o) closes contacts (p) and (q). These contacts are usually wired so that the regulating unit is driven either to its minimum output condition or stays in the position it held at the moment the supply failed.

3.3 Control Units

3.3.1 Control Unit for Cone-pivot Relay

Two versions of this circuit exist, an earlier one shown in Fig. 3.3 and a later one shown in Fig. 3.4. The regulating unit and its drive motor are shown in Fig. 3.7. The action of these circuits is self-explanatory.

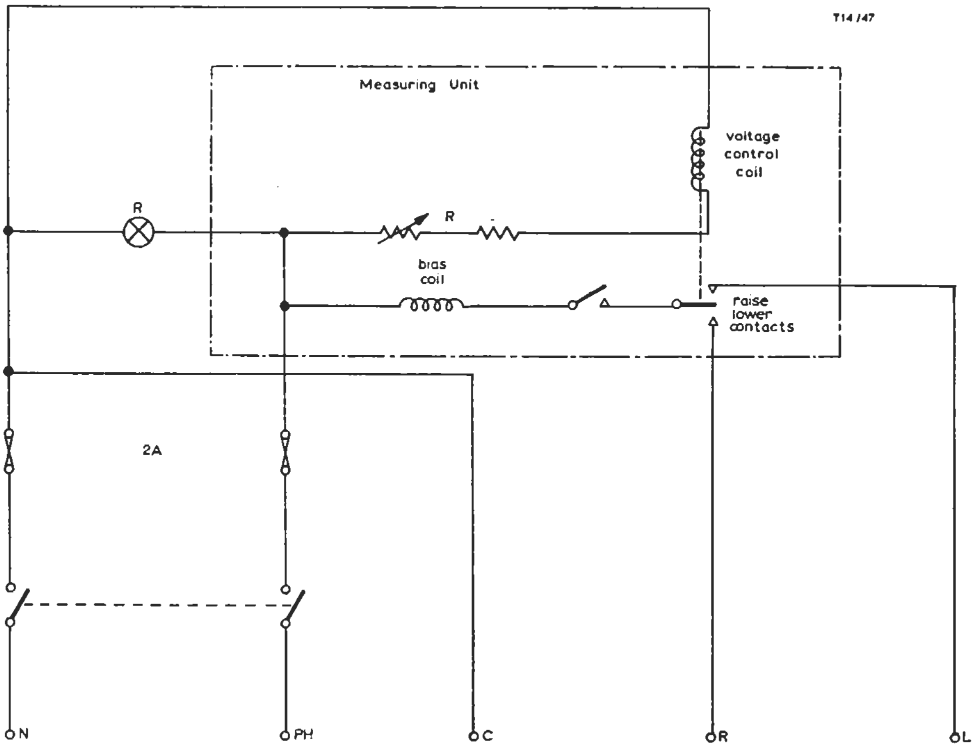


Fig. 3.3 Control Unit for Cone-pivot Relay: Early Version

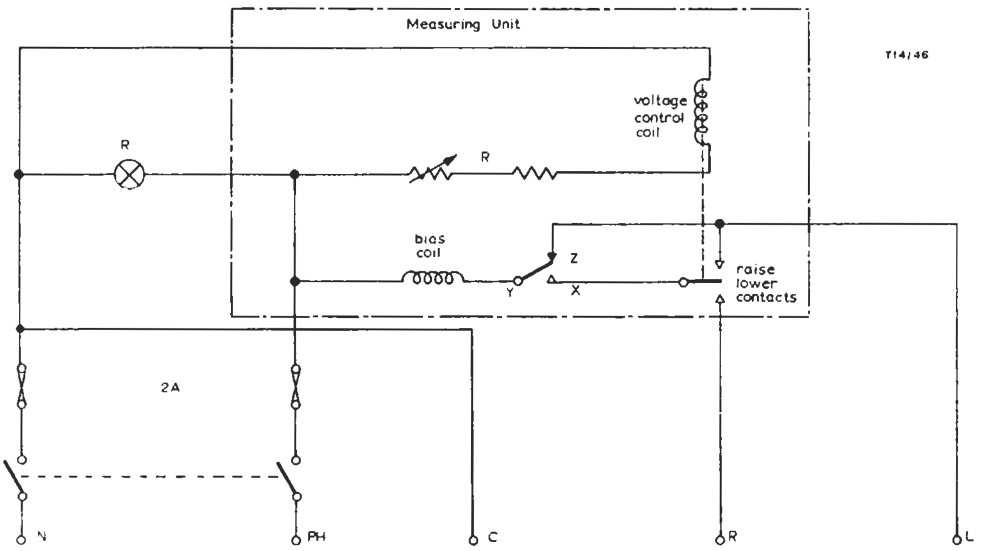


Fig. 3.4 Control Unit for Cone-pivot Relay: Later Version

3.3.2 Control Unit for MVR2 Relay

The circuit of this unit is shown in Fig. 3.5. There are three possible regulator output voltage conditions:

(*a*) *Output Voltage Below 240*

A *raise* signal is received from the measuring unit, which makes a connection, via a relay contact, across control-unit terminals 4 and 5. The following sequence then takes place:

Relay RR is energised via OVR-1.

RR-1 completes the motor circuit via LR-1 to restore the output voltage to 240.

(*b*) *Output Voltage 240*

No signal is received from the measuring unit and the motor remains stationary.

(*c*) *Output Voltage Above 240*

The measuring unit gives a *lower* signal, which makes a connection between terminals 5 and 12. The following sequence takes place:

Relay LR is energised.

LR-1 completes the motor circuit via RR-1, to restore the output voltage to the correct value.

LR-2 prevents the motor being powered by a false *raise* signal.

As well as controlling the motor circuit in accordance with signals received from the MVR2 relay, the control unit prevents an overvoltage condition from arising due to any fault which causes a continuous *raise* signal.

When the output signal is normal, relay ORR is unoperated. Variable resistor R2 is adjusted so that if the output voltage from the regulating unit reaches 245 volts, relay ORR is operated. If, therefore, a permanent *raise* signal is received, ORR operates as soon as the output voltage rises above 245 and:

Relay OVR is energised via ORR-1.

OVR-1 changes over and completes the circuit to the motor to reduce the output voltage to its minimum value.

OVR-2 closes across ORR-1 and holds in relay OVR, preventing relay RR from being energised.

OVR-3 completes the circuit to an *Overvoltage Fault* lamp.

3.3.3 Control Unit for an 11-kV/415-volt Regulating Transformer

A simplified circuit diagram of this unit is given in Fig. 3.6. It is a discontinuous control unit which is used in conjunction with a type AVC3 measuring unit.

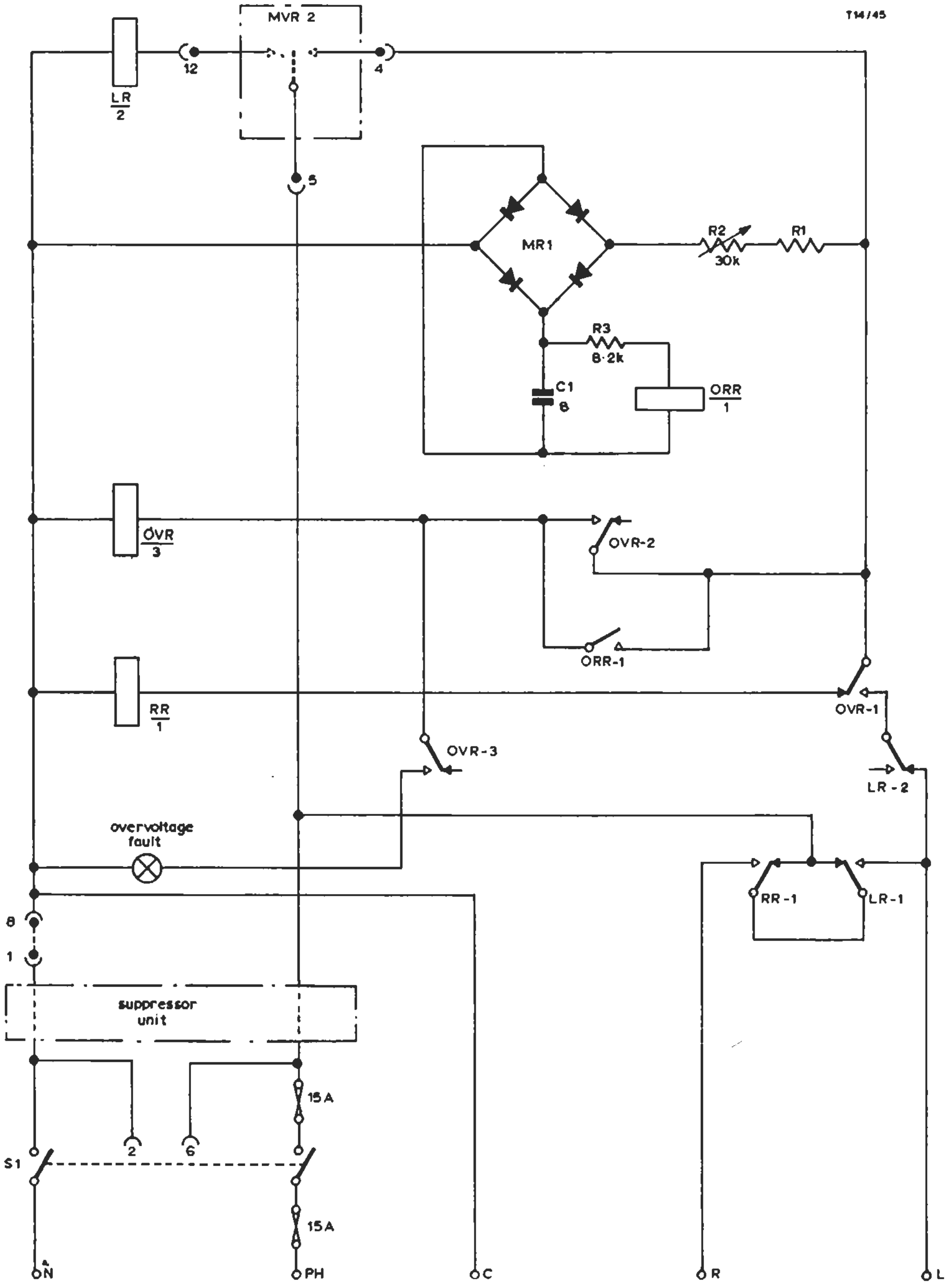


Fig. 3.5 Control Unit for MVR2 Relay

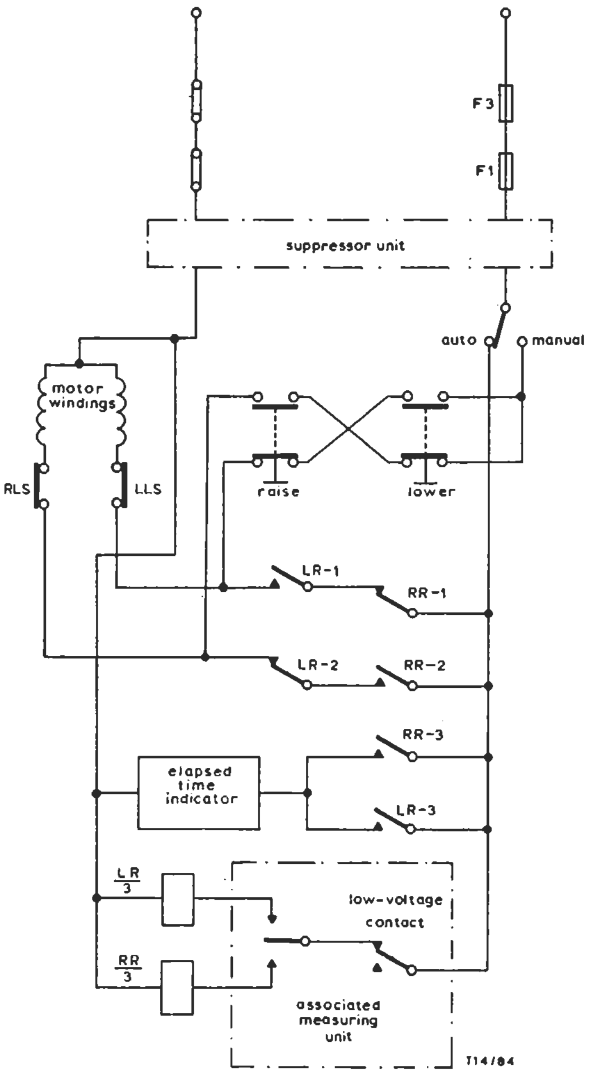


Fig. 3.6 Simplified Circuit Diagram of a Control Unit for use with an 11-kv/415-volt Regulating Transformer

The control unit and the associated measuring unit are usually housed together in a steel cabinet with a hinged door. The measuring unit, fuses, an *Auto/Manual* switch and *Raise* and *Lower* push-button switches are mounted on a panel inside the cabinet.

Operation

The contacts of the measuring unit can complete circuits to energise either a raise relay, RR, or a lower relay, LR, which cause the associated regulating unit to be driven in the appropriate direction. Raise and lower limit switches, RLS and LLS respectively, limit the extent of travel of the brushes on the auto-transformer. The *Electrical Distance Recorder*, an elapsed time indicator, records hours of operation of the motor.

An *Auto/Manual* switch is fitted. When the switch is in the *Manual* position *Raise* and *Lower* push-button switches can be used to control the output of the regulating unit.

3.4 Regulating Unit

The regulating unit is a variable-ratio auto-transformer. The winding consists of a single layer of rectangular cross-section insulated copper wire which is wound on a circular cross-section core. A section of the insulation is removed from the outer surface of the winding to provide a copper track against which graphite brushes can bear. The brush mechanism is driven by either an a.c. or d.c. motor through an endless chain-drive. Certain models are used in conjunction with a booster transformer and have two separate brush mechanisms which bear against tracks on opposite sides of the winding.

A typical circuit arrangement is shown in Fig. 3.7. Limit-switches are arranged to break the motor circuit to prevent over-run in either direction. The motor is connected to the chain drive through a spring-loaded clutch which can be disengaged to allow emergency manual adjustment of the output voltage. The auto-transformer, the motor and chain drive and the limit-switches are all mounted on the same framework.

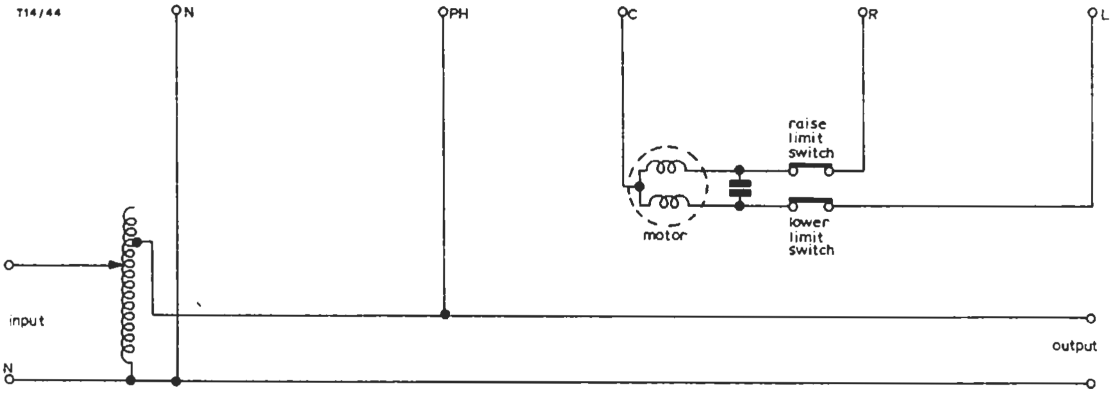


Fig. 3.7 Regulating Unit and Drive Motor: Typical Circuit Arrangement

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SECTION 4

FOSTER REGULATING EQUIPMENT

4.1 General

Various types of regulator made by Foster Transformers Ltd. are in use at transmitting stations. These regulators comprise standard units interconnected in different combinations. Examples from the range of units used are described in this Section. Details of the interconnections and mechanical arrangement of the units at individual stations are given in Instructions for the relevant sites.

The measuring units used are called Control Units by the maker and are subsequently described under headings appropriate to that designation.

4.2 Regulating Unit Type VR/TOR

This regulating unit comprises a tapped auto-transformer and a double-wound booster transformer. The auto-transformer has two tappings; one is fixed at the centre-point of the winding and the other is adjustable over the full winding. A voltage derived from these two tappings is applied to the booster transformer to aid or oppose the input voltage. Fig. 4.1 is a circuit diagram of a complete regulator which incorporates this type of regulating unit.

The auto-transformer, known by the trade-name Troidac, has a toroidal winding which is anchored to its core during manufacture. One surface of the winding is then machined to remove the insulation and provide a track over which carbon brushes can travel to make contact with every turn of the winding in sequence.

The carbon brushes are mounted on the inside of one leg of an L-shaped arm, the other leg of which is pivoted on the axis of the toroid. The arm is thus able to rotate and move the brushes over the machined surface of the winding to give a tapping point on every turn. The brushes are connected in parallel and so aligned as to ensure that all make contact with the same turn of the winding at any point in the travel of the arm.

Two or more Troidacs can be used in a single regulator to provide increased rating. Fig. 4.2 shows an arrangement in which three Troidacs are used. The moving portions of the individual Troidacs are accurately aligned with each other during manufacture and special care must be taken to ensure that the alignment is not disturbed during servicing or maintenance. The initial alignment gives a coarse adjustment of load-sharing among the individual units, but additional measures are adopted to deal with minor irregularities. One such measure, shown in Fig. 4.2, is the connection of auto-transformers between the adjustable tappings and the booster transformer. An alternative method is the use of a booster transformer with special windings.

One form of control unit used with the Type-VR/TOR regulating unit comprises an integral motor and gearbox, the output of which drives the regulator-unit brush-arm via a friction clutch.

The motor is a series commutator type which can operate from either a.c. or d.c. supplies at 220-250 volts. It has two independent field windings, used one for each direction of rotation. In some installations provision is made for 'manual' (push-button) control of the motor as well as for automatic operation from one of the measuring units described later. Fig. 4.1 includes circuit details of an installation of this type.

In an emergency, the regulating unit can be adjusted by hand. A lever welded to the output side of the friction clutch is provided to give this facility. Before any attempt is made to rotate the brush-arm by means of this lever, the control and measuring units must be isolated by putting the *Hand/Manual/Auto* switch to the *Hand* position.

High-speed regulators incorporate a shunt-wound d.c. motor in which the reversal of motion is achieved by changing the polarity of the supply to the commutator while the field is permanently connected. Figs. 4.3 and 4.4 show a control circuit using this type of motor, which is in turn controlled by an Electronic Control Unit Mark 8P (Section 4.4.). When the commutator supply is disconnected by the measuring unit, the commutator is short-circuited; because the field remains energised, this provides dynamic braking and thus helps to prevent overshoot and consequent hunting.

Limit switches are provided to cut off the motor supply when the brush-arm reaches either limit of rotation. These switches are actuated by a cam on the driving shaft to the brush-arm.

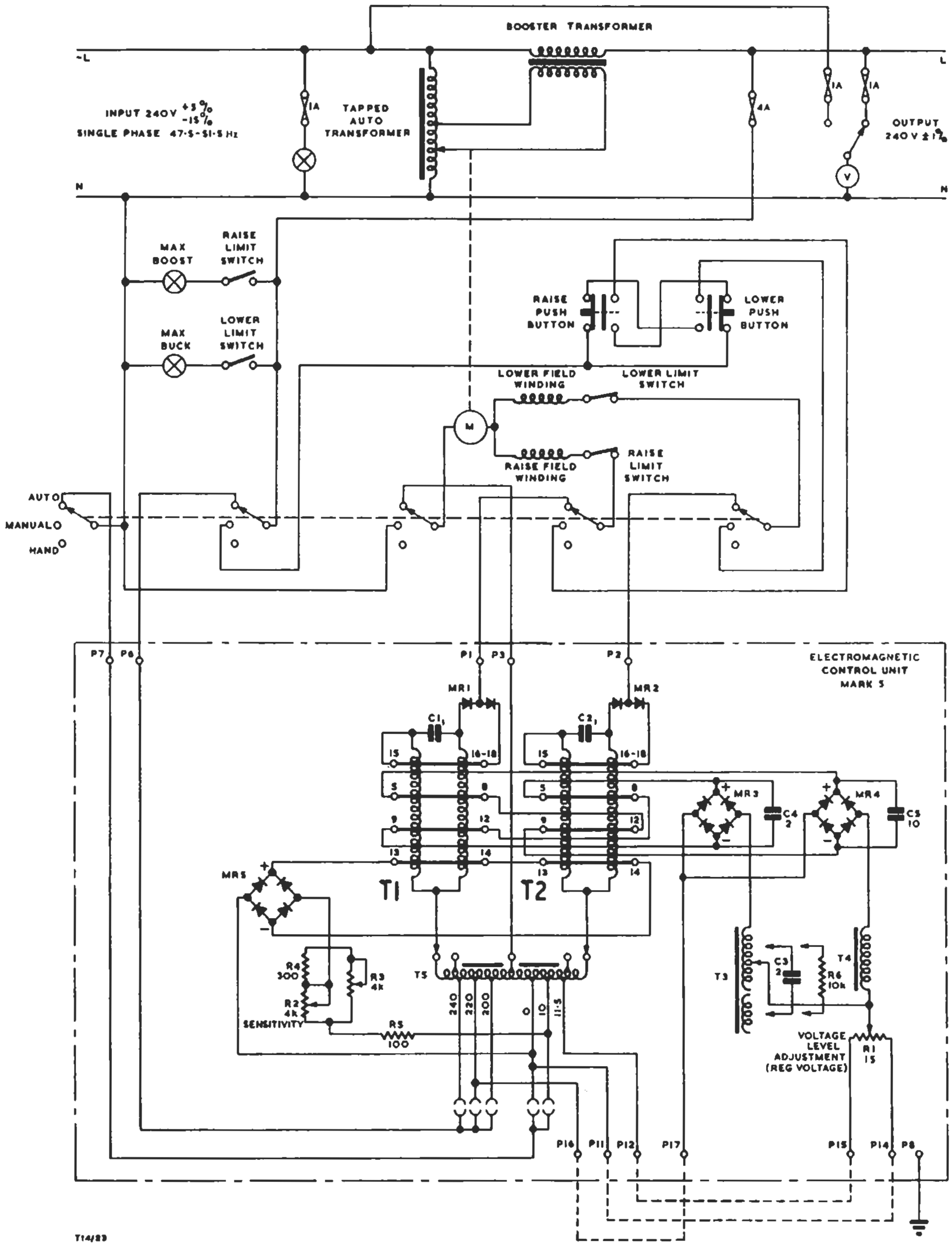


Fig. 4.1 VR/TOR Regulating Unit with Electromagnetic Control Unit Mark 5

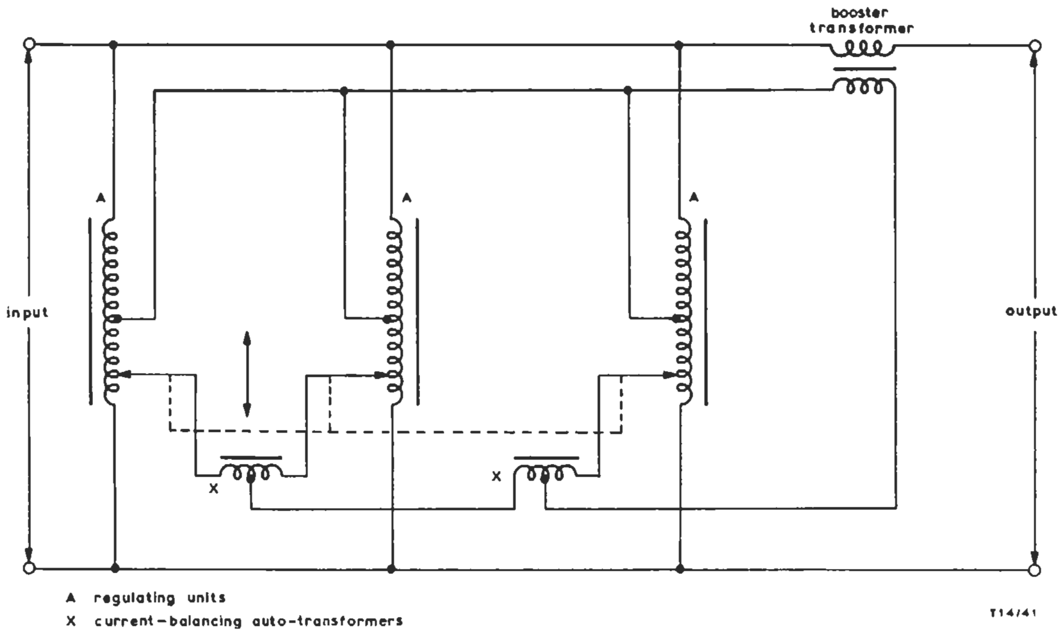


Fig. 4.2 Example of VR/TOR Regulating Units in Parallel

4.3 Electromagnetic Control Unit Mark 5

The complete regulator circuit given in Fig. 4.1 includes this type of measuring unit, which is built on a separate plug-in chassis.

Two magnetic amplifiers, T1 and T2, are used to switch a supply to *raise* and *lower* circuits respectively of the regulator control motor. The magnetic amplifiers are full-wave types and each has four control windings which are shown on the circuit diagram as bars instead of inductor symbols. A description of the basic principles of magnetic amplifiers is given in Instruction L.4.

Fig. 4.5 is a simplified circuit of the Mark-5 unit. The magnetic-amplifier windings have been arbitrarily lettered to assist description. The function of each winding is given in Table 4.1.

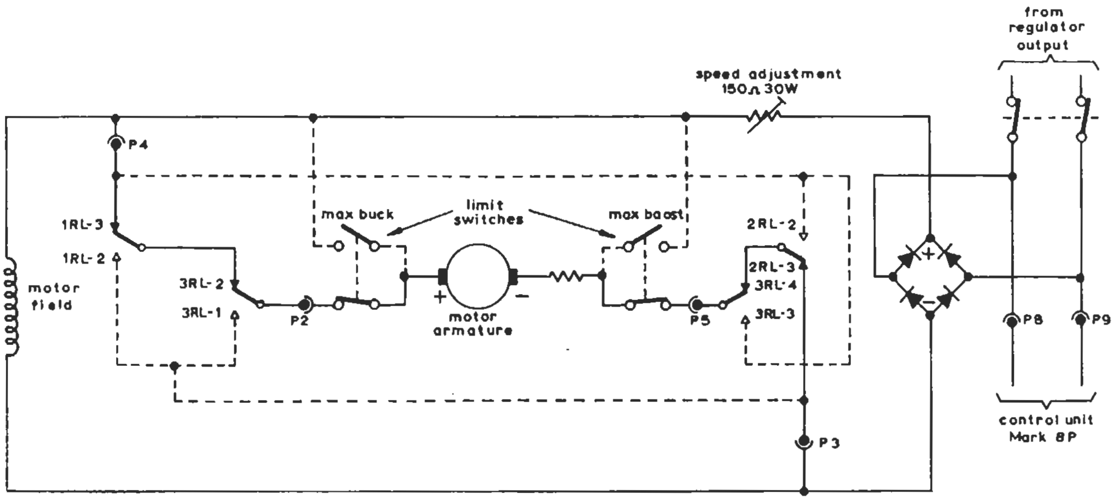
Supplies to operate the unit are derived from an input transformer T5 which is supplied from the output of the regulating unit. T5 is an auto-transformer with tappings to give the required voltages for control, bias and motor-operating circuits.

Selection of input tapping points on T5 provides a means of adjusting the regulated voltage output from the equipment in coarse steps of about 10 volts. Fine control of the output voltage is achieved by adjustment of *Voltage Level Adjustment* control R1. This is a preset potential-divider with fixed connections to 0 and 11·5-volt taps on T5 and feeds the control-winding circuits via its slider. The other side of the control-winding circuits is returned to a 220-volt tap on T5.

T3 and T4 are inductors which control the current through the control windings of the magnetic amplifiers via rectifiers MR3 and MR4. The control-current path influenced by T3 is HJ (T2)-GF(T1), and that due to T4 is HJ(T1)-GF(T2); thus when these currents are equal the

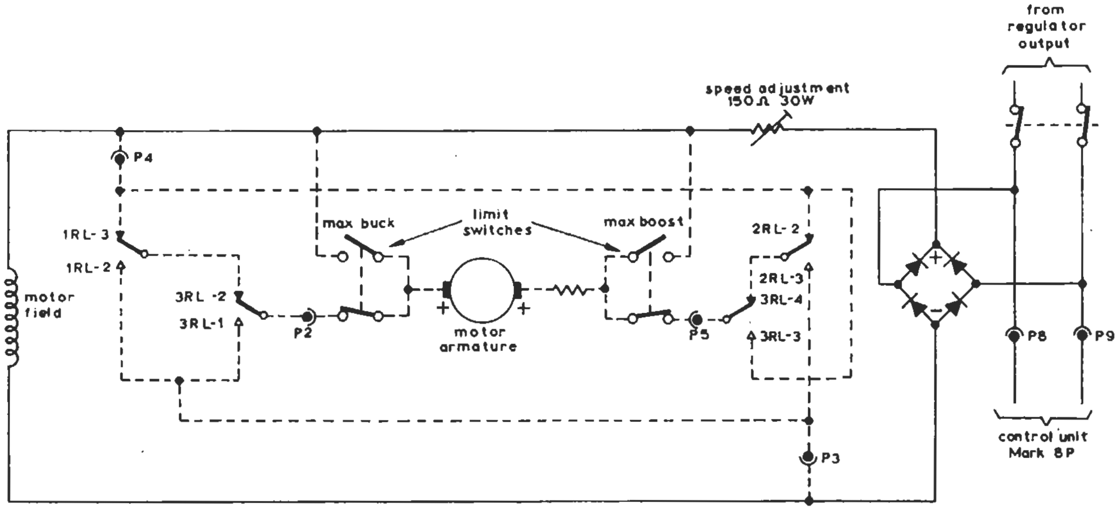
TABLE 4.1

Winding	*Function*
AB AC	Full-wave supply to motor via rectifiers MR1 or MR2
DE	Bias winding to provide dead zone
FG HJ	Control
KL	Feedback



Relay Conditions
1RL de-energised
2RL de-energised
3RL de-energised

(1)
low output
motor running to boost

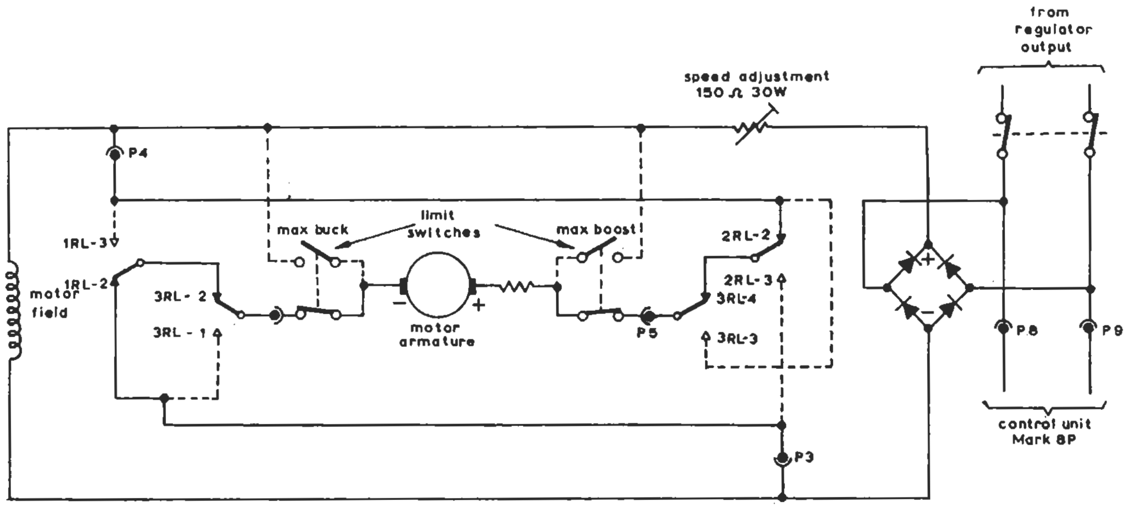


Relay Conditions
1RL de-energised
2RL energised
3RL de-energised

(2)
output within dead zone
motor not running

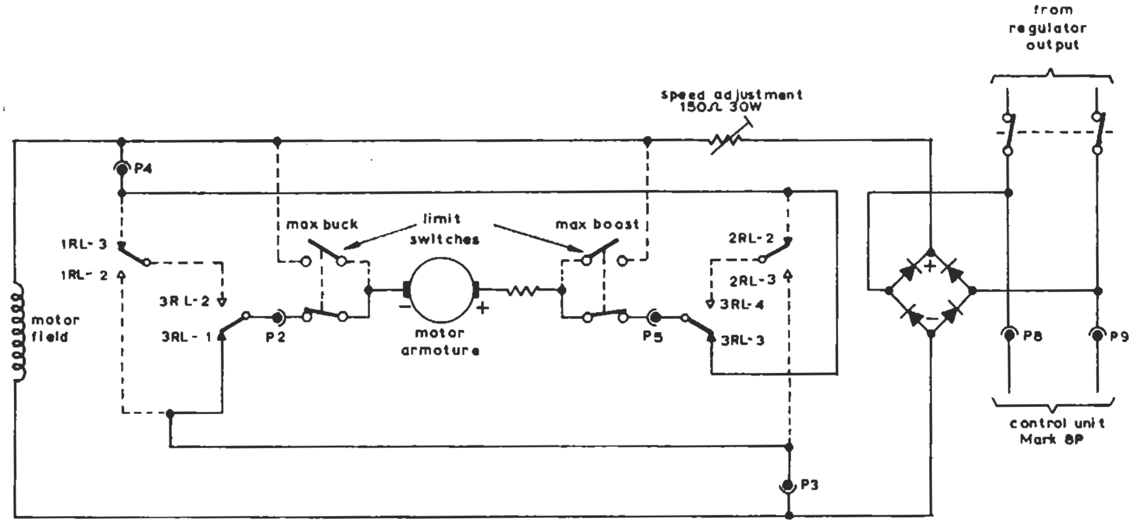
T14/27

Fig. 4.3 High-speed Regulator: Control Motor Circuit: Diagrams 1 and 2



Relay Conditions
1RL energised
2RL energised
3RL de-energised

(3)
high output
motor running to buck



Relay Conditions
1RL de-energised
2RL de-energised
3RL energised

(4)
abnormally high output
overvoltage protection
circuit operative: motor
running to buck

T14/49

Fig. 4.4 High-speed Regulator: Control Motor Circuit: Diagrams 3 and 4

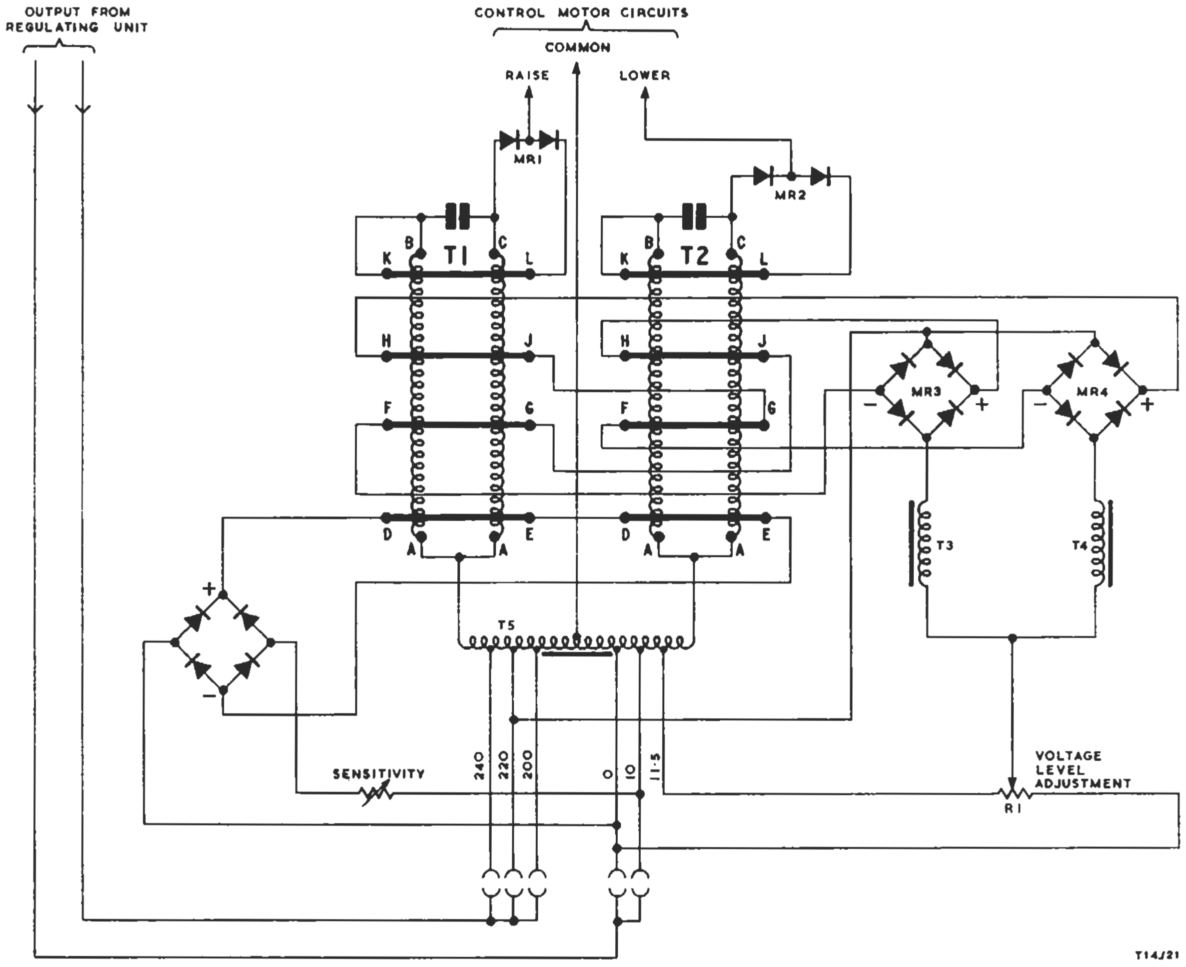


Fig. 4.5 Mark-5 Control Unit: Simplified Circuit

fluxes produced by them in T1 and T2 are equal and in opposition. This condition occurs when the regulator output is of the correct nominal voltage. The magnetic amplifiers are then both held in the off state by the flux due to the bias current flowing in the windings DE. Thus the currents flowing in the a.c. windings, and hence in the motor circuits, are small and the motor does not operate.

With the correct voltage from the regulator applied to T5, inductors T3 and T4 operate with their cores in unsaturated and saturated conditions respectively. Any change in the value of the regulator output voltage therefore causes a larger change in current through T4 than through T3. To illustrate the action of the unit assume that the regulator output voltage increases.

In magnetic amplifier T2, serving the *lower* field-circuit of the control motor, the magnitude of current flowing through winding GF increases more than that in winding HJ. The resultant flux due to the changes of current is in such a direction as to oppose the flux due to the bias circuit, and if the change of voltage is sufficient, the amplifier is turned on to allow current to flow in the a.c. windings. This a.c. is rectified by MR1 and flows in the *lower* circuit of the motor, which then operates to restore the output voltage of the regulating unit to the correct value. As the amplifier begins to turn on, part of the rectified motor-current is passed through feedback winding LK in such a direction as to assist the turn-on operation.

In magnetic amplifier T1, serving the *raise* field-circuit, the current flowing through winding HJ increases more than that in winding GF. The resultant flux aids the bias flux, to keep the amplifier turned off and thus hold the *raise* field-current at a low value while the motor is operating in the *lower* direction.

To avoid possible operation of the regulator due to a change in supply frequency causing a differential change in T3 and T4 currents, C3 and R6 are connected to suitable tappings on T3 to modify its impedance with small frequency changes.

4.4 Electronic Control Unit Mark 8P

4.4.1 *General Description*

The Mark 8P is a discontinuous measuring unit built on a plug-in chassis which fits into the main body of the regulator. The unit includes an overvoltage protection circuit, so that a fault which would tend to produce an abnormally high output voltage makes the regulating unit run to its minimum output position. Circuit details are shown in Fig. 4.6.

A high-speed-regulator motor circuit used with the Mark-8P unit is mentioned in Section 4.2 and the circuit action is illustrated in Figs. 4.3 and 4.4.

4.4.2 *System Description*

The unit can be considered as comprising three interacting stages (a), (b) and (c) which govern the action of the control-unit motor under normal circumstances, and an entirely separate overriding protection circuit which has no effect on the normal duty.

The three interacting stages are:

(a) A voltage-sensing circuit actuated by the regulator output.
(b) A triggering circuit operated by the output signal from (a).
(c) A relay-drive circuit controlled by the state of (b).

The principle upon which the unit operates is best described by considering the requirements of the stages in reverse order.

4.4.3 *Relay-drive Circuit*

The relay-drive circuit, stage (c), is required to operate two relays according to a pattern determined by the control-motor circuit. The pattern is given in Table 4.2 for three conditions of regulator output voltage. (See also Figs. 4.3 and 4.4.)

TABLE 4.2

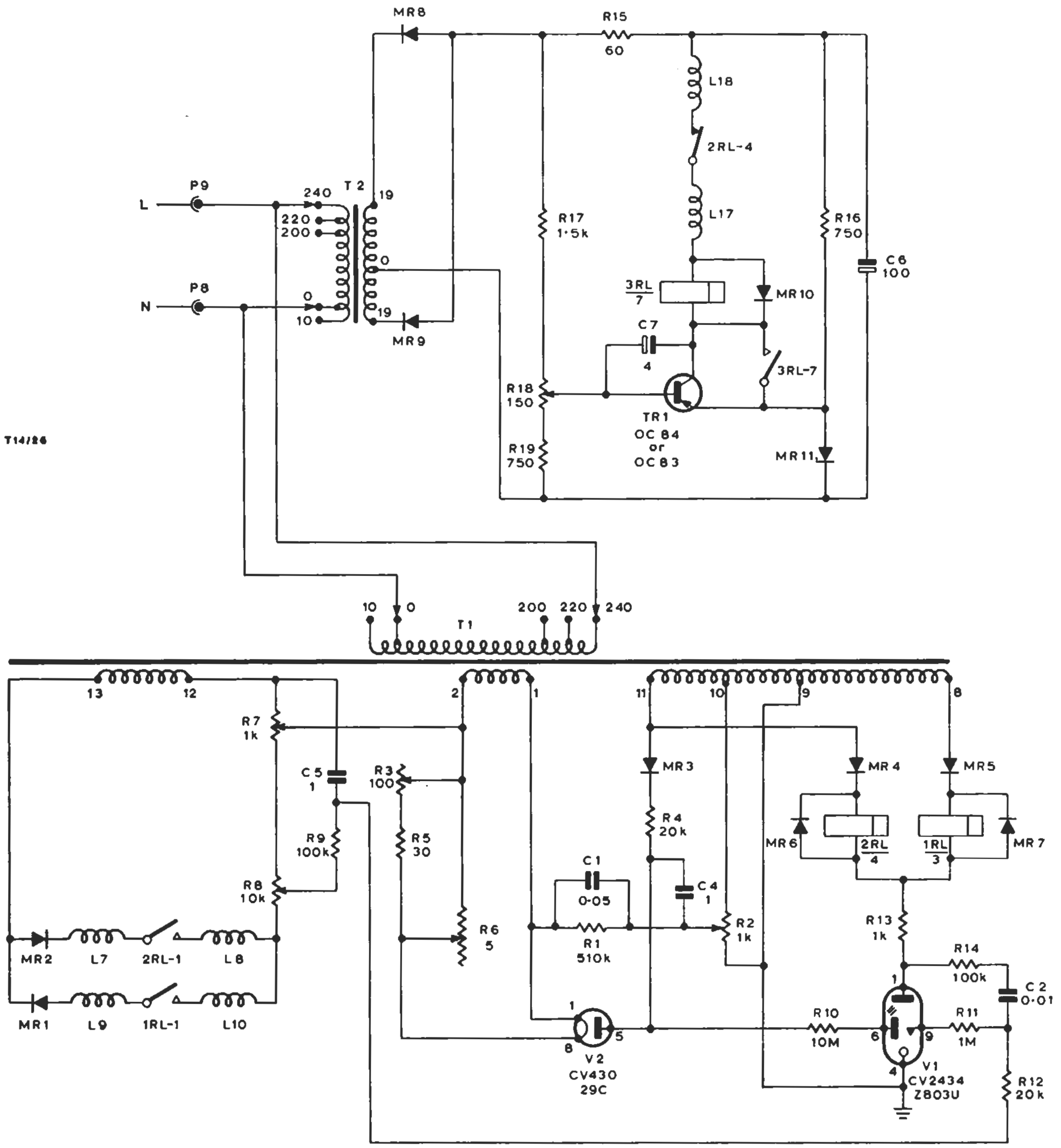
Regulator Output	*Relay 1RL*	*Relay 2RL*	*Control Motor*
Low	De-energised	De-energised	Running to boost
Normal	De-energised	Energised	Not running
Low	Energised	Energised	Running to buck

The two relays are connected in the anode circuit of a cold-cathode trigger tube V1 so that each is in series with one of two half-wave rectifiers MR4 and MR5 fed from opposite ends of a 180-0-180-volt secondary of transformer T1. The centre-tap of this secondary is returned to V1 cathode. Thus if V1 were permanently conducting, alternate half-cycles of anode current would flow through, and energise, each relay. This condition applies when the regulator output is high, as explained later. Diodes MR6 and MR7 are connected across the relays to prevent chatter.

A cold-cathode trigger tube such as V1 cannot pass anode current unless a positive potential higher than a particular critical value is applied between its cathode and trigger electrode. It follows therefore that in this unit part of the pattern required can be achieved by maintaining the cathode-trigger potential below the critical value when the regulator output is low and above this value when the regulator output is high. When the regulator output voltage is normal, it is arranged that V1 conducts only when T1 secondary tapping 11 is positive with respect to tapping 9. The triggering circuit, stage (b), is used to achieve the necessary control.

4.4.4 *Triggering Circuit*

A composite voltage comprising a d.c. potential, a fixed a.c. ripple and a variable a.c. ripple is applied, via a feedback network, between the cathode and trigger electrode of V1. The d.c. potential is developed across R1, which is part of the voltage-sensitive circuit stage (a), described later. The fixed a.c. ripple is added to this d.c. potential by the inclusion of T1 secondary 1-2 in series, and the variable ripple is added by potential-



T1 secondary tappings	
8.9.10.11.	180-0-16-164 volts
1:2.	6 volts
12.13.	90 volts
R6	5Ω total tapped at 5% 70% 80% 90%
L1 – L18	r.f. suppression chokes

MR1. MR2.	STC Type Q8/5
MR3.	STC Type K 8/10
MR4. MR5.	STC Type 4205D–16H1–Z
MR6. MR7.	STC Type 4205D–4H1–Z
MR8. MR9. MR10.	INTERNATIONAL RECTIFIER Type SD92
MR 11.	INTERNATIONAL RECTIFIER Type 1Z6·8T5

Fig. 4.6 Mark-8P Control Unit

divider R2, the ends of which are connected across part of T1 secondary 8-9-10-11. The two ripple voltages are in phase and are positive-going when T1 tapping 11 is positive-going.

In the first instance it is convenient to ignore the action of the feedback network between the slider of R7 and the junction of R9 and C5, and to examine the action of the triggering circuit as the d.c. potential across R1 increases. The operation of the feedback network is discussed in Section 4.4.6.

Assume that the d.c. potential is so low that the composite voltage never reaches the critical value to trigger V1. This is the requirement during low regulator-output conditions.

As the d.c. potential increases, the positive peaks of the composite voltage reach the critical triggering value and V1 conducts. As already mentioned, the ripple component of the composite voltage is positive during those half-cycles in which tapping 11 of T1 is positive with respect to tapping 9. Thus V1 anode current energises relay 2RL, but no current passes through relay 1RL. This gives the pattern required when the regulator output is normal, that is, within the dead zone.

As the d.c. potential is further increased no change in the pattern is introduced until the composite voltage reaches the critical triggering figure during negative ripple half-cycles. The ripple voltage thus determines the width of the dead zone. Potential divider R2 can be adjusted to vary the width of this from about ±0·5 per cent to ±2 per cent of the nominal regulator output voltage. These values correspond to the positions of R2 in which no variable ripple and maximum variable ripple occur in the composite voltage.

When the d.c. potential is sufficiently high, V1 conducts during both half-cycles of ripple, and both relays are energised. This is the requirement when the regulator output is high.

4.4.5 Voltage-sensing Circuit

From the foregoing it can be seen that the voltage-sensing circuit, stage (a), must produce a d.c. potential across C1 which increases as the regulator output increases. Means of adjustment must also be provided so that the normal output from the regulator can be set.

A saturated thermionic diode, V2, is used as the voltage-sensing device. The anode current of the diode is a function of its filament temperature, and therefore depends on the filament voltage. In this unit the anode current of V2 is thus determined by the regulator output voltage via secondary 1-2 of T1 and an adjustment circuit comprising R3, R5 and R6. V2 anode is supplied from tapping 11 on T1 via MR3. (This supply is used also for a priming anode on V1.) The anode-current return path from the negative side of the anode supply is via load resistor R1 to the filament.

An increase in regulator output voltage causes a corresponding increase in V2 anode current and hence an increase in the voltage drop across R1. This voltage drop is the d.c. portion of the composite triggering voltage.

4.4.6 Triggering-Circuit Feedback Network

The feedback network comprising R7, R8, R9, C5, MR1, MR2, T1 secondary 12-13 and relay contacts 1RL-1 and 2RL-1 is included in the triggering circuit to ensure definite relay action for small errors in regulator output voltage, and also to prevent overshoot and hunting.

With the regulator output within the dead zone, 1RL-1 and 2RL-1 are both open and the feedback network has no effect on the triggering voltage. When the output falls outside the dead zone, 2RL is de-energised. 2RL-1 closes and the junction of C5 and R7 becomes negative with respect to the slider of R7. Because C5 is uncharged at the instant 2RL-1 closes, the junction of C5 and R9, and hence V1 trigger electrode, is driven towards negative; this ensures that V1 is cut off. As 2RL-1 remains closed while the regulator output is increasing, C5 charges via R9 and part of R8. The voltage drop across R9 due to the charging current is thus added to and aids the increasing triggering voltage and therefore compensates for the inertia of the moving parts of the control and regulating units.

A rise in regulator output from within the dead zone causes a similar feedback action to occur when 1RL-1 closes.

4.4.7 Overvoltage Protection Circuit

If a fault prevents the operation of relays 1RL and 2RL as the control motor runs towards the maximum output position, the regulator tends to produce a dangerously-high output voltage. The overvoltage protection circuit is included to prevent such an occurrence.

Transformer T2 primary is supplied from the output of the regulating unit and thus produces from its secondary winding a voltage which is proportional to the regulator output. This secondary voltage is rectified by MR8 and MR9 and applied to potential-divider chain R17, R18, R19.

Part of this voltage, tapped off by the slider of R18, is compared with a reference voltage derived from zener diode MR11. The difference voltage is applied between base and emitter of transistor TR1 which has relay 3RL in its collector circuit. R18 is adjusted so that with a regulator output voltage about 5 per cent above normal the difference voltage is sufficient to cause TR1 to conduct, if its collector supply is present, and to energise 3RL.

For the collector supply to be available, relay 2RL must be de-energised and 2RL-4 closed; this normally represents a low regulator output. Therefore a combination of 5 per cent overvoltage and 2RL-4 closed is a potentially-dangerous fault condition which is corrected by the operation of 3RL. Contacts of 3RL are arranged to energise the control motor to run towards the minimum regulator-output position and also to hold in 3RL. The control motor thus runs to the minimum output position, where its supply is interrupted by the limit-switch. Before normal operation of the regulator can be resumed it is necessary to disconnect the supply to the Mark-8P unit to allow the protective circuit to reset.

4.4.8 Setting-up Details

Setting-up details for the unit are given in an individual handbook supplied with each regulator by the maker. Some of these adjustments are critical. The components should therefore not be disturbed unless essential and then only if the maker's instructions are to hand.

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PART 3: PROTECTION OF POWER INSTALLATIONS

Important Note: The protective scheme for an installation is set up in consultation with the supply authority when the equipment is first commissioned. Subsequent changes may be made only on instructions from the appropriate Superintendent or specialist-department engineer. This statement must be treated as mandatory, to apply without exception

SECTION 1

INTRODUCTION

1.1 General

All electrical power-distribution networks require some form of automatic protection to reduce the risk of human injury and equipment damage under fault conditions. A fault may occur in the power-supply system feeding the network, in the network itself or in the connected load. Part 3 of this Instruction outlines some protective systems installed at transmitting stations and describes some of the practical equipment used. Further information on protection can be found in *The J. & P. Switchgear Book* and in relevant publications of the British Standards Institution.

1.2 Types of Fault

The two conditions against which protection is most usually provided are overcurrent faults and earth faults.

An overcurrent fault occurs when a circuit passes a current greater than it is designed to take. This may happen, for example, because of insulation breakdown between conductors or because of the connection of an excessive load.

An earth fault occurs when current flows to earth by an unintended path, and if of sufficient magnitude may also be an overcurrent fault. A small earth-fault current is known as earth leakage; some installations have earth-leakage alarm systems as well as or instead of earth-fault protection. There is no rigid dividing line between an earth fault and earth leakage, and the two terms are often used synonymously. In this Instruction, however, the term earth leakage means a low-current earth fault.

1.3 Requirements of a Protective System

The basic requirements of a protective system are that it must be able to:

detect a fault,

clear the fault detected by disconnecting it from the supply, and

operate only when required.

The first two requirements are sometimes met by using a separate device for each, for example a relay and a circuit-breaker, and sometimes by using a single device such as a fuse.

The choice of a particular protective system and of practical equipment depends largely on the point in the distribution network at which the protection is to be applied. This point determines three main factors which govern the choice. These are:

(a) normal working conditions,
(b) prospective short-circuit fault-current, and
(c) discrimination.

1.3.1 Normal Working Conditions

The main requirement under normal working conditions is that the equipment permits the *normal* current flow. A given current (e.g., 5 amperes) at an early point in the network may be well within the safe limit. The same current in a final sub-circuit may be many times greater than the normal, and may thus constitute an overcurrent fault which must be cleared. Thus, the protective system at the early point in the network must be relatively insensitive.

Transient overcurrent conditions, such as occur during the starting period of an induction motor, are regarded as normal and are usually allowed for by an operating delay in the protective system.

Because the normal current-flow to earth is generally small, earth-fault detecting devices can usually be made fairly sensitive, consistent with adequate stability.

Earth-fault protection is usually provided only at major distribution points such as main switchboards, or on installations such as mast-circuits which are particularly liable to earth-faults and where conditions are exceptionally hazardous. An earth fault on a subsidiary circuit can often be cleared by the overcurrent protection.

1.3.2 Prospective Short-circuit Fault-current

This, for a particular circuit, is broadly the current which would flow into a zero-impedance fault, and depends on the impedance of the supply. The preceding definition is an oversimplification of a complex concept. However, it is necessary to appreciate that the current due to a fault can in practice be many times the normal.

The disconnecting equipment in a protective system must be capable of interrupting the prospective short-circuit current. In some instances the same equipment also performs a closing duty; a fault may be present before power is applied, and if the equipment is closed on to the fault, it must still be capable of clearing it.

Severe electromagnetic and thermal stresses are imposed by high-fault-current operation, and the equipment must be able to withstand these stresses without suffering damage itself or causing damage to other parts of the installation. Repeated closure and fault-clearance in rapid succession can be dangerous, however, and must therefore be avoided.

1.3.3 Discrimination

This term implies the ability of a protective system to disconnect faulty circuits from a network without unduly disturbing healthy sections. Various forms of discrimination are possible. An example is given below.

Consider the network shown in Fig. 4.5, with a power-intake circuit-breaker A controlling the supply to busbars from which transmitters 1 and 2 are fed via circuit-breakers B and C. If the detection devices for all three breakers were identical, a fault in transmitter 2 would be detected by the A and C protective systems and could be cleared by tripping either breaker. If the fault tripped breaker A, transmitter 1 would lose its supply, causing an unnecessary break in service. The tripping of breaker A is therefore restrained so that B and C may clear faults in their local circuits.

SECTION 2

FUSES

2.1 Introduction

The most common form of protective device is the fuse. The requirements of a fuse for any given application must be considered in relation to the prospective fault-current and to the operation of the device in conjunction with other parts of the protective scheme.

Fuses can be either rewirable or non-rewirable. Both kinds are used in power distribution networks, and in this application the non-rewirable fuses are generally of the high breaking capacity (h.b.c.) type*, suitable for use in circuits with high prospective fault-currents. Preference for this type rather than rewirable fuses is almost general in respect of BBC distribution networks.

2.2 Fuse Characteristics

2.2.1 Fusing Factor

This is defined as the ratio, greater than 1, between the minimum current at which the fuse will rupture, and the maker's rating. The ratio lies in the range between 1·25 and 2·2, and is influenced by the type, situation and rating of the fuse. The fusing factor of an h.b.c. fuse can normally be specified fairly closely, but for rewirable fuses the ratio is less easy to determine.

2.2.2 Operating Time

The operating time of a fuse is a function of current, as indicated by the typical characteristic shown in Fig. 2.1. Ambient temperature affects the characteristic, and is one of the variables making difficult the specification for a rewirable fuse. However, for an h.b.c. fuse the characteristic normally remains within 5 per cent for ambient temperatures up to 25 degrees C.

The Fig. 2.1 curve shows an asymptotic condition for small overloads, and this can be a disadvantage if accurate discrimination is required. For such application an improvement is obtainable by use of an h.b.c. fuse with a dual element providing a short-circuit zone and a time-lag zone. To show the essential difference, Fig. 2.2 gives the typical characteristic for this type of fuse and also that for a standard fuse of the same rating.

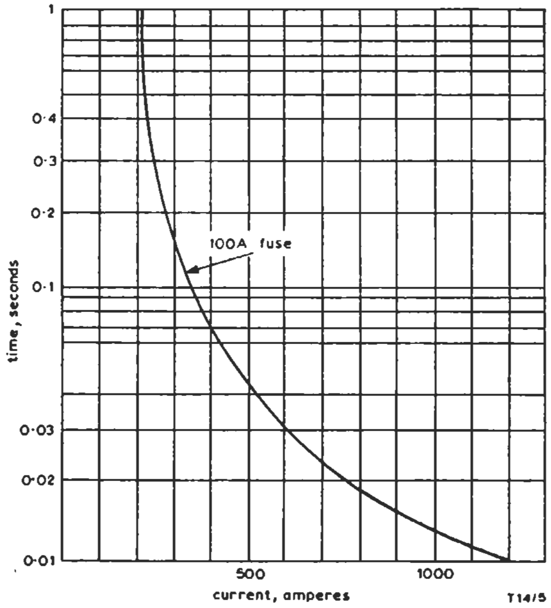

Fig. 2.1 Typical Time/Current Characteristic for an H.B.C. Fuse

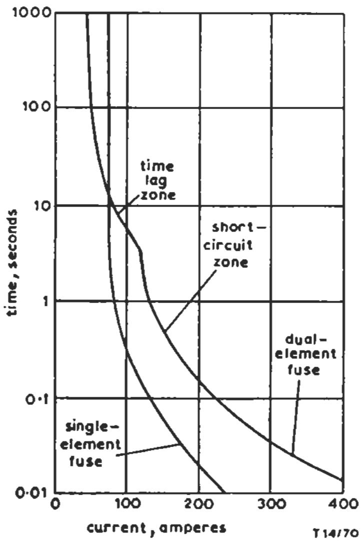

Fig. 2.2 Time/Current Characteristics of Dual-element and Standard H.B.C. Fuses

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* *High breaking capacity* (h.b.c.) is the term preferred in British Standards. A frequently-used alternative is *high rupturing capacity* (h.r.c.).

2.2.3 Rupturing Process

Rupture of a fuse involves two distinct processes. First there is melting of the element, and then establishment of an arc across the ends of the fused element. The energies dissipated during these processes are referred to as the pre-arcing energy, during melting, and the arcing energy, which flows until the arc is extinguished. Both quantities are proportional to (a) the square of the current I flowing, (b) the time t for which current flows, and (c) the resistance of the current path; for a given fuse these energies can be expressed in terms of I^2t.

The arc drawn across the ends of the fused element is a low-impedance path formed by ionised gases which briefly sustain the fault current. Under large fault-current conditions the energy level in the arc can be sufficient to maintain the ionisation unless some positive means of suppression is provided.

The h.b.c. fuse overcomes this problem, by providing rapid action with good arc-extinction at high currents. Usually the element is contained in an insulated housing filled with a finely-powdered non-conducting material. When rupture occurs, the energy in the arc raises the temperature within the cartridge sufficiently for the vapourised element and the powder to combine into a high-resistivity substance.

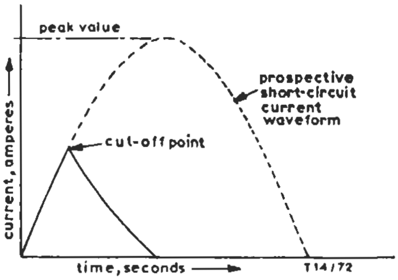


Fig. 2.3 Current Waveform illustrating Cut-off Characteristic of an H.B.C. Fuse

2.2.4 Cut-off

An h.b.c. fuse has the ability to interrupt a circuit before the peak value of a large prospective fault-current is reached. This cut-off property is due to the extremely-high level of energy available to rupture the element. The effect is illustrated by Fig. 2.3, but note that the cut-off point depends upon the rate at which fault current increases, and therefore upon prospective fault-current. The cut-off characteristics for a number of h.b.c. fuses are shown in Fig. 2.4.

By restricting fault currents to less than the possible maxima, the cut-off sets limits to mechanical and thermal stresses in associated conductors, so permitting economies in respect of conductor ratings.

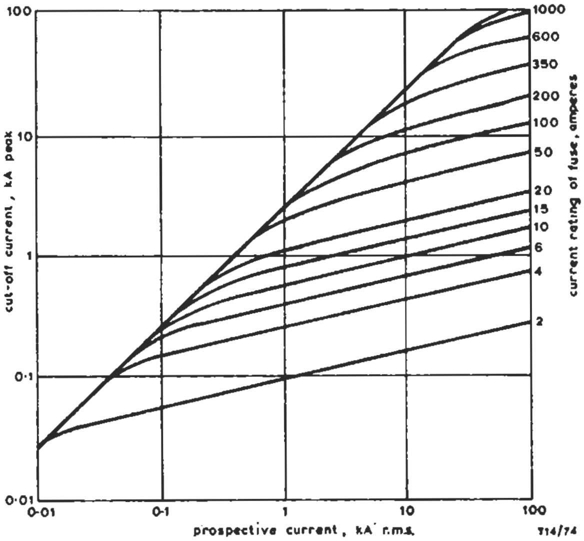


Fig. 2.4 Cut-off-current/Prospective-current Characteristics for Typical H.B.C. Fuses

2.3 Protection by Fuses

2.3.1 Overcurrent and Short-circuit Protection

From preceding explanation it is evident that the h.b.c. fuse gives protection against both moderate overcurrent faults and short-circuit faults. The fuse required for any given application necessitates detailed knowledge of a number of factors including the normal operating condition and the prospective fault-current at the point where it is fitted. Use of a fuse with a too-liberal rating or inadequate fault-handling capacity can be serious, because the risk of fire and personal injury is greatly increased. The warning note on page 1.1 is particularly relevant to fuses, in that their specification is the exclusive responsibility of specialist-department engineers. It is therefore essential:

(a) not to alter fuse ratings without authority;
(b) never to bypass a fuse, and;
(c) to investigate and clear a circuit fault before substituting a new fuse for one which has ruptured.

2.3.2 Discrimination

Fig. 2.5 shows a simple distribution network in which discrimination is required between a major fuse (A) and a minor fuse (B). The method of determining the relative fuse ratings depends upon the prospective fault-current. If this is low, the ratings are determined from the time/current characteristics of the fuses. If high, the operating times are so short that use of these characteristics is difficult. A more accurate method is to make the choice such that the pre-arcing time of the major fuse is always greater than the total operating time of the minor fuse. This selection is based on data of pre-arcing times and total I^2t values for various ratings. In general, a ratio of 2:1 between ratings is required to obtain satisfactory discrimination for high fault-currents.

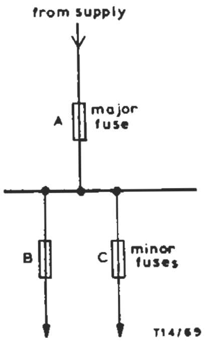


Fig. 2.5 Network to illustrate Discrimination

2.3.3 Coordination

This term denotes the combined use of h.b.c. fuses and some other protection device in what is effectively a single protective system. The application concerns circuit-breakers, particularly m.v. types in circuits which have high prospective fault-currents, and the object is to use switchgear economically. Although ordinarily ignored for Instruction purposes, the cost factor is a necessary part of the following explanation of a technique employed occasionally in distribution networks.

For the circuit-breaker, inclusive of the usual fault-detecting equipment, the advantages are that it can:

(a) be reclosed immediately after clearance of a non-sustained fault up to the limit of its breaking capacity;

(b) provide accurate protection against over-current faults;

(c) be operated in conjunction with an earth-fault protective system.

A disadvantage is that breakers become increasingly expensive as their breaking capacity is raised.

The advantages of h.b.c. fuses are that they:

(a) have high breaking capacities;

(b) can restrict fault current by virtue of their cut-off characteristic;

(c) are relatively inexpensive.

Disadvantages are the time needed to fit new fuses subsequent to fault clearances, and that they are unable to give protection against small earth-faults.

The coordination technique provides complementary association of these advantages. By relying on their cut-off property, the fuses can be the means of imposing a limit on the fault current which can flow in the circuit. This maximum can be much smaller than the prospective fault-current, and consequently it is possible to employ a circuit-breaker with a breaking capacity which otherwise would be inadequate. In any given instance the fuse rating has to be a compromise value, such that it offers the requisite protection but leaves the breaker and its fault-detecting equipment to deal with overcurrent and earth-fault conditions of a less drastic nature.

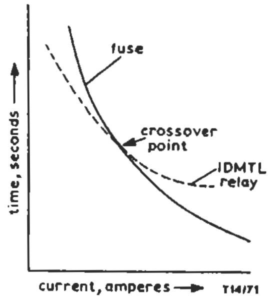


Fig. 2.6 Characteristics to illustrate Coordination

The overall characteristic of a coordinated system is derived from a composite graph showing the characteristics of the constituent devices. Fig. 2.6 is an example, relating typical curves for an h.b.c. fuse and a fault-sensing relay of a type commonly used with circuit-breakers; see 4.3.2. This diagram makes clearly evident the sharing of circuit interruption between the breaker, for comparatively small fault currents, and the fuse, when fault current exceeds the cross-over value.

PART 3: PROTECTION OF POWER INSTALLATIONS

PART 4: MISCELLANEOUS EQUIPMENT

SECTION 4

FAULT-DETECTING DEVICES

4.1 Introduction

The function of a fault-detecting device is to identify the presence of an abnormal condition, and either to remove this condition, e.g., by tripping a circuit-breaker, or to give an indication or alarm.

This Section provides an introduction to the concepts of fault detection and gives details of practical equipment based on these. No attempt is made to describe all the devices met in practice, and the descriptions are therefore limited to those which exemplify standard features. Details of particular items not covered can often be found in makers' handbooks.

4.2 Requirements

Detecting devices must be stable under normal working conditions, including transient overloads. To achieve this stability, their response to fault conditions is delayed. The delay decreases as the fault current increases, but any current greater than a fixed minimum causes operation if it persists longer than its corresponding delay time. The *inverse time lag* characteristic provided is chosen after taking into account the fault current-time product which can safely be allowed and the requirements of the overall protective scheme. A typical characteristic is shown in Fig. 4.1.

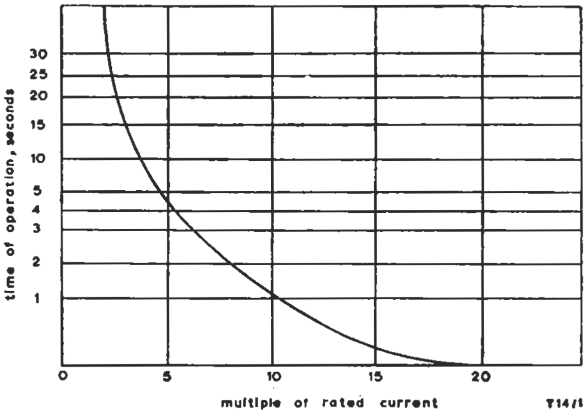


Fig. 4.1 Typical Time-lag Characteristic

Where discrimination between protective systems in cascade is required, it is often desirable that the associated detecting devices should have a definite minimum operating time, or *D.M.T.* This should be nominally independent of the magnitude of the fault level and is often provided in devices already

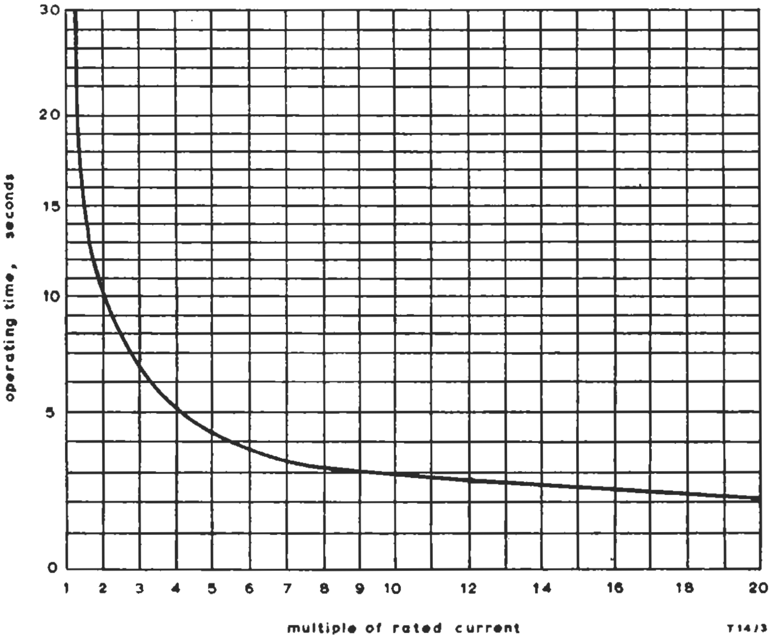


Fig. 4.2 Typical I.D.M.T.L. Characteristic

possessing an inverse time lag, to give an inverse time lag with definite minimum, or *I.D.M.T.L.* characteristic. A typical example is shown in Fig. 4.2. To achieve a true D.M.T. together with sufficient stability of operating characteristics, it is normally necessary to use some form of relay in conjunction with a shunt-trip arrangement.

4.3 Practical Devices

4.3.1 Direct-acting Trip Coils

One of the simplest forms of detecting device is the series-connected direct-acting trip coil incorporated in a circuit-breaker.

Although the series-connected trip coil provides adequate protection in certain circumstances, its application is somewhat restricted. In circuits where the normal current is large it is difficult to produce a trip coil of sufficient cross-section to carry the possible fault current. Conversely, where the current at which the device is required to operate is low, the coil must have a large number of turns if it is to produce sufficient force to operate a tripping mechanism; such a coil is likely to be subjected to unduly heavy electrical, thermal and mechanical stresses on the passage of short-circuit currents.

A convenient solution is found by arranging for the device to be operated via a current-transformer. This enables an optimum size and design of coil to be produced which can be used for a wide range of normal currents by suitably choosing the turns ratio of the current-transformer. In addition the transformer can be designed to saturate at some selected value of overcurrent and thereby protect the coil from the effects of short-circuit currents in the main circuit.

A further disadvantage of direct-acting trip coils is that they are unable to provide a sufficiently accurate time delay for discriminative tripping under heavy overload conditions. For this reason the use of relays is normally preferred.

The required delay in operation can be achieved in a number of ways, but only three of the more common are dealt with here.

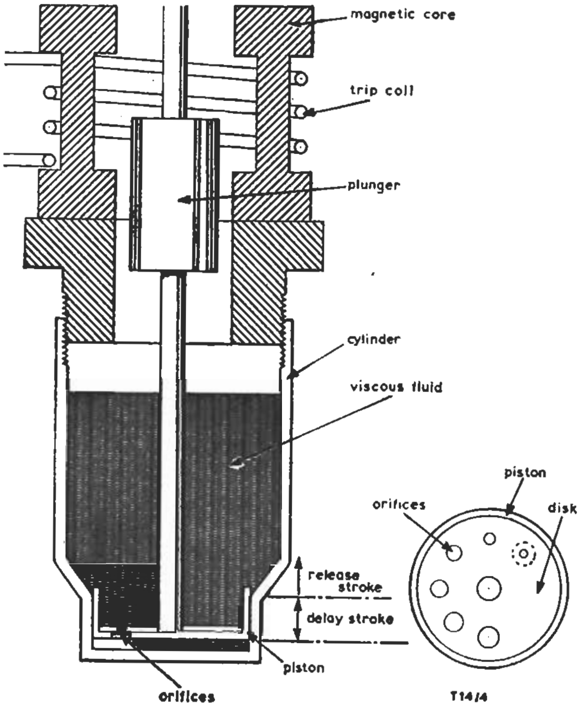


Fig. 4.3 Direct-acting Trip Coil: Dashpot Arrangement

(*a*) *Hydraulic Systems*

These usually comprise a dashpot and piston arrangement, similar to that shown in Fig. 4.3, in which the piston forms part of the breaker tripping mechanism, and its movement is retarded by a viscous fluid in the dashpot. The piston is connected to a plunger which lies in a magnetic core on which the trip coil is wound, and when this coil is sufficiently energised the plunger moves into the core. The rate at which the plunger and piston move is determined by the rate at which the fluid can flow through an orifice in the piston. A disk covers the upper face of the piston and contains a series of orifices of graded size, any one of which can be superimposed on the orifice in the piston and thereby provide different degrees of delay. The internal diameter of the upper part of the dashpot is enlarged so that, when the piston reaches this part, the retarding effect of the fluid is reduced and the mechanism can move more rapidly and acquire sufficient momentum to complete the tripping action.

The fault level at which the device operates is determined by the depth of initial insertion of the plunger into the core of the trip coil.

(*b*) *Fuses*

Fuses have an inherent delay between overloading and rupture, and this is often utilised to secure conditionally deferred operation of protective devices. The delays are a function of their time/current characteristics, explained in Section 2 and exemplified for a typical h.b.c. fuse by Fig. 2.1.

Probably the most common application is found in the parallel combination of fuse and trip coil, as in Fig. 4.4. Ordinarily the fuse carries nearly all the circuit current, but if a fault causes its rupture, then all current is diverted to the coil and tripping action is initiated.

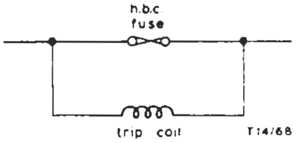


Fig. 4.4 Time-delay Arrangement using H.B.C. Fuse

(*c*) *Thermal-delay Units*
These units usually depend on a bimetal strip which is bent by the heating effect of a fault current. The units are normally used in conjunction with a trip coil in a similar manner to a fuse.

4.3.2 Fault-sensing Relays
Many types of fault-sensing relay have been developed for various applications, but most operate on similar principles and contain common basic elements.

In most instances the relay is energised via a current-transformer, with its primary in the circuit to be protected. Thus a standard relay wound for a particular operating current can be used over a wide range of primary currents by choosing a suitable current-transformer ratio. The secondary rating of the current-transformer must always match the relay rating. This is usually 5, 1 or 0·5 amperes and is indicated on the relay nameplate as shown in Fig. 4·9.

The coil of the relay is tapped to allow the operating current to be varied, the tapping points being usually taken to a plug-bridge to simplify selection. The tappings are marked in terms of the nominal percentage of rated current which can flow without the relay operating. Because of bearing friction, however, a relay may not operate until the current reaches about 1·3 times the nominal. This ratio may be compared with the fusing factor of a fuse: see 2.2. With a 500/5-ampere current-transformer and a plug setting of 50 per cent, a 5-ampere relay might thus operate with about 500 × 0·5 × 1·3, i.e. 325, amperes in the main circuit.

As mentioned under heading 4.2, it is often necessary to use relays in discriminatory protective schemes, because their time/current characteristics can be closely controlled and they can be made to have a definite minimum operating time. With a suitable design, these properties can be retained even under extremely high fault-current conditions.

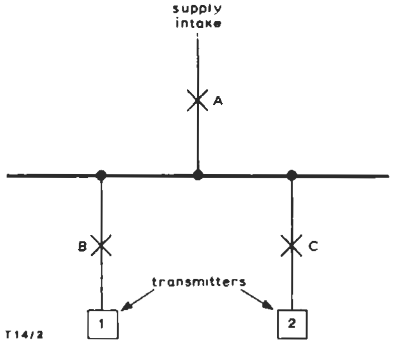


Fig. 4.5 Simple Schematic to illustrate Discrimination

In connection with the network of Fig. 4.5 such relays can provide the kind of discrimination discussed in 1.3.3. The total minimum discrimination time between the operation of breakers C and A is generally made about 0·4 second. Thus breaker A is provided with an I.D.M.T.L. relay adjusted so that, under any fault condition, the tripping time is at least 0·4 second greater than that for breaker C, which can itself be operated by a direct-acting trip coil. Fig. 4.6 shows the characteristics of a suitable relay and trip coil. One method of obtaining the required characteristics is indicated in the following description of a typical I.D.M.T.L. relay.

4.3.3 I.D.M.T.L. Relay Type PBO
This relay operates on the induction-disk principle and consists essentially of a metal disk which can rotate between the poles of a pair of electromagnets. The disk spindle carries a moving contact which bridges two fixed contacts when the disk has rotated through a predetermined angle. Fig. 4.7 shows a relay of this type and its internal connections are indicated in Fig. 4.8.

The upper electromagnet has two windings, one of which is tapped and fed from the current-transformer via the plug setting bridge. The other winding is energised by induction and feeds the lower electromagnet. The alternating flux from the two electromagnets gives rise to a torque, and the disk tends to rotate. A spiral spring prevents the disk from rotating until the torque is sufficiently high. The angular speed of the disk is then a

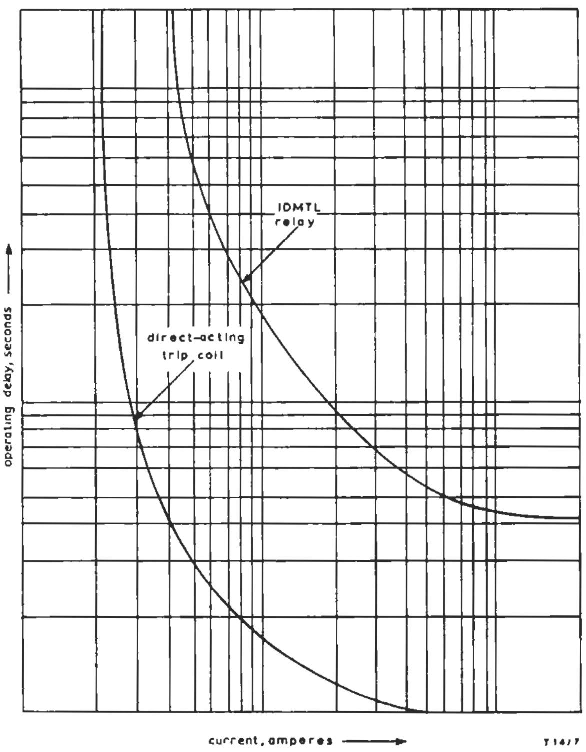


Fig. 4.6 Time/Current Characteristics of Devices suitable for use in Discriminating Circuits

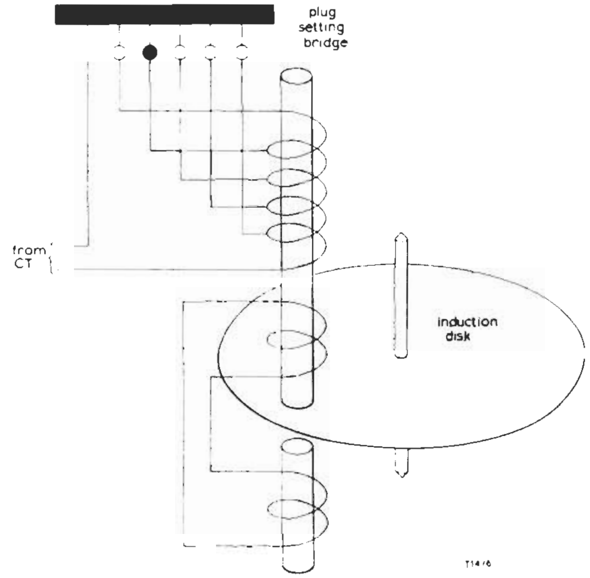
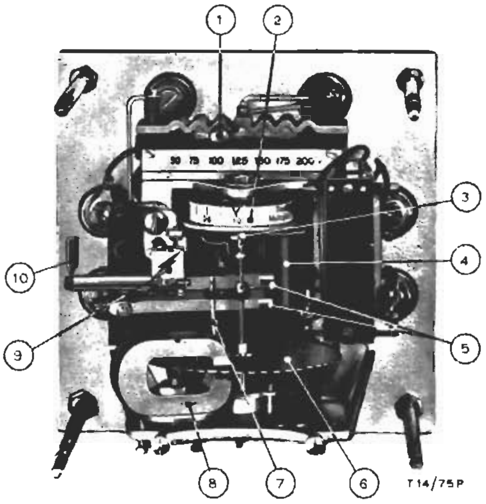


Fig. 4.8 I.D.M.T.L. Relay Type PBO: Basic Arrangement



1. Plug setting bridge
2. Time-multiplier adjuster
3. Resetting spring
4. Upper electromagnet
5. Fixed contacts
6. Disk
7. Moving contact
8. Damping magnet
9. Flag indicator
10. Flag-indicator resetting lever

Fig. 4.7 I.D.M.T.L. Relay Type PBO: Construction function of the operating current and thus provides the required inverse time/current characteristic.

The definite minimum time requirement is met by arranging that the upper electromagnet saturates at a predetermined current, there being no significant increase in disk speed beyond the saturation point. Provision is made to adjust the definite minimum time setting by restricting the angle through which the disk must move before the contacts are bridged. The adjustment is made by turning a time multiplier wheel, which is calibrated in fractions of the maximum D.M.T. and carries with it a stop against which the disk resets under the action of the spring.

The time/current characteristic of the relay is engraved on its nameplate. An example is given in Fig. 4.9. This shows the operating delay, with a time multiplier setting of unity, for overcurrents up to twenty times that given by the plug setting and the current-transformer primary rating. To use the curve, it is necessary to convert actual overcurrent values to Plug Setting Multipliers, given by:

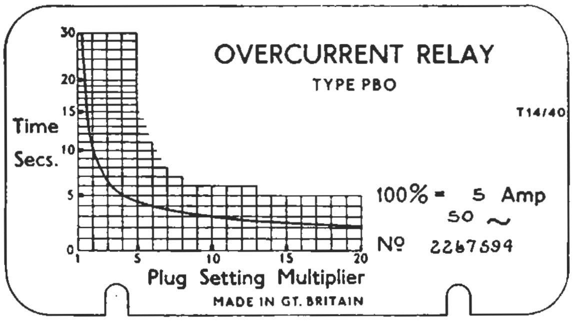


Fig. 4.9 I.D.M.T.L. Relay Type PBO: Nameplate, showing Operating Characteristic

$$\text{Plug Setting Multiplier} = \frac{(\text{Overcurrent Value})}{\left(\begin{array}{l}\text{Current Rating}\\ \text{of C.T. Primary}\end{array}\right)} \times \frac{100}{\left(\begin{array}{c}\text{Plug Setting}\\ \text{per cent}\end{array}\right)}$$

To take an example, assume the following figures:

Overcurrent Value = 2,500 A
C.T. Primary Rating = 500 A
Plug Setting = 50 per cent

Then

$$\text{Plug Setting Multiplier} = \frac{2{,}500}{500} \times \frac{100}{50} = 10$$

The corresponding delay time can be taken from the curve and converted to actual delay time by multiplying by the time multiplier setting.

The accurate working range of the curve for discriminatory purposes is regarded as being between plug setting Multiplier values of 2 and 20. Below this the operating time may be affected by bearing friction, but a measure of protection is still retained.

A number of relays are often connected in the tripping circuit of one breaker. To assist in identifying the source of a tripping operation, each relay is fitted with a mechanical flag indicator. This is actuated by the disk movement just prior to the bridging of the trip contacts.

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SECTION 5

OVERCURRENT AND EARTH-FAULT PROTECTIVE SYSTEMS

5.1 Introduction

This Section deals with some of the more common protective systems for overcurrent and earth faults. These faults are discussed briefly in 1.2, but here it is appropriate to repeat two statements under that heading. One is that an earth fault is often severe enough to constitute an overcurrent fault. The other is that in this Instruction the term *earth leakage* is used only in the particular sense of denoting a low fault-current condition, possibly of a persistent nature.

5.2 Requirements

The main requirements of protective systems are specified in 1.3, and those relating to overcurrent need no further explanation.

Earth-fault protective systems can be arranged to offer either restricted or unrestricted operation. There are no formal definitions for these terms, but broadly the *restricted protection* is limited to a particular part of the network, depending on the position of the protective apparatus, whereas *unrestricted protection* may extend over the whole network.

Where people can come into contact with metalwork liable to carry earth-fault current, it is essential that an associated protective system acts before the potential on the metal work exceeds a low and safe figure.* The development of a potential is unavoidable because the metalwork itself must have some impedance, and the earth to which it is bonded is inevitably inferior to a perfect (zero impedance) earth. Given a low-impedance earth, the earth current has to reach a fairly high value before the potential becomes appreciable, and the associated protective system is therefore designed to isolate the network when the current becomes excessive. Such systems are usually referred to as *current-operated.* Where only a high-impedance earth is available, the protective system is designed to isolate the circuit when the potential of the metalwork exceeds the value regarded as an acceptable maximum. This sort of system is usually known as *voltage-operated.*

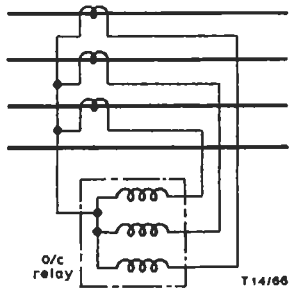

Fig. 5.1 Overcurrent Protective System for Three-phase Four-wire Distribution

5.3 Practical Systems

5.3.1 Overcurrent Systems

Overcurrent systems for single-phase networks may use either (a) a direct-acting trip coil (series-connected or fed through a current-transformer) or (b) a shunt-trip coil operated via a relay.

The systems to protect three-phase four-wire circuits are essentially triplicate forms of the arrangement used with single-phase circuits. Fig. 5.1 shows a typical configuration using current-transformers to feed the individual coils of an overcurrent relay. On three-phase three-wire circuits it is possible to obtain full protection by employing only two overcurrent devices, as in the motor-starter circuit illustrated in Fig. 5.2. This method has a wide application and is not confined to direct-acting trip coils.

The current-transformers of an overcurrent protective system are often utilised also in connection with earth-fault equipment.

5.3.2 Earth-fault Systems

One of the simplest means of detecting earth faults is the so-called core-balance system. This

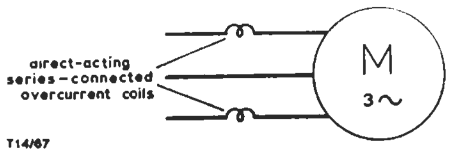

Fig. 5.2 Overcurrent Protective System for Three-phase Three-wire Distribution

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* The maximum recommended in B.S.I. publication CP 1013 (Earthing) is 40 volts r.m.s.

employs a magnetic core which surrounds the power-circuit conductors and carries a winding (effectively a secondary) connected to a relay. Operation is based on the fact that the vector sum of currents in a healthy network is zero. Therefore the flux induced in the magnetic core is zero provided all conductors, including a neutral where used, pass through the core.

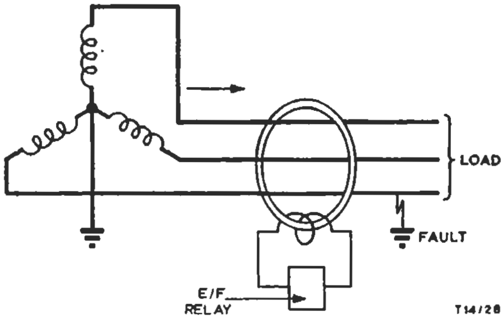


Fig. 5.3 Core-balance Earth-fault Protective System

Fig. 5.3 is a semi-pictorial diagram of the core-balance system for a three-phase three-wire network. If a fault develops on the load side of the core-balance transformer, the fault current does not return via the core. Consequently the core produces an out-of-balance flux, which promotes a flow of secondary current and operation of the relay if the fault current exceeds a predetermined value.

The core-balance transformer, essentially a single current-transformer with several primary windings, is used to only a limited extent because greater flexibility is possible with current-transformers on individual power-circuit conductors. The separate current-transformers can be combined into various arrangements to provide overcurrent protection and metering facilities, where required, in addition to earth-fault protection. The equivalent of the core-balance system in Fig. 5.3 is as shown in Fig. 5.4. Operationally this differs in the minor respect that energising of the relay results from unbalance of the currents contributed by the three transformers, which are said to be *residually-connected.*

Full earth-fault protection for a network supplied from a star-connected source can be obtained by using a relay fed from a single current-transformer in the earth connection from the star-point; see Fig. 5.5. This protection is unrestricted, because fault current from any point in the network must pass through the star-point connection.

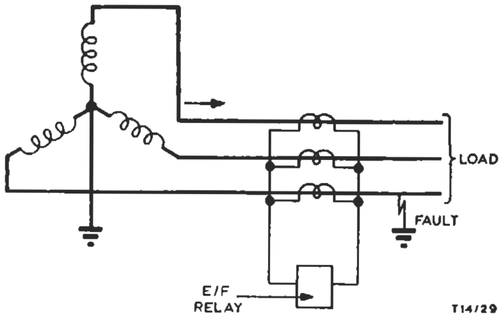


Fig. 5.4 Earth-fault Protective System using Residually-connected Current-transformers

The system for a three-phase three-wire network applies equally to a four-wire network provided the current-transformer is in the neutral-to-earth connection. This arrangement can be made very sensitive and is often employed for the purpose of providing earth-leakage alarm and indication facilities.

Restricted earth-fault protection may take a variety of forms. For example, a three-phase three-wire circuit could be fitted with a residually-connected combination of four current-transformers and one relay, as shown in Fig. 5.6. Note the interesting feature that restriction is imposed by a system which combines the two forms of unrestricted protection illustrated by Figs. 5.4 and 5.5. Suppose a fault occurs on the source side of the point where the line current-transformers are placed. The fault current flows through only one current-transformer, that in the star-point earth connection, and the resultant *spill* current energises the relay. If, however, the fault is on the load

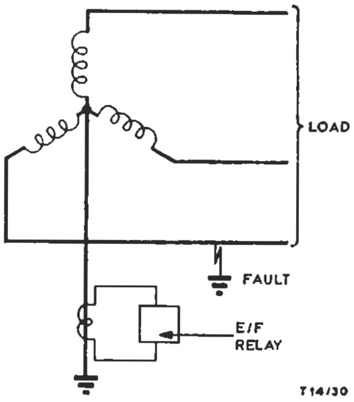


Fig. 5.5 Unrestricted Earth-fault Protective System using Single Current-transformer

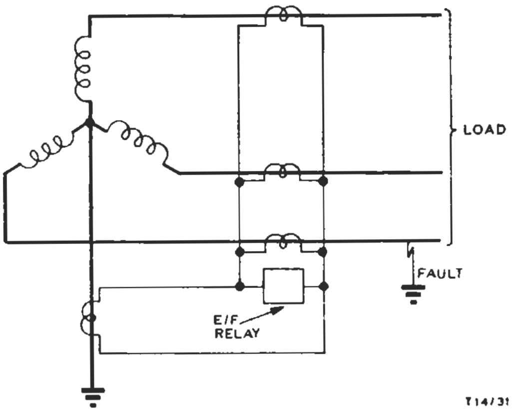


Fig. 5.6 Restricted Earth-fault Protective System for Three-phase Three-wire Distribution Network

side of the line current-transformers, the fault current passes through two current-transformers, one in the star-point connection and the other in the affected line, and therefore the system remains balanced. Thus protection is restricted to the source windings and that part of the network up to the position occupied by the line current-transformers.

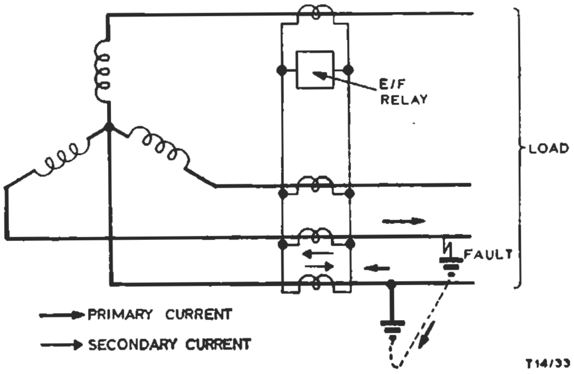


Fig. 5.7 Restricted Earth-fault Protective System for Three-phase Four-wire Distribution Network (Neutral Earthed on Load Side of Current-transformers)

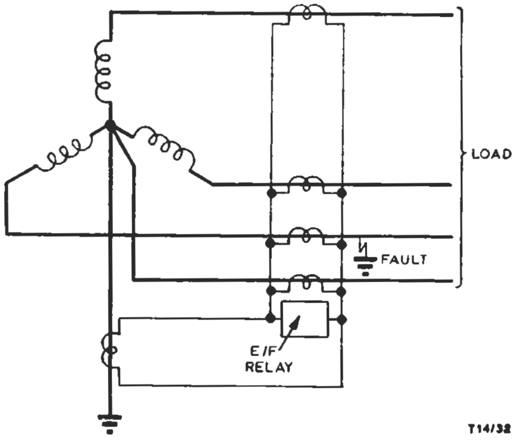


Fig. 5.8 Restricted Earth-fault Protective System for Three-phase Four-wire Distribution Network (Neutral Earthed on Source Side of Current-transformers)

Where three-phase four-wire networks are concerned it is necessary to introduce an extra current-transformer in the neutral conductor, thereby allowing for possible unbalance of loading. By residually connecting all four transformers, unrestricted protection is given provided the neutral is earthed on the source side of the neutral current-transformer; operation is similar to that of the system depicted in Fig. 5.4. If, however, the neutral is earthed on the load side of the neutral current-transformer, the same arrangement provides restricted protection; see Fig. 5.7 and compare it with Fig. 5.6.

Fig. 5.8 shows how five current-transformers can be used for restricted protection when the neutral is earthed on the source side of the neutral current-transformer. This is simply the four-wire network version of the system shown in Fig. 5.6.

SECTION 6

ZONE PROTECTION SYSTEMS

6.1 Introduction

Zone protection systems are characterised by an ability to respond sensitively to faults affecting one part of a power circuit while remaining immune from operation for faults elsewhere. The zone to which protection is confined may be an alternator and associated conductors local to the machine, but it could equally well be the whole of a very lengthy power feeder. In distinction from *zone faults*, which is self-explanatory, the term *through-faults* is used to refer to faults on the load side of the protection zone.

Further description explains the general principles and provides information about typical practical systems in common use.

6.2 Principles of Operation

The various systems, some proprietary, function on the principle that normally there is identity of the current at the entry and exit points of a given zone; see special exception mentioned later. Thus by comparing the current at these extremes it is possible to detect disparities resulting from flow of current into faults on the intervening circuit. Comparisons are made with the aid of current-transformers, which in most instances are identical. If, however, a power transformer is inside the protection zone, its ratio has to be taken into account and consequently the current-transformers have different ratios suited to production of similar currents from their secondaries.

Fig. 6.1 shows the arrangement to protect a single-phase machine. This is known as a circulating-current system, because the current-transformer interconnection promotes a flow of current around the secondary circuit. The relay, being connected between points which are at equipotential while the transformers contribute equal currents, is normally unenergised. This condition is not disturbed by a through-fault, symbolised in Fig. 6.1(a), because that increases the current-transformer outputs equally. With zone faults the current from the transformer at the source end is increased to a degree depending on the severity of the fault, and consequently the relay is energised as indicated in Fig. 6.1(b).

The method can be extended to three-phase working by using a pair of current-transformers and a relay on each phase, but this basic approach has a number of disadvantages. For example, where long feeders are concerned the requisite pilot wires to interconnect the individual pairs of current-transformers would involve considerable expense. It is therefore usual to combine the current-transformer outputs in a summation transformer at each end of the zone, thus reducing the number of pilot wires to two.

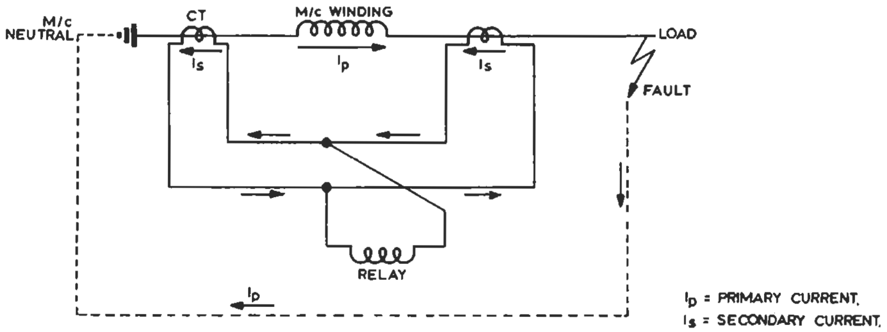
One general problem is the virtual impossibility of producing pairs of current-transformers which maintain exact equality of output over a wide range of primary current. Because discrepancies increase with the magnitude of primary current, this difficulty is relevant particularly to possible system operation in the event of serious through-faults. As a counteracting measure, the stability of a system is often improved by employing some form of biasing. This is usually arranged to increase as the through-current increases, so that the greater the current the lower is the sensitivity.

6.3 Practical Systems

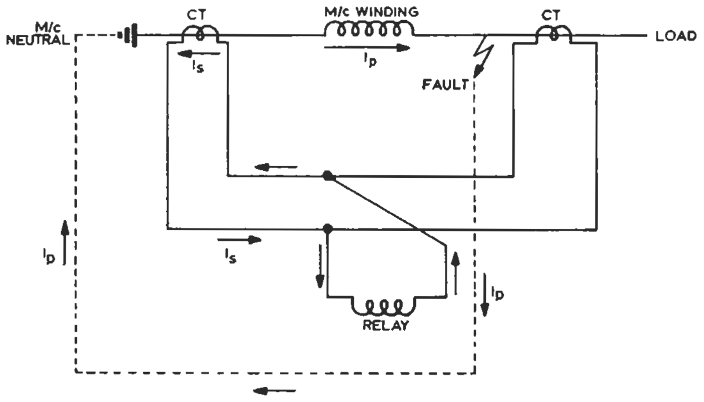
Basic three-phase protection is given by the Merz-Price circulating-current system described in 6.3.1. There are a number of proprietary variations designed to overcome disadvantages referred to previously, and the 'Simtrip' feeder-protection system described under 6.3.2 can be regarded as a representative example. Information about other commercial systems is readily obtainable from maker's handbooks and also from Station drawings at sites where they are installed.

6.3.1 Merz-Price Protection

Fig. 6.2 shows the Merz-Price system applied to an alternator. A four-wire pilot circuit is sufficient to link the star-connected secondaries of the two groups of current-transformers. The relay coils, also star-connected, bridge this circuit and are individually able to operate trip-circuit contacts. These contacts and the associated circuits have differing arrangements, but essentially their purpose is to suppress the alternator output as rapidly as



(a) Healthy or Through-fault Condition



(b) Zone-fault Condition

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Fig. 6.1 Principle of Circulating-current Protective System

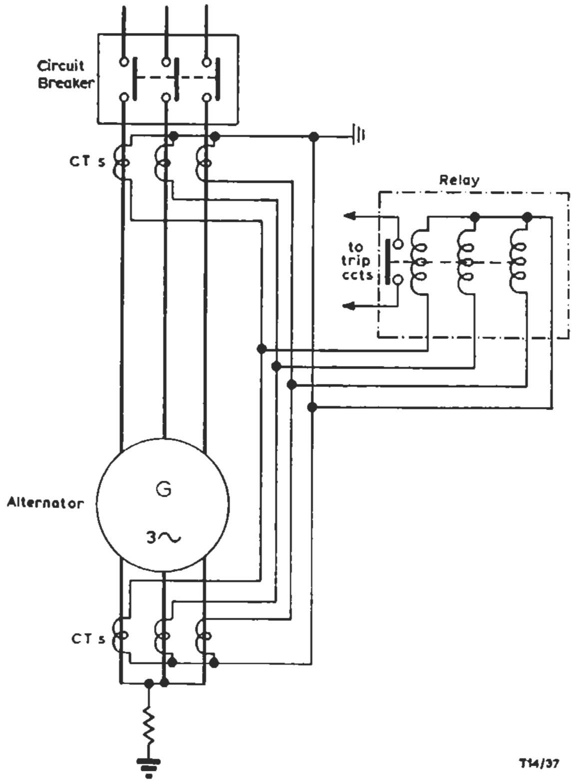

Fig. 6.2 Merz-Price Circulating-current Protective System

possible and to make a supply to trip the circuit-breaker. Methods of suppression also differ, one widely-used means being disconnection of the excitation supply. In isolating the fault, the tripping of the breaker is especially important where machines are working in parallel.

To achieve optimum stability with this system it is necessary to match the current-transformers as closely as possible and to undertake a relay adjustment for the elimination of any residual unbalance.

6.3.2 'Simtrip' Feeder-protection System

This scheme is in effect a single-phase circulating-current system incorporating summation transformers in order to provide three-phase protection. The transformers are embodied by induction-disk relays, placed one at each end of the feeder and intended for simultaneous tripping of local circuit-breakers. The system arrangement shown in Fig. 6.3 includes circuit details of one of these identical relays.

Each of the auxiliary transformers T1 and T2 has two primary windings, N_R and N_D, and a secondary which supplies one of the coils providing magnetic fields for the induction disk. The primary windings of T1 are connected to produce opposing fluxes, whereas those on T2 are arranged to aid each other. The current in the relay coil fed from T2 is phase-shifted through 90 degrees by a CR combination.

Normally, with equal outputs from the summation transformers, there is a circulating current I_R energising the N_R windings of both auxiliary transformers. With this condition the N_D windings do not carry current. The resultant outputs of T1 and T2 energise the separate relay coils, and they produce a restraining torque on the disk. This torque depends on the value of through-current, thereby providing an inherent bias feature.

When a zone fault develops, there is a flow of spill current through the N_D windings. If this current is large enough for the ampere-turns product of the N_D windings to exceed that of the N_R windings, the output of T1 is phase-reversed. Hence the direction of torque is reversed and relay operation occurs through rotation of the disk.

The basic sensitivity of the scheme depends upon the turns ratio of N_D to N_R, but some variation of sensitivity is possible by alteration of summation-transformer tapping connections and by disk control-spring adjustment. The variable resistors identified as pilot-wire compensators permit adjustment giving simultaneous tripping at both ends of the feeder.

See overleaf for Fig. 6.3.

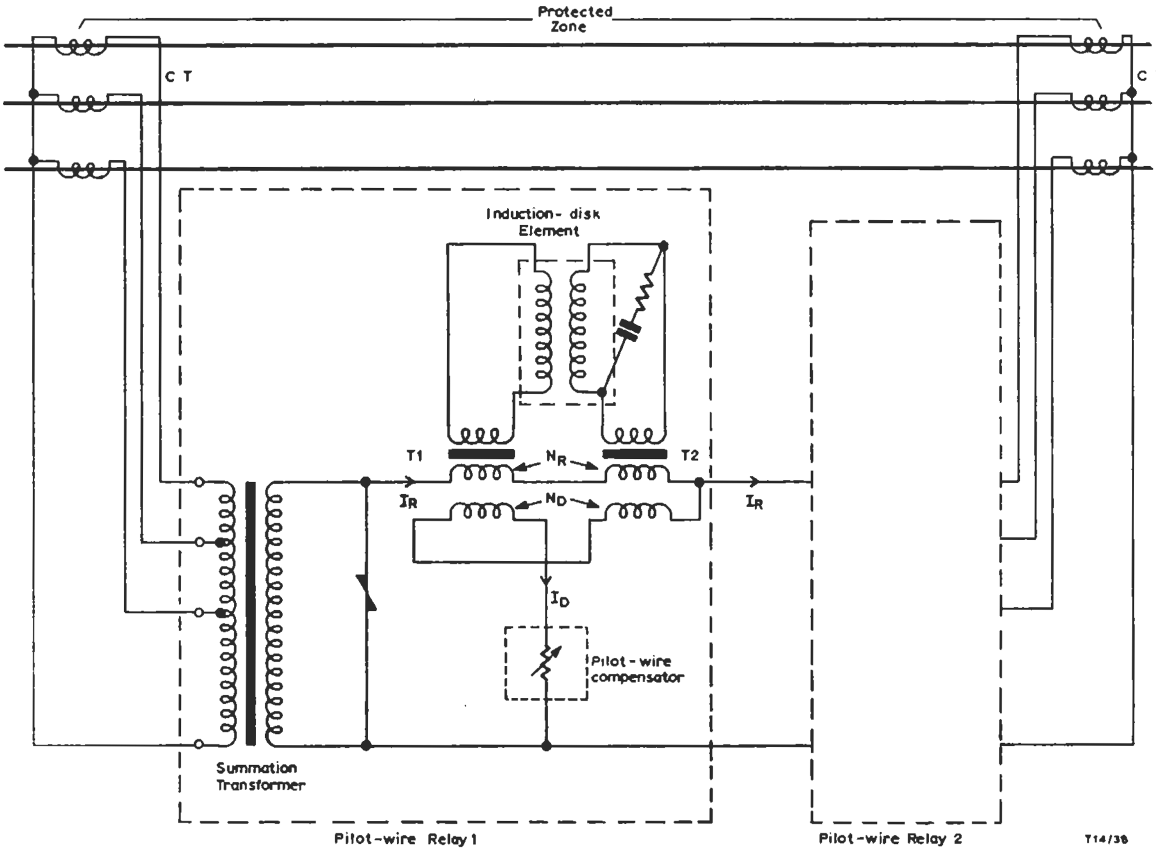

Fig. 6.3 Simtrip Feeder-protection System

SECTION 7

PROTECTIVE AUXILIARIES

7.1 Buchholz Relay

7.1.1 Protection of Oil-cooled Transformers

Oil-cooled transformers present a special problem because they are liable to faults which in their early stages are difficult to detect using the standard earth-leakage and overcurrent systems. These faults can cause more serious damage if allowed to persist and special equipment has been developed to detect them. Typical examples of such faults are local overheating of windings, short-circuited core laminations and faulty core-bolt insulation. All these conditions cause overheating, which produces gas bubbles in the oil. This effect is used to operate a Buchholz relay.

The Buchholz relay operates when an accumulation of gas lowers the oil-level in its housing. A moderate fall in oil-level, caused by an incipient fault, operates an alarm system. A greater fall causes interruption of the power supply to the transformer. A sudden severe fault, accompanied by the rapid generation of gas, causes oil to surge through the relay. The flow of oil is directed at a pivoted baffle plate and trips the circuit-breaker immediately.

7.1.2 Buchholz Relay

The essential features of a Buchholz relay, as made by English Electric Co. Ltd., are shown in Fig. 7.1. The relay housing is fitted in the pipe which connects the transformer tank to the oil expansion-chamber, or conservator. The housing contains two closing mechanisms, each comprising

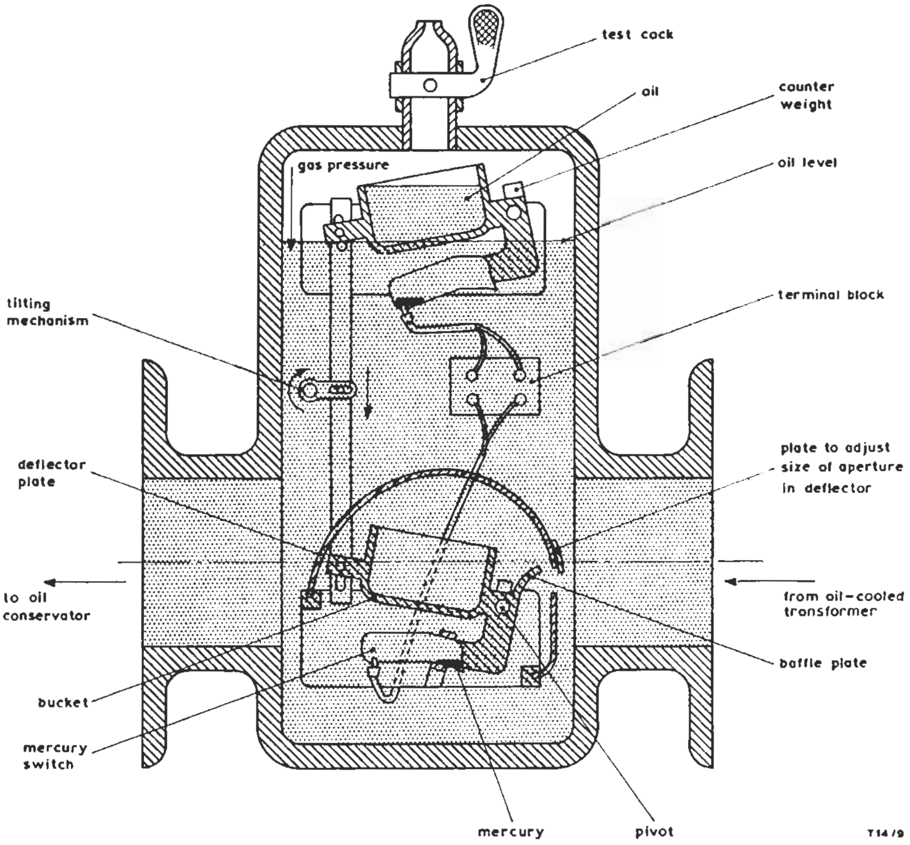

Fig. 7.1 Buchholz Relay

a pivoted arm with an aluminium bucket at one end and a counterweight and a mercury switch at the other. Leads from the switches are taken to a terminal block.

In both assemblies, the counterweight tilts the mechanism to the position shown. This condition exists both with the housing completely filled with oil ready for service, and with the housing including the buckets completely empty.

When a slight fault occurs on the transformer, small gas bubbles are generated and some of these, while passing from the transformer to the conservator, become trapped in the top of the relay housing. As gas accumulates in the relay, the level of oil is forced down, exposing the upper bucket. The weight of the oil in the bucket and the reduced upthrust of flotation together cause the whole assembly to tilt. This closes the mercury switch in the alarm circuit. If the fault is not cleared, the oil-level continues to fall until the lower bucket-assembly is exposed and operates a tripping circuit to isolate the transformer.

When a sudden serious fault occurs, the oil surges through the relay and impinges on the baffle plate fitted to the weighted end of the lower bucket assembly; this causes the assembly to tilt and operate the tripping circuit as before.

The relay is provided with a simple mechanical arrangement to enable the operation of the electrical circuits to be checked. A small shaft is connected to a mechanism which, when rotated, causes the upper and lower assemblies to tilt simultaneously. The shaft protrudes through an oil-tight gland into the terminal box, and is held by a locknut which also ensures a positive oil-seal.

Although the tilting arrangement obviates the necessity of pumping air through the relay to check its electrical operation, a test-cock is provided on the top of the housing to allow a functional check to be carried out if required; this cock is also used to release accumulated gas. A second test-cock is provided for checking the action of the surge assembly. Windows for checking the oil-level are fitted on both sides of the relay.

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PART 4: MISCELLANEOUS EQUIPMENT

SECTION 1

CONTROL OF VENTILATION LOUVRES

1.1 Introduction

The air-flow through a ventilated area is often controlled by the use of one or more sets of louvres or 'dampers'. In simple systems, the angular position of the louvres is set manually, but it is often desirable to provide automatic regulation of the air flow. This can be achieved by operating the louvres via a motor which is controlled by a sensing device in the ventilated area. At transmitter sites it is usually the temperature of the air which requires to be regulated, and a heat-sensitive controlling device (or thermostat) is therefore used.

A simple form of automatic control is one in which the louvres are fully opened when the temperature exceeds a set level; and fully closed when the temperature falls below the level desired. This is known as a two-position or *On/Off* control system, and is adequate where close control of temperature is not required. The control of temperature within narrower limits can be achieved by the use of more complex systems, some of which will be described.

1.2 Proportional Control

1.2.1 Principles of Operation

In this system the angular position of the louvres is a function of the difference between the actual and desired air temperatures.

A typical arrangement is shown in Fig. 1.1 and consists essentially of a Wheatstone bridge which controls the operation of the louvres via a balancing relay. When the temperature in the area is correct, the bridge is in balance and the angular position of the louvres is such that the air flow maintains the required temperature. A change in temperature unbalances the bridge and energises the motor, causing the louvres to take up a position which tends to restore the temperature to its correct level.

The bridge is formed by two potential dividers, A and B, connected as shown. The two coils of the balancing relay are connected so that the currents

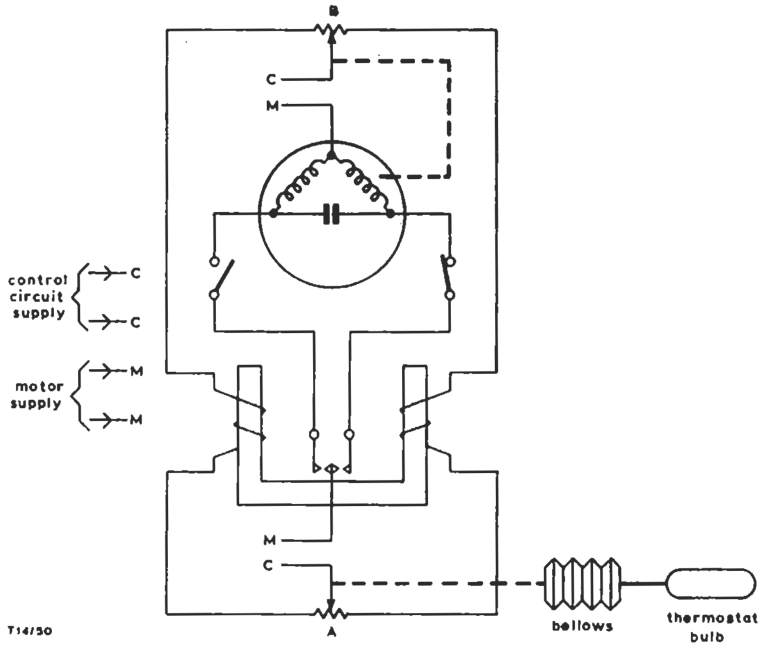

Fig. 1.1 Basic Louvre-motor Control Circuit

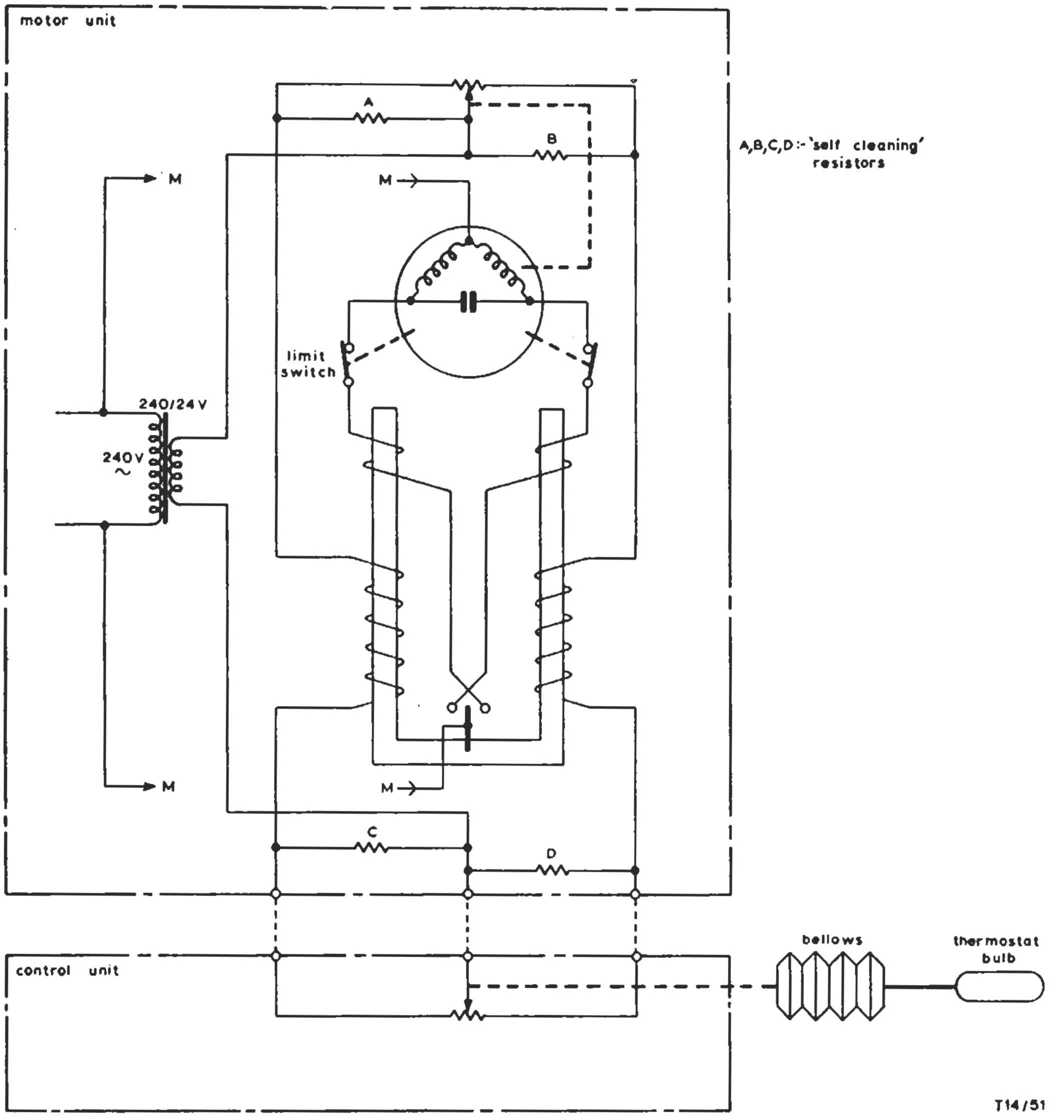

Fig. 1.2 Typical Louvre-motor Control Circuit

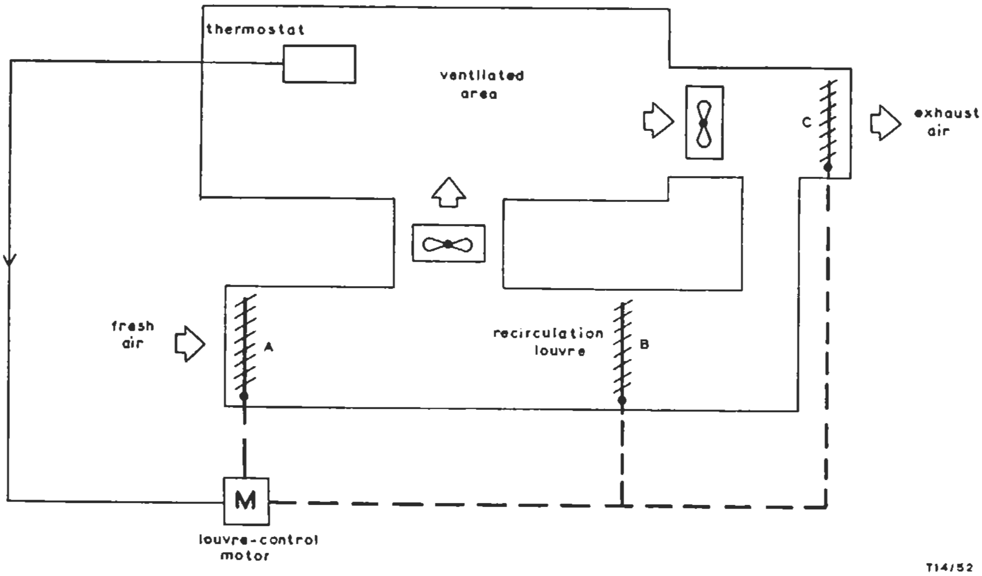

Fig. 1.3 Louvre-control Arrangement using One Motor with Mechanical Linkages Operating Three Sets of Louvres

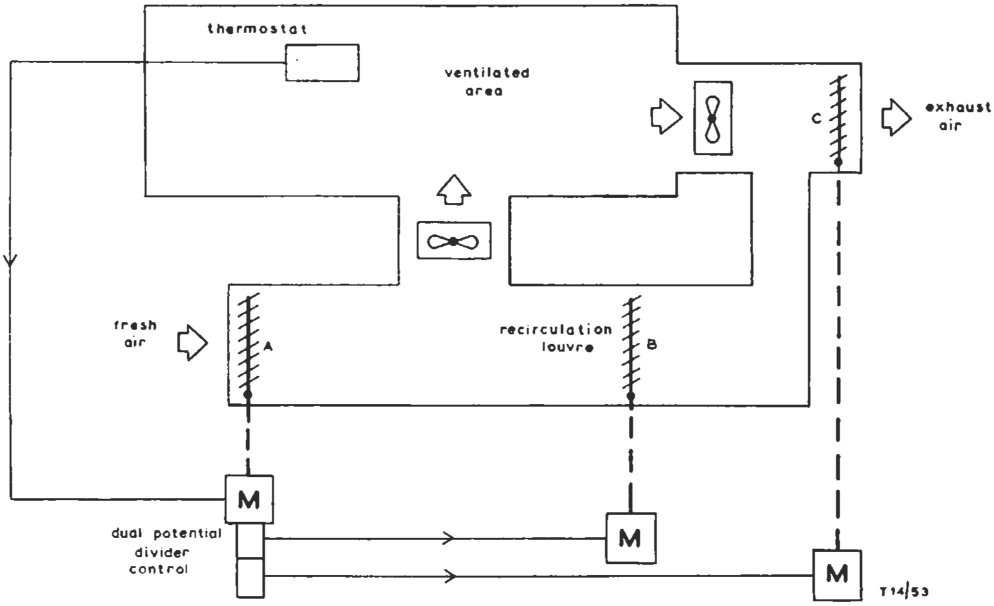

Fig. 1.4 Louvre-control Arrangement using Three Separate Motors Controlled by Dual Potential Divider

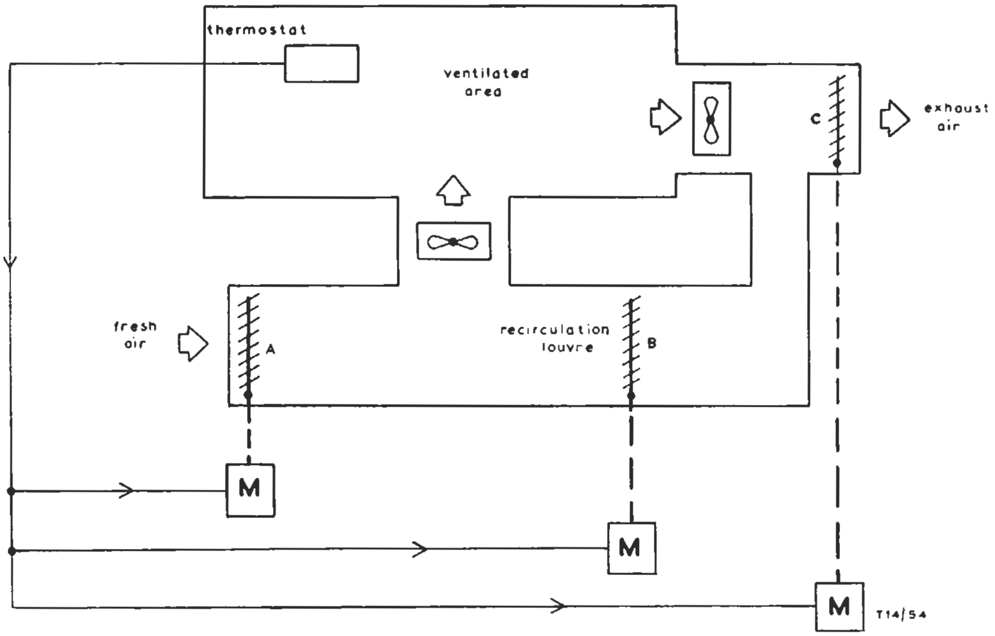

Fig. 1.5 Louvre-control Arrangement using Three Separate Motors Controlled by One Potential Divider

flowing in each of them are equal when the bridge is balanced, and in this condition both relay contacts are open. The position of the wiper of divider A is controlled by the thermostat; the wiper of divider B is coupled mechanically to the shaft of the louvre motor. An error in temperature causes the wiper of divider A to move to a position determined by the magnitude and sign of the error, and the resultant unbalance operates the balancing relay to one of its closed positions. This energises the motor, which runs until the wiper of divider B assumes a position at which the bridge is rebalanced and the relay released. As the temperature of the air returns to the required level, the bridge adjusts the position of the louvres to maintain the system in equilibrium.

1.2.2 Practical Systems

These are usually developments of the basic circuit of Fig. 1.1, and a typical example is shown in Fig. 1.2.

Contact chatter is eliminated by relay feedback windings which are connected in series with the field windings of the louvre-control motor. Operation of the relay due to unbalance in the control circuit causes the motor to become energised as before, but the current in the feedback windings ensures positive operation.

Dirt between the wipers and the tracks of the potential dividers can produce unbalance in the bridge circuit, and to prevent this, a self-cleaning action is imparted to the wiper movement by resistors A, B, C and D. These cause the motor to cycle continuously from one end of its travel to the other until the obstruction is removed.

Many ventilation systems require the use of more than one set of louvres, and various methods of controlling these are available. One system, shown in Fig. 1.3, uses three sets of louvres to control the proportion of fresh to recirculated air which is passed to the ventilated area. All three louvres are operated by one control motor, and the mechanical linkage is arranged so that as louvres A and C open, louvre B closes. In certain circumstances it is impracticable to provide such a mechanical linkage, and a more flexible system is shown in Fig. 1.4, in which each set of louvres has a separate control motor. Only one of the motors is controlled directly by the action of the thermostat; the others are controlled by auxiliary potential dividers which are coupled mechanically to the shaft of the first motor. This system has an inherent time lag, which can be reduced if all the louvre motors are controlled by one potential divider (in the thermostat) as shown in Fig. 1.5.