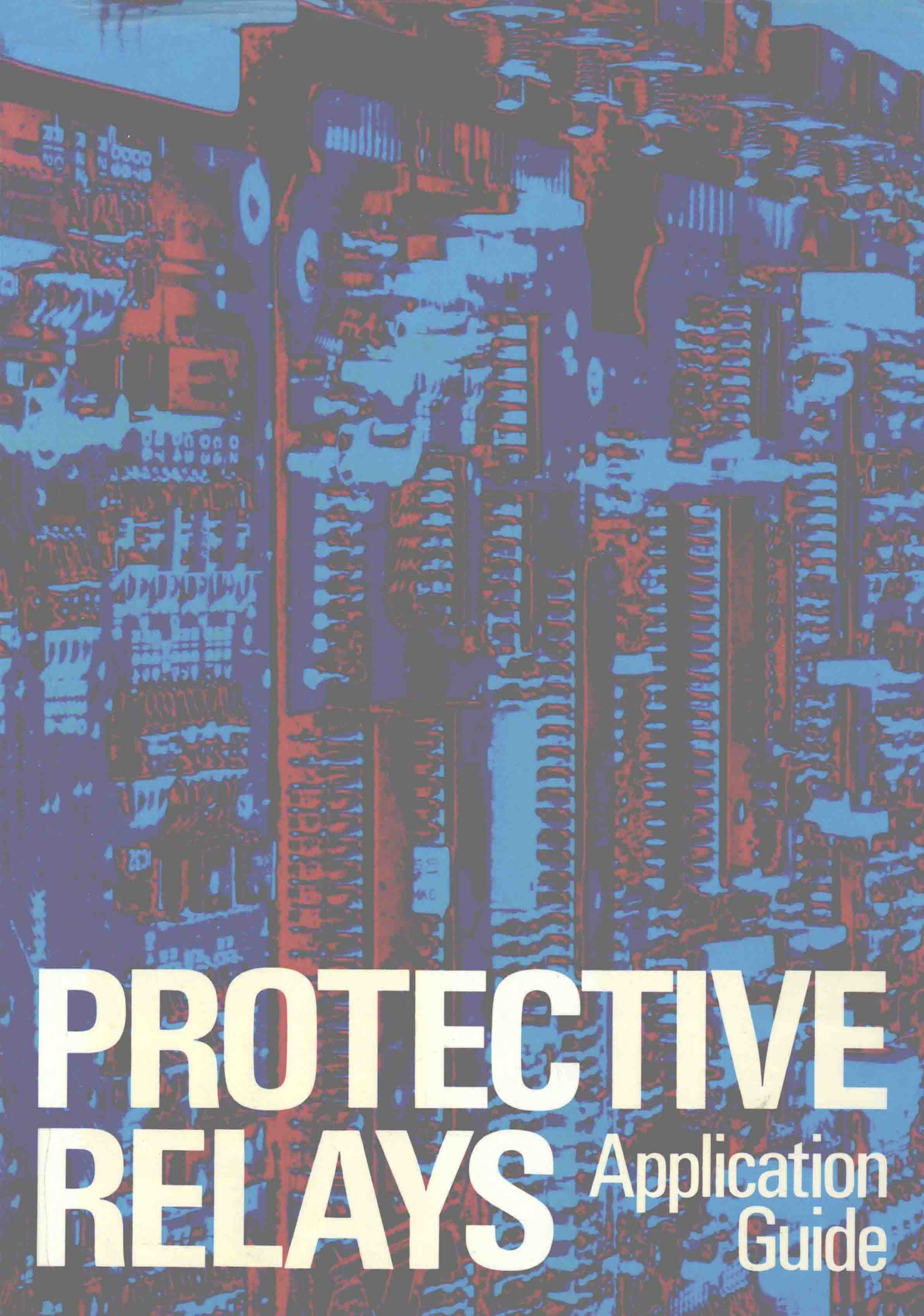

PROTECTIVE RELAYS

Application Guide

GEC ALSTHOM

T&D

PROTECTIVE RELAYS

Application Guide

FIRST EDITION

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- GEC ALSTHOM Low Voltage Equipment Limited.

DEDICATION

Cliff Trickey, CEng, MIEE, Marketing Planning Manager completed the planning and design of this extensively revised edition just prior to his untimely death at the age of 59. This edition is dedicated to his memory.

Preface

Relaying technology has advanced dramatically since the Second Edition was issued, most notably for the part some form of computer now plays in the various functions. The uses range from the microprocessors employed in the relays themselves, for measurement or control, to testing by computer for development including power systems simulation, production testing and even site testing.

Although the book is principally concerned with the applications of relays, particular advances in relay design can significantly affect the way they are used. For example, alternative schemes may be selected within some standard designs, simply at the flick of a switch, sometimes involving a closer integration of protection and control functions. So the relay hardware is becoming even more standardized, to the point where versions of a relay may differ only by the software they contain.

This progress has made it both exciting and desirable to tackle the production of a new, Third Edition of this popular book. Several of the chapters have been totally or substantially rewritten, but the changed scene is perhaps best exemplified by the inclusion of a new chapter on the Application of Microprocessors to Substation Control. This sets out to introduce many of the computation terms which may be unfamiliar to some protection engineers of an older generation.

At what some may regard as the simpler end of the application scale, the scope of the book has been widened to include another new chapter, on the protection of industrial power systems.

The correct application of protective relays requires not only a knowledge of the relay design parameters but also a good understanding of the behaviour of the power system in which the relay is to be applied. The book attempts to present the practising engineer with sufficient information to assist him in his everyday work, including testing and commissioning, without overstressing the more complex problems. Such problems are, in any case, usually dealt with as a combined effort between the user and the manufacturer, for specific applications.

For the last edition a presentation format was chosen which we believed would be both easy to follow and convenient to use. In response to the many complimentary comments we received, this format has been largely retained for the new edition.

The first part of the book deals with the fundamentals of protective gear practice, basic technology, fault calculations and the circuits and parameters of power system plant, including the transient response and saturation problems that affect the instrument transformers associated with protective relays. The book then goes on to cover the parameters of electromechanical relays, solid state relays and protection signalling and ends with a detailed analysis of the relays systems associated with power system plant. The final chapter is a guide to good relaying practice, with references to the various types of relays manufactured by GEC ALSTHOM T&D Protection & Control. The recommended relays and schemes for the main items of power system plant are listed in the various relay application tables.

It is our sincere hope that this book with continue to be used by the many application engineers throughout the world, to serve both as a guide to users and to assist them in training young engineers in relay application.

GEC ALSTHOM T&D
PROTECTION & CONTROL LIMITED
St Leonards Works
Stafford
England

Contents

Fundamentals of protection practice

1

1.1 INTRODUCTION

The purpose of an electrical power system is to generate and supply electrical energy to consumers. The system should be designed and managed to deliver this energy to the utilization points with both reliability and economy. As these two requirements are largely opposed, it is instructive to look at the reliability of a system and its cost and value to the consumer, which is shown in Figure 1.1

It is important to realize that the system is viable only between the cross-over points *A* and *B*. The diagram illustrates the significance of reliability in system design, and the necessity of achieving sufficient reliability. On the other hand, high reliability should not be pursued as an end in itself, regardless of cost, but should rather be balanced against economy, taking all factors into account.

Security of supply can be bettered by improving plant design, increasing the spare capacity margin and arranging alternative circuits to supply loads. Sub-division of the system into zones, each controlled by switchgear in association with protective gear, provides flexibility during normal operation and ensures a minimum of dislocation following a breakdown.

The greatest threat to the security of a supply system is the short circuit, which imposes a sudden and sometimes violent change on system operation. The large current

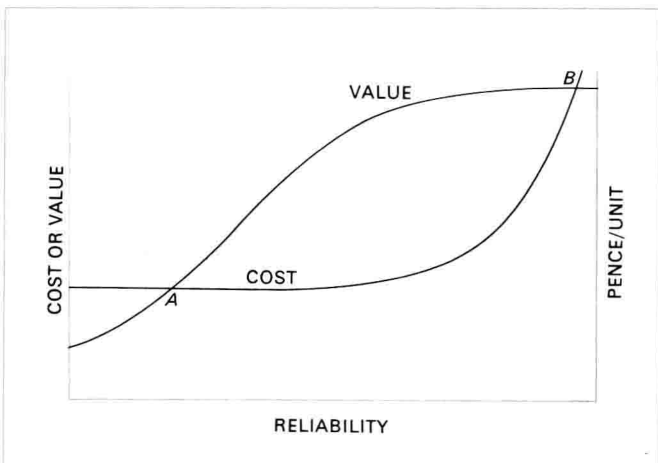

Figure **1.1** *Relationship between reliability of supply, its cost and value to the consumer.*

which then flows, accompanied by the localized release of a considerable quantity of energy, can cause fire at the fault location, and mechanical damage throughout the system, particularly to machine and transformer windings. Rapid isolation of the fault by the nearest switchgear will minimize the damage and disruption caused to the system.

A power system represents a very large capital investment. To maximize the return on this outlay, the system must be loaded as much as possible. For this reason it is necessary not only to provide a supply of energy which is attractive to prospective users by operating the system within the range *AB* (Figure 1.1), but also to keep the system in full operation as far as possible continuously, so that it may give the best service to the consumer, and earn the most revenue for the supply authority. Absolute freedom from failure of the plant and system network cannot be guaranteed. The risk of a fault occurring, however slight for each item, is multiplied by the number of such items which are closely associated in an extensive system, as any fault produces repercussions throughout the network. When the system is large, the chance of a fault occurring and the disturbance that a fault would bring are both so great that without equipment to remove faults the system will become, in practical terms, inoperable. The object of the system will be defeated if adequate provision for fault clearance is not made. Nor is the installation of switchgear alone sufficient; discriminative protective gear, designed according to the characteristics and requirements of the power system, must be provided to control the switchgear. A system is not properly designed and managed if it is not adequately protected. This is the measure of the importance of protective systems in modern practice and of the responsibility vested in the protection engineer.

1.2 PROTECTIVE GEAR

This is a collective term which covers all the equipment used for detecting, locating and initiating the removal of a fault from the power system. Relays are extensively used for major protective functions, but the term also covers direct-acting a.c. trips and fuses.

In addition to relays the term includes all accessories such as current and voltage transformers, shunts, d.c. and a.c. wiring and any other devices relating to the protective relays.

In general, the main switchgear, although fundamentally protective in its function, is excluded from the term 'protective gear', as are also common services, such as the station battery and any other equipment required to secure operation of the circuit breaker.

In order to fulfil the requirements of discriminative protection with the optimum speed for the many different configurations, operating conditions and construction features of power systems, it has been necessary to develop many types of relay which respond to various functions of the power system quantities. For example, observation simply of the magnitude of the fault current suffices in some cases but measurement of power or impedance may be necessary in others. Relays frequently measure complex functions of the system quantities, which are only readily expressible by mathematical or graphical means.

In many cases it is not feasible to protect against all hazards with any one relay. Use is then made of a combination of different types of relay which individually protect against different risks. Each individual protective arrangement is known as a 'protection system', while the whole coordinated combination of relays is called a 'protection scheme'.

1.3 RELIABILITY

The need for a high degree of reliability is discussed in Section 1.1. Incorrect operation can be attributed to one of the following classifications:

a. Incorrect design.
b. Incorrect installation.
c. Deterioration.

1.3.1 Design

This is of the highest importance. The nature of the power system condition which is being guarded against must be thoroughly understood in order to make an adequate protection design. Comprehensive testing is just as important, and this testing should cover all aspects of the protection, as well as reproducing operational and environmental conditions as closely as possible. For many protective systems, it is necessary to test the complete assembly of relays, current transformers and other ancillary items, and the tests must simulate fault conditions realistically. This subject will be dealt with at greater length in Chapter 23.

1.3.2 Installation

The need for correct installation of protective equipment is obvious, but the complexity of the interconnections of many systems and their relationship to the remainder of the station may make difficult the checking of such correctness. Testing is therefore necessary; since it will be difficult to reproduce all fault conditions correctly, these tests must be directed to proving the installation. This is the function of site testing, which should be limited to such simple and direct tests as will prove the correctness of the connections and freedom from damage of the equipment. No attempt should be made to 'type test' the equipment or to establish complex aspects of its technical performance; see Chapter 23.

1.3.3 Deterioration in service

After a piece of equipment has been installed in perfect condition, deterioration may take place which, in time, could interfere with correct functioning. For example, contacts may become rough or burnt owing to frequent operation, or tarnished owing to atmospheric contamination; coils and other circuits may be open-circuited, auxiliary components may fail, and mechanical parts may become clogged with dirt or corroded to an extent that may interfere with movement.

One of the particular difficulties of protective relays is that the time between operations may be measured in years, during which period defects may have developed unnoticed until revealed by the failure of the protection to respond to a power system fault. For this reason, relays should be given simple basic tests at suitable intervals in order to check that their ability to operate has not deteriorated.

Testing should be carried out without disturbing permanent connections. This can be achieved by the provision of test blocks or switches. Draw-out relays inherently provide this facility; a test plug can be inserted between the relay and case contacts giving access to all relay input circuits for injection. When temporary disconnection of panel wiring is necessary, mistakes in correct restoration of connections can be avoided by using identity tags on leads and terminals, clip-on leads for injection supplies, and easily visible double-ended clip-on leads where 'jumper connections' are required.

The quality of testing personnel is an essential feature when assessing reliability and considering means for improvement. Staff must be technically competent and adequately trained, as well as self-disciplined to proceed in a deliberate manner, in which each step taken and quantity measured is checked before final acceptance.

Important circuits which are specially vulnerable can be provided with continuous electrical supervision; such arrangements are commonly applied to circuit breaker trip circuits and to pilot circuits.

1.3.4 Protection performance

The performance of the protection applied to large power systems is frequently assessed numerically. For this purpose each system fault is classed as an incident and those which are cleared by the tripping of the correct circuit breakers and only those, are classed as 'correct'. The percentage of correct clearances can then be determined.

This principle of assessment gives an accurate evaluation of the protection of the system as a whole, but it is severe in its judgement of relay performance, in that many relays are called into operation for each system fault, and all must behave correctly for a correct clearance to be recorded.

On this basis, a performance of 94% is obtainable by standard techniques.

Complete reliability is unlikely ever to be achieved by further improvements in construction. A very big step, however, can be taken by providing duplication of equipment or 'redundancy'. Two complete sets of equipment are provided, and arranged so that either by itself can carry out the required function. If the risk of an equipment failing is x/unit, the resultant risk, allowing for redundancy, is x^2. Where x is small the resultant risk (x^2) may be negligible.

It has long been the practice to apply duplicate protective systems to busbars, both being required to operate to complete a tripping operation, that is, a 'two-out-of-two' arrangement. In other cases, important circuits have been provided with duplicate main protection schemes, either being able to trip independently, that is, a 'one-out-of-two' arrangement. The former arrangement guards against unwanted operation, the latter against failure to operate.

These two features can be obtained together by adopting a 'two-out-of-three' arrangement in which three basic systems are used and are interconnected so that the operation of any two will complete the tripping function. Such schemes have already been used to a limited extent and application of the principle will undoubtedly increase. Probability theory suggests that if a power network were protected throughout on this basis, a protection performance of 99.98% should be attainable.

This performance figure requires that the separate protection systems be completely independent; any common factors, such as common current transformers or tripping batteries, will reduce the overall performance.

1.4 SELECTIVITY

Protection is arranged in zones, which should cover the power system completely, leaving no part unprotected. When a fault occurs the protection is required to select and trip only the nearest circuit breakers. This property of selective tripping is also called 'discrimination' and is achieved by two general methods:

a. *Time graded systems.*
Protective systems in successive zones are arranged to operate in times which are graded through the sequence of equipments so that upon the occurrence of a fault, although a number of protective equipments respond, only those relevant to the faulty zone complete the tripping function. The others make incomplete operations and then reset.

b. *Unit systems.*
It is possible to design protective systems which respond only to fault conditions lying within a clearly defined zone. This 'unit protection' or 'restricted protection' can be applied throughout a power system and, since it does not involve time grading, can be relatively fast in operation.

Unit protection is usually achieved by means of a comparison of quantities at the boundaries of the zone. Certain protective systems derive their 'restricted' property from the configuration of the power system and may also be classed as unit protection.

Whichever method is used, it must be kept in mind that selectivity is not merely a matter of relay design. It also depends on the correct co-ordination of current transformers and relays with a suitable choice of relay settings, taking into account the possible range of such variables as fault currents, maximum load current, system impedances and other related factors, where appropriate.

1.5 ZONES OF PROTECTION

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Ideally, the zones of protection mentioned in Section 1.4 should overlap across the circuit breaker as shown in Figure 1.2, the circuit breaker being included in both zones.

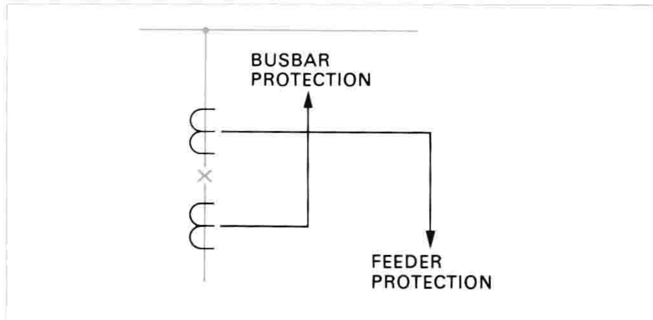

Figure **1.2** *Location of current transformers on both sides of the circuit breaker.*

For practical physical reasons, this ideal is not always achieved, accommodation for current transformers being in some cases available only on one side of the circuit breakers, as in Figure 1.3. This leaves a section between the current transformers and the circuit breaker *A* within which a fault is not cleared by the operation of the protection that responds. In Figure 1.3 a fault at *F* would cause the busbar protection to operate and open the circuit breaker but the fault would continue to be fed through the feeder.

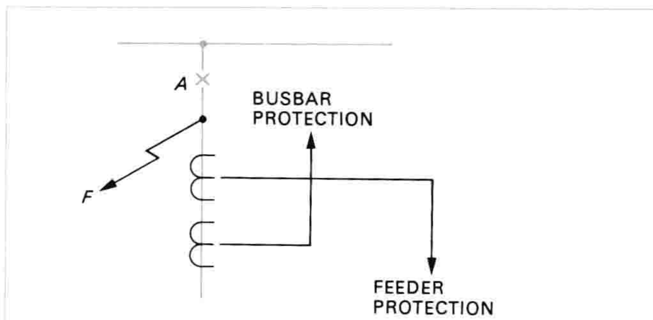

Figure **1.3** *Location of current transformers on circuit side of the circuit breaker.*

The feeder protection, if of the unit type, would not operate, since the fault is outside its zone. This problem is dealt with by some form of zone extension, to operate when opening the circuit breaker does not fully interrupt the flow of fault current. A time delay is incurred in fault clearance, although by restricting this operation to occasions when the busbar protection is operated the time delay can be reduced.

The point of connection of the protection with the power system usually defines the zone and corresponds to the location of the current transformers. The protection may be of the unit type, in which case the boundary will be a clearly defined and closed loop. Figure 1.4 illustrates a typical arrangement of overlapping zones.

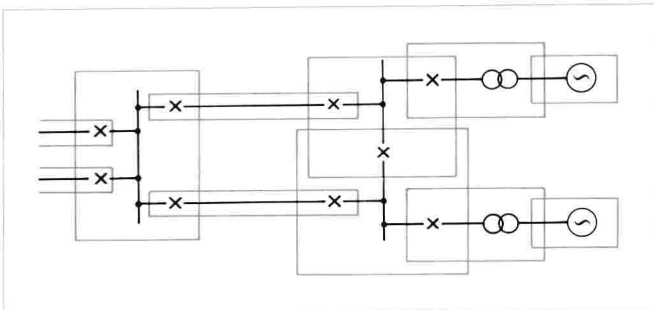

Figure **1.4** *Overlapping zones of protection systems.*

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Alternatively, the zone may be unrestricted; the start will be defined but the extent will depend on measurement of the system quantities and will therefore be subject to variation, owing to changes in system conditions and measurement errors.

1.6 STABILITY

This term, applied to protection as distinct from power networks, refers to the ability of the system to remain inert to all load conditions and faults external to the relevant zone. It is essentially a term which is applicable to unit systems; the term 'discrimination' is the equivalent expression applicable to non-unit systems.

1.7 SPEED

The function of automatic protection is to isolate faults from the power system in a very much shorter time than could be achieved manually, even with a great deal of personal supervision. The object is to safeguard continuity of supply by removing each disturbance before it leads to widespread loss of synchronism, which would necessitate the shutting down of plant.

Loading the system produces phase displacements between the voltages at different points and therefore increases the probability that synchronism will be lost when the system is disturbed by a fault. The shorter the time a fault is allowed to remain in the system, the greater can be the loading of the system. Figure 1.5 shows typical relations between system loading and fault clearance times for various types of fault. It will be noted that phase faults have a more marked effect on the stability of the system than does a simple earth fault and therefore require faster clearance.

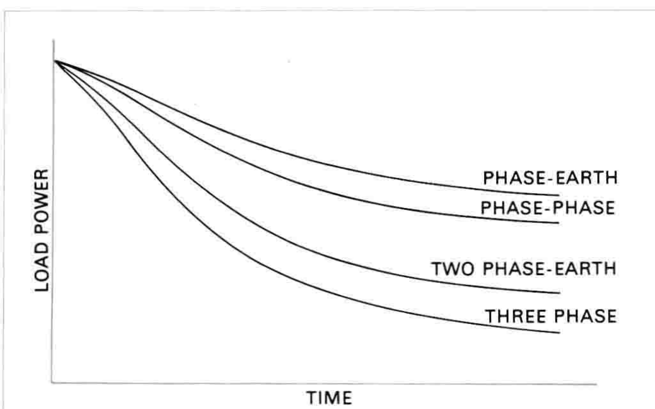

Figure **1.5** *Typical values of power that can be transmitted as a function of fault clearance time.*

It is not enough to maintain stability; unnecessary consequential damage must also be avoided. The destructive power of a fault arc carrying a high current is very great; it can burn through copper conductors or weld together core laminations in a transformer or machine in a very short time. Even away from the fault arc itself, heavy fault currents can cause damage to plant if they continue for more than a few seconds.

It will be seen that protective gear must operate as quickly as possible; speed, however, must be weighed against economy. For this reason, distribution circuits for which the requirements for fast operation are not very severe are usually protected by time-graded systems, but generating plant and EHV systems require protective gear of the highest attainable speed; the only limiting factor will be the necessity for correct operation.

1.8 SENSITIVITY

Sensitivity is a term frequently used when referring to the minimum operating current of a complete protective system. A protective system is said to be sensitive if the primary operating current is low.

When the term is applied to an individual relay, it does not refer to a current or voltage setting but to the volt-ampere consumption at the minimum operating current.

A given type of relay element can usually be wound for a wide range of setting currents; the coil will have an impedance which is inversely proportional to the square of the setting current value, so that the volt-ampere product at any setting is constant. This is the true measure of the input requirements of the relay, and so also of the sensitivity. Relay power factor has some significance in the matter of transient performance and this is discussed in Chapter 5.

For d.c. relays the VA input also represents power consumption, and the burden is therefore frequently quoted in watts.

1.9 PRIMARY AND BACK-UP PROTECTION

The reliability of a power system has been discussed in earlier sections. Many factors may cause protection failure and there is always some possibility of a circuit breaker failure. For this reason, it is usual to supplement primary protection with other systems to 'back-up' the operation of the main system and to minimize the possibility of failure to clear a fault from the system.

Back-up protection may be obtained automatically as an inherent feature of the main protection scheme, or separately by means of additional equipment. Time graded schemes such as overcurrent or distance protection schemes are examples of those providing inherent back-up protection; the faulty section is normally isolated discriminatively by the time grading, but if the appropriate relay fails or the circuit breaker fails to trip, the next relay in the grading sequence will complete its operation and trip the associated circuit breaker, thereby interrupting the fault circuit one section further back. In this way complete back-up cover is obtained; one more section is isolated than is desirable but this is inevitable in the event of the failure of a circuit breaker.

Where the system interconnection is more complex, the above operation will be repeated so that all parallel infeeds are tripped.

If the power system is protected mainly by unit schemes, automatic back-up protection is not obtained, and it is then normal to supplement the main protection with time graded overcurrent protection, which will provide local back-up cover if the main protective relays have failed, and will trip further back in the event of circuit breaker failure.

Such back-up protection is inherently slower than the main protection and, depending on the power system configuration, may be less discriminative. For the most important circuits the performance may not be good enough, even as a back-up protection, or, in some cases, not even possible, owing to the effect of multiple infeeds. In these cases duplicate high speed protective systems may be installed. These provide excellent mutual back-up cover against failure of the protective equipment, but either no remote back-up protection against circuit breaker failure or, at best, time delayed cover.

Breaker fail protection can be obtained by checking that fault current ceases within a brief time interval from the operation of the main protection. If this does not occur, all other connections to the busbar section are interrupted, the condition being necessarily treated as a busbar fault. This provides the required back-up protection with the minimum of time delay, and confines the tripping operation to the one station, as compared with the alternative of tripping the remote ends of all the relevant circuits.

The extent and type of back-up protection which is applied will naturally be related to the failure risks and relative economic importance of the system. For distribution systems where fault clearance times are not critical, time delayed remote back-up protection is adequate but for EHV systems, where system stability is at risk unless a fault is cleared quickly, local back-up, as described above, should be chosen.

Ideal back-up protection would be completely independent of the main protection. Current transformers, voltage transformers, auxiliary tripping relays, trip coils and d.c. supplies would be duplicated. This ideal is rarely attained in practice. The following compromises are typical;

a. Separate current transformers (cores and secondary windings only) are used for each protective system, as this involves little extra cost or accommodation compared with the use of common current transformers which would have to be larger because of the combined burden.

b. Common voltage transformers are used because duplication would involve a considerable increase in cost, because of the voltage transformers themselves, and also because of the increased accommodation which would have to be provided. Since security of the VT output is vital, it is desirable that the supply to each protection should be separately fused and also continuously supervised by a relay which will give an alarm on failure of the supply and, where appropriate, prevent an unwanted operation of the protection.

c. Trip supplies to the two protections should be separately fused. Duplication of tripping batteries and of tripping coils on circuit breakers is sometimes provided. Trip circuits should be continuously supervised.

d. It is desirable that the main and back-up protections (or duplicate main protections) should operate on different principles, so that unusual events that may cause failure of the one will be less likely to affect the other.

1.10 DEFINITIONS AND TERMINOLOGY

All-or-nothing relay

An electrical relay which is intended to be energized by a quantity whose value is either higher than that at which it picks up or lower than that at which it drops out.

Auxiliary relay

An all-or-nothing relay energized via the contacts of another relay, for example a measuring relay, for the purpose of providing higher rated contacts or introducing a time delay.

Back-up protection

A protective system intended to supplement the main protection in case the latter should be ineffective, or to deal with faults in those parts of the power system that are not readily included in the operating zones of the main protection.

Biased relay

A relay in which the characteristics are modified by the introduction of some quantity other than the actuating quantity, and which is usually in opposition to the actuating quantity.

Burden

The loading imposed by the circuits of the relay on the energizing power source or sources, expressed as the product of voltage and current (volt-amperes, or watts if d.c.) for a given condition, which may be either at 'setting' or at rated current or voltage.

The rated output of measuring transformers, expressed in VA, is always at rated current or voltage and it is important, in assessing the burden imposed by a relay, to ensure that the value of burden at rated current is used.

Characteristic angle

The angle between the vectors representing two of the energizing quantities applied to a relay and used for the declaration of the performance of the relay.

Characteristic curve

The curve showing the operating value of the characteristic quantity corresponding to various values or combinations of the energizing quantities.

Characteristic quantity

A quantity, the value of which characterizes the operation of the relay, for example, current for an overcurrent relay, voltage for a voltage relay, phase angle for a directional relay, time for an independent time delay relay, impedance for an impedance relay.

Characteristic impedance ratio (C.I.R.)

The maximum value of the System Impedance Ratio up to which the relay performance remains within the prescribed limits of accuracy.

Check protective system

An auxiliary protective system intended to prevent tripping due to inadvertent operation of the main protective system.

Conjunctive test

A test on a protective system including all relevant components and ancillary equipment appropriately interconnected. The test may be parametric or specific.

a. *Parametric conjunctive test.*
A test to ascertain the range of values that may be assigned to each parameter when considered in combination with other parameters, while still complying with the relevant performance requirements.

b. *Specific conjunctive test.*
A test to prove the performance for a particular application, for which definite values are assigned to each of the parameters.

Dependent time measuring relay

A measuring relay for which times depend, in a specified manner, on the value of the characteristic quantity.

Discrimination

The ability of a protective system to distinguish between power system conditions for which it is intended to operate and those for which it is not intended to operate.

Drop-out

A relay drops out when it moves from the energized position to the un-energized position.

Drop-out/pick-up ratio

The ratio of the limiting values of the characteristic quantity at which the relay resets and operates. This value is sometimes called the differential of the relay.

Earth fault protective system

A protective system which is designed to respond only to faults to earth.

Earthing transformer

A three-phase transformer intended essentially to provide a neutral point to a power system for the purpose of earthing.

Effective range

The range of values of the characteristic quantity or quantities, or of the energizing quantities to which the relay will respond and satisfy the requirements concerning it, in particular those concerning precision.

Effective setting

The 'setting' of a protective system including the effects of current transformers. The effective setting can be expressed in terms of primary current or secondary current from the current transformers and is so designated as appropriate.

Electrical relay

A device designed to produce sudden predetermined changes in one or more electrical circuits after the appearance of certain conditions in the electrical circuit or circuits controlling it.

NOTE: The term 'relay' includes all the ancillary equipment calibrated with the device.

Electromechanical relay

An electrical relay in which the designed response is developed by the relative movement of mechanical elements under the action of a current in the input circuit.

Energizing quantity

The electrical quantity, either current or voltage, which alone or in combination with other energizing quantities, must be applied to the relay to cause it to function.

Independent time measuring relay

A measuring relay, the specified time for which can be considered as being independent, within specified limits, of the value of the characteristic quantity.

Instantaneous relay

A relay which operates and resets with no intentional time delay.

NOTE: All relays require some time to operate; it is possible, within the above definition, to discuss the operating time characteristics of an instantaneous relay.

Inverse time delay relay

A dependent time delay relay having an operating time which is an inverse function of the electrical characteristic quantity.

Inverse time relay with definite minimum time (I.D.M.T.)

An inverse time relay having an operating time that tends towards a minimum value with increasing values of the electrical characteristic quantity.

Knee-point e.m.f.

That sinusoidal e.m.f. applied to the secondary terminals of a current transformer, which, when increased by 10%, causes the exciting current to increase by 50%.

Main protection

The protective system which is normally expected to operate in response to a fault in the protected zone.

Measuring relay

An electrical relay intended to switch when its characteristic quantity, under specified conditions and with a specified accuracy attains its operating value.

Notching relay

A relay which switches in response to a specific number of applied impulses.

Operating time

With a relay de-energized and in its initial condition, the time which elapses between the application of a characteristic quantity and the instant when the relay operates.

Operating time characteristic

The curve depicting the relationship between different values of the characteristic quantity applied to a relay and the corresponding values of operating time.

Operating value

The limiting value of the characteristic quantity at which the relay actually operates.

Overshoot time

The overshoot time is the difference between the operating time of the relay at a specified value of the input energizing quantity and the maximum duration of the value of input energizing quantity which, when suddenly reduced to a specific value below the operating level, is insufficient to cause operation.

Pick-up

A relay is said to 'pick-up' when it changes from the un-energized position to the energized position.

Pilot channel

A means of interconnection between relaying points for the purpose of protection.

Protected zone

The portion of a power system protected by a given protective system or a part of that protective system.

Protective gear

The apparatus, including protective relays, transformers and ancillary equipment, for use in a protective system.

Protective relay

A relay designed to initiate disconnection of a part of an electrical installation or to operate a warning signal, in the case of a fault or other abnormal condition in the installation.

A protective relay may include more than one unit electrical relay and accessories.

Protective scheme

The co-ordinated arrangements for the protection of one or more elements of a power system.

A protective scheme may comprise several protective systems.

Protective system

A combination of protective gear designed to secure, under predetermined conditions, usually abnormal, the disconnection of an element of a power system, or to give an alarm signal, or both.

Rating

The nominal value of an energizing quantity which appears in the designation of a relay. The nominal value usually corresponds to the CT and VT secondary ratings.

Resetting value

The limiting value of the characteristic quantity at which the relay returns to its initial position.

Residual current

The algebraic sum, in a multi-phase system, of all the line currents.

Residual voltage

The algebraic sum, in a multi-phase system, of all the line-to-earth voltages.

Setting

The limiting value of a 'characteristic' or 'energizing' quantity at which the relay is designed to operate under specified conditions.

Such values are usually marked on the relay and may be expressed as direct values, percentages of rated values, or multiples.

Stability

The quality whereby a protective system remains inoperative under all conditions other than those for which it is specifically designed to operate.

Stability limits

The r.m.s. value of the symmetrical component of the through fault current up to which the protective system remains stable.

Starting relay

A unit relay which responds to abnormal conditions and initiates the operation of other elements of the protective system.

Static relay

An electrical relay in which the designed response is developed by electronic, magnetic, optical or other components without mechanical motion.

It should be noted though that few static relays have a fully static output stage, to trip directly from thyristors for example. By far the majority of static relays have attracted armature output elements to provide metal-to-metal contacts, which remain the preferred output medium in general.

System impedance ratio (S.I.R.)

The ratio of the power system source impedance to the impedance of the protected zone.

Through fault current

The current flowing through a protected zone to a fault beyond that zone.

Time delay

A delay intentionally introduced into the operation of a relay system.

Time delay relay

A relay having an intentional delaying device.

Unit electrical relay

A single relay which can be used alone or in combinations with others.

Unit protection

A protection system which is designed to operate only for abnormal conditions within a clearly defined zone of the power system.

Unrestricted protection

A protection system which has no clearly defined zone of operation and which achieves selective operation only by time grading.

The above is a summary of principal relay terms and definitions in current British and international practice. It is not complete and further reference should be made to the following standards.

B.S. 142:1982	Electrical Protective Relays.
B.S. 5311:1976	A.C. Circuit Breakers of Voltage above 1 kV
B.S. 3938:1982	Current Transformers.
B.S. 3941:1982	Voltage Transformers.
B.S. 4727:1971 (Part 1)	Relay and Measurement Terminology
B.S. 4727:1971 (Part 2)	Terms Particular to Power Engineering
B.S. 3939:1966-78	Graphical Symbols for Electrical Equipment
C37-90:1978	American National Standard for Relays and Relay Systems
IEC 255 (1971-83) Parts 1-19	International Electrotechnical Commission Standards for Electrical Relays
IEC 50 (446):1983	International Electrotechnical Vocabulary: Electrical Relays

1.11 LIST OF SYMBOLS

A	Alarm
AA	Alarm acceptance
ACC	Acceleration
ACCR	Acceleration receive
ACCS	Acceleration send
ACCS/R	Acceleration send/receive
AN	Annunciator
AUX	Auxiliary
AVC	Automatic voltage control
AVR	Automatic voltage regulator
AVS	Automatic voltage selection

B	Buchholz
BAT E	Battery earth fault
BB	Busbar
BLK	Blocking
BV	Balanced voltage
CA	Check alarm or alarm cancellation
CACL	Carrier current, direction-comparison
CACϕ	Carrier current, phase-comparison
CC	Circulating current
CK	Check
D	Discriminating
DAR	Delayed auto-reclose
DEIT	Directional earth fault, inverse time
DIF	Differential
DIFB	Biased differential
DIFPB	Plain balance differential
DOCIT	Directional overcurrent, inverse time
DOCITI	Directional overcurrent, inverse time, inhibited
E	Earth fault, instantaneous
EIT	Earth fault, inverse time
FE	Frame earth fault
FFR	Fuse failure
FG	Flag
FP	Feeder protection
FPFM	Feeder protection, first main
FPSM	Feeder protection, second main
FPBU	Feeder protection, back-up
FPM	Feeder protection, main
HSAR	High speed auto-reclose
HSASC	High speed ammeter shorting
HSOC	High set overcurrent
I	Current
I OB	Current out-of-balance
IP	Interposing
INT	Intertrip
INTR	Intertrip receive
INTS	Intertrip send
INT S/R	Intertrip send/receive
INTSPR	Intertrip, surge proof, receive
INTSPS	Intertrip, surge proof, send
LDC	Line drop compensator
LE	Loss excitation
LFA	Low frequency alarm
LFT	Low frequency trip
LO	Lock-out
LP	Low power
LS	Loss of synchronism
MCP	Mesh corner protection
MHO	High speed distance (mho)
MHO INT	High speed distance (interlocked mho)
NEFA	Neutral earth fault alarm
NEF CK	Neutral earth fault check
Nϕ	Negative phase sequence or phase unbalance
NV	No-volt
NVD	Neutral voltage displacement
OC	Overcurrent, instantaneous
OCCK	Overcurrent check
OCDT	Overcurrent, definite time
OCINT	Overcurrent, interlocked
OCIT	Overcurrent, inverse time
OF	Overfrequency
OL	Overload
OLA	Overload alarm
OV	Overvoltage
PCF	Pilot channel fail
POP	Post Office pilot
PP	Private pilot
PPH	Positive phase sequence
PR	Protective relay
PS	Pilot shorting
PSF	Pilot supply fail
PSS	Protection d.c. supply supervision
REF	Restricted earth fault
ROT	Rotor earth fault
RP	Reverse power
RPH	Reverse phase
SBE	Standby earth fault
ST	Stalling
SY	Selection (synchronizing)
SYN	Synchronizing
SYN AUTO	Automatic synchronizing
SYN CK	Check synchronizing
SYN SYS	System synchronizing
SYS BU	System back-up
T	Tripping
TC	Circuit breaker trip coil
TCS	Trip circuit supervision
TD	Definite time
TE	Tripping, electrically reset
T E/H	Tripping, electrically and hand reset
TE RESET	Trip relay reset
TH	Tripping, hand reset
THOC	Thermal overcurrent
TM	Time delay or timing relay
TS	Tripping, self reset
TSEQ	Tripping, sequential
TSS	Trip supply supervision
UC	Undercurrent
UF	Underfrequency
UP	Underpower
UV	Undervoltage
UVIT	Undervoltage, inverse time
V	Voltage
VR	Voltage regulating
VS	Voltage selection
X	Distance (reactance)
Z	Distance (impedance)

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1.12 LIST OF DEVICE NUMBERS

2	Time delay starting or closing relay
3	Checking or interlocking relay
4	Master contactor
21	Distance relay
25	Synchronizing or synchronism check relay
27	Undervoltage relay
30	Annunciator relay
32	Directional power relay
37	Undercurrent or underpower relay
40	Field failure relay
46	Reverse phase or phase balance current relay
49	Machine or transformer thermal relay
50	Instantaneous overcurrent or rate-of-rise relay
51	A.c. time overcurrent relay
52	A.c. circuit breaker
52a	Circuit breaker auxiliary switch—normally open
52b	Circuit breaker auxiliary switch—normally closed
55	Power factor relay
56	Field application relay
59	Overvoltage relay
60	Voltage or current balance relay
64	Earth fault protective relay
67	A.c. directional overcurrent relay
68	Blocking relay
74	Alarm relay
76	D.c. overcurrent relay
78	Phase angle measuring or out-of-step protective relay
79	A.c. reclosing relay
81	Frequency relay
83	Automatic selective control or transfer relay
85	Carrier or pilot wire receive relay
86	Locking-out relay
87	Differential protective relay

1.13 RELAY CONTACT SYSTEMS

a. *Self-reset.*
The contacts remain operated only while the controlling quantity is applied, returning to their original condition when it is removed.

b. *Hand or electrical reset.*
These contacts remain in the operated position after the controlling quantity is removed. They can be reset either by hand or by an auxiliary electromagnetic element.

The majority of protective relay elements have self-reset contact systems, which, if it is so desired, can be made to give hand reset output contacts by the use of auxiliary elements.

Hand or electrically reset relays are used when it is necessary to maintain a signal or a lock-out condition. Contacts are shown on diagrams in the position corresponding to the un-operated or de-energized condition, regardless of the continuous service condition of the equipment. For example, a voltage supervising relay, which is continually picked-up, would still be shown in the de-energized condition.

A 'make' contact is one that closes when the relay picks up, whereas a 'break' contact is one that is closed when the relay is un-energized and opens when the relay picks up. Examples of these conventions and variations are shown in Figure 1.6.

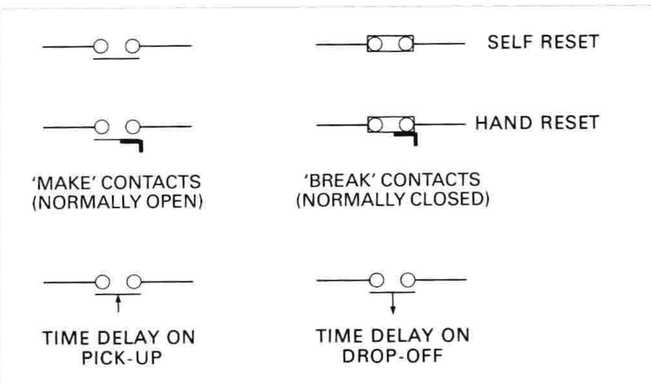

Figure **1.6** *Indication of contacts on diagrams.*

A protective relay is usually required to trip a circuit breaker, the tripping mechanism of which may be a solenoid with a plunger acting directly on the mechanism latch or, in the case of air-blast or pneumatically operated breakers, an electrically operated valve. The relay may energize the tripping coil directly, or, according to the coil rating and the number of circuits to be energized, may do so through the agency of another multi-channel auxiliary relay.

The power required by the trip coil of the circuit breaker may range from up to 50 watts for a small 'distribution' circuit breaker, to 3000 watts for a large, extra-high-voltage circuit breaker.

The basic trip circuit is simple, being made up of a hand-trip control switch and the contacts of the protective relays in parallel to energize the trip coil from a battery, through a normally open auxiliary switch operated by the circuit breaker. This auxiliary switch is needed to open the trip circuit when the circuit breaker opens since the protective relay contacts will usually be quite incapable of performing the interrupting duty. The auxiliary switch will be adjusted to close as early as possible in the closing stroke, to make the protection effective in case the breaker is being closed on to a fault.

Protective relays are precise measuring devices, the contacts of which should be not expected to perform large making and breaking duties. Attracted armature relays, which combine many of the characteristics of measuring devices and contactors, occupy an intermediate position and according to their design and consequent closeness to one or other category, may have an appreciable contact capacity.

Most other types of relay develop an effort which is independent of the position of the moving system. At setting, the electromechanical effort is absorbed by the controlling force, the margin for operating the contacts being negligibly small. Not only does this limit the 'making' capacity of the contacts, but if more than one contact pair is fitted, any slight misalignment may result in only one contact being closed at the minimum operating value, there being insufficient force to compress the spring of the first contact to make, by the small amount required to permit closure of the second.

For this reason, the provision of multiple contacts on such elements is undesirable. Although two contacts can be fitted, care must be taken in their alignment, and a small tolerance in the closing value of operating current may have to be allowed between them. These effects can be reduced by providing a small amount of 'run-in' to contact make in the relay behaviour, by special shaping of the active parts.

For the above reasons it is often better to use interposing contactor type elements which do not have the same limitations, although some measuring relay elements are capable of tripping the smaller types of circuit breaker directly. These may be small attracted armature type elements fitted in the same case as the measuring relay.

In general, static relays have discrete measuring and tripping circuits, or modules. The functioning of the measuring modules will not react on the tripping modules. Such a relay is equivalent to a sensitive electromechanical relay with a tripping contractor, so that the number or rating of outputs has no more significance than the fact that they have been provided.

For larger switchgear installations the tripping power requirement of each circuit breaker is considerable, and further, two or more breakers may have to be tripped by one protective system. There may also be remote signalling requirements, interlocking with other functions (for example auto-reclosing arrangements), and other control functions to be performed. These various operations are carried out by multi-contact tripping relays, which are energized by the protection relays and provide the necessary number of adequately rated output contacts.

1.14 OPERATION INDICATORS

As a guide for power system operation staff, protective systems are invariably provided with indicating devices. In British practice these are called 'flags', whereas in America they are known as 'targets'. Not every component relay will have one, as indicators are arranged to operate only if a trip operation is initiated. Indicators, with very few exceptions, are bi-stable devices, and may be either mechanically or electrically operated. A mechanical indicator consists of a small shutter which is released by the protective relay movement to expose the indicator pattern, which, on GEC ALSTHOM T&D Protection & Control relays, consists of red stripes on a white background.

Electrical indicators may be simple attracted armature elements either with or without contacts. Operation of the armature releases a shutter to expose an indicator as above.

An alternative type consists of a small cylindrical permanent magnet magnetized across a diameter, and lying between the poles of an electromagnet. The magnet, which is free to rotate, lines up its magnetic axis with the electromagnet poles, but can be made to reverse its

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orientation by the application of a field. The edge of the magnet is coloured to give the indication.

In static relays the operation indicators increasingly take the form of light emitting diodes (LEDs).

1.15 RELAY TRIPPING CIRCUITS

Auxiliary contactors can be used to supplement protective relays in a number of ways:

a. Series sealing.
b. Shunt reinforcing.
c. Shunt reinforcement with sealing.
These are illustrated in Figure 1.7.

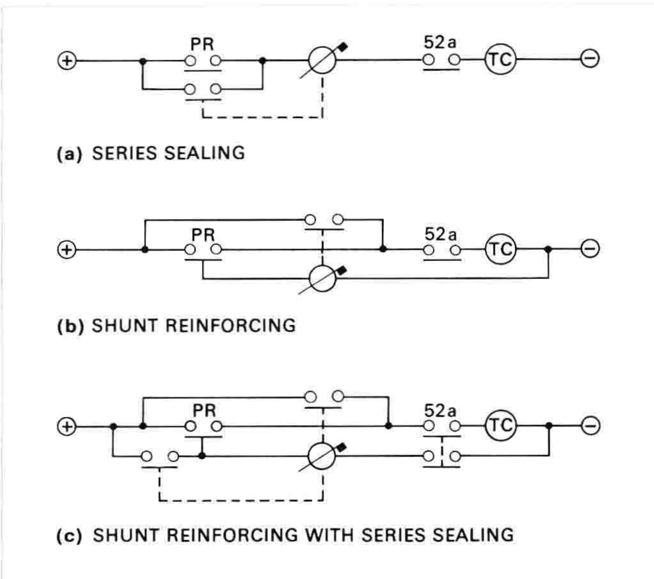

Figure **1.7** *Typical relay tripping circuits.*

When such auxiliary elements are fitted, they can conveniently carry the operation indicator, avoiding the need for indicators on the measuring elements.

Electrically operated indicators avoid imposing an additional friction load on the measuring element, which would be a serious handicap for certain types. Another advantage is that the indicator can operate only after the main contacts have closed. With indicators operated directly by the measuring elements, care must be taken to line up their operation with the closure of the main contacts. The indicator must have operated by the time the contacts make, but must not have done so more than marginally earlier. This is to stop indication occurring when the tripping operation has not been completed.

a. *Series sealing*
The coil of the series contactor carries the trip current initiated by the protective relay, and the contactor closes a contact in parallel with the protective relay contact. This closure relieves the protective relay contact of further duty and keeps the tripping circuit securely closed, even if chatter occurs at the main contact. Nothing is added to the total tripping time, and the indicator does not operate until current is actually flowing through the trip coil.

The main disadvantage of this method is that such series elements must have their coils matched with the trip circuit with which they are associated.

The coils of these contactors must be of low impedance, with about 5% of the trip supply voltage being dropped across them.

When used in association with high speed trip relays, which usually interrupt their own coil current, the auxiliary elements must be fast enough to operate and release the flag before their coil current is cut off. This may pose a problem in design if a variable number of auxiliary elements (for different phases and so on) may be required to operate in parallel to energize a common tripping relay.

b. *Shunt reinforcing.*
Here the sensitive contacts are arranged to trip the circuit breaker and simultaneously to energize the auxiliary unit, which then reinforces the contact which is energizing the trip coil.

It should be noted that two contacts are required on the protective relay, since it is not permissible to energize the trip coil and the reinforcing contactor in parallel. If this were done, and more than one protective relay were connected to trip the same circuit breaker, all the auxiliary relays would be energized in parallel for each relay operation and the indication would be confused.

The duplicate main contacts are frequently provided as a three point arrangement to reduce the number of contact fingers.

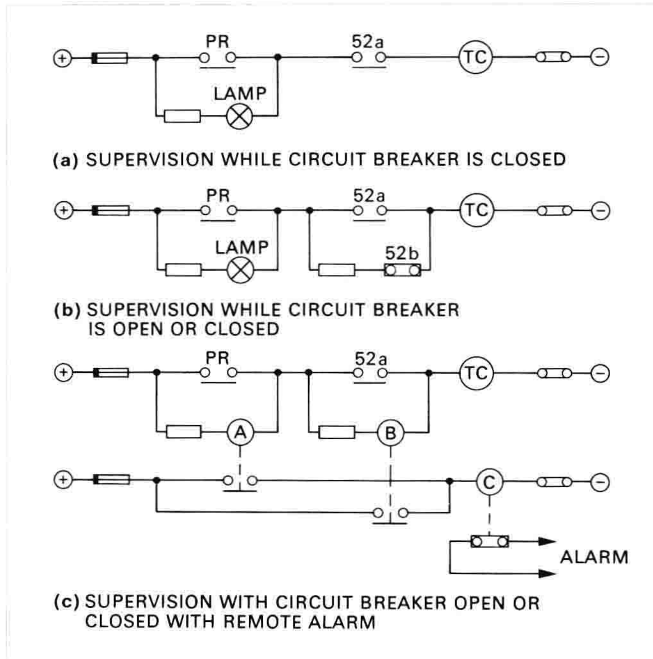

Figure **1.8** *Examples of trip circuit supervision.*

c. *Shunt reinforcement with sealing.*
This is a development of the shunt reinforcing circuit to make it applicable to relays with low torque movements or where there is a possibility of contact bounce for any other reason.

Using the shunt reinforcing system under these circumstances would result in chattering on the auxiliary unit, and the possible burning out of the contacts not only of the sensitive element but also of the auxiliary unit. The chattering would end only when the circuit breaker had finally tripped.

It will be seen that the effect of bounce is countered by means of a further contact on the auxiliary unit connected as a retaining contact.

This means that provision must be made for releasing the sealing circuit when tripping is complete; this is a disadvantage, because it is sometimes inconvenient to find a suitable contact to use for this purpose.

1.16 SUPERVISION OF TRIP CIRCUITS

The trip circuit extends beyond the relay enclosure and passes through more components, such as fuses, links, relay contacts, auxiliary switch contacts and so on, and in some cases through a considerable amount of circuit wiring with intermediate terminal boards. These complications, coupled with the importance of the circuit, have directed attention to its supervision.

The simplest arrangement contains a healthy trip lamp, as shown in Figure 1.8(a).

The resistance in series with the lamp prevents the breaker being tripped by an internal short circuit caused by failure of the lamp. This provides supervision while the circuit breaker is closed; a simple extension gives pre-closing supervision.

Figure 1.8(b) shows how, by the addition of a normally closed auxiliary switch and a resistance unit, supervision can be obtained while the breaker is both open and closed.

In either case, the addition of a normally open push-button contact in series with the lamp will make the supervision indication available only when required.

Schemes using a lamp to indicate continuity are suitable for locally controlled installations, but when control is exercised from a distance it is necessary to use a relay system. Figure 1.8(c) illustrates such a scheme, which is applicable wherever a remote signal is required.

With the circuit healthy either or both of relays *A* and *B* are operated and energize relay *C*. Both *A* and *B* must reset to allow *C* to drop-off. Relays *A, L, B* and *C* are time delayed by copper slugs to prevent spurious alarms during tripping or closing operations. The resistors are mounted separately from the relays and their values are chosen such that if any one component is inadvertently short-circuited, a tripping operation will not take place.

The alarm supply should be independent of the tripping supply so that indication will be obtained in the event of the failure of the tripping battery.