Chapter 6

40 kVA, 400 C/S, ENGLISH ELECTRIC CONSTANT FREQUENCY A.C. SYSTEM

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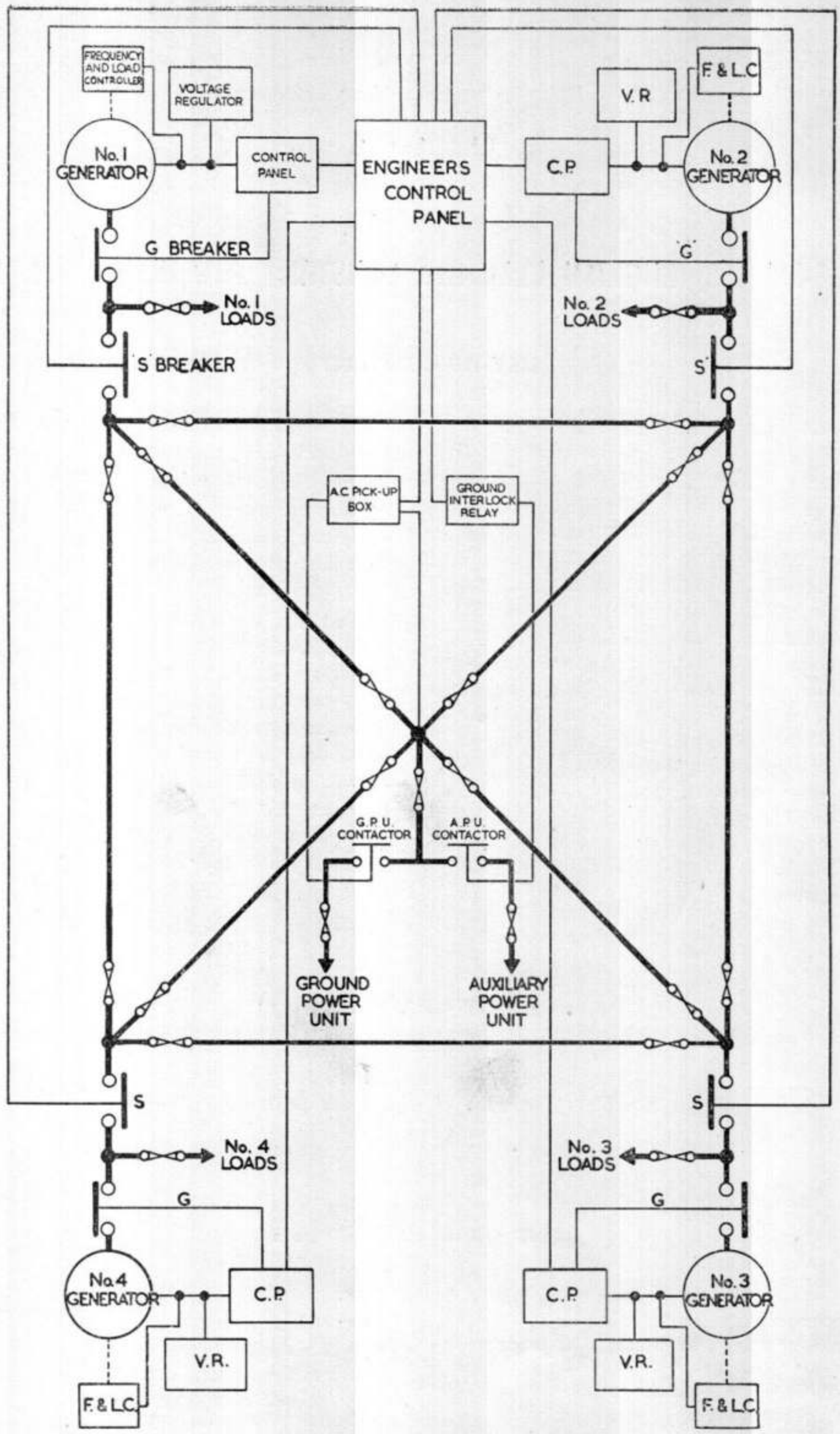

Fig. 1. Block diagram showing general system layout and bus-bar arrangement

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Introduction

1. The system provides a three-phase 200V 400 c/s a.c. supply from four a.c. generators, driven through constant speed drives from the aircraft engines. The 40 kVA generators are normally synchronized and paralleled on synchronizing bus-bars, but provision is made, for emergency operations, etc., for one or more machines to feed the essential loads on the bus-bars, whilst the remainder are switched off or each is feeding a group of loads individually.

2. The bus-bars may also be supplied from a ground power unit ("G.P.U.") or the aircraft's own auxiliary power unit ("A.P.U."), but interlocking is incorporated so that only one form of supply may be switched to the bus-bar at one time.

3. Direct current for operation of relays, indicator lamps and battery charging is obtained from a transformer-rectifier unit.

DESCRIPTION

General

4. Although, for convenience, the paragraphs which follow are headed by the main components of the system, the primary purpose is to describe the functioning of the system as a whole, rather than of these individual units. Diagrams are included for purposes of explanation and are therefore to some extent simplified—e.g., smoothing circuits, temperature compensating resistors, etc., may not be shown. For full details of the components, reference should be made to appropriate chapter enumerated in Table 1.

Bus-bar arrangement

5. A block diagram showing the general layout for four generators, and the bus-bar arrangement, is given in fig. 1.
The aircraft essential loads are split into four groups, each group being associated with one generator and connected to it, via a feeder bus-bar, by the Generator ("G") circuit breaker.

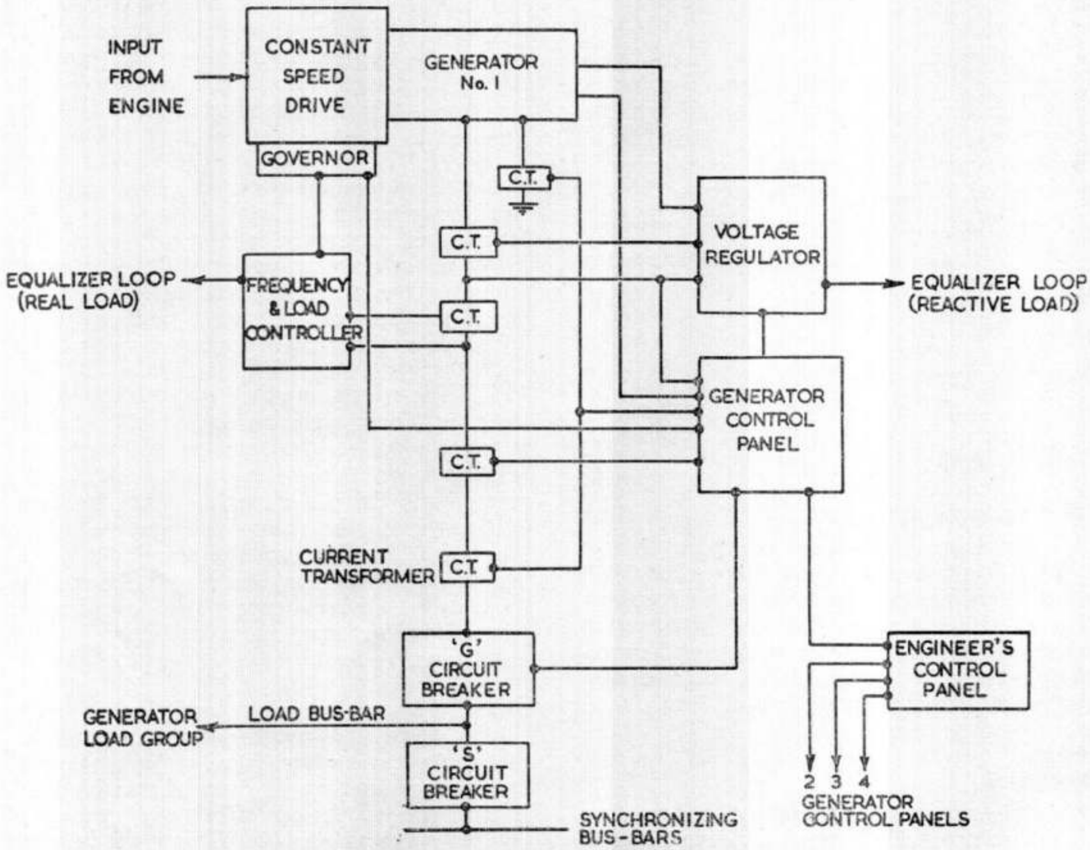


Fig. 2. Block diagram of equipment associated with one generator

The machines and their respective loads are paralleled to the synchronizing bus-bars by the synch. (" S ") circuit-breaker.

6. It will be seen from the diagram that, as mentioned earlier, there are several possibilities for load distribution, e.g.: —

(1) Loads supplied by all four generators running in parallel and synchronized (all " G " breakers, all " S " breakers closed)

(2) Essential loads supplied by one generators (G.P.U. or A.P.U. contact- (one " G " breaker, all " S " breakers closed)

(3) Two machines in parallel on bus-bars, two machines supplying their own loads (all " G " breakers, two " S " breakers closed)

(4) G.P.U. or A.P.U. supplying two load groups from synch. bars, two load groups supplied individually by generators (G.P.U. or A.P.U. contactor and two " S " breakers closed, two opposite " G " breakers closed).

Other combinations will be obvious.

7. The synch. bars comprise three limbs per phase, and each limb follows, so far as is practicable, a different path through the aircraft. In the event of an earth fault, damage or fusing in one limb, continuity is maintained. The three paths are: —

(1) Direct from one machine to another.

(2) Via the A.P.U.–G.P.U. connection point.

(3) Round the " S " breaker loop.

System components

8. Fig. 2 is a simple block diagram of the equipment associated with one generator. Table 1 details these components.

Constant speed drive unit

9. The drive is of the differential hydraulic type giving a constant output speed of 6,000 r.p.m. for engine speeds varying between 3,000 and 8,100 r.p.m. The output speed is controlled primarily by a centrifugal governor, but this is trimmed by a motor-driven servo-gearbox for correction of (*real*) load and frequency variations.

Generator

10. The generator is a conventional rotating field machine with integral d.c. exciter unit. Voltage regulation of the main generator is obtained by regulating the exciter field current.

Voltage regulator

11. The voltage regulator is essentially of the conventional carbon-pile type with additional components for operation from a.c. The operating coil is supplied with d.c. from a bridge rectifier across the 3-phase generator output and the carbon-pile controls current in the exciter field.

12. A damping transformer is connected with its primary across the exciter output and its secondary in the control coil circuit. Under normal conditions the windings carry d.c. only and the transformer has no effect on the operation of the regulator. Under transient conditions, however, current is induced in the secondary, in opposition to the current flowing through the control coil, damping oscillation of the pile.

Reactive load sharing

13. When a generator is working into bus-bars whose voltage is kept sensibly constant, a rise or fall in its excitation will result in the machine increasing or decreasing its reactive loading. Since the generated voltage is also dependent upon excitation it will be seen that the voltage regulator controls both the output voltage and the reactive loading of the generator.

14. Consider the operation of two generators in parallel. Their respective voltage regulators cannot be adjusted to have the same exact response under all loading conditions. Thus when the machines are paralleled the bus-bars assume a voltage which depends on the mean of the two characteristics.

15. The regulator which is set to the higher level will now sense an under-volting condition and will try to correct by increasing excitation on its associated generator. At the same time the other regulator, sensing over-volts, will do the reverse. Therefore, whilst the mean, bus-bar, voltage remains approximately constant, the generator voltages progressively diverge and the over-volting machine takes over more and more of the total reactive load.

16. If it can be so arranged that the regulators, instead of sensing the bus-bar volts, sense a voltage which increases as a machine takes on more than its share of reactive load, and vice versa, the out of balance can be kept within reasonable limits. This is the function of the reactive load sharing circuit.

TABLE 1
Major components of system

Component	Description and function	A.M. Type No.	Stores Ref. No.	Fully described in
1. Constant speed drive	Constant speed to generator of 6000 r.p.m. for input speeds from 3000—8100 r.p.m. (50 h.p.)			
2. Generator	400 c/s 3 phase 40 kVA 200V, a.c.	A.M.158	5UA/6332	
3. Voltage regulator	Voltage control 200V ±2% Reactive-load equalization			
4. Frequency and load controller	Frequency control 400 c/s ±1%. Real-load equalization	A.M.41	5UC/6104	
5. Generator control panel	Generator control Over/under voltage protection Differential current detection Underspeed detection Paralleling control			
6. Generator circuit breaker (" G " breaker)	Generator to load connection	6Y.No.1	5CW/5756	
7. Synchronizing circuit breaker (" S " breaker)	Load to synch. bus-bar connection	6Y.No.1	5CW/5756	
9. A.C. pick-up box	A.P.U.-generator supply interlocking			
10. Ground interlock relay	G.P.U.-supply interlocking			
11. Engineer's control panel	Generator control—on/off Generator isolation and resetting pushes Synchronization-control Generator selector switch Indicators for various relays, etc. Volt and frequency meters			
12. Current transformer	Used in conjunction with various control and detection circuits			
13. Transformer/ rectifier unit	28V, 7KW d.c. supply for d.c. bus-bars		5UB/6657	

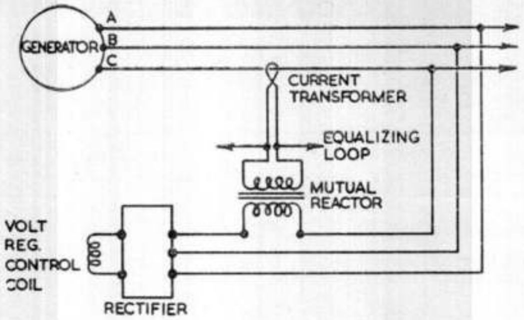


Fig. 3. Mutual reactor in voltage regulator circuit

17. The reactive load sharing system consists of a current transformer in one phase of the feeder from each generator operating a mutual reactor (*para.* 20), which appropriately modifies the voltage applied to the regulator.

18. The current transformers are connected in a series loop so that when the machines are carrying equal load the current induced in the current transformers circulates only round the loop. If unbalance occurs, the induced currents will not be equal, and, since the circulating current can have only one value, difference current proportional to the out-of-balance load of a particular machine flows through its mutual reactor.

19. When a generator is switched off or run singly, its current transformer must be short-circuited, so that a false under-volt signal is not passed on to the remaining machines and so that, at the same time, continuity of the equalizing loop is maintained.

Mutual reactor

20. Briefly, a mutual reactor is a transformer with an air gap in the iron circuit, a condition which produces a phase difference between primary current and secondary voltage of approximately 90 deg. The primary is supplied from a current transformer round the phase " C " line from the generator, and the secondary is in series with phase " C " supply to the rectifier network (*fig.* 3).

21. In a three-phase system, for purely *reactive* load, the current in one line Ic will be in phase with another line voltage VA/B (*fig.* 4a).

22. Considering line voltage vector diagrams (*figs.* 4b, c and d) current vector Ic for line C is in phase with voltage vector A–B and, due to the shift through the mutual reactor, voltage C–D in the mutual reactor secondary, is in quadrature with Ic. The voltage supplied to the rectifier will now be the average of AB, BD and DA.

23. If the machine is over-exciting it will take on more of the normal, inductive reactive load, Ic will be in the direction shown and the average voltage will increase (*fig.* 4b). If the machine is under-exciting (*fig.* 4c) and shedding inductive load, it will act as if it were capacitative, Ic will be in the opposite direction and the average volts to the rectifier will decrease. Another way of considering this is to regard the generator as a load on the bus-bar during its under-excited condition so that Ic is flowing " into " the machine instead of being supplied by it.

24. For real load Ic is at 90 deg. to AB, and CD will be parallel to AB. It will be seen from fig. 4d that the averages of ABC and ABD are very nearly the same, so that real load has no effect on the reactive load sharing circuit.

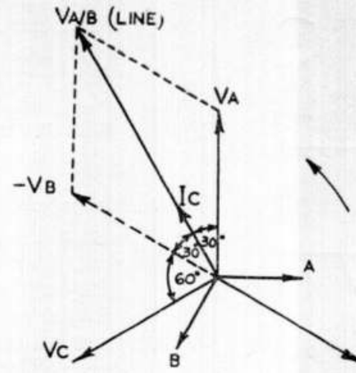
Current transformer loop

25. Figs. 5a and b show the arrangement for two machines. If each is supplying 125-amp. reactive and the current transformer ratio is 125:1, 1 amp. will circulate in the loop. Since the mutual reactor primaries are of high impedance compared with the current transformer little current will flow through them (*fig.* 5a).

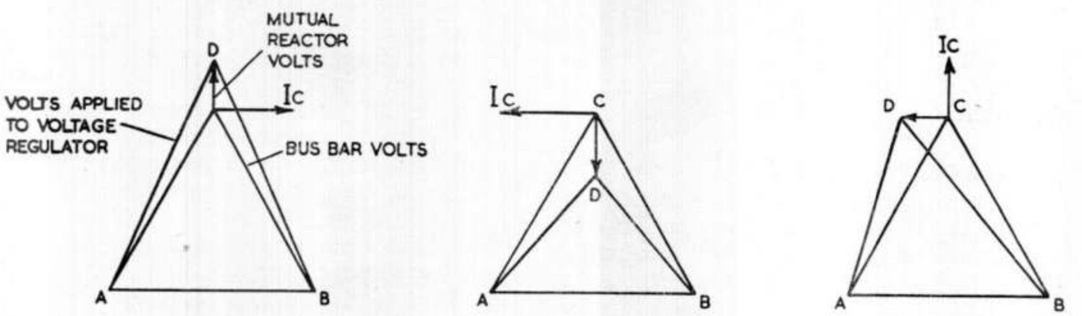
26. Suppose now No. 1 generator takes on 63-amp. reactive overload then the total current supplied by No. 1 will be 188 amps. and that supplied by No. 2 will be reduced to 62 amps. (*fig.* 5b).

27. The current induced in No. 1 current transformer will be about 1·5 amp. and that in No. 2 current transformer 0·5 amp. Since only one value of current can flow through the loop, 0·5A will flow through each mutual reactor primary, but in opposite sense. The terminal voltage of machine No. 1 will be reduced and at the same time that of machine No. 2 increased so that there is a " push-pull " effect tending to accelerate correction of the unbalance.

Note . . .
The figures quoted in the foregoing are purely illustrative and should not be taken as actual working values.



(a) LINE VOLTAGE AND CURRENT VECTORS FOR PURELY REACTIVE LOADS

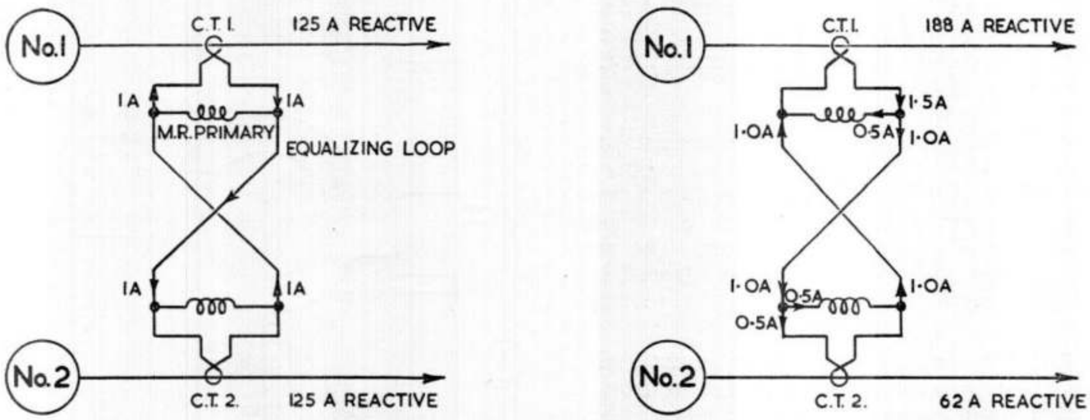


(b) GENERATOR OVER EXCITED

(c) GENERATOR UNDER EXCITED

(d) EFFECT OF REAL LOAD

Fig. 4. Effect of mutual reactor



(a) BALANCE LOAD CONDITION

(b) No. 1. GENERATOR OVER EXCITED

Fig. 5. Current transformer loop circuit

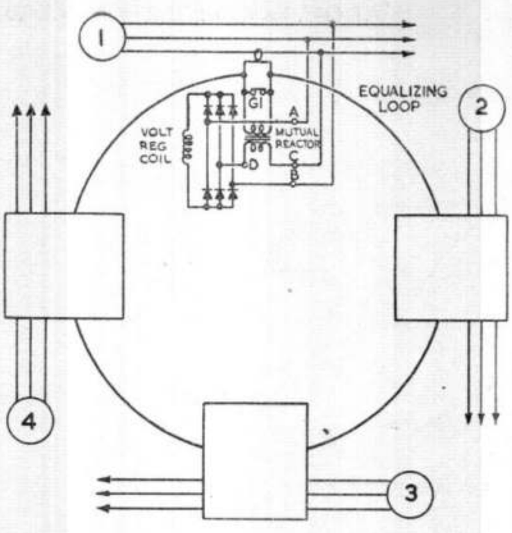


Fig. 6. Arrangement for four generators

28. Fig. 6 shows the arrangement for four generators.

Frequency and load controller

29. When generators are operated in parallel they will all of necessity run at the same speed. Any tendency of a controller to try and increase its associated generator's speed (i.e., frequency) will result in the generator's advancing its voltage vector, with respect to the others, and taking on more real load, and vice versa.

30. Since all the controllers cannot be set to control at exactly the same level, it will be apparent that, by a similar argument to that which was applied for the reactive load sharing system, the real load sharing circuit must apply a correcting signal to the controller, proportional to the generator's out-of-balance loading.

31. The load sharing system consists of a current transformer in one phase of each generator, which, in conjunction with a transformer-rectifier circuit, operates one control winding of a magnetic amplifier. The magnetic amplifier in turn controls a speed trim servo motor on the hydraulic drive governor.

32. The magnetic amplifier control windings are connected in an equalizing loop, so that under steady-state no current flows through them, but under unbalanced conditions current in them is proportional to the out of balance.

33. The frequency control circuit proper supplies a second control winding on the magnetic-amplifier, so that, whilst both this and the real load sharing circuit ultimately affect the speed trim motor, they function independently of each other.

34. Both circuits are described in detail in the following paragraphs.

Real load sharing circuit

35. A simplified diagram of the real load sharing circuit is shown in fig. 7. The potential divider " P " is connected via " D.1 " and " D.2 " to the secondary of the single-phase transformer, whose primary is between phase A and earth. The electrical centre of " P " is connected to the transformer centre tap through resistor " R," and the current transformer is connected across the resistor.

36. Ignoring any effect by the current transformer for each half-cycle, current may flow in one rectifier loop but will be blocked by the rectifier in the other loop. The voltages (say 10V) produced across " P " for each half-cycle will be equal and opposite, and the nett voltage appearing across capacitor " C " will be zero for a complete cycle.

37. Considering now the effect of the current transformer, current flowing from it will produce a voltage across " R " (say 3V) which will add to the voltage for one half-cycle but subtract from the total voltage for the other half-cycle. For a complete cycle a d.c. voltage will appear across the capacitor equal to

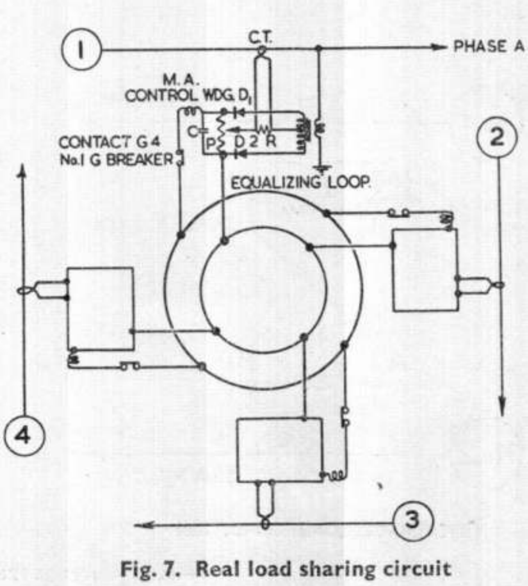


Fig. 7. Real load sharing circuit

$\sqrt{2}\times$ the difference between the half-cycle voltages; i.e., $\sqrt{2}$ (13 − 7) = 8·5V. After smoothing, this d.c. signal is applied to the magnetic amplifier control windings which ultimately operate the two-phase speed trim motor on the hydraulic drive.

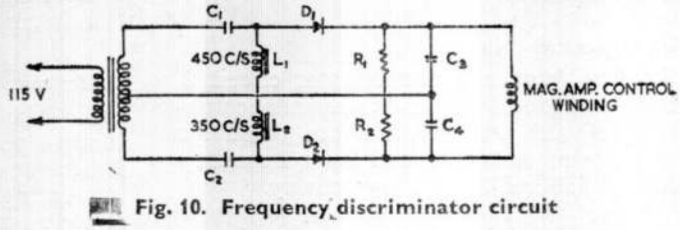


Fig. 10. Frequency discriminator circuit

38. It will be seen from the diagram that the magnitude and direction of the current flowing through the magnetic amplifier control windings will be dependent upon the magnitude and direction of the real load current.

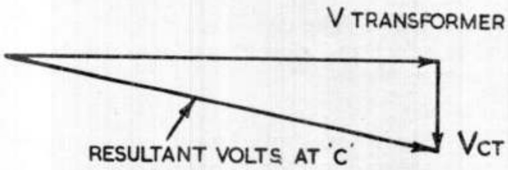


Fig. 8. Effect of reactive load

39. The control windings of the magnetic amplifiers for all four machines are connected by a loop (*para.* 32). Under balanced-load conditions the voltages across all the control windings balance out and no current flows through them. If one machine tends to take on real load, the voltage across its magnetic amplifier will increase proportionally and the voltage across the other magnetic amplifiers will be decreased by one-third of this value. Current will circulate round the loop through the magnetic amplifier control windings to correct the change.

40. As can be seen from the vector diagram (*fig.* 8), an increase in reactive load will not materially affect the output voltage of the single-phase transformer and hence will not operate the magnetic amplifier.

Operation of magnetic amplifier

41. The magnetic amplifier control winding is in two sections, each of which controls a transductor as shown in fig. 9. The transductors act as variable impedances sensitive to the magnitude and direction of current through the magnetic amplifier control winding. Thus, if at some instant the control signal makes T.1 a high impedance and T.2 a low impedance, the instantaneous current through the control phase will be in the direction shown by the arrows. If the control signal is reversed the relative values of impedance of T.1 and T.2 will also be

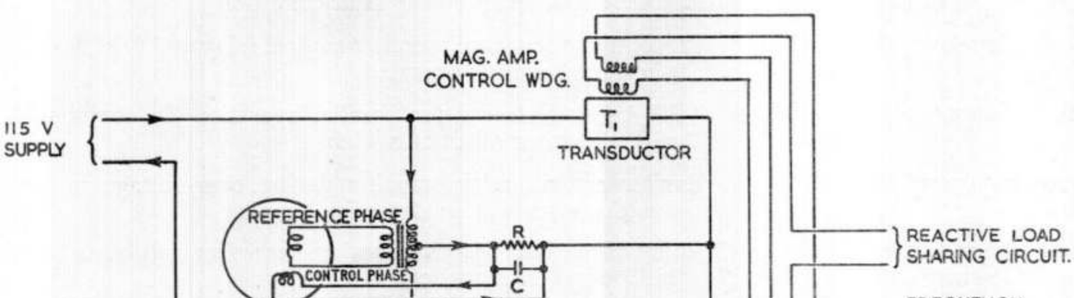


Fig. 9. Magnetic amplifier—servo motor circuit

reversed, current will flow in the opposite sense, and the governor control motor will change direction.

Frequency control circuit

42. The frequency discriminator circuit is shown in fig. 10. The choke-capacitance circuits L.1, C.1 and L.2, C.2 are tuned for resonance at the upper and lower frequency limits of 450 and 350 c/s respectively.

43. Assuming similar response characteristics for each L.C. circuit, at 400 c/s the voltage across each choke and hence across C.3 and C.4 will also be equal and opposite and no current will flow through the magnetic amplifier control winding. If the frequency tends towards the resonant frequency of L.1–C.1, the voltage across L.1 will be greater than that across L.2 and current will flow through the magnetic amplifier. Similarly, if the frequency tends towards the lower limit, current flow will be in the opposite direction.

Generator control panel

44. The control panel fulfils various fault detection and control functions. Although the protection circuits are described in this section, only brief reference is made to the various control relays, etc., as operation of these units is more conveniently covered in "Operation" (*para.* 66). Table 2 summarizes the functions of the panel.

Under/over voltage protection circuit

45. The circuit (*fig.* 12) operates to shut down a generator and open the "G" breaker when the voltage is below 175 or above 220, or, during parallel running, when the out-of-balance reactive loading exceeds 20 KVAR (faulty generator over-excited) or 16 KVAR (faulty generator under-excited).

46. When a generator is running singly, the protection unit can be arranged to operate simply on the generated voltage. This is not possible when generators are in parallel, since an over-voltage in one of them will increase the bus-bar volts and affect all the protection units equally. The circuit must now be modified to select and close down only the faulty generator.

47. This is done by a looped current transformer-mutual reactor network operating in an exactly simliar manner to that of the reactive load sharing circuit (*para.* 13).

TABLE 2

Main components of generator control panel

Component	Major function
Master relay	Generator main control Control of "G" and "S" breakers
Exciter control relay	Exciter field breaking during fault conditions Master relay control during fault condition
Lock-out relay	Prevention of cycling in exciter control relay and field flashing when reset push is operated
Paralleling relay	"S" breaker closing for parallel operation, in conjunction with generator selection switch
Over-voltage unit	Exciter control relay tripping during over-voltage in conjunction with voltage detection circuit
Under-voltage three phase torque switch	Opening of master relay circuit when generator voltage is below 180V or phase sequence is incorrect
Time delay unit	Tripping of exciter control relay (if this is not already tripped) when master relay is open-circuited. Time delay of about 10 sec. is incorporated to prevent nuisance tripping
Differential protection relays	Tripping of exciter control, relay on line-to-line or line to earth fault, in conjunction with differential protection network

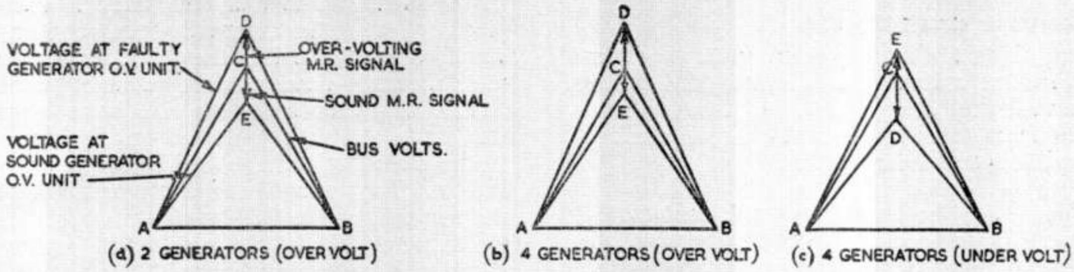


Fig. 11. Effect of mutual reactor in under/over voltage circuit

48. If one generator over-volts it will take on excess reactive load. Its mutual reactor increases the voltage applied to its associated over-voltage unit, which trips the machine when the out of balance exceeds 20 KVAR. At the same time, the voltage applied to the protection units of the sound generators is reduced to a value approximating to normal bus-bar volts so that they do not trip.

49. Figure 11a shows the condition for two generators. Voltage C–D injected by the over-volting machine's mutual reactor produces a voltage, which is the average of ABD, at the over-voltage unit. An equal and opposite voltage CE is produced by the mutual reactor of the sound generator giving a voltage which is the average of AEB, at its over-voltage unit.

50. Fig 11b shows the condition for four generators. The mutual reactor's signal in each sound machine is now one-third that of the faulty machine's, but as the bus-bar volts have been increased by a smaller amount by the fault, the average of AEB still approximates to normal bus-bar volts.

51. The action during under-volts is the opposite of the foregoing. The voltage applied to the faulty generator's under-voltage unit is decreased and that to the sound generators increased. Fig. 11c illustrates this condition.

52. When the generator is switched off auxiliary contacts on the " G " breaker short-circuit its current transformer, so that the remaining generators are not affected. Similarly, the current transformer is shorted by contacts on the " S " breaker when a generator is run singly, since there is now no load sharing with other generators.

Under-voltage unit

53. The under-voltage unit is a three-phase torque switch supplied from tappings on a three-phase transformer (*fig.* 12). Its contact UVI opens, de-energizing the master relay (*para.* 84).

Over-voltage unit

54. The over-voltage unit comprises a slave relay in the anode circuit of a trigger tube supplied through a bridge rectifier from the three-phase transformer. When the trigger tube fires, the relay is energized and its contact OVSR2 closes to trip the exciter control relay (*para.* 82). A second contact OVSR1 by-passes the tube to earth so that it is cut off immediately after operating the relay.

55. Firing of the tube is controlled by the voltage on the triggering anode, which is set by potentiometer PT 1. Capacitors C1 and C2 and resistor R3 provide a time delay of 4 to 6 seconds.

Differential protection circuit

56. The circuit detects line-to-line and line-to-earth faults in the generator and on the feeders up to the " G " breaker. A current transformer round each generator neutral lead is looped with a similar current transformer round each phase of the feeder and a relay is connected across each loop.

57. Considering one loop, under normal conditions, currents in the neutral and feeder current transformers are equal and current circulates round the loop. Under faulty conditions a heavy current will flow from the feeder current transformer, but the normal current will still be produced by the neutral current transformer. The difference current is therefore " forced " through the relay. The relays are adjusted to operate and trip the exciter control relay when the fault current in the feeder exceeds 45 amps.

Generator circuit breaker

58. This is a latch type unit with short time rated set and trip coils which are opened immediately after operating. In addition to the main three-phase contacts, five auxiliary contacts are incorporated.

59. With the breaker tripped, contacts G.1 and G.2 respectively (*fig.* 12) short out the reactive load sharing and over/under-voltage current transformers and contact G.4 open circuits the real load sharing magnetic amplifier control winding. Contact G.5 provides interlocking with the "S" breaker, in conjunction with the control panel, and contact G.3 operates the indicator.

Synchronizing circuit breaker

60. The synchronizing breaker is of the same type as the generator breaker. The auxiliary contacts fulfil the same functions as their opposite numbers on the "G" breaker.

Auxiliary and ground power supply circuit breakers

61. Both these units are identical and are very similar to the "G" and "S" breakers.

A.C. pick-up box

62. The a.c. pick-up box provides interlocking between the generator and A.P.U. supplies. The box contains two relays, the coils of which are energized from phase "A" and "C" of the synchronizing bars via two transformer-rectifier circuits. The contacts for each relay, which consist of one normally-open and two normally-closed, are connected in series. The normally-open contacts supply an indicator on the Engineer's control panel indicating when a.c. is on the synchronizing bars.

63. The set coil of the A.P.U. contactor is fed through one pair of normally-closed contacts from the extra supply switch, so that if a.c. already exists on the synchronizing bars, these contacts are open and the A.P.U. cannot be connected. The other pair of normally-closed contacts are not used.

Ground interlock relay

64. This unit provides interlocking between the generator and ground power supply. The relay has two normally-open contacts and one normally-closed contact. Its coil is supplied from the G.P.U. position of the extra supply switch via a shorting link in the ground power socket. One pair of normally-open contacts short-circuits the link in the ground power socket as soon as the relay is energized. The other normally-open contacts supply the closed coil of the G.P.U. contactor via a normally-closed auxiliary contact on the A.P.U. contactor from the d.c. bus-bar, so that if the A.P.U. is switched on the circuit to the closed coil of the G.P.U. contactor is broken. The normally-closed contacts supply the trip coil of the G.P.U. contactor so that the latter is tripped as soon as the ground interlock relay is de-energized.

Engineer's control panel

65. The various controls and instruments which comprise this unit are detailed below and shown on fig. 12. Its function in the main system is fully described in para. 66 onwards.

Individual controls for each generator:—

- ON/OFF switch
- Isolate push
- Reset push

System controls:—

- Generator selector switch
- Synchronizing push
- Bus-bar volt and frequency meters
- Incoming generator volt and frequency meters
- Synchronization indicator lamp.

OPERATION

66. Fig 12 is a schematic diagram of the system, including one generator and its associated control gear. Reference should be made to the diagram in reading this description.

67. Before the engines can be started, or any supplies switched on, the battery isolating switch must be closed. If this is not done, damage to the system may result. D.C. is now applied to the control panels, tripping any "G" breakers which are closed and closing the "S" breakers. All "G" breakers are now open, all "S" breakers closed, and the ground power unit may be switched to the synchronizing bus-bars for engine starting.

Note . . .

In reading the following paragraphs it should be noted that the exciter control relay is normally in the "set" position and contact EC4 is closed unless some fault has occurred on the system previously, and the relay has not been reset. If the generator fails to build-up the control switch should be placed *in the* OFF *position, the reset push operated and the control switch returned to the* ON *position.*

Normal starting

68. The generator control switches are placed in the ON position and each engine is started in turn. When the frequency reaches 360 ± 10 c/s the drive-underspeed-switch, an oil-pressure operated device on the hydraulic drive (*fig.* 12), closes. The under-voltage relay (contact UV1) also closes and the master relay is energized via normally-open contact EC4 on the latched exciter control relay.

69. Master relay contacts M.5 and M.3 are opened, breaking the circuit to the trip coil of the "G" breaker and to the set coil of the "S" breaker, via auxiliary contact G.5, on the "G" breaker. Contact M.2 closes tripping the "S" breaker and completes the circuit to the closed coil of the "G" breaker as soon as auxiliary contact S.5 on the "S" breaker is made when the latter trips. Master relay contact M.1 open-circuits the time delay unit.

70. The "S" breaker is now open and the "G" breaker closed so that the loads associated with the generator are transferred, from the synchronizing bars, to the machine.

71. The generator control switch may be left in the OFF position for testing, etc., if desired, and transfer of the loads will then occur, as above, when the switch is placed in the ON position. There is a time delay of about 0·1 sec. during this change-over. When all engines are running, each generator is supplying its own loads individually and the G.P.U. can be switched off the synchronizing bars preparatory to paralleling the generators.

Paralleling

72. With the extra supply switch in the central, OFF, position, d.c. is supplied via auxiliary interlocking contacts on the A.P.U. and G.P.U. contactors, to one side of the synchronizing push. There should now be no voltage on the synchronizing bars and the synchronizing bar voltmeter and a.c. pick-up indicator lamp must be checked to ensure that this is the case.

73. An indicator lamp is connected between phase "B" of the synchronizing bars and phase "B" of each generator, via one bank of the generator selector switch. The voltage across this lamp depends upon the difference, frequency and voltage, between the generator and the bus-bars, and it will therefore be zero when the two are of the same voltage and frequency, and are in phase.

74. The first machine to be connected is selected on the generator selector switch and, since no volts exist on the synchronizing bars, the lamp will glow brightly. The synchronizing push is now pressed, momentarily closing paralleling relay contact P.1 on the particular machine's control panel and hence closing its "S" breaker. The synch. lamp will now extinguish.

75. The next generator may now be selected and the lamp will glow and darken at the rate of about once every two seconds. If the lamp remains bright for a lengthy period—indicating that the generator and bus-bar are at the same frequency, but about 180 deg. out of phase—a resistive load should be switched on. This will upset the system sufficiently to cause the necessary frequency difference. The synchronizing push is operated momentarily in the middle of a dark period and the second machine is paralleled via its paralleling relay and synchronizing breaker. The same procedure is followed for each machine.

Closing down

76. As each engine is shut off, its generator is automatically brought off load and the only action necessary by the operator is to open the battery isolating switch when all engines have stopped.

77. As the speed falls the drive under-speed switch drops out, the master relay is de-energized and its contact M.5 trips the "G" breaker. The "S" breaker remains closed and the particular generator's loads are now fed from the synchronizing bars.

78. This will also occur if an engine fails or its speed falls below the normal limit. However, if the generator selector switch is left in the ON position the generator will automatically take over its own loads again from the synchronizing bars (as with normal starting, described in para. 68). The generator must now, of course, be re-synchronized on to the bus-bars.

79. If more than one engine is closed down, so that the total load on the synchronizing bars is approaching the maximum capacity of the remaining generators, the auxiliary power unit should be started. The generators which are still running are isolated by pressing the appropriate isolating push which completes the circuit to the trip coil of the appropriate "S" breaker and leaves the machine supplying only its own loads individually.

80. Since no a.c. now remains on the synchronizing bars, contacts on the a.c. pick-up box will be closed, and auxiliary contacts on the G.P.U. contactor are already closed. Circuit to the set coil of the A.P.U. contactor is completed by switching the extra supply switch to the A.P.U. position, and the loads of the inoperative generators are now supplied from the A.P.U. via the synchronizing bus-bars.

Operation under fault conditions

81. The fault-detecting circuits have already been described and their operation in conjunction with the various control relays will now be considered.

Line-to-line/line-to-earth faults

82. A line or earth fault in one of the phases energizes one of the differential protective relays, D.P.A./1, D.P.B./1 or D.P.C./1 closing contacts D.P.A.1, D.P.B.1 or D.P.C.1. The circuit to the trip coil of the exciter control relay is completed through its contact E.C.1, which then opens as the relay trips. Contacts E.C.2 open, breaking the exciter field and E.C.6 closes tripping the "G" breaker. Contact E.C.4 opens, de-energizing the master-relay, whose contact M.4 opens and prevents tripping of the "S" breaker, via contact G.5, when the "G" breaker trips. The remaining exciter control relay contacts, E.C.3 and E.C.5 perform subsidiary functions, in connection with re-setting and over-voltage faults, respectively, and are dealt with in the appropriate paragraphs. The "G" breaker indicator will now show a fault and the generator control switch will then be moved to the OFF position for re-setting.

Over-voltage fault

83. The trigger tube fires and the over-voltage slave relay operates closing its contact OVSR2 which trips the exciter control relay. Immediately the exciter control relay trips, its contact E.C.5 opens and de-energizes the slave relay.

Under-voltage fault

84. Three-phase torque switch contact UV1 opens, de-energizing the master relay. Contact M.1 closes completing the circuit to the time delay unit and after 10 seconds contact T.D.1 closes, tripping the exciter control relay.

Generator open-circuit

85. The under-voltage unit will operate as in para. 84.

Generator fails to build up

86. Again the under-voltage unit will operate and the "G" breaker indicator will show the fault. The normal reset procedure will then follow.

Resetting

87. The generator control switch is moved to the OFF position and d.c. is then applied to master relay contact M.5 directly—instead of via the drive under-speed switch—and to one side of the reset push. When the reset push is closed, the circuit to the exciter control relay set-coil is completed, through lock-out relay contacts L.O.1 and L.O.4, and the exciter control relay closes. At the same time the exciter field is flashed, through rectifier R.E.3, and lock-out relay contacts L.O.3 and L.O.5.

88. As the exciter control relay is energized, the contacts mentioned in paragraph 82 change-over, and, in particular, contact E.C.3 closes the circuit to the lock-out relay. Lock-out relay contacts L.O.1 and L.O.4 in the close-coil circuit open, contact L.O.2 closes and contacts L.O.3 and L.O.4 break the field-flashing current.

89. If the fault on the system still exists, the exciter control relay trips again and its set coil circuit is now broken by lock-out relay contacts L.O.1 and L.O.4. The lock-out relay is itself held in by its contact L.O.2, so that further attempts to reset the exciter control relay cannot be made until the reset push is released and pressed again.

90. If the fault has cleared, the reset push is released, the lock-out relay is de-energized and its contacts L.O.1, L.O.4 and L.O.3 close, and L.O.2 opens. The generator control switch may now be returned to the ON position, master relay contacts M.4 and M.2 close, tripping the "S" breaker and closing the "G" breaker. The generator's loads are transferred back from the synchronizing bus-bars and the generator must be re-paralleled.

TABLE 3

Sequence of operation of control and protective devices

Normal operation

STARTING

Ground power supply connected.

Battery isolating switch closed.

" G " breakers trip—" S " breakers close.

Extra supply switch set to " G.P.U."

Ground power supply on synch. bus-bars.

Generator control switches on.

Engines started in turn

" S " breaker trips—" G " breaker closes, and load transferred to generator as each engine comes up to speed.

Extra supply switch OFF when all engines running.

All loads supplied individually by generators.

G.P.U. disconnected.

PARALLELING

Check for no power on synch. bus-bars.

Bus-bar voltmeter—a.c. pick-up box indicator.

Generator selector switch set to No. 1 generator.

Synch. lamp glows brightly.

Synch. push pressed momentarily.

Synch. lamp goes out, No. 1 " S " breaker closes.

Generator selector switch set to No. 2 generator.

Synch. lamp glows and extinguishes periodically.

Synch. push pressed momentarily during dark period.

No. 2 " S " breaker closes.

Repeated for generators 3 and 4.

CLOSING DOWN

Engines shut off.

" G " breaker opens as speed of each falls.

" S " breaker remains closed.

Battery isolate switch opened.

TO RUN GENERATOR SINGLY

Generator's isolate push pressed.

" S " breaker opens, generator supplies its own load group only.

TO CLOSE DOWN GENERATOR

Generator's control switch off.

" G " breaker opens, " S " breaker remains closed and generator's load group supplied from synch. bus-bars.

Operation under fault conditions

Fault protection circuit opens " G " breaker and exciter field circuit.

Generator control switch OFF.

" G " breaker opens.

Generator selector switch set to faulty generator.

Reset push pressed.

Exciter field tickled, then closed.

Generator volts shown on voltmeter.

Generator control switch returned to ON position.

If fault has cleared.

" S " breaker opens, " G " breaker closes.

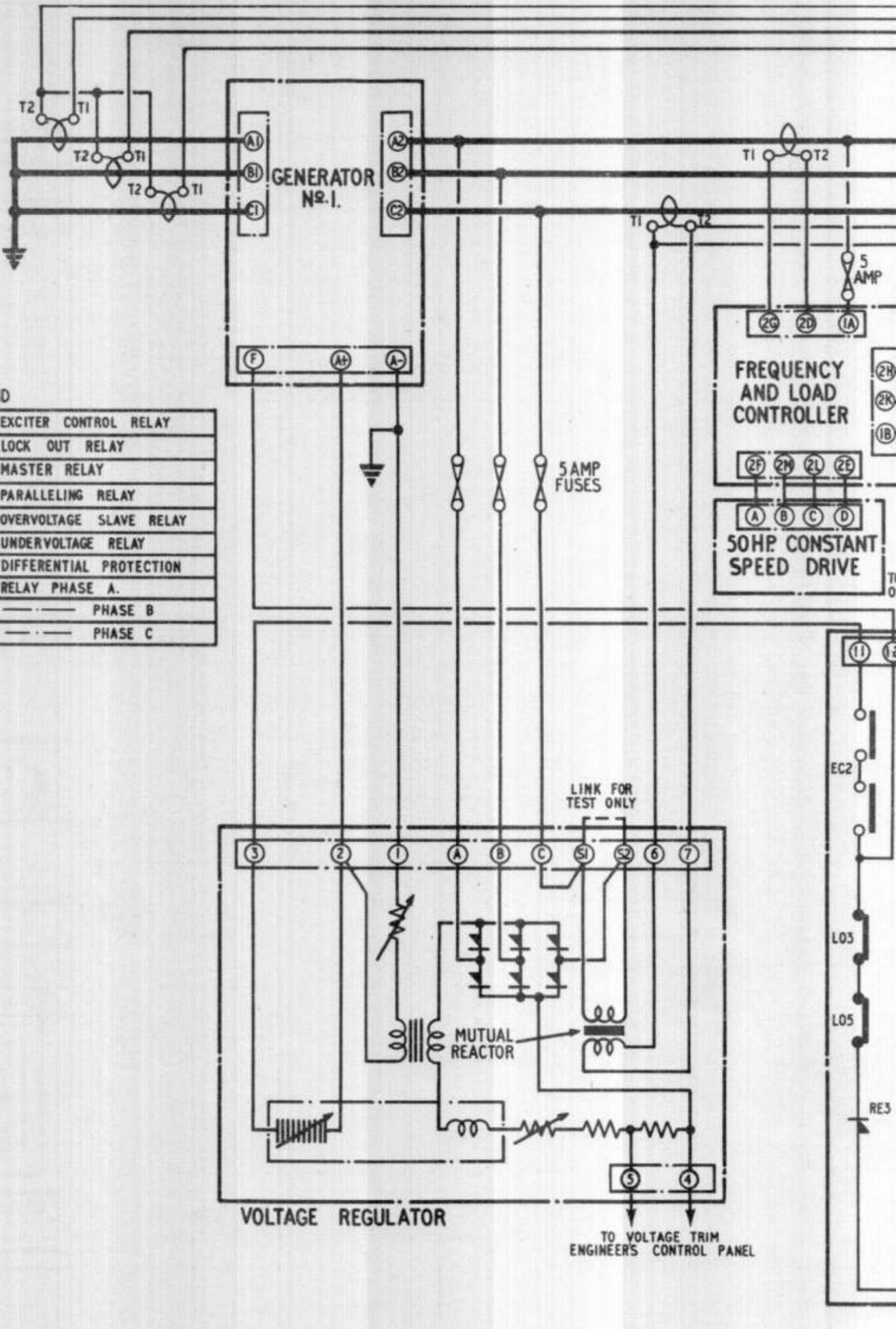
Generator re-synchronized.

If fault still exists.

" S " breaker opens, " G " breaker closes then opens again and " S " breaker recloses.

Re-setting attempted again and if fault still has not cleared generator left closed down.

48118 240745 3297 9/57 3500 CWSLtd2378 Gp539-2

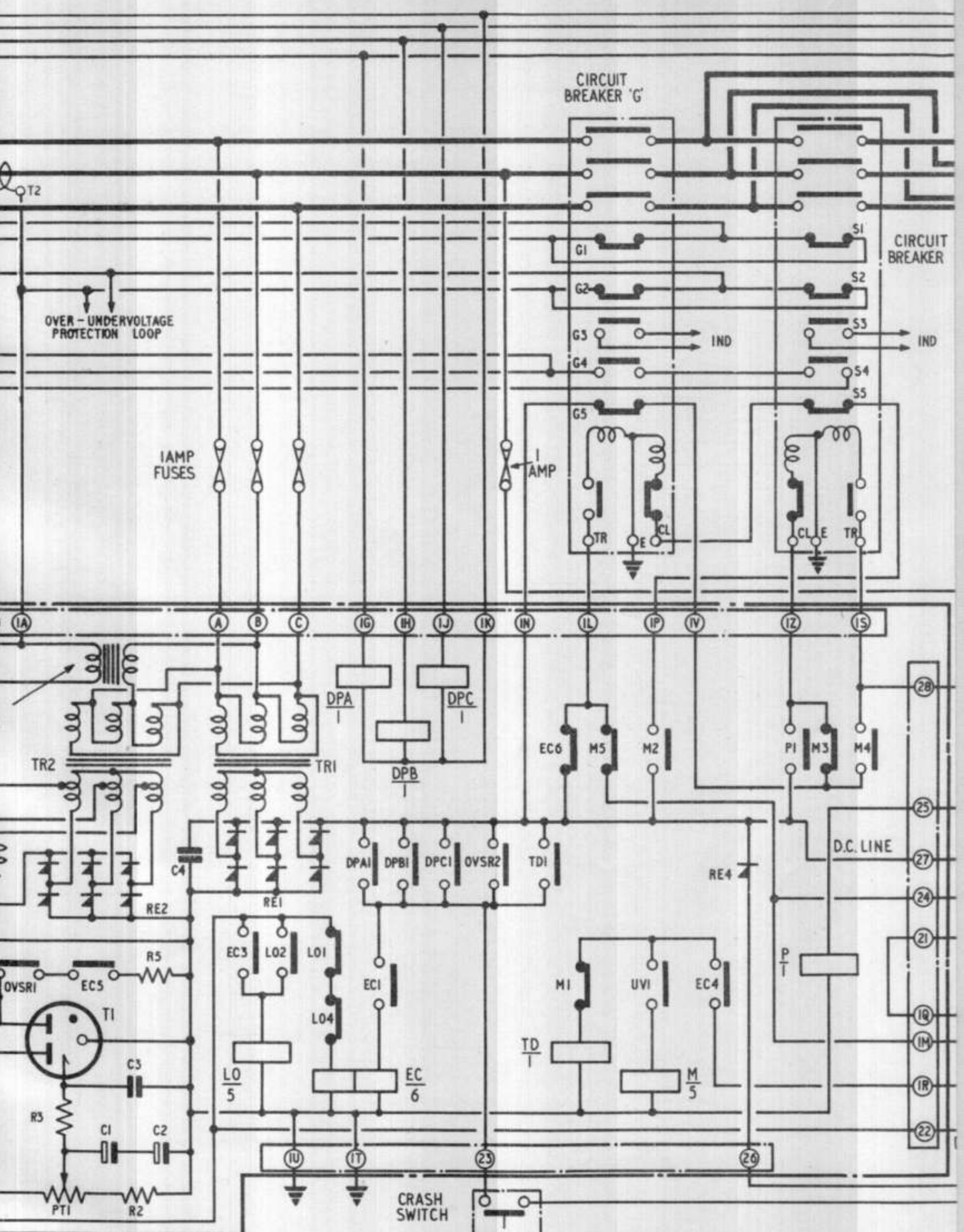


LEGEND

EC 6	EXCITER CONTROL RELAY
LO5	LOCK OUT RELAY
M/5	MASTER RELAY
P/1	PARALLELING RELAY
OSVR/2	OVERVOLTAGE SLAVE RELAY
UV/1	UNDERVOLTAGE RELAY
DPA/1	DIFFERENTIAL PROTECTION RELAY PHASE A.
DPB/1	—·— PHASE B
DPC/1	—·— PHASE C

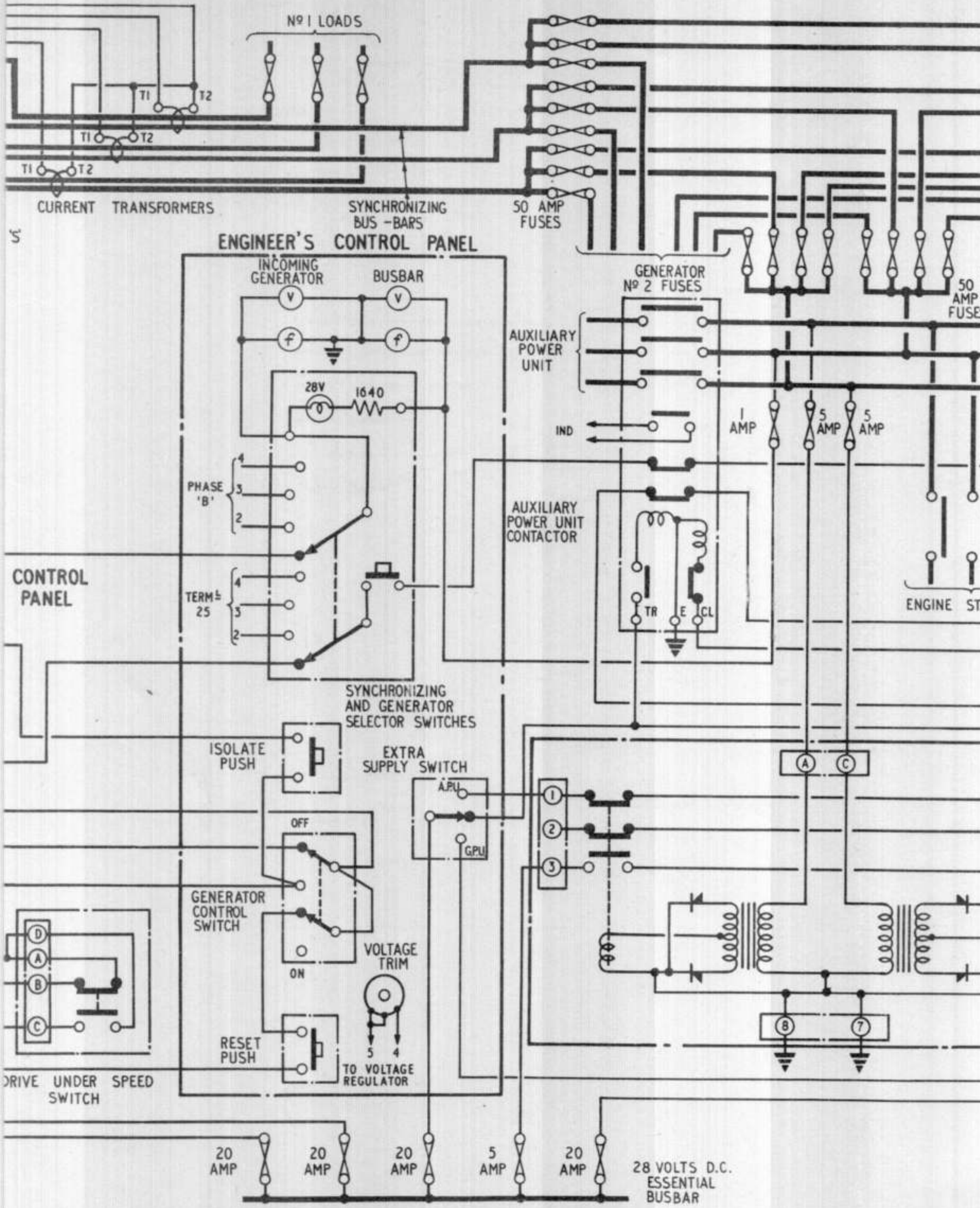
Fig. 12

246958 48118 3297 11/57 3500 CWSLtd2435 Gp979-2



atic diagram of system showing one generator

RESTRICTED



and associated equipment

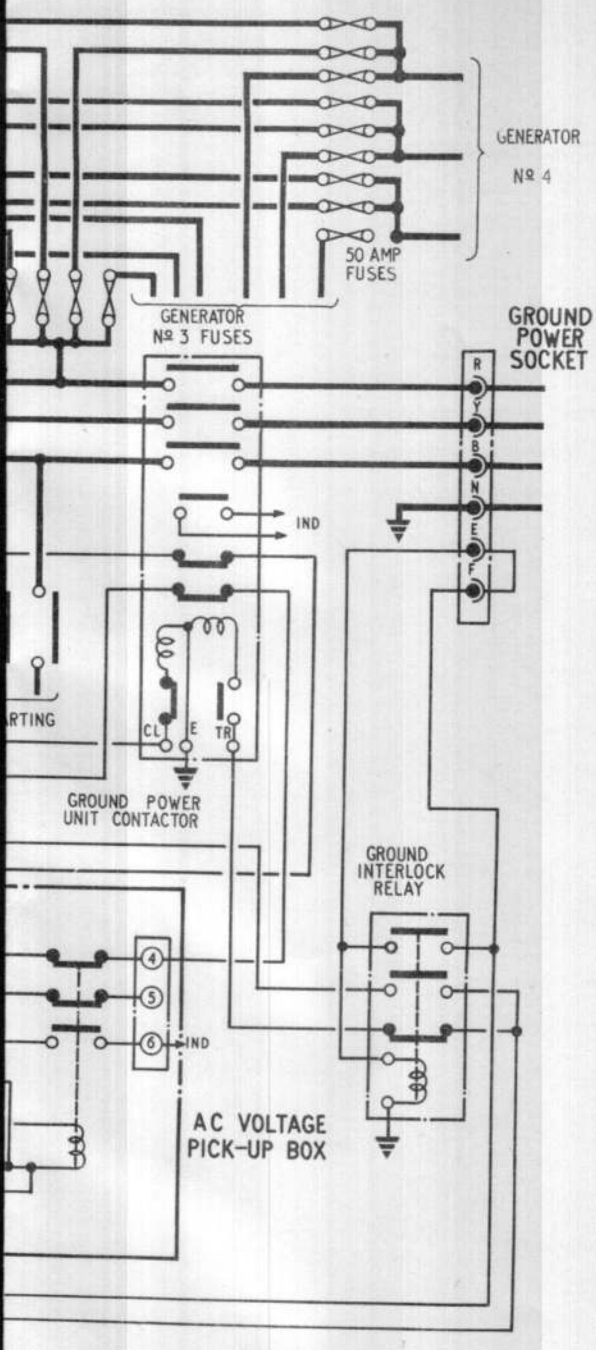

GENERATOR
Nº 4
50 AMP
FUSES
GENERATOR
Nº 3 FUSES
GROUND
POWER
SOCKET
R
Y
B
N
E
F
IND
CL
E
TR
GROUND POWER
UNIT CONTACTOR
GROUND
INTERLOCK
RELAY
4
5
6
IND
AC VOLTAGE
PICK-UP BOX

Fig.12