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Paper 5

The Power Supply

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1 Introduction

The power supplies required by the British Transport Commission for the 50 c.p.s. single phase electrification of its surface railway lines are obtained from the Central Electricity Generating Board. Normally the supplies are obtained from the 132 kV National Grid System but in some localities the supplies are from lower voltage sources (see Paper 28 for details). The supplies are taken by the railway in duplicate as single phase current at 25 kV through 132/25 kV transformers supplied by the Supply Authority. These transformers are normally banked with existing Area Electricity Boards supply transformers utilising a common 132 kV circuit breaker. The supplies are taken to Railway Feeder Stations spaced 20-30 miles apart and the supplies at any one Railway Feeder Station are given at the same phase. The supplies between adjacent stations are not paralleled which enables the Electricity Authority to have the facility of balancing the Railway load between the three phases of its system whilst avoiding possible difficulties in regard to protection and load transfer for the 132 kV system. Where there are severe difficulties in obtaining the required clearance for 25 kV, the overhead lines are operated at the reduced voltage of 6·25 kV.

2 Power Supplies

At the present time the Commission has three main schemes of electrification in hand viz. London Midland Region Main Line, Glasgow Suburban and the Eastern Region suburban aggregating some 790 route miles comprising some 2,500 single track miles. Some individual particulars for each scheme are shown in Table 1. The total demand for all the schemes mentioned therein – allowing for diversity will be of the order of 200 MW and the annual consumption about 950 million units.

The London Midland Region Main line scheme has very special merit in that it caters for all classes of traffic from main line express to heavy goods and a load factor of over 65 per cent is expected to result overall for the year. The curve shown in fig.1 shows the estimated simultaneous max. demand for the scheme through a winter weekday 24 hour period. Consideration is still being given to variations which would have the effect of further improving the load factor. Fig.2 shows estimated daily load curves for two typical supply points.

For the electrified lines included in the Electrification of the Glasgow Suburban Area the power supplies are derived wholly from the 132 kV systems of the South of Scotland Electricity Board and the North of Scotland Hydro-electric Board. The supplies are taken at four points at 25 kV single phase for distribution to the overhead traction system. For the inner area of the scheme due to severely restricting tunnel and bridge clearances the lines are fed at the reduced voltage of 6·25 kV. These 6·25 kV supplies are obtained from the normal 25 kV supplies by means of step down transformers provided by the Commission and installed at Sub-feeder stations.

The lines from Liverpool Street to Southend and Chelmsford are at present electrified on the 1500V D.C. overhead system and the conversion of these lines to operation at

6·25 kV single phase presents a special problem. Although the adoption of 6·25 kV as the nominal voltage enables the insulators to remain generally unchanged as the majority of the existing types of 1500V D.C. insulators are suitable for working at 6·25 kV A.C. nevertheless a separate single A.C. distribution system has to be established for the supply of the requisite power and it is necessary to change all the track feeder cables. All this work has to be carried out without disturbance to the running of the existing electric train services on a route which serves one of the busiest of the London Termini which is a task of the first magnitude. Where applicable the existing 33 kV three-phase supplies are being used by the installation of step down transformers.

Where these 33/6·25 kV transformers are supplied from the existing 33 kV three-phase system the transformers are of the single phase type and the transformers at the ends of the same section but installed in adjoining feeder stations are at the same phase which has the advantage of enabling the overhead supplies to be paralleled on the section. Elsewhere where 6·25 kV supplies are derived from the Area Boards 33 kV network Scott-connected transformers are used to provide a better balance of the Railway load between the three phases of the supply system than would otherwise be the case if single phase transformers were used.

3 Power Supply to the Railway

Paper 28 describes how the C.E.G.B. gives the supplies required by the railway and the main factors to be considered in providing single phase supplies from the national supply system.

There has been very close co-operation with the Board to determine what is mutually the best siting of feeder stations.

4 Location of Railway Feeder Stations

There can be no general answer to the question of the value to be adopted for the distance between the points of supply to the overhead contact system. Primarily the distance is determined from consideration of the traffic to be handled, the performance required of the electric tractors and the electrical characteristics of the overhead and supply systems. Such considerations result in an optimum spacing which it is not often possible to achieve and the desirability of locating the feeder stations at strategic points such as junctions or route intersections frequently results in a shorter spacing being used. Again the feeder stations are preferably situated in close proximity to Grid Substations in order to avoid the disadvantages of long feeders. Generally the Grid Substations are of necessity located near to the large towns which in this country are situated relatively close together. In France the larger towns are further apart which enables a wider spacing to be used. The result of the foregoing consideration is that for the Commission lines the average distance works out at about 25 miles for a nominal line voltage of 25 kV.

For the Commission's 50 c.p.s. electrified lines, the size of the overhead conductors has been chosen to be equivalent to a copper conductor 0·222 sq. in. On some routes (in connection with the measures adopted to limit the voltage induced by the traction currents in nearly parallel running telecommunication cables) booster transformers with return conductors are installed. The size of the return conductors varies from 0·22 sq. in. for the heaviest loaded lines down to ·085 for those lightly loaded.

Having regard to the position of the conductors relative to the track, the values of the impedance of the overhead line used in the calculations are as follows:—

> 0·47 ohm per mile per two track length where no booster transformers and return conductors are installed.
>
> and
>
> 0·7 ohm per mile per two track length with booster transformers and return conductors.

With these typical impedances, it can be shown that for a 25 mile spacing between railway feeder stations and with booster transformers and return conductors installed, this spacing is suitable for working a service of ten trains an hour at an average speed of 60 m.p.h. when hauled by electric locomotives each taking the maximum accelerating current of 270 amps. This is on the basis of a minimum voltage at the locomotives of 16·5 kV for a nominal line pressure of 25 kV.

The curve attached (fig.3) shows the variation of the maximum permissible value of the peak accelerating current per locomotive from a range of distance up to 30 miles. The curve shows the relationship with the conditions with and without booster transformers and return conductors.

Calculations for the 6·25 kV system show that for the conditions where booster transformers and return conductors are installed the ideal spacing for this lower voltage system is about 5½ miles on the basis of a max. value of the peak accelerating current of 1050 amps per train and on the assumption that both ends of the overhead line section are fed in parallel. Curve (fig.4) shows the relationship between spacing and peak accelerating current per train for the 6·25 kV system.

5 The Power Circuit

The supplies from the Central Electricity Generating Board which are given via stepdown 132/25 kV single phase transformers are normally taken in duplicate and are fed to the railway feeder stations usually through concentric 25 kV cables, but overhead lines are used where circumstances permit. Fig.5 shows the arrangement of a Typical 25 kV A.C. Power Supply Installation.

At the railway feeder stations the inner conductor of the concentric cable is taken through a single pole circuit breaker to a busbar from which the supply is distributed through single pole circuit breaker equipments to the overhead conductor lines. The outer conductor of the concentric cable is taken to a busbar designated the 'earthy' busbar which is connected by insulated cables to the running rails. Pantographs fitted to the electric tractors collect the required traction current from the overhead lines and the return current passes via the wheels of the vehicle to the running rails and thence to the supply point through the earthy bar connection. For the operation of the protective system fitted to the circuit breaker equipments as well as for the protection of personnel an earth bar connected directly to an earth electrode is provided at each railway feeder station. At the C.E.G.B. end of the incoming feeder earthing is provided through a spark gap – normally the 25 kV supply is only earthed at the railway end. This is essential for the satisfactory operation of the railway signal track circuiting arrangements. The earth bar is directly connected to the earthy bar. Midway between adjacent feeder stations, a neutral section is provided in the overhead lines to separate electrically the supplies at adjacent feeder stations. At this point a track sectioning cabin is provided containing a group of single pole circuit breakers with a bus coupler switch to provide facilities for through feeding in the event of the loss of supply at the feeder station on either side and also to enable full advantage to be taken of the conductivity of the conductors of parallel tracks and reduce voltage drops in the overhead lines. Midway between this position and the railway feeder station secondary track paralleling cabins are located for overhead line sectioning purposes. In this way the zone of disturbance caused by a fault is kept small and in the event of its being necessary to isolate a section of the overhead line because of a fault the length of the line affected is kept within an acceptable limit.

6 Characteristics of the Circuit Breaker Equipments

The standard arrangement is to take the 25 kV supplies required from the C.E.G.B. 132 kV three-phase network via 132/25 kV single phase transformers connected in parallel with the C.E.G.B. main three-phase transformers for bulk supplies to local undertakings and controlled by the same 132 kV circuit breaker. To cater for the railway load a range of sizes of step down transformer is used viz. 15, 10, 7½ and 5 MVA. The short circuit duty of the 132 kV circuit at the point of the supply ranges from 1500 MVA to 3000 MVA at large capacity stations. The supplies are given in duplicate and the short circuit duty at the railway feeder station busbars is as given in the following table.

Installed Transformer Capacity for Supply to Railway	*Short Circuit Level MVA*
2 × 15 MVA	250—273
2 × 10 MVA	215—228
2 × 7½ MVA	168—174
2 × 5 MVA	116—125

The fault level for the switchgear in the track sectioning cabins attains the following values.

Position of T.S.C.	*Short Circuit Level MVA*	
	2 *Track*	4 *Track*
¼ distance	120	166
Mid point position	76	120

For the 25 kV switchgear required to cover the above range of duty two short circuit ratings have been adopted viz. 300 MVA and 150 MVA. An impulse withstand test voltage of 200 kV has been adopted for all 25 kV switchgear. All switchgear is supplied to a common railway specification.

7 Feeder Circuit Breaker Equipment

When the electrification project was commenced there existed in this country no proved design of 25 kV single phase equipment of the required capacity and duty suitable for railway service. Two designs were selected from the types offered by manufacturers. Both designs are cubicle type but in one the equipment is air insulated and in the other oil insulated. The air insulated type described in Paper 30 and made by Fuller Electric Ltd is installed generally on the Eastern Region new electrification whilst the oil insulated type described in Paper 29 and made by Switchgear and Cowans Ltd is installed generally on the London Midland and Scottish Regions.

There is as yet insufficient service experience to settle a final choice between air or oil insulated equipment but the latter type is very attractive since it has the economic advantage in that the buildings are smaller with lower costs. Furthermore, smaller buildings enable sites for them to be found easier on railway premises so giving greater freedom in locating the feeder stations and T.S.Cs. to meet technical requirements. On the other hand a serious breakdown with air insulated equipment can be much more quickly remedied than is the case with the oil insulated type and it has not the same fire risk. Air insulated switchgear however must be kept carefully and regularly cleaned to remain fit for duty although with the present designs attention has been given to keep the air inside the buildings as dust free as possible so as to make frequent cleaning unnecessary.

Both designs are solenoid operated and arranged for remote control by the supervisory control system and are fitted with fully interlocked hand operated isolators on both incoming and outgoing sides.

7.1 *25 kV Air Insulated Circuit Breaker Equipment*

These 25 kV circuit breakers are single pole indoor oil minimum extraction type of similar design to a smaller version which has proved very satisfactory in service on the Swedish State Railways 16⅔ c.p.s. 16 kV single phase electrification system. This type of circuit breaker is used for the control of incoming and outgoing feeders and for bus section circuit breaker duties.

7.2 *25 kV Oil Insulated Circuit Breaker Equipments*

The circuit breakers are of the single pole indoor fixed dead tank type. Whilst the circuit breaker is built on well proved principles the design was a new application to meet the Commission's specification. The circuit breakers are fitted with a patented single break compensated pressure arc interrupter and trip free solenoid closing mechanism. Each circuit breaker is provided with hand operated isolators to provide for complete isolation. The isolators are interlocked with the circuit breaker. Each circuit breaker is equipped with bushing type current transformers for the feeder protection system and for metering where required.

Each circuit breaker and its component isolators form a unit for combination with other similar units to form a complete switchgroup. Connection to the equipment is by cable by means of an integral oil filled cable box mounted on the underside of the rear isolator chamber. The assembly is supported by four pedestals and in order to facilitate transport the pedestals are bolted into position during erection.

7.3 *6·25 kV Circuit Breaker Equipments*

All 6·25 kV circuit breaker equipments are of the oil insulated type. Those used on the Scottish Region are made by Switchgear and Cowans Ltd and follow the same general design as the 25 kV oil insulated equipments. Those used on the Eastern Region are made by South Wales Switchgear Ltd and are of the truck-mounted type, arranged for isolation by vertical withdrawal. Both makes are solenoid operated and arranged for remote supervisory control.

7.4 *Feeder Protective Systems*

Following normal practice the supply transformers are provided with balanced earth fault protection on both the H.V. and L.V. sides, together with Buchholz winding temperature and high voltage overcurrent protection. The supply feeders are protected by a Merz-Price balanced voltage system of protection with provision for intertripping. The system is usually of the Solkor pattern.

The protection of the overhead contact system is of the definite distance impedance type similar to that which has been very successfully applied to the overhead contact system of both the French and Swedish railway electrification systems. The system varies slightly with the manufacturers, one type providing for two zones and the other which is more extensively applied, for three zones. Both are described in Paper 31. The system has the advantage over an overcurrent system in that variation in tripping time is determined by variation of impedance instead of current magnitude. This is particularly advantageous in the case of faults to the overhead system where prolongation of the fault current necessary to give an overcurrent system time to act might severely damage the conductors. The system is backed up by a long time thermal relay to provide for tripping on the occurrence of a long sustained overload. Information concerning tripping times is given in Section 5 of Paper 31.

The 25/6·25 kV step down transformers where installed are protected either by a bias differential system or a restricted earth fault system of protection of conventional design. Definite minimum inverse time relay protection is fitted at the supply end of the 25 kV feeders and on the H.V. side of the 25/6·25 kV transformer.

7.5 *Lightning Arresters*

Lightning arresters of the silicon carbide negative resistance type, made by A.S.E.A., Västerås, Sweden, are fitted on the outgoing feeders to the overhead contact system at 25 kV Feeder Stations and on all 6·25 kV outgoing feeders to the contact system.

The lightning arresters are fitted on the adjacent overhead equipment supporting structures and are connected to the connection between the track feeder cables and the overhead equipment, the earth connection being made to an earth rod system at the base of the structure.

8 Supervisory Remote Control Equipment

Following British Railways standard practice, all the circuit breakers used to control the overhead distribution system are remotely operated and indicated from centrally situated control stations by means of supervisory control equipment.

On the D.C. electrification systems the control is effected by D.C. currents transmitted over pilot cables, connecting the various groups of switchgear with the control station, but for the 50 c.p.s. single phase A.C. electrification system in order to avoid magnetically induced disturbances from the traction currents affecting the proper working of the apparatus, a voice frequency system of signalling is employed. The two systems employed on the present Electrification schemes are described in some detail on Paper 32 which explains the extent to which design has been controlled by the Commission specifications to ensure that the two systems are operationally compatible with one another.

All switch operations are effected from a vertical mimic switchboard at the control station. The switchboard is formed of a mosaic of one inch squares on which the circuit of the overhead lines are represented by coloured lines the switchgear being represented by ‘ discrepancy ’ type switches inserted in their appropriate positions in the diagram. The system embraces a comprehensive telecommunication system to facilitate maintenance.

The supervisory system is served by duplicate pilot cables and in the event of the pilot cable in use becoming faulty an alarm is given and the supervisory equipment is changed over to the sound pilot cable. The supervisory equipment may be changed from one pilot to the other at will.

9 Booster Transformers

The normal arrangement of the conductors (overhead wires and running rails) for the A.C. single phase system of railway electrification forms an unbalanced circuit. The effect is that by magnetic induction the traction currents cause induced voltages to appear in neighbouring parallel conductors such as telecommunication cables, the effect varying directly with the traction currents. The decision to install booster transformers either with or without return conductors as a means of limiting the magnitude of the induced voltage discussed in Paper 9 has introduced special problems for power supply.

The booster transformers are in effect power current transformers with unity ratio and are used with their primary windings connected in series with the overhead line and with their secondaries connected either directly to the running rails (rail return type) or to a special return conductor (return conductor type).

The effects of the installation of booster transformers require particular study in order that an economic result can be achieved.

The most important effect is the increase in impedance of the power circuit which because of its influence on voltage drop on the distribution system requires special attention to ensure that the performance of the traction equipment is not adversely affected.

There is also the effect on the action on the definite distance impedance protective system fitted to the track feeder equipment. Although the sensitivity of this equipment is increased to some extent by the increase in impedance per unit length the step in impedance at the booster transformer itself causes the location of the fault by the system to be less exact.

There is also the effect on rail potential to earth. With the system with the booster transformers connected directly to the running rails the potential of the rail when several trains are taking current becomes progressively higher in steps until the feeder station is reached. For the system with return conductors, however, the value of this potential is highest at the individual train.

Overall these are the disadvantages of increased losses and consequently increased running costs.

The following table gives characteristic values of the impedance for the system.

Normal System ohms/mile	*System fitted with Booster Transformers* — *With direct connection to rails. ohms/mile*	*With Return Conductors. ohms/mile*
Per single track		
·75 —·85	1·16—1·40	1·4
Per double track		
·445—·5	·58— ·70	·70

In designing the booster transformer installation the magnitude of induced voltages from normal service has to be assessed from the load due to the service. The information is produced in the form of a diagram which shows the distribution of the traction current for each section of line. The distribution is based on the maximum values of the traction current per train, the frequency of train service and on the interval between trains and an estimate of the probability of all trains taking current at the same time. All trains must be taken into consideration. In addition information is prepared of the calculated value of the fault current for an all metallic short circuit at each position in the section.

The capacity of the booster transformers required depends on the length of the section to be fed by the transformers and whether direct rail connections or return conductors are to be employed, and on the mean value of the traction current.

For the peak accelerating currents for the electric locomotives and multiple unit trains consideration of the induction compensating requirements result in a spacing of about one mile for booster transformers with direct rail connection and about two miles for transformers with return conductors.

In the case of boosters with return conductors the secondary voltage varies with the impedance of the return conductor and consequently the capacity of the transformer varies with the size of the conductor e.g. a large capacity transformer is required to deal with return conductors of relatively small cross sectional area. Consequently the most economical arrangement results from comparison of the costs including losses of different sized return conductors and their matching booster transformers always bearing in mind that the lower limit of the size of the return conductor is determined by the ability of the conductor to carry the current without deterioration. It is also necessary for the conductor to be of adequate mechanical strength to resist wind and ice loading.

Booster transformers of the following sizes have been adopted—

Rail return type.

Working voltage	25 kV	25 kV
Mean current amps	150	200
Peak current amps	495	660

Return Conductor type.

Working voltage	25 kV	25 kV	25 kV	25 kV	
Mean current amps	100	150	200	300	
Peak current amps	500	600	600	600	
Working voltage	6·25kV	6·25 kV	6·25 kV	6·25 kV	6·25 kV
Mean current amps	100	150	200	300	400
Peak current amps	900	900	1200	1500	2000

Contracts have been placed with Fuller Electric Ltd and with Foster Transformers Ltd for all these types.

10 Cables and Accessories

10.1 *Main Power Supply Cables*

10.1.1 *25 kV Concentric Cables*

The Incoming 25 kV Supplies from the C.E.G.B. are delivered to the railway feeder stations through two-core concentric pressure cables at 25 kV to earth. The same type of cable is also used where connections are required between railway feeder stations. Generally the cables are of the oil-filled type but some are gas filled. This latter type which has the advantage of a lower charging current is favoured for tunnel use. Cables having copper conductors and lead alloy sheaths and also cables having aluminium conductors and corrugated aluminium sheaths have been installed.

At Crewe the incoming 25 kV supply cables have copper conductors of 0·85 sq. in. cross sectional area but usually

0·50 sq. in. conductors are sufficient where the supply transformers are rated at 15 MVA as at Crewe.

On the Colchester–Clacton–Walton electrification the 25 kV cable terminations are of the outdoor sealing end type but on the London Midland and Scottish Regions and for the further schemes on the Eastern Region the 25 kV concentric pressure type cables are connected to indoor type switchgear by means of oil immersed sealing ends.

10.1.2 33 *kV Cables*
On the Great Eastern Electrified lines there are existing substations with interconnecting 33 kV three core cables. The lines will be converted to the A.C. system but the 33 kV distribution system will be retained with modifications to permit of different feeding arrangements to suit the A.C. system as well as for the augmented traction loads.

One of the existing 33 kV three core solid type cables will be extended with similar type cable but two additional 33 kV cables will be installed. These latter two cables will be of the oil filled type with shaped aluminium conductors laid up without fillers and corrugated aluminium sheathed.

10.1.3 *Pilot Cables for Main Supply Feeder Protection*
The pilot cables for the main supply feeder protection purposes are laid with the cables. They are of the 110V mass impregnated type and have either four or seven conductors each 7/·036 sq. in.

10.2 *Track Feeder Cables*

10.2.1 25 *kV*
The connections from the switchgear to the 25 kV overhead contact system are formed of 25 kV single core solid type cables. To date either 0·15 sq. in. or 0·2 sq. in. copper conductor lead alloy 'B' sheathed mass impregnated paper insulated cables have been installed but on later installations trials are being made at suitable locations of 25 kV mass impregnated non-draining type cable side by side with the more conventional type of cable.

10.2.2 6·25 *kV*
The connections from the switchgear to the 6·25 kV overhead system are formed of 6·25 kV to earth single core solid type cables. The cables have either 0·25 or 0·50 sq. in. copper conductors with mass impregnated paper insulation and lead alloy 'B' sheathed.

10.3 *Traction Return Feeder Cables*
The connections from the running rails to the feeder station traction return busbars and also from the running rails to booster transformer secondaries are formed of rubber insulated 660V single core cables. These cables which are duplicated where necessary have 0·15 sq. in. copper conductors and are braided and compounded over the rubber insulation.

10.4 *Transformer Connections*
The H.V. connections to the terminals of the single phase transformer winding are of the same type of cable as is used for connections to the overhead system. The same range of sizes is employed 25 kV or 6·25 kV being used as required, with the addition of a 0·75 sq. in. cable for 6·25 kV connections. The connections to the earthy end of the single phase transformer windings are formed of 660V rubber insulated single core cable with copper conductors 0·15 sq. in. for 25 kV windings and 0·75 sq. in. for 6·25 kV windings. Where necessary connections are in duplicate.

10.5 *Cable Routes*
The high voltage cables are installed in precast concrete troughing laid at surface level in the cess or the verge of the railway, where they cannot be buried direct.

At other locations where there are space restrictions or obstructions a post route is adopted. In this case the cables are supported; in continuous asbestos cement tubes in the case of lead alloy sheathed cables and by hangers in the case of aluminium sheathed cables.

10.6 Contracts for the supply of cables to a standard specification have been awarded to the undermentioned firms:—

Aberdare Cables Ltd
Associated Electrical Industries Ltd
British Insulated Callenders Cables Ltd
Enfield-Standard Power Cables Ltd
Johnson & Phillips Ltd
Pirelli-General Cable Works Ltd
Scottish Cables Ltd
W. T. Glover & Co. Ltd.

11 Auxiliary Supplies
Auxiliary supplies are derived from the 25 kV traction supply – 6·25 kV in 6·25 kV areas – by means of step down transformers controlled by fuse units. The supplies provide a standby supply for signalling purposes, and for battery charging, lighting, heating, and reference voltages at feeder stations and T.S.Cs. In the case of signalling the normal supplies are taken from the local town medium voltage supply. The fuse unit controlling the 25 kV or 6·25 kV supply to the transformer consists of a cubicle of the same general dimensions as the circuit breaker equipment. It contains isolators and busbar and an air insulated H.R.C. fuse. The auxiliary supply transformers are 25 kV or 6·25 kV/625V/240V, the 625V output being fitted with a voltage regulator. The signalling supplies are distributed at 625V, auxiliary signalling supply transformers with ratio 415/625V are used to step up the local supply to the requisite voltage for the signalling main. The voltage regulators deal with variations in supply of + 10 per cent and − 30 per cent to give an output of 625V within ± 3 per cent and with a speed of correction of 6 per cent per second.

In general the signalling supplies are given at 50 c.p.s. single phase but for the Great Eastern Conversion scheme and in certain areas in the Eastern Region where D.C. track circuits are precluded, the signalling supplies are given as two separate fixed phase related single phase supplies each at $83\frac{1}{3}$ c.p.s. These $83\frac{1}{3}$ c.p.s. supplies are derived from duplicate synchronous motor alternator sets operated from the local town low voltage 50 cycle supply. Each set consists of a motor coupled to two alternators. Standby supplies in the above area are given by diesel alternator sets arranged to come into operation in four secs. following a failure or voltage fluctuation exceeding + or − 6 per cent of the normal supply.

The reference voltage for the distance impedance protective system is derived from 25000/110V voltage transformers. Usually two of these transformers are fitted per busbar section, one for normal supply and the other standby. Changeover from normal to standby is effected manually. In the case of oil insulated H.V. feeder equipments the reference voltage transformers are mounted on incoming and outgoing feeder equipments. In the case of air insulated equipment the transformers are housed in separate cubicles designated voltage transformer units.

A contract for auxiliary supply transformers has been placed with Foster Transformers Ltd and for voltage regulators with Brentford Transformers Ltd.

12 Battery Equipments

Batteries are used for circuit breaker closing operation and supervisory control. 110V batteries are used for circuit breaker closing having a capacity of 50 A.Hr. where there are less than four circuit breakers and 75 A.Hr. where there are four or more circuit breakers. For supervisory control 50V batteries are provided, 100 A.Hr. or 150 A.Hr. capacity at the control stations and 20 A.Hr. or 40 A.Hr. at the controlled points. The batteries are of the normal lead acid enclosed type.

The batteries are charged from equipments operated from a 240V single phase supply. The chargers are equipped with selenium rectifiers and arranged for full wave rectification. Two rate charging equipments are used with the circuit breaker closing batteries. For the supervisory control system the chargers are arranged for quick charging, floating and trickle charging. These equipments are fitted with an output smoothing choke to limit the ripple on the D.C. output to 2 mV on float charging and to 5 mV on boost charge in order to give the requisite degree of smoothing required for use on telecommunication apparatus.

A contract was awarded to Tungstone Products Ltd for the supply of all the batteries including chargers made by Partridge Wilson & Co. Ltd as sub-contractors.

13 Feeder Station and T.S.C. Buildings

As it is essential for efficient electric railway operation for all maintenance work to be performed at any time of the day or night and unhampered by adverse weather conditions all circuit breaker equipment and its associated control gear and auxiliaries is of the indoor type housed inside buildings. The buildings are brick built with cavity walls and have flat concrete roofs. In order to simplify the construction the minimum of fixing holes are used. No cables are laid in the floor. All ducts in the walls for cable entries and outlets and bushings (when used) are arranged by the use of precast units inserted in their proper positions during the construction of the building. The floors are of concrete with an anti-dust finish of the granolithic type and with a final coating which takes a polish improving with time giving a very attractive finish overall. A minimum of heating is used and this is applied at the most effective positions. Apart from the telephone associated directly with the supervisory remote control system a separate telephone is provided for direct communication with the exchange at the central control station and with all stations and depots on route as well as at strategic points such as tunnel entrances etc. A feature of the telephone instrument is that it is also accessible from outside the building even when the building is closed.

14 Main Transformers

The 132/25 kV Single Phase Transformers are of conventional design of the oil filled naturally cooled type. Off load tap changing of ± $2\frac{1}{2}$ and 5 per cent is now normally provided but for the first three supply points viz. Colchester, Stockport and Crewe transformers with supervisorily controlled 'on' load tap changing were installed. Although the transformers are naturally cooled it is likely that future supply points will be equipped with arrangements to enable the blowing of all transformers if required to meet developing load. All 132/25 kV transformers are purchased by the C.E.G.B. and the sizes of transformers have been standardised as follows:—

15 M.V.A.
10 M.V.A.
$7\frac{1}{2}$ M.V.A.
and 5 M.V.A.

Where the 25 kV supplies are derived from networks operating at voltages lower than 66 kV i.e. 33 kV and 11 kV and where 6·25 kV supplies are derived from the 25 kV supplies the transformers are purchased by the Commission. These transformers are also of conventional design of the oil filled naturally cooled type. All the transformers with 25 kV output are of single phase type as is also the case generally for the transformers with 6·25 kV outputs. At certain supply points on the Shenfield – Southend line and on the London – Tilbury – Southend line the 33/6·25 transformers are of the Scott connected type. The sizes of the transformers with 25 kV outputs are the same as those for the C.E.G.B. purchased units and the sizes of the 6·25 kV output transformers are standardised as follows:—

7·5 M.V.A.
5·0 M.V.A.
3·0 M.V.A.

Contracts for the supply of main transformers to a standard specification have been awarded to the following firms:—

Bruce Peebles and Co. Ltd
C. A. Parsons and Co. Ltd
Crompton Parkinson Ltd
Hackbridge and Hewittic Electric Co. Ltd.

15 Conclusion

In spite of the additional problem of supplying 6·25 kV, the Paper shows the essential simplicity of the power supply arrangements for 50 cycle A.C. electrification. The electrification schemes in hand do not show that system to the best advantage. The suburban electrifications include a high proportion of 6·25 kV working and the extent to which the problem of supply is complicated by the use of booster transformers is probably not representative of all lines suitable for electrification. To some extent the assessment of this matter must depend upon the effects observed in the System Test programme and on the development of other techniques for interference prevention to which reference is made in Paper 9.

TABLE I.

Power demands for Electrification in hand at 25 and 6·25 kV.

Scheme	*Route Mileage*	*Single Line Miles*	*No. of Supply Points*	*Max. Demand*	*Power Consumption Annual*	*Approx. Load Factor Annual*
				M.W.	*K.W. hrs. (million)*	*per cent*
L.M. Main Line						
Euston Manchester Liverpool	500	1780	12	109	640	67
Scottish Region						
Glasgow Suburban (Stage 1)	71	163	4	18	56	35
Eastern Region						
G. E. Conversions	52	174	6 }			
Chelmsford Colchester	22	49	0 }	49	148	34
Colchester Clacton Walton	24	50	1 }			
London Chingford Enfield Bishops Stortford ...	45	105	4	13	34	30
London Tilbury Southend	75	172	3	27	61	26
Total	789	2493	29	—	—	—

SUMMARY

The Paper refers to the different nature of the power supply to a railway electrified with a 25 kV 50 c.p.s. single phase system in comparison with one electrified with a D.C. system and refers to Paper 28 for information of how the C.E.G.B. supplies are given to the railway.

It assesses the scope of the power supply requirements for the lines now being electrified with some particulars of load and shows to what extent natural circumstances determine the location of the feeding points, track sectioning positions and control stations.

It discusses the special problems introduced by the decision to use booster transformers with and without return conductors for the reduction of interference with special reference to the effect on voltage distribution.

It is shown that only two short circuit ratings for 25 kV are required and contrasts the type of circuit breaker equipments being used and the methods of circuit protection employed.

The extent of standardisation of remote control equipment and of the divergencies permitted is discussed.

The Paper concludes by giving brief particulars of the power supply transformers bought by the Commission and of the types of cables used for track feeders and of the arrangements for giving auxiliary and ancillary supplies.

RÉSUMÉ

Cet exposé fait mention des différences entre l'alimentation en énergie d'une ligne électrifiée en courant monophasé 25 kV 50 Hz et celle d'une ligne électrifiée en courant continu et réfère à l'exposé 28 pour des renseignements concernant les méthodes d'alimenter, du réseau de la Central Electricity Generating Board, les lignes du chemin de fer.

Il évalue l'étendue des conditions requises pour l'alimentation en énergie des lignes actuellement en cours d'électrification et donne quelques details concernant la charge électrique. Il démontre à quel degré l'implantation des stations d'alimentation, des postes de sectionnement et des postes de commande a été imposée par des circonstances géographiques.

Il traite les problèmes spéciaux posés par la décision d'employer les transformateurs-suceurs, avec et sans conducteurs de retour, pour réduire les effets d'induction, et il traite particulièrement l'effet de l'emploi de cet équipement sur les valeurs de la tension en ligne.

On démontre que deux valeurs de capacité de coupure suffisent pour les disjoncteurs 25 kV. On compare les différents types de disjoncteur employés à présent ainsi que les systèmes de protection adoptés.

On fait mention du degré de normalisation introduit pour les appareils de télécommande et des divergences permises entre l'équipement fourni par les différents fabricants.

Enfin de brefs détails sont donnés des transformateurs d'alimentation achetés par la Commission et des types de câbles employés comme feeders de voie et des dispositions faites pour l'alimentation en énergie des appareils auxiliaires et accessoires.

ZUSAMMENFASSUNG

Der Bericht bezieht sich auf die verschiedenen Eigenschaften der Stromversorgung für die mit dem 25 kV, 50 Hz, einphasen System elektrifizierten Eisenbahnen, und gibt einen Vergleich mit einem Gleichstromsystem. Für weitere Auskunft, wie die Eisenbahnen durch die ' Central Electricity Generating Board ' gespeist werden, wird auf Bericht 28 verwiesen.

Der Spielraum der Stromversorgungsanforderungen der jetzt elektrifizierten Linien wird abgeschätzt und einige Belastungseinzelheiten angegeben, ferner wird gezeigt, in wie weit natürliche Umstände die Lage der Speisepunkte, Fahrleitungstrennstellen und Kontrollstationen bestimmen.

Spezielle Probleme, die durch die Entscheidung Hilfstransformatoren mit oder ohne Rückleiter anzuwenden um die Beeinflussung zu reduzieren, werden mit besonderer Verweisung auf die Wirkung der Spannungsverteilung diskutiert.

Es wird gezeigt, dass bei 25 kV nur zwei Nennkurzschlussleistungen benötigt werden. Die angewendeten Arten der Unterbrecher-Ausrüstungen und Stromkreis-Schutzmethoden werden durch Gegenüberstellung verglichen.

Das Ausmass der Normalisierung der Fernsteuerungseinrichtung und der erlaubten Abweichungen werden diskutiert.

Der Bericht gibt abschliessend kurze Einzelheiten der von der ' British Transport Commission ' gekauften Stromversorgungstransformatoren, der für die Schienen-Speiseleitungen verwendeten Kabel und der Anordnungen für die Hilfsspeisungen und Nebenversorgungen.

RESÚMEN

Este folleto compara el suministro de fuerza motriz entre un ferrocarril electrificado a 25 kV 50 ciclos con uno electrificado con corriente continua. Tambien se relaciona con el folleto 28 en lo que se refiere a como la ' C.E.G.B.' suministra la fuerza motriz al ferrocarril.

Estudia el problema de la fuerza motriz en las lineas que se estan electrificando en estos momentos detallando las cargas. Tambien se refiere a la influencia que sobre la ubicacion de los puntos de alimentacion tienen las condiciones existentes. Esto mismo se refleja tambien en los puntos de seccionalizacion y estaciones de control.

Se analizan los problemas que introducen la incorporacion de transformadores compensadores con o sin conductores de retorno en especial se consideran problemas de interferencia y efectos secundarios en el voltaje de distribucion.

Se demuetra que solamente dos tipos de capacidad de ruptura son utilazados a 25 kV. Se comparan los interruptores utilizados y los sistemas de proteccion.

Se analizan normas para equipos de control remoto, asi como la posibilidad de alternativas en las mismas.

Finalmente se detallan los transformadores comprados por la comision, cables utilizados para los alimentadores y detalles de los suministros auxiliares y circuitos suplementarios.

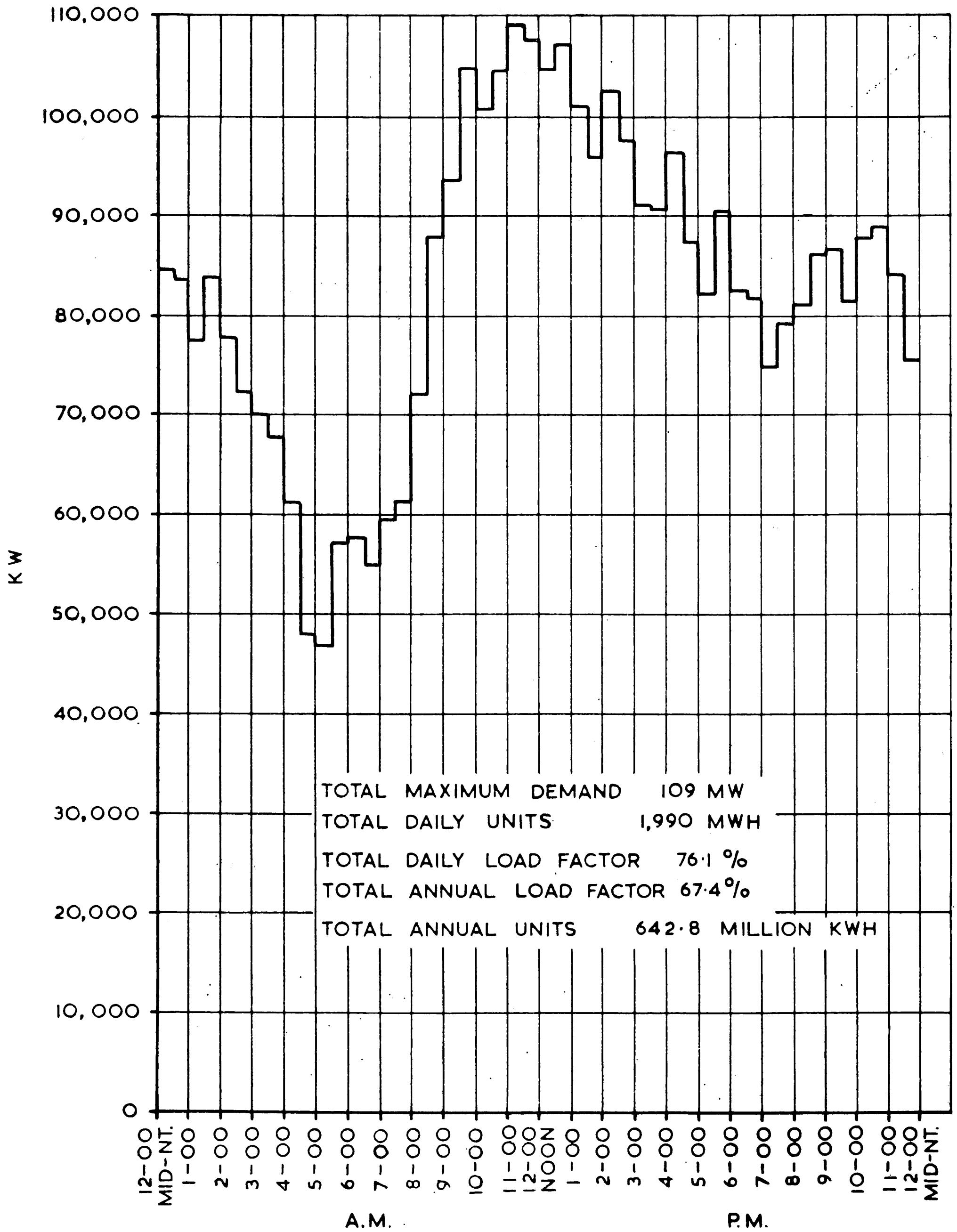

Fig.1 Euston – Manchester – Liverpool electrification. Total 24-hour feeder station loading winter weekday.

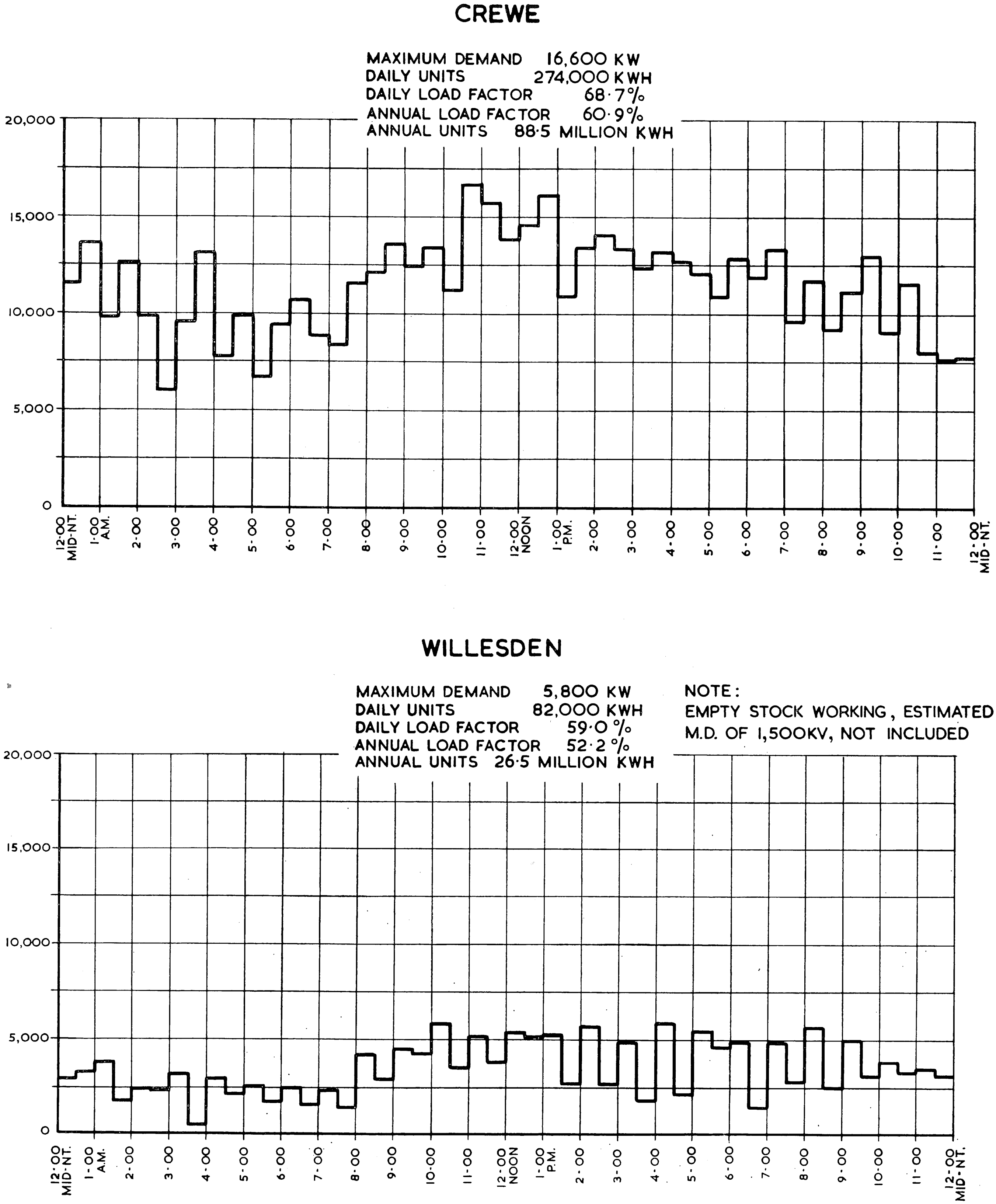

Fig.2 Euston – Manchester – Liverpool electrification. Daily load curves for typical supply points.

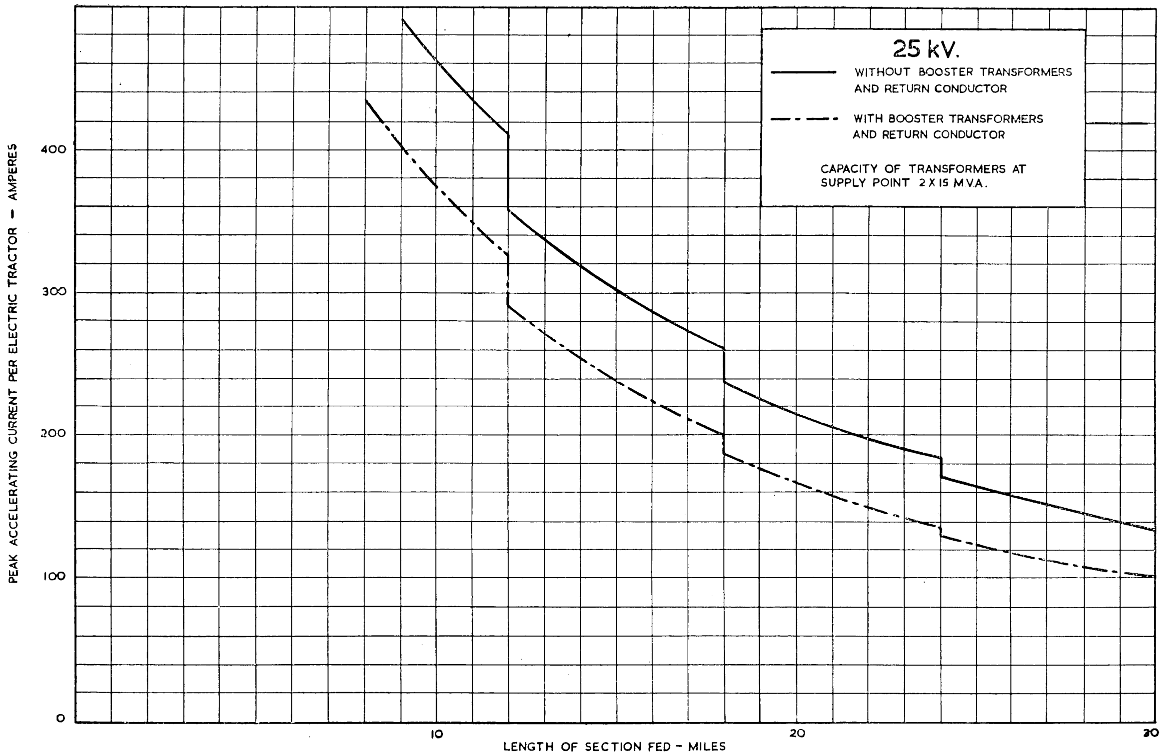

Fig.3 **25 kV–relationship of peak accelerating current per electric tractor to length of section for a service of 10 trains an hour on each track running at an average speed of 60 m.p.h.**

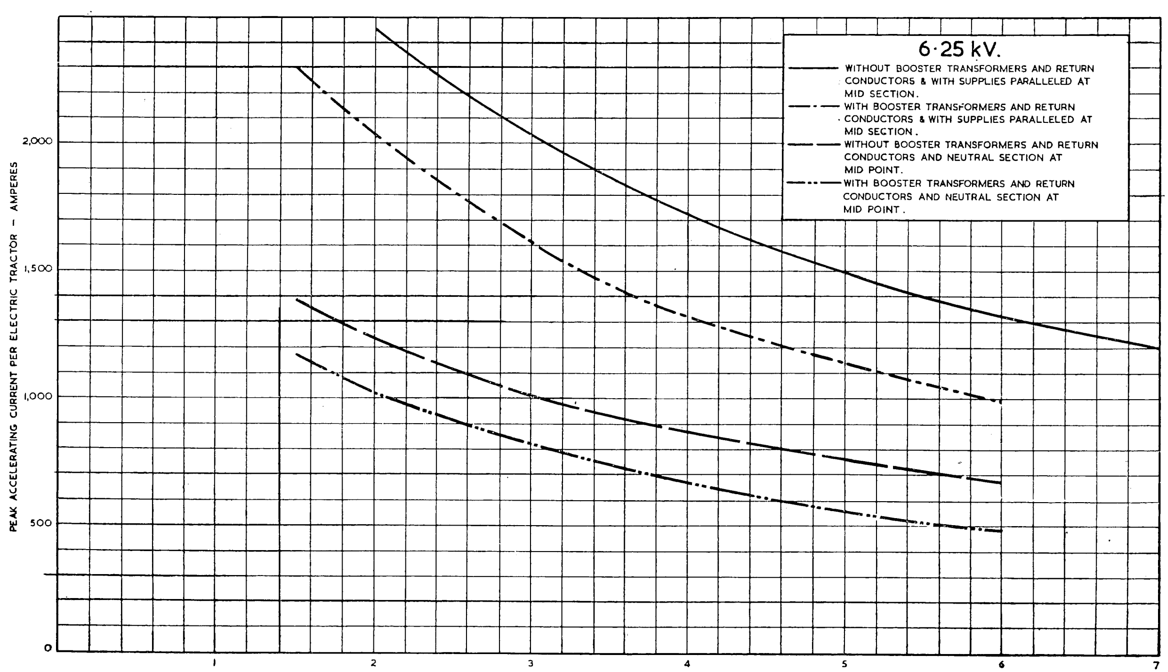

Fig.4 **6.25 kV–relationship of peak accelerating current per electric tractor to length of section for one train on each track in position to give highest voltage drop.**

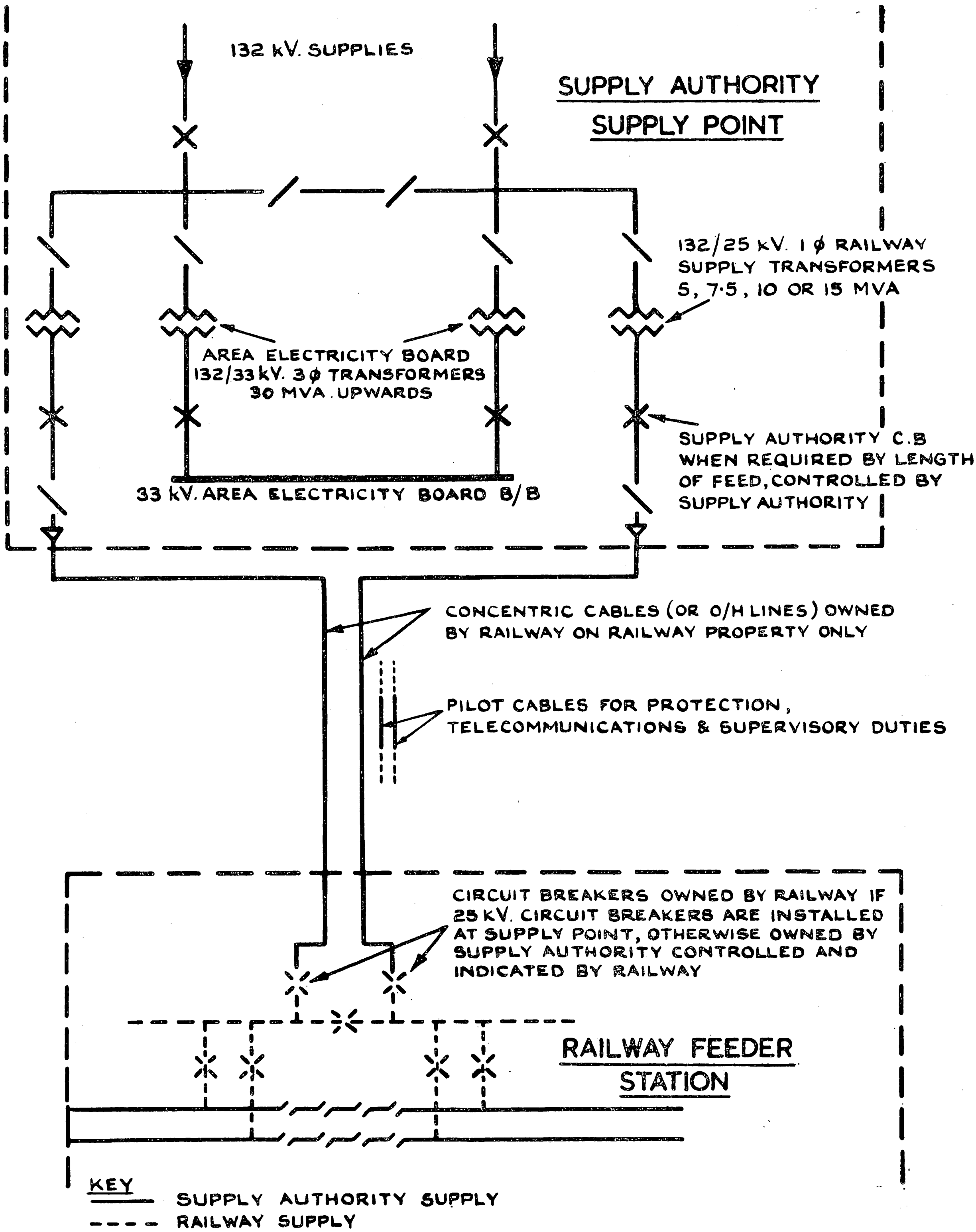

Fig.5 Typical 24 kV power supply installation.

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