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Paper 30

Power Supply: Air-insulated Switchgear

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1. Introduction

The duty imposed on single-phase railway switchgear is of a different type to that imposed on three-phase distribution switchgear and may well be more arduous. It is of the utmost importance that the switchgear should function with complete reliability under all conditions and the circuit breakers described in this paper were specially developed over 15 years ago in Sweden for the $16\frac{2}{3}$ cycles single-phase traction system employed there. The first installation was in 1944 and the equipment has been thoroughly proved in service and has given excellent performance both in Scandinavia and in this country. The contraction chamber, which is the heart of the circuit breaker, has a long record of satisfactory service from 1933, being first used as an arc control device on bulk oil circuit breakers. Certain 33 kV units on the Southern Railway's London – Portsmouth and London – Sevenoaks electrification schemes were uprated by the fitting of contraction chambers in 1938. Three-phase oil minimum contraction type circuit breakers have been extensively used since 1935. In this country they are in service on supply systems up to 132 kV and on the Gillingham – Maidstone line in the Southern Region they have been in service since 1938 in the 33 kV substations.

On the 25 kV 50 cycle single-phase electrification of the Eastern Region oil minimum circuit breakers are installed for the control of incoming and outgoing circuits at the various sub-stations and at the track sectioning cabins. The fault levels at feeder substations dictate the use of circuit breakers rated at 800 amps and 300 MVA and the same type of breaker is employed as the bus section circuit breaker at track sectioning cabins where two out-of-phase supplies might be inadvertently connected. All other applications can be met by a circuit breaker rated at 600 amps and 150 MVA.

The design insulation level of the switchgear is 200 kV for a 1/50 μs impulse, and 103 kV RMS for the power frequency test.

2. Layout of Switchgear

2.1 *Earlier Design of Switchgear*

The original design of switchgear is in use on the Colchester – Clacton – Walton section of the Eastern Region and will be available for inspection by Conference delegates. The equipment at the one feeder station and the three track sectioning cabins consists of 31 units of switchgear housing 24 circuit breakers.

Although the basic components are the same as those used for the present design the general layout of the switchgear differs from that now adopted. This earlier design required an access aisle at both the back and the front of the switchboard and, consequently, necessitated a greater floor area for the substation building.

This equipment has been in actual service for 18 months, a period long enough to prove the soundness of the design.

2.2 *General Layout of Present Design*

The sectional sketch (fig.1) shows the layout of the latest design of switchgear in which a careful re-arrangement of the components gives a more compact layout as compared with the earlier design and eliminates the need for an access aisle at the rear of the switchboard.

At the bottom left is the busbar chamber which runs unpartitioned the whole length of a busbar section. It is accessible through end doors and also, where necessary, through 'escape hatches' at the rear of bus section circuit-breaker compartments.

The busbar isolators have 'closed' and 'earthed' positions. From the moving blade of an isolator a connection passes through a bushing into the circuit-breaker compartment (bottom right).

Access to this compartment is obtained through a door in the front of the switchboard (see figs.7 and 8). Since the circuit breaker itself is mounted on wheels and has a flexible plug-in connection for small wiring it may be wheeled out into the aisle for inspection and maintenance (see fig.9).

From the other side of the circuit breaker the high voltage connection runs through an inclined bushing into the upper or circuit isolator compartment. The circuit isolator is similar to the busbar isolator in that it has 'closed' and 'earthed' positions.

In most cases incoming and outgoing connections are by cable. The nose of the right-angle cable box passes into the substation through an aperture in the wall and only a short connection is required to the circuit isolator. Where a direct connection to an overhead line is required a through-bushing can be used instead of the right-angle cable box. The same basic layout is used for both incoming and outgoing circuits.

Current transformers are mounted on either the horizontal or the inclined through-bushing or on both.

2.3 *Busbar Sectioning*

Where the busbar is sectioned a permanent sheet steel barrier divides the two adjacent busbar compartments. The bus section circuit breaker is connected between two busbar isolators as is shown on fig.4.

Since there are no circuit isolators associated with a bus section circuit breaker the upper compartment, normally housing circuit isolators, provides spare space for other purposes. By locating incoming feeder units immediately adjacent to the bus section circuit breaker the spare space in the upper compartment may be used for housing the voltage transformers associated with these incoming feeders.

2.4 *Interlocking*

Circuit breakers, isolators and access doors are fully interlocked. Mechanical interlocking is employed between the isolators and the circuit-breaker compartment doors whilst all other functions are key interlocked.

3. Description of Switchgear

3.1 *Isolators*

All isolators have two positive positions, namely 'closed' and 'earthed'. All are operated by handle gear on the front of the switchboard and are appropriately interlocked with circuit breakers and with access doors.

Suitably placed reinforced glass inspection panels permit a visual check of isolator blade position.

3.2 *Circuit Breakers*

The oil minimum contraction type circuit breaker contains only about 5·2 gall. of oil and is solenoid operated. The breaker may be electrically closed and tripped either remotely over the supervisory system or locally. The local trip button operates mechanically on the trip coil armature thus tripping the circuit breaker irrespective of whether or not a normal tripping supply is available. On outgoing circuits an auto-reclosing device is fitted to give a single reclosure after fault clearance with a time interval adjustable 5-20 seconds. Provision is also made for slow manual closing during maintenance.

The basic principle of arc control is the contraction chamber in which a piston moves downwards under the gas pressure of the initial arc and, by differential action, creates a pressure to drive a flow of clean oil radially inwards towards the arc thus contracting and cooling it. The sequence of operations is shown in fig.5.

Technical data of the circuit breakers is as follows:

	Type HKSJB 1/33/800	*Type HKSJ 1/33/600*
Rated voltage	25 kV	25 kV
Rated current	800 A	600 A
Breaking-capacity (symmetrical)		
At 25 kV	12 kA	6 kA
	300 MVA	150 MVA
At 44 kV	6 kA	—
Making current	30·6 kA peak	15·3 kA peak
Short-time current for 3 sec.	12 kA	6 kA
Weight, including mechanism and oil	680 lbs	650 lbs
Quantity of oil	5·2 gall.	3·6 gall.

Type test results are given in a separate sheet at the end of the paper and a typical oscillogram of a make-break test is given in fig.6.

An unusual feature of the circuit breaker is the inclusion of a direct acting overcurrent release actuated by primary current. Since it operates the circuit breaker tripping latch direct without requiring energisation of the trip coil the advantage of very rapid fault clearance (3·5–4 cycles total time) is obtained. This is well shown in the oscillogram of fig.6.

4. Auxiliary Equipment

4.1 *Current Transformers*

One or more current transformers are mounted as required on through-bushings between switchgear compartments thus eliminating any need for additional insulation.

On standard track feeder units two current transformers are mounted on the inclined bushing between the circuit-breaker compartment and the circuit-isolator compartment. Only one of these current transformers is used for protection and thus the other is available for test and metering purposes.

When required, additional current transformers can be mounted on the horizontal bushing of the busbar isolator.

4.2 *Voltage Transformers*

Voltage transformers have graded insulation; by first packing the space between the windings and the porcelain housing with quartz sand, the quantity of oil required is reduced to only 2 gall. per transformer and additional support is given to the windings.

A sand-filled fuse protects each voltage transformer. As has been mentioned above, the voltage transformers associated with incoming feeders can conveniently be housed above bus section circuit breakers (see fig.4). Busbar voltage transformers are housed in a compartment similar to a circuit-breaker compartment and are connected to the busbar via a fuse and a busbar isolator (see fig.2).

4.3 *Auxiliary Transformers*

Outdoor auxiliary transformers for standby signalling and auxiliary power supplies are also fed from the busbar via a fuse and an isolator. Economy of space is effected by using a combined unit which both houses a busbar voltage transformer and feeds an auxiliary transformer (see fig.3).

4.4 *Relays, etc.*

Protective relays, auto-reclosing devices and ancillaries are mounted on the front panel of the switchboard (see fig.7). Relay terminals and small wiring are completely shrouded from high voltage equipment by an earthed steel barrier. The relay equipment is described in Paper 31.

Facilities have been provided for the secondary injection testing of relays while the switchgear is in service. The necessary test terminals are accessible on the front of the switchboard. Appropriate switching of relay circuits is performed by special relay test switches; no permanent wiring need be disturbed.

The detachable operating knobs of relay test switches can only be removed when the switches are in the 'service' position. It is intended that these knobs should be retained centrally by a responsible person; the fact that all knobs have been received back is in itself an indication that no test switch has been inadvertently left in the 'test' position.

5. Operational Experience

The switchgear supplied for the Colchester – Clacton – Walton section of the Eastern Region was put into commercial service in April, 1959. Six of the 24 circuit breakers are not yet in normal service as they are intended for feeding sections of track that have not yet been electrified.

The performance of the switchgear has been entirely satisfactory and the present policy of the Eastern Region based on experience to date is to change the oil once a year and to test the condition of the oil every 3 months or after about 15-20 fault clearances. The number of fault clearances between oil tests is being gradually increased as experience is gained.

7. Extensions in Hand

Work at present in hand includes the manufacture and erection of switchgear for some 17 substations on the Chingford – Enfield – Bishops Stortford, the London – Tilbury – Southend, the 'D.C. Conversion' and the 'Gap' schemes of the Eastern Region. Some 110 cubicles of switchgear (including 85 circuit breakers) have been or will be installed in the 17 substations.

8. Conclusions

The design and performance of the switchgear has been fully proved in service on the Eastern Region during the last 18 months. Amongst the more important advantages of this type of switchgear are:

(*a*) The use of a direct-acting overcurrent release permits very rapid clearance of heavy faults thus helping to minimise damage by the fault arc.

(*b*) All equipment is readily available for inspection and maintenance.

(*c*) The division of each switchgear unit into 3 main components (busbar compartment, circuit-breaker compartment and circuit-isolator compartment) facilitates erection work at site and any necessary future additions to the switchboard.

(*d*) The use of inflammable material has been reduced to a minimum. On an 11-panel switchboard including 9 circuit breakers and 4 voltage transformers the total quantity of oil is only 55 gal. This quantity is divided between various metal enclosed compartments and building costs have been kept to a minimum by the omission of fireproof barriers between different busbar sections.

(*e*) No fixed oil-handling installation is required as the oil content of a circuit breaker is not more than 5·2 gal. which can easily be handled in a portable drum.

(*f*) The 'earthed' position of isolators avoids the need for portable earthing equipment.

(*g*) The facility of being able to check visually the actual position of isolator blades.

9. Extract from Type Test Report of Making and Breaking-Capacity Tests on HKSJB 1/33/800 Oil Minimum Circuit Breaker

Standard test duty	*Operating duty*	*Applied voltage*	*Making current*	*Breaking current*			*Recovery voltage*	*Recovery voltage as % of rated service voltage*	*Restriking voltage amplitude factor*	*Restriking voltage rate of rise*	*Symmetrical breaking capacity*	*Arc duration*
				Symmetrical	*Asymmetrical*	*D.C. component*						
		kV	*kA peak*	*kA*	*kA*	*%*	*kV*	*%*		*V/μs*	*MVA*	*sec.*
10%	MB	27·5	1·92	1·15	—	<20	29·0	116	1·4	480	33	0·010
	3 min.											
	MB	27·2	2·13	1·15	—	<20	28·5	114	1·4	475	33	0·015
	3 min.											
	MB	27·5	1·84	1·15	—	<20	29·0	116	1·4	480	33	0·018
30%	MB	27·2	9·6	3·35	—	<20	27·5	110	1·6	900	92	0·020
	3 min.											
	MB	27·0	8·2	3·45	—	<20	28·8	115	1·6	940	100	0·020
	3 min.											
	MB	27·5	7·2	3·45	—	<20	28·8	115	1·6	940	100	0·019
60%	MB	27·5	12·7	7·35	—	<20	28·2	112	1·4	1220	205	0·030
	3 min.											
	MB	27·5	11·0	7·35	—	<20	28·6	114	1·4	1240	210	0·019
	3 min.											
	MB	27·5	15·8	7·35	—	<20	28·4	113	1·4	1230	210	0·022
100% make-break tests (symm)	MB	31·0	19·8	13·3	—	<20	31·0	124	1·5	2370	410	0·020
	3 min.											
	MB	31·0	28·3	13·2	—	<20	31·2	125	1·5	2400	410	0·020
	3 min.											
	MB	31·0	29·7	13·0	—	<20	31·0	124	1·5	2370	405	0·027
100% break tests (asym)	B	—	—	12·5	16·0	56	29·0	116	1·5	2220	—	0·021
	3 min.											
	B	—	—	12·7	15·9	52	30·0	120	1·5	2300	—	0·018
	3 min.											
	B	—	—	12·0	15·3	55	28·0	112	1·5	2150	—	0·030
100% make tests	M	29·5	36·0	—	—	—	—	—	—	—	—	—
	3 min.											
	M	29·5	32·2	—	—	—	—	—	—	—	—	—

SUMMARY

After a brief introduction the paper gives particulars of indoor air-insulated switchgear with minimum oil circuit breakers in service on 25-kV, 50-cycle traction systems. The history of the development of this type of circuit breaker for traction and general duties is noted in the introduction.

The paper refers to the two types of switchgear layout in use and describes the present design of substation giving details of the components, including the facilities for testing and maintenance and for the supply of auxiliaries through high rupturing capacity fuses.

Selected particulars of type tests in a short-circuit testing laboratory are also given and some details of service experience.

The paper concludes with a general statement of the merits of this design of switchgear, in particular:

(*a*) The use of a direct-acting release to give rapid clearance of heavy faults.
(*b*) Easy accessibility for inspection and maintenance.
(*c*) The separation of each unit into compartments, coupled with a reduction of inflammable material to a minimum by the use of air or solid insulation whenever possible.
(*d*) External visual inspection of isolator blade position in the closed, and in the earthed positions.

RÉSUMÉ

Après une courte introduction l'article décrit l'appareillage éléctrique du type intérieur tels que les interrupteurs dans l'air et les disjoncteurs à volume d'huile réduit installés sur les réseaux de traction éléctrique à 25 kV, 50 Hz.

L'introduction retrace également l'évolution de ce type de disjoncteur et de son application à la traction et aux réseaux éléctriques en géneral.

Ayant indiqué les deux types d'installations existantes l'article donne le schéma de principe des sous-stations actuelles ainsi que des détails relatifs aux différents éléments constitutifs y compris les dispositions prises pour faciliter les essais, l'entretien et l'alimentation des services auxiliaires protégés par des coupe-circuits à haut pouvoir de coupure.

Les auteurs donnent des details relatifs aux essais de court-circuit obtenus dans une station d'essais ainsi que sur le comportement de l'équipement en service.

L'article se termine par un relevé des avantages de l'appareillage en question parmi lesquels nous signalerons:

(*a*) L'emploi d'un mode de déclenchement à action directe qui assure la coupure rapide des courants de court-circuit les plus sévères.
(*b*) Facile accessibilité facilitant le contrôle et l'entretien.
(*c*) Chaque unité est subdivisée en un nombre de compartiments; à cet avantage s'ajoute le fait que l'emploi de matière inflammable est réduit au minimum, l'isolant étant, si possible, l'air ou une masse solide isolante.
(*d*) Indication visuelle montrant la position des sectionneurs à couteaux dans chacune des positions fermée ou mise à la terre.

ZUSAMMENFASSUNG

Nach einer kurzen Einführung werden Einzelheiten über luftisolierte Innenraum-Schaltanlagen mit Ölschaltern vom ölarmen Typ mit Einschnürungslöschung für den Betrieb von Bahnanlagen mit 25 kV, 50 Hz gegeben. Die Entwicklungsgeschichte dieser Art von Ausschaltern für Bahn- und allgemeine Zwecke wird in der Einführung kurz umrissen.

Der Vortrag behandelt die beiden in Gebrauch befindlichen Ausführungsarten von Schaltanlagen und beschreibt die gegenwärtige Bauweise einer Unterstation mit ihren Einzelteilen einschliesslich der Einrichtungen für Prüfung und Wartung und für die Stromversorgung von Hilfsgeräten über Stromsicherungen mit hoher Ausschaltleistung.

Weiter werden ausgewählte Einzelheiten über Typenprüfungen in einem Kurzschlussprüflaboratorium sowie einige Betriebserfahrungen mitgeteilt.

Der Vortrag schliesst mit einer Herausstellung der Vorzüge der beschriebenen Art von Schaltanlagen. Diese sind im besonderen:

(*a*) Die Verwendung einer unmittelbar wirkenden Überstromauslösung zwecks schnellster Abstellung von schweren Störungen.
(*b*) Leichte Zugänglichkeit für Wartung und Kontrolle.
(*c*) Die Aufteilung jeder Anlage in einzelne Unterabteilungen bei gleichzeitiger Beschränkung entzündlichen Materials auf ein Minimum durch möglichst weitgehende Verwendung von Luft- oder Feststoffisolierung.
(*d*) Visuelle Beobachtung der Lage der Trennschaltermesser in der geschlossenen und geerdeten Stellung von aussen her.

RESUMEN

Después de una breve introducción, este estudio aporta detalles de los mecanismos de distribución aislados por aire e instalados dentro de edicifios, con interruptores de poco contenico de aceite en servicio en las instalaciones de tracción de 25 kV y 50 períodos. En la introducción se hace constar la historia del desarrollo de este tipo de interruptor para la tracción y las utilizaciones generales.

Dicho estudio hace alusión a los dos tipos de disposición de los sistemas de distribución en uso y describe el diseño actual de las sub-centrales dando detalles de los componentes, incluso los aparatos para las pruebas y el mantenimiento y para el suministro a los servicios auxiliares por medio de fusibles de elevada capacidad de ruptura.

También se consignan datos seleccionados de pruebas tipo en un laboratorio de ensayos de corto-circuitos, así como algunos detalles de las experiencias en el servicio.

El referido estudio termina con una declaración general sobre los méritos de este diseño de mecanismo de distribución, en particular:

(*a*) El empleo de un dispositivo de suelta de efecto directo para permitir despejar rápidamente cualesquiera defectos pesados.
(*b*) La fácil accesibilidad para la inspección y el mantenimiento.
(*c*) La separación de cada unidad en compartimientos, unida a una reducción de materia inflamable a un mínimo mediante empleo del aislamiento por aire o sólido siempre que sea posible.
(*d*) La inspección visual externa de la posición de la hoja aisládora en sus posiciones cerrada y de contacto con la masa.

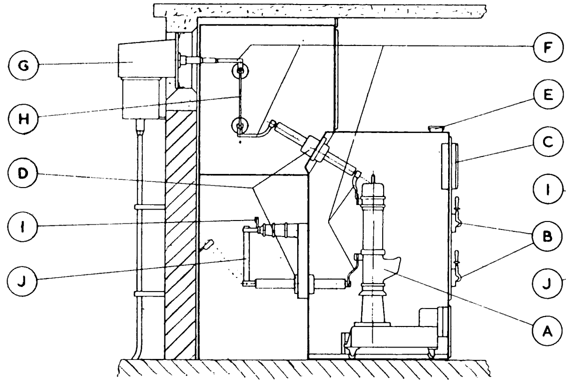


Fig.1 Sectional layout of standard Incoming or Outgoing cubicle

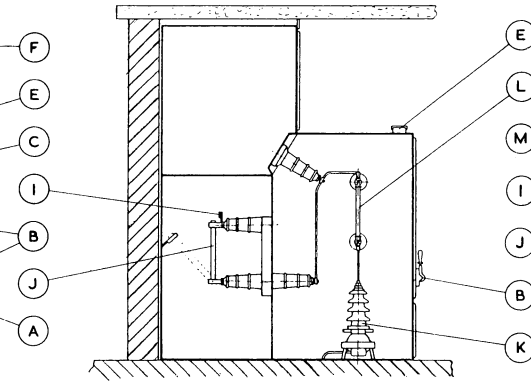


Fig.2 Sectional layout of busbar voltage transformer cubicle

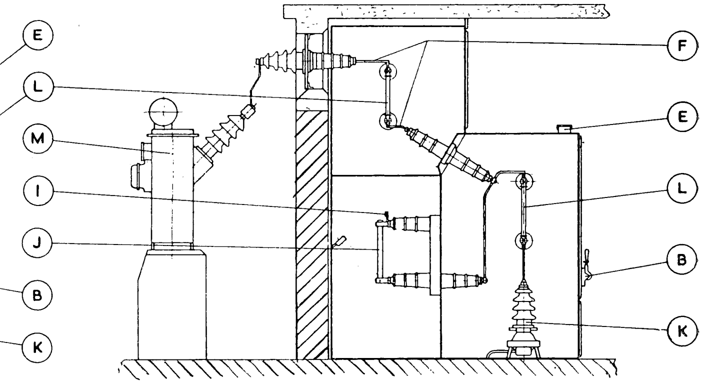


Fig.3 Sectional layout of combined auxiliary transformer and voltage transformer

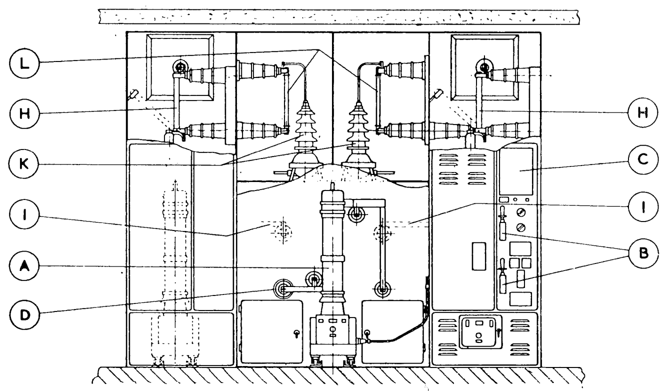


Fig.4 Layout of bus section circuit breaker and adjacent incoming feeder cubicles

Item	Description
A	Oil minimum contraction type circuit breaker
B	Isolator handle and operating gear
C	Relay equipment
D	Current transformer
E	Trunking for auxiliary circuits
F	Flexible connections
G	Oil filled cable box
H	Circuit isolator
I	Busbar
J	Busbar isolator
K	Oil minimum voltage transformer
L	Fuse
M	Auxiliary transformer

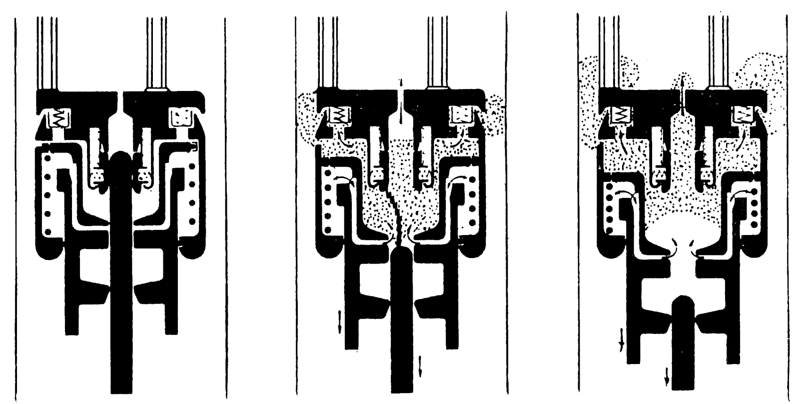
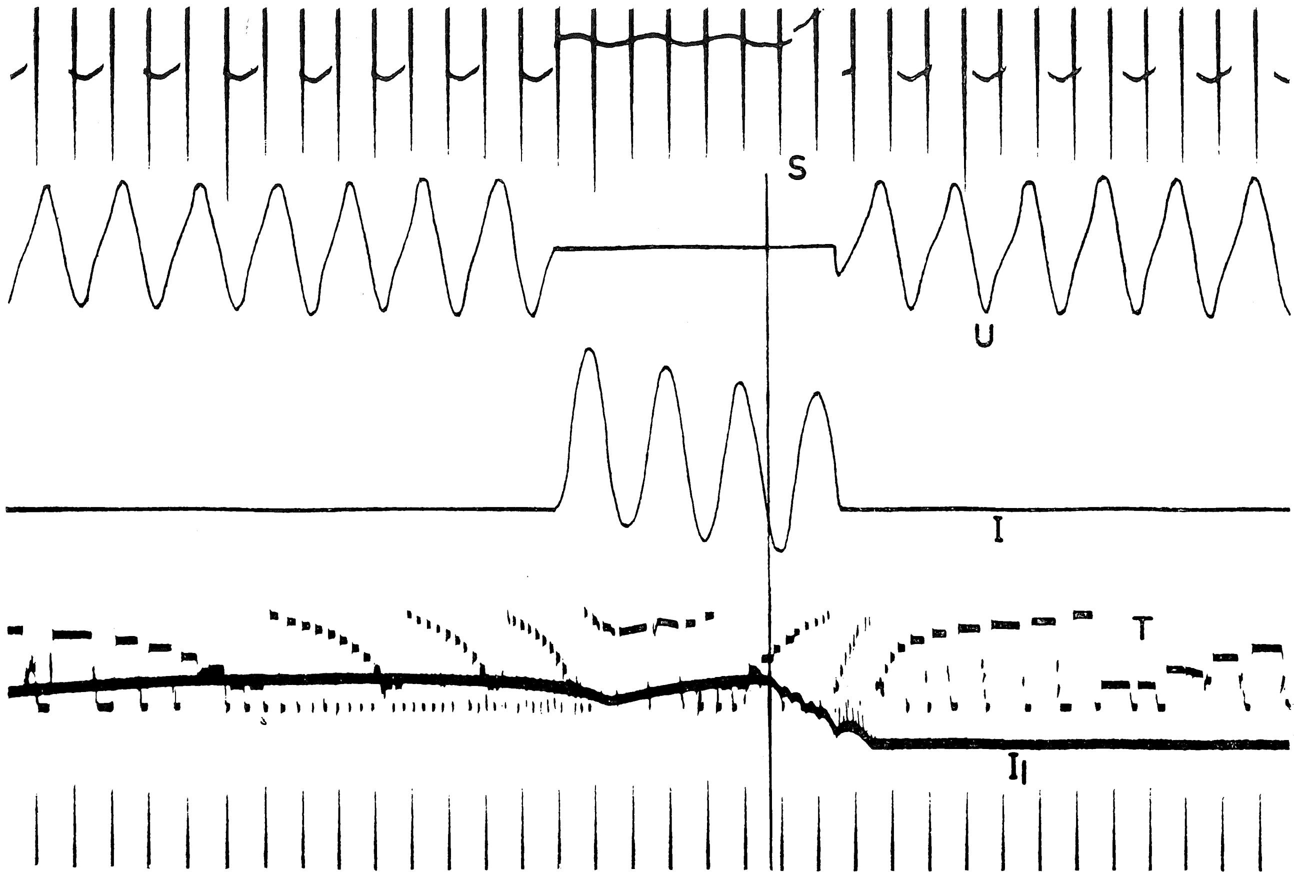


Fig.5 Operation of circuit breaker contraction chamber



U – Voltage.
I – Current.
I_1 – Closing solenoid current.
T – Travel of contact.
S – Instant of separation of contacts.

The circuit breaker type HKSJB 1/33/800 (25 kV, 800 A, 300 MVA) was closed by its normal solenoid operating mechanism on to a short circuit. Tripping was initiated by instantaneous overcurrent release which operates the circuit breaker tripping latch direct.

Applied voltage	29·5 kV.
Recovery voltage	28·8 kV. (115% rated voltage)
Amplitude factor of restriking voltage	1·5
Rate of rise of restriking voltage	2200 V per micro-second.
Making current	36·7 kA.
Breaking current – symmetrical	13·8 kA.
Breaking current – assymmetrical	16·7 kA.
D.C. component	48%
Arc duration	0·019 seconds.
Timing marks at intervals of	0·01 seconds.

Fig.6 Typical oscillogram of make-break test on oil-minimum circuit breaker

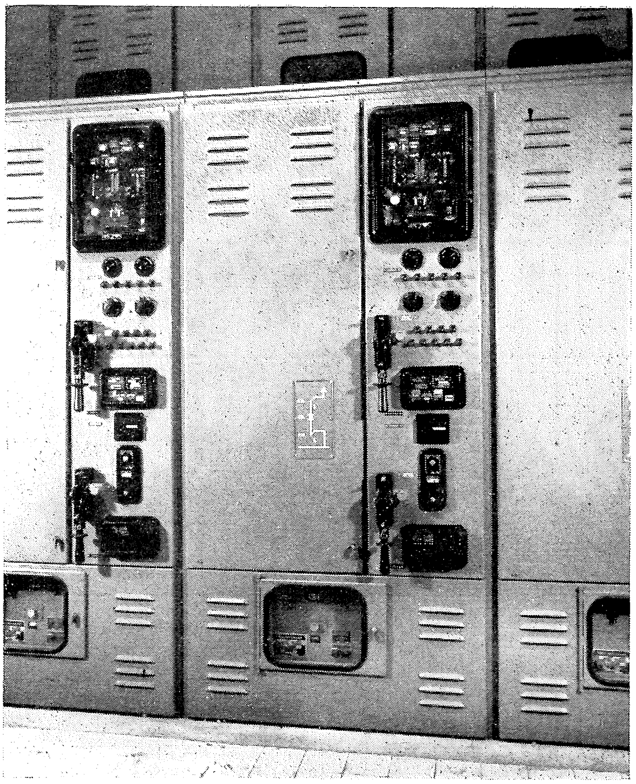


Fig.7 Standard track feeder cubicle

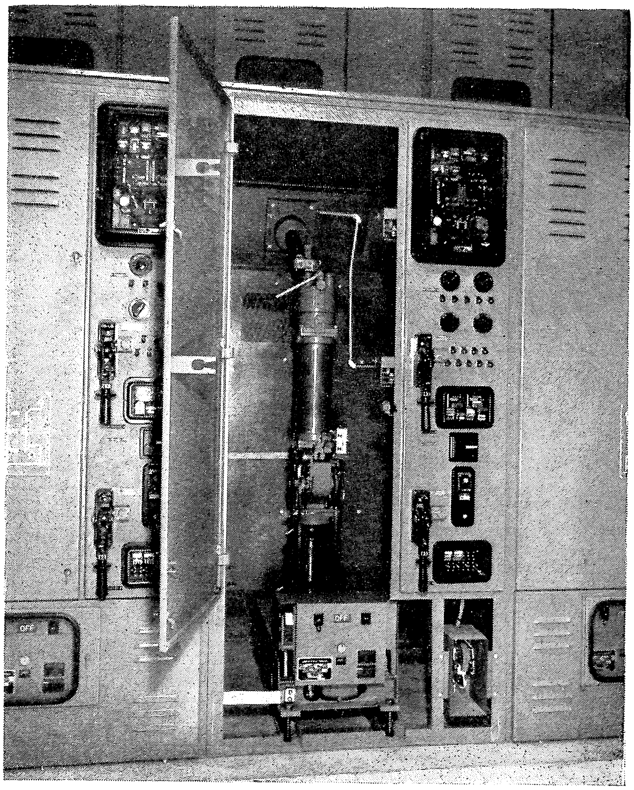


Fig.8 Track feeder cubicle with door open

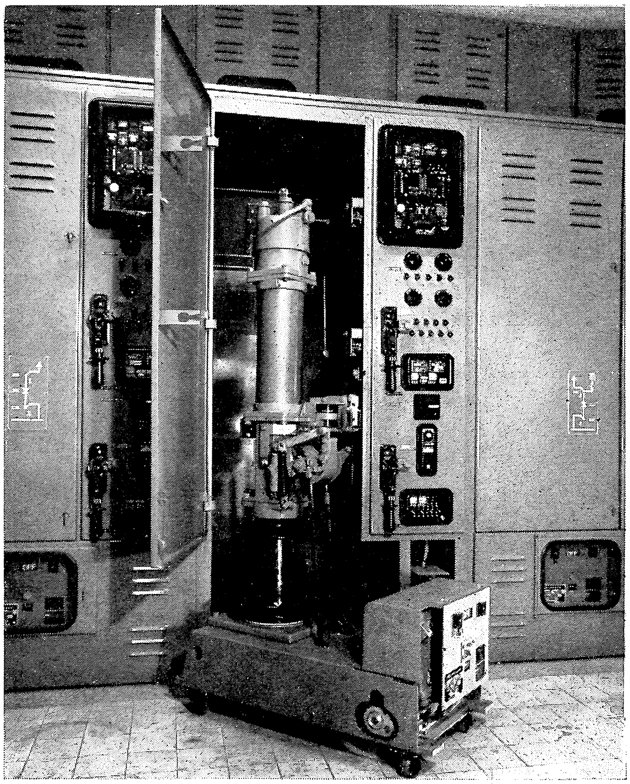


Fig.9 Track feeder cubicle with circuit breaker wheeled out for maintenance.

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