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Paper 31

Power Supply: Protection Systems

F. M. Pearce, BSc(Eng), AMIEE
Engineer, Instrument and Meter Department, Instrumentation Division, Associated Electrical Industries Ltd

G. T. D. Ingle, MA
Manager (Power Department), Fuller Electric Limited

1. Introduction

As on a conventional power system the protective equipment should have sufficient sensitivity to detect all faults but should also have sufficient stability and discrimination to ensure that only the faulty section is isolated. However on a railway system certain special problems arise:

1.1 Travelling load(s) – impracticability of balancing all infeeds and outfeeds to and from the protected section – hence the motive power units have rather similar characteristics to faults.

1.2 The magnitude of the peak load current e.g. when several motive power units in the same track section start simultaneously, may be of the same order as the minimum through fault current for a fault at the end of a section. The protection must not only discriminate between these conditions but must also respond to sustained currents slightly in excess of the rating of the overhead line equipment which could cause softening of the contact wire.

1.3 Speed. High speed fault clearance is essential to assist discrimination and to avoid arcing damage to the contact wire.

1.4 Complexity of network. The current to a fault may flow through many series and parallel circuits. Although any track section is normally fed from one source the possibility of alternative feeding positions must be considered.

1.5 Overhead line circuits must be protected against uncleared faults on the motive power units.

1.6 The protection must operate in the event of the inadvertent connection of out-of-phase track sections.

1.7 A single phase system connected to earth at a number of points precludes the use of certain conventional methods of protection depending on phase compensation or balance.

1.8 Protective systems requiring pilots must be designed to avoid interference between pilots and other circuits.

1.9 Arrangements must be compatible where protection of one make is in adjacent sections of line to that of another.

2. Methods of protection

The maintenance of supply during fault conditions can be by simple protective arrangements in conjunction with extensive reclosing of healthy circuits or by a closely co-ordinated system of circuit breakers and highly discriminative protective equipment with inherent back-up features. The latter arrangement has been chosen in which tripping is closely confined to the two ends of the faulty section thus eliminating any transient supply interruptions to traffic on other sections. Furthermore removal of only the faulty section is automatic and fast because there is no longer a need for trial and error methods of fault location by the control room staff.

Conventional inverse-time overcurrent protection is unsuitable for use with railway track feeder circuit breakers largely because it cannot adequately deal with the conditions specified in 1.2, 1.3 and 1.4 above.

The simplest alternative is a system of protection involving a comparison of the quantities entering and leaving the protected zone but this is impracticable owing to 1.1. In practice more complex relay systems operating on the distance measuring principle have offered an attractive solution.

Distance protection has been an accepted system on conventional supply networks for some 30 years and is used on railway systems in several European countries.

The ratio of voltage to current at a substation on a faulted circuit is proportional to the impedance of the loop formed by the overhead line and the return path between the substation and the fault; it is therefore a measure of the distance of the fault from the substation. This reasoning applies equally to all circuits in cases where the fault is fed over more than one circuit.

Distance protection schemes adapted for use on railway networks fulfil all the above requirements when supplemented by a simple relay to detect sustained currents slightly in excess of the contact wire rating.

3. Method developed by A.E.I. Ltd

Some 400 equipments have been supplied to the London Midland Region, the Scottish Region and the Eastern Region for service on the 6·25 kV and 25 kV systems including the Crewe–Manchester–Liverpool, the Glasgow suburban area, the Liverpool Street–Shenfield–Southend, the Chingford–Enfield–Bishops Stortford and the London–Tilbury–Southend lines (see figs.6 and 7).

In this method the fault is detected by a 'rough' impedance measuring element with a mho-type characteristic whose function is starting and assessment of fault direction. An accurate measurement of the fault position is made by a second element controlled from the first, having an impedance-type characteristic and measuring in three zones.

The first element consists of a disc-type induction relay element with two separate sets of torque producing electromagnets. The first set is energised from system current and voltage reference in the manner of a simple directional relay, producing a contact-closing torque in the disc; the second set is energised from only system voltage reference and produces a contact-opening force. With healthy conditions up to peak load the restraining force is greater than the operating force and the relay contacts remain open. The relay characteristic is represented by the circle A in the R/X diagram fig.1, operation occurring only for points falling within the circle. In this diagram O represents the point at which the relays are situated and a vector such as OZ may be drawn to represent the impedance as measured from O to solid faults at various positions down a track section. As the circle A passes through O, the associated relay element operates only for faults in one direction along the track. To ensure satisfactory operation for faults adjacent to the relaying point the voltage circuit of the directional element electromagnet is tuned by a series capacitor; this circuit will resonate for sufficient time to ensure transient operation of the contacts when complete collapse of the voltage at the relaying point occurs.

The second element is of the axial moving coil type in which two windings are carried on a coil former suspended in a radial field provided by a permanent magnet. The windings are supplied through rectifiers and auxiliary transformers from the system current and voltage reference, the relative polarities being arranged such that the voltage coil produces a restraining force and the current coil produces an operating or contact-closing force. The element contacts will close only if the ratio of applied voltage to applied current is less than a specific value, i.e. the element responds to the circuit impedance irrespective of phase angle. Adjustment of impedance setting is by three coarse taps on the auxiliary current transformer and three current coil shunts which enable the preset values to be adjusted.

The current coil of the distance relay is normally short-circuited by a contact of an auxiliary element controlled by the first (starting) element. When the latter detects a fault in the correct direction its contact closes and causes the auxiliary element to release the second (measuring) element, which will only close its contact if the fault is within the first measuring zone. The circuit breaker trip coil would then be energised through the series-connected contacts of the auxiliary directional and measuring element. The initial operation of the starting element also energises a separate timing element and should the fault not be detected in the first zone, this element will cause the distance-measuring relay to be readjusted to a longer (zone 2) setting after the lapse of a preset time.

A third and longer setting is similarly obtained by a further timer stage and appropriate auxiliary relay. These three distance zones are shown at B, C & D in fig.1 and their normal arrangement along the track is shown in fig.2.

To extend the ability of the distance protection to provide high speed fault clearance, particularly on short track sections, an optional pilot acceleration feature is provided, which enables the tripping of the distance protection at one end of a track circuit to send a d.c. signal over a pair of signalling pilots to cause instantaneous operation of the protection at the opposite end, i.e. overriding any zone time delay.

Distance protection will not generally operate for excess current in the overhead equipment unless this arises from a primary short circuit. Each track section is accordingly equipped with a simple thermal-type overload relay.

4. Method developed by ASEA

Some 180 equipments have been supplied for service on 25 kV systems of the Eastern Region including the Chingford–Enfield–Bishops Stortford, the London–Tilbury–Southend, and the Shenfield–Colchester–Clacton–Walton lines.

With this method faults are detected by a relay sensitive to sudden current increases; this initiates tripping of the circuit breaker if the location of the fault, as determined by an accurate induction cup impedance measuring relay, lies in the protected zones.

The measuring relay simultaneously measures impedance and senses direction. The aluminium cup to which the moving contact part is fitted is free to rotate in the air gap between a 4-pole magnet system and a central core.

Of the four relay poles, one is excited by the restraining voltage and another by the operating current. The two remaining poles form part of a reference circuit fed from a voltage transformer connected to the line.

When the reference circuit and the restraining voltage circuit are fed with currents in which the phases are mutually displaced a torque results on the relay cup. In the same way, the reference circuit and the operating current circuit give rise to a torque which, however, operates in the opposite direction.

For certain quotients of restraining voltage and operating current the resulting torque on the cup will be zero.

Again the relay characteristic takes the form of a circle when plotted in an R/X plane (fig.3) with operation occurring only for points lying within the circle. The circle passes through the origin O representing the connection point of the relay and again it follows that, in addition to its measuring function, the relay has a directional sensitivity.

The relay is adjusted so that the diameter of its characteristic that passes through O is at an angle $\varnothing_L$ to the R axis where $\varnothing_L$ is the inherent phase angle of the overhead line; it follows that the 'reach' of the relay will be a maximum for impedance vectors of this phase angle.

These characteristics apply when the electrical quantities change slowly. On the sudden application of a short circuit instantaneous values are obtained which give rise to transient conditions in the measuring relay; the characteristic for the first stage is displaced as shown by the dotted line in fig.3.This transient displacement increases the ability of the relay to function for high resistance and arcing faults.

The relay is switched to its second step after a definite time (adjustable 0·05–0·5 seconds). Conditions may now be regarded as stationary for any appreciable transients will have died away. Nevertheless it is again possible to obtain a greater margin for fault resistance by rotating the characteristic downwards in the direction of the R axis. This effect is obtained by arranging for the 'step 1' to 'step 2' switching to short circuit certain elements of the measuring relay.

Fig.4 shows the characteristic 1 (as shown in fig.3); it also shows the characteristic 2 for the second step. The reach of the relay along the line drawn at the angle $\varnothing_F$ is represented by the vector Z_F and, in the case illustrated, the reaches for zones 1 and 2 have been set to the same impedance value. The shaded area shows the increased margin for fault resistance.

Again the reference circuit has been designed as a series resonant circuit enabling the relay to operate reliably even with very close faults.

Suitable setting arrangements are provided to enable the first and the second step to be set to different impedance reaches corresponding to line lengths within the range approximately 2–40 miles (see fig.8).

The protection described above is supplemented by two additional devices. A simple thermal type overcurrent relay connected to a current transformer secondary winding provides protection against relatively low overcurrents of long duration. Furthermore a direct acting instantaneous overcurrent release is fitted to the circuit breaker and actuated by primary current. This protection gives very rapid fault clearance (3·5–4 cycles total time) since it operates the circuit breaker tripping latch direct. (See Paper 30 Section 3.2.) This protection is set to clear faults close to the substation rapidly whereas the distance protection unit is relied upon to clear more distant faults.

5. Overall Co-ordination

Reliability of feeder stations is of particular importance as these stations may be responsible for the supplies to many miles of track. Inverse definite minimum time lag relays are used at some stations to protect the busbars and to provide back-up protection for the track circuits.

At other stations a separate method of bus zone protection has been adopted. Each incoming feeder circuit breaker equipment is fitted with an instantaneous overcurrent relay (in addition to other standard protection) but the tripping impulse from this relay is delayed for 50 milliseconds by a time delay relay. If the current surge relay on the distance protection of any one of the track feeder circuit breaker equipments *being fed by that particular incoming feeder* operates during the delay period the tripping impulse from the instantaneous overcurrent relay to the incoming feeder is interrupted, for obviously the fault that has occurred does not lie in the bus zone. Connections over the bus section circuit breaker auxiliary switch and the bus section isolator auxiliary switches ensure that with this protection only those track feeders that are at that time being fed by a particular incoming feeder are able to block the relevant incoming feeder instantaneous overcurrent protection.

Conventional inverse-time overcurrent protection is used for back-up protection and requires no comment. Similarly the protection used for cables and for power transformers (whether incoming supply transformers or 25/6·25 kV interbus transformers) follow conventional methods.

Bus section circuit breakers at both feeder stations and track sectioning stations are fitted with a fairly sensitive overcurrent protection which is blocked as soon as the circuit breaker is fully home. This ensures rapid tripping of the breaker if it is inadvertently closed to connect sections which are out of phase.

Fig.5 shows schematically the protection employed at typical substations.

The overall clearance time for track feeder faults (excluding those which are cleared by the circuit breaker direct-acting instantaneous overcurrent release) occurring over most of the length of Zone 1 is 110–200 milliseconds, of which 70–110 milliseconds are accounted for by circuit breaker operating time. The range covers various fault positions, system operating conditions etc., and some variations between the different equipments. Faults at the end of Zone 1 are of course cleared in longer times as the distance setting is approached. More distant faults are cleared in Zone 2 in from $\frac{1}{4}$ to $\frac{1}{2}$ second and back-up protection (overcurrent or distance Zone 3) clears in approximately one second.

Facilities are provided for testing the protective gear without disturbing any wiring. (See Paper 29, Section 16 and Paper 30, Section 4.4.)

Automatic reclosing equipment is fitted to track feeder circuit breakers. Automatic reclosure only occurs after a trip initiated by the distance protection unit or by the direct-acting overcurrent release.

6. Conclusion

Protective gear performance is a material factor in the maintenance of supplies to healthy traction equipment. Service experience has confirmed that, by using a system of protection based upon distance measuring, faults can be automatically removed from a dense railway network without any interruption of supplies to healthy equipment. The decision to consider protection requirements at an early stage in system planning has ensured that discrimination is not limited by avoidable restrictions imposed by conflicting system layout. The speed of operation of the protection on the railway network facilitates co-ordination with the Supply Authority's network.

SUMMARY

The statement of the problem shows the difference between a conventional power system and the electrified railway, leading to the proposition that distance relay protection for the overhead line circuits in conjunction with conventional protection schemes for the rest of the network is the most suitable form to adopt.

Two such systems developed by firms with which the authors are associated are then described in some detail and particulars are given of the way these two solutions are both applied on stated sections of the lines now electrified. Both can be co-ordinated so as to function correctly on adjacent sections of track and a diagram shows the protective equipment used for typical stations.

In one solution the main feature is a fault-detecting relay with a directional mho characteristic followed by an accurate three zone distance measuring relay of the moving-coil impedance type.

In the other solution faults are detected by a relay sensitive to sudden current increases. An accurate directional impedance measuring relay is used to determine whether or not the faults lie in the protected zones.

RÉSUMÉ

L'exposé du problème démontre les différences entre un réseau classique de distribution d'énergie et celui d'un chemin de fer électrifié et par conséquent de ces différences on conclut qu'un système de protection qui fonctionne par des relais de distance est le plus convenable pour les circuits de la caténaire, conjointement avec des dispositifs de protection classiques pour les autres parties du réseau.

Les auteurs donnent une description assez detaillée de deux systèmes de ce genre, perfectionnés par les entreprises auxquelles ils sont associés, et ils précisent les méthodes adoptées pour l'application de ces deux solutions à des sections données des lignes déjà electrifiées. On peut coördonner les deux systèmes d'une telle façon qu'ils fonctionnent correctement l'un et l'autre installé sur deux tronçons de voie contigus. Un diagramme montre un arrangement typique de dispositifs de protection.

La particularité principale de la première solution est la prévision d'un relais mho, à caractéristique directive, suivi d'un relais de distance exact à trois zones, du type d'impédance à bobine mobile. Le relais mho réagit aux défauts et met le relais de distance en circuit.

Pour la seconde solution on emploie un relais sensible aux brusques augmentations du courant pour mettre en circuit le relais d'impédance exact à caractéristique directive qui détermine si ou non le défaut se trouve dans les zones protégées.

ZUSAMMENFASSUNG

Die Problemstellung zeigt den Unterschied zwischen einem herkömmlichen Stromversorgungs–System und der elektrifizierten Eisenbahn. Daraus geht hervor, dass die Anwendung von Distanzrelais zum Schutz der Fahrleitungs–Stromkreise in Verbindung mit den konventionellen Schutzeinrichtungen für die übrigen Netzteile die vorteilhafteste lösung darstellt.

Zwei solche Systeme, die von Firmen entwickelt wurden mit denen die Verfasser im engen Kontakt stehen, werden ziemlich ausführlich beschrieben. Die Art der Anwendung dieser beiden Lösungen auf bestimmte, jetzt elektrifizierte Streckenteile, wird im Einzelnen dargelegt. Beide Systeme lassen sich so koordinieren, dass sie in angrenzenden Geleiseabschnitten richtig funktionieren. Eine Zeichnung zeigt die in typischen Unterwerken angewendeten Schutzeinrichtungen.

Ein charakteristisches Merkmal der ersten Lösung ist ein fehleranzeigendes Relais mit einer richtungsabhängigen Leitwert – Charakteristik in Reihe mit einem Präzisions – Dreizonen – Distanzmessrelais des Drehspul – Impedanzrelais – Types.

Bei der zweiten Lösung benützt man zur Fehlernachweisung ein gegen plötzliche Stromanstiege empfindliches Relais. Um festzustellen, ob die Fehler in den geschützten Zonen liegen oder nicht, bedient man sich eines richtungsabhängigen Präzisions – Impedanzmessrelais.

RESUMEN

La exposición del problema hace resaltar que hay una diferencía entre un sistema convencional de alimentación de fuerza electrica y una línea de ferrocarril electrificada; por lo tanto, se propone que la forma de protección mas idónea esta compuesta de relés de

distancia para los circuitos de la catenaria, junto con los dispositivos de protección clásicos para lo demás del red.

Los autores dan una descripción bastante detallada de dos sistemas de este genero, perfeccionados por las compañias con las cuales ellos estan asociados, y en dicha descripción se hallan informaciones sobre los métodos de aplicarse las dos soluciones juntamente, a unas secciones de via ya electrificadas. Ambos sistemas pueden ser coordenados para funcionar correctamente sobre tramos adyacentes de linea. Una esquema representa los equipos protectores expleados para estaciones típicas.

En una de las soluciones el rasgo principal es un relé detector de faltas, de caracteristica de admitancia direccional, seguido de un relé de distancia muy exacto, del tipo de impedancia a bobina móvil; para tres zonas.

Para la otra solucion las faltas son reveladas por un relé sensible a subidas repentinas de corriente. Se emplea un relé direccional de medición de impedancia; para decidir si falta se encuentra en las zonas protegidas o no.

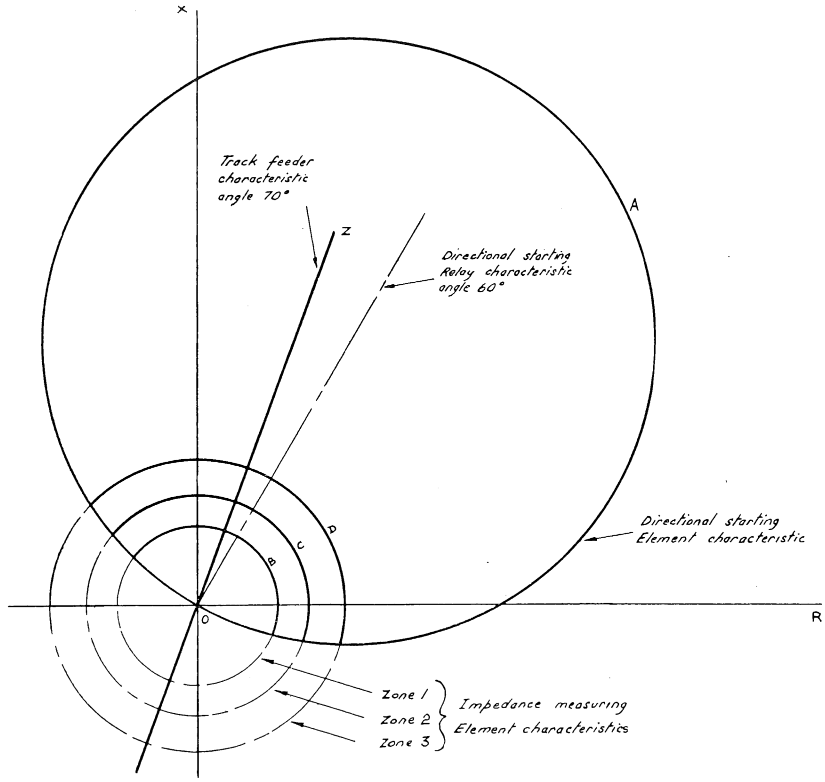


Fig.1 Composite characteristics for Distance Protection plotted on an R/X diagram. (A.E.I. System)
R Resistance X Reactance

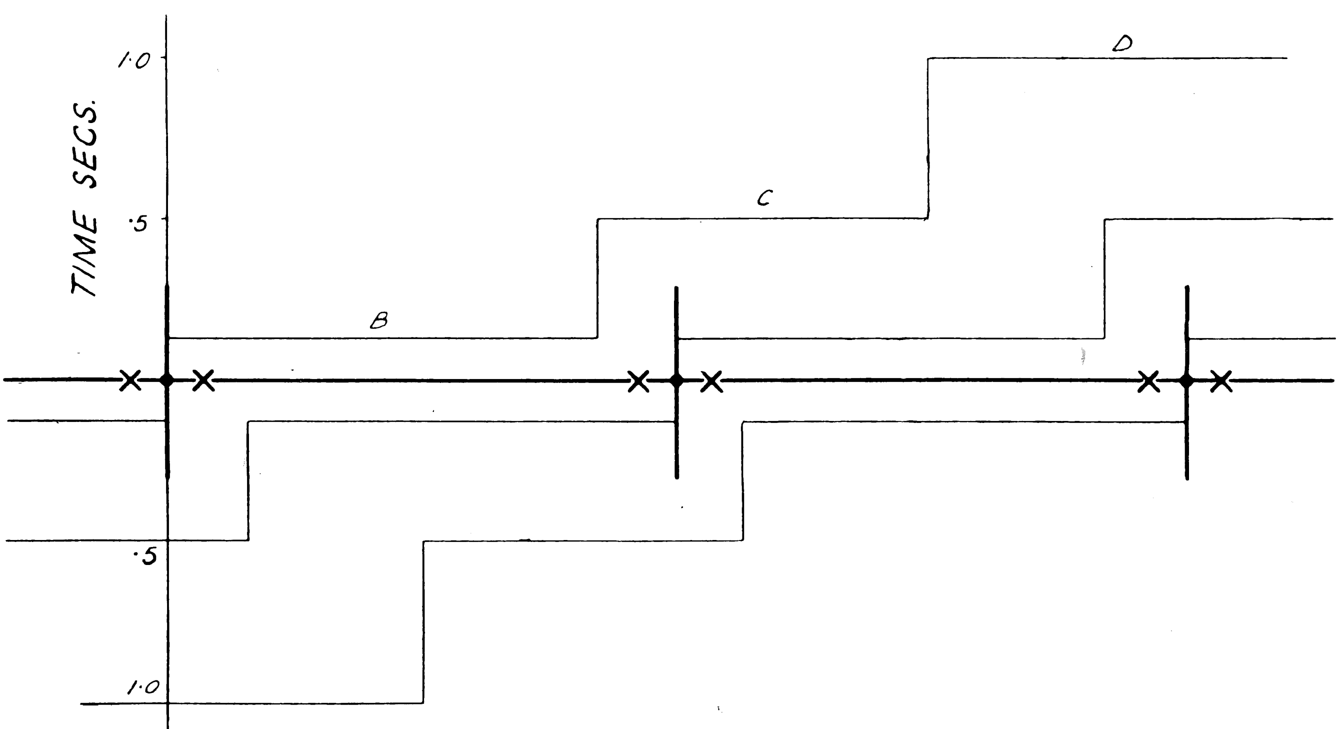


Fig.2 Arrangement of distance zones on a simplified layout of track feeders (A.E.I. System)

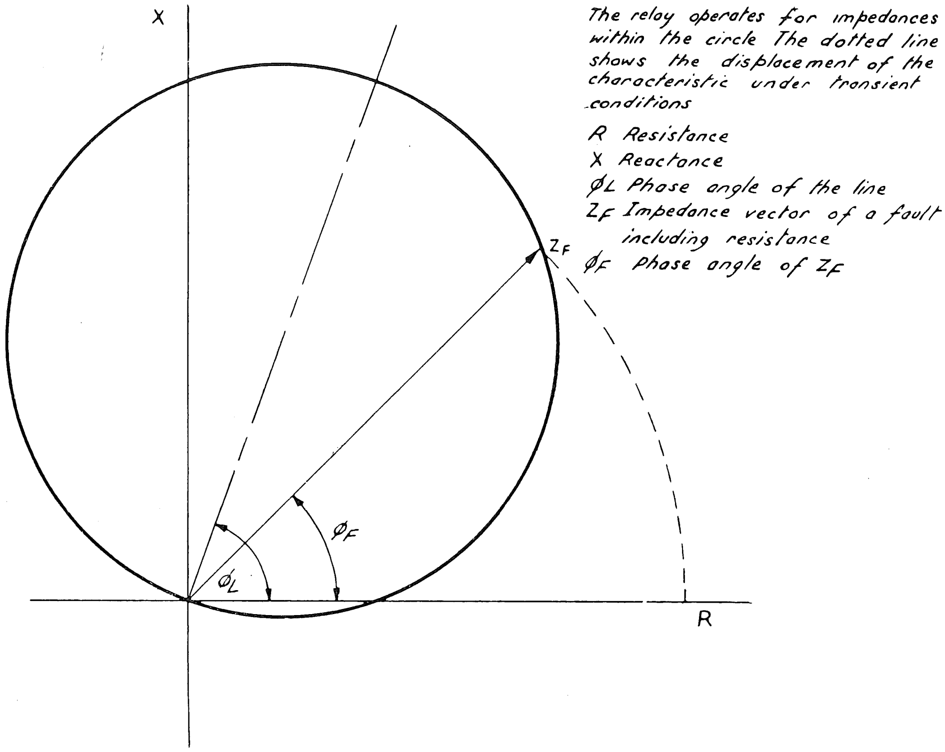


Fig.3 R/X Characteristic of the measuring relay when measuring on the first step. (A.S.E.A. System)

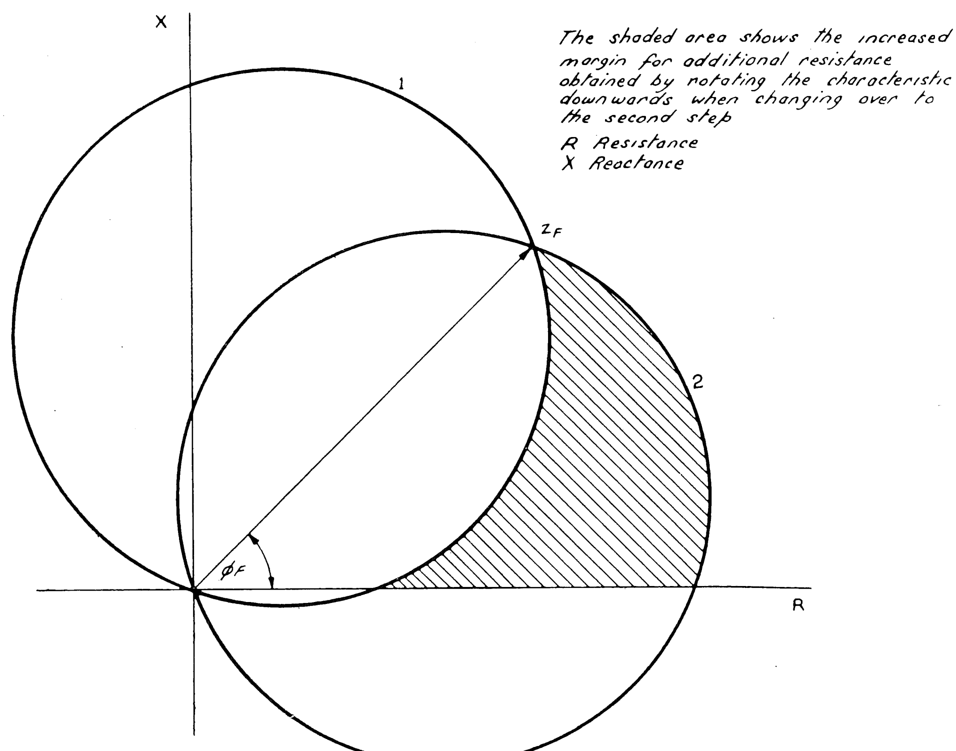


Fig.4 R/X Characteristic of the measuring relay when measuring on the first and second steps. (A.S.E.A. System)

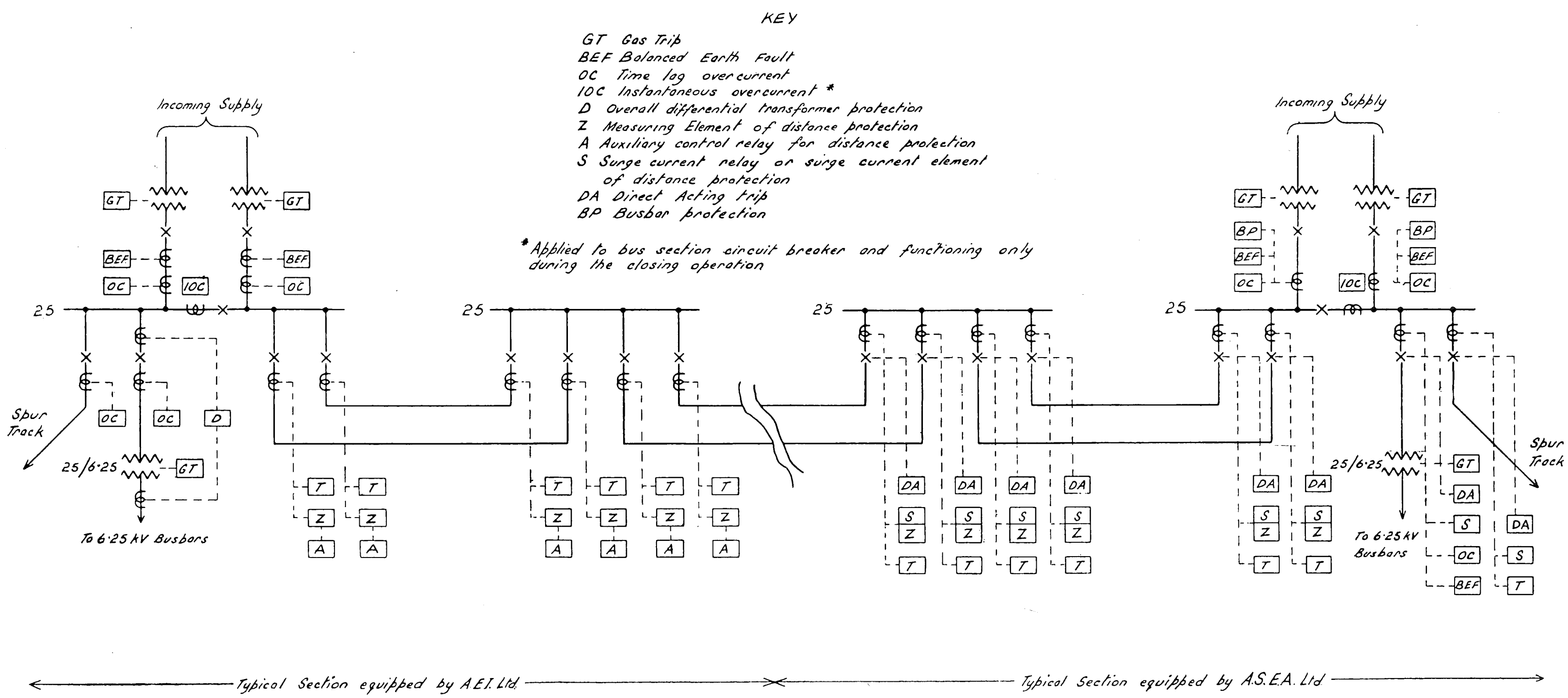
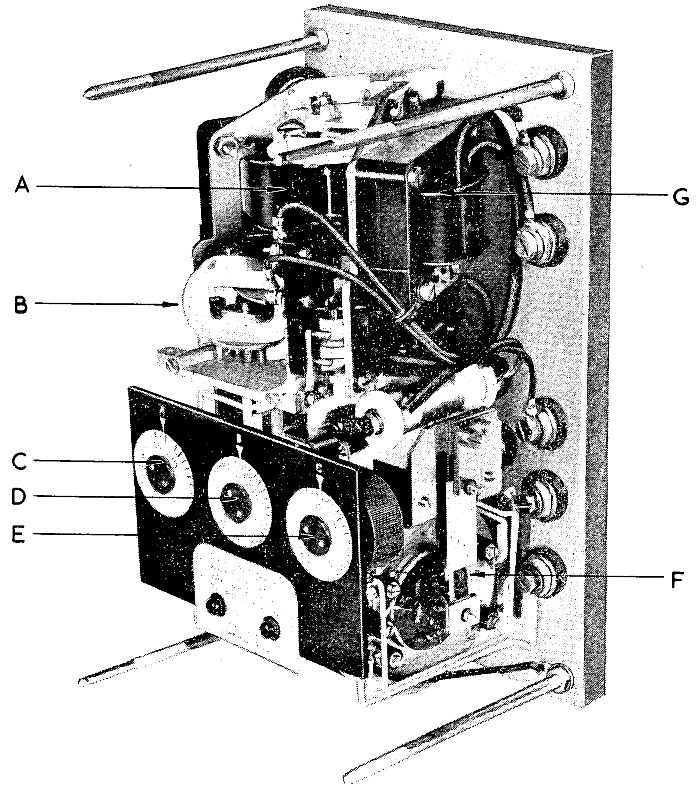


Fig.5 Simplified Block Diagram of main protection arrangements on a typical section of 25 kV system

Fig.6 A.E.I. type DZA2 distance relay without case and cover

- A Restraint magnet assembly
- B Directional element
- C Distance setting adjuster—zone 1
- D Distance setting adjuster—zone 2
- E Distance setting adjuster—zone 3
- F Distance measuring element
- G Directional magnet assembly



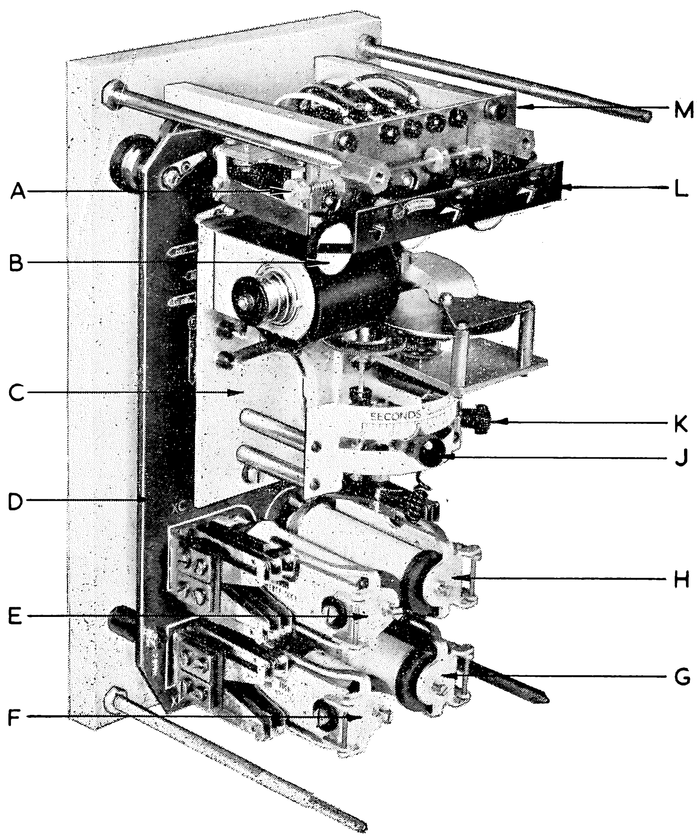


Fig.7 A.E.I. type AKE auxiliary relay without case and cover

- A Resetting device for indicator
- B Operation indicator flash
- C Zone timing element
- D Printed circuit
- E Auxiliary relay—zone 3 control
- F Auxiliary relay—pilot control
- G Auxiliary relay—direction control
- H Auxiliary relay—zone 2 control
- J Time adjuster for zone 2
- K Time adjuster for zone 3
- L Interlocking plate
- M Operation indicator sub-assembly

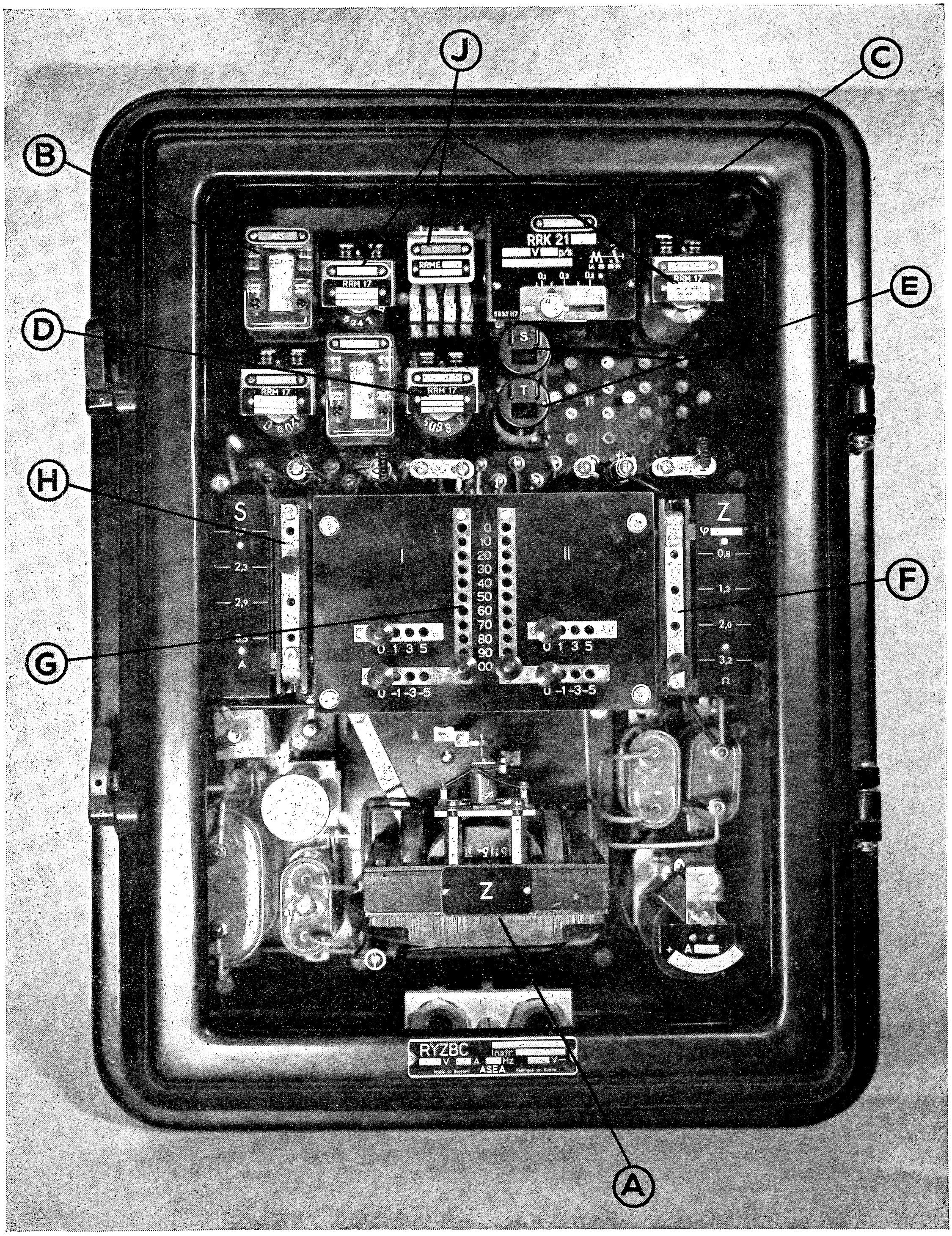


Fig.8 A.S.E.A. Single Phase distance protection relay

- **A** Induction cup impedance measuring relay
- **B** High speed tripping relay
- **C** Timing relay for zone 2
- **D** Surge current relay
- **E** Indicating flags
- **F** Plug bridge for coarse setting of secondary impedance
- **G** Plug bridges for fine setting of zone 1 and zone 2 secondary impedances
- **H** Setting bridge for surge current relay
- **J** Auxiliary relays

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