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Volume 45 MARCH 1954 Part 3

PROCEEDINGS AT THE FOUR HUNDRED AND FORTY-SECOND GENERAL MEETING

Held at Kelvin House, corner Marshall and Hollard Streets, Johannesburg

Thursday, 25th March 1954

PROFESSOR G. R. BOZZOLI (Senior Vice-President) was in the Chair and opened the meeting at 8 p.m.

There were present 85 members and visitors and the Assistant Secretary.

The Chairman, before declaring the meeting open, said he had to apologize for the absence of the President who, as most of those present would know, was seriously ill. It was learned that he was progressing as well as could be expected under the circumstances, and he was sure all present wished a message of good cheer to be sent to him and all hoped that he would soon be fully recovered and back in his normal routine.

MINUTES

The minutes of the monthly general meeting held on the 25th February 1954 were taken as read and were confirmed.

MEMBERSHIP

The Chairman announced that in terms of By-Law 5.2.4 the Council had elected the undermentioned candidates to membership of the Institute in the following grades :—

Associate Members : ERVIN BIDERMAN, PATRICK OXTON REID.

Associates : REGINALD WAR GUEST, JOHN WILLIAM RICE.

Students : ARTHUR HAROLD ROEBL, DEMETRIUS JOHN STRATOUDAKIS.

Transfer from Associate Member to Member : HEINZ DIETER EINHORN.

Transfer from Graduate to Associate Member : JAMES DOUGLAS BURNELL, MARCEL ETTER, NATHAN KIRSCHNER.

Transfer from Student to Graduate : NORMAN ERIC FISHER, DOUGLAS GELLING, MICHAEL JOHN LAY, NORMAN MORRISON, DAVID FRANCOIS ODENDAAL, WALTER JAMES TAYLOR.

Transfer from Student to Associate : ERNEST IVAN VISSER.

PAPER AND DISCUSSION

T. G. Baird (Associate Member) presented his paper entitled 'Modern switchgear installations in Great Britain.'

The Chairman proposed a vote of thanks to the author for his paper. H. G. Val Davies (Associate Member), E. W. Dixon (Associate Member), H. L. Black (Associate Member) and A. G. V. Pearce (Associate Member) contributed to the discussion.

The Chairman declared the meeting closed at 10.5 p.m.

Institute Notes

Cape Western Local Centre

Members of the Institute visiting Cape Town are cordially invited to attend general meetings of the Cape Western Local Centre which are held in Demonstration Theatre, Electricity House, Strand Street, Cape Town, on the second Thursday of each month.

A general meeting of the Cape Western Local Centre was held in the Railway Recreation Tea Room, Railway Institute Building, Cape Town, on Thursday, 18th March, 1954.

Mr C. G. Downie (Chairman of the Centre) was in the Chair and declared the meeting open at 8.20 p.m. Thirty members and visitors were present.

A paper entitled 'Workshop testing of 160 h.p. induction motor to obtain circle diagram and practical application thereof,' was presented by S. T. Smith (Associate Member).

The author dealt very ably with both the technical and practical aspects of the subject which evoked favourable comment from those present and he was congratulated on the ingenuity displayed in testing the motor with the equipment at his disposal and on the degree of accuracy obtained. Contributors to the discussion on the paper were :—The Chairman Dr H. D. Einhorn (Member), C. N. Larkin (Member) (Vice-Chairman of the Section), J. F. MacHutchin, J. K. Georgala (Associate), B. Morison (Associate Member).

The Chairman extended a very hearty welcome to Mr A. J. Adams, Secretary of the Institute who was on a visit to Cape Town. Mr Adams in reply, thanked the Chairman for his cordial welcome and expressed his pleasure at being present, and although he had attended the meeting in an unofficial capacity, he was sure that the Council would wish him to convey their very best wishes for the continued success and progress of the Cape Western Local Centre.

The meeting concluded with a vote of thanks to the lecturer at 10.15 p.m.

Membership

In accordance with By-Law 7.7.1, the membership of the following has ceased as from the 1st January, 1954 :—

Associate Members :

J. R. Phipps.

Graduates :

A. Levin.
S. P. Meltzer.
G. F. E. Wolmarans.

Associates :

E. F. Darker.
P. F. Davis.
B. F. Fouche.
W. D. Holmes.
B. W. Munks.
V. E. North.

Students :

J. H. Coulson.
E. J. De Groot.
C. J. De Lange.
C. J. Du Plessis.
C. H. Pretorius.
G. J. Putterill.
M. B. Shapiro.
J. J. Van der Linde.
F. A. Webster.
L. L. Wilson.

MODERN SWITCHGEAR INSTALLATIONS IN GREAT BRITAIN

By T. G. BAIRD* (Associate Member)

Paper received on 17th November 1953

SUMMARY

The paper describes some of the modern high-voltage switchgear recently and now being installed in Great Britain and in particular the 132-kV and 275-kV switching and transforming stations of the British Electricity Authority.

Typical layouts of switching and transforming stations are given together with reasons for the ever increasing use of reinforced concrete for strain structures. Reasons are also given for the trend towards air-blast and pneumatically operated circuit-breakers for the higher voltages.

Reference is made to the control, supervisory, protection and auxiliary equipment as are details of measures taken to avoid danger to the operating personnel and damage to plant.

Brief references are also made to lower-voltage switchgear installed in recent years.

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2. PLANNING
3. TYPICAL LAYOUTS
4. MAIN SWITCHGEAR
5. CONTROL SUPERVISORY AND PROTECTION EQUIPMENT
6. AUXILIARY PLANT
7. CONCLUSIONS
8. ACKNOWLEDGMENTS
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1. INTRODUCTION

Prior to the 1st April 1948, 541 separate electricity undertakings carried out the generation and distribution of electricity, a function now performed by the British Electricity Authority who were created under the Electricity Act 1947.

Amongst these various undertakings who were vested in the Authority on 1st April 1948 was the Central Electricity Board who twenty-one years earlier had been formed under the Electricity Act 1926 to co-ordinate and control the economic operation of the many undertaking's power stations (although they did not own or staff them), to construct and operate a vast network of 132-kV inter-connectors between the various power stations and associated transforming and switching stations and to a lesser degree 66-kV and 33-kV networks to supply the smaller undertakings whose generating capacity was either inadequate or it was not possible for one reason or another to extend the station or whose generating plant was uneconomic to operate. The output of the power stations was purchased by the 'Board' and resold to the undertakings, the undertakings being responsible within the limits of their statutory authorized areas for distributing supplies to their consumers at voltages in general not greater than 66 kV.

The British Electricity Authority (B.E.A.) is broadly subdivided into (*i*) the Central Authority, responsible for policy, generation, transmission and research and (*ii*) fourteen Electricity Area Boards who are concerned with the distribution to the consumer of energy bought from the Central Authority. The Central Authority is subdivided into fourteen Divisions each having the same geographical areas as the Electricity Area Boards.

The size of the undertaking can be assessed from the fact that the actual cost of assets taken over by the B.E.A. was of the order of £830 million which by 1950 had passed the £1 000 million mark and in that year they had in addition some £300 million of outstanding contractual capital commitments.

It can be readily understood that before vesting day it had not been possible to plan and carry out efficiently and economically the distribution of electricity, neither was it possible to promote to any extent

* Mr. Baird is Assistant System Extensions Construction Engineer, Electricity Supply Commission—Rand Undertaking. Formally Senior Assistant Engineer (Co-ordinating) Chief Engineers Dept., B.E.A.

standardization of systems of supply and distribution nor standardization of equipment. The reorganization of the industry has made possible long-term planning and enables new generating, transforming and switching stations to be sited in the most advantageous position both in regard to the consumer and the Authority.

Sir John Hacking,[1] Deputy Chairman of the Authority, in his address as President of The Institution of Electrical Engineers

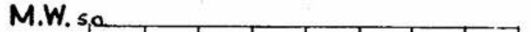

Fig. 1—Curve showing new generating plant—M.W. sent out commissioned annually for the years 1945-1952

gave in some detail the phenomenal growth of demand in Britain during the ten years 1939–1949 and quoted a figure of 83 per cent as being the increase over this period with a National load figure of 30 000 MW by 1965 and he gave for that reason the urgent necessity for greatly increased capacity of generating plant and transmission equipment and in particular high-voltage switchgear.

The 132-kV switchgear originally installed by the Central Electricity Board on the Grid from 1929 onwards and now vested in the B.E.A. had in general a rating of 1 500 MVA. Because of a far greater measure of interconnection and therefore an ever-increasing complexity of the transmission system coupled with the additional generating capacity regularly coming into commission (Fig. 1) more arduous conditions will prevail which high-voltage switchgear will have to contend with when interrupting system faults. In certain cases it will be possible to modify the existing switchgear to increase its short-circuit capacity but it became increasingly evident that a large proportion would have to be replaced by switchgear having ratings of 2 500 and 3 500 MVA.

The majority of new 132-kV switchgear would have to be capable of withstanding short circuits of this order and, in the case of the proposed 275-kV switchgear, 7 500 MVA. For the same reasons much of the lower-voltage switchgear would also have to be replaced by more robust types.

The 132-kV Grid system was initially designed (*i*) on a regional basis to enable maximum economies to be effected in so far as standby generating plant was concerned and (*ii*) to permit the most efficient stations to cover base loads whilst the less efficient covered peak loads and emergency conditions only. It was never intended generally that large bulks of power should be transmitted from one end of the country to another.

The Authority have been faced with the difficulty of finding and obtaining sites for new power stations and this coupled with the varying costs of coal and high costs of transporting coal from the coalfields have made it necessary to locate new power stations on the coalfields and transmitting their output over a 275-kV network to the large load centres.

It is the purpose of this paper to describe some of the more recent installations of switchgear which have been or are going to be established in switching and transforming stations as a result of the foregoing.

2. PLANNING

The planning of the 275- and 132-kV stations both electrically and their siting geographically is the prerogative of the Central Authority working in close collaboration with the various Electricity Boards. The whole of the works are let out to contract, the engineering being supervised either by the Authority's staff or by consulting engineers operating on behalf of and in conjunction with the Authority.

The selection of sites in relation to existing or proposed power stations, supply points, overhead lines or cable routes has presented some difficulty particularly in regard to the major transforming and switching stations, since such large areas are required. The area of a normal double-busbar 132-kV switching station comprising four generator bays, two station-transformer bays, four feeder bays, bus-coupler and bus-section bays, excluding transformers and control room, is of the order of 3 acres and for a typical 275-kV transforming station comprising ten 275-kV bays with transformers and associated 132-kV equipment about 12 acres. It has become increasingly difficult to obtain such sites in the places they are required. In many cases, particularly in built-up areas, such large parcels of land are unobtainable and it is possible that in any case their cost would be prohibitive. The Authority have therefore had to resort to 132-kV switch houses (Fig. 2) and indoor switchgear where by careful design the amount of floor area can be considerably reduced. The costs of such buildings to house the 132-kV switchgear are immense but, however, it is perhaps fortunate that in those cases where the Authority have been forced into installing 132-kV switchgear in switch houses they would have been faced with additional costs for higher levels of insulation since without exception these cases occur in areas where atmospheric pollution is pernicious.

3. TYPICAL LAYOUTS

3·1 *Structures*

The trend towards the use of reinforced-concrete structures in preference to fabricated steel is most marked. Considerable thought has been given by the British Electricity Authority to the use of cast-in-situ reinforced-concrete structures, and pre-cast reinforced-concrete structures instead of fabricated steel structures. At the time when the stations now coming into commission were designed, fabricated steel was in short supply whilst reinforcing steel although not plentiful was more readily obtainable. Past experience has shown that the reinforced-concrete structures are less costly to maintain and for that reason alone the reinforced-concrete structure designs, whether of the cast-in-situ or pre-cast type, are regarded as being superior in so far as British conditions are concerned ; their disadvantage is the slightly greater initial cost and the longer period required for their erection. This is particularly so in the case of the cast-in-situ structure, the pre-cast structure, however, can be mass produced once the initial moulds have been made but they do not lend themselves to

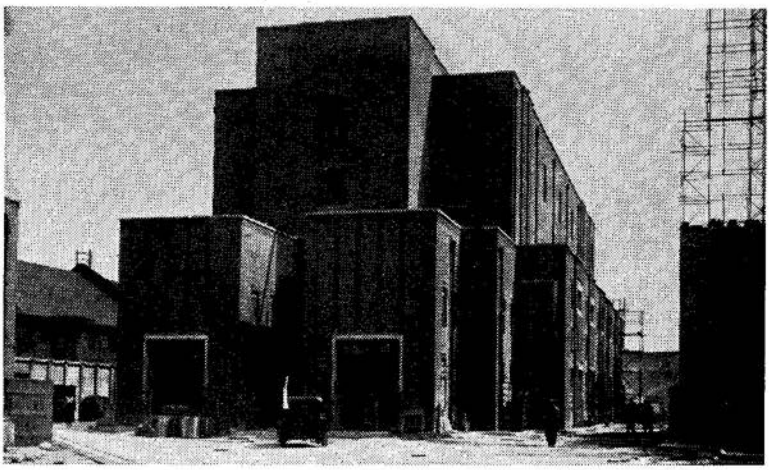

Fig. 2—132-kV switchhouse as installed at Brunswick Wharf, Polar, London

modification subsequent to their erection. Fig. 3 shows typical reinforced-concrete strain structures of cast-in-situ and pre-cast types in general use which are capable of sustaining in one direction a maximum tension of 2 000 lbs per conductor.

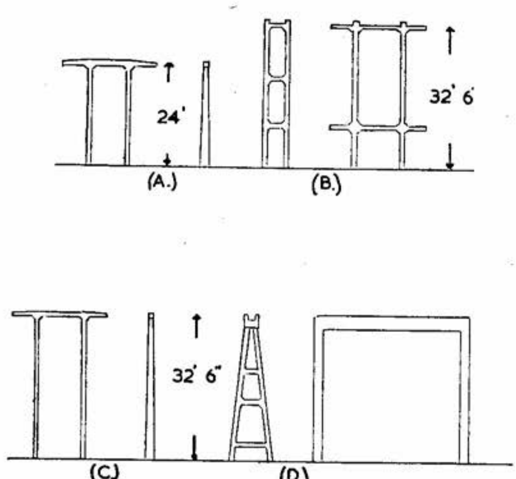

Fig. 3—Typical reinforced-concrete structures

Busbar strain structure pre-cast concrete
ii Aerial crossover strain structure pre-cast concrete
iii Intermediate aerial crossover structure pre-cast concrete
iv Aerial crossover strain structure cast-in-situ concrete

The assumed conditions of loading and the minimum factors of safety for outdoor switchgear are given in Table I.

TABLE I

Assumed conditions of loading for outdoor switchgear

Minimum temperature of busbars and connections	—6°C
Maximum temperature of busbars and connections	85°C
Wind pressure per sq.ft. of whole of projected area of busbars, connections, insulators and apparatus	25 lb
Wind pressure on structures per sq.ft. of one and a half times the projected area of members of one face	25 lb

Minimum factors of safety for outdoor switchgear

Busbars or other connections based on ultimate strength	2
Complete insulator units based on electromechanical test	2½
Insulator metal fittings based on elastic limit	2½
Structures based on elastic limit of tension members and on crippling loads of compression members	2½
Foundations for structures against overturning or uprooting under maximum working loadings	2½

3·2 *Schematic diagrams of 132-kV stations*

In Fig. 4 are shown in schematic form the primary connections of three designs of 132-kV stations in general use, namely the feeder-transformer station, the 3-switch station and the double-busbar station.

The feeder-transformer station has been installed in those cases where a second point of supply is required adjacent to an existing supply point or adjacent to a major switching station.

The 3-switch station developed by the Central Electricity Board is a modification of the ring-main station and gives a measure of duplicate supply at minimum cost and is readily extendable to double busbar should future conditions demand it.

The double-busbar design is that used for the majority of stations now coming into commission.

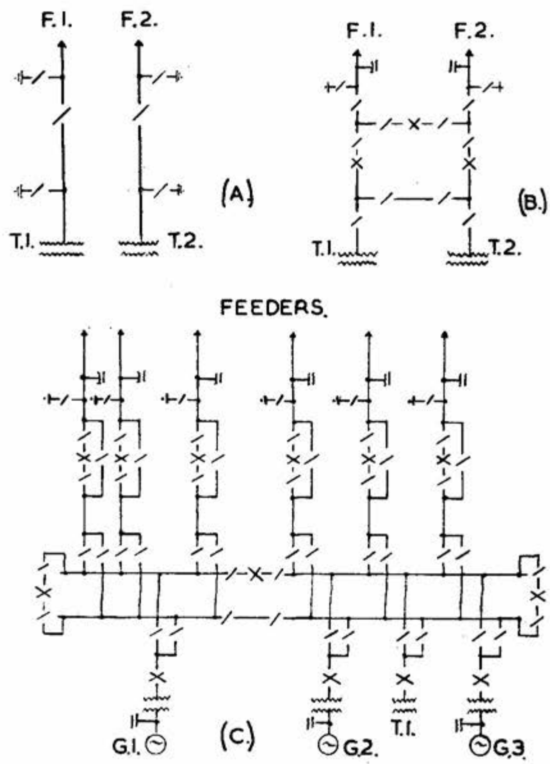

Fig. 4—Typical schematic diagrams of 132-kV substations

i Feeder transformer station
ii 3-switch station
iii Double bus-bar station

3·3 132-*kV feeder transformer station*

Fig. 5 shows a typical layout of the feeder-transformer station, its main feature being its simplicity and the absence of 132-kV circuit-breakers and high structures, the 132-kV circuit-breakers controlling the two incoming lines being positioned at the switching station at the remote end of the lines. The lead-in from the overhead 132-kV lines are anchored to cast-in-situ concrete post insulator supports and connections taken via a similarly mounted combined line and transformer isolator to the transformer terminals. The combined line and transformer isolators have earthing switches on the line and transformer sides each mechanically interlocked with their associated isolator.

The use of high strain structures to carry the low-voltage connections from the transformer to the cable-sealing ends and auxiliary earthing transformer permits the transformer to be removed without having to dismantle cumbersome transformer low-voltage support structures, a feature incidentally which is common to all the newer stations of all types.

The transformers are normally operated in parallel, no 132-kV paralleling connection at the feeder-transforming station is necessary since the incoming 132-kV lines at their remote end are connected to the same busbar of the major switching station.

3·4 132-*kV* 3-*switch station*

A typical layout of this design is shown in Fig. 6 and in this case all strain structures

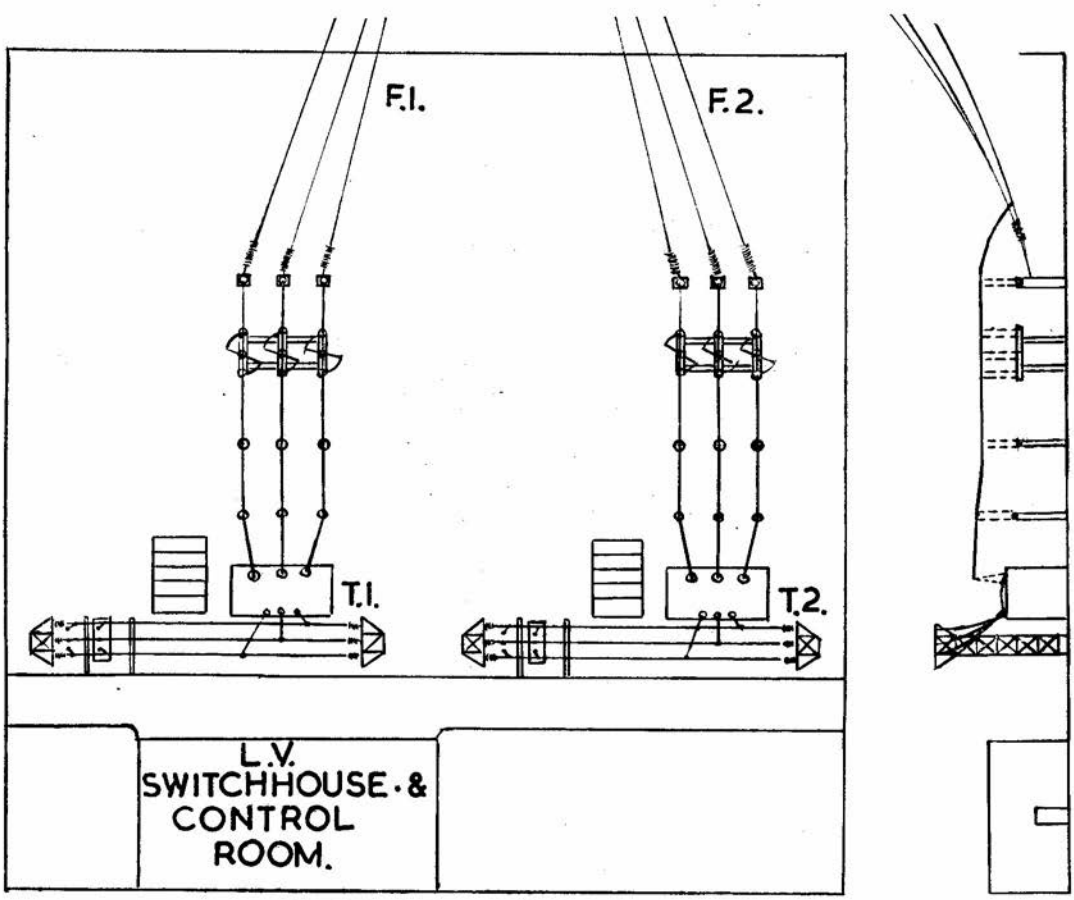

Fig. 5—Typical layout of feeder transformer station

are fabricated steel and all isolator and post insulator supports are cast-in-situ reinforced concrete.

The main feature of these stations is the use of only three circuit-breakers to carry out the duty normally performed by five. Furthermore the layout permits the station to be extended to double busbars should future conditions demand it. The installed equipment per line and transformer consists of a line isolator with a mechanically interlocked earthing switch in the line side, a circuit-breaker isolator, circuit-breaker and transformer isolator. Since the station is essentially a ring-main station the lines are coupled by means of a bus-section switch and two bus-section isolators to complete the line ring. An additional feature of this design is the by-pass connection on the transformer side of the transformer circuit-breakers. This arrangement enables any circuit-breaker to be overhauled without disturbing the line ring, and enables both transformers to be fed from one line or both lines from one transformer.

When the station is converted to double busbars the bus-section connections become the main busbar and the by-pass connection the second or reserve busbar.

The low-voltage connections are arranged in a similar manner to the feeder-transformer station, cable being used for the connections between the transformer low-voltage terminals and the low-voltage switchgear.

3·5 132-*kV* *double-busbar switching and transforming stations*

3·5·1 Intermediate busbar level

A typical layout of the intermediate busbar level is shown in Fig. 7a, the station being designed for an ultimate capacity of 22 circuits, comprising nine 132-kV feeder bays, two of which will have series reactors, four generator bays, four 132/275-kV bus-interconnector-transformer bays, two station-transformer bays, two bus-coupler bays and one bus-section bay. The area

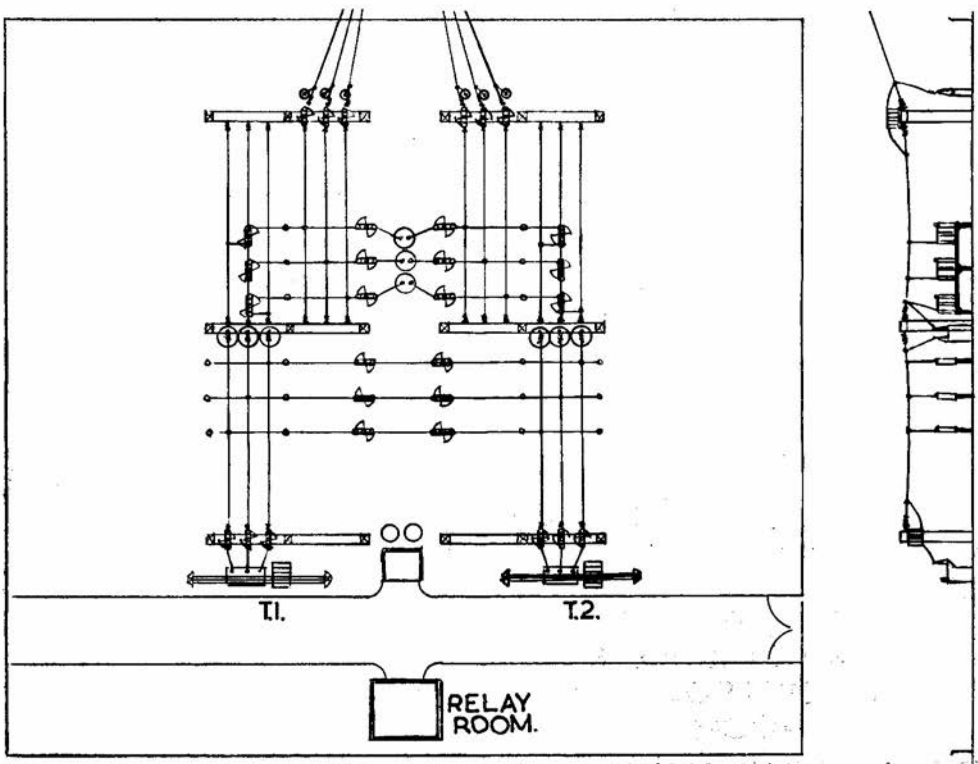

Fig. 6—Typical layout of 3-switch station

required for this station is of the order of 13 500 sq. yds. or approximately $2\frac{3}{4}$ acres.

The station differs from earlier designs in so far as it has its busbars of flexible conductor strained at an intermediate level 24 ft from ground level, the cross-over aerials are at 32 ft 6 in from ground level, whilst the live portion of the busbar

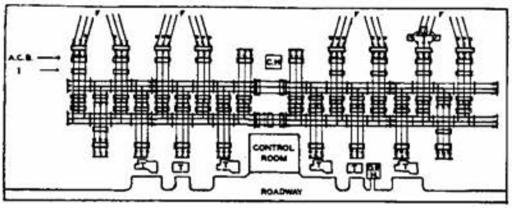

Fig. 7A—Layout of Carrington 132-kV Intermediate Level, Double Busbar

T. Transformers
F. Feeders
I. Isolators
A.C.B. Air-blast circuit-breaker
O.P.H. Oil plant house
C.H. Compressor house

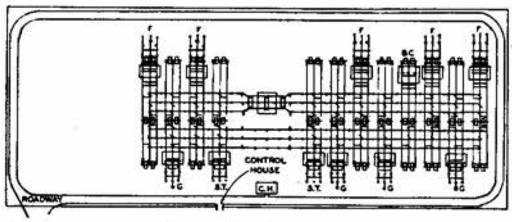

Fig. 7B—Layout of Keadby 132-kV Low Level, Double Busbar

S.T. Station transformers
G. Generator
B.C. Bus coupler
F. Feeders

isolators are 15 ft from ground level. Normal spacing of the bays is at 34-ft centres minimum to 38-ft maximum and the length of the bays between strain structure centres is 90 ft. These dimensions permit working clearances in excess of the minimum requirements, as given in Table II.

TABLE II

ABSOLUTE MINIMUM CLEARANCES FOR 132-kv OUT-DOOR STATIONS

Equipment	*Clearance*
Busbars—phase to phase	78 in
Busbars—phase to earth	44 in
Other then busbars—phase to phase ...	63 in
Other than busbars—phase to earth ...	39 in
Section clearance (i.e. to give safe working clearance	135 in

All strain structures, intermediate busbar-insulator supports, circuit-breaker and isolator supports are pre-cast reinforced concrete, multi-core cable, oil-pipe and compressed-air-pipe line trenches are pre-cast concrete 'U' shaped sections keyed together and covered with pre-cast reinforced—concrete slabs.

Provision has been made for the accommodation of 132-kV cables and necessary 132-kV cable-sealing ends which will be required in connection with future reactors and the 132/275-kV transformers.

The normal feeder bays are equipped with a line isolator, line-earthing switch, circuit-breaker-bypass isolator, circuit-breaker, circuit-breaker isolator and two busbar selector isolators. The circuit-breaker-bypass isolator is positioned on top of the associated incoming line strain structure and permits the circuit-breaker to be by-passed whilst still retaining the feeder in commission, one or other of the coupler switches being used as a feeder switch.

The transformer and generator bays are equipped with a circuit-breaker and two busbar-selector isolators. The bus-coupler and bus-section bays are each equipped with a circuit-breaker and an isolator on each side of the breaker.

The reserve busbar has no bus-section circuit-breaker but provision is made for sectionalizing by the use of two isolators. All circuit-breakers installed are 800-ampere 3 500-MVA rupturing capacity airblast and are mounted on high supports.

The capacity of Carrington Power Station which is adjacent to the switching and transforming station will be 240 MVA having four 60-MVA sets. The outgoing feeders supply the Manchester area and the station is of course interconnected to the Grid.

Fig. 8 is a photograph of that portion of the station already commissioned.

3·5·2 Low busbar level

The layout of the station shown in Fig. 7b is of low busbar design, this being the essential difference between it and the station described in Paragraph 3·5·1. The busbars in this station are rigid tubular copper supported at 15 ft from ground level by the busbar isolators themselves and at intermediate positions by post insulators mounted on cast-in-situ reinforced-concrete supports. This arrangement avoids the necessity for high and costly busbar strain structures, gives a cleaner design and affords a convenient method of connecting the isolator to the busbar.

A typical feeder bay at Keadby is illustrated in Fig. 9, and Fig. 10 is an end view of Beddington showing the busbar arrangement.

At Keadby the crossover aerials are strained at 32 ft 6 in from ground level from cast-in-situ reinforced-concrete structures whilst those at Beddington are strained from fabricated-steel structures also at 32 ft 6 in from ground level.

Normal spacing of the bays is at 32 ft centres which permits clearances not less than those given in Table II. The circuit-breakers at each station although of different manufacture are air-blast 600-ampere and rated at 2 500 MVA and in each case they are mounted on low plinths thus necessitating the provision of screening to prevent danger to the operating personnel.

Keadby deals with the export from Keadby Power Station and supplies the Hull and Grimsby areas. The station will eventually have twenty circuits. Beddington is associated with the export requirements of the new Croydon 'B' Power Station and supplies a large portion of South West London suburbs and Surrey. The ultimate capacity of this substation is twenty-four circuits of which fifteen have already been commissioned.

A feature of interest to South African transmission engineers concerning British 132-kV outdoor-type switching and transforming stations is the absence of earth screening to provide protection against direct lightning strokes.

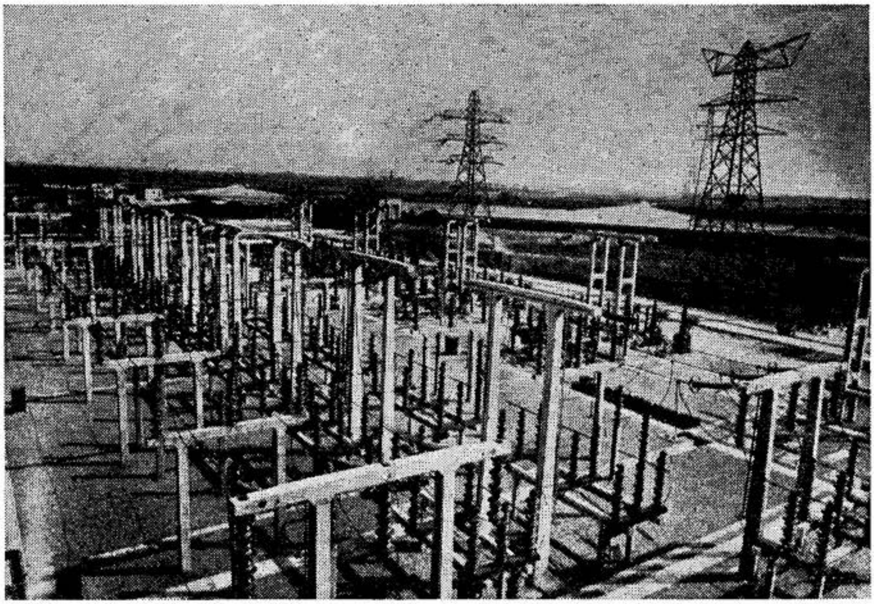

Fig. 8—Carrington 132-kV switching station

The tower earth wires are not strung to the substation structure except in rare cases where it is not possible nor desirable to connect the terminal-tower footing earths to the substation main earth. In the majority of cases an underground earth connection is made from the terminal-tower footing earths to the station earth.

J. S. Forrest in his I.E.E. paper 'The Performance of the British Grid System in Thunderstorms'[2] gave figures for faults at Grid substations during the period 1934–1947. The number of switchgear breakdowns, bushing flashovers, post- or string-insulator flashovers and cable-box failures attributable to lightning during this period was given as 25, or 12 per cent of the total

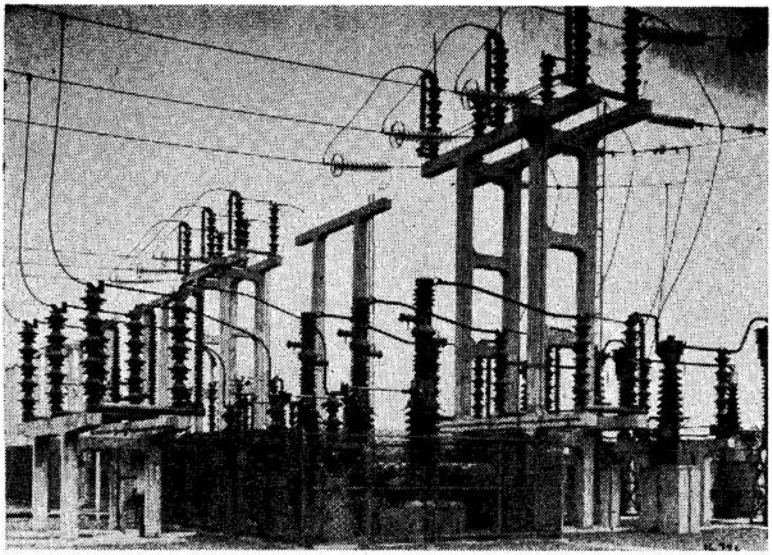

Fig. 9—Keadby 132-kV switching station
(Feeder bay line side)

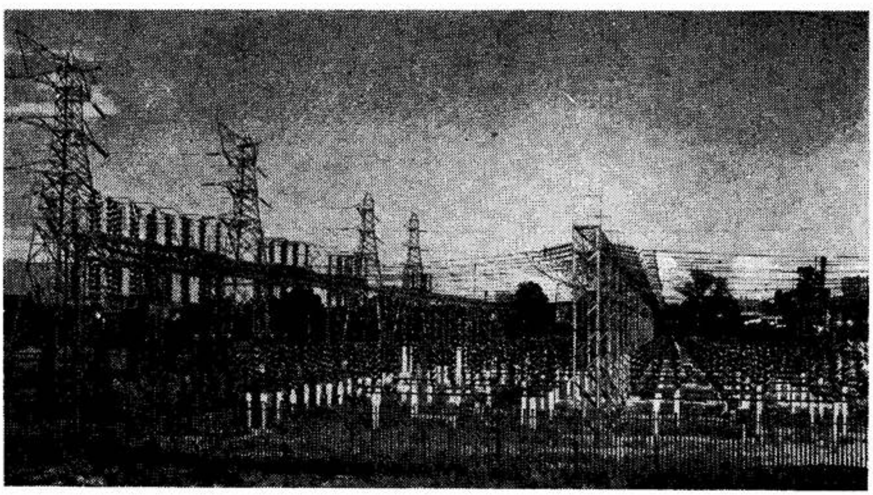

Fig. 10—Beddington 132-kV switching station
(End view showing busbars)

faults due to lightning. In his conclusion Mr Forrest suggests that the probability of a Grid substation in Britain having a fault due to a direct lightning stroke is one fault per 70 years and for that reason the additional cost of providing earth screening at switching and transforming stations is not justified.

3·6 132-*kV* *double-busbar indoor switchgear*

A perspective view and section of a typical 132-kV switch house which has a capacity for twenty-eight circuits and will be associated with the export from Barking 'C' London Power Station is given in Fig. 11.

The building which is of reinforced-concrete frame design with external brick finish has the following dimensions: length 257 ft, width 150 ft and height above ground level 64 ft with a cable basement 8 ft. The ground area required to accommodate the twenty-eight circuits is 38 550 sq. ft. which is approximately only 30 per cent of that required for Carrington designed for twenty-two circuits, a considerable saving where space is limited and land values costly. All feeder entries are by 132-kV underground cables and the equipment with exception of

TABLE III

Typical design characteristics for 132-kV indoor switchgear

Normal voltage between phases ...	132 kV
Minimum dry flashover voltage of insulators or bushings without horns ...	320 kV
Designed impulse withstand level (crest kV of 1/50 wave)	550 kV
Minimum clearance in air between live metal of different phases	63 in
Minimum clearance in air between live metal and earth	44 in
Minimum clearance between live metal and any permissible point of work or access way with interposition of earthed screens	135 in
Minimum total length of air gap between terminals of isolating switches in the open position	63 in

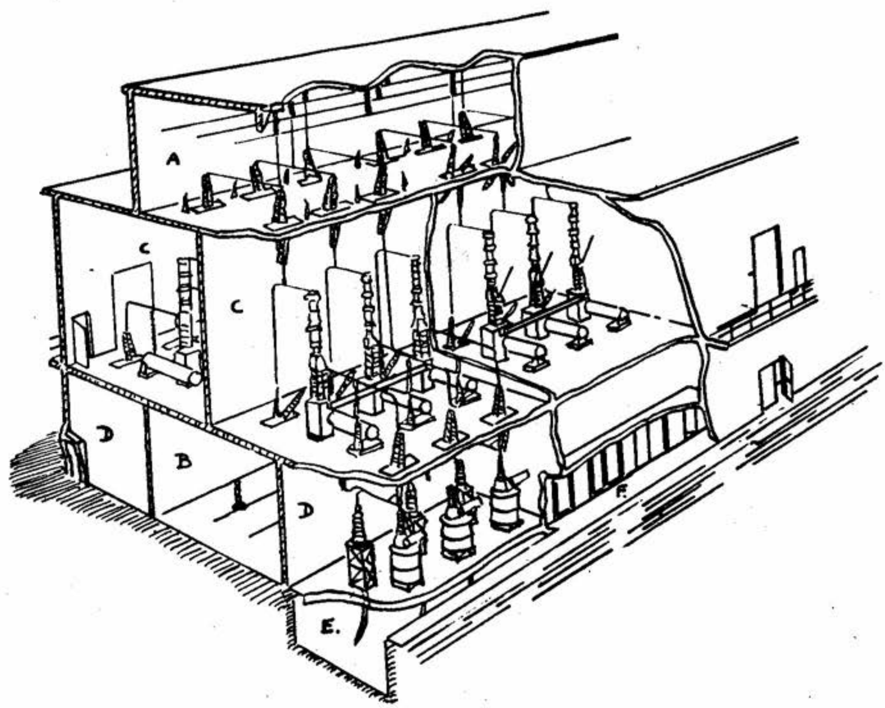

Fig. 11—Perspective View of 132 kV Switch-house

A. Main busbar floor
B. Reserve busbar floor
C. Air blast circuit breaker cubicle
D. Cable sealing end and voltage-transformer cubicle
E. Cable basement
F. Local control panel gallery

the busbar support insulators, circuit-breakers and voltage transformers is of special design.

Design characteristics for typical 132-kV indoor switchgear are given in Table III.

3·7 *275-kV double-busbar switching and transforming stations*

Low busbar

The layout of this 275-kV station which is to be established at Drakelow in the East Midland Division is somewhat similar to the layout of the 132-kV low-busbar stations already described.

All structures supporting the busbar isolators, circuit-breaker isolators, circuit-breakers, intermediate busbar post insulators are of reinforced concrete as are also the crossover aerial strain structures. The strain structures are of the 'H' construction, both legs of each structure being 'A' shaped. The length of each transformer bay including the 275/132-kV transformer and associated 132-kV cable-sealing ends is 358 ft and that of the feeder bay 256 ft. The width of each feeder and transformer bay is 55 ft and that of the bus-section and bus-coupler bays 78 ft. Two heights of strain structure are used, one at 42 ft 9 in and one at 36 ft 9 in, the phase clearance between the aerials being 18 ft whilst the busbars are spaced at 22 ft 6 in centres. The centres of the busbars are 20 ft from ground level and 17 ft 6 in is the minimum distance from live metal to ground level.

These dimensions permit clearances for the busbars and connections not less than those given in Table IV.

TABLE IV

MINIMUM CLEARANCES FOR 275-kV STATIONS

Equipment	*Clearances*
Minimum clearance between live metal and earth	84 in
Minimum clearance between live metal of different phases	98 in
Minimum total air gap between terminals of the same pole, e.g. isolators ...	98 in
Minimum safety clearance between live metal positions to which access is permissible with other equipment alive	180 in

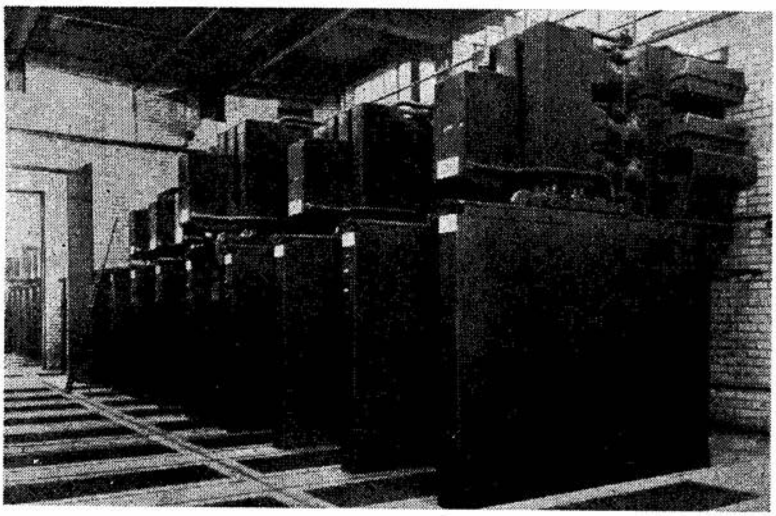

Fig. 12—33-kV 1 500-MVA metalclad switchgear, horizontal isolation

The clearances given above are applicable only to the equipment not subject to impulse-voltage tests and they apply for conditions of maximum swing and sag of strained flexible conductors.

The air-blast circuit-breakers are 1 200-ampere and have a rating of 7 500 MVA. This station will be one of the links by means of which the output from power stations in the coalfields will be transmitted to the heavy-load areas.

Unlike the 132-kV feeder bays in double busbar stations the 275-kV feeder bays are not equipped with isolators for bypassing the circuit-breaker. However the layout of equipment permits temporary by-pass connections to be readily made should the need arise. Provision has also been made in the design of the feeder strain structures, and sufficient room left between the circuit-breaker and the adjacent busbars for the necessary isolators to be installed should operating experience prove the desirability of a by-pass feature. These isolators were omitted initially to cut down the capital cost.

3·8 *33-kV and lower-voltage double-busbar switching stations*

3·8·1 Indoor switchgear

In general the majority of substations for the lower voltages in Great Britain are of the indoor type, and the switchgear invariably metalclad with horizontal or vertical isolation of the circuit-breaker.

This switchgear owes its popularity to the comparatively small area it occupies, its compactness, the low height of the building required to house the gear, its freedom from the troubles associated with vermin and, because of the total enclosure of live metal, the safety of operating personnel. In view of the fact that metalclad gear is usually either compound filled or oil filled with bulk-oil type circuit-breakers; fire-barrier walls, automatic fireproof doors and oil drains are installed and a greater degree of sectionalization is carried out. Due to the compactness of the equipment headroom between the switchgear and the ceiling seldom exceeds 2 ft and building costs are thereby reduced. A typical installation of 33-kV 1 500 MVA duplicate-busbar horizontal drawout metalclad switchgear as installed at Huncoat Power Station is shown in Fig. 12.

3·8·2 Outdoor switchgear

Outdoor switching and distributing stations are being installed primarily in rural districts and their general layout follows that of the higher-voltage stations although single-busbar stations are quite common. The use of pre-cast and cast-in-situ reinforced-concrete structions for straining crossover aerials, for line terminations and for supporting post insulators, busbars, isolators and other equipment is again favoured in preference to fabricated-steel structures.

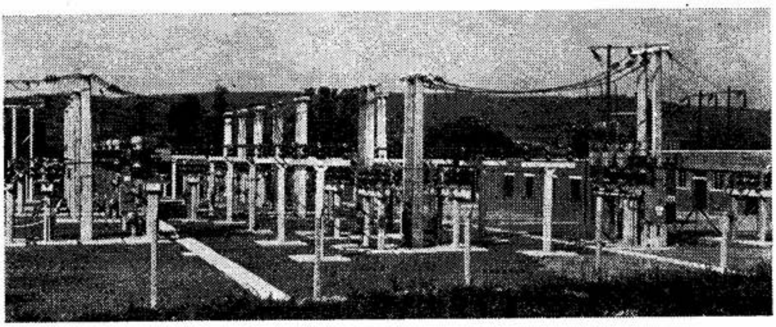

Fig. 13—33-kV outdoor station

Fig. 13 shows a general view of the outdoor 33-kV switchgear installed recently at Churchill.

4. MAIN SWITCHGEAR

4·1 *Circuit-breakers*

Before 1945 the majority of circuit-breakers in Grid substations were bulk-oil although a few prototype small-oil-volume breakers had been installed and had given good service. It was not until after the war that 132-kV switching and transforming stations began to be equipped with air-blast breakers and pneumatically-operated bulk-oil breakers, but the trend is towards the air-blast circuit breaker as can be seen in Table V.

TABLE V

i Number of circuit-breakers completed in 1952–53

ii Number of circuit-breakers put in hand 1952–53

i

Type of circuit-breaker	Voltage kV	Rating MVA	Number installed
Air-blast ...	132	2 500	17
,, ,, ...	132	3 500	14
,, ,, ...	33	1 500	2
Low-oil-volume	132	2 500	2
Bulk-oil ...	132	2 500	16
,, ,, ...	66	2 500	9
,, ,, ...	33	1 500	8
Bulk-oil modernized from 1 500 to 2 500 MVA	132	2 500	2 existing breakers

ii

Type of circuit-breaker	Voltage kV	MVA	Number planned
Air-blast ...	275	7 500	30
,, ,, ...	132	3 500	64
Low-oil-volume	132		Nil
Bulk-oil ...	275	7 500	4
,, ,, ...	132	3 500	27
,, ,, ...	132	2 500	14
,, ,, ...	66	1 500	2
,, ,, ...	33	750	11
Bulk-oil modernized from 1 500 to 2 500 MVA	132	2 500	30 existing breakers

Taking only the 132-kV and 275-kV breakers it can be seen that 16 bulk-oil breakers were installed in 1952–53 and 31

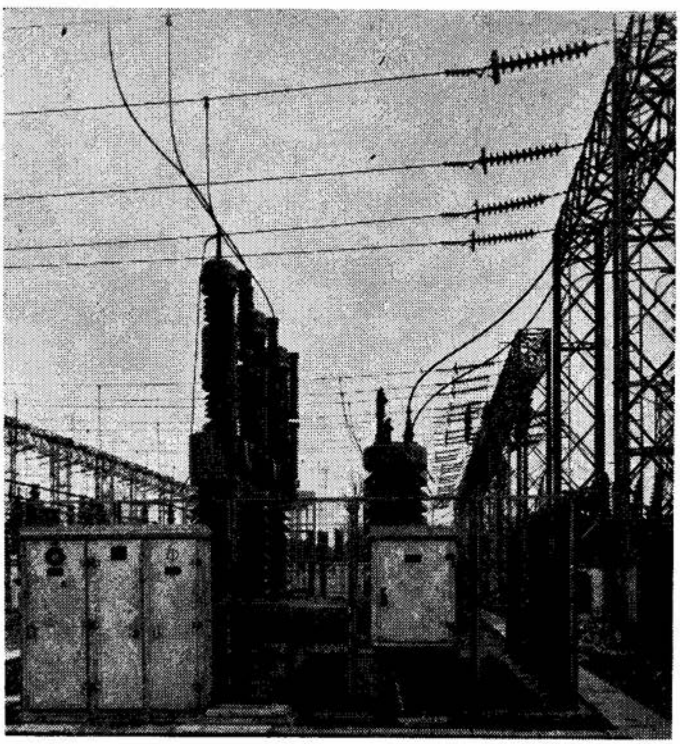

Fig. 14—132-kV, 600-ampere 2 500-MVA air-blast circuit-breaker installed at Beddington

air-blast breakers, and in connection with the work put in hand in 1952–53, 94 air-blast breakers are scheduled as against 45 bulk-oil.

4·1·1 132-kV air-blast circuit-breakers

The 132-kV air-blast circuit-breakers which have and are being installed have in general one of two ratings, a current-carrying capacity of either 600 or 800 amperes with respective ratings of 2 500 and 3 500 MVA, and are essentially high-speed having a closing time of the order of 0·3 seconds, a total opening time of the order of 0·5 seconds and since they have in general a maximum period from arc extinction to contact remake of 0·2 seconds they are eminently suitable for auto-reclosing.

. Some designs have non-linear resistances shunted across the interrupters to provide positive means of voltage control and to damp out overvoltage peaks which may be produced when small inductive or capacitance currents such as line-charging currents are interrupted. A typical design is shown in Fig. 14. Others rely upon the air turbulence caused by the interaction of the hot residual gases remaining after arc extinction with the cool air blast. This interaction and air turbulence breaks up the ionized gas and enables the residual arc path to regain its electric strength immediately and to withstand the restriking-voltage transient. The circuit-breakers are multi-break, have at least two interrupters or turbulators per phase and these are in series with either a double-break horizontal rotating sequential isolator or a single-break vertical sequential isolator. A space-saving feature of some designs is the use of the sequential-isolator fixed-contact-support insulator as a housing for protection and instrument current transformers.

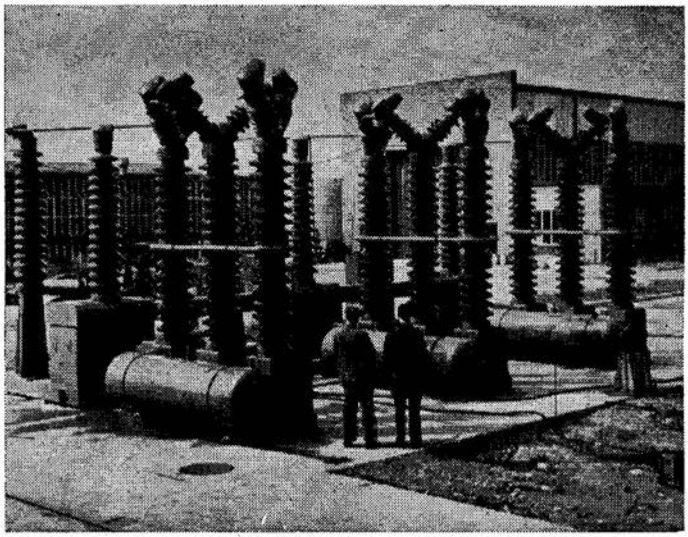

Fig. 15—275-kV, 1 200-ampere 7 500-MVA air-blast circuit-breaker for Drakelow

4·2 275-*kV circuit-breakers*

The 275-kV circuit-breakers which are to be installed in the new transforming and switching stations are of two types, the bulk-oil pneumatically operated and air-blast.

The bulk-oil are multiple-break oil circuit-breakers with typical arc-quenching devices common to lower-voltage circuit-breakers together with linear shunt resistances across the main contacts. The pneumatic operation permits high-speed closing and opening.

Two designs of multi-break air-blast circuit-breakers are to be installed each having a current-carrying capacity of 1 200 amperes and both are rated at 7 500 MVA. One design has single-flow double twin arc interrupters each with their non-linear silicon-carbon shunt resistors with a double-break sequential horizontal-rotating isolator in series with each interrupter head making a total of ten breaks in series per phase including the isolator. The other is of the multi-break air-blast turbulator design with series horizontal-rotating sequential isolators a total including the isolator of eight breaks in series. (Fig. 15.)

The design of the interrupters and turbulators follows closely those on the 132-kV air-blast circuit-breakers and their operation is similar.

4·3 132-*kV and* 275-*kV air-blast circuit-breakers*

A feature common to air-blast circuit-breakers is that the phases are not mechanically coupled. The operation of the phases together is achieved by careful timing of the blast valves, isolator air motors and by interlock devices.

The insulator stacks supporting the interrupters are hollow and as well as serving as insulating supports are the means of conducting the compressed air from the local air receivers to the interrupters and isolator air motors. In those cases where air pipes are not used it is essential that the internal surfaces of the insulators should be smooth with no projections so as to avoid air eddies. The internal surfaces have therefore a considerably shorter surface leakage path to earth than the external surfaces which have weatherproofing sheds. Service conditions are such that it is possible that the breaker is not opened or closed for several weeks and, under normal conditions of temperature, breathing takes place despite the use of exhaust valves, and the possibility of moisture condensing on the internal surfaces under varying conditions of temperature cannot be eliminated entirely. Accumulation of such moisture together with dirt can quickly lead to an internal flashover. In the case of all air-blast circuit-breakers installed in the open, dry conditioned air is bled continuously from the main-bus air line into the support insulators effectively preventing the formation of and accumulation of moisture on the internal surfaces. The compressed-air plant and the method of obtaining dry conditioned air at all times is fully described in Section 6.

Air-blast circuit-breakers have the advantage over other types of breakers in that they can be unit tested,[3] thereby enabling short-circuit tests to be made under conditions giving the maximum stress in respect of recovery voltage and rate of restriking voltage. At high ratings the known performance characteristics of air-blast circuit-breakers enable tests to be made giving the equivalent of the full test conditions. Breakers consisting of two or more breaks in series share the recovery voltage and the rate of rise of restriking voltage between the breaks in constant proportions which can be determined by preliminary tests and calculations. The air-blast circuit-breaker can therefore be proved by testing part of it with the proportional recovery voltage and rate of rise of restriking voltage that gives the equivalent of the full values when referred to the complete circuit-breaker.

Since highly inflammable mediums are not used for arc extinction, fire hazards are completely eliminated. The comparative lightness of the moving elements of the breaker enables high speeds of closing and opening to be achieved. The sequential isolators are power driven for both the closing and opening stroke and do not rely upon strong throw-off springs to obtain high speeds.

4·4 132-*kV and* 275-*kV isolators*

Three designs of isolators are in general use in the 132-kV switching and transforming stations, the double-break horizontal-rotating, the single-break vertical operation and the double-break through floor tilting design, the latter being used only in indoor 132-kV switching stations.

The double-break horizontal-rotating design has been used successfully on the Grid since 1926 and until recently the design of the fixed and moving contacts had remained unchanged. It has the advantage of simplicity, all bearings and linkages being at earth potential, and since the moving and fixed contacts of recent design are self aligning they require little maintenance. The single-break vertical isolator has been installed in recent years. The mechanism for changing the direction of and reducing the motion is a simple linkage at the top of the insulator stack. The moving blade is heavy tubular copper with a circular machined solid contact which makes contact with a phosphor-bronze finger-type fixed contact backed with stainless-steel springs.

The tilting type of through-floor isolator installed in the indoor switch houses is a double-break isolator, an interesting feature being its use as a through-floor bushing.

The 275-kV isolators which are to be installed are a horizontal double-rotating-arm design with a single break, the contact being made by both arms meeting and engaging mid-way between their supports. This design avoids the difficulties of height which a vertical-operation isolator would introduce. It also avoids the excessive spacing which would be required by the use of the orthodox double-break horizontal-rotating type.

To prevent mal-operation of the equipment and to ensure that isolators are operated in the correct sequence, complex interlocking schemes are used, one being a lock-and-key system manually operated, and the other an electrical interlocking system. The manual system depends on a sequential locking scheme whereby the key giving access to the operating handle of an isolator is only available when the associated circuit-breaker is open. At all other times the key is trapped in the associated isolator or circuit-breaker mechanism and cannot be removed.

In the electrical system each isolator mechanism box is fitted with an electro-magnetic bolt the coil of which is not normally energized. This electro-magnetic bolt is released only when other essential operations have been carried out in a correct and predetermined sequence.

Electrical interlocks of a similar nature are also provided in the case of 132-kV indoor switchgear on all doors giving access to the various cubicles. These door interlocks are arranged so that it is impossible to enter a cubicle without first opening all isolators and circuit-breakers which would make that cubicle alive.

4·5 132-*kV and* 275-*kV busbars and crossover aerials*

4·5·1 Low-level busbars

The rigid conductor used for the low-level busbar is 3-in external diameter hard-drawn copper tube with 14 s.w.g. walls for bars of 1 200-ampere capacity and 16 s.w.g. walls for 600-ampere capacity. They are supported by the isolator itself and at intermediate points between the isolators by post insulators. The method of support permits longitudinal expansion and contraction without imposing strain on any support insulator. Each length of bar is connected to the next at each support and to the isolators by flexible copper braids.

4·5·2 Intermediate level busbars and crossover aerials

The stranded hard-drawn copper conductor used for the strained type of busbar and crossover aerials is of special design to eliminate corona effects and has a large overall cross section. For 600-ampere capacity it consists of 46/·093-inch copper, stranded round a hard-drawn copper spiral centre, its overall diameter being 0·9 in with a nominal copper section of 0·3 sq. in, and weighs only 1·297 lb per foot length. The maximum working tension for this conductor is 2 000 lb.

The crossover aerials in the 275-kV stations are 1 200-ampere capacity and are flexible conductors of 1·375-inch external diameter consisting of 114/·087-inch stranded copper wound on a hard-drawn copper spiral. The conductor has a nominal copper section of 0·66 sq. in, weighs 2·87 lb per foot length and has a maximum horizontal working tension of 3 000 lb. In the stations described a maximum sag of 8 ft is permitted.

Multi-bolted dead-end clamps are used at all strain points and to enable correct tensioning of the conductor turnbuckles are used at one attachment point. The droppers down from the aerials to the equipment at lower levels are connected to the aerials by typical tee clamps and to the isolators, circuit-breakers and other equipment by concentric connectors.

4·6 132-*kV and* 275-*kV post and strain insulators*

Porcelain is used exclusively for the post insulators. The number of units in a stack is decided by the atmospheric conditions at a particular station. Usually one additional unit is added to a normal stack in particularly dirty areas. Two designs are used, the cap-and-pin and the cylindrical type, the total length overall being 72·5 in for 132-kV installations and for 275-kV the length of the stack is of the order of 114 in.

Toughened glass and porcelain ball-and-socket type insulators are used for strain sets with normally twelve units per string for 132-kV installations and eighteen units per string for 275 kV, although the number of units may vary with the type of insulator employed. The total length of the string in both 132-kV and 275-kV stations is largely dictated by the degree of atmospheric pollution encountered at any particular site.

On the 132-kV system arcing gaps between arcing horns or rings of 38/39 in are used on substation insulators and bushings. Typical arcing gaps for the 275-kV station equipment are given in Table VI.

TABLE VI

Equipment	*Gap between arcing horns or rings*
Strain insulators	85 in
Isolators	92 in
Current transformers	75 in
Inverted post insulators	92 in
Normal post insulators—busbar side of the circuit-breaker	92 in
Normal post insulators—feeder side of circuit-breaker	75 in

4·9 *Earthing*

Three methods of obtaining low earth resistances are employed, (*i*) a group of copper rods driven into the ground and connected together, (*ii*) cast-iron plates 4 ft by 4 ft buried on edge and surrounded by fine coke, and (*iii*) 6-inch diameter cast-iron pipes 10 ft long buried in the ground and surrounded by fine coke. Four or more such earths are used in each station, the number being dependent upon the size of the station and the value of the specific resistance of the subsoil so as to give a final figure of not greater than 1 ohm. All earth plates are connected to the main earth bars through a bolted removable link so that the value of the earth plate resistance and continuity of the main earth bar can be checked from time to time. The main members of all steel structures are connected by continuous copper connections to the main earth bar, in fact all metal parts other than those forming part of any electrical circuit are earthed to the main earth bar direct or in groups by separate branch connections. All joints have their surfaces tinned to prevent oxidization and are riveted and soldered or welded. The minimum sectional area of the main earth bar is 0·25 sq. in. and that of each branch connection 0·1 sq. in., except in the case of instrument and relays on control and relay panels when the size of the earth connection is not less than 0·004 5 sq. in.

TABLE VII

Equipment	*Rating MVA*	*Line current Amp*	*Overcurrent and instrument c.t. Ratio*	*Ammeter scales*
132-kV transformers	45	197	250/0·5	0— 300
	60	262	300/0·5	0— 400
	70	328	350/0·5	0— 500
275-kV transformers	120	524	600/1	0— 800
	180	786	800/1	0—1 200
	240	1 048	1 200/1	0—1 500
132-kV overhead line circuits				
Copper equivalent 0·175	100	500	500/1	0— 750
Copper equivalent 0·4	150	650	1 200/1	0—1 200
132-kV generator transformer circuits ...	36	158	250/0·5	0— 200
	72	316	300/0·5	0— 400
Bus-coupler and bus-section circuits (^bus-bar rating)	—	^600	500/1	0— 750
	—	^800	800/1	0—1 200
	—	^1 200	1 200/1	0—1 800

5. CONTROL, SUPERVISORY AND PROTECTION EQUIPMENT

5·1 *Current transformers*

A parallel development with the small oil-volume and air-blast circuit-breaker has been the post-type current transformer, and in all the newer stations where small-oil-volume and air-blast circuit-breakers have been installed current transformers of the post type have also been used.

132-kV bushing current transformers are still installed where possible since they can be accommodated in transformer bushings and bushings of the bulk-oil-type circuit breaker at a considerably cheaper cost.

The ratios of current transformers used for 132-kV and 275-kV equipments have

TABLE VIII

THREE-SWITCH STATION INDICATING TYPICAL DISPOSITION OF CURRENT TRANSFORMERS

Equipment	*Purpose of c.t.*	*Where positioned*	*No*	*Type*	*Ratio*
132-kV transformer equipments 60 MVA	Balanced earth fault	Mounted in 132-kV neutral of transformer	1	Bushing	250/0·5
	High-speed ammeter	Mounted in 132-kV neutral of transformer	1	Bushing	250/0·5
	High-speed impedance	Mounted in 132-kV neutral of transformer	1	Bushing	250/0·5
	Overcurrent and instruments	132-kV transformer bushings	3	Bushing	300/0·5
	Balanced earth fault	On line side of 132-kV circuit-breaker between the circuit-breaker and isolator	3	Bushing or post type dependent upon type of breaker	250/0·5
132-kV feeder equipments	Overcurrent and instruments	Transformer side of associated transformer circuit-breaker	3	Bushing or post type dependent upon type of breaker	500/1
	Overcurrent and instruments	Opposite feeder side of bus-section-circuit breaker	3	Ditto	500/1
	High-speed impedance	Transformer side of associated transformer circuit-breaker	3	Ditto	500/1
	High-speed impedance	Opposite feeder side of bus section circuit-breaker	3	Ditto	500/1
Bus-section	Overcurrent	On each side of bus-section circuit-breaker integral with feeder overcurrent	6	Ditto	500/1
	Instruments	Opposite feeder side of bus-section circuit breaker integral with feeder overcurrent	3	Ditto	500/1

TABLE VIII—continued.

132-kv DOUBLE-BUSBAR INDOOR SWITCHGEAR SHOWING TYPICAL DISPOSITION OF CURRENT TRANSFORMERS

Equipment	*Purpose of c.t.*	*Where positioned*	*No*	*Type*	*Ratio*
Generator transformer 132-kV equipment	Overcurrent and instruments	132-kV transformer bushings	3	Bushing	250/0·5
	Translay protection	between generator transformer and circuit-breaker	3	Floor bushing	To suit generator equipment
	Bus-zone protection double Merz-Price balance pattern	Mounted over 132-kV incoming cables below the cable-sealing ends	6	Slip-on type	500/1
	High-speed neutral ammeter	Mounted in 132-kV neutral connection of main transformer	1	Bushing	250/0·5
Station transformer 132-kV equipment	Overcurrent and instrument	Transformer 132-kV bushings	3	Bushing	250/0·5
	Magnetic balance overall protection	Between transformer and circuit-breaker	3	Floor bushing	To suit transformer equipment
	Bus-zone protection double Merz-Price	Mounted over 132-kV outgoing cables below the sealing ends	6	Slip-on type	500/1
	High-speed neutral ammeter and magnetic balance pivot	Mounted in 132-kV neutral connection of station transformer	1	Bushing	250/0·5 two windings
132-kV feeder equipment 600 ampere	Overcurrent and instruments	Feeder side of circuit-breaker	3	Floor bushing	500/1
	Pilot-wire protection	Feeder side of circuit-breaker	3	Floor bushing	500/1
	Bus-zone double Merz-Price balanced pattern	Mounted over outgoing cables below 132-kV cable-sealing ends	6	Slip-on	500/1
132-kV bus-coupler equipment 600 ampere	Overcurrent and instruments	Reserve busbar side of circuit-breaker	3	Floor bushing	500/1
	Bus-zone double Merz-Price balanced pattern	Main bus-bar side of circuit-breaker	3	Floor bushing	500/1
		Reserve busbar side of circuit-breaker	3	Floor bushing	500/1

Note : The disposition of current transformers in outdoor switching stations for 132-kV generator-transformer, feeder, station-transformer, bus-section and bus-coupler equipments would be similar to that for the indoor equipment dependent upon the type of protection installed.

TABLE VIII—continued.

275/132-kv SWITCHING AND TRANSFORMING STATION SHOWING TYPICAL DISPOSITION OF CURRENT TRANSFORMERS

Equipment	*Purpose of c.t.*	*Where positioned*	*No*	*Type*	*Ratio*
275-kV feeder equipment 1 200 ampere	Overcurrent and instruments	Line side of isolator	3	Post type	1 200/600/1
	High-speed superimposed carrier current ; phase comparison	Line side of line isolator	3	Post type	1 200/600/1
	Bus-zone protection	Line side of line isolator	6	Post type	To suit bus-zone protection equipment
275-kV bus coupler equipment 1 200 ampere	Overcurrent and instrument	Main busbar side of circuit-breaker	3	Post type	1 200/600/1
	Bus-zone protection	Main busbar side of circuit-breaker	3	Post type	To suit bus-zone protection equipment
		Reserve busbar side circuit-breaker	3	Post type	Ditto
275/132-kV interbus auto-transformers banked 120 MVA per transformer	Ammeter	Transformer side of 275-kV breaker	3	Post type	600/1
	Bus-zone protection	Transformer side of 275-kV breaker	6	Post type	To suit bus-zone protection equipment
	Biased differential protection	Transformer side of 275-kV circuit-breaker	3	Post type	600/1
		Neutral end of each phase of each banked transformer 3 per transformer	6	Bushing type	600/1
		Busbar side of 132-kV circuit-breaker 3 per transformer	6	Post type	600/1
	High-speed neutral ammeter	Neutral of each transformer 1 per transformer	2	Bushing	600/1 double winding
	Overcurrent and instrument	Busbar side of 132-kV circuit-breaker	3	Post type	600/1
	Bus-zone protection 132-kV	Busbar side of 132-kV circuit-breaker	6	Post type	To suit bus-zone protection

been standardized wherever possible. Table VII shows standard current transformer ratios now used for overcurrent relay protection and indicating instruments, and Table VIII the disposition of the current transformers in typical stations.

5·2 *132-kV and 275-kV voltage transformers*

Low-voltage supplies for metering, indicating instruments, distance-measuring and directional-protection equipment are supplied from either electro-magnetic voltage transformers or from capacitor voltage transformers. At those stations which are purely switching stations double-winding voltage transformers have been installed with a rating of 50 KVA per phase having a ratio of 76·5/0·240/0·063 5 kV, three such units comprising a three-phase bank.

The 240-volt phase-to-neutral voltage being used for such duties as lighting, battery charging and heating, the 415-volt three-phase supply being used for oil handling plant or compressor plant whilst the 63·5-volt winding is used for metering, protection and indicating instruments.

Where auxiliary or earthing transformers are installed single-phase voltage transformers with a ratio of 76·5/0·063 5 kV, 500-VA rating are used either singly or in three-phase banks depending upon the duties required from them.

Carrier-protection equipment is being used to an even greater extent in Britain and at stations where this type of equipment has been installed, voltage transformers of the capacitor type with a rating of 150 VA are being employed.

Bulk-oil circuit-breakers with condenser-type bushings are arranged to have the centre-phase bushings tapped. The tapping is brought out to a small transformer mounted on the side of the circuit-breaker tank and the low-voltage side of the transformer used for indicating voltage instruments, and has been used for synchronising purposes. The output from the tapped bushing is small however, and cannot be used for other purposes.

At 275-kV stations low-voltage supplies for metering and indicating instruments are derived from single-phase capacitor units having a ratio of 159/0·11 kV.

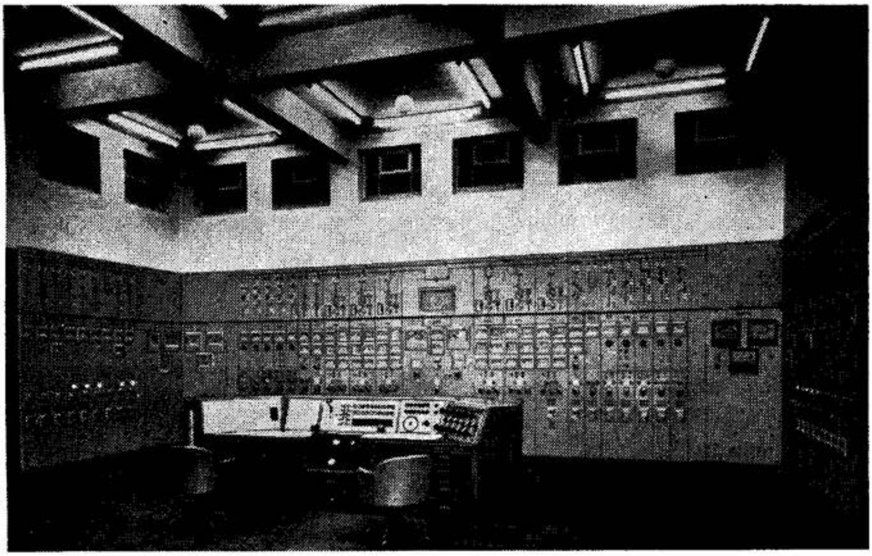

Fig. 16—Cliff Quay Power Station control room showing generator control desk, 132-kV control panels and 33-kV control panels

5·3 *Control rooms and control boards*

For a variety of reasons a very wide diversity of design, layout and siting of control rooms has been necessary in the recent installations. Many of the modern control buildings have little or no window space and in consequence carefully designed artificial lighting installations are employed so that glare and shadow can be reduced to a minimum. The use of highly polished refractive surfaces has been discontinued in favour of matt finish surfaces in shades of pastel green. It is reputed that such lighting and colour schemes minimize the possibility of misreading instruments and for that reason the frequency of mal-operations is corresondingly reduced.

TABLE IX

TYPICAL EQUIPMENT INSTALLED ON 132-kV CONTROL PANELS

Equipment and instruments installed	*60-MVA generator equipment*	*Station transformers*	*Feeders*	*Bus-coupler or bus-section*	*Series reactors*
Automatic semaphore indicators					
132-kV isolators	2	2	5	2	2
Earthing switches	1	1	1	–	–
132-kV circuit-breakers	1	1	1	1	1
Generator field switch	1	–	–	–	–
L.V. circuit-breaker	1 Unit trans	1	–	–	–
Indicating lamps					
Red (circuit-breaker closed)	1	1	1	1	1
Green (circuit-breaker open)	1	1	1	1	1
Amber (automatic trip)	1	1	1	1	1
White (trip healthy)	–	1	1	1	1
Ammeter	0-350 amp	0-60 amp	0-600 amp	0-600 amp	0-600-amp
Ammeter switch (3-way)	1	1	1	1	1
Ammeter (main field)	1	–	–	–	–
Indicating wattmeter	7-0-70MW	1-0-13MW	100-0-100MW	–	–
Indicating reactive MVA meter ...	25-0-50MVAR	–	–	–	–
Synchronising voltmeter and frequency meter selection sockets	1 set	1 set	1 set	1 set	1 set
Circuit-breaker control switch	–	1	1	1	1
Tap-position indicator	1	–	–	–	–
Generator neutral alarm relay	1	–	–	–	–

EQUIPMENT AND INSTRUMENTS INSTALLED

Control room desk panel

132-kV circuit-breaker control switches (generators)

Generator main field switches.

Indicating lamp white. Trip supply healthy.

Indicating lamp white. Tap change in progress.

Double push button control switches.
(turbine governor).
(transformer tap change).
(exciter field rheostat control).

Main field ammeters.

Main field voltmeters.

Indicating wattmeters 0–75 MW.

Indicating varmeters 25–0–75 MVAR.

Turbine room telegraph equipment.

Telephone type alarm annunciator (accept and cancel pushbuttons).

Synchronizing panel

Voltmeter 0–160 kV

Rotary synchroscope

Synchronizing lamps

Central indication panel

Frequency meter (47–51 cycles)

Voltmeter 80–160 kV.

Rotating-dial time-error indicator.

Impulse slave clock (standard time).

Synchronous clock (frequency time).

Total generated load repeater wattmeter.

Battery voltmeters 0–150 volts (2),

,, ,, 0–300 volts (1).

Recording voltmeter 80–160 kV.

Recording frequency meter.

Recording wattmeter (total generated load).

Steam temperature gauge (selective).

Steam pressure gauge (selective).

Bus-zone protection in commission (white indicating lamps).

Bus-zone protection cut-out (amber indicating lamps).

The switching stations associated with power stations have their control rooms positioned in the main building or in certain of the more recent stations an entirely separate building houses only the control, metering, relay and telephone equipments. Switching and transforming stations remote from power stations have their own control room within the confines of the switching station and in some cases they are controlled by supervisory control equipments from a remote power station and in others from an existing control point which may also be some distance away from the switching station.

Fig. 17 shows the miniature telephone-type supervisory control cubicles controlling nine 132-kV circuits at Windyhill, namely a bus-section and bus-coupler circuit, three incoming circuits from the North of Scotland Hydro Electric Board from the Sloy Hydro Station and four outgoing 132-kV circuits to connect into the B.E.A. 132-kV system.

The total length of these cubicles is 7 ft 6 in and they are 6 ft in height. Operation is by means of selector keys and push-button ; all alarms are centralized on the board thus obviating the necessity for a separate annunciator cubicle. In this particular case all incoming and outgoing feeders are equipped with indicating MW and MVAR meters in addition to ammeters, and provision has been made for synchronising the incoming or outgoing feeders.

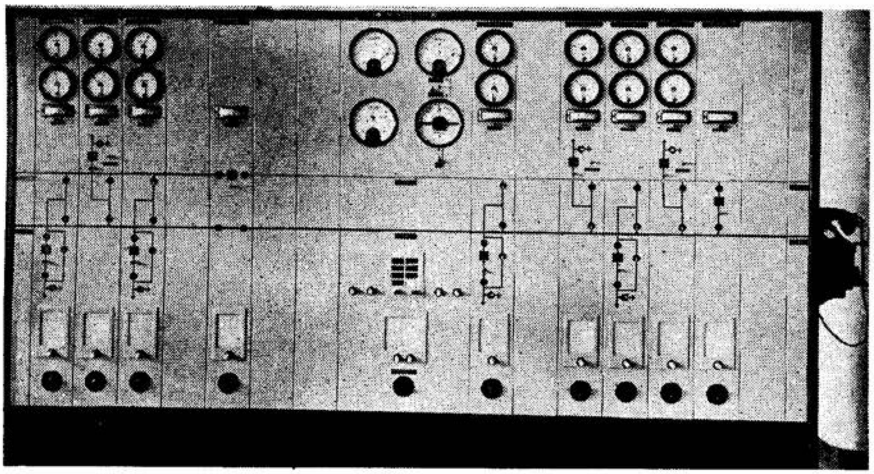

Fig. 17—Windyhill 132-kV switching station supervisory miniature telephone-type control panel

Fig. 16 shows the control room of the Cliff Quay Power Station, 132-kV switching station and the local 33-kV system, and is positioned in the main power station building.

The equipment and instruments normally mounted on the control and desk cubicles for a typical power station whose generators are switched at 132-kV is listed in Table IX.

Integrating kW and kVAR meters, summator meters and printometers are arranged on separate metering cubicles, central indicating equipment for transmitting over private telephone circuits essential information concerning the operation of the generating and switching station to the Central Area Control Room, is also mounted on a separate cubicle.

All the stations are now being equipped with complex annunciator equipment of the telephone type. The annunciator cubicle has an illuminated display board with 'accept' and 'cancel' pushbuttons and may provide up to 180 ways so arranged that any failure of essential equipment gives a visible indication and an audible alarm. It is so designed that the audible alarm can be cancelled leaving the visual indication on until such time as the fault causing the alarm has been corrected and permits the audible alarm to be available for any further fault which may arise. At any particular station all or any of the faults listed in Table X give visual indication on the annunciator panel, and also audible alarms.

TABLE X

ANNUNCIATOR ALARMS AND INDICATIONS

Equipment	*Fault*
Circuit-breaker	Tripped on fault
	Low air pressure (local receiver air-operated circuit-breaker)
	Phases not together (air-operated circuit-breaker, phases not mechanically coupled)
Transformers	Buchholz gas or low oil level
	High temperature
	Cooling equipment failure
	Tap change incomplete
	Transformers out of step
Cables	Low oil pressure (oil-filled cables)
	Low gas pressure (gas-filled or gas-compression cable)
Compressed air	High air pressure
	Low air pressure
	Wet air
	Supply failure to compressor motors
Carrier protection	Fuse failure
	Valve failure
	Anode battery charger failure
	Filament battery charger failure
Fire equipment	CO_2 operated
	CO_2 locked out.

5·4 *Relay rooms and relay boards*

The practice of locating the relay room in a separate building positioned centrally within the confines of the switching station has still been maintained in the newer stations. However where the control room building is also on the site, the relay room and auxiliary plant is located in the same building, usually on different floors.

The multiplicity of protective equipment precludes any comprehensive description but the Authority have laid down standards in regard to the layout of relay boards and the equipment and relays mounted on them. Cubicle-type boards of sheet-steel construction have been installed, a separate cubicle being provided for each primary circuit. The cubicles are bolted together and arranged in exactly the same order as the control boards and the main primary circuit bays. All relays except interposing relays associated with supervisory equipments are mounted on the front of cubicles and no relay is mounted at a height greater than 6 ft nor less than 1 ft 6 in from floor level. D.C. fuses and links controlling tripping circuits, voltage-transformer fuses, current-transformer test link boxes are all mounted on the front of the cubicle. All links and fuses are coloured in accordance with a colour code, link carriers and bases are white, fuse carriers and fuse bases up to 5-ampere rating are black and fuse carriers and fuse bases of 15-ampere rating are coloured sea green.

Cubicles separate from the main relay board are employed for such items as bus-zone protection, carrier equipment and supervisory equipment. The latter when installed is equipped in a manner similar to the supervisory control panel at the remote control room and is equipped with a local/remote change-over switch which permits the station to be controlled from the local relay room should the need arise.

Feeder protection equipment, transformer protection equipment and 132-kV generator-transformer protection equipment trip their respective circuit-breakers or breaker via inter-tripping or tripping relays, back-up overcurrent protection relays for feeders; transformers and reactor equipments trip direct whilst back-up earth-fault and Buchholz relays on transformers, reactors and 132-kV voltage transformers trip their associated circuit-breakers via hand-reset tripping or inter-tripping relays. Bus-section and bus-coupler circuit-breakers have overcurrent protection and trip direct.

Many of the new installations have electrically-reset tripping and intertripping relays and in the case of supervisory equipment all tripping relays are electrically reset.

Bus-zone protection trips all the circuit-breakers on the section of bar which is faulty by a master trip relay which is hand reset.

Multicore and pilot cables are either terminated in wall-mounted terminating boxes and connections carried over in conduit to the relay cubicles or they are terminated at the bottom of the relay cubicle itself and tails taken up to terminal boards mounted on the sides of the cubicle.

6 AUXILIARY PLANT

6·1 *A.C. auxiliary supplies*

Since the early days of the Grid the majority of the main transformers installed in 132-kV transforming stations have been star/delta connected, the 132-kV neutral of star winding being earthed solid. To provide a neutral point on the l.v. side of the main unit an interstar/star-connected transformer is connected on its interstar side to the l.v. side of the main unit, the neutral from this interstar winding being connected through a resistance of the liquid type to earth. The interstar winding is of special design and is capable of passing the maximum earth-fault current of the main unit limited of course by the neutral earthing resistance.

The star side of this earthing transformer is wound to give a phase voltage of 415 and under normal conditions the average rating of the unit is 120 kVA.

The low-voltage side of the earthing transformers is used to provide a.c. supplies for the station auxiliaries. In several of the newer stations no main transformers are installed, and in these cases low-voltage auxiliary supplies are obtained from the 132-kV voltage transformer banks as described in Section 5·2.

In both cases duplicate low-voltage a.c. supplies are available and are connected on to an auxiliary a.c. board of the metalclad type, interlocks being provided to ensure that the two incoming supplies are not paralleled, although the arrangement is such that the total auxiliary load may be supplied from either of the two incoming supplies or shared between them.

The a.c. auxiliary boards now being installed are equipped with high-rupturing-capacity switch-fuses on the incoming and outgoing feeders. Essential auxiliaries such as constant-voltage battery chargers and compressed air equipment are taken via automatic change-over contactor equipment to ensure continuity of supply in the event of the failure of one or other of the incoming supplies.

6·2 *D.C. auxiliary supplies*

A measure of standardization has been carried out in regard to the number and the ampere-hour capacity of the batteries installed in the recent 132-kV stations. The battery requirements are of necessity dependent upon factors such as the design of the 132-kV circuit-breakers, method of control, type of feeder protection and the size of the metering equipment, all of which may differ between wide limits from station to station.

Typical battery installations for a switching station associated with a power station having air-blast or pneumatically-operated circuit-breakers, normal control equipment, large metering installation, carrier-current feeder protection, telephone-type annunciator and central indication equipment is given in Table XI.

The d.c. switchboard for all except the metering battery are of the corridor pattern comprising insulating board panels on which are mounted the necessary feeder switches, fuses, instruments and charger control equipment. The trickel chargers and booster chargers are mounted integral with the panels. All circuits outgoing from the switchboard have their own switches and fuses, subcircuits being fused only.

The d.c. switchboard together with the a.c. auxiliary board are now installed in an auxiliary plant room usually between the relay room and the battery rocm, except in

TABLE XI

TYPICAL BATTERY INSTALLATIONS FOR 132-kV SWITCHING STATIONS

Type of battery	*Voltage*	*Ampere-hour capacity*	*Duties*
Lead acid	110	150	Closing, tripping, indication and emergency lighting
Lead acid	50	250	Telephones, annunciator, central indication, carrier current protection
Lead acid	300	15	Carrier current protection
Lead acid	32	50	Metering equipment, synchronome clock

the smaller stations where this equipment together with the relay boards are placed in one room.

6·3 *Compressed air equipments*

A reliable source and continuous supply of compressed air at all times for the correct operation of pneumatically-operated and air-blast circuit-breakers is essential and to ensure that this condition exists the Authority have installed duplicate compressor plants at all stations equipped with such circuit-breakers. Since the characteristics of circuit-breakers differ quite considerably it has not been possible, neither has it been desirable to lay down rigid standardization for compressor plant. For instance, the compressors installed at a station equipped with six pneumatically-operated bulk-oil circuit-breakers deliver 5 cubic feet of free air per minute at a pressure of 450 lb per sq. in., whilst at a station equipped with a similar number of air-blast circuit-breakers each compressor delivers 14 cubic feet of free air per minute at a pressure of 600 lb per sq. in. The quantities stated are in cubic feet of free air at 15°C at sea level.

The normal compressor equipment supplied for such stations comprises two 3-stage air-cooled compressors with automatic unloaders which deliver compressed air at 450–600 lb per sq. in. via after coolers, water filters and non-return valves to the common high-pressure main air receivers.

The air at high pressure is reduced to a lower pressure of 200–350 lb per sq. in. by means of reducing valves and fed into the main air pipe lines and so to the local air receivers of each circuit-breaker. Carryover of oil from the compressor, which might contaminate valve seatings and insulated air pipes and internal insulator surfaces are taken care of by the filters, and excessive moisture in the main air receivers by regularly draining.

De-hydrators are no longer fitted since the greater differences in pressure between the high- and low-pressure sides of the system, and for that reason a greater expansion of air, have eliminated the need for them.

Mention has already been made in Section 4·3 of the necessity for maintaining in a dry and clean state all insulated air pipes and the internal surfaces of support insulators used to convey the air from the local air receiver to the interruptors and air motors so as to avoid internal flashovers. The method of achieving this is briefly described in the following paragraph.

Air is bled from the low-pressure main pipe line and is continually passed over the internal insulation surfaces on all three phases of the circuit-breaker. Since the air in the main pipe line has already been expanded it is fairly dry. A further expansion to almost atmospheric pressure reduces its humidity to a negligible value. The quantity of conditioning air flow is measured by visual flow meters and is controlled by an air choke and adjustable needle valves and is between 15 and 20 cubic feet per hour per breaker.

7 CONCLUSIONS

Since the paper is primarily descriptive in character it is possible to draw attention to only certain salient points and trends in the planning, design and layout of recent high-voltage switching and transforming stations now commissioned or in the course of erection on the British Electricity Authority's network.

The planning of the 132-kV and 275-kV stations has been done at National level in consultation with the Divisions and the various Electricity Area Boards and in consequence overlap has been avoided and considerable economies have been effected.

Standardization of layout has not been rigid and for that reason it has permitted a certain amount of latitude in regard to the design of the main switchgear and has not curtailed advancement in manufacturing design.

The use of cast-in-situ and pre-cast reinforced concrete for strain and support structures in preference to fabricated steel is well established. Standardization of the design of pre-cast reinforced-concrete structures has enabled erection time and costs to be reduced.

The additional generating plant regularly coming into commission coupled with a greater measure of interconnection has necessitated faster operating times for circuit-breakers so as to avoid system stability problems. Pneumatically-operated circuit-breakers and in particular air-blast circuit-breakers which have the necessary high-speed characteristics are being installed in ever-increasing numbers.

The high rating of modern circuit-breakers coupled with inadequate test machines precludes testing and proving the circuit-breakers as complete units. The design of the multi-break air-blast circuit-breaker for ratings up to 7 500 MVA does permit proportional testing and proving of each series break from which the rating of the complete circuit-breaker can be calculated within fine limits.

Interlocking arrangements, careful design of control and relay rooms and boards, central annunciator equipment and high-speed protective gear have been installed at the majority of stations to minimize the possibility of mal-operation and faults which in a complex system can quite easily lead to cascade tripping with disastrous consequences.

8 ACKNOWLEDGMENTS

The author wishes to acknowledge his indebtedness to the British Electricity Authority for permission to publish this paper and for the facilities given to him during its preparation. However the opinions expressed in the paper are not necessarily those of the British Electricity Authority. He also wishes to thank Messrs A. Reyrolle & Co., Ltd., Messrs English Electric Co., Ltd. and Messrs Metropolitan Vickers for photographs, drawings and helpful suggestions.

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DISCUSSION

H. G. Val Davies (Associate Member): In this country some 6 000 miles from Europe in general and Great Britain in particular, we are somewhat detached from developments and Mr Baird's paper on modern switchgear installation in Great Britain is a generous contribution to the cause of bringing us up to date.

The general impression gained in reading this paper is that Mr Baird is a staunch protagonist of the air-blast circuit-breaker. He rightly states that the space problem in England in many instances necessitates indoor 132-kV switchgear. The obvious choice in this instance is air-blast gear and the illustration in Fig. 1 of Mr Baird's paper is a typical example of such an installation by the company with which I am associated. The switch-house illustrated is that at Brunswick Wharf Generating Station in the Borough of Poplar, part of Greater London. The turbine and boiler houses have been built in a disused dock, part of which is used for coal storage. The switch-house and step up transformers have been located on the wharf adjacent to this dock. The site has a frontage on the river and sea borne coal is consequently employed as the principal fuel. The station has been laid out for an ultimate capacity of 330 MW with four 52·5-MW and two 60-MW turbo-generators. The initial installation comprises three 52·5-MW sets. Fig. A shows a cross section of this switch-house. The circuit-breakers are air-blast 600-amp units rated 2 500 MVA at 132 kV and have a number of special features including blast heads mounted directly on the air receivers, radial-flow double-blast contacts, linear resistance switching and all porcelain primary insulation (Fig. B). The present installation comprises nine equipments, the ultimate capacity being twenty-one. Breakers of this type have been used for many years outdoors on the Grid and have given excellent service.

The author's general conclusion, however, that air-blast switchgear is preferred to bulk oil outdoors is somewhat broad. Referring to the author's Table V giving the number of breakers for the Grid completed between 1952 and 1953 and put in hand during that period, it may be interesting to compare similar figures for my company. Between 1948 and 1954 we supplied:

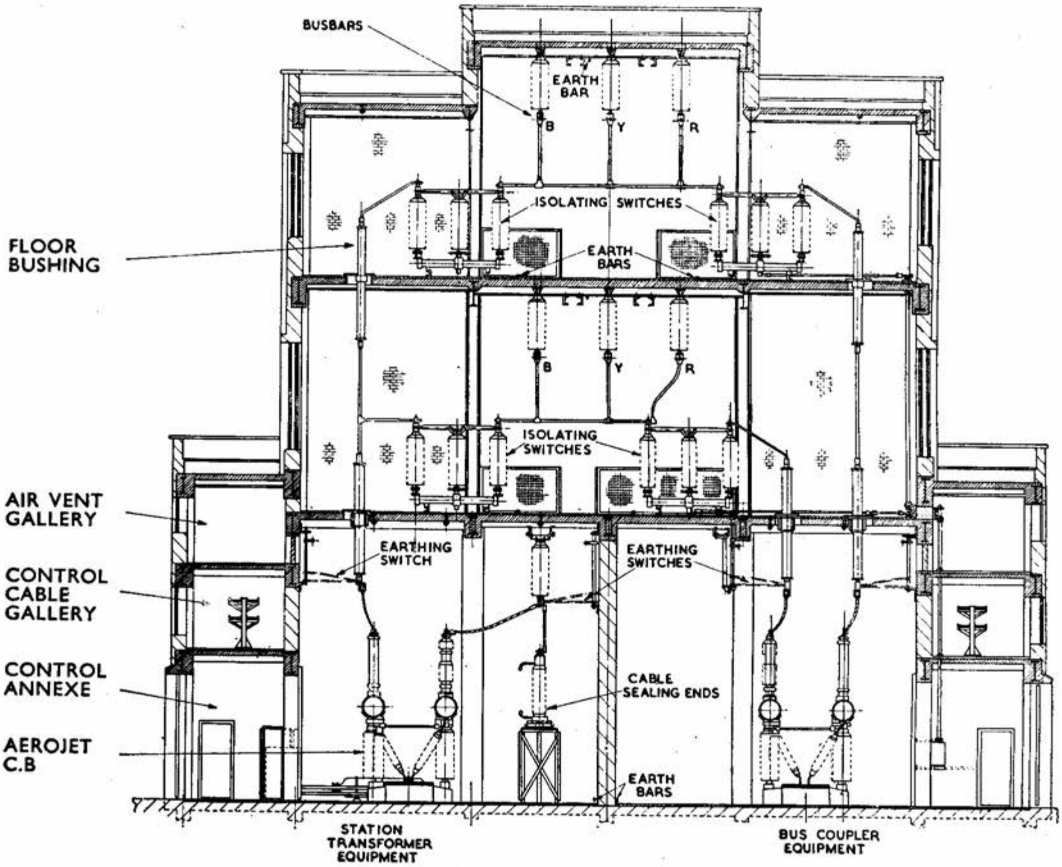

Fig. A—Sectional elevations of switchgear

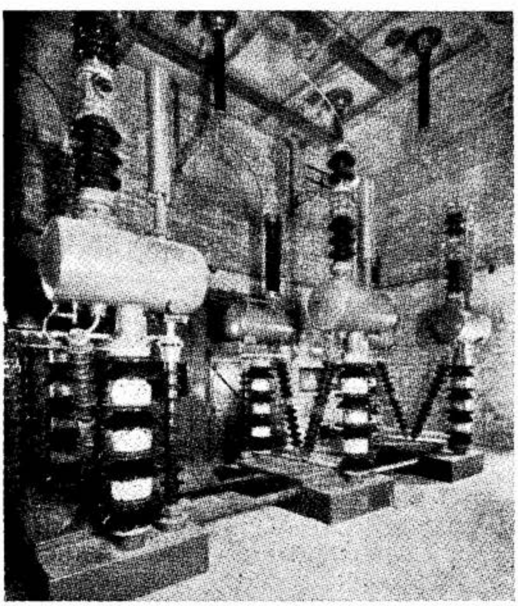

Fig. B—Aerojet breaker

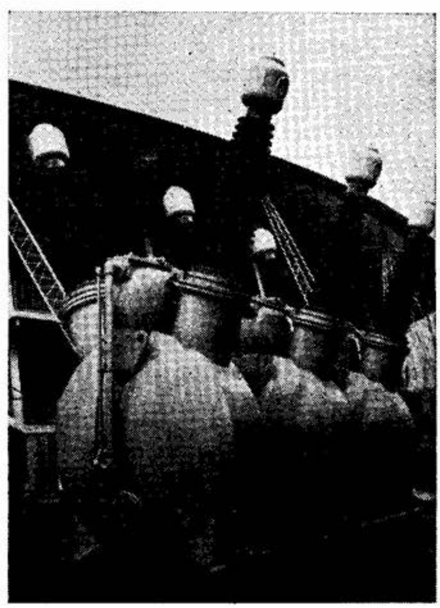

Fig. D—7 500 MVA 275 kV bulk oil breaker

70-132-kV, 2 500- and 3 500-MVA bulk-oil breakers, and 20, 33- and 66-kV bulk-oil breakers. (See Fig. C).

In manufacture at present, the majority of which are for installation this year, we have:

63-132-kV, 2 500- and 3 500-MVA bulk-oil breakers and 17, 275-kV, 7 500-MVA bulk-oil breakers. (See Figs. C and D).

All these units were and are being supplied to the British Grid *alone*. It is noteworthy that these totals are for but one manufacturer from 1948 to 1954.

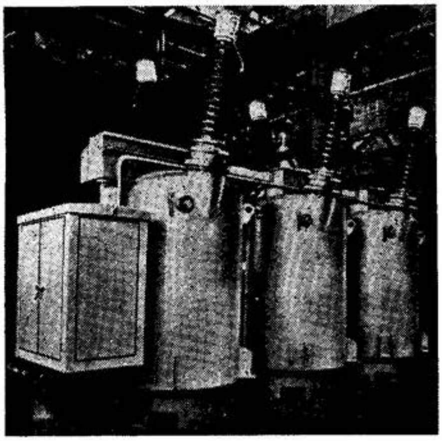

Fig. C—3 500 MVA 132 kV bulk oil breaker

All the 132- and 275-kV breakers mentioned are 3-cycle design suitable for high speed auto-reclosure and are fitted with wire wound resistors not non-linear resistors as stated by the author. We have supplied and commissioned overseas both three-pole and single-pole high-speed auto-reclosing bulk-oil breakers fitted with wire-wound linear resistors, one of the most notable installations being that in South Africa at Taaibos Power Station, the rating of which is 3 500 MVA at 132 kV fitted with three-pole high-speed auto-reclosing.

Mr Baird contends in paragraph 4·3 of his paper that the air-blast circuit-breaker has the advantage over other types of breaker in that it can be unit tested, thereby enabling short-circuit tests to be made under conditions giving maximum stress in respect of recovery-voltage and rate-of-restriking voltage.

The bulk-oil circuit-breaker is eminently suited to unit testing which was adequately dealt with as early as 1947 and reported by Cox and Wilcox in a paper read before The Institution of Electrical Engineers, London, entitled 'The performance of high-voltage oil circuit-breakers incorporating resistance switching,' Volume 94, Part 2, No. 40, August 1947.

The 275-kV, 7 500-MVA design has four breaks-per-phase with linear resistors. It is also the design used at 220 kV and recent site tests on a 5 000-MVA unit at Fontenay in France produced outstanding results for three-phase line-dropping tests interrupting reactor and transformer currents. The maximum system overvoltage recorded was 1·65 times the line-to-ground volts. This breaker was unit tested before delivery at 100 per cent rating and gave a three-cycle performance.

In conclusion, I believe it is fair to say that where adequate space is available as is the case in South Africa, there is nothing to support a contention that air-blast switchgear is preferred to bulk-oil for outdoor switching stations.

E. W. Dixon (Associate Member): The author has provided a very comprehensive survey of what is commonly referred to as the 'grid scheme.' As such, the vast networks are now able to supply power to the large and rapidly developing industrial areas which hitherto, for various reasons political and otherwise, suffered appalling neglect, to the despair of the masses of workers situated therein. Many will recall the distressed areas of the years after the 1914–18 war, when the sad fact emerged that the coal mining industry—the prime mover of all things in Great Britain—was paradoxically enough, one of the hardest hit.

As a result of the long-term planning initiated by the Central Electricity Board in 1926 and now in the hands of the B.E.A., de-centralization of industry is being rapidly carried out to the benefit of all concerned and most certainly to the benefit of Great Britain in her manufacture for the export markets. It is truly a great achievement, and in the execution of this undertaking a high degree of standardization has been made possible by the co-operative spirit prevailing amongst the leading switchgear manufacturers and designers, together with the technical committees of the British Standard Institution and other research bodies. The author mentions some of the difficulties of obtaining sites for new power stations but, logically enough, they have chosen to locate many of them on the coal fields. One would have assumed, that, in a welfare state with a nationalized electricity supply industry, powers of appropriation are a mere formality and the acquisition, rather than the removal of 'black spots,' is an invaluable asset.

As described, 132-kV indoor switchgear must be very costly indeed and it would be interesting to know if the saving effected on insulation levels offsets to any great extent the extra building costs involved. It is also appreciated that, in heavily polluted areas, serious consideration must be given to the nature of the deposit on insulators, and the author also may like to describe the method and extent of maintenance which is carried out in the switching yard of a power station situated in the centre of the coal fields. Some badly sited stations come to mind, especially one of 33 kV operating on the windward side of the screening plant of a large colliery in Derbyshire. The explosive qualities of coal dust, assisted by mountain mist, need not be enlarged upon.

The typical station layouts illustrated which employ reinforced concrete structures are a big improvement on the old lattice girder construction and infinitely more pleasing to the aesthetic senses. Where space is not a handicap, the relatively low level structures provide a neat and clean arrangement combined with easy maintenance and essential safeguards for the operating staff. A salient feature is that this type of construction provides yet another profitable outlet for the building and cement industries with the consequent saving of steel for other important purposes at an economic price.

Three designs of 132-kV station layouts are discussed which will, in future, presumably be equipped with air-blast circuit-breakers of the series-interrupter design with phase - associated sequentially - operated isolators. In the early days of air-blast and pneumatically-operated circuit-breakers, considerable difficulties arose with the complex air-valve systems which were employed, mainly due to extreme temperature conditions, icing, condensation and leakage problems. The compressors, air pipe lines, the remote-operated electro-pneumatic valves, the air receivers on each breaker, the automatic high- and low-pressure switches which form part of the ancillary apparatus, were liable to failure and consequent disruption on a system. No doubt a big improvement has been effected in these matters, but perhaps the author can give us some idea as to the extent of maintenance work carried out, or alternatively, details of outages due to these causes.

In the case of the three-switch and double-busbar stations, considerable numbers of isolators are used for various facilities of switching to give maximum flexibility. As compressed air is already available, would it not be a practical and economic step forward to operate them by this means, providing the sequence interlocking can be maintained and proved nearly as infallible as the figure-key system. Under extreme icing conditions, hand-operated isolators can be troublesome even when provided with toggle-link operating mechanisms having a high mechanical advantage.

Table V gives a very interesting comparison of the types of circuit-breakers now in use, and an indication of the future trend. By virtue of their high operating speeds, the air-blast circuit-breaker is, apparently, very much in favour, although the low-oil-volume or oil-minimum circuit-breaker is also capable of operating at high speeds, and obviates the use of expensive compressor and air-distribution equipment. In 1946/47 several stations—notably Chichester and Aldershot—were equipped with 132-kV oil-minimum circuit-breakers at a cost which must be much less than the modern air-blast circuit-breaker installation. Can the author inform us whether the saving effected is considerable, or do the technical advantages of the airblast circuit-breaker outweigh these cost differences ?

On the question of rupturing capacity, the figure of 7 500 MVA on the 275-kV air-blast breaker appears astronomical, though a more onerous duty is apparently carried out on the 33-kV breaker, with a rated rupturing capacity of 1 500 MVA. It is noted that two only of these circuit-breakers are installed so, presumably, they presented certain technical difficulties, or proved uneconomic to manufacture as compared with the air-blast circuit-breakers of higher voltage rating. Taking all design considerations into account, one is prompted to ask what is the foreseeable limit to the rupturing capacity at, say, 132 and 275 kV, if these voltages provide the optimum conditions on distribution networks in Great Britain. The vulnerability of large generating stations is also a matter for some concern by the defence authorities, and the limitation to capacity is a matter for consideration. Before leaving the question of circuit-breaker ratings, it would be interesting to know what the Continental designers are now doing, and how their switchgear compares in price and performance. In dealing with the question of post and strain insulators, the author stresses again the fact that atmospheric pollution generally decides the type and number of units which will be employed in a stack. Some ten or twelve years ago, there was considerable discussion amongst engineers on the subject of insulators manufactured with a self-conducting glaze. At that time it was thought that insulators with these characteristics would overcome many of the difficulties experienced in bad situations, by virtue of the even potential-stress distribution on the surfaces of the insulator, so that any further deposits of an injurious character would have little or no influence on the performance of the unit as designed. A number of the prominent insulator manufacturers in Great Britain were conducting researches, but nothing further appears to have emanated from them, either in technical publications dealing with new developments, or through the various research associations.

Can the author provide any further information on this interesting development, or tell us whether the insulator manufacturers have found that this was not a practicable or economic commercial proposition.

H. L. Black (Associate Member): I would also like to add my thanks to Mr Baird for this most interesting paper; I think we are all agreed that it will form a very valuable source of reference when published in the *Transactions*.

I have a few minor points to raise. The first I do not think Mr Baird actually mentioned in his address this evening, although it appears in a printed version of the paper. In Table IX details of a typical instrumentation scheme for a power station are given, and I notice with some surprise that indicating reactive MVA instruments are included on the generator panel only, and that the familiar power-factor meter has disappeared completely. I would like to know a little more about this, particularly the reason why reactive-power indication is omitted from the feeders whereas it is apparently commonly included on generator panels. It would seem that the reactive-power distribution on the transmission lines is, from the operating viewpoint, relatively of more importance than that on generators.

The second point; I was very interested to see the reference to potential transformers capable of providing an appreciable output for use for auxiliary supplies. In this connection, it would be interesting to know what influence this new facility has on the cost of a typical potential transformer, and whether any special precautions are taken when such a transformer is used to supply some form of distance protection, that is, are any steps taken to present mal-operation of distance protective gear in the event of a fault on one of the auxiliary circuits? Also has this particular feature any influence on the standard of accuracy obtainable from these potential transformers?

One further small point; in Table I it is stated that the factor of safety for bus-bars and connections, based on the ultimate strength, is 2. This seems to be an extremely low value, and must surely be lower than that of the associated transmission lines. Perhaps Mr Baird could give us some amplification of this point.

Finally, as a matter of interest, could Mr Baird tell us whether single-pole automatic reclosing is used on the British grid?

A. G. V. Pearce (Associate Member): I would first like to congratulate the author on an extremely interesting and informative paper.

In Table VI, arcing-horn gaps for various items of equipment, such as strain insulators, current transformers, post insulators, etc., are given. It would be interesting to know the insulation level adopted in terms of impulse and power-frequency withstand values for all items of equipment from incoming line terminals onwards including bushings and windings for both 132 and 275 kV.

From the characteristics given in Table III it is observed that the 1/50 wave withstand level, adopted for 132-kV indoor switchgear, is 550 kV which is the value specified in the T.M.A. specification of 1946 for 110 kV. Does this mean the B.E.A. have accepted the International Electro-Technical Commission's recommendations in this respect ?

On the other hand, the 50 cycle per second withstand values comply with B.S. 223 (Electrical performance of h.v. bushing insulators) which are considerably higher than proposed by the latter Commission.

Whilst appreciating that the subject of insulation co-ordination and in particular, impulse testing is as yet under investigation, the subject is of particular interest in this country where lightning conditions are onerous. Any comments the author may have to offer on B.E.A.'s choice of levels would therefore be of considerable interest.

It is noted that guard wires have been omitted for the reasons given in the paper and that no mention of surge arrestors has been made. Have these been omitted as well as the guard wires and, if not, could the author indicate where these are situated —presumably close to the main transformer terminals.

Brief mention has been made of switchgear- and transformer-oil treatment plant. It is understood that the B.E.A. have adopted the policy of installing permanent filter units and storage tanks at larger substations to enable routine upgrading of oil to be accomplished, and it would be useful to know what the practice is in this regard. Could Mr Baird tell us, in particular, for what size of substation, in terms of quantity of oil, a permanent filter and storage installation is considered necessary, and what procedure is used in the case of substations in which a permanent unit is not installed.

It is interesting to see that the principle of isolation of all sources of supply by means of key or electrical interlocks has been adopted in the case of cubicle housed equipment. Could the author give an indication of how isolation of the stepdown transformers shown in Fig. 6 is effected ? Is the indoor low-tension transformer breaker interlocked with the transformer h.v. disconnects ?

Reading the three switch substation layout as shown in Fig. 6, in conjunction with Table VIII, the bus-section breaker is presumably calibrated to trip on overload in either direction. Does this mean that faults outside the zone of high speed impedance equipment and in the vicinity of the three switch substation busbars is cleared on inverse time overload, or is some form of intertripping used ?

A. Trevor Williams (Member) (*contributed*): The paper provides a useful and interesting summary of B.E.A. Publications and Purchasing Specifications and the most important conclusion seems to be the stated trend towards air-blast gear at 132 and 275 kV, as far as Great Britain is concerned ; in other countries, however, and particularly North America and Canada, pride of place is still held by the bulk-oil outdoor breakers, right up to the highest voltages.

I would like to comment on some of the sections of the paper as follows :—

Section 3.5.1—*Table II*

The clearances between busbars and to earth are not in line with the latest figures discussed between B.E.A.M.A. and the B.E.A. They have obviously been taken from an early edition of the B.E.A. Purchasing Specification for outdoor switchgear. The latest proposed figures have been appreciably modified and a warning should be given that this Table should not be regarded as final. The values apply to busbars and connections but not to equipment which is subjected to impulse voltage tests. In other words, the paragraph immediately below Table IV should also apply to Table II. The reason for this is that it is not considered necessary to have two standards of insulation level and the impulse voltage test is now regarded as the main criterion. Where, however, there are assemblies of equipment which cannot be subjected to works tests, then a minimum clearance distance will be specified.

Section 3.6—*Table III*

This Table only purports to give typical characteristics for 132-kV indoor switchgear. It is important to note, however, that the latest agreed trend between manufacturers and users is to specify a minimum dry withstand voltage of insulators or bushings without horns, and not a flashover voltage. This applies also to outdoor gear. It is expected that design margins are the responsibility of the manufacturer and that provided the test can demonstrate that the minimum voltage level is reached without breakdown, there is no useful purpose served in stressing the gear up to the actual flashover level.

Section 3.8.1—*Indoor 33-kV metalclad switchgear*

In his description of 3·3-kV equipments, the author has mainly drawn attention to the compactness of modern designs and in this connection it is interesting to note that such units can now be accommodated within 3 ft 9 in centres and in relatively low buildings. Furthermore, although compound-filled busbars are most commonly used therewith, there is no difficulty in supplying air-insulated busbars for indoor equipments and, in fact, are being installed at the new station at Johannesburg.

Section 4—*Main switchgear*

There is a mistake in the lower portion of Table IV which should read 'Bulk-oil modernized from 1 500 MVA to 2 500 MVA.' From the numbers of different types of breaker put in hand during 1952/53, it is noted that the air-blast is predominate at 132 kV in the ratio of 64 to 41. On the other hand, it must be noted that 30 existing bulk-oil breakers have been planned for uprating and this will involve an appreciable volume of work to the factories concerned and should, therefore, not be left out of the picture. In my opinion, the case for air-blast operation is much stronger at 275 kV than at 132 kV and I am not aware of any strong evidence yet to support the belief that the bulk-oil breaker is going to be superseded at the latter voltage by the air-blast breaker.

The number of breakers quoted at 33 kV in the Table are not sufficient to show any trend, but it must be remembered that the majority of 33-kV installations are supplied to the Area Boards of B.E.A. and are obviously not quoted in the statistics given. By far the majority of these are still bulk-oil designs and there is no evidence that they will be supplemented by air-blast. The final answer will undoubtedly be determined by economics and the air-blast breaker tends to be increasingly more expensive as the voltage is reduced. It is known that at least one leading manufacturer of air-blast gear in Great Britain and another in Switzerland has reverted to oil breakers at the lower voltages, 11 kV, on account of the relative cost of manufacturing air-blast. It is quite true that the multi-unit air-blast breaker can conveniently be tested in stages on the short-circuit test plants, provided that the voltage distribution is correctly graded across each breaker. On the other hand, this is also possible with multi-break oil circuit-breakers, although not quite so readily carried out.

Pneumatic operation can also be applied equally satisfactorily to either type of breaker and this form of operation has certain advantages. It is important to remember, however, that there are complications with the compressed-air system and loss of air pressure means that the air-blast breaker can neither be opened nor closed, whereas it is always possible in an emergency to trip a bulk-oil breaker, because the opening operation is dependent only on charged springs.

Reference is also made in this Section to the advantageous performance of the air-blast breaker for high-speed reclosing duties. There is no inherent difficulty, however, in obtaining a similar performance with oil circuit-breakers.

I am aware that tests have recently been conducted on high-speed reclosing duties with an oil circuit-breaker during which 1 000 MVA at 33 kV was successfully interrupted, re-made and interrupted a second time with no reduction in efficiency on the second operation and with 'dead' times as low as 0·24 seconds; the tests were carried out using a spring closing mechanism.

Section 5.1—*Current transformers*

The cost of separately mounted post type current transformers is one of the biggest disadvantages of air-blast gear. This difference in cost is mentioned by the author, but it may not be realized that the ratio of costs is of the order of 10–20 times.

Section 6.3—*Compressed air equipments*

I am not in disagreement with the data given on compressed air equipments, but the importance of ensuring dry air and continuity of air supply might usefully be stressed. Any serious defect in the compressed-air supply would have immediate consequences in the reliability of the switchgear. This necessitates rather special attention being drawn to maintenance and also expensive duplication of all equipment.

Section 7—*Conclusions*

It may be argued that the advantages of the air-blast gear have been rather overstated. The impression is given that the necessary high-speed performance cannot be obtained with oil breakers. This is not a fact and there is ample evidence that 3-cycle performance can readily be obtained with bulk-oil breakers and, as mentioned earlier, high-speed reclosing can also be achieved with modern oil breakers. The question of fire risk is, of course, an ancient bogey, but really the relative degree of risk is not alone sufficient to intensify one type or the other. It is well known that there have been disastrous failures of air-blast switchgear, not necessarily in Great Britain, where the destruction and disturbance was at least as great as would have occurred with failure of an oil circuit-breaker.