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DESIGN AND MAINTENANCE PRATICE FOR SUBSTATION SECONDARY SYSTEMS

Working Group 23.05
(Substation Secondary Systems)

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PREFACE

This report deals with the main features of substation secondary systems. It includes in its scope relay-based and computer-based equipment. The emphasis in much of the report is on large-scale transmission substations. However, many of the systems discussed are applicable also to subtransmission and distribution level substations even though they are generally less complex. The report content is primarily directed at practising utility engineers engaged in the planning, design, operation and maintenance of secondary systems. Its primary objective is to review current design and maintenance practice. A secondary objective is to provide an overview of trends and developments currently taking place in components and systems which are likely to feature in new substation designs in the foreseeable future.

For many decades past the operational requirements of substations could be achieved by the use of conventional relay technology. In more recent times, however, with the steep increase in electricity consumption and with systems being subjected to ever increasing peak demands the process of electricity supply has become very much more complex. With equipment being operated closer to its design limits the importance of monitoring has increased. In addition more and more substations are being operated without local manual intervention. In these circumstances to ensure reliable system operation and to provide comprehensive performance analysis data the emphasis has shifted to the provision of remote control systems, switchgear interlocking systems and the presentation of large volumes of data both in the substations themselves and at remote control centres. The relatively simple control circuitry of earlier substations has consequently evolved into large-scale complex systems. In fact, secondary control systems in substations are among the fastest developing technologies in power systems.

In view of the increasing complexity described above it is, perhaps, not surprising that the application of digital technology to substation control and protection systems has been considered in recent years. This technology offers exciting new possibilities at substation level. Improved plant condition monitoring, diagnostics, predictive maintenance techniques and expert systems to support the judgement of skilled operations personnel are already operational in pilot schemes.

Digital technology is also being applied on a large scale to protection systems. Conceptually, totally integrated systems combining control, metering, protection and telecontrol are feasible. Current thinking, however, seems to favour autonomous protection systems which interface with the control system in a co-ordinated manner. Regardless of these points of finer technical detail it is absolutely certain that digital technology will be applied on a large scale in the substation of the future. Utilities will be anxious to avail of its technical and economic benefits but must also be aware of the fact that it will require a design and maintenance approach which differs significantly from conventional equipment.

For the foreseeable future relay-based and computer-based systems will co-exist in substation secondary installations. Consequently, utility staff will have to develop and maintain expertise in both technologies. Our hope is that this report will make a useful contribution in this regard. Suggestions for improvements in content and format are invited and will be incorporated in future editions.

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CHAPTER 1

INTRODUCTION TO SUBSTATION SECONDARY SYSTEMS

1.1 The role of a substation

Substations form vital nodes in high voltage systems. They are used in transmission networks transporting high power often over large distances at the highest voltages (170 - 800 kV) and in sub-transmission and distribution networks covering shorter distances and lower voltages (sub-transmission: 52 - 145 kV, distribution: 3,6 - 36 kV) because:

- they are in-feed points for generation capacity or delivery points for consumption
- they permit alterations of network configuration during operation

Information from the primary equipment of a substation is collected and processed by the substation secondary systems with special reference to protection and control of the high voltage system.

This information includes these features:

- faulty transmission elements are automatically switched off by circuit breakers
- commands changing the network configuration are issued and executed
- the network configuration and loading of circuits is displayed (on control boards, instruments or other kinds of display units)
- the network voltages are regulated to predetermined values
- important events are registered and time tagged
- alarms indicating abnormal or dangerous events are displayed tc., etc.

1.2 Primary Equipment

The planning of a substation and its equipment, primary as well as secondary, must take into account several criteria, some of which are contradictory. Consequently the final design will be based on a certain degree of compromise.

Types of primary equipment

The insulating media employed in HV and EHV switchgear can either be air at atmospheric pressure - air insulated substation (AIS) - or a compressed gas - gas insulated substation (GIS).

The AIS is normally designed for erection in the open air, but can also be erected indoors. For GIS the situation is normally just the opposite. Adverse climatic conditions however, can favour a GIS solution which can generally be expected to have a higher reliability.

Configuration of busbars

The different busbar and circuit breaker arrangements offer different degrees of flexibility and ability to maintain continuity of operation even with part of the equipment out of service for maintenance. The price however, for higher flexibility and availability is higher investment cost.

The most common busbar and circuit breaker arrangements are:

- single busbar system
- double busbar system
- single busbar system with transfer busbar
- ring busbar system
- one and a half circuit breaker system
- two circuit breaker system
  (See fig. 1.1 - 1.6)

Fig. 1.1: **Single busbar system**

is adopted usually only for sub-transmission or distribution substations. In case of maintenance or a defect on a busbar section half the substation is lost, and without busbar sectionaliser the whole substation is lost.

The control circuits are simple, each bay being to a high degree independent in regard to interlocking and protection, and only one voltage reference is needed for synchronisation.

Fig. 1.2: **Double busbar system**

is frequently adopted for transmission substations in HV and EHV networks.

The scheme allows the two busbars to be maintained independently. In case of maintenance or of a defect on one busbar, the substation can remain in service with all bays connected to the other busbar.

Compared to the single busbar system, the control circuits are more complex. The interlocking depends upon the position of disconnectors in all circuit bays and upon the circuit breaker and disconnectors in the bus coupler bay. For synchronisation, the appropriate busbar reference voltage has to be selected, and busbar protection involves switching of current transformer secondary circuits and tripping commands.

Fig. 1.3: **Single busbar system with transfer busbar**

is often used in distribution substations and sometimes in transmission substations.
The scheme allows a line or a transformer to be kept in service even if equipment (e.g. the circuit breaker) is defective or undergoing maintenance. The control circuits are similar to those of a single busbar system but are more complicated.

Fig. 1.4: **Ring busbar system**

is often used in transmission and distribution substations with few lines connected. The scheme is not very flexible but has high availability because each line or transformer is connected to two circuit breakers.

The control circuits for interlocking and synchronisation are similar to the previous types, but the protection circuits are completely different. To get a line or transformer current, two current values have to be summated. The protection relay has to trip two circuit breakers and to clear the fault, both must trip. After a line fault, only those circuit breakers that were in closed position before the line fault must reclose. Busbar protection is normally not used, as line and transformer protection overlap.

Fig. 1.5: **One and a half circuit breaker system**

The scheme is often used in HV and EHV transmission substations with many bays, but the cost is quite high.
The scheme is more flexible than the ring busbar and has very high availability.
The control circuits are in many respects similar to those of a ring bus station. Busbar protection is always used, and its circuitry is quite simple.

Fig. 1.6: **Two circuit breaker system**

is rarely adopted in transmission substations because of its cost.
The scheme offers very high flexibility and availability. The control circuits for interlocking are simple, and for synchronisation a selection of bus reference voltage is necessary. To clear a fault, two circuit breakers can be involved, and for a selective busbar protection, the circuits become more complicated involving one set of current transformers for each circuit breaker.

Air insulated and gas insulated substations

Air insulated substations are often cheaper to build than gas insulated ones, but in addition to the previously mentioned climatic factor, other factors such as pollution, space restrictions, public regulations , etc. can favour the GIS solution. The secondary systems of GIS are generally more complicated than those of AIS (monitoring of gas density, supervision of the numerous earthing devices, countermeasures to avoid electromagnetic interference in secondary circuits, etc.).

1.3 Protection and control

Protection

Protection provides for switching off, by means of circuit breakers, a network element effected by a fault.

For each network element there is always installed:

- one or two primary protections, which trip the circuit breaker(s) directly connected to the defective element
- one or more back-up protections that operate only in case of failure of the primary protection or of a circuit breaker failure. The time for tripping by the back-up protection is longer and a larger part of the network is disconnected.

Local control

In the past, HV substations were normally attended by a resident staff and supervision and control of the substation was normally carried out from the substation control room by local control.

The local control consists of a system for collecting data and a system for issuing commands sometimes referred to as the man-machine interface (MMI).

The data collection system gives information on the position of circuit breakers, disconnectors and earthing switches, line loading, transformer temperatures and loadings, voltage levels, relay functions, time tagged events, etc.

In the substation control room this information is displayed on wall boards and mimic diagrams (in the case of conventional equipment) or on visual display units (in the case of computerised equipment). Control commands to circuit breakers, disconnectors, tap changers, etc. are issued from the substation control room and thus it is possible from here to exercise full control of the substation by means of the MMI.

Should control from the substation control room fail, a back up control of circuit breakers, disconnectors and earth switches, etc. can be established from control cubicles located on, or adjacent to, the primary equipment.

Remote control

In the past 20 - 25 years, all utilities have progressively introduced remote control, reducing the number of manned substations and thereby reducing the number of staff and the operational cost.

At present, substations are normally unmanned and the control function is performed from an area control centre that also receives information from and controls several other substations. This is done by means of a "supervisory control and data acquisition" system (SCADA system).
A "remote terminal unit" (RTU) transmits from each substation to the area control centre the information needed to draw a complete picture of the supervised network and in the reverse direction it transmits commands from the area control centre to the substations.

In large networks with several area control centres, the procurement of energy and the optimal arrangement of the power transmission network is managed and monitored from a load dispatching centre which in turn gets its information from power plants, area control centres, etc.

Local control in unmanned substations is still kept for stand-by purposes and for use during maintenance, but it is now generally of a simplified design. However, in newly built substations, the normal local control facility is frequently a display unit with keyboard. It can be based upon and integrated with the remote control equipment, provided there is a back up control facility at a lower level.

With the introduction of substation automation functions such as automatic switching between busbars, automatic switching-on of transformers and reactors it is possible to reduce the amount of information transmitted to the regional control centres thus relieving the control centre staff. But besides being utilised for network control, information from the substations is essential for maintenance and for specialist relay staff in monitoring the relay protection; thus there is a need for increased transmission of information, but this is now devolved to different centres according to category.

Lay-out of secondary equipment with or without relay kiosks

With GIS and AIS at lower voltages (or with most indoor installations) distances between primary and secondary equipment are short and this favours a centralised arrangement of the protection and control equipment.

When distances become long, especially with AIS for higher voltages (transmission substations), it can be advantageous to locate a larger part of the control and protection equipment in relay kiosks in close proximity to the primary equipment and a smaller part in a central control house. The arrangement adopted depends in each case on such factors as:

- the requirement for secure operation and maintenance
- the physical size and lay-out of the HV plant (voltage level, AIS or GIS etc.)
- type of control equipment employed (traditional or computer based) and type of internal connections (cables or optical fibres)
- environmental conditions (adverse climatic conditions can make it desirable to group the secondary equipment within a common central building)
- the overall cost of installation (cost of building and cost of installation)

Auxiliary equipment

To ensure reliable and secure performance of the protection and control equipment, operation is based on stored energy (batteries, compressed air etc.) and equipment providing this auxiliary supply must consequently be capable of responding to these onerous demands. The risk of fire breaking out is always present and can, especially in unmanned substations, have disastrous consequences for primary equipment as well as for secondary equipment. Installation of automatically released fire fighting and fire retarding equipment is becoming more common. Rooms are mainly protected by the release of carbon dioxide or halon and transformers by water spray systems. See also section 4.8 "Fire detection & extinguishing systems".

1.4 Future developments and trends

In their choice of equipment for protection and control, the utilities tend to demonstrate a conservative attitude, favouring long-established practices and familiar components.

In order to obtain the degree of availability and reliability considered necessary for the protection

- it is duplicated for the highest voltages
- its functioning is examined
- its settings are manually checked at regular intervals

These precautions have resulted in satisfactory performance but have involved an extensive use of manpower.
In the near future, however, the following trends in the philosophy of HV substation control can be foreseen (some of these are already in course of implementation in some countries):

- substations are becoming unmanned; they are remoted controlled from a RCC, and maintenance is performed by central maintenance staff common to several installations.
- automatic switching sequences within the substation such as opening or closing of a bay, change-over of busbar, switching of ransformers, all assist the maintenance staff and ill become more common
- equipment based on computer technology for rotection, control and automation with built in elf-check acilities will reduce the need for servicing at regular intervals
- serial data transmission within the substation area with twisted pair, coaxial or optical fibre cables will replace parallel data transmission with traditional multicore cables
- in the long term a partial or even full integration of substation protection and control equipment is possible on the assumption that the performance of basic protection functions is not endangered

With these developments, the complexity of the control process of a HV substation will be considerably increased but many advantages are envisaged:

- reduction of maintenance staff
- easier maintenance
- shorter erection time
- unchanged or even improved reliability (e.g. by implementation of condition-based monitoring systems)

The advantages of new components and new techniques, already in use in other industrial fields, are increasingly being recognised by the electric utilities when designing future protection and control equipments.

1.5 Applications of computers, advantages/disadvantages

Traditional systems for protection and control have until recently been implemented with electromagnetic relays. They have proved highly reliable and allow easy maintenance at an acceptable cost.

Since 1965, electronic devices have been introduced especially for remote control and event recording, but also in some cases for protection. These devices have resulted in a reduction of equipment dimensions, faster operation, the implementation of more complex functions and in certain instances cost reduction. However as the construction techniques of these new types of equipment differ from traditional equipment types new maintenance problems have arisen.

Since 1975 there has been a universal application of computer-based equipment for remote control, event recording and automation systems. Its use for protection - at least for experimental purposes - has been more frequent.

The trend for the future seems to indicate a large scale replacement of electromagnetic and electronic relay equipment with computer-based equipment.

Advantages and disadvantages of computer-based equipment can be considered from many points of view. The main aspects are:

Dimensions

Computer-based control equipment has in general smaller dimensions but the type of interfaces and connections to the primary circuits have a significant influence on the resulting dimensions.

Structure of control system

The increased complexity of modern substations favours computer-based control equipment which offers more sophisticated functions and the possibility of an integrated system for protection and control. Significant reductions in control cabling and wiring can be anticipated and also some reduction in commissioning and maintenance costs.

Design

Traditionally relay systems have been designed by engineers who have had detailed knowledge of the functions to be fulfilled. They have utilised approved components produced by specialised manufacturers.

With computer-based equipment, in which the central unit usually is a general purpose device, the system must be designed by a team consisting of:

- hardware engineers who adapt the computer to the required functions and to the specific installation
- system software engineers who master the computer language, know the possibilities of the central unit, define criteria and develop the protocols of communication between central unit, peripheral units and the plant
- application software engineers who specify the functions required by the specific installation.

The design procedure is more complex but in general great benefit is obtained by the fact that the same hardware and system software can be used for different applications.

Construction, cabling and commissioning

Computer-based equipment must be assembled by manufacturers more qualified than those involved in assembling equipment based on traditional relay techniques. A reduction of construction costs can be obtained by standardisation of components (cards, racks, etc.) of different types of equipment.

Because of the very large reduction in cabling it is feasible to more-or-less fully assemble and test the control system in the manufacturers works prior to delivery. This should result in reduced erection and commissioning time on site.

Commissioning and maintenance strategy

Substation engineers are very familiar with traditional relay equipment.

The expertise required to apply and maintain computer-based equipment is very different and the diagnostic and self-testing facilities lead to a new approach. The technique for repairing a defective component is very specialised.

All this may lead to a change in the commissioning and maintenance strategy and perhaps even in the organisational structure of the utility.

CHAPTER 2

GENERAL CONSIDERATIONS AND REQUIREMENTS

2.1 Economic aspects

Economic considerations are very important in relation to secondary systems. To get the total life cycle cost of a secondary system the following component parts have to be summated:

- initial investment cost
- commissioning cost
- cost of operation, maintenance and repair
- cost of personnel training
- cost of extending the system at a later date

For new digital integrated secondary systems, most utilities expect a life time span of at least 20 years. At present, for certain components, a figure closer to 10 years would seem to be more realistic (1).

This underlines the fact that it is not realistic to compare the whole life cycle cost of conventional and digital secondary systems at present. It may be more realistic to do this for a dedicated item of equipment, e.g. a line protection relay.

In HV-substations with a conventional secondary system, the initial investment cost of the whole secondary system will be in the range of 10 to 20 % of the total cost of the substation. The life expectancy of the secondary system is equal to, or greater than, the life expectancy of the HV-equipment.

For secondary systems (both conventional and digital) it is recommended that a standard configuration be developed with detailed specifications for the different functions and for all important system parameters and interfaces. The benefits for the user are obvious:

- less engineering for substation design
- use of CAD
- shorter erection and commissioning times
- easier maintenance, repair and extension
- less spare parts to be stored
- better control of system costs

Secondary systems of the future will have to be evaluated from a completely different economic perspective. A shorter life cycle - of the order of 10 years as compared to the 30/35 year life cycle of current 'conventional' systems - combined with rapidly changing technology will mean that complete replacement of the secondary system hardware will have to be considered at shorter and shorter intervals.

The architecture of the system including precisely defined and co-ordinated interfaces plays an important role and can have a significant influence on the economic assessment. At present there are still multiple solutions to system architecture and the degree of integration of control and protection functions is still a subject for debate.

The flexibility of software and its customisation to the user's requirements makes estimating cost difficult; to a large extent these requirements are inter-dependent. The only way to achieve acceptable costs of software is to use standardised products. Software cost estimates must still be approached with caution.

The major economic consideration to be addressed in relation to the application of digital control systems in the future is the issue of the shortened life cycle.

The need to replace systems after a 10-year life span with the consequent outage time for installation and testing and perhaps, more importantly, the cost implications, will require careful assessment.

2.2 Operational and maintenance requirements

The important operational and maintenance requirements are listed below:

- safety of personnel and security of operational functions
- speed of operation (protection equipment)
- reliability/availability
- meet environmental conditions
- long life time
- easy to operate
- easy to maintain
- easy to repair
- easy to get spare parts (over the life time of the system)
- easy to extend (over the life time of the system)
- easy on-site testing

Today's secondary equipment has high quality standards. It meets functional requirements, is reliable and has a simple structure and a long life expectancy. Periodic tests on control and protection equipment in a defined sequence can verify reliability of function.

Unfamiliarity with the new technology leads to operational requirements that should at least match those of conventional equipment, i.e. not show any disadvantage. However, additional features are welcome and are expected to be a spin-off from the new technology. Features such as higher flexibility and the possibility of achieving more intelligent decisions at all hierarchical levels in response to operation or network disturbance can be expected.

As regards maintenance effort, the availability of self-check facilities (on-line diagnosis for hard and software) should lead to less preventive maintenance work and favours predictive maintenance. Periodic tests will decrease due to improved system reliability. Consequently, maintenance intervals are expected to increase.

Defective components (cards) can be easily changed by the maintenance staff; but also in this new technology test equipment is needed to monitor the security functions (interlocking) without interruption of operation.

- Influence of system architecture
  (see chapter 3)

  Decentralised architecture operating on the bay level is the favoured solution today. This means that control and protection functions have to be implemented at bay level as well as data integrity. The central processor unit performs data registration and evaluation, event monitoring and facilitates remote control coupling.

  In GIS and small substations, architecture at bay level is usually implemented in a central control building; large plants favour additional relay kiosks located in the HV-feeders. It seems not to be possible to operate the sensitive digital equipment mounted in traditional non-insulated kiosks as used for conventional secondary equipments mainly because of temperature and also humidity problems. The ambient temperature has a remarkable influence on the life span and the failure behaviour of digital equipment. A 10°C rise in temperature can double the frequency of component malfunction. To ensure high availability of the equipment, the average temperature at the installation site should therefore be kept low.

  The advantages of a decentralised architecture are obvious:

  - independent items at bay level
  - limited influence of central processor unit outage

- Organisation/Training

  The organisational arrangement of operation and maintenance functions is structured differently for different utilities. The arrangements as they currently exist however, may not always suit the requirements of the new technology. Difficulties may arise when applications which were traditionally functionally separate are integrated into the same item of electronic hardware. There will almost certainly be implications for organisational structures and for staff training. The problem will be further complicated by the fact that conventional and digital control systems are likely to co-exist for many years to come and that whatever solutions are put in place will have to recognise and cater for this period of parallel operation of both technologies. This issue is dealt with in greater detail in Chapter 7.

2.3 Environmental requirements

Different environmental conditions can affect the ratings and the performance of electrical plant and equipment. Accurate knowledge of the environmental factors involved is particularly important for designers and suppliers of substations.

Climatic conditions are the most important of the many environmental influences.

Climate, as a factor affecting the performance of electrical equipment, is the main physical and chemical condition of the atmosphere in the open air or in-doors, including daily and seasonal changes (3).

Climate thus involves natural factors such as air-pressure, temperature, temperature variations, humidity, etc. as well as environmental effects such as pollution by dust, salts and gases. The two factors must never be treated separately since as far as technical equipment is concerned, they usually appear in combination.

The basic natural climatic components are air temperature and air humidity. However, to determine the overall effect of climatic stresses, additional components such as daily and seasonal temperature changes, site altitude and, in some cases, direct solar radiation, precipitation, thunderstorms and wind must be taken into consideration. In addition to natural and civilisation-related climatic parameters, various other environmental factors may have an important influence. These may include adverse soil conditions, the effects of flora and fauna, risk of seismic activity, etc.

Classification of Climates

Strongly differing climatic areas are spread over the earth's surface. Several IEC Committees (e.g. TC 17, 'Switchgear and control gear'; TC 41, 'Electrical relays'; TC 57, 'Power Line Carrier Systems and Telecontrol Equipment'; TC 65, 'Industrial process measurement and control'; and TC 75, 'Classification of environmental conditions') are concerned with the classification of climates and with the associated requirements for various types of substation equipment. For example, a classification of the earth's climatic areas has been issued by IEC TC 75 as shown in Fig. 2.1.1.

IEC TC 57 and TC 65 describe a comprehensive range of climatic conditions which is also suitable for substation use. Fig. 2.1.2 presents this climate classification taking the various equipment environments into consideration (4).

Air-conditioned Locations (Class A)

Facilities are provided to control air temperature and humidity within the specified limits. When utilising equipment which needs an air-conditioned environment, it is necessary to consider the consequences of failure of the air-conditioning installation. Redundancy in the air-conditioning system may be required.

Heated and/or Cooled Enclosed Locations (Class B)

The equipment is enclosed in a location provided with heating and/or cooling facilities. The climatic conditions are maintained within specific limits which are much wider than in Class A and which may or may not be automatically controlled.

Temperature and humidity control within the limits of Class B is normally recommended for a working area within which maintenance personnel may have to work for prolonged periods. Control rooms in unmanned substations and individual relay rooms in outdoor substations usually belong in this category.

Sheltered Locations (Class C)

The equipment is protected against direct exposure to sunlight, rainfall and other precipitations, wind-pressure etc. The minimum temperature may be as low as for outdoor atmospheric conditions; the maximum temperature may be considerably higher than outdoor atmospheric conditions due to solar radiation on the enclosure.

Outdoor Locations (Class D)

The equipment is exposed to all outdoor atmospheric conditions without any protection.

This climatic classification applies also to all primary and secondary installations and may generally be used for all substation electrical plants and equipment. In comparison, several IEC Standards (e.g. Publication 694, 'Common clauses for high-voltage switchgear and control gear standards') recommend a temperature range of -25° C to +40° C for indoor installations and an extreme case temperature range of -40° C to +40° C for outdoor installations.

It should also be noted that during transport and storage on site, the equipment can sometimes be exposed to climatic conditions that are more severe than those encountered in operation. Thus, for example, a temperature range of -20° C to +60° C is recommended in IEC Publication 255, 'Electrical relays'. If no accurate climatic information is available, the standard atmosphere applies: ambient temperature = 20° C, absolute air humidity h_o = 11 g/m^3 and air pressure p_o = 1013 hPa.

Additional Climatic Factors

Altitude
Atmospheric pressure decreases with increasing altitude at about
10 hPa per 100 m. The reduction of the natural cooling effect should also be considered for primary installations above 1000 m and for secondary installations above 2000 m.

Temperature Variations
Daily variations of approximately 20° C are observed in the open, but can increase to 40° C in well-sheltered locations.

It should also be noted that dew/condensation effects appear continuously if the relative air humidity attains values of close to 100 %. The installation of permanently energised space heating systems inside switchgear cubicles, control cabinets and relay cabinets becomes necessary. Such extreme conditions may also occur for equipment during transport and/or storage on site. Moisture-absorbing material is put into the transport packing case in order to prevent corrosion damage. An additional heating system may be called for in the event of long-term storage.

External and Internal Heat
Some thermal problems may be caused by extreme environmental conditions. In such cases, particular attention must be paid to the thermal equilibrium which exists between the heat losses in the operating equipment itself (internal heat) and the heat from the environment (external heat).

An increase in equipment operating temperature may lead to malfunctions. In particularly severe cases, fires can break out. On the other hand, a marked surface temperature increase must be expected if equipment is exposed to intensive solar radiation. In these circumstances a rise in surface temperature of up to 35° C may occur depending on zonal and seasonal intensity of radiation.

The maximum solar radiation intensity measured in desert regions is about 1,25 kW/m^2 (5). The largest part of the solar radiation spectrum (approx. 98 %) lies in the ultra-violet, visible and near infrared ranges. When the sun is at its zenith, approximately 50 % of the direct radiation is infrared, 45 % visible and less than 5 % ultra-violet. For design purposes maximum densities of heat flow of 1,15 kW/m^2 with a reaction time of 5 to 6 hours are often required.

In the case of indoor installations, the necessary ambient conditions for electrical equipment are assured by special constructional measures such as cavity walls, forced ventilation, air-conditioning etc. Indoor ambient conditions in the desert can thus be the same as those in temperate zones.

However, special steps must be taken to ensure that the permissible operating temperature values are not exceeded when ventilation or air-conditioning systems fail. As a rule, equipment specifications require that the equipment should operate correctly for a considerable period of time even at the specified maximum ambient temperature. Air-conditioning systems are primarily used to improve the working conditions of operating and maintenance personnel and are often restricted to the control room.

Rain, Thunderstorms, Wind

Heavy rain, thunderstorms and strong wind are additional climatic factors in tropical zones. They can temporarily change the environmental conditions in a sufficiently drastic manner to put the installation out of operation.

For outdoor kiosks and cubicles the degree of protection against the ingress of water and dust should be determined according to IEC Publication 529.

The wind as an environmental factor has a number of effects, such as on the design of the supporting pedestals and terminal structures for equipment, suspensions and transmission line terminations. On the other hand, wind influences the rate of heat transfer between equipment and the air surrounding it. In many places, moisture, dust, salts etc. are carried by the wind into the equipment's environment where they may detrimentally affect the operating conditions.

Frequently, dust-bearing winds which reduce visibility to between 1000 and 6000 m occur in desert areas and sometimes develop into sandstorms. When a substation building is being planned, attention must be paid to the prevention of sand and dust ingress. For this reason, the internal pressure of the building is often increased with respect to the outside pressure by suitable intake and exhaust devices. The air aspirated from the outside must be filtered so that the correct operation of the dust filters may be assured, especially during a sandstorm.

Air Pollution

Dust, salts or gases in the air may adversely affect service life and proper operation of equipment and of total installations.

A dust-laden atmosphere is not necessarily restricted to desert areas. It occurs in all areas which are exposed to extreme solar radiation with little precipitation for long periods of time. Salt-laden atmosphere is limited to coastal areas, although wind may carry the salt pollution further than 50 km inland, particularly in tropical areas. Industrial pollution results from the discharge of large quantities of H_2S, CO_2, SO_2, combustion products, acids, dust etc., into the atmosphere where they combine with water vapour and/or salts. The sources of this type of pollution are numerous and include oil refineries, steam power stations, cement mills, paper mills and many others.

Under these environmental conditions, a contamination layer is formed on surfaces. The high temperatures and humidities which occur, usually in conjunction with salt pollution, may cause severe corrosion problems.

When equipment is installed in enclosed rooms, good protection against air pollution can be provided by filtering the air and by maintaining an over pressure in the room.

Additional Environmental Factors

In addition to the climatic factors discussed above, locally specific environmental influences must also be considered, e.g. adverse soil conditions, biological effects, risk of earthquake.

Adverse Soil Conditions

Adverse soil conditions may cause unsatisfactory earth resistance values. It is not unusual to find resistance values of between 10 Ohm and 100 Ohm measured on a normal earth rod. Under such conditions, dimensioning of the earthing system must be carefully considered. Acceptable values (< 10 Ohm) can be obtained by extending the station earth mat and/or by supplementing it with deep rods.

Biological Effects (Flora and Fauna)

The biological effects requiring attention include the influences of fungi and small animals such as rats, mice, termites, birds and reptiles.

Among the effects of fungi, those of moulds require special mention. Moulds grow on all suitable substrates like plastic or contamination layers and in all damp climates where there is little air movement and the temperatures range between 25° C and 30° C. The effects caused by moulds can include additional moisture accumulation, surface discoloration, decomposition and destruction of plastics as well as the reduction of surface insulation resistance. They can also cause malfunctioning of electrical contacts and of sensitive mechanical components.

In order to prevent the development of moulds, the simultaneous occurrence of air pollution creating contamination films, high relative humidities and critical temperatures should be avoided during operation. This should also be considered during storage of equipment on site and during periods when the equipment is taken out of service. Concerning the problems associated with small animals, the damage caused by rats and termites is most significant. Rats gnaw cables and may thus provoke short circuits, particularly in secondary installations. Termites gnaw anything that stands between them and their food. Wood and plastics, even metals and other materials that can be scratched by fingernail are subject to attacks by termites. Effective countermeasures include the selection of suitable material such as termite-proof insulation and the careful caulking of all openings.

2.4 Use in seismic areas, shocks and vibrations

Horizontal and vertical forces transmitted to the support structures by the ground during earthquake may cause extremely high mechanical stresses to all substation components. The risk of unwanted switching operations exists as the result of acceleration forces developed in switchgear and/or electrical relays.

The components of a secondary system have to be capable of proper operation during and after earthquakes. In regions with seismic activity special measures are necessary to ensure proper operation.

Users of substations should provide information to the manufacturer that will adequately describe the seismic environment that the equipment will be expected to withstand. Any condition that may be of consequence during a seismic event should be described.

Characteristics of the expected earthquakes in a certain area can be obtained from recorded earthquakes in the past. Seismic zone maps are readily available, for all regions of the world.

The following earthquake characteristics are of major concern:

- Maximum acceleration (horizontal and vertical)
- frequency spectrum
- duration

Maximum acceleration

The maximum acceleration is the maximum value of acceleration input to the equipment during a given earthquake for a particular site. Typical design values of maximum acceleration range from 0,1 g (g is the acceleration due to gravity) to 0,5 g, with values over 0,5 g being required in some special instances.

On the basis of the observation data so far obtained, the ratio of vertical acceleration to horizontal acceleration is considered to be almost one half. However, most of the substation equipment and apparatus are not much influenced by the vertical acceleration of an earthquake due to their structures so that it is usual not to consider vertical acceleration.

Frequency content

The frequency range observed is 0,5 to 30 Hz but normally does not exceed 10 Hz. Natural frequencies of supporting structures above 1 Hz can lead to a magnification of the acceleration (resonances); in the higher-frequency range (usually above 30 Hz) there is no change of acceleration with frequency.

The plant internal power supply (storage battery, charger, inverter, closed-type switchboard, etc.) has a natural frequency of 7 Hz or more. This equipment is generally installed in the plant building. In view of the fact that the building cannot transmit a seismic vibration of greater than 5 Hz, there is little possibility of resonance.

Switchboards, even though some have low natural frequencies, are in many cases liable to show a large damping constant because of their construction i.e. equipped with various relays and complex wiring. Besides, there is a tendency for the damping constant to become larger as the acceleration increases.

Seismic test

For a seismic test secondary equipment is usually submitted to vibrating table tests.

In an IEE-recommendation (6), the following are described:

- seismic criteria
- performance requirements
- qualification methods
- design and construction practices

The components or systems are divided into Class A and Class B:

Class A:	Any component or system whose failure, malfunction, or need for repair prevents the proper operation of the substation during or after the design earthquake.
Class B:	Any component or system whose failure, malfunction, or need for repair does not prevent the operation of the substation during or after the design earthquake.

Design techniques - Power and Control Cabling:

The earthquake performance of power and control cabling is considered to be very secure as witnessed by the absence of damage due to earthquakes in the past. However, it is essential to be careful in designing and executing cabling so as to leave no possibility of cable disconnection when an earthquake occurs.

Switchboards

The seismic response of switchboards is comparatively small owing to their vibration characteristics even though some switchboards have low natural frequencies. On the other hand, this equipment and apparatus has a high mechanical strength resulting from its structural features. Those produced by the conventional static design techniques have suffered little damage due to earthquakes in the past. Therefore, it is considered that dynamic design techniques are not necessary and that static design techniques are adequate.

Plant internal power supply

Most of the apparatus for this purpose will have a natural frequency of 7 Hz or more and a damping constant of 10 % or more. In many cases, they are installed on the ground floor or the basement floor of the building. The response magnification of this apparatus to earthquake is presumed to be almost 1.6 times less. Accordingly, 0,5g (0,3 g x 1,6) is adopted as the design seismic power.

Power generators

With regard to internal-combustion power generators, considering the structure and other features of the apparatus, the design seismic power is defined as 0,6 g (0,3 g x 2,0) if the apparatus is installed on the ground floor.

Secondary equipment in the upper floors of a building

There may be a need, in certain circumstances, to install certain apparatus on the first or second floor of a building. It then becomes necessary to consider the dynamic response of the building.

The amplitude ratio of the first and second floor of a building is considered to be close to two. It may be less depending on the actual measurements and response analysis.

2.5 Electromagnetic Compatibility (EMC)

Electromagnetic interference due to different noise sources in AIS and GIS may cause maloperation or even damage to the equipment. In the last ten years, this subject has created much interest in CIGRE, IEC and national working groups. Various specifications have been developed or are under consideration.

Today the noise sources and the coupling mechanisms are well understood for AIS but less so for GIS.

The problem of EMC can be considered in three parts:

- to define the level of transient overvoltage at the terminations of secondary equipment
- to define the withstand capability of the secondary equipment and provide recommendations for test requirements
- to give recommendations for the complete layout of secondary circuits including the earthing system in order to reduce the influence of transient overvoltages on secondary equipment

In the existing specifications it is common practice to divide substation secondary equipment into several classifications according to the amplitude of the interference signals to be expected. Classes are typically separated into severe categories, where the equipment is situated close to the switchgear and low level classes where the equipment is situated within control and equipment rooms and separated by a certain distance from the HV-equipment.

These classifications are not relevant in the case of GIS installations where the control room can be in the same building as the HV equipment. If atmospheric discharges are regarded as significant noise sources in an AIS the resulting levels of transient overvoltages in the control room are comparable to those values observed in the control cubicles of GIS switchgear.

For GIS, only one value for the withstand capability of secondary equipment is recommended. Different configurations and conditions in the GIS may alter this value (see Figure 2.2).

2.5.1 Noise sources in AIS and GIS

Noise sources in AIS and GIS causing transient overvoltages in secondary systems are:

- Switching in primary circuits
  (i.e. on the HV level)
  Switching of disconnectors or circuit breakers is a frequent source of noise in HV substations. The guided waves are transmitted by the current transformer (CT) and the voltage transformer (VT) to the measuring and protection circuits. Current flow on cable-screens, produced by guided waves and magnetic fields, and currents fed into the earthing system through CT, VT and stray capacitance to earth generate common mode voltages that also influence the secondary circuits.

- Atmospheric events
  A lightning stroke generates travelling waves on the HV line. These waves can be produced by a flash-over to the conductor, to the earth shield wire or the tower. The shape of the travelling wave depends on the amplitude and the shape of the lightning current. A flash-over of the insulation can be caused by a lightning stroke to the line or to conductors in the substation, or by insulator contamination. Whatever the cause of the flash-over, it will produce electro-magnetic waves that affect the secondary circuits. The lightning current fed directly or via an arc into the earthing system may result in high potential differences within the earthing system and with consequential current flow over cable screens and common mode transient overvoltages.

- On-site tests
  High-voltage on-site tests involving lightning and/or switching voltage wave-forms are commonly used for commissioning GIS. In the event of flash-over a high frequency very fast transient voltage (VFT) is generated which influences (via CTs and VTs) the transient ground potential rise of the secondary equipment.

- Earth faults
  Earth faults caused by the events described and by switching overvoltages, conductor galloping or fault switching produce effects mainly thought the electromagnetic waves radiated.

- Switching in secondary circuits
  De-energising of inductive loads generates transient high frequency over-voltages in secondary circuits.

- Electrostatic discharge
  Electrostatically charged persons produce a very steep current with a rise time of some nanoseconds when touching earthed equipment.

- Radio transmitters (walkie-talkies)
  The high frequency field generated by radio transmitters, including those used by maintenance staff, can influence sensitive electronic equipment.

The noise sources described effect the secondary circuits. One has to distinguish between the interference by conductive (direct) inductive and capacitive coupling on the one hand (guided waves) and interference by radiated waves (interference fields) on the other hand. The influence of radiated waves on secondary circuits which act as an antenna becomes significant for high frequency events in the MHz-range.

An overview of the noise sources and the coupling is presented in Figure 2.3.

The frequency range of transient overvoltage is described in Appendix A.

2.5.2 Recommendations on how to minimise EMC problems

The effects (including the transient ground potential rise), the measures to minimise the coupling and to desensitise secondary equipment and the associated test procedures have been reported in detail (7, 8, 9, 10, 11). The most important measures are:

- suitable construction of instrument transformers (CT, VT); effective screening between primary and secondary winding, test of HF-transmission behaviour

- exclusive adoption of screened secondary cables, if necessary with special screen construction; generally it is advantageous to earth the screen at both ends

- earthing conductors that are laid in parallel to cables in trenches to reduce screen current and to couple inductively the secondary system and the earthing system

- additional measures specifically relating to GIS:
  - connection of reinforcement steel to the earthing system at various points, especially in the floor
  - good screening at the GIS/air bushings by multiple connection between enclosure and wall (reinforcement, metallic wall) and additionally multiple connections between wall and earthing grid at ground level

- galvanic connections between HV cable screens and GIS enclosure; if only single point earthing for the screens is allowed leave opposite end open

- adequate design and test of secondary equipment in relation to amplitude, frequency and energy content of interference stresses.

For more detailed information see par. 5.5 and (10).

2.6 Ergonomic requirements

Conventional mimic diagrams as applied in substations have the advantage of good comprehensibility but from a technical point of view are not necessary when using digital control equipment. With digital systems visual displays are usually used even in the case of large and complex substations. The technology of visual display units is still undergoing rapid development.

To maintain a reasonable legibility, it is necessary to limit the information presented on the visual display. Considerations of legibility dictate that the degree of filling of the screen should not exceed about 6%. On the other hand this requirement may conflict with the desirability of minimising the number of process displays.

A careful balance has to be struck. The way in which the information is presented on the display should meet certain ergonomic requirements. In fact, the design of man-machine interfaces requires a multi-disciplinary approach because of its technical, ergonomic and psychological aspects. The interface has to be designed in such a way that operator actions are minimised and that only relevant data are presented.

To meet ergonomic requirements, the arrangement and design of the system have to be adapted to match human capabilities:

- information on displays or screen must be easily visible (readability) and logically classified (shape, colour)
- screens, displays and/or operation panel must be arranged properly for the operator to allow easy operation
- rapid system response after operator action is necessary
- ambience (light, temperature, humidity) should be comfortable.

It may be advantageous to implement a pre-programmed test procedure and to standardise switching sequences (e.g. change of busbars) for operations, thereby providing support for the operator and minimising the opportunities for operator error.

Appendix A:
Frequency range of transient overvoltages

Transient overvoltages in secondary system exist in the frequency range of about 100 kHz to 100 MHz in GIS and of about 100 kHz to 10 MHz in AIS.

Lightning strikes, switching of disconnectors in AIS and switching in secondary systems generate transient overvoltage in the frequency range of up to 10 MHz.

As a result of disconnector switching in GIS and of flashovers due to site tests, very fast transient overvoltage with high steepness can be produced. In 123kV GIS the shortest front time of the first impulse of a VFT is of the order of 3 to 5 ns. This steep impulse can generate oscillations of up to 100 MHz in the secondary parts of CTs and VTs.

Transient overvoltage with frequencies of more than 50 MHz (up to 200 MHz) can be measured, superimposed on dominant voltages with frequencies up to 50 MHz. The amplitudes of the superimposed voltages normally are less than 20 % of the dominant voltages.

Suitable measuring equipments for transient overvoltagess in secondary system are (as an example):

1. CRT storage oscilloscope

oscilloscope	bandwidth 500 MHz	
plug in	bandwidth 200 MHz	
probe	bandwidth 120 MHz, attenuation	100 : 1
probe	bandwidth 250 MHz, attenuation	10 : 1
probe	bandwidth 75 MHz, attenuation	1000 : 1

2. Digital storage oscilloscope

Maximum digitising rate 500 MHz; probes see 1.

Examples of transient overvoltages measured in a 123kV GIS are shown below:

Substation	A	B
Feeder	HV-line	Coupler
Switching device	disconnector of HV-line	busbar-connector
Measuring point	CT	input of an electronic amplifier connected to a voltage divider

Maximum Voltage	500 V	480 V
Maximum frequency	100 MHz	120 MHz

Substation	A	B
Oscilloscope	400 MHz	As for A
Plug in	200 MHz	
Probe	120 MHz	

The voltages were measured phase to earth.

The oscilloscope was connected to the power network over an isolating transformer.

Figure 2.2 shows the oscillograms.

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(4) CIGRE SC 23, WG 05: Design and Installation of Substation Secondary Equipment
Electra, No. 82, pp 57 - 86, 1982

(5) IEC TC 50 (Secretariat) 213
Appendix II - Description of the Components of an Open-Air Climate

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(10) Electromagnetic Compatibility (EMC) for secondary systems in gas-insulated metal enclosed switchgear for rated voltages of 72,5 kV and above. Draft IEC/SC17C-WG2.

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CHAPTER 3

DESIGN PHILOSOPHY OF SECONDARY SYSTEMS

3.1 Secondary systems functions

Substation secondary systems can be categorised into the following subsystems:

- protection
- automation
- control / operation
- control / monitoring
- AC and DC auxiliaries
- fire-fighting
- air conditioning

Each of the above subsystems are interconnected with wiring/cabling.

Secondary system functions are not necessarily associated with physically discrete pieces of equipment.

The functional requirements of the secondary subsystems include:

Protection (P)

P1 - system
P2 - substation
  P2.1 - busbar protection (BBP)
  P2.2 - breaker failure protection (BFP)
P3 - bays
  P3.1 - feeder (line)
  P3.2 - transformer and reactor bank
  P3.3 - bus-coupler
  P3.4 - capacitor banks

Automation (A)

A1 - system / network
  A1.1 - restoration
  A1.2 - load shedding (frequency control)
  A1.3 - ripple control (scheduled time order-instruction)
  A1.4 - network splitting (islanding)
  A1.5 - load restoration (after ripple control or load shedding)

A2 - substation
  A2.1 - sequential switching
  A2.2 - load transfer for transformers, switching-in of stand-by transformers
  A2.3 - control of parallel operation of transformers

A3 - bay
  A3.1 - auto-reclosing
  A3.2 - synchronisation
  A3.3 - tap-changer control (voltage regulation)
  A3.4 - change of relay settings
  A3.5 - capacitor bank control
  A3.6 - reactor bank control

Control / Operation (C/O)

C/O.1 - operating (switch-on, switch-off, tap-change, etc.)
C/O.2 - bay interlocking
C/O.3 - substation interlocking

Control / Monitoring (C/M)

C/M.1 - position (status) indications
C/M.2 - alarms and annunciations
C/M.3 - measurement / load monitoring - I, U, P, Q, t, f; synchronising
C/M.4 - metering (energy measurement)
C/M.5 - reports
C/M.6 - event recording
C/M.7 - disturbance recording
C/M.8 - fault location

AC/DC auxiliaries
Fire-fighting
Air conditioning

The functional requirements of the secondary subsystems (protection, automation and control) are illustrated in fig. 3.1 and can be further subdivided by way of:

- grade of functions
- range of use (always, usually, on request, needs extra analysis)
- method of application (conventional, computer-based)
- place of application (equipment - on site, bay, substation, remote control centre - RCC)
- scope of redundancy requirements (essential-appropriate, recommended, not necessary)

Tasks of AC and DC auxiliary subsystems:

- generating, conversion, transmission, supply to substation equipment

Tasks of fire-fighting subsystem:

- fire detection
- fire extinguishing

Air conditioning

- required by indoor equipment and/or human requirements

3.2 Possible architecture of protection and control subsystems

The following factors should be taken into consideration:

1. Requirements of the power system and the substation primary equipment:
   - necessity to achieve certain fault clearing time (short-circuit level, network stability, etc.)
2. Physical size and lay-out of substation, highest voltage, ultimate development of substation:
   - size/area
   - indoor, outdoor
   - AIS, GIS
3. Manning of substation
   - manned
   - unmanned

   Currently, most substations are planned as unmanned. Occasionally a utility may decide to operate a substation on a manned basis for any one of a number of reasons such as:

   - continuation of traditional utility practice
   - specific technical reasons (i.e. unreliability of HV-equipment and/or remote control communication links)
4. Choice of secondary systems functions to be implemented
5. Technology of protection and control subsystems
   - conventional
   - computer-based
6. Estimated life cycle cost which includes:
   - investment
   - training, education and operation
   - maintenance

The above-mentioned aspects should be considered in detail together with the availability / reliability requirements of the transmission network and of the energy consumer. These considerations provide a basis for the selection of the architecture for the protection and control subsystems.

It is important to realise that functional integration and location are to a major degree separate issues.

It should be noted that generally there are three levels of control:

- remote control centre level
- substation level
- bay level

The coupling between substation level and bay level can be achieved in a variety of ways. Various arrangements illustrating location , functions and the method of realisation are shown on fig. 3.2 and figs. 3.3.1 to 3.3.8. The layout of secondary equipment (with or without relay kiosks) is presented in paragraph 1.3.

3.3 Extension and modification requirements

Substation secondary systems may be extended or modified for any of the following reasons:

- additional primary bays are required
- the substation configuration is altered
- primary equipment is changed
- additional secondary equipment is installed (e.g. busbar protection or remote control)

In order to facilitate the extension of the secondary system in a substation, the following spare capacity should be incorporated at the initial design stage:

- in centralised services, such as the auxiliarysupply system, alarm equipment, event recording, compressed air facilities, etc.
- in cable trenches ducts and tunnels
- in the central control building
- in connection terminals for each group of circuits

The standard control building consists of two distinct functional areas which can be categorised as being:

- independent of substation size (e.g. staff related service areas)
- dependent on substation size (e.g. relay room)

The part which is dependent on substation size should have the capacity to accommodate any extensions or modifications that can reasonably be anticipated.

3.4 Degree of reliability/availability of systems/components, need for redundancy

Availability is a combination of:

- reliability (dependability, security)
- maintainability
- supportability

Availability is defined as the relation between the time in "healthy" state and total time and can be expressed as:

$$A = \frac{MTBF}{MTBF + MTTR}$$

MTBF = Mean time between failures

MTTR = Mean time to repair

Availability of secondary systems depends on:

- planning
- design
- erection and commissioning
- quality of equipment / components and software
- scope and type of redundancy
- maintenance and self-supervision
- ease of functional testing with appropriate test systems
- protection against electrical interference (noise)
- environmental conditions

The reliability can be improved by duplicating the critical (highest grade) functions/equipment i.e. so-called redundancy. Redundancy is an option, the extent of which should be decided during the planning phase.

Two types of redundancy can be applied:

- parallel (systems operate independently of each other, i.e. 1 out of 2)
- series (function performed only if both systems have provided the same output i.e. 2 out of 2)

Relationships between dependability (function will be executed correctly when wanted) and security (function will not be performed when unwanted) for both types of redundancy are shown in fig. 3.4.

It should be noted that self-supervision increases reliability and therefore it is very important to incorporate such features. This is relatively easy to achieve by the use of digital technology (computer-based systems).

In the table below the numerical values are compiled for a distance relay having an availability / reliability ratio of p = 0.94, a probability of non-operation of Fp = 0.06 (i.e. 1 - 0.94) and a probability of false tripping (security) of Fs = 0.008.

Redundant protection systems

	Availability/ Reliability	Probability of non-operation	Security
One relay	p=0.94	Fp=0.06	$Fs=8*10^{-3}$
One-out-of-two	0.9964	0.0036	
parall. arr.	$(2p-p^2)$		(2Fs)
Two-out-of-two. series arr.	0.88 (p^2)	0.12	$6.4*10^{-5}$ (Fs^2)
Two-out-of-three	0.99 $[p^2(3-2p)]$	0.01	$19*10^{-5}$ $[Fs^2 (3-2Fs)]$

Unlike series connection, with parallel connection the two units/components must be completely separated.

If an equipment has n elements x of which are identical, and if all these elements are necessary (series arrangement), the availability of this equipment is:

$$A = \left(\frac{MTBF}{MTBF + MTTR}\right)^n = (Ax)^n$$

If an equipment has n elements x of which are identical, and if only one is necessary (parallel arrangement), the availability of this equipment is:

$$A = 1-\left(\frac{MTBR}{MTBF + MTTR}\right)^n = 1-(1 - Ax)^n$$

Parallel redundancy is used more frequently than series. Typical practical examples are:

- AC and DC supply equipment (i.e. battery, auxiliary transformer, etc.)
- cabling and cable routing
- protection systems (particularly bay protection) and trip coils of circuit breakers
- power supply fed from separate circuits and/or dual supply units
- communications (bus communications)
- control/operation of equipment

There are also other types of redundancy that can be applied in computer-based equipment:

- Duplication of system components which operate in parallel but with one system (or system component) active and the other one automatically active if the active one has failed.
- Processing of signals or commands in one system (or system component) to different algorithms or in different paths and output only if both of them provide the same result (decision 2 out of 2).
- Serial redundancy by several repetitions of a signal in one system and verifying if all signals show the same result.

The primary process determines the degree of reliability and safety necessary for secondary systems. Active or passive malfunctions restrict reliability or safety.

General assessment of malfunctions

	active malfunction	passive malfunction
Protection	detrimental, e.g. maltripping of a CB	dangerous, e.g. tripping of CB not effected by fault
Control	dangerous, e.g. disconnector operated under load	detrimental, e.g. intended switching operation not effected
Position indication	dangerous, e.g. release of interlocks due to faulty indication	dangerous, e.g. release of interlocks due to missing indication

Malfunctioning of secondary systems which gives rise to dangerous conditions endangers safety.

Malfunctioning of the secondary system which has only detrimental effects is not dangerous but restricts availability.

Redundant systems are essential to ensure the necessary degree of reliability and freedom from malfunction.

Redundant systems must fulfil the following conditions:

- failure of system components or parts of them must not endanger safety
- failure of system components or parts of them must not restrict availability

The scope within which these conditions must be fulfilled, will be dependent on the type and importance of the primary installation and should be determined at the design stage.

Results of substation reliability calculations for some common substation arrangements, with particular reference to the influence of secondary failures on the overall reliability of the substations, can be summarised as follows [4]:

- Secondary failures causing a spontaneous unwanted functioning of the circuit breaker (security) do not have a significant influence on the results.

- Depending on the scheme, the "failure to operate" probability of CB due to secondary failures (dependability) may have a dominant effect on the overall reliability of the substation.

- The most favourable results of the ring bus scheme and the 1½ circuit breaker scheme show extreme sensitivity to secondary failures in non-redundant secondary systems. To maintain the superior performance of the HV scheme, the secondary system must be designed carefully having regard to this factor.

3.5 Control and protection schemes

General

Control and protection subsystems are closely interrelated in the substation.

Protection (fault clearing) subsystems including protection relays should:

- prevent or limit the damage to primary equipment
- protect power system stability

Protection is fundamental and its role is to trip, generally speaking as quickly as possible (main protection 10 - 50 ms, not incl. the operation time of the circuit breaker), only the faulted circuit. Although this function (protection) may differ between countries and between utilities, it is generally a dedicated system and organised as follows:

- bay level (line, transformer, etc.)
- substation level (BBP, BFP)

In the highest range of protection function, it is commonly accepted that the protection unit and function should be segregated as much as possible from other subsystems.

The advantages of this segregation include:

- Protection is not compromised in any way by the requirements of other functions
- Protection is permanently "on line" (better performance)
  Protection can tolerate faults in both hardware and software at bay and substation levels
- Even with total loss of communication (bay level - substation) level the continuity of the protection function is still ensured

The protection subsystems (relays) should communicate with control / monitoring to provide information regarding:

- operation
- faulted phase
- settings, etc.

This information should be available at some location whether or not it is available on site.

It should be noted that some new designs of protection relays incorporate as an integral part such functions as:

- auto-reclosing
- fault recording and fault location
- synchronisation (synchro-check)

The general structure of protection and control subsystems for conventional designs is shown in fig. 3.5. The recommended computer-based structure is shown in fig. 3.6. BBP, BFP and interlocking central unit, which are not shown in this figure, should be located in the bay level, as in fig. 3.3.8.

Protection of substation

Protection of substations can be divided into:

- bay level protection (line, transformer, bus coupler)
- substation level protection (BBP, BFP)

The range of operation of protections is presented in fig. 3.7. The commonly used arrangement of protection for different bays is shown in:

-	fig. 3.8	line
-	fig. 3.9	bus coupler
-	fig. 3.10	main transformer

The aim of busbar protection (BBP) is to initiate immediate tripping of all circuit breakers (CB) connected to a faulted section of busbar.
Breaker failure protection (BFP) trips, after a delay, all the CB's connected to the same busbar in the event of non-operation of the faulted bay CB.

Control of substation

The functions of subsystem controls are specified in item 3.1 and generally presented in fig. 3.5 and fig. 3.6.

In the conventional design they are implemented by hardware units and provided with conventional MMI (refer to Chapter 4).

The main disadvantage of this solution is that extensions to, or modifications of either the primary equipment or of the control functions can be difficult to implement retrospectively.

In practice, problems concerning the implementation of some functions can cause a restriction in their range of application (i.e. interlocking) or even an inability to implement certain functions (i.e. automatic sequential switching).

In computer-based control systems it is recommended that a configuration be adopted with separate:

- substation computer with adequate MMI (refer to chapter 4)
- bay level computer
- local back-up (emergency) bay control

Refer to fig. 3.6. for the arrangement.

For the basic advantages / disadvantages of computer-based and conventional (relay-based) systems refer to chapter 1.

The main advantages of the recommended configuration (distributed for substation level and each bay level with "fishbone" data base communication arrangement) are as follows:

- high availability because bay protection with associated automatic functions (i.e. auto-reclosing) are performed autonomously and independently of adjacent bays, substation functions and units

- the hardware / software failure of substation computer does not cause the loss of:
  - bay dedicated functions
  - RCC possibilities (bay-oriented)

- bay computer hardware / software and communication failure does not lead to the loss of:
  - basic bay functions, (control, specific alarms, metering) due to the use of a simple back-up bay level control panel
  - main range of substation computer functions (except automatic 11with other bays and substation itself

- failure of MMI at substation level (see chapter 4) still allows performance of RCC dedicated functions

- hardware / software can easily be adapted from modules for reconfiguration, extension or adaptation to specific requirements of bays, substation or specific utility user requirements

Software expectations and requirements

Software should be divided into:

- system software which complements the features of the hardware with specialised functions and should use an operating system suited to:

    - real-time operation using the interrupt handling technique with priority based supervision
    - multiprogramming and multitasking technique, i.e. each event is handled by its own task

- application software (to accomplish specific functions) which has to incorporate such features as:

    - not require additional complex analysis
    - partial modification and extension should be easy to implement.
    - flexibility to allow the operator to make modifications, and enlargement and to add additional new functions in application software, while the system is in service, by means of on-line programming.

The software should include different testing features for both hardware and software.

The process of software development is both difficult and time-consuming.
Considerations such as:

- costs and complexity
- requirement of quality
- need for close co-operation between substation engineers and software specialists.

have to be confronted to ensure a satisfactory end product.

3.6 Updating of secondary systems with computer-based system Transition from existing secondary system

The renewal of existing secondary systems is effected usually in conjunction with:

- renewal of the remote control centre (RCC) and the requirement to implement new functions
- tension of substation or replacement of HV equipment
- maintenance and performance pro$blems related to the fact that the secondary system is technically and commercially obsolete
- inordinate increase in maintenance costs of the obsolescent secondary equipment

It is appropriate to effect the updating of secondary systems of all substations which are controlled from a common RCC through a co-ordinated strategy based on a fixed concept of the end-functions to be achieved. As a result of this, hardware and software standardisation is achieved which facilitates the necessary training of staff and simplifies the maintenance.

It is necessary to phase in the capital expenditure as quickly as possible in order to achieve an acceptable return on investment in the economic life time of digitally based equipment.

The new secondary systems should be installed and tested in the traditional manner. The new system must be checked out first in the factory, set up in the substation and then retested prior to commissioning.

Standard protocols for communication between substation and control centre (long distance communication) and inside the substation (local communication) should be applied. They will permit the association of equipment from different sources for use within or outside the substation. They will also facilitate the extension or modification of the digital system and its replacement in the future.

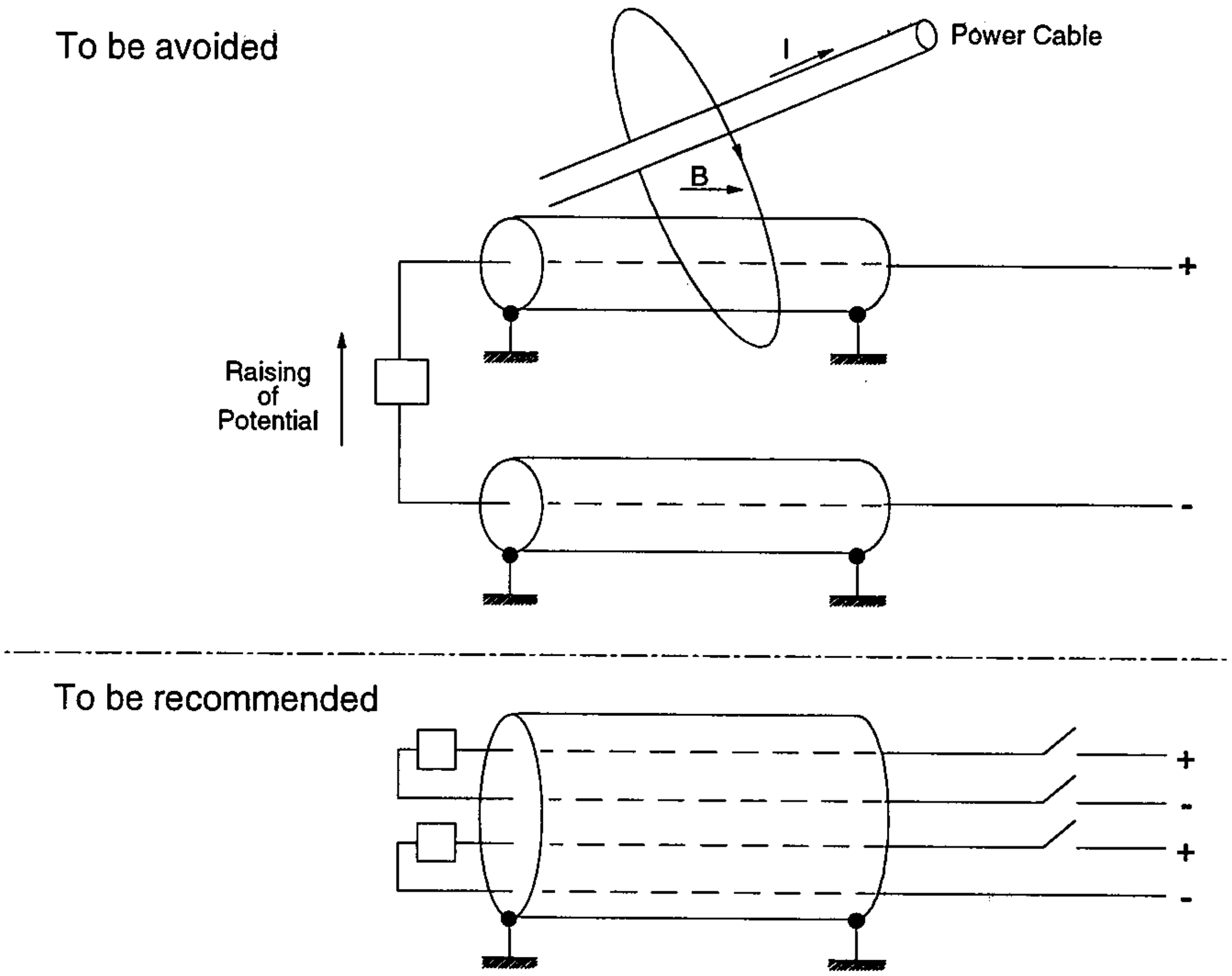
3.7 AC and DC auxiliary power supply and distribution

Some aspects of AC and DC power supply subsystems are mentioned in Chapters 4 (Requirements) and Chapter 5 (Installation).

AC substation supplies are fed from auxiliary transformers associated either with the bulk supply transformers or with incoming distribution lines (refer to fig. 3.11).

A diesel generating set can be utilised to maintain essential supplies to the substation during the loss of the normal source of supply and during the erection and commissioning stages.

Generator sets can be used either as stationary (permanently installed in substation) or as mobile units. The choice of the appropriate option is dependent on:


To be avoided

To be recommended

Fig. 5.8.2 Earthing Practice

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CHAPTER 4

PERFORMANCE REQUIREMENTS OF SYSTEM COMPONENTS

4.1 Man-machine interfaces for operation & maintenance purposes

General

Secondary equipment for substations includes control & monitoring, protection, AC & DC supplies, fire fighting, air conditioning etc. Each system has an associated man-machine interface (MMI) of greater or less complexity. However, in this section only the control and monitoring equipment associated with the operation and maintenance of the substation is addressed.

In most cases the substation control and monitoring system allows for 3 levels of supervision and control (or points of MMI). However, the number of levels employed will be dependent on local practice and may be restricted to the first two levels of control.

- In the switchyard/switchgear buildings
  (bay control)
- At the substation control room
  (station control)
- From a central network control centre
  (network control, remote control centre, regional control centre)

Selection between bay or station control will be from the bay control point and may be on an individual equipment basis. Selection between station or network control will be from the station control point and may be on a per-circuit basis.

The facilities at each point will vary in terms of the equipmebeing controlled, the indications and the alarms available.

Alarms may be grouped for station and network control points to suit individual requirements. Generally alarms and indications necessary for the safe and satisfactory operation of the substation should be provided at each control point. Special facilities, such as synchronising, may be available at the station or bay control point.

Reference should be made to figure 4.1 which illustrates the type of equipment at the man machine interfaces.

With the continued increase in the use of equipment using digital technology, there is now a clear distinction between the conventional and the new computer based man-machine interfaces. Computer based MMI is commonly found at network control level but is becoming increasingly more common in station control rooms. However, there are still a large number of conventional MMI's at the station level. MMI at bay level is invariably direct wire control and is therefore conventional.

Details of conventional MMI

MMI at bay level will comprise: control switches, indicator lamps and meters mounted on the equipment or in adjacent local control cubicles. Generally these facilities are used during maintenance of the controlled plant, or as back-up for use in the event of failure of the station level or central network control centre.

At the station level, control panels should be located in the main control room. The MMI equipment should be grouped on a per-circuit basis and trip and close switches should only control equipment on the same section of the substation as the control panel represents.

A mimic diagram representing the substation layout, usually in single line diagram form, should be provided. The mimic board is intended to give operating personnel an overall view of the switchgear state. It may be made up from the individual circuit control panels mounted side by side. The arrangement should correspond to the primary equipment layout.

Alarm annunciation equipment should be mounted adjacent to the mimic diagram, or form an integral part of the control panel. Operation of an alarm should cause the appropriate window to flash and sound an audible warning. Operation of an accept button will silence the audible warning, steady the flashing window and prepare the annunciation to respond to subsequent initiation. A reset button should be provided to extinguish alarms which have reset.

A lamp test button is necessary which will initiate steady state illumination of all alarm windows. Trip or protection initiated alarms should have windows distinct from others (e.g. red display instead of white).
Control and selector switches should be of approved types complying with accepted standards such as IEC 337. Control switches will require two independent motions or two handed operation to effect operation. Indicating instruments should be of approved types complying with accepted standards such as IEC 51.

Details of computer-based MMI

Computer-based man-machine interfaces function through computer systems using distributed architectures. Such systems are commonly found at network level, but only more recently at substation control level.
Remote terminal units (RTU's) form the interface with equipment and communicate information to the central system(s). RTU's will collect analogue and digital data and issue control commands.

The man-machine interface should make use of the following items in varying quantities depending on the degree of redundancy required:

- Visual display unit (VDU)
- Alphanumeric keyboard
- Printer
- Plotter
- Trackball
- Joystick
- Special function panel
- Mouse

A mimic display either in the form of a board for large substations or VDU "pages" should be available.

Operator consoles capable of operating the substation (at substation level), or power system (network level), should be comprised of the required components from the above list. The console should be capable of operating in on-line, maintenance, training and programming mode. Special software interlocks should prohibit two or more consoles working "on-line" simultaneously.

VDU's should be of the full graphic, multi-colour type designed for 24 hour a day continuous operation. The following information should be displayed:

- Static (fixed) information (e.g. substation single line diagram)
- Operating parameters which may be changed
- Dynamic (real-time) variables

An operator's keyboard, which contains special function keys, should be provided at each console; this will allow execution of commands. The system keyboard is for data entry and general operation of the computer system and substation(s). In addition, an alphanumeric keyboard may also be required for system purposes.

When the substation is only manned occasionally, consideration should be given to the provision of a touch screen VDU or special function panel to simplify the task of the operator in controlling and monitoring the plant. The special function panel would only have a small number of dedicated push buttons and switches for plant control, selection of VDU pages and acknowledgement of alarms.

4.2 Computer performance criteria

The type and configuration of computer-based control equipment for substation secondary system applications should be such as to produce a system with the necessary reliability, functional availability and ease of equipment maintenance.

Master station

The master station computer system which supports the MMI should have a very high reliability with virtually continuous functional availability. The usual technique for fulfilling these requirements is to introduce hardware redundancy for critical major elements. The redundant elements are usually configured to function automatically on detecting failure of the on-line unit.

Outstations

Distributed data acquisition computer sub-systems should have a very high reliability but an occasional failure can normally be tolerated since it will usually only effect a small part of the overall system. Redundancy is not normally employed for reasons of economy but component selection should be to a high standard to give long mean-time-between-failures.

Communications

Distributed computer systems are reliant on communications. Where communication channel physical routing is not provided a high degree of mechanical or electrical protection is required. Where the functions associated with an outstation are important, then main and standby channels should be provided over physically segregated routes. Otherwise the provision of a single channel normally gives satisfactory availability.

Computer loading

While a power network is operating in a normal state, which it is for most of the time, computer-based control systems generally have no difficulty in performing all the tasks associated with updating telemetered data and supporting the MMI. During major network disturbances however, the volume of telemetered data and the processing associated with the MMI will both increase of the same order. During major disturbances, these requirements can be relaxed to some extent but on no account must data be lost.

4.3 Protection relay performance criteria

The general aim of protection equipment is to isolate every fault on a power system reliably and in the minimum possible time consistent with the need for good SELECTIVITY. All equipment must remain inoperative during transient phenomena which may arise during fault, switching or other disturbances to the system.

The cost of protection equipment represents a relatively small proportion of the cost of the main electrical plant in a substation, but its role is essential to the safe and successful operation of that plant. It is vital that the greatest possible care is taken in both its design and manufacture, particularly as much of it will stand idle for the greater part of its life yet must be in perfect working order when called upon to operate. Relays which are at the heart of protective schemes are of many diverse designs, each aimed at achieving particular results.

Relays can be segregated into two classes, those which measure and those which repeat a controlling signal. Measuring relays receive and measure fundamental quantities and compare the input quantity with a standard or other input. Repeat relays are intended to be energised with a power input which is substantially above their minimum setting.

The fundamental quality that all protection must possess is that of SELECTIVITY. This is the quality where a relay or protective system selects and disconnects only the faulty element in a power system, leaving all others in normal operation so far as that may be possible. The term STABILITY is used to describe the quality of a protective system by virtue of which it remains inoperative under specified conditions associated with high values of fault current. It is the quality that only UNIT systems can possess because they are required to remain inoperative under all conditions associated with faults outside their own zone. SENSITIVITY refers to the low level of fault current at which operation occurs. RELIABILITY refers to the ability of the protection to operate consistently for all faults to which it should respond and remain inoperative to all faults to which it should not.

With the advances in solid-state equipment, particularly the introduction of microprocessor technology, the electromagnetic relay is disappearing. Relays are normally flush-mounting and of the significantly. It is essential that computers of sufficient processing power are used which will give the required response times at periods of high activity. For power network supervisory applications under normal conditions, system alarms and changes of state should be processed and displayed on the MMI within a few seconds of occurrence. Responses to operator requests, such as display selection, should be withdrawable type with printed circuit cards sliding into withdrawable modules.
Relays should be supplied by experienced and reputable manufacturers and comply with internationally accepted and approved standards such as IEC 255. Electro-mechanical and solid state relays may be arranged for conventional panel flush mounting or alternatively in standard 19" rack-mounted modules and installed in cubicles. The cubicles should not permit the ingress of falling water drops and should provide a degree of protection to at least IP51, in accordance with IEC 529. It should be established that the relays and overall protection scheme are adequately designed to ensure satisfactory protection performance under all possible system conditions.

A protection cubicle will, when received on site, require many interconnections with remote parts of the substation and beyond. The complete protection system will comprise the relays and ancillary equipment mounted in the relay cubicles, current and voltage transformers, auxiliary switches in the primary switchgear, DC power supplies, tripping connections and interconnections with other substations to complete a UNIT system for intertripping or indication purposes. Such a complex system of equipment and connections which must be completed on site, should be proved to be correct before the system can be considered fit for service. It is necessary to carry out a comprehensive programme of examination and testing to prove that:

- all items of equipment are undamaged by transport and handling
- the correct items are connected together
- all connections are correct
- the correct settings and adjustments are applied in accordance with the design of the protection scheme.

For transmission systems of 220 kV and greater, it is normal practice to provide two high speed discriminative protections per circuit. The protections are designated first and second main protection. In selecting the types of protection, the following points should be considered:

- Where possible avoid the use of two unit schemes.
- Use protections based on different operating principles
- Use protections of different manufacture.

4.4 Measuring & metering equipment

Conventional circuit control panels will include indicating and integrating meters to monitor and measure the primary conditions, e.g. amps, volts, watts, vars, temperature, tap position, frequency and phase angle. The mounting height of the centre of all indicating instruments should generally not exceed 2000 mm with the possible exception of certain common instrumentation, e.g. system frequency, system time clock. All instruments and meters should be fitted with glasses of low reflectivity which should not cause pointer deflection due to electro-static charging through friction. All indicating instruments are generally of the flush mounted type with dust and moisture proof cases and are provided with readily accessible zero adjustment. The dials should, in general, be white with black markings and be of such material that no discolouration takes place. System voltmeters have expanded scales to display the nominal service voltage + 20 %. Wattmeters and varmeters should have linear positive and negative reading scales. Frequency meters should be of the pointer type and biased to swing to one end of the scale on loss of voltage. The user should provide electrical instrument and meter schedules to include manufacturer, type, current and voltage rating, accuracy class and circuit designation. They should be of approved types complying with accepted standards such as IEC 51.

Accuracy class

Instruments are classified by the following accuracy classes:

0.05-0.1-0.2-0.5-1.0-1.5-2.0-2.5-5

The accuracy is expressed as one hundred times the quotient of the absolute error and the upper limit of the effective range (Total Scale Length). The absolute error being the difference obtained by subtracting the true value of the quantity from its measured value.

Typical accuracy classes for measuring equipment would be:

Amps	1.0
Volts	1.0
Watts	1.5
Vars	1.5
Frequency	0.5
Phase Angle	2.5
Power Factor	2.5
kWatthour	2.0
kVarhour	2.0

Digital measuring equipment

Typically digital measuring equipment consists of a three phase digital transducer which accepts signals from VT and CT secondaries and is able to digitally calculate three phase volts, three phase currents, three phase summated watts, three phase summated vars and frequency.The digital measuring equipment output is normally via a port, such as RS 232.

The main application of digital measuring equipment is in substations where a co-ordinated microprocessor control system is employed.

Transducers

Transducers play an important role in the field of measurement and control. Instead of the movement of a pointer, the transducer output is a DC analogue current signal which is proportional to the input quantity to be measured. Used in conjunction with instruments and recorders, these units are convenient for local and remote indication. Installation costs are reduced due to a low burden on current transformers and where summation is required for power measurement, the elimination of a summation transformer. Modern techniques using microprocessor based control and indication functions rely heavily on the use of suitable transducers for supervisory control and data acquisition (SCADA) systems. Transducers should be of approved types complying with accepted standards such as IEC 688.

Digital transducers

Digital transducers measure an analogue input, such as current, and convert it into a digital voltage output.

This has the advantage that the transducer can be interfaced directly to a microprocessor controlled system without the need for any supplementary signal conditioning equipment. Another advantage is that digital signals can be transmitted with a much better immunity to electrical noise and electromagnetic interference. Signal transmission can be by screened cable or by fibre optic link.

4.5 Hardware and software specifications

The hardware and software systems for power network applications should be procured as an integrated package and preferably be a system which has been developed specially for power network control.

Master station computer systems

For small substations a single computer system is sufficient, however a dual redundant computer system should be employed for large substations, each of which should be capable of supporting all functions according to the required response times. Each computer should incorporate integral memory by means of mass storage devices such as hard disc drive sub-systems. The computers should operate in an "on-line"/"stand-by" mode so that if the on-line system fails, the stand-by system can take over on-line within a short period of time. If a local area network system (LAN) is used then the master station computer function can be divided in MMI-computer, station function computer and gateway function computer. This division guarantees a very high availability and reliability of the station system so that no further dual computers are necessary.

Bay level computer systems

Computer systems of a single board or modular construction should be employed. Programs should be stored in non-volatile memory such as EPROM's to give high availability and disc drives should be avoided. The following facilities should be incorporated:

- digital input/output for interfacing to switchgear indication and control circuits
- analogue input for interfacing with transducers
- pulse counting acquisition for interfacing with kWhr energy meters

Communications

The communication between master station computer and bay level computer can be of end-end type or via a local area network system (LAN). The LAN has to be built as a fibre optic communication system with a star coupler. Both master station and bay level computer need to be equipped with data terminal equipment for intercommunication purposes. The data terminal equipment should be interfaced to the communication network through modems connected to a hard-wire or optical fibre carrier medium. The characteristics of the data communications equipment are covered by CCITT recommendations.

System software

The computer systems should be equipped with real-time, multi-tasking operating systems capable of supporting all on-line functions. Other software such as assemblers, high-level language compilers, editors, diagnostics etc. should also be supplied as part of the package.

Application software

The control system software should be developed for the particular application, and the principle functions associated with substation secondary supervisory systems are:

- Interlocking function
- Data Acquisition - provides the link between master station and the out stations
- Alarm/Event Processing - the detection and a nnunciation of alarm conditions or changes in state in the power network
- Remote Control - allows the operator at the master station to remotely change the state of a device on a power network
- Data processing and recording - mathematical operations on basic acquired data and periodic storage of values on magnetic disc or tape for retrieval at a later date
- VDU display - the display of information on VDU's in the form of alphanumeric lists, graphic displays and trend curves
- Report Generation - the grouping together of various VDU displays to form reports
- Data Base Management - facilities to generate or re configure the data-base to reflect physical changes
- Tap changer and transformer control
- Synchrocheck function
- Switching sequences
- Control of reactive power
- Network restoration

4.6 Batteries, Chargers

General

Batteries perform a key role in the operation of a substation. Their cost however, is relatively low in proportion to total plant cost.

Substation secondary equipment is powered by DC supplies provided by battery equipment. The principle reason for using batteries for the essential duties of tripping, closing, control etc. is to provide continuity of service in the event of loss of low voltage AC. supplies. Often two voltage levels of DC supply are required in a substation to satisfy the variety of equipment in use. These nominal voltage levels are typically in the range 24 V, 48 V, 60 V, 110 V and 220 V. The selection of battery voltage is dependent on the power requirements of the equipment and on local standards for such equipment. Consideration should be given to the voltage drop between the battery terminals and the equipment terminals. The following factors are central in determining which methods are employed to overcome this problem:

- Battery type
- Battery voltage selection
- Standby period
- Charging requirements (boost charging facilities)
- Cross sectional area of cabling between the

battery and load
- Routing of cabling
- Relative position of the battery and the equipment

For transmission systems of 220 kV and above, duplicate systems at either or both voltages are generally employed to ensure availability, security and reliability.

Batteries

Of the many different types of batteries used for industrial applications the lead/acid and nickel/cadmium types are specially suitable for substation applications where the battery is continuously charged and subjected to infrequent discharges.

Nickel/cadmium batteries, being of higher initial cost, are specified for conditions where a greater tolerance to abuse is required, particularly in respect of being able to be left in a partially or fully discharged condition and also in respect of vibration resistance. They are also able to provide high-rate discharge capabilities that are advantageous for some applications. They have a high energy density (electrical capacity per unit volume) and can be used in high ambient temperatures. Their life expectancy is 25 years.
There are three main types of lead/acid batteries currently in use: Plante, Tubular and Flat Plate. The flat plate types have met the greater part of the need for substation battery installations. This type of battery has a flat gravity cast grid with the active mass applied as a paste for both positive and negative plates. It has a high life expectancy of 12 years and low initial cost.

A new type of lead/acid battery has been introduced in the form of Sealed Gas Recombining Cells. The gas recombining technology allows the batteries to be constructed in a fully sealed form. A glass microfibre separator which together with special electrochemical features in the cell, provide efficient chemical recombination of the gas produced on overcharge.

As a consequence, water loss is effectively eliminated and correspondingly levels of emission of flammable gases are relatively small. The electrical characteristics of cells using this technology are improved, particularly at high discharge rates. The lack of emission of flammable gases and the elimination of maintenance requirements permits batteries to be introduced in immediate proximity to electrical and electronic equipment rather than in purpose built battery rooms.

Effect of low temperature on battery

It is important to maintain the electrolyte temperature to at least 5^{o} C and preferably higher due to the increased internal resistance of the battery at low temperatures. The nominal Ah capacity of Plante positive plate batteries is defined at the 10 hour rate discharging down to 1.85 V/cell at 15^{o} C. If the temperature falls below this value then there is a reduction in battery capacity. Typically a drop in capacity of 15 % at 5^{o} C and 20 % at 0^{o} C.

Standby period

Battery charger supplies should be taken from the essential AC supply system. The period for which a battery is required to perform without recharge from this supply is known as the STANDBY PERIOD. Individual users have their own requirements in this respect, but 6 hours is generally considered acceptable and allows time for restoration of AC supply or replacement of battery and/or charger by operational personnel. If alternative standby arrangements such as diesel generators are installed, then consideration may be given to reducing this period. Obviously, the longer the standby period the more costly will be the battery installation, the larger its physical size and cost of accommodation.

In sizing a battery, consideration must be given to its ability to supply a continuous load for the standby period; it must also be capable of providing the high-current short-period duty of multiple tripping associated with a bus zone fault without the voltage falling below a pre-determined level. Attention must be paid to the relatively high power consumption requirements of computer based control and protection equipment.

Battery Chargers

Battery chargers should operate from an LVAC supply, single or three phase, depending on the rating. The battery, charger and load should be connected in parallel. The charger output should be adequate to cover any normal continuous loads with sufficient excess to re-charge the battery after an emergency discharge. With this system, the charger supplies the normal loads with the battery supplying any peak loads over and above the capacity of the charger. Facilities should be available to boost charge the battery by means of an interlocked selector switch on each charger. This should take place separately on each battery when off-load, the load being supplied by the in-service battery. When the battery is in a fully charged state, it will take a trickle charge current from the charger so that it will remain fully charged. In such a system, the battery will remain fully charged and will not require any freshening charges except following an emergency discharge.

Distribution board

The distribution board will comprise busbars with pairs of fuses and links or miniature circuit breakers for each circuit.

4.7 Emergency generator sets

The operational security of a transmission substation is dependant on the availability of the auxiliary supplies. These supplies are obtained from either incoming supplies or from auxiliary transformers associated with the bulk supply transformers.

On the loss of the normal source of LVAC supply, diesel generating plant can be utilised to maintain the substation in operation during the emergency.

The start up and load transfer to the diesel plant should be applied automatically. The LVAC system should be segregated into sections so that on the loss of normal supplies the diesel plant can supply selected sections.

Economic considerations regarding the relative importance of the substation should be taken into account in deciding the necessity for generator sets.

The loads required within a substation can be categorised as follows:

Essential load

The load necessary to maintain the substation operational with limited auxiliary supplies for a period of hours. A typical period would be 6 hours.

e.g. Air compressors
Motor operated equipment
Battery chargers
Equipment heaters
Tap changer drive(s)
Partial lighting
Partial air conditioning
Fire services
AC supplies

Non-essential load

The total substation load less the essential load.

Standby load

The load necessary to maintain the substation fully operational for a period of days. It involves the essential load plus other loads e.g. transformer coolers, air-conditioning.

The diesel generator set should be capable of supplying the standby load. In addition, it may be used to provide AC supplies during the erection and commissioning stages.

4.8 Fire detection & extinguishing systems

General

The substation represents a large investment of capital in high technology plant and equipment, the loss of which would entail disruption to the power system and a large reduction in revenue to the operating company. It is necessary to protect this investment against fire damage and to this extent a Fire System should be provided to:

a) protect personnel
b) detect smoke and abnormal temperatures to enable action to be taken to prevent fire
c) in the event of fire, to limit damage as far as possible so that rectification is kept to a minimum.

Due to the deleterious effects of chlorofluorocarbon (CFC's) on the ozone layer, the use of halon gas (which is one form of CFC with one of the highest depletion potentials) as a fire protection medium has been stopped in many countries. This has resulted from the international thrust to phase out the industrial use of CFC's, in any form, over the next few years. An alternative medium is being sought to replace existing halon installations over the same period.

4.9 Air conditioners and heaters

Secondary equipment housed in the sub-station control and relay buildings dissipate heat. This heat raises the relative ambient temperature and it is necessary, especially with the introduction of microprocessor based equipment, to maintain a reasonably constant humidity and air temperature.
In moderate climates, temperature regulation can be accomplished using a ventilation system. However, in more extreme climatic conditions heating, ventilation and air conditioning is required.

A simplified heating, ventilation and air conditioning system is illustrated in figure 4.2 and consists of the following main plant items:

- compressor
- condenser
- liquid line receiver
- evaporator
- air handling unit

The above are interconnected with copper pipework and together are located external to the control, relay and telecommunications room.

Heat is removed from the air by the refrigeration system evaporator and air heating, if required, is supplied by electrical elements. Both the evaporator and electrical elements are housed inside the air handling unit. Temperature control is achieved by means of thermostats located inside the environmentally controlled zone. Separate thermostats are used for the cooling & heating systems and changeover between cooling & heating is usually automatic.

A percentage of air can be recirculated but atmospheric air must be introduced to maintain volume air changes. A positive air pressure is maintained in the building to keep out dust.

Typical design conditions for areas to be conditioned would be:

- Control Room, Office Areas
  20° C - 25° C
- Switchgear & other Electrical Equipment Areas
  0° C - 40° C
- Battery Room
  20° C - 30° C
  (Air conditioned with extraction system)

Supplementary to the heating, ventilation and air conditioning system is an exhaust air system. This may vary from a central extract system to individual extraction units located in toilets, workshops, battery rooms etc.

From the most basic wall mounted heater/air supply fan arrangement, to complex centralised heating, ventilation and air conditioning systems, maintenance requirements are relatively small.

Choice of system is governed by climatic conditions, as previously mentioned, and standards should comply with local authority requirements / regulations. Careful system choice and good commissioning practices usually culminate in years of trouble free operation.

CHAPTER 5

INSTALLATION PRACTICE

5.1 Separation of cubicles/rooms

In a substation, the secondary equipment provides the functional interface for the control, supervision and protection of the network. The equipment is organised into substation level or bay level depending on whether it operates on an overall substation basis or only for a single bay.

The secondary equipment can be located in different buildings or in separate rooms within a central building.

The normal practice is to use a central area for metal enclosed sub-stations and open air sub transmission substations.
A typical example of this arrangement is shown in Fig. 5.1.

For high voltage open air substations and for high security metal-clad substations the usual practice is to provide dispersed relay kiosks/rooms for bay level equipment and a centralised control building for substation level equipment.

DC Distribution

Substation secondary equipment must be powered by sources which are not subject to interruption at times of AC power faults. This requirement is met by the use of battery systems kept in a fully charged condition by battery chargers supplied from the AC network. Inverter systems operating from a battery give the same high level of security to equipment powered by AC.

Each DC system includes a battery, a charger and a distribution board. They may be located in the same ventilated room, if sealed gas recombining cells are used. This has the effect of minimising the length of cables between the battery, the charger and the distribution board and also simplifies maintenance. Hydrogen releasing batteries, due to the risk of explosion, must be located in a separate room closed by means of a self-closing door.

The floor of the battery room must be acidproof, except when using new lead/acid or Ni/Cd sealed gas recombining cells.

Duplicate DC systems are generally employed for substations rated 220 kV and above, to ensure availability, security and reliability. A typical application of the duplicate systems could be:

	SYSTEM A	SYSTEM B
VOLTAGE LEVEL 1	- PROT GROUP A - CB TRIP COIL A - CB CLOSING - FAULT RECORDER	- PROT GROUP B - CB TRIP COIL B
VOLTAGE LEVEL 2	- COMMUNICATION EQUIPMENT A - ALARMS - CONTROL	- COMMUNICATION EQUIPMENT B - ALARMS - CONTROL

Ideally protective relays should be mounted as close as possible to their associated current and voltage transformer and circuit breakers. This keeps the lengths of interconnecting cables to a minimum, reduces lead burden and voltage drop problems. To achieve this, a number of relay rooms may be built and dispersed across the switchyard or alternatively a single building housing both control and protection equipment may be utilised. Possible battery systems for both housing arrangements are shown in figs. 5.2.1, 5.2.2 and 5.3.

Measures to be taken to limit interferences from DC sources to the secondary equipment

Direct current delivered by a charger is rectified from an LVAC supply. This rectified current contains AC components of different frequencies (50 or 60 Hz and harmonics). These components must be filtered by the rectifier to obtain levels (1 % or less) compatible with the design specifications of secondary equipment. The life expectancy of a battery may be reduced if the rectified AC current component level is significant. This is one of the factors involved in the reduction of the battery capacity.

Batteries must be connected to distribution boards and rectifiers by HF low impedance connections so as to reduce interference from the rectifier and from the wiring itself (see fig. 5.4).

AC Distribution and generator set

In normal operation, the substation AC supply is from auxiliary transformers and/or distribution lines. These sources are subject to interruption.

A high level of security can be obtained by the use of a diesel generator set with automatic starting such that AC supplies can be restored in an acceptable time.

The AC distribution board and the generator set are situated in two different rooms to avoid the risk of a common mode failure. The generator set room must be ventilated. These rooms are located either in the central accommodation or in a cubicle location so as to reduce the length of the power distribution cables to the relay kiosks and the HV equipment.

In the case of very large substations, two energy systems may be used.

Relay rooms

Protective and control equipment are located in a central building and/or in dispersed relay kiosks/rooms (see figs. 5.5 and 5.6).

With GIS and AIS at lower voltages (or where the primary plant is erected indoors) distances between primary and secondary equipment are short and favour a centralised arrangement for the protection and control equipment.

When distances become long, especially with AIS for higher voltages (transmission substations), it can be advantageous to locate a larger part of the control and protection equipment in small relay kiosks/rooms close to the primary equipment and a smaller part in a central control house. The arrangement adopted depends in each case on such factors as:

- the physical size and layout of the HV plant (voltage level, AIS or GIS etc.)
- the requirements for secure operation and maintenance and the risk of a common mode failure in case of fire
- the type of control equipment employed (traditional or computer based) and type of internal connections (cables or optical fibres)
- the cabling from VT and CT to the secondary equipment. Lead burdens must be limited to values which permit the correct functioning of the equipment
- environmental conditions (adverse climatic conditions can make it desirable to group the secondary equipment within a common central building)
- the overall cost of installation
  - building
  - cabling and wiring
  - heating/cooling equipment
  - installation

5.2 Cabling / wiring

The wiring must be designed so as to simplify construction, testing and maintenance and to allow for any subsequent revisions that may arise.

Simplification of construction

It is necessary to determine which part of the wiring is to be prepared in the factory and which part has to be carried out on site.

The prefabrication ensures a better quality but is subjected to a wiring design with a high degree of standardisation. The degree of standardisation to be adopted depends on the volume of construction work. With the benefits of prefabrication, the work on site is restricted to screw connections and wire wrapping which are easy to carry out and to check.

Over the life of a substation, extensions and modifications will take place which will necessitate the modification/reconnection of the secondary equipment. To facilitate these future changes with minimum cabling and retermination work, the use of interfacing cubicles may be recommended (cabling to HV equipment for example).

Testing

Site tests are carried out before putting the equipment into operation. Provision must be made during the design of the wiring to incorporate suitable test switches and connection points. The use of plugs and sockets saves time during commissioning tests.

Preventive maintenance

Functional testing of the secondary equipment, similar to the original commissioning tests can be carried out periodically. These tests involve an outage of the bay for a short time. It may also be possible to carry out maintenance on equipment without taking the bay out of service provided that it can be isolated without risk to the operation of the rest of the system. This requirement can be met by:

- a scheme which permits isolation of protection and control equipment to enable testing of it without affecting the ability of the equipment to work

- the duplication of equipment (protection relay) fitted with plugs for VT and CT simulated signal injection.

Layout of cables

All the external cabling between one building and the external plant and between buildings is laid in pipes, conduits or trenches. Provision must be made for good access and to avoid the propagation of fire from generator set/transformers. Sand can be used to seal tubes. Cable entries into a building must be animal/vermin proof.

5.3 Accommodation of equipment, ventilation

The design of premises must take into account basic requirements. which include:

- pollution
- protection against the environment: both climatic and electrical
- facilities to simplify maintenance and repairs
- flexibility to allow future extensions and modifications
- minimum space requirements
- ease of installation on site
- safety of personnel

Control and protective equipment

Secondary equipment is mounted either in traditional boards of sheet steel construction or in frames intended for 19" rack mounting.

Two basic arrangements are in use:
- accessible front and rear boards
- boards accessible from the front only with a hinged door allowing access to the terminations and wiring on the rear surface, or terminated in plugs that fit into cabling terminations mounted on the wall.

Most control and protective equipment is available for 19" rack mounting. However, some control equipment such as mimic diagrams is not adaptable for 19" rack mounting, but it can be put on the front of a rack.

Electronic equipment dissipates more heat than conventional relays. The heat must be dissipated by natural or forced ventilation. The use of open racks instead of cabinet type enclosures may be a solution to this.

When some cooling is needed (hot environment), it is preferable to provide air conditioning for the equipment room as a whole.

DC power system

Minimum space requirements must be provided for:

- battery charger repairs
- change of battery cells
- filling of battery cells with water

The room which contains the battery must be ventilated and the battery cells arranged for good accessibility.

Generator set

The room must be ventilated by a different system to that of the exhaust gas from the engine.

5.4 Fire detection & extinguishing systems

General precautions for reducing fire risk

Ventilation

A ventilation system must be designed

a) to keep passages free from smoke

b) to limit the development of flashovers (ignition of material at a distance from the original fire source because of smoke pollution) and back draught (risk of an explosion caused by unburnt residues)

Air conditioning

The fire protection system when operated should shut down the central air condition plant to alleviate the spread of fire.

Segregation of cables

Segregation means the installation of cables in different tunnels or physically separated by a fire resistant barrier of an adequate rating. Separation is taken to mean separated by a distance in air.

a) power cables should be segregated from control cables where economically practicable or as a minimum should be separate

b) external communications and important internal communication cables should be separate from other services.

c) main and back-up protection should be independently cabled and routed.

Materials

The use of combustible materials should be eliminated as far as it is practicable and economic.

Building construction

False floors or ceilings should be avoided if possible in areas where the risk of fire is high or the consequences of a fire are serious. However, if a false floor or ceiling has to be used to accommodate multiple cable runs, e.g. control room floors, fire detectors should be installed.

Smoke protection zones

Smoke detection systems should have each alarm covering a relatively small hazard area. Due to possible false alarms, it is recommended that two different types of detectors are used and carefully located so that each will verify the other within their zone before the alarm actually initiates. Entrances to each area should have notices specifying the smoke detection zone.

Fire protection during station construction

There must be strict attention to cleanliness during construction so that no combustible rubbish is allowed to accumulate.

The capability of the fire fighting service should be determined in periodic consultation with the local fire officers so that it is always commensurate with the growth of the fire risk on site in terms of buildings and plant erected.

A temporary site fire alarm system consisting of special telephones should be provided for the site security staff to call the local fire brigade immediately upon receipt of an alarm, without awaiting an assessment of the severity of the fire.

Permanent equipment

The local fire authority should be consulted on the fire precautions to be provided. They should be requested to familiarise themselves with the facilities installed.

Built-in fire protection schemes must be operative on the commissioning date of the associated plant.

Personnel should be trained in the use, testing and maintenance of all protective equipment.

Factors in the design of fire protection systems

The detailed design of the fire protection equipment should comply with good design principles and practice of the utility and should meet the requirements of the local fire authority.
Valves for manual operation should be of a quick acting type and situated in sight of the fire risk but shielded from it for safe access by personnel.

In all fire risk areas, fire detectors must initiate audible and visual local alarms for any staff in the area.

This must be repeated at the local control point and any appropriate remote central control point.

The reliability of automatic detectors, alarms and extinguishers must be high. All automatic systems must be capable of manual initiation.

Full testing of the complete system is likely to be a frequent operational requirement.

Diesel generators

The engine, as a whole, must be covered by a suitable fire protection system arranged to cut off the fuel supply to the engine on detection of fire.

Switchgear

Switchrooms are fire enclosures. Walls, doors and partitions should, therefore, be designed for the grade of fire resistance appropriate to the risk of penetration of fire from outside the switchrooms.

Power transformers

Being oil filled, power transformers need full consideration in the application of fire protection systems. The conventional approach for the larger system transformers comprises:

a) the provision of an oil retaining bund wall around the transformer to contain both a major oil spill in the event of a rupture due to fire/explosion, and the water from the fire protection system. The drainage from the bunded area is by a pit and flame trap and is connected by pipes to a remote oil displacement tank.

b) the filling with sand of the conduits located around power transformers and HV switchgear to retain burning oil

c) a pressurised water mist spray system to deal with any fire or at least to prevent the spread of fire

d) the erection of walls between power transformers to avoid the spread of fire

5.5 Earthing practice

Measures have to be taken in designing and installing secondary equipment to reduce the effects of electromagnetic interference to acceptable values consistent with the EMC capability of the equipment.

Sources of noise are the following:

Low frequency: 50 Hz -> 10 kHz

- HV busbar current and earth faults inside or outside the substation

High frequency: 100 kHz -> 50 MHz (full amplitude) in GIS

100 kHz -> 10 MHz (full amplitude) in AIS

- switching in primary circuits (CVT transmit more interference than VT due to the HF current flow through capacitors; see figure 5.7.1 and 5.7.2).
- atmospheric events (lightning stroke)
- switching in secondary circuits
- electrostatic discharge
- radio transmitters (walkie-talkies)

Measures to be taken on secondary equipment

- The various circuits incorporating devices having different degrees of interference level should be separated.

- The I/O signal circuits and the auxiliary supply should have a galvanic separation provided by isolating relays, optical diodes, transformers and coupling condensers.

- Each secondary equipment must be earthed by means of low impedance connections. The screen of the cables from the switch bay should be earthed at the bottom of the board/cabinet and not adjacent to unshielded circuits to avoid HF radiation from current flow in cable-screens.
- Each part of a board/cabinet should be earthed to improve screen effect.

- Use of filters and transient suppressors.

Measures to be taken in the installation

- Interconnection of the various separate parts of the earthing system (see Fig. 5.8.1).
- Current-flow circuits are arranged so that corresponding outward and return - flow cores are located in the same cable (see Fig. 5.8.2)
- Control Cables displaced from power supply cables and capacitor VT's (see Fig. 5.8.4)
- HV equipment should be located directly adjacent to a conductor of the earth grid.
- Network meshing strengthened in the area where the occurrence of high transient currents are more likely (e.g. lightning arrestors, VT, CVT, CT, spark gaps)

- Screened cables positioned as close as possible in order to benefit from their mutual screening effects.

The best system to reduce HF interference in circuits is the adoption of screened cables earthed at both ends. The practice is to use screened cables for control circuits positioned outside a building. Use only one earth for CT, VT and CVT cables if double earthing is not required for security purposes (see fig. 5.7.2).

The reduction of interference at HF is mainly due to the copper screen effect which is more significant with twisted or rippled copper screens. This effect is of little importance at LF, as the screen has a low capability to reduce 50 - 60 Hz interference.

Therefore, the action of screened cables must be completed by the reduction of the size of the loop of wiring outside cubicles.

- Use a radial configuration for DC auxiliary supply or control cables in preference to a ring configuration so as to avoid the creation of circulating current in the event of an HV earth-fault. (see fig. 5.8.3).

- Use screened telecommunication cables because these circuits offer a small loop to radiation. Their use however, is limited by the resistance of the conductor.

Screening of relay rooms and control rooms

This measure is only necessary when the secondary equipment does not have adequate withstand capability to the anticipated transient fields. Protection equipment of the dedicated type with adequate interface circuits does not require particular precautions even if located near the HV equipment because of the screening effect of the building metallic structure and of the metallic cabinet/housing.

Control equipment is installed in the control building. When it is located distant from HV equipment, the screening effect explained above is sufficient. But in the case of GIS which is in the same building as the control and protection equipment, then the latter should be located in rooms provided with earthing systems in the walls and roof.

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CHAPTER 6

QUALITY ASSURANCE

6.1 Introduction

A crucial factor in the performance of an organisation is the quality of its products or services.

Quality for the manufacturer means that its products or services should conform with client's requirements and expectations.

For the client it means a high level of availability of the equipment supplied and optimal cost.

The quality system of an organisation is influenced by its objectives, by the particular products or services and by the specific practices of the organisation. Thus, quality systems may vary from one organisation to another. The following describes a generalised model based on general principles.

6.2 General

To regulate the diverse quality systems applicable to the differing requirements of varying products and services, the following standards are relevant:

- ISO 9001	Model for quality assurance in design / development, production, installation and services.
- ISO 9002	Model for quality assurance in production and installation.
- ISO 9003	Model for quality assurance in final inspection and test.

The corresponding numbers of the European Standard are EN 29001, EN 29002 and EN 29003.

When speaking about quality, we can consider different levels:

"Quality inspection" which consists of performing measurements and tests during the production of equipment with the purpose of evaluating conformity with the specifications.

"Quality control" which is the result of several inspections, comparing the measured values with the nominal ones and when necessary introducing improvements in the methods of manufacturing.

"Quality assurance" which is not only the test and inspection of manufacture but also the technical and organisational requirements to obtain the desired specifications for the equipment.

Quality assurance programmes arose from the need to implement major capital projects in accordance with specifications and within tight time scales.

Quality assurance was associated with the construction of nuclear power plants, submarines and the space programme.

The quality system is concerned with and interacts with all the activities pertinent to the quality of a product or service. It involves all phases from initial identification of the customers needs, to final satisfaction of requirements and customer expectations. We can represent this by the "quality loop" (fig. 6.1).

All the activities related to the delivery of a product or service can be conceptualised as a chain that is only as strong as its weakest link. The final quality is dependant on every link in the chain.

The quality assurance is based on the following essential basic ideas:

- The job of the manufacturer is to demonstrate the correct quality of the product The task of the client is to evaluate the quality assurance programme of the manufacturer.

- The goal is to create and convey confidence about the achievement of a certain level of quality.

The functions are to ensure correct performance of the equipment and when necessary to introduce improvements in manufacturing methods.

The methods are:

- Planning and scheduling
- Organisation
- Control and inspection
- Identification of nonconformities
- Improvement process
- Audits

The final expected result is to eliminate shortcomings in the quality of products and to avoid the resulting cost implications.

The advantages of implementing an effective quality assurance system from a manufacturer's perspective can be summarised as:

For the client:
- Lower cost for the evaluation of the quality
- No major additional costs on the acquired product
- Improvements in scheduling
- Increased reliability

For the manufacturer:
- Optimal cost for a product or service involving manufacturing, installation and operation
- Increased reliability
- Improvement of security aspects
- Decrease in the total cycle time
- Competitive prices
- Fewer after-sales problems

6.3 Quality Costs

The costs resulting from the activities involving the quality assurance system are classified as follows:

Prevention costs (related to the activities that contribute to preventing nonconformities)
- Preparation of procedures
- Planning of control methods
- Planning of inspection schedules
- Quality staff management
- Staff training

Inspection costs (related to the activities of quality verification)
- Incoming inspection
- In-process inspection
- Final inspection
- Calibration of measuring and test equipment

Non conformance costs (related to the nonconformities)
- Internal failure: Included are the costs of the scrap and of the repair of non conforming products.
- External failure: Included are the costs of the failures during the warranty period.

6.4 Quality Assurance - Manufacturer's Perspective

6.4.1 Quality policy

The manufacturer must define a quality policy. He is responsible for planning and developing a programme to control the production process as well as the inspection and test verifications and corrective actions when necessary. This policy must be stated in written form and must be circulated to all personnel.

6.4.2 Quality system documents

- Quality assurance manual
- Quality assurance procedures
- Inspection and test plans
- Quality records

6.4.3 Organisational authority

- Organisation chart of the company
- Organisation chart of each functional department in the life-cycle of the product
- Definition of the general and specific responsibilities for all personnel
- Independent inspection must be performed by personnel who shall be other than those performing or directly supervising the work being accepted.

6.4.4 System functions

The manufacturer must have written documents that cover the following items:

- **Contract review**
  The manufacturer must review the contract before acceptance in order to resolve differences from the tender.

- **Design assurance**
  A design check is made to ensure that it reflects user's specifications, relevant standards and that everything is correctly translated into drawings, specifications and work instructions.

- **Document control**
  The responsibility and authority for preparing, reviewing, approving and amending documents as well as for removing them when they are obsolete, must be defined.
- **Control of measuring and testing equipment**
  Measuring and testing equipment must have the necessary accuracy, and calibration records must exist to ensure that valid measurements are made. Calibration schedules and procedures are also required.

- **Purchase control**
  The manufacturer must select his suppliers based on their ability to meet quality requirements. He must have a list of qualified suppliers and must assess their quality system.

- **Incoming inspection**

  The manufacturer must inspect incoming products in accordance with inspection procedures, identify and hold non conforming products, initiate corrective action with suppliers when necessary.

- **In-process inspection**

  The manufacturer must inspect products in accordance with the requirements of the quality system, monitor special process methods and identify and hold non conforming products.

- **Final inspection**

  The manufacturer must inspect the final products in accordance with inspection procedures, identify and hold non conforming products and make inspection and test records available to the customer before acceptance testing. He has to submit for acceptance only those products that meet specified requirements.

- **Special processes**

  A special production process is one where conformance is assured by using evidence generated during the process. The manufacturer must assure that these processes are accomplished under controlled conditions by qualified personnel.

- **Packaging, storing and shipping**

  The manufacturer inspects the final cleaning, packaging and marking of the equipment and verifies the shipping operations to ensure that specified requirements are met.

- **Quality records**

  The manufacturer must maintain quality records to prove that the quality assurance programme meets the requirements of the relevant standards and that the product and documentation meet specified requirements.

- **Control of nonconformances**

  The manufacturer is responsible for the issue of all nonconformances including those of sub suppliers.

- **Corrective actions**

  The manufacturer reviews and analyses the cause of detected nonconformances and develops corrective actions to prevent recurrence.

6.5 Quality Assurance - Utility's Perspective

6.5.1 Quality policy

This is to design and manage the construction of substations while taking account of the following:

- Scheduled dates of the plan for the development of network
- Requirements and needs of departments responsible for the operation and maintenance of substations
- Requirements related to service characteristics, safety, reliability and expansion
- Highest quality at the lowest cost

6.5.2 Organisational authority

Considering the multiple functions of each department and their interconnections, it is necessary to establish an organisational chart and to define the activities, functions and responsibilities of each organisational unit.

6.5.3 System functions

- **Design assurance**
  In the scope of the design assurance, the written procedures of the appropriate project departments must assure that:
  - The development of the project is in accordance with a well defined sequence
  - The requirements of the customer are studied in order to be complied with
  - All standards and regulations are complied with
  - New projects are discussed with the appropriate departments

- **Document control**
  All documents (drawings, specifications etc.) are registered and issued to all interested departments. The reviewing of approved drawings and specifications is handled in the same manner as for the originals. Obsolete documents and drawings are removed or stamped "obsolete".

- **Purchasing requirements**
  All suppliers are selected for their ability to meet quality requirements. The suppliers are informed of all nonconformities found in their supplied items or rendered services. The results of the inspections and tests are periodically evaluated and the results are used in the selection of suppliers.

- **Inspections and tests**
  The inspections and tests are made by experts in accordance with procedures or approval tests. The results of inspections and tests are registered. The equipments with nonconformities are well identified and segregated. All nonconformities are registered and are communicated to the appropriate departments to avoid their repetition. All equipment is submitted to a final acceptance test before starting its industrial service.

- **Measuring and testing equipment**
  All the measuring and testing equipment is periodically calibrated. Calibration of instruments is made according to written procedures. Records of the periodic calibrations are kept. Equipment being well identified is a condition of the calibration procedure.

- **Corrective actions**
  The nonconformities are studied, presented in a written document in order to eliminate their causes and to prevent recurrence. The responsible departments provide the necessary corrective actions.

- **Handling and storing**
  When necessary, the equipment is provided with instructions concerning handling and storing. The equipment is well protected to prevent damage when stored or handled.

- **Maintenance**
  The equipment is provided with instructions concerning its maintenance. These instructions must cover the following points:
  - Actions required
  - Equipment necessary to execute the actions
  - Maintenance interval
  - Relevant documentation

- **Quality records**
  Every important piece of data relating to the quality is registered on adequate forms. Copies are distributed to the appropriate departments. The following quality records are filed for periods of five to twenty years:
  - Nonconformity records
  - Test records
  - Test certificates

- **Internal audits of quality**
  There are written procedures concerning quality assurance for all activities that influence the final quality of a substation. The quality control programme is periodically audited in order to determine if it is complete, up to date and being duly applied.

- **Training**
  The staff that controls the quality has adequate training and is familiar with the equipment and plant necessary for its examination.

6.6 Laboratory, Factory and on-Site Tests

6.6.1 Laboratory Tests (Type Test)

The purpose of these tests is to qualify new equipment for use in the substation environment. Type tests are defined in order to establish the adequacy of the design of the equipment. These tests are concerned with:

- Electrical Insulation

- Electrical Characteristics

- Mechanical Endurance

- Climatic Endurance

- Electrical Interference (Lightning)

6.6.2 Factory Tests (Routine Tests)

The purpose of these tests is to establish that the equipment has been manufactured in accordance with the design specification. They cover:

- Verification that the equipment has been built with specified materials and components.(Visual Inspection)
  These tests will be concerned with:

  - Quality of materials and components
  - Dimensions
  - Protection grade
  - Painting and final appearance
  - Support structures
  - Arrangement of the equipment
  - Accessibility of the components
  - Wiring and layout of cables
  - Ground connections
  - Labelling
- To verify the functional characteristics of the equipment (functional inspection).
  These tests must be made under conditions as near to the real situation as possible. So, not only measuring equipment but also simulation equipment (sometimes based on computer technology) are required. The tests include:

  - Measuring of power consumption
  - Measuring of line voltage tolerance
  - Test of short circuit protections

- Test of the equipment's reaction when inputs are applied
- Test of man-machine interface
- Test of the system's reaction to operator's mistakes
- Test of the maintenance and extension dialogues

- Electrical tests, no matter how comprehensive, cannot provide assurance of a quality product. Certain conditions can reveal themselves in the early stages of the in-service life cycle of the product which can lead to mal-functioning and failure. Test procedures can be devised which simulate in an accelerated manner the influence of such factors as:

  - Temperature
  - Voltage
  - Vibration
  - Humidity

  These are the so called "burn-in tests", for which temperature and humidity cycles must be defined.

6.6.3 On-site testing

The design of the secondary system allows the equipment to be completely tested at the factory where the functional tests are however only simulated.

Then, the on-site tests include:
- visual inspection
- functional tests

The purpose of the visual inspection is to verify that no damage occurred during the transport and that the equipment is correctly installed.

The purpose of the functional tests is to verify the correct performance of the equipment when connected to the high voltage apparatus.

The functional tests include:

A: The checking of polarities

- To assure that there are no reversed polarities
- To assure that each function in the HV switchgear and in the protection relays are supplied with the correct polarity
- To assure that the voltage drops are within the allowable limits

B: The checking of the following circuits:

- Current circuits (to ensure continuity)
- Voltage circuits (to eliminate short-circuit)
- Position-indication signals for:
  - circuit-breakers
  - isolators
  - transformers tap-positions
- Alarms for:
  - circuit-breakers
  - isolators
  - transformers
- Control circuits for:
  - circuit-breakers
  - isolators
  - tap changers
  - cooling fans
  - oil circulation pumps
- Interlocking circuits for HV switchgear
- Protection circuits:
  - tripping circuits
  - reclosing circuits
  - alarm circuits
- Drive mechanism circuits for:
  - circuit-breakers
  - isolators
- Heating elements for outdoor cubicles

C: Checking of the following functions

- Individual controls of HV switchgear
- Sequential controls of HV switchgear
- Protection relays settings

6.7 Test of software

6.7.1 General

Any quality assurance methods used must take account of certain characteristics which are inherent features of software:
- Software has no physical form.
  There is no physical law that allows us to test some components and assume a linear behaviour.
- There is no degradation in the performance of software with use. An error is a singular event.

6.7.2 Software failure modes

Software errors can arise from:

- The specification
  - The software specification must cover all the input conditions and output requirements.

  - There is no place for ambiguities, inconsistencies or incomplete statements.
  - There is no safety margin.

- The design
  - In the software system design, errors can occur from incorrect interpretation of the specification or from incorrect logic.
  - It is at the design stage that the response of the program to error conditions is defined. Care must be taken to ensure that a highly "robust" program is produced .

- The coding process
  Typical errors of code generation are:
  - Typographical errors
  - Incorrect numerical values
  - Omission of symbols
  - Inclusion of expressions which can become indeterminate

6.7.3 Programming style

Structure
Structured programs require the use of control structures which have a single entry and a single exit. Structured programming leads to fewer errors, and results in clearer and more easily maintained software which is much easier to understand and inspect.

Modularity
Modular programming consists of breaking down the overall program into separate smaller separate programs or modules, each one of which can be separately specified, written and tested. Each module is easier to understand, thus reducing the probability of errors and assisting in the task of checking.

Remarks
The use of remark statements to explain the program assists in its testing.

Defensive programming
Defensive programming consists of introducing routines to check for errors and allowing the program to indicate the source of the error.

6.7.4 Software checking

In general, a new program must undergo a long development and debugging phase before all errors are eliminated.

To verify compliance with the specification the program must be checked against each requirement of the specification. Checking is made much easier if the program is structured into well specified modules.

Some function of the program can only be checked in a "line-by-line check" of the program listing. A test schedule which stipulates the tests required to demonstrate compliance with specification must be prepared.

6.8 Test of printed circuit boards

In electronic equipment, the printed circuit boards are the type of prevailing assembly, with a set of associated technologies, which influence in a very strong way the quality and the reliability of the system in which they are inserted.

6.8.1 Principles of good printed circuit board design

These are:

- simplicity
- accessibility
- ease of fault-finding
- ease of replacement
- impossibility of incorrect assembly
- minimal adjusting
- ease of production

The printed circuit boards must be manufactured and tested individually before being integrated into the whole equipment.

6.8.2 Tests of printed circuit boards before assembly

- **Visual inspection**
  In this test we must verify:
  - Type and quantity of holes
  - Uniformity of metallic deposits
  - Short circuits and open circuits
  - Dimensions
  - Wrapping
  - Correct fit of solder resist and silk screen

- **Test of physical characteristics**
  - Thickness measurement
  - Flexibility tests
  - Measurement of surface resistance
  - Measurement of insulation resistance

  These tests are only made on a sample batch of printed circuit boards, for approval of total production run.

- **Test of components**
  - Environmental tests
  - Mechanical tests
  - Electrical tests
  - Burn-in tests

6.8.3 Tests of printed circuit boards after assembly

- **Solder inspection**
  The solder points must have:
  - metallic brightness
  - flat surface of board
  - convex surface of solder
  - small contact angle

- **Tests of assembly**
  The following points must be considered:
  - missing components
  - incorrect components
  - incorrectly assembled components.
  - mislocated components
  - unidentified components
  - damaged components

- **Functional tests**
  With these tests we can detect:
  - open circuits
  - short circuits
  - incorrect assembly of components
  - missing components
  - incorrect components
  - components with parameters out of limits
  - incorrect performance of the circuits

The purpose of the functional tests is to verify the correct performance of the equipment for the high voltage apparatus.

6.9 Cost benefit

The implementation of a quality system in accordance with the relevant national and international standards will almost certainly involve additional costs. In the medium and long term, however, these costs should be compensated by reduced nonconformance costs and by the benefits which will accrue to the company by its improved image in the market place. The client will benefit by improved system reliability and by an enhanced quality of service.

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(3) ISO 9000
(4) ISO 9001
(5) ISO 9002
(6) ISO 9003
(7) ISO 9004
(8) CSA Z299

CHAPTER 7

MAINTENANCE

7.1 General

Maintenance can be summarised as, precautions to be taken in order to keep an item of equipment or an installation capable of functioning as specified.

Preventive maintenance means that the maintenance of the equipment will be carried out in such a way that acute failures can be prevented as far as possible.

The efforts to obtain a high availability by minimising failure rates start at the specification stage and continue by including the design and production stages in a quality assurance program that continues through to commissioning.

During commissioning a complete test report will be prepared with all relevant measured values, relay parameter settings etc. This report will be part of a comprehensive "as built"-documentation for use by the operation and maintenance staff. In addition, a maintenance programme should be prepared well in advance of commissioning.

The performance of the secondary equipment is influenced by many factors. Some are caused by inherent defects, e.g. stochastic faults in components due to manufacture, ageing factors such as wear and tear, deterioration of insulation etc.

Replacement of equipment for secondary systems today generally takes place before the end of the real life time because:

1. the components become obsolete with respect to their technical function

and/or

2. the components have gone out of production and it is very difficult to get spare parts.

For digital equipment, the first item will be less important.

Present day maintenance mainly concentrates on diagnostic tests including the periodic testing of protection equipment with respect to preventive maintenance and modifications, supported by self-checking facilities.

The depth or thoroughness of maintenance will depend upon many factors and, accordingly, it is difficult to give general guidelines. Issues such as whether the whole scheme should be checked fully at each maintenance period should be considered by the utility. For instance, there is a great deal of difference in time (and cost) between testing a distance relay for correct operation at characteristic angle and testing a whole distance scheme including full polar diagrams, end to end test to check the signalling, doing trip checks and checking all the auxiliary relays included in the scheme.

In future, more and more self-checking facilities will detect malfunctions or defects without fixed maintenance intervals. Therefore, for many components of secondary systems, the regular maintenance interval will be extended to several years. In future the occurrence of defects in secondary systems will be detected by on-line diagnostic facilities. The faulty components will then be repaired or replaced as needed or the functions automatically switched over to redundant components.

7.2 Cause and effects of deterioration and ageing factors

Electrical
- slow destruction insulation ageing, contact pressure and wear)
- direct effects (insulation breakdown or flashover caused by overvoltages)

Mechanical
- vibration (bearing play of relays and meters)
- rotation (leaking and sealing)
- pollution (dust, humidity, rust, mice, spiders)
- attrition on contacts

Chemical
- life cycle of special components (battery Pb or NiCd/average life of electrolytic capacitor)
- environmental influence

Thermal
- short term overload
- long term overload
- influence of environmental temperature

Technical
- not according to actual standards
- inefficient
- inaccurate
- slow reaction time (relays)
- polluting
- wrong setting
- operating errors

Economical - uneconomic service conditions (spare parts, time, age of components)

7.3 Maintenance of secondary equipment

Maintenance can be divided into the following items:

- Inspection
- Periodic checks
- Self-checking with diagnostics
- Overhauling due to maintenance programme
- Repairs of acute faults
- Fault reporting and registration

Some of these items will be considered in detail in the following Sections.

An alternative approach to maintenance of protection relays is currently under trial using diagnostic testing. The intention is to do maintenance on a sample basis of selected terminal stations and zone substations.

The complete diagnostic testing of all equipment in these stations should give a broad cross section of secondary equipment installed on the system. The diagnostic results should then give a good indication of the integrity of this equipment and similar equipment installed elsewhere on the system. In the event of a particular type of equipment demonstrating a high failure rate, a more comprehensive diagnostic testing programme would then be put into place to test all similar equipment wherever installed.

7.3.1 Periodic checks

Periodic tests shall be carried out for the preventive checking of protective, control and annunciation equipment in order to verify safety of function after a defined operating time. Periodic testing should be done continually in a clearly defined sequence.

Manual test
- lamp test
- go-no-go test by switch (qualitative)

Functional check of scheme (quantitative)
- with meters, test units according to test description and test sheets

Automatic testing
- automatic testing equipment (mostly additional equipment) is initiated by a clock or manually (testing once a day or week); up to 60 % can be checked by these systems.
- self-checking systems detect inherent faults and initiate alarm signals. After repair of the respective system component, safety of function is to be verified by a periodic test. Periodic tests can be reduced (3 - 6 years) if the self-checking feature incorporates both initiation and tripping circuits for the protective devices as well.

Frequency of periodic maintenance depends on the component in question and will be stated in the maintenance programme.

7.3.2 Self-checking facilities

If wear and tear can take place on very important equipment, such as protective schemes in transformer and busbar protection, computer or control systems, self-checking facilities should be installed.

On new systems with microcomputers and other new technologies, maintenance often seems to be very complex but it does not have to be. Modern systems are programmed with continuous checks to diagnose their own state of health. Error codes indicate clearly what is going wrong. These checks have no influence on the actual operating time.

Continuous supervision
- in solid-state protection, voltage levels are continuously checked.
- simultaneous presence of signals (Io, Uo) or summation signals are checked

Extensive self-monitoring
- check of system faults and incorrect setting

7.3.3 Repairs of acute faults

The consumers of electrical energy expect a high reliability of supply. Repair of equipment has to be carried out according to economical and technical considerations while fulfilling all safety rules for staff.

If an acute fault occurs the utility's own staff may be able to cope with the necessary trouble-shooting and repair work. In other cases, the fault may be of such a character that specialists from the factory will be needed. It is therefore recommended to set up an on-call maintenance plan together with the manufacturer so that the proper measures can be taken for urgent trouble shooting. Faulty parts will be repaired on the spot as far as possible by taking the most suitable measures, while those which cannot be repaired on the spot will be carried back to the factory for shop repair after being replaced with spares.

7.3.4 Fault reporting and documentation

It is important that every fault in the secondary system is described in a fault report which will be part of the fault statistics.

By modifications and changes it is also important that he "as-built"-documentation is subsequently corrected so that the documentation is always up to date. This requires a strong discipline within the utility.

All maintenance tests have to be recorded in a similar manner to the original commissioning tests. The documentation and evaluation of maintenance results are recommended to be handled by computer systems to allow for a better analysis and to optimise future planning.

7.3.5 Maintenance programmes

Every utility has some sort of maintenance practice. A maintenance programme is a list of the various maintenance activities with a description of the works that have to be done and a time when they have to be done.

The programme can either be a simple manual system or a more advanced computerbased system. The latter has obtained a wider acceptance in latter years especially in large utilities.

7.4 Conventional equipment

A tabular schedule shows the main components in a conventional installation and typical periodic checks for preventive maintenance in unmanned substations.

Equipment	Visual Inspection	Periodic check	Comments
Rectifiers	monthly	1 - 3 years	
DC-distribution	monthly	1 - 3 years	
Inverters, UPS	monthly	1 - 3 years	
Power supply units		1 - 3 years	
Fire detection		1 year	
Air-conditioning		1 year	
Control equipment:			
- Mimic diagrams	weekly		
- Instruments, indicating	weekly	3 - 5 years	
- Instruments, recording	weekly	5 - 10 years	
- Meters		5 - 10 years	
- Protection relays	flags weekly	3 - 5 years	Mech. parts see 7.2
- Fault recorders *	monthly	2 - 3 years	*Ink + paper to be checked monthly
- Event recorders *	monthly	2 - 3 years	
- Remote terminal units		2 - 3 years	
- Signalling devices (alarms)	weekly	2 - 3 years	
- Interlocking devices		2 - 3 years	
- Communication units		2 - 3 years	

7.4.1 Battery and battery charger

The DC supply , without the battery connected, has to be within limits for ripple content as required by the electronic equipment.

DC/DC converters can produce dangerous overvoltages if a battery charger is supplying an AC voltage superimposed on the DC level.

The battery chargers are practically maintenance free, but they have to be checked during weekly inspection for abnormal noise and smell. Batteries have to be kept clean and the level of electrolyte has to be checked once a month. The change of the electrolyte depends on prevailing operating conditions. A change might be useful after a period of approximately 5 years (NiCd).

7.5 Microcomputer-based equipment

This equipment performs the control system functions on a digital basis by means of microcomputers. The information exchange between the various units is realised by serial digital communication. Equipment based on microcomputers makes it feasible to integrate different functions that were previously performed by separate functional units in conventional equipment. It consists functionally of data acquisition, data transmission, data storage and data processing. It has both a hardware and a software (or firmware) to maintain.

7.5.1 Hardware maintenance

The equipment is mainly composed of the following units:

- visual display units
- keyboards
- printers and plotters
- input/output units
- processing units
- storage units
- communication units

Although more complicated than conventional equipment, computerbased equipment has built-in features for self-checking routines for detecting inherent faults combined with a precise indication of the defective component or sub-unit. This will reduce maintenance of the hardware to replacing defective sub-units. Preventive maintenance will be reduced, except for the mechanical parts in plotters and printers and other parts exposed to wear and tear.
Computer systems need periodic inspection and attention. It is difficult to be specific about the nature and content of the work and the time required for its execution as it depends on the system configuration and operational condition. The following may be recommended as guidelines.

Inspection	Interval	Description
Yearly regular	Once a year	minute inspection of the whole computer system
3-monthly regular	once/three months	inspection focusing on the peripheral devices
Weekly inspection	once a week	inspection under operating condition
Overhaul	Occasionally	Dismantle the system, inspect the wear condition of mechanical parts, replace with new ones if necessary and perform cleaning, lubrication, reassembly and readjustment.

Yearly regular inspection
The functional tests of the system itself, design life check, the replacement of worn out parts, operational tests for error detection mechanism, etc. and operation margin tests will be executed. In performing these tests the service history and the error data are taken into account.

3-monthly regular inspection
Lubrication, cleaning, inspection and investigation and the replacement of worn out parts will be executed periodically, mainly for the mechanically operating parts of the peripheral devices to lengthen the remaining serviceable life of those devices and to prevent problems occurring. The 3 month regular inspection will be included in the one -year regular inspection.

Weekly inspection
The user is recommended to execute weekly inspections on the environmental management of the computer installation workplace, cleanliness, servicing, operating condition check and data arrangement.

Overhaul
For 1/0 devices with moving parts stable operation over a long period can only be achieved through a programme of regular inspections combined with a regular regime of lubrication, cleaning and adjustment.

The long term planning and control of overhauls would be more effective to improve the operational efficiency and to maintain the system reliability. Taking this into account and also the intention to prevent the occurrence of problems, a plan for the overhaul should be worked out in co-operation with the manufacturer. The execution can be agreed to take place at the working location or perhaps by carrying the system or parts of the system back to the factory for overhaul.

The preventive maintenance activities mentioned above are illustrated in Fig (7.1), and shown in comparison with failure rate curve (bathtub curve). Theoretically, the bathtub curve is valid for all types of equipment. Here it is shown for electronic parts.

As indicated above, overhauling is a scheme to lengthen the service life of the system which is undertaken at fixed periods. The main work is the replacement and readjustment of life parts which may then have no safety margin to maintain their reliability.

Those parts that will deteriorate in performance and reliability throughout the course of service life and which finally become inadequate are generally called "life-parts".

The categories of life parts and non-life parts are as follows:

	Life-parts	Non-life parts
Electrical components	- CRT - Fuse - Aluminium electrolytic capacitor	- IC, LSI and other ligic forming elements - Resistor, transistor, capacitor (exept aluminium electrolytic capacitor)
Mechanical	- Bearing - Accessories for rotating parts - Packing - Filter, belt - Cooling fan	- Static components

The lives of the parts are determined by the life tests (accelerated life test, forced deterioration test, etc.) which are conducted as part of the reliability tests at the production stage. (Also by estimating the period of time during which the prescribed performance will be maintained).

For an overhaul of the system, the execution interval is established on the basis of the life determined as above.

Particularly, with mechanical life parts, regular inspections have difficulties in the determination of fatigue, wear and ageing, compared with electrical parts. So, they seem to cause unplanned problems due to fatigue limits.

7.5.2 Software maintenance

The software can be divided into areas covering

- system functions
- application functions

System functions
are defined and tested in the system design and will not undergo major alterations during the system life time. Modifications and trouble shooting in this part of the software will normally require the assistance of the manufacturer.

Application functions
will normally be implemented initially by the manufacturer. However, the utility engineers (protection, control, metering engineers) must be familiar with the application software covering their fields.

After initial implementation and testing of the application software it is very unlikely that faults will occur. Application software will be altered and modified, however, due to the operational requirements of the primary system. These might be the changing of relay parameter settings, change of automatic sequences, addition of new bays etc. These tasks should normally be handled by the utility staff.

In addition, there may be modifications and/or adaptations caused by

- reform of statutory regulations, by new standards and/or by changes of organisation

- further development of electronic data processing (EDP) methods, e.g. supply of a new software version with more user oriented operating methods (such as macro commands, menu controlled operation, window techniques etc.). Such modifications may have influence on the total concept of electronic data processing. Therefore, it has to be determined that in such cases the management must be informed.

- where the modifications of the software did not have their origin with the users, the timing of the modification and the necessary training has to be agreed with the users.

7.6 Spare parts

For conventional equipment, consisting of separate functional units, both the utilities and the manufacturers normally have a good idea of what is needed for spare parts, and these are normally provided from a central stock. This guarantees short delivery and quick repair as conventional techniques have no serious problems with interfaces. The amount of spare parts in store at the utility will depend on:

- how critical the part is

- delivery time from the manufacturer
- capability of repair within the utility

For computerbased equipment, where several functions are integrated in the same units, it is very important to have a sufficient amount of spare parts in order to minimise down-time. On the other hand, this equipment is composed of many identical sub-units that will reduce the necessary amount of spare parts. Another aspect of spare parts for computerbased equipment is the very fast rate of change of products from the manufacturers. From the date of obsolescence of a product, ten year's field support has to be achieved by the manufacturer by delivery of the same product or a compatible product with the same function or a replacement component based upon updated technology while covering the required functions.

An alternative could be to negotiate a contract with the manufacturer where he guarantees:

1. delivery of spare parts within the lifetime of the system and a maximum repair time
2. the failure rate of the system and of important parts of it.

7.7 Training of staff

The training of staff for maintenance of secondary equipment varies from utility to utility.

Large utilities which may also design, build, install and maintain the equipment themselves can afford to have specialists in each discipline.

On the other hand, small utilities where each engineer has to undertake a variety of tasks will normally only be able to maintain their equipment up to a certain level and beyond that will have to rely on the services of the manufacturer.

Accordingly, the training of staff will vary depending on the level of maintenance which utilities find economically justifiable to provide from their own resources.

For conventional equipment, utility engineers traditionally are grouped by professional specialisation:

- protection / relay engineers
- control engineers
- instruments / metering engineers
- primary equipment engineers
  etc.

The distinctions between these fields of activity are well defined for conventional equipment where each function is generally handled by one or more dedicated units.

The training of staff is a continuous process of learning and of acquiring knowledge on new equipment being installed within the utility. Normally this training will be acquired by attending specialist courses arranged by the manufacturer and this should be part of the terms when new equipment is purchased.

Basically, these distinctions between the professions will also be upheld when computerbased equipment is introduced either as single items or as whole systems because the professions reflect the various control systems functions to be performed. These functions will be the same but it will now be the software or the firmware that dictates how they will be performed.

The fundamental difference is that in order to change, modify or extend functions, the utility engineer has to communicate with the equipment with the assistance of visual display units and keyboards. The manufacturers make great efforts to make this man-machine-communication user-friendly, knowing well that the acceptance of the new technology by the customers will depend upon this.

The transition to computerbased equipment will be a gradual process and during the transition period utility engineers must master both systems.

This might be achieved by selecting persons with solid basic experience who will be trained to get an all round knowledge of the systems hardware and software and become what we can call systems engineers. As remote control systems, for a long time, have used the same technology, this might be a recruiting field for systems engineers.

In addition, the established professions such as relay, control engineers etc. have to be "upgraded" so that they master the communication with the equipment and are able to express and implement their respective functions through software instead of hardware components.

For the time being, the best way of acquiring training is to attend specialist courses provided by manufacturers.

It is important that the staff obtains practice in handling the equipment. If maintenance work is rarely required because of the small number of substations, it may be difficult to maintain the necessary skill levels of the maintenance staff. An alternative may be to hand over the maintenance activity to the supplier or to another utility.

The extent to which utilities are willing to go in the maintenance, modification or even the design and manufacture of new systems is a question of company policy. This will be influenced also by tradition, and by the plans of the utility for the introduction of computerised equipment into their networks at some point in the future.

Figures

and

List of Abbreviations

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CIGRE 23.05

Design & Maintenance Practice For Substation Secondary Systems

AIS - air insulated substation
B - flux density
BBP - busbar protection
BFP - breaker failure protection
BP - buchholz protection
BT - battery
C - charger
CAD - computer aided design
CB - circuit breaker
CT - current transformer
CVT - capacitor voltage transformer
D - distribution board
DACU - data aquisition and control unit
DIF.P - differential protection
DP - distance protection
EDP - electronic data processing
EFP - earth fault protection
EHV - extra high voltage, i.e. transmission (170-800kV)
EMC - electromagnetic compatibility
GIS - gas insulated substation
HF - high frequency
HV - high voltage, i.e. subtransmission (52-145kV)
IP - impedance protection
LV - low voltage (0-0.4kV)
MMI - man-machine interface
MTBF - mean time between failure
MTTR - mean time to repair
MV - medium voltage, i.e. distribution (3,6-36kV)
OCP - overcurrent protection
PI - main protection I
PII - main protection II
PLC - power line carrier
RCC - remote control centre
RTU - remote terminal unit
SCADA - supervisory control and data aquisition (system)
TEV - transient earth voltage
TP - thermal protection
VDU - visual display unit
VT - voltage transformer

Abbreviations

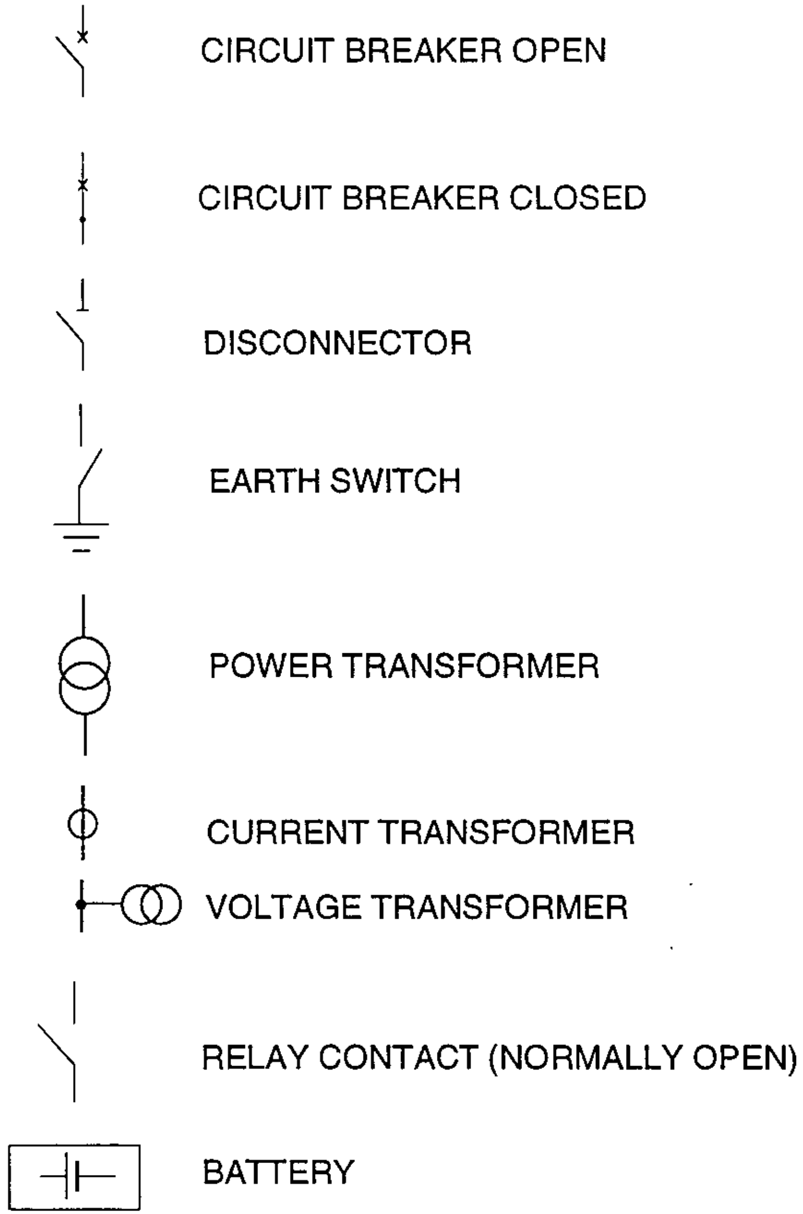

Fig. 1.0.1 Symbols

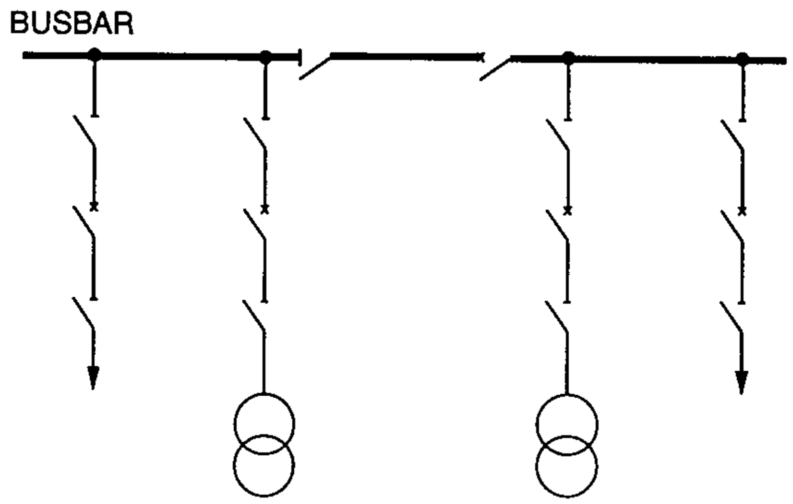

Fig. 1.1 Single Bus

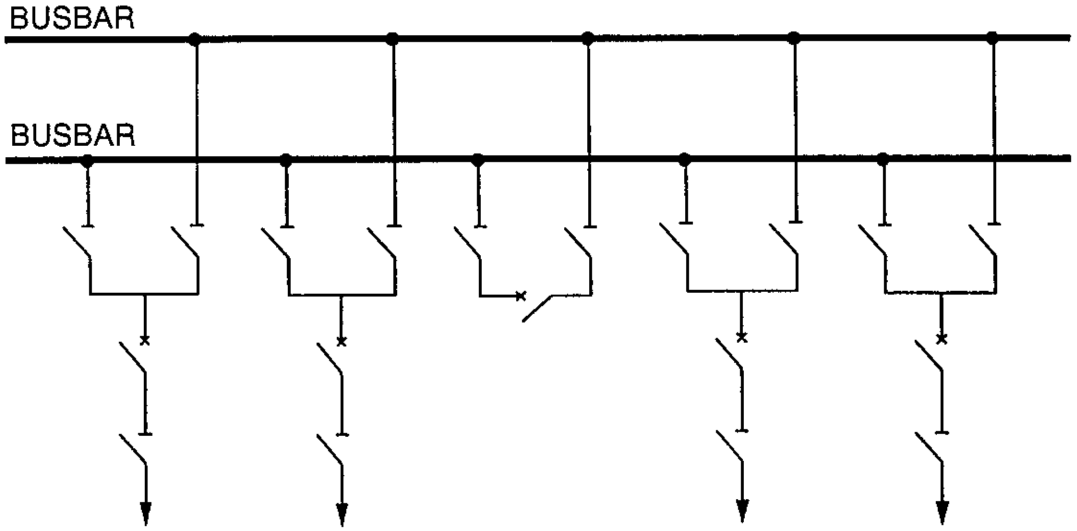

Fig. 1.2 Double Bus

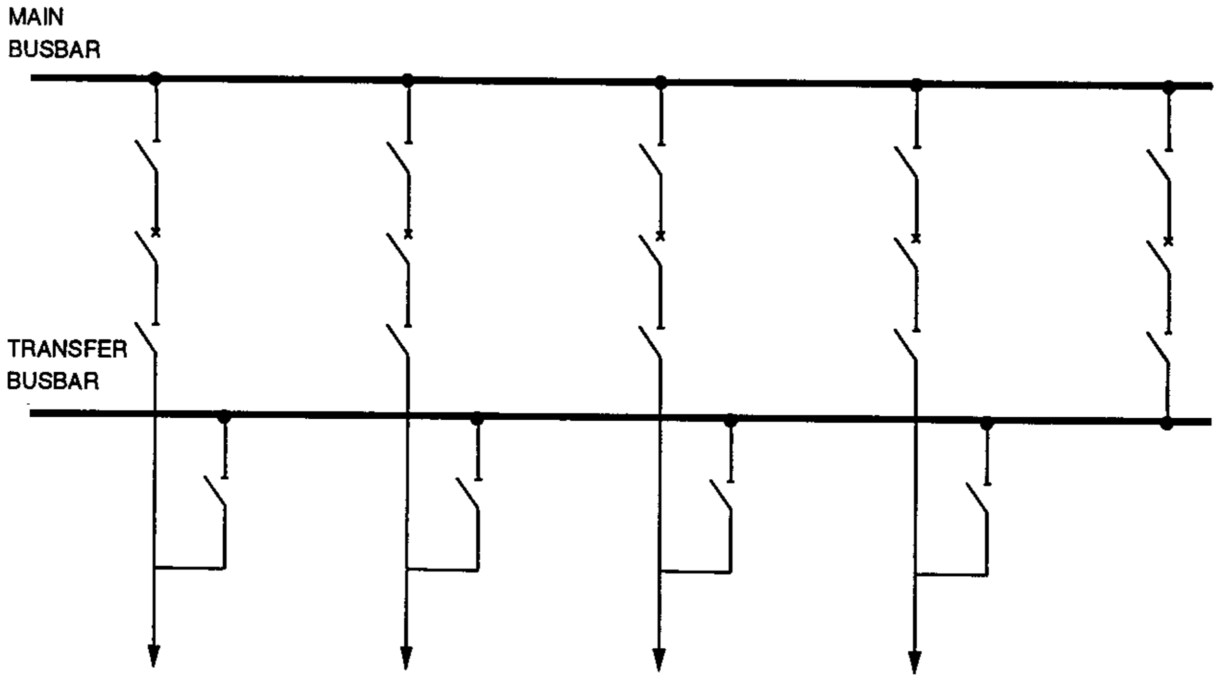

Fig. 1.3 Transfer Bus

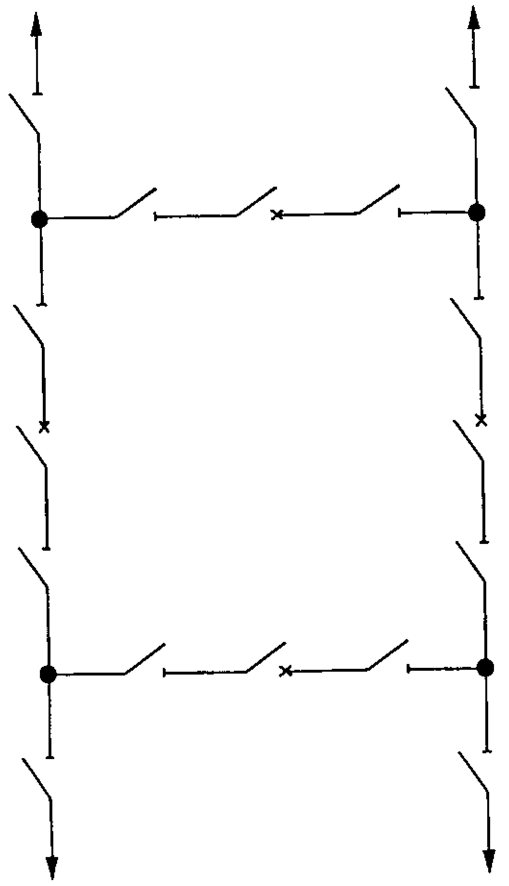

Fig. 1.4 Ring Bus

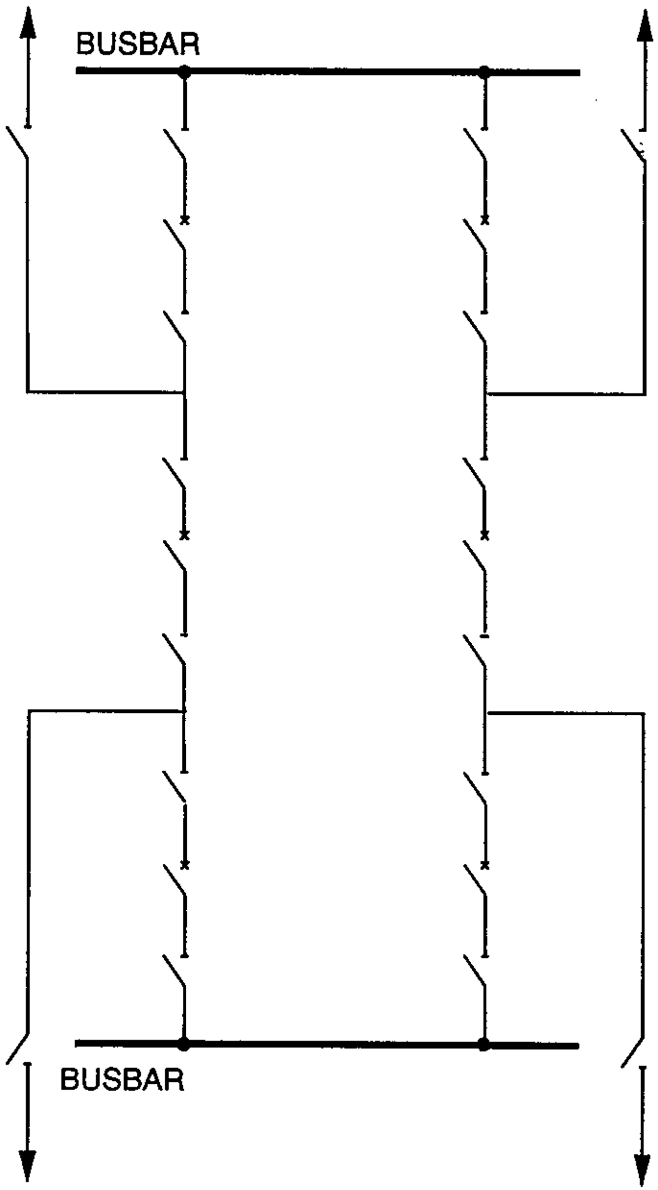

Fig. 1.5 One and a Half Breaker

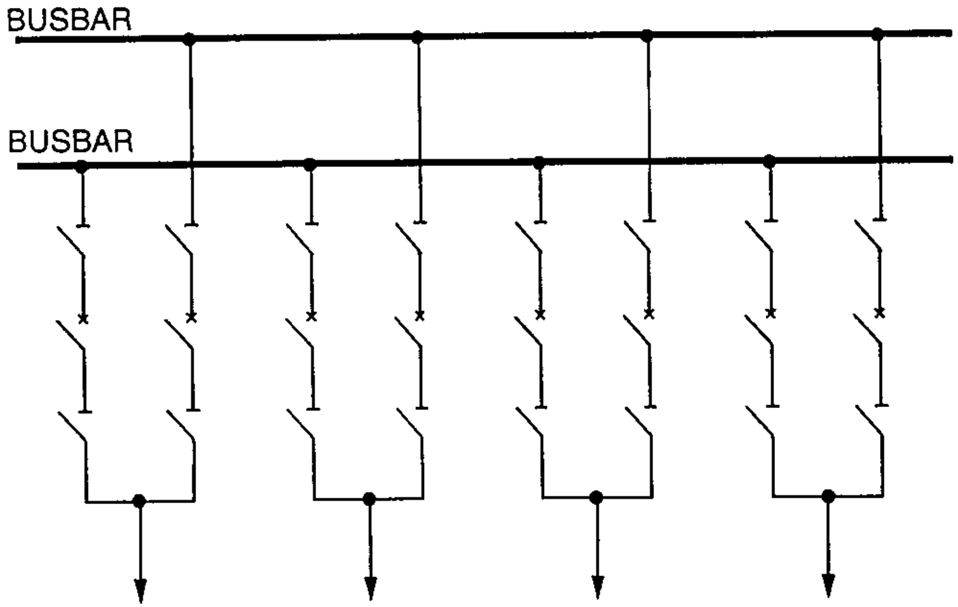

Fig. 1.6 Two Breakers

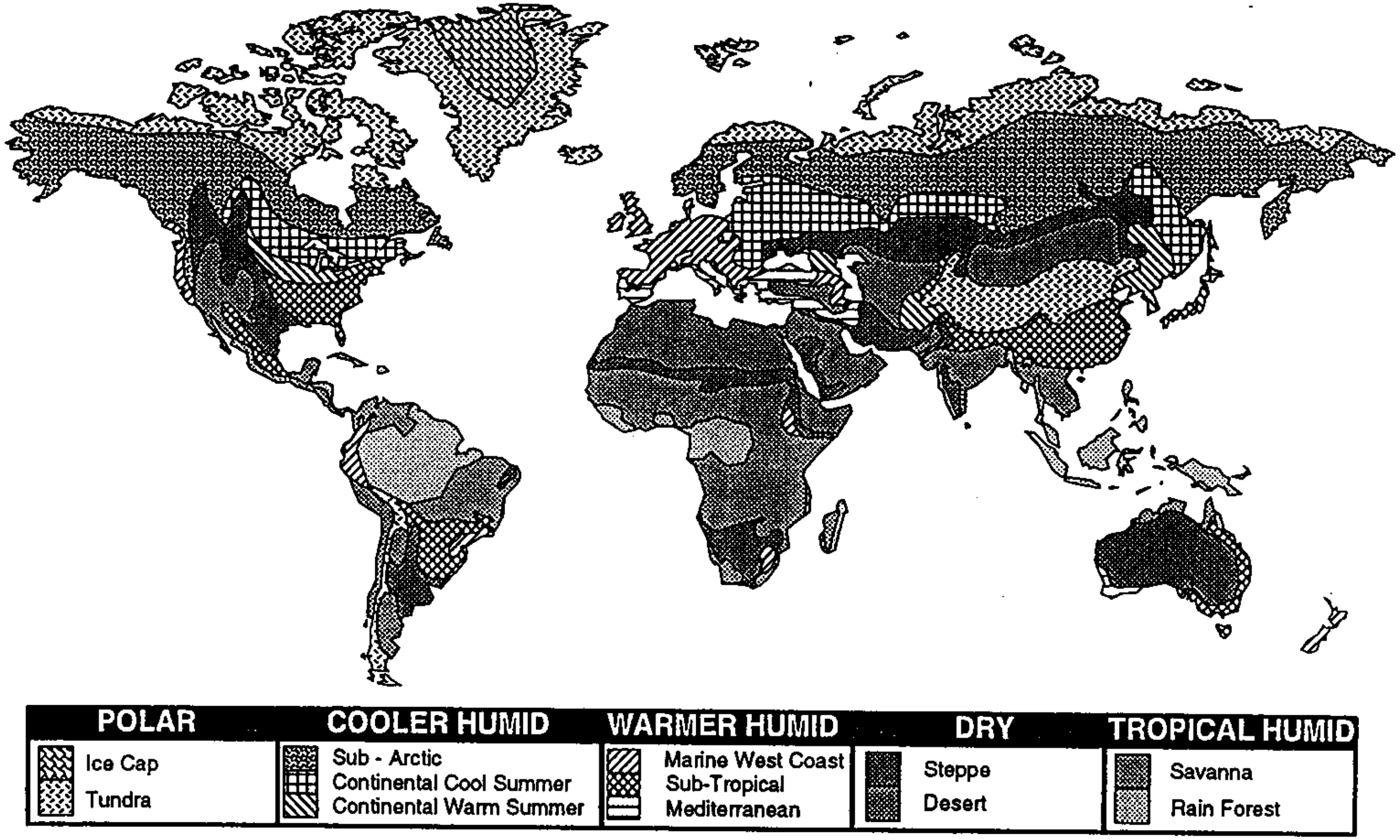

Fig. 2.1.1 World Climatic Zones

Locations	Class	Temperature	Air Humidity
Air Conditioned	A1	$18^{\circ}\mathrm{C} < T < 27^{\circ}\mathrm{C}$	35 - 75%
	A2	Controlled to within ±2°C	20 - 80%
Heated and/or Cooled Enclosed	B1	$15^{\circ}\mathrm{C} < T < 30^{\circ}\mathrm{C}$	10 - 75%
	B2	$05^{\circ}\mathrm{C} < T < 40^{\circ}\mathrm{C}$	10 - 75%
	B3	$05^{\circ}\mathrm{C} < T < 40^{\circ}\mathrm{C}$	05 - 95%
Sheltered	C1	$-25^{\circ}\mathrm{C} < T < 55^{\circ}\mathrm{C}$	up to 100%
	C2	$-40^{\circ}\mathrm{C} < T < 70^{\circ}\mathrm{C}$	up to 100%
Outdoor, Unprotected	D1	$-25^{\circ}\mathrm{C} < T < 55^{\circ}\mathrm{C}$	up to 100%
	D2	$-40^{\circ}\mathrm{C} < T < 85^{\circ}\mathrm{C}$	up to 100%

Fig 2.1.2 Climatic Classification of Equipment Environment.

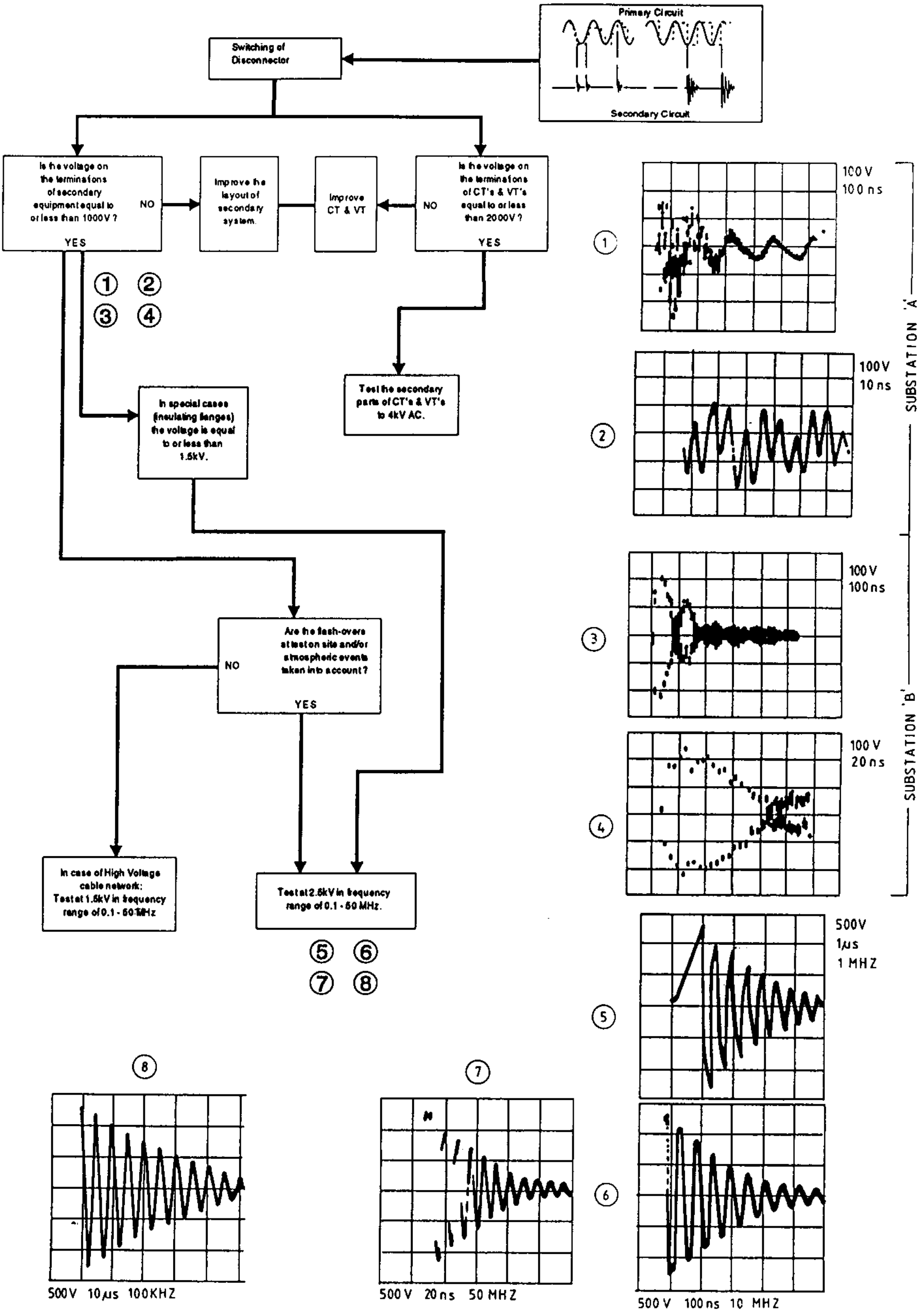

Fig. 2.2 Value of Test Voltage of Secondary Equipments in GIS/AIS.

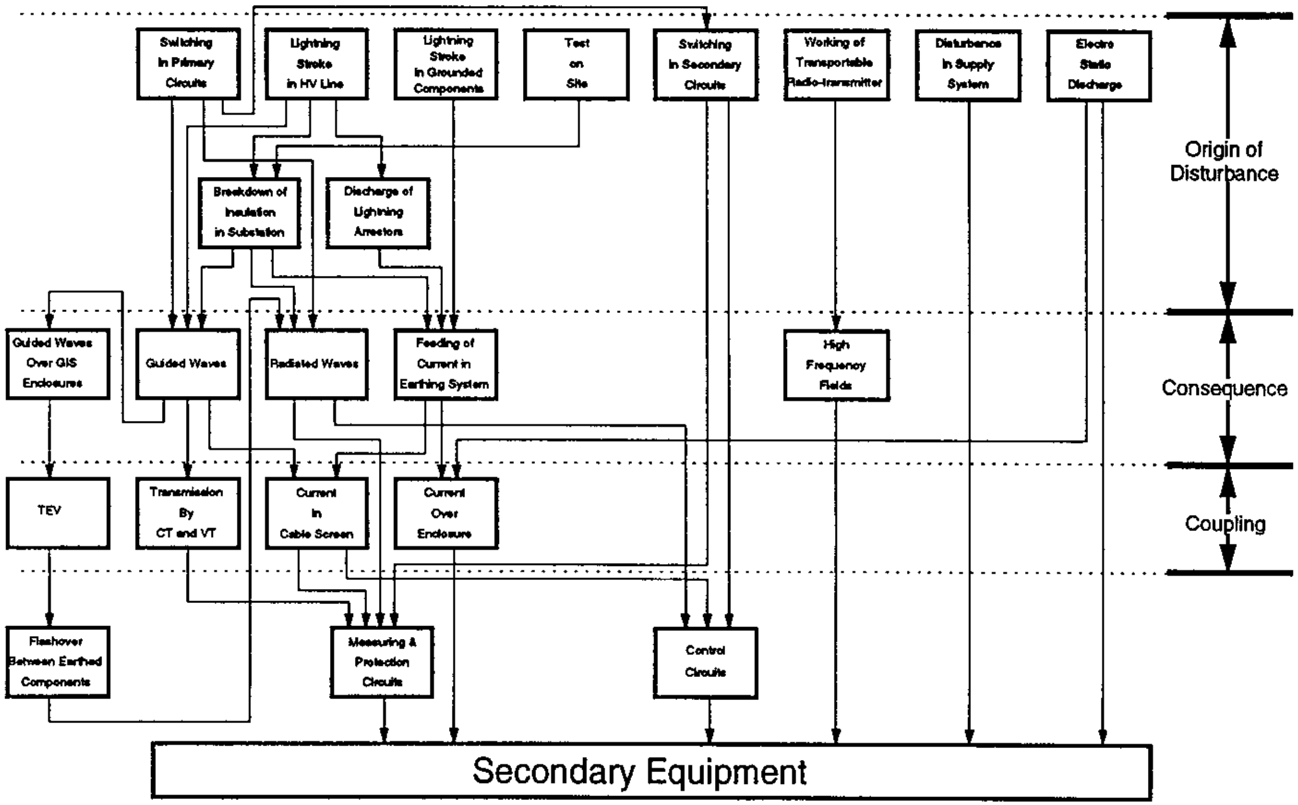

Fig. 2.3 Interference of Secondary Equipments in GIS/AIS Caused by Different Noise Sources

No. Of Function	1					2						3							4									5						6					No. Of Function
	Grade Of Function					Range Of Use						Way Of Realisation																Place Of Realisation / Fulfilling						Scope Of Need Of Redundancy					
												Conventional							Computer - Based System																				
	Extra High	High		Lower	Comments	Always	Commonly /Usually	On Request		Need Extra Analysis	Comments	Relays Elec-Mech. / Electronic / Processor Based		Conventional MMI		Circuits		Comments	Relays /Units		Computer		Computer Related MMI				Comments	H.V. Equipment / On Site	Local \ In Substation		Remote /RCC		Comments	Purposeful	Recommended		Not Necessary	Comments	
												b	a	b	a	b	a		b	a	b	a	b	a					b	a									
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	2.6	3.1	3.2	3.3	3.4	3.5	3.6	3.7	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.1	5.2	5.3	5.4	5.5	5.6	6.1	6.2	6.3	6.4	6.5	
P1																																							P1
P2.1	X					X					(1)		X									X								X							X		P2.1
P2.2		X				X											X					X								X							X		P2.2
P3.1	X					X						X							X										X					X				(2)	P3.1
P3.2	X					X						X							X										X					X				(2)	P3.2
P3.3	X					X						X							X										X					X				(2)	P3.3
P3.4		X				X						X							X										X					X					P3.4
A1.1		X								X		X										X								X	X						X		A1.1
A1.2		X						X				X										X								X	X						X		A1.2
A1.3				X				X				X										X								X	X						X		A1.3
A1.4		X								X		X										X								X	X						X		A1.4
A1.5				X						X		X										X								X	X						X		A1.5
A2.1				X				X									X					X								X	X						X		A2.1
A2.2		X						X				X										X								X	X						X		A2.2
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A3.1	X					X						X									X								X								X		A3.1
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A3.3		X				X						X									X							X	X								X		A3.3
A3.4	X							X		X												X								X	X						X		A3.4
A3.5		X					X					X										X								X	X						X		A3.5
A3.6		X					X					X										X								X	X						X		A3.6
C/o.1	X					X								X							X		X					X	X	X	X						X		C/o.1
C/o.2	X					X										X					X								X								X		C/o.2
C/o.3	X					X											X					X								X							X		C/o.3
C/m.1		X				X								X							X			X					X	X	X						X		C/m.1
C/m.2	X					X								X	X						X			X					X	X	X		(3)				X		C/m.2
C/m.3		X				X								X							X			X					X	X	X		(3)				X		C/m.3
C/m.4		X					X					X	X								X	X							X	X	X						X		C/m.4
C/m.5				X				X							X						X			X						X	X						X		C/m.5
C/m.6		X					X									X					X			X					X		X						X		C/m.6
C/m.7		X					X					X							X										X								X		C/m.7
C/m.8		X					X					X							X										X								X		C/m.8

Comments
(1) Excluding certain busbar configurations (ie. ring)
(2) Referring to main protection
(3) Normally a reduced range of quantities in RCC.

Fig. 3.1 Splitting Of Functions (General) Including Protection, Automation, Control / Operations & Control / Monitoring

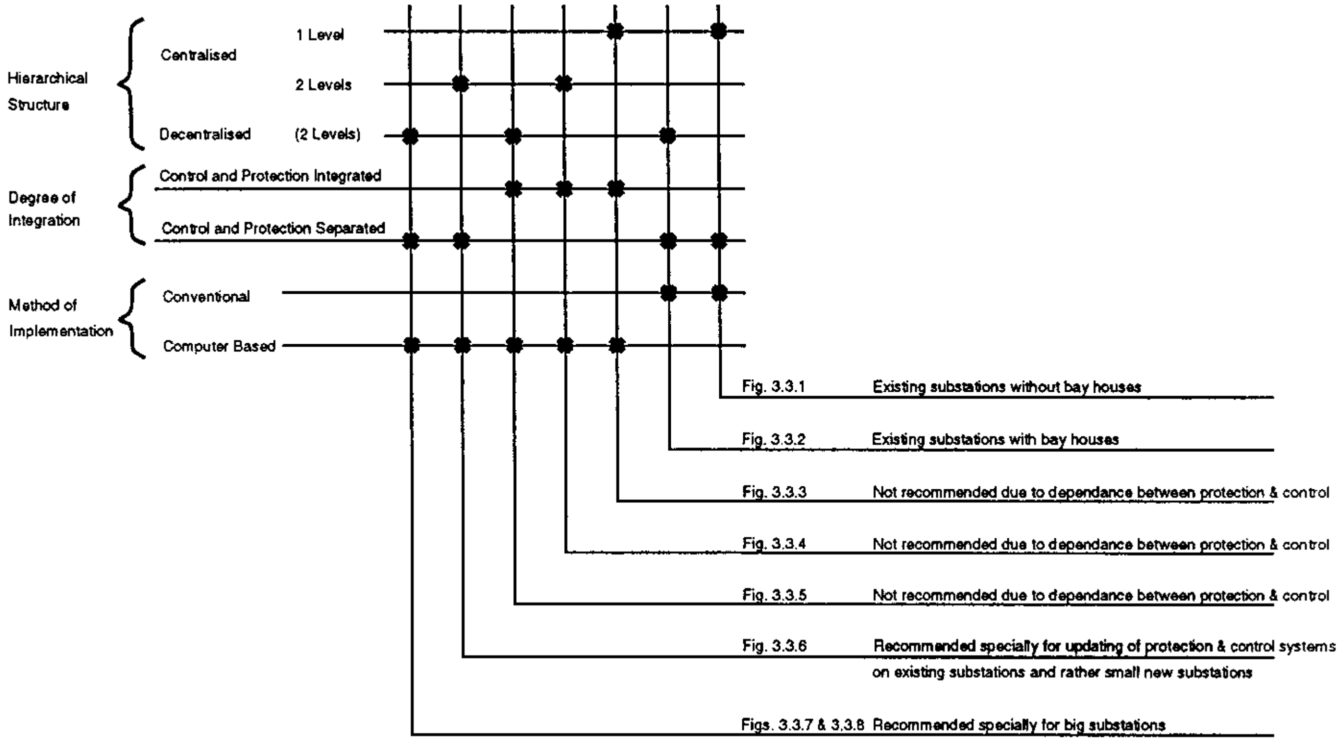


Fig. 3.2 Possible Architectures of Substation Secondary Systems

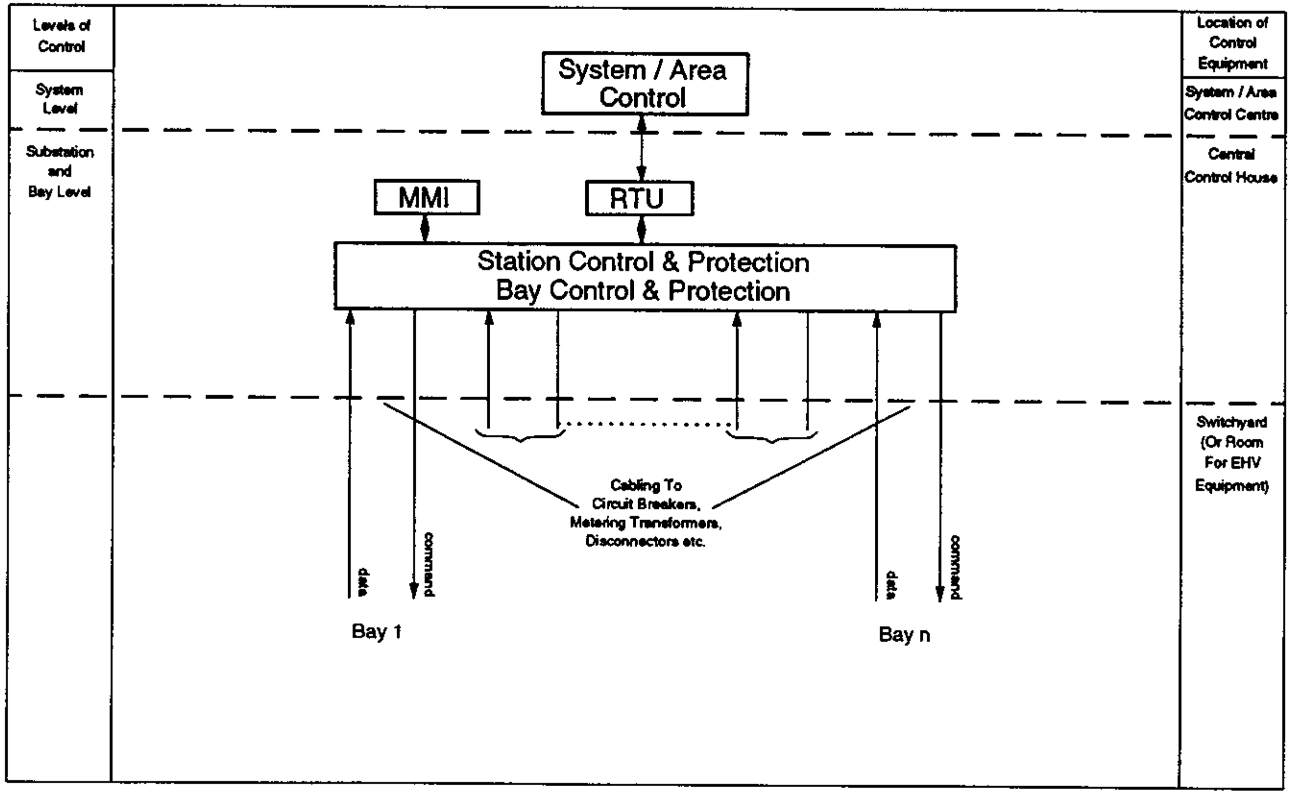


Fig. 3.3.1 Present Substation Secondary Systems Architecture - Without Bay Houses

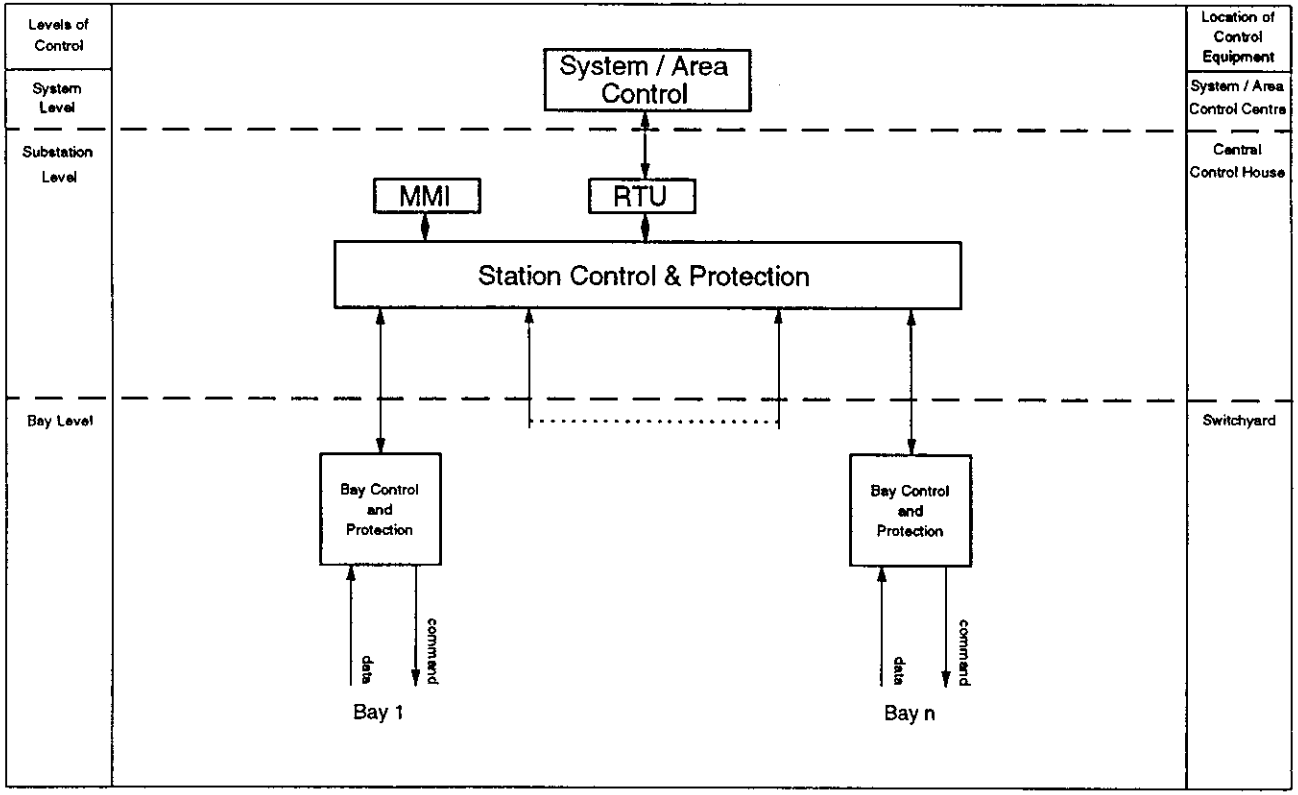


Fig. 3.3.2 Present Substation Secondary Systems Architecture - With Bay Houses

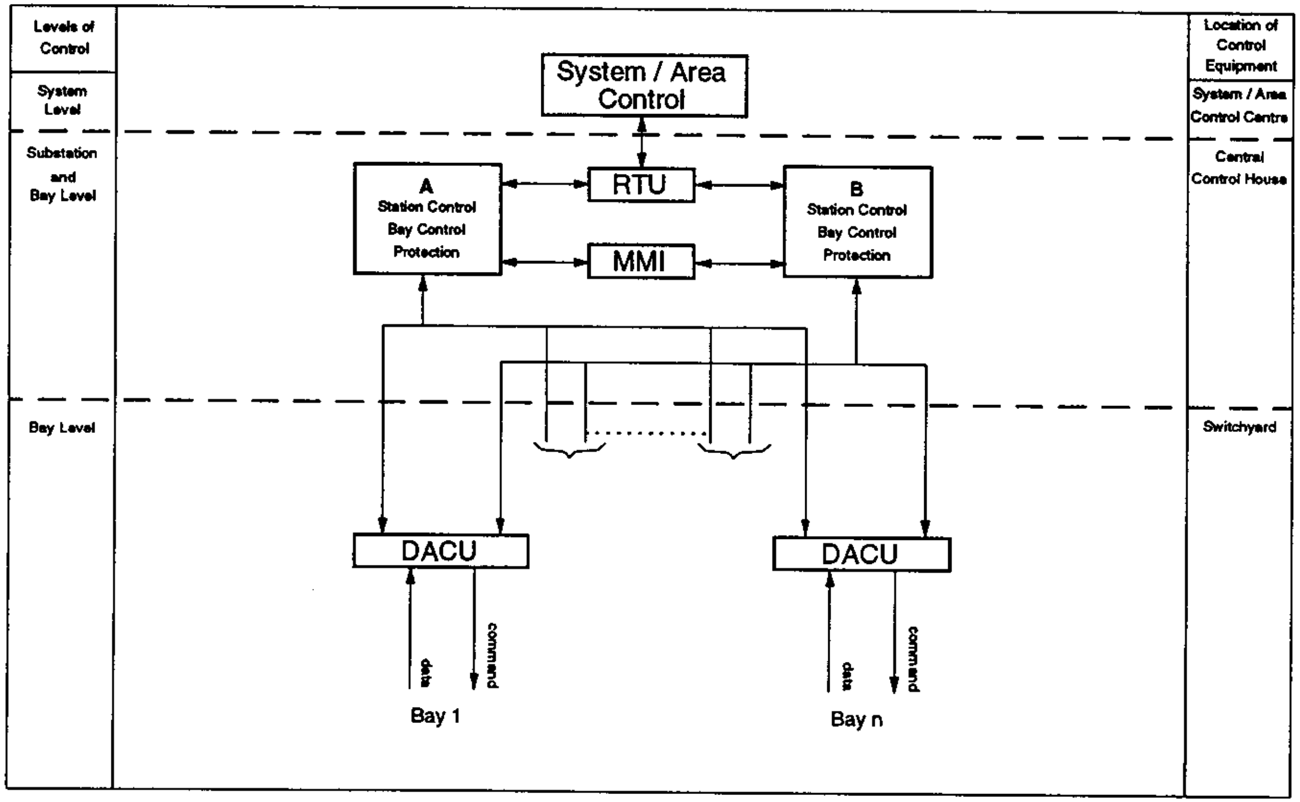


Fig. 3.3.3 Computer Based Substation Secondary Systems Architecture - Centralised and Integrated (1 Level)

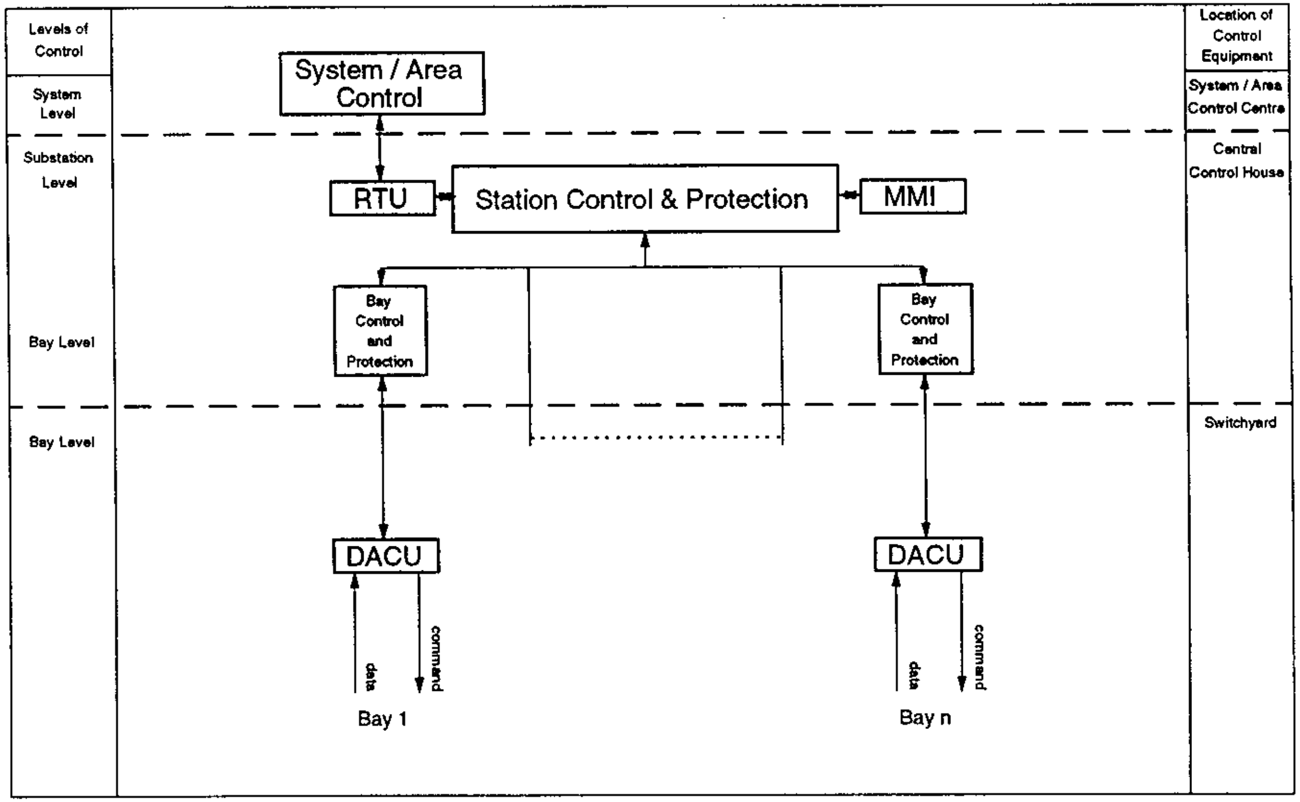


Fig. 3.3.4 Computer Based Substation Secondary Systems Architecture - Centralised and Integrated (2 Levels)

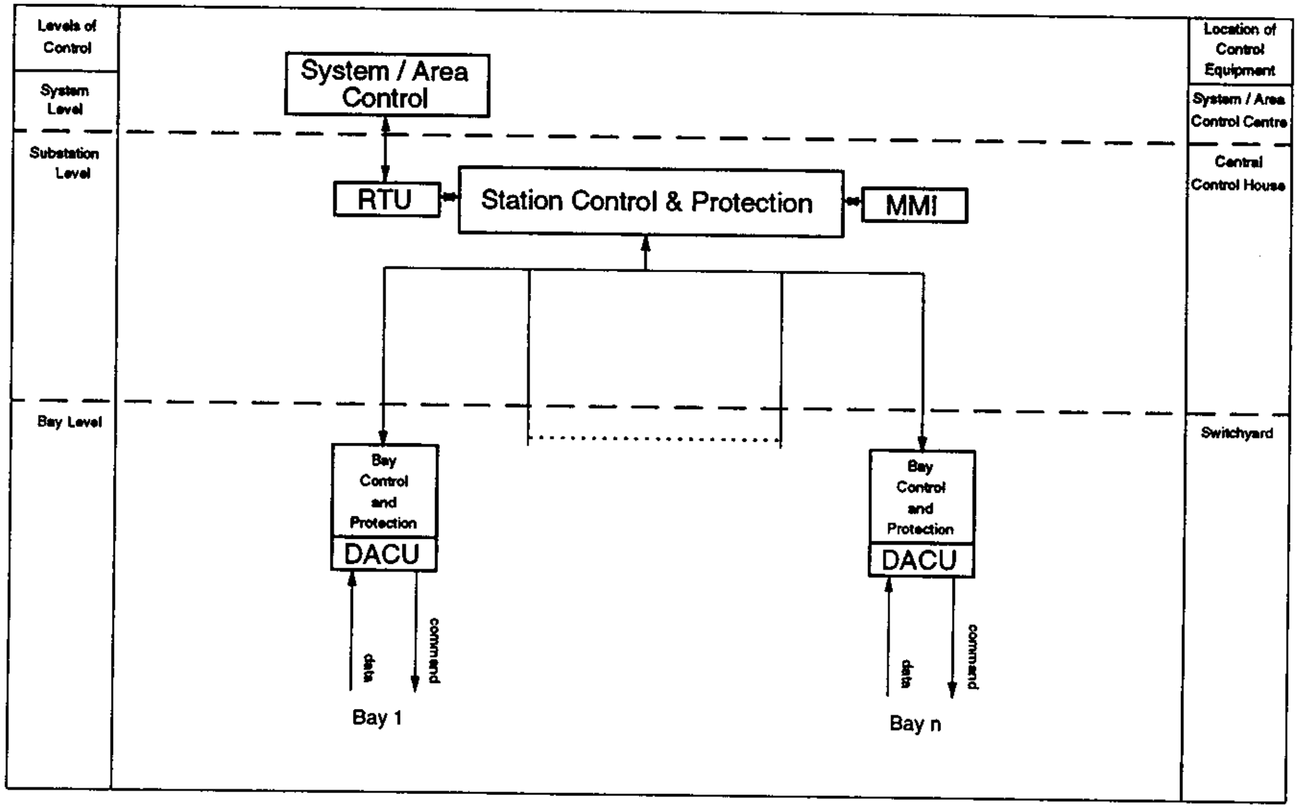


Fig. 3.3.5 Computer Based Substation Secondary Systems Architecture - Decentralised and Integrated (2 Levels)

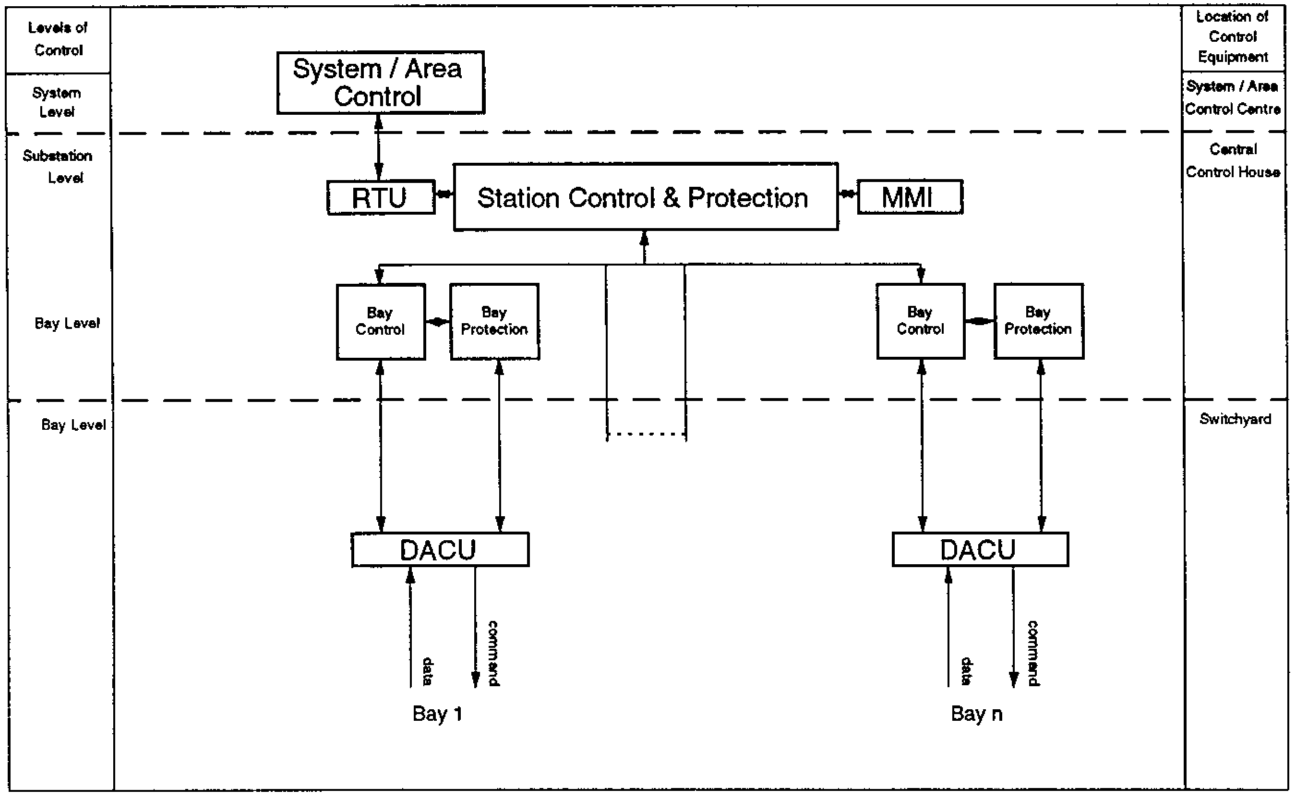


Fig. 3.3.6 Computer Based Substation Secondary Systems Architecture - Centralised, Protection Separated

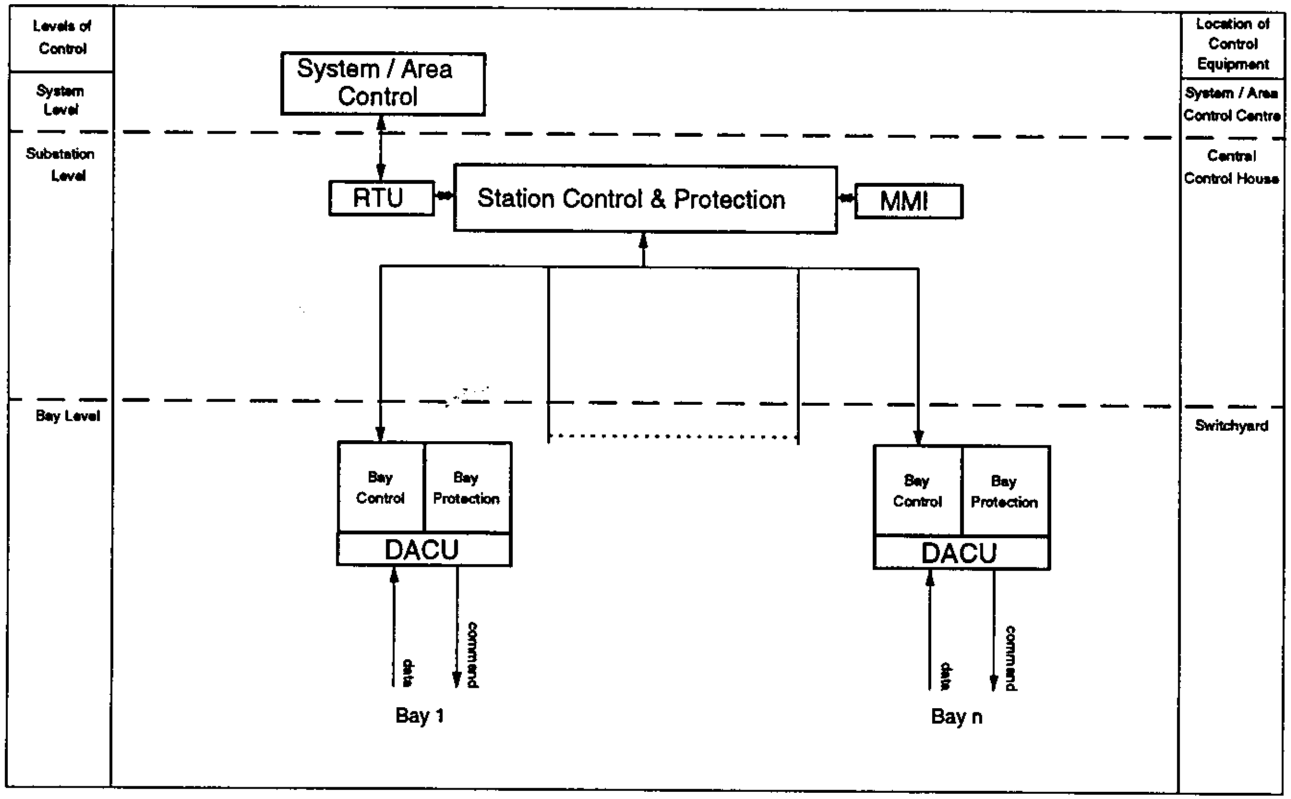


Fig. 3.3.7 Computer Based Substation Secondary Systems Architecture - Decentralised, Protection Separated

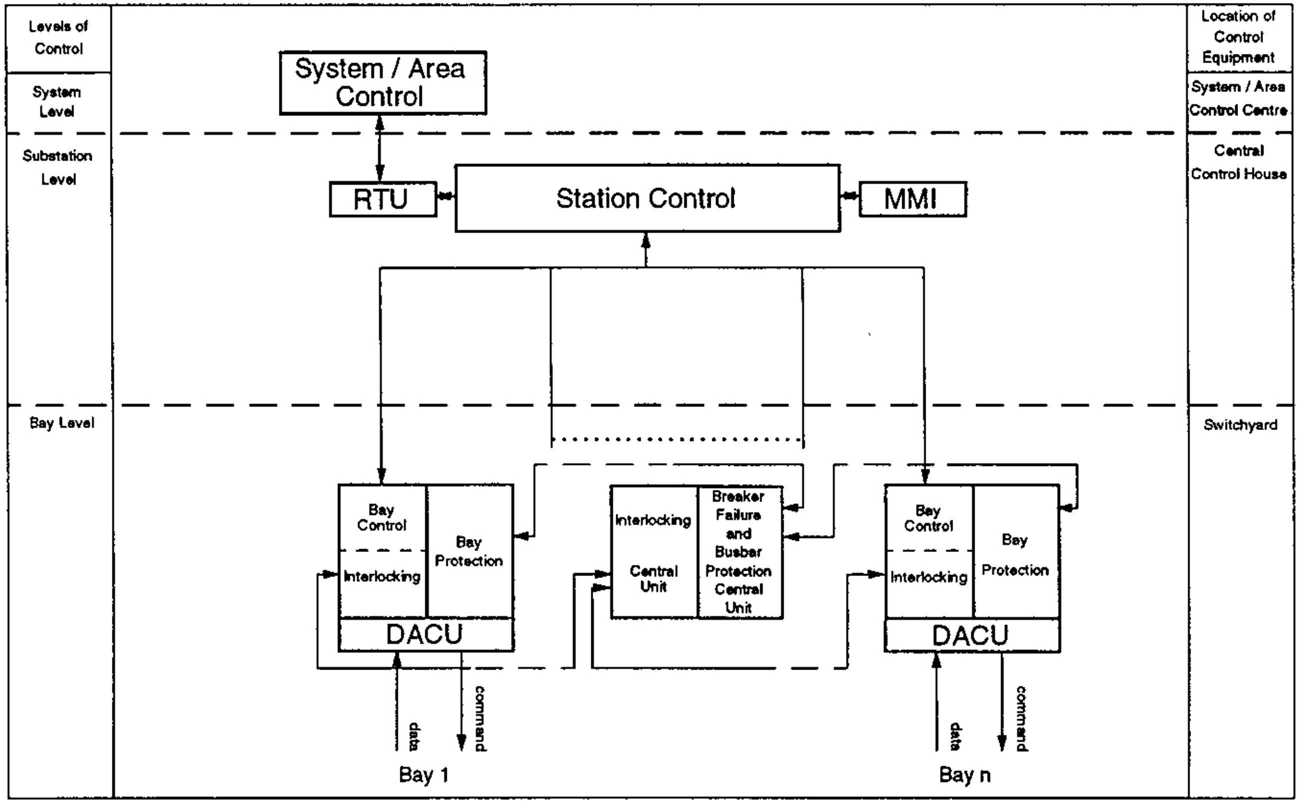


Fig. 3.3.8 Computer Based Substation Secondary Systems Architecture - Decentralised, Protection Separated

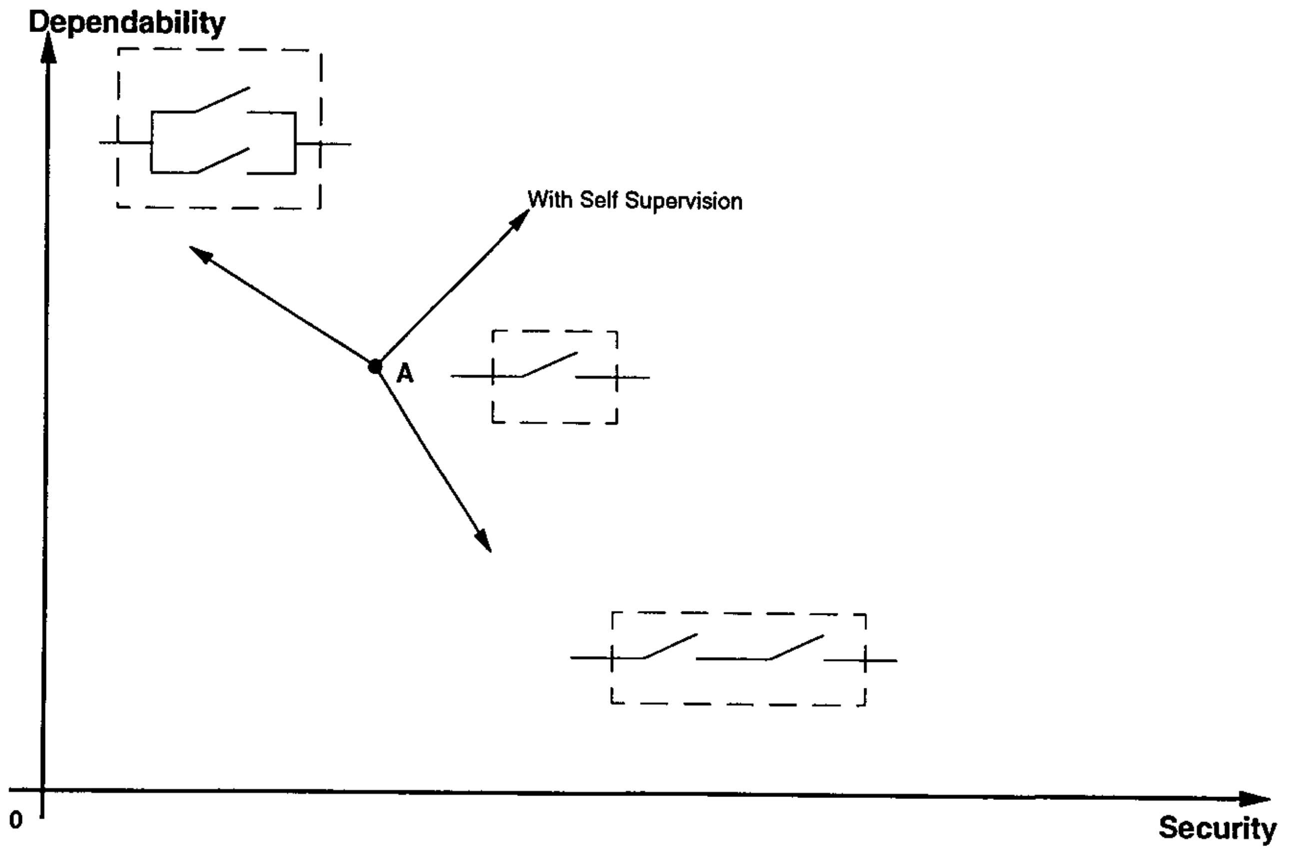


Fig. 3.4 Relationship Between Dependability / Security For Parallel & Series Redundancy

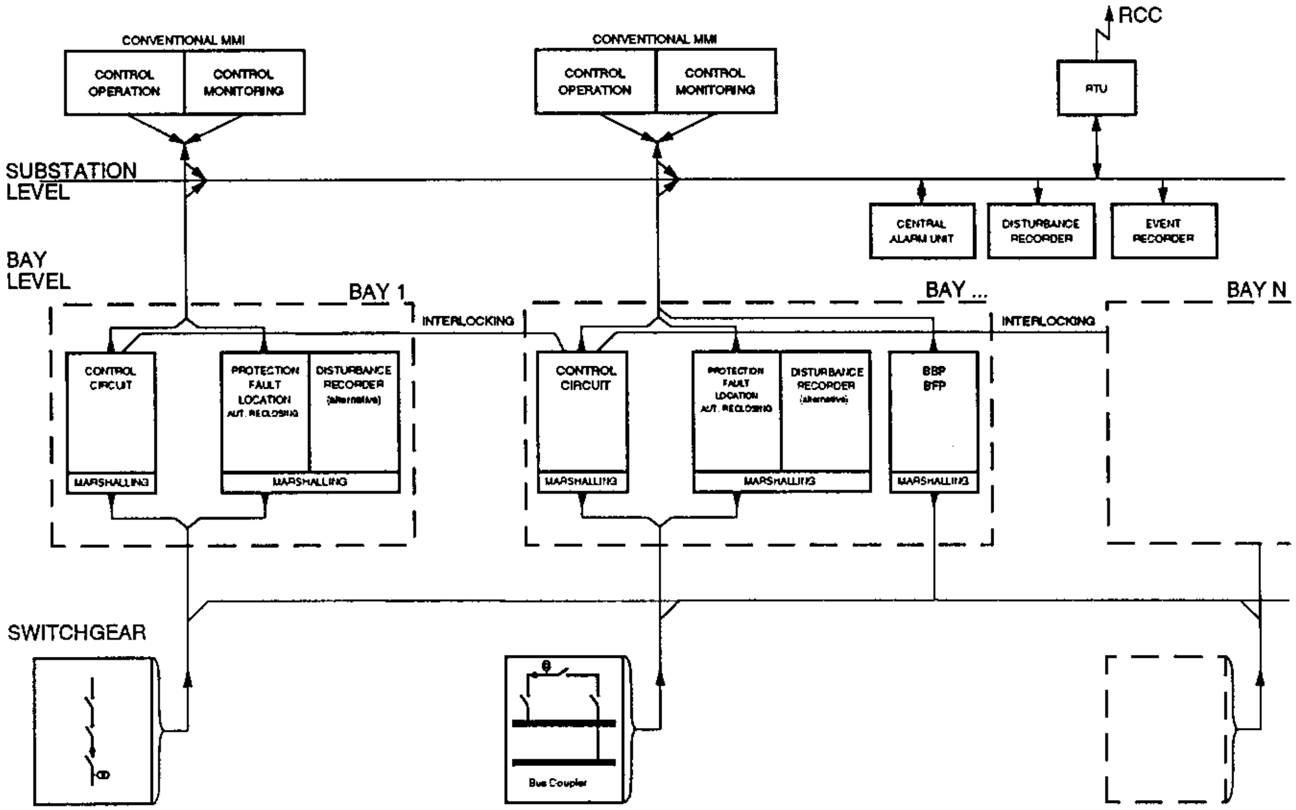


Fig. 3.5 Protection & Control - Conventional Method of Realisation

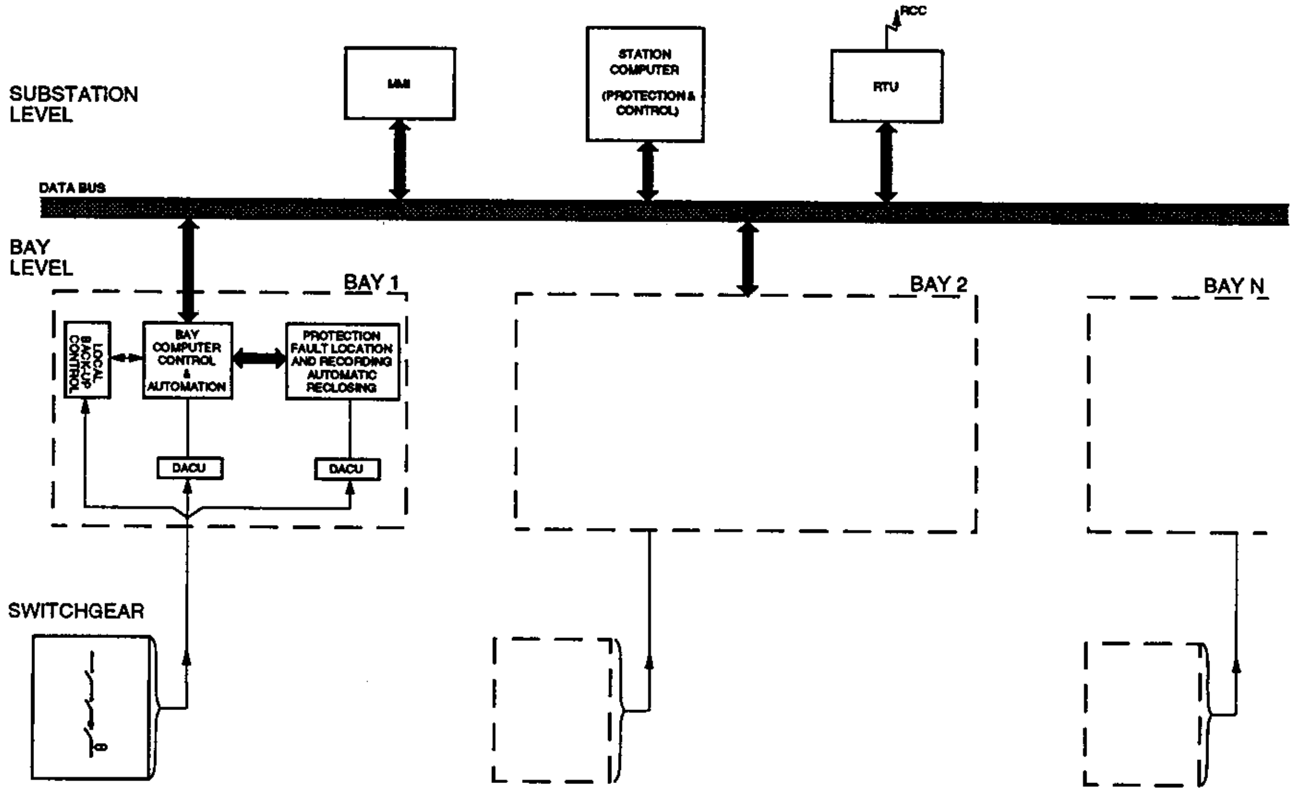
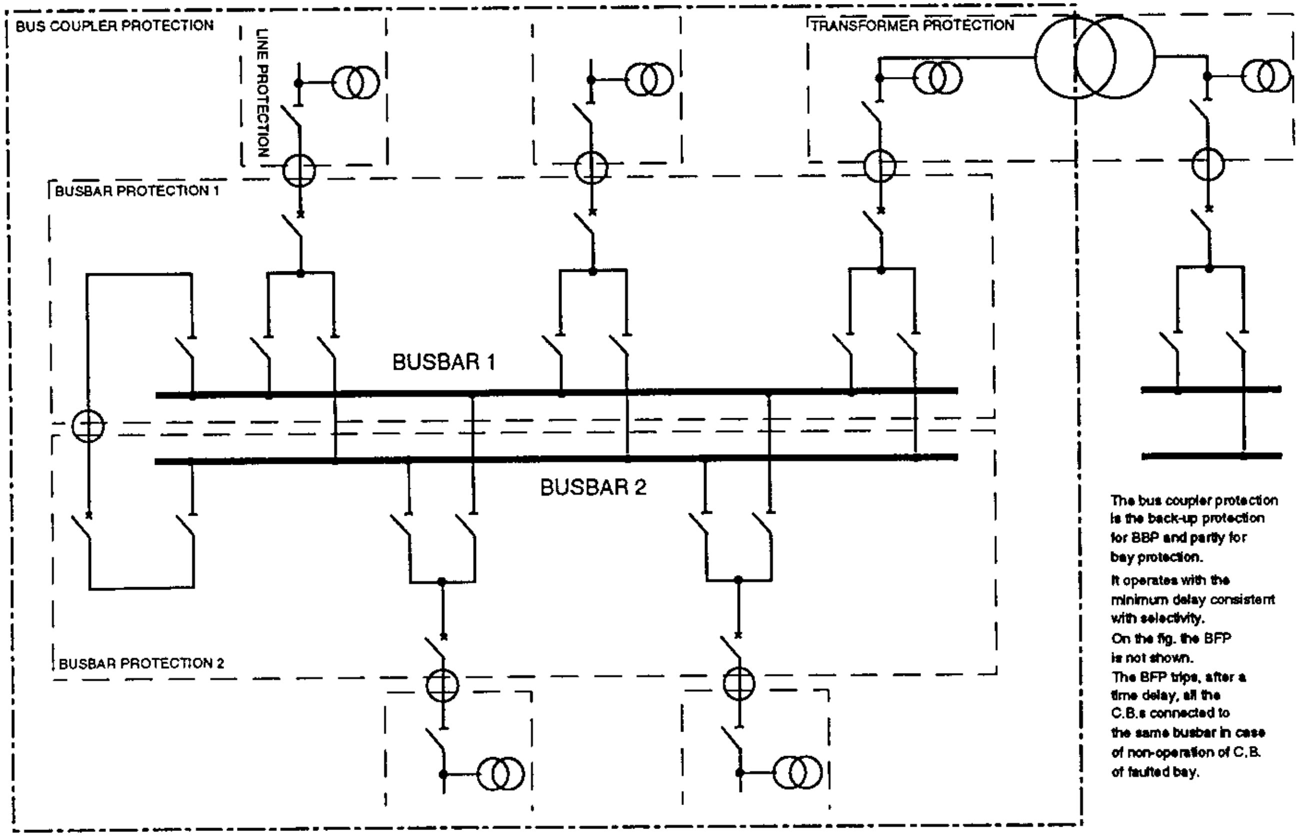


Fig. 3.6 Protection & Control - Recommended Computer Based Method of Realisation



The bus coupler protection
is the back-up protection
for BBP and partly for
bay protection.

It operates with the
minimum delay consistent
with selectivity.
On the fig. the BFP
is not shown.
The BFP trips, after a
time delay, all the
C.B.s connected to
the same busbar in case
of non-operation of C.B.
of faulted bay.

Fig. 3.7 Performance Zones of Protection System

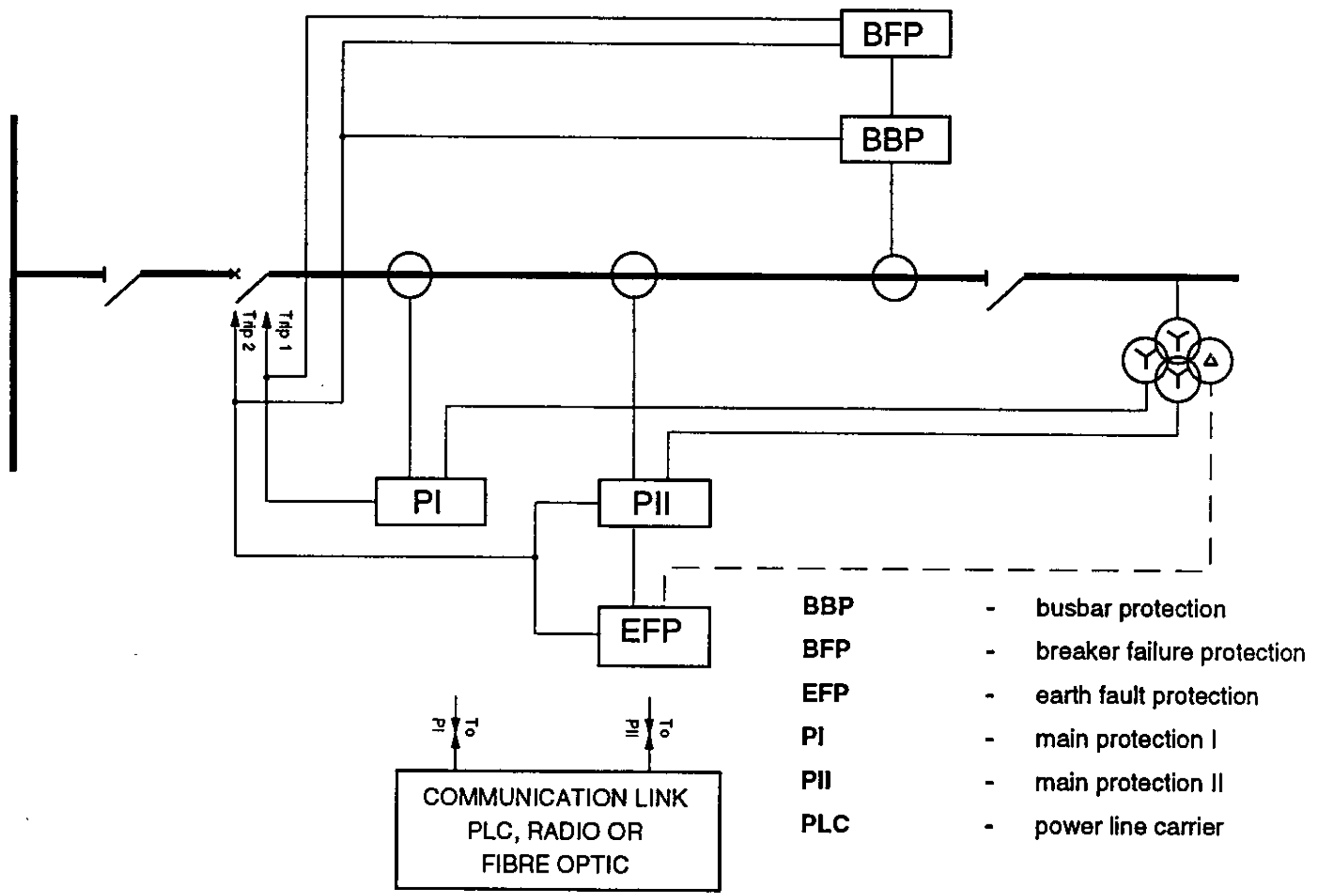


Fig. 3.8 Line Protection Scheme - General

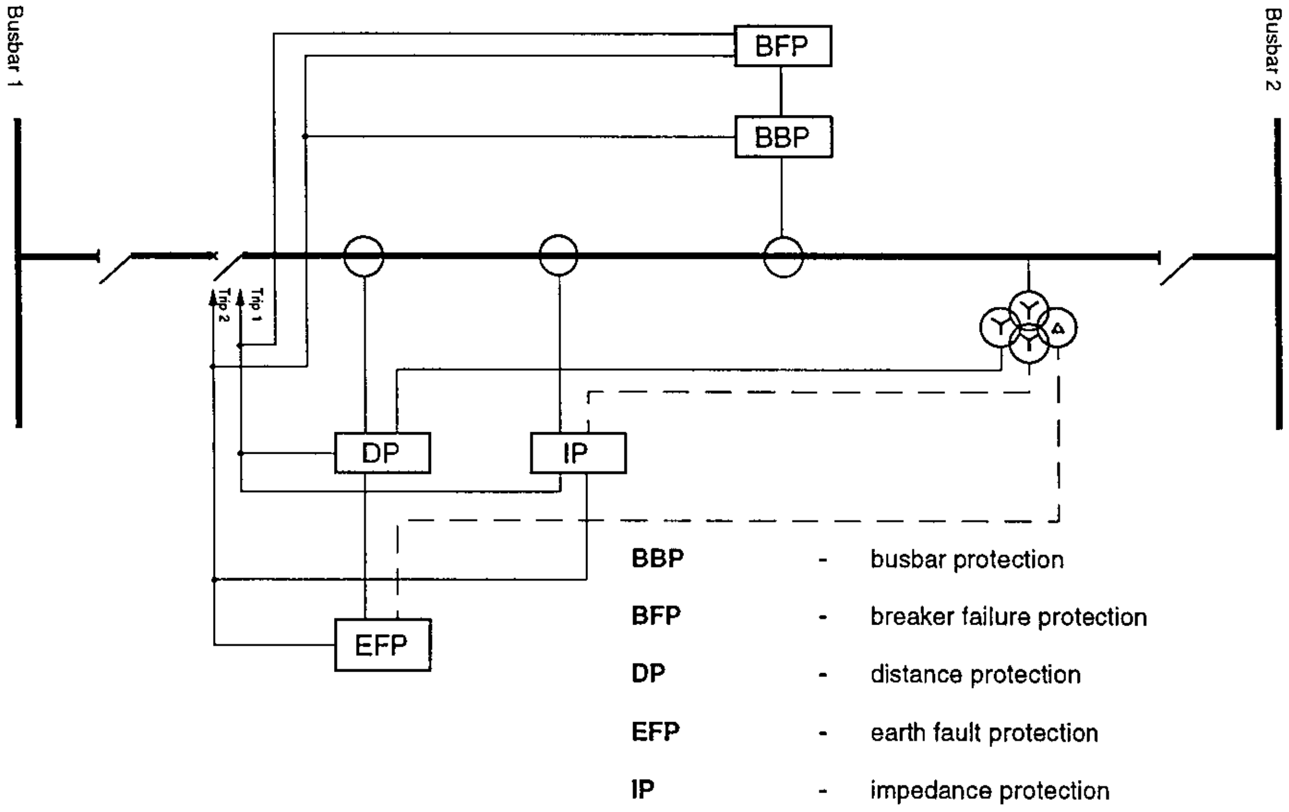
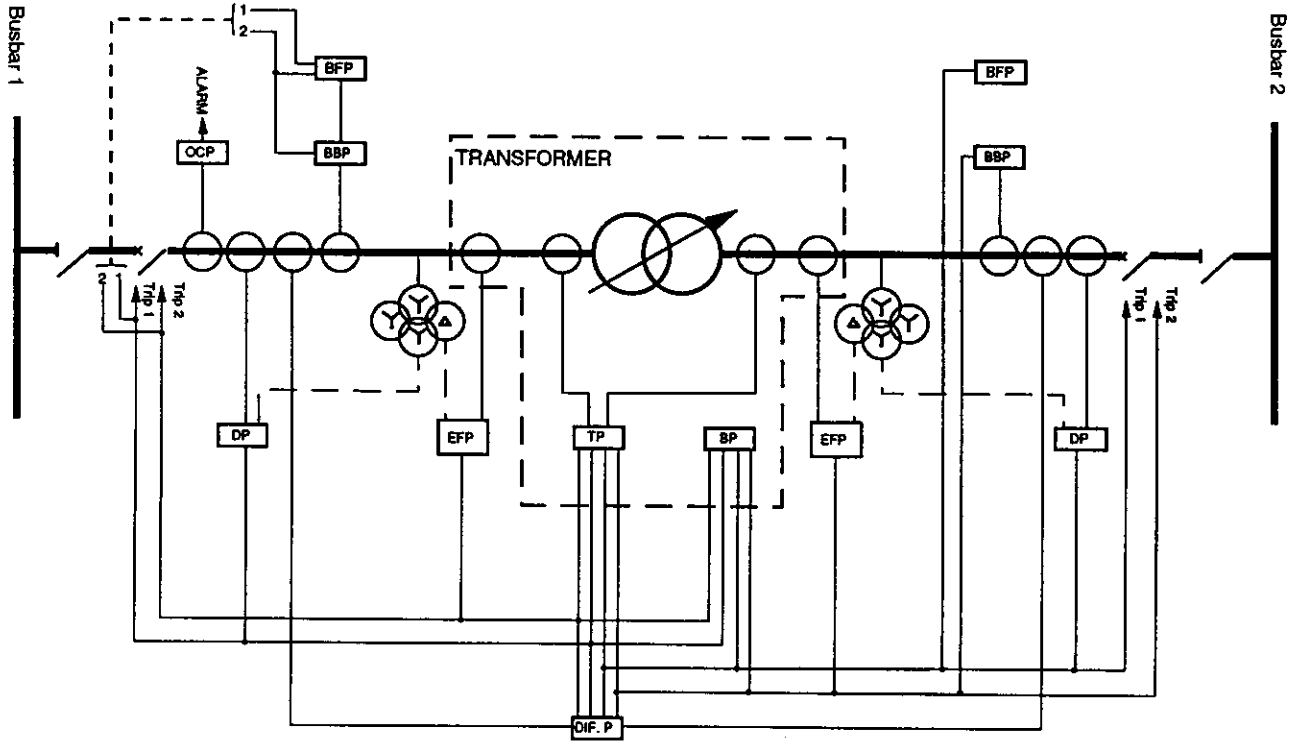


Fig. 3.9 Bus Coupler Protection Scheme - General



BBP	-	busbar protection
BFP	-	breaker failure protection
BP	-	buchholz protection
DIF.P	-	differential protection
DP	-	distance protection
EFP	-	earth fault protection
OCP	-	overcurrent protection
TP	-	thermal protection

Fig. 3.10 Main Transformer Protection Scheme - General

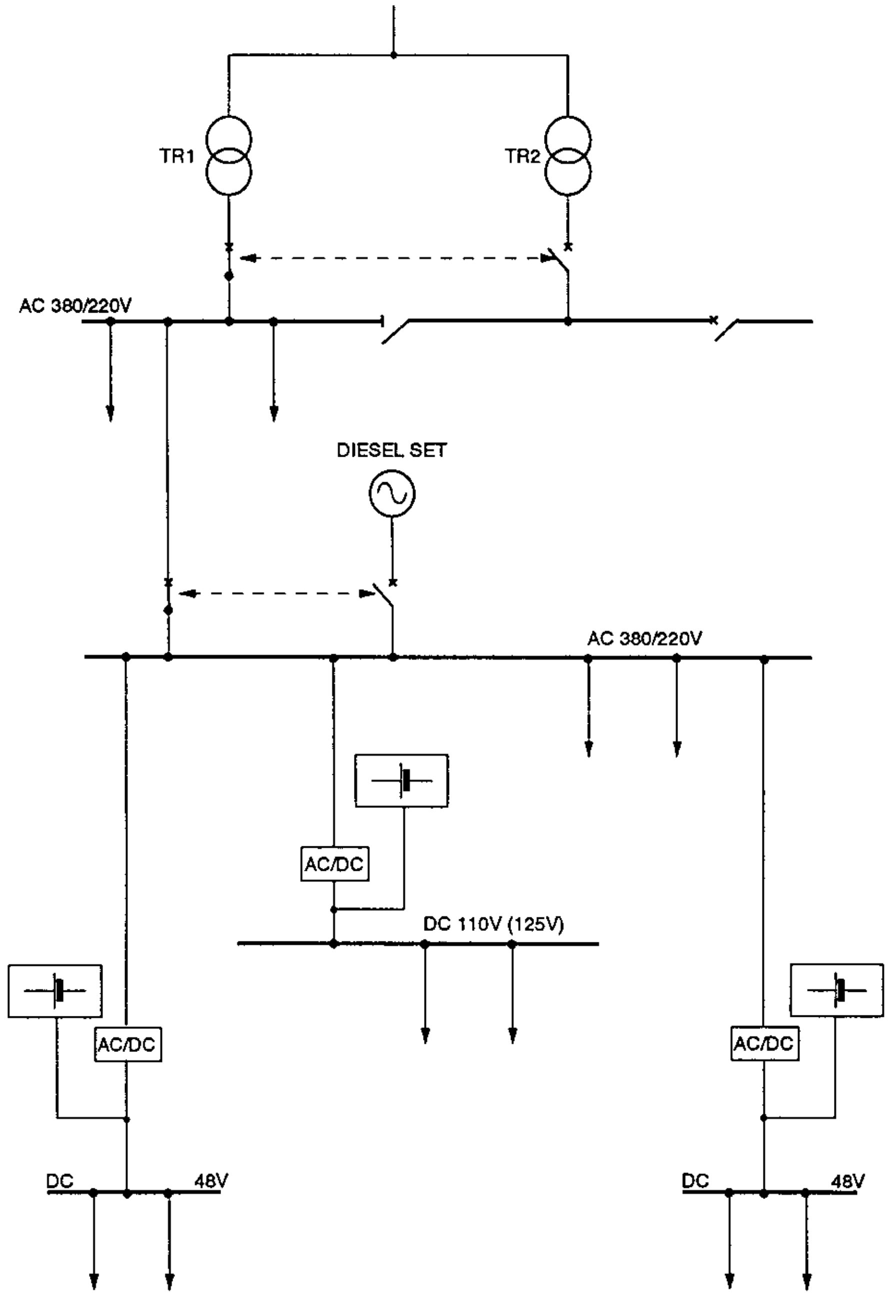


Fig. 3.11 AC/DC Auxiliaries Power Supply - An Example of the Simplified Version

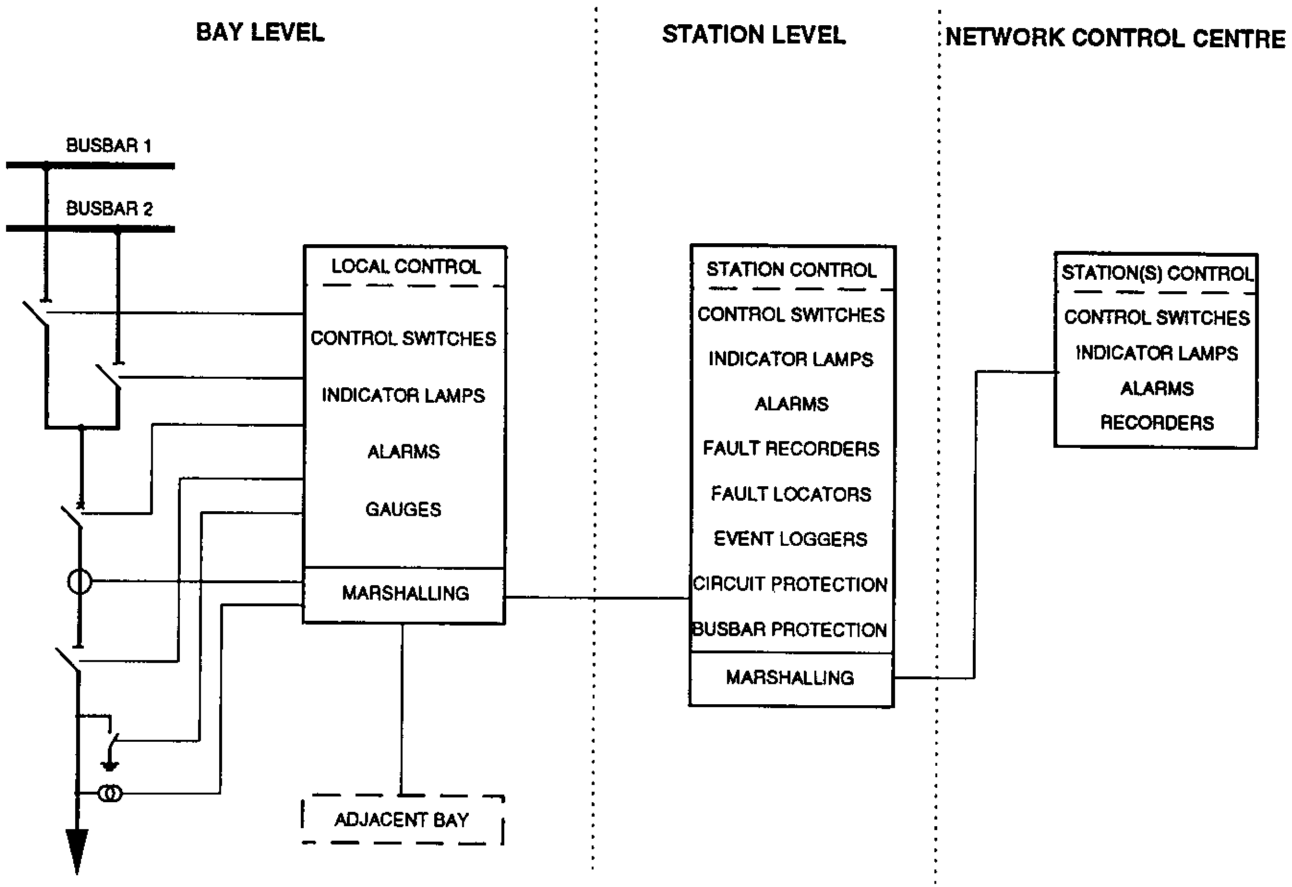


Fig. 4.1 Man Machine Interface Locations

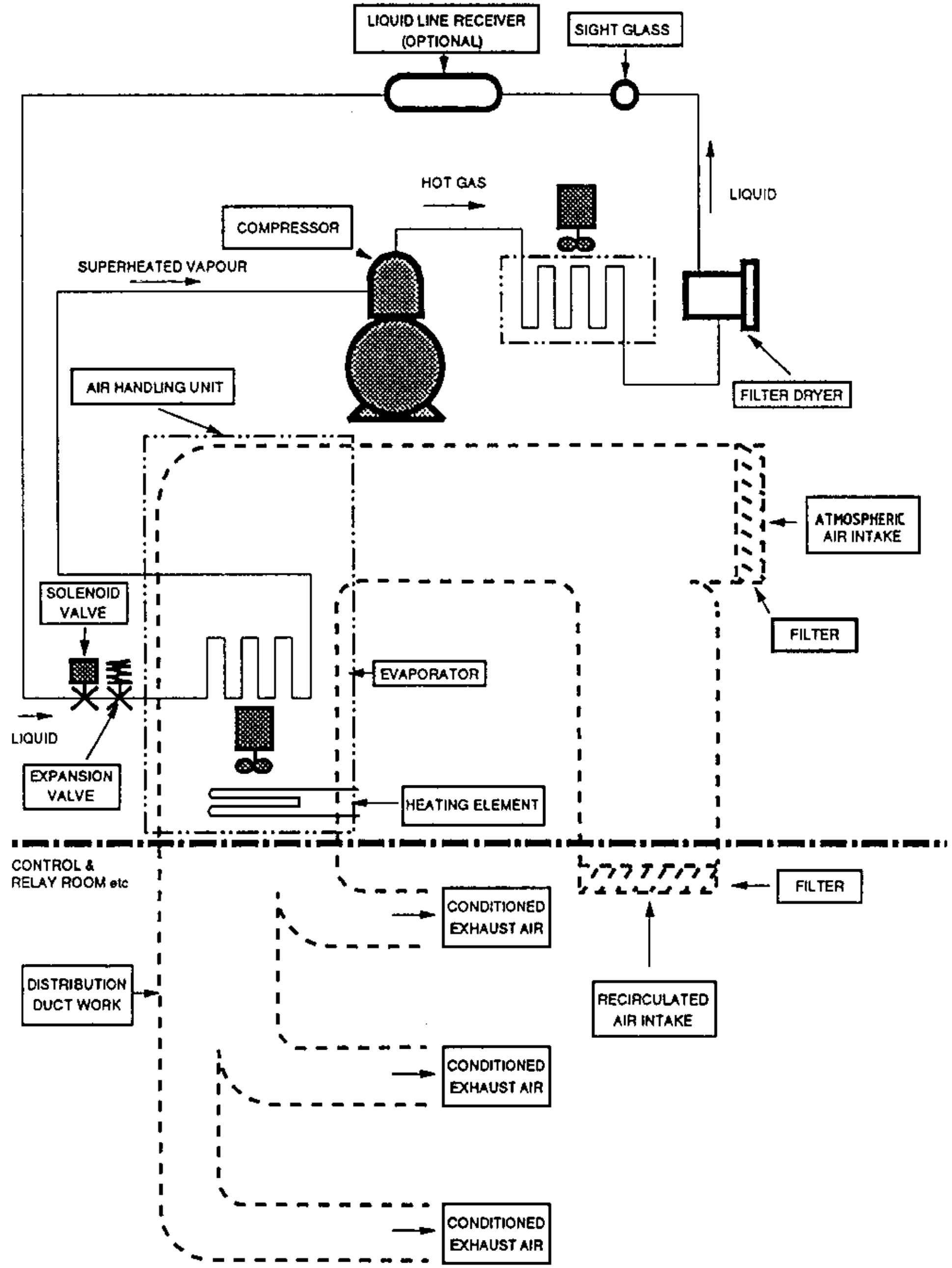


Fig. 4.2 Heating, Ventilation and Air Conditioning System - Simplified Version

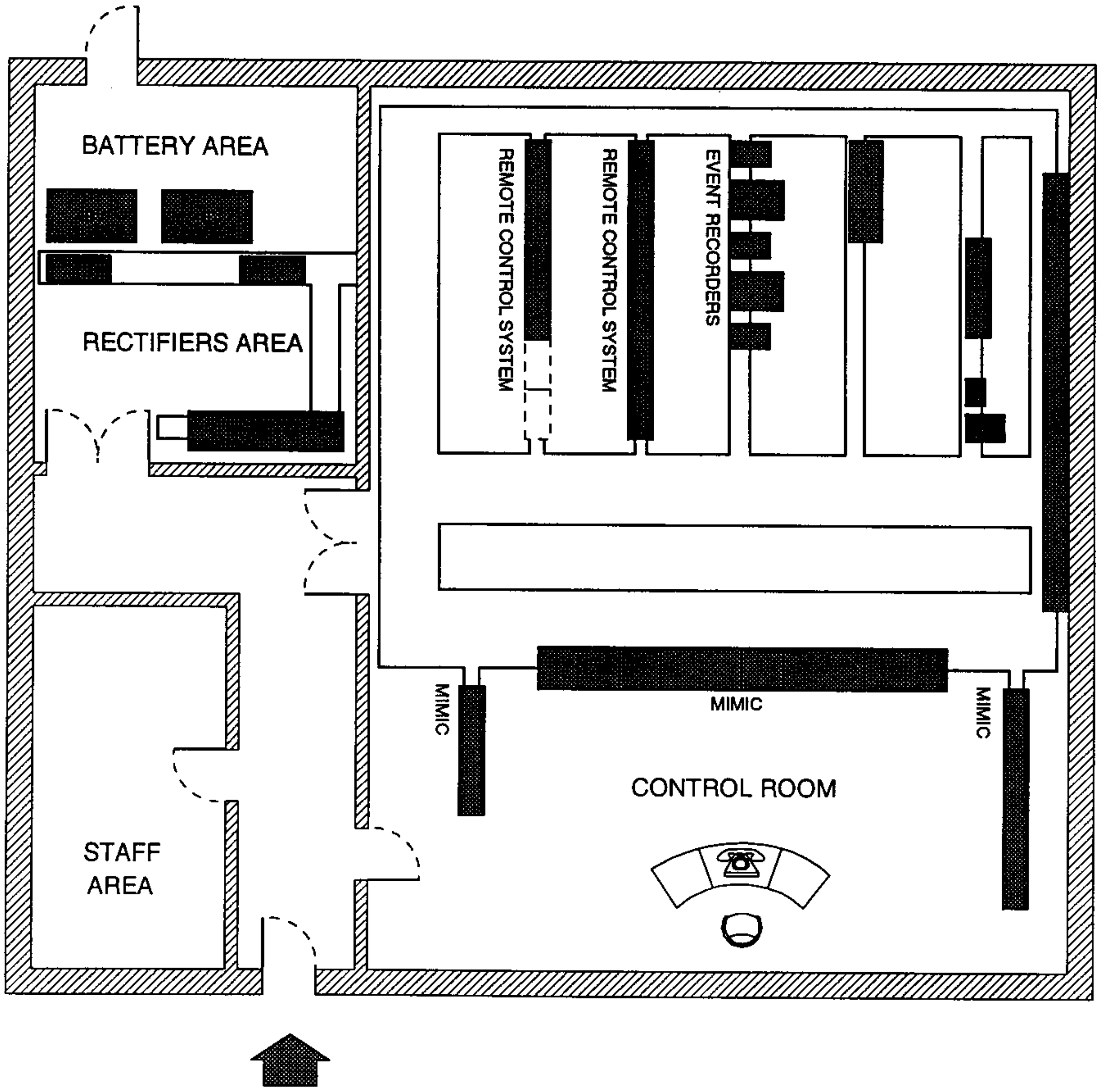


Fig. 5.1 Typical Example of Central Control Building Layout Showing Secondary Equipment Locations

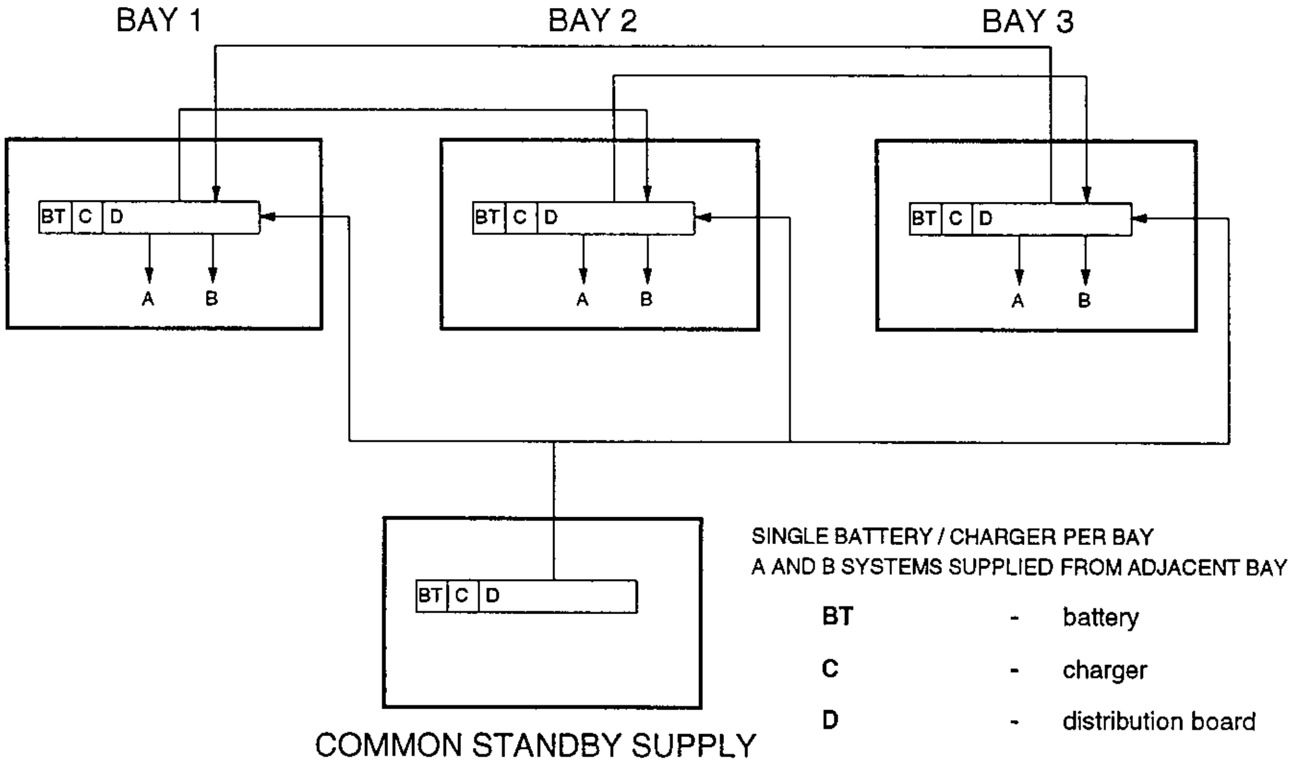


Fig. 5.2.1 Battery Arrgt. for Substation with De-centralised Relay Rooms

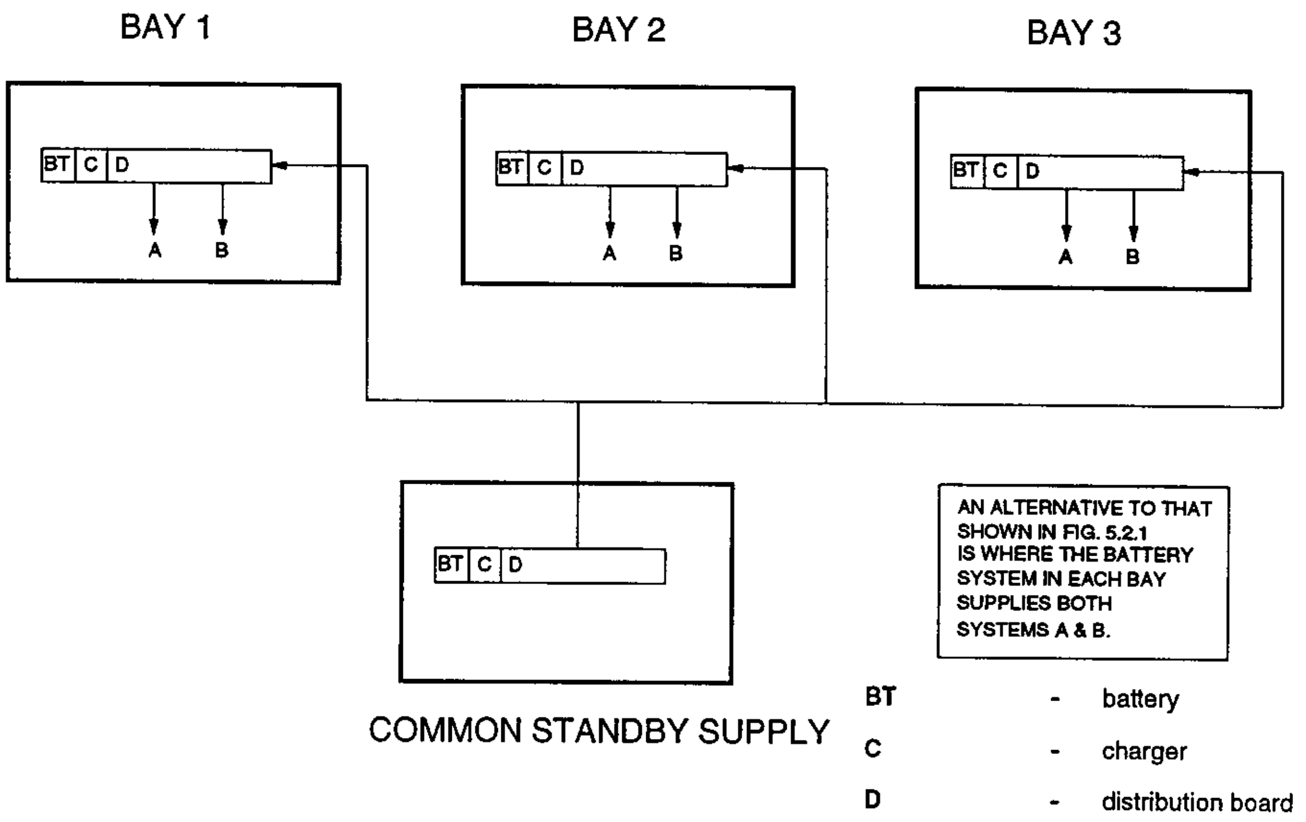
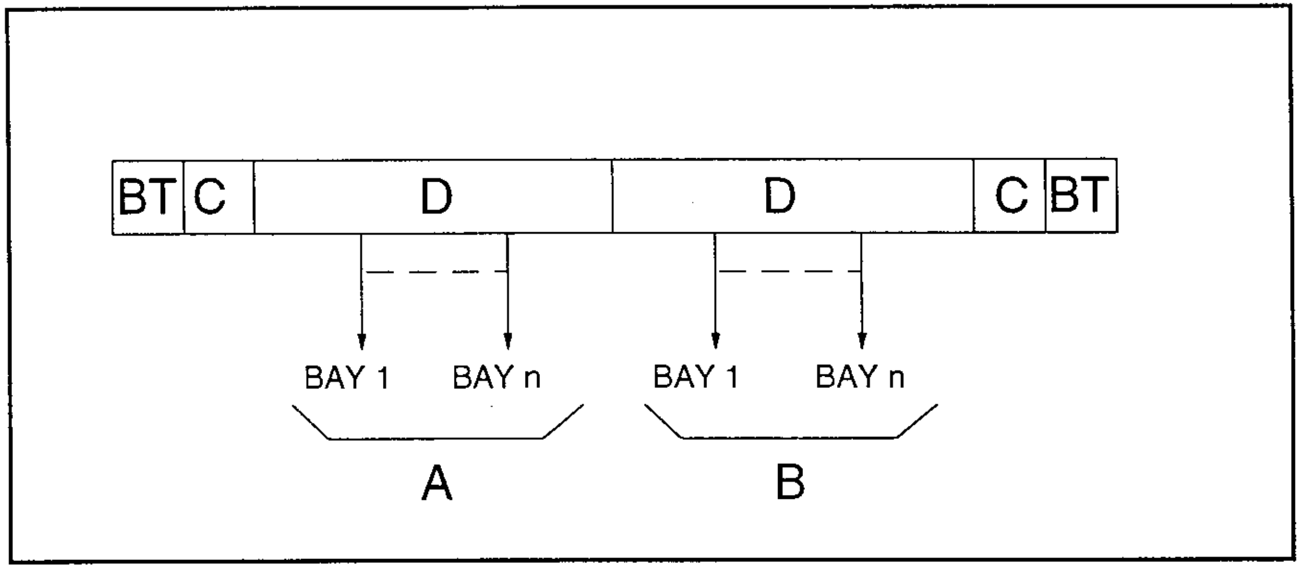


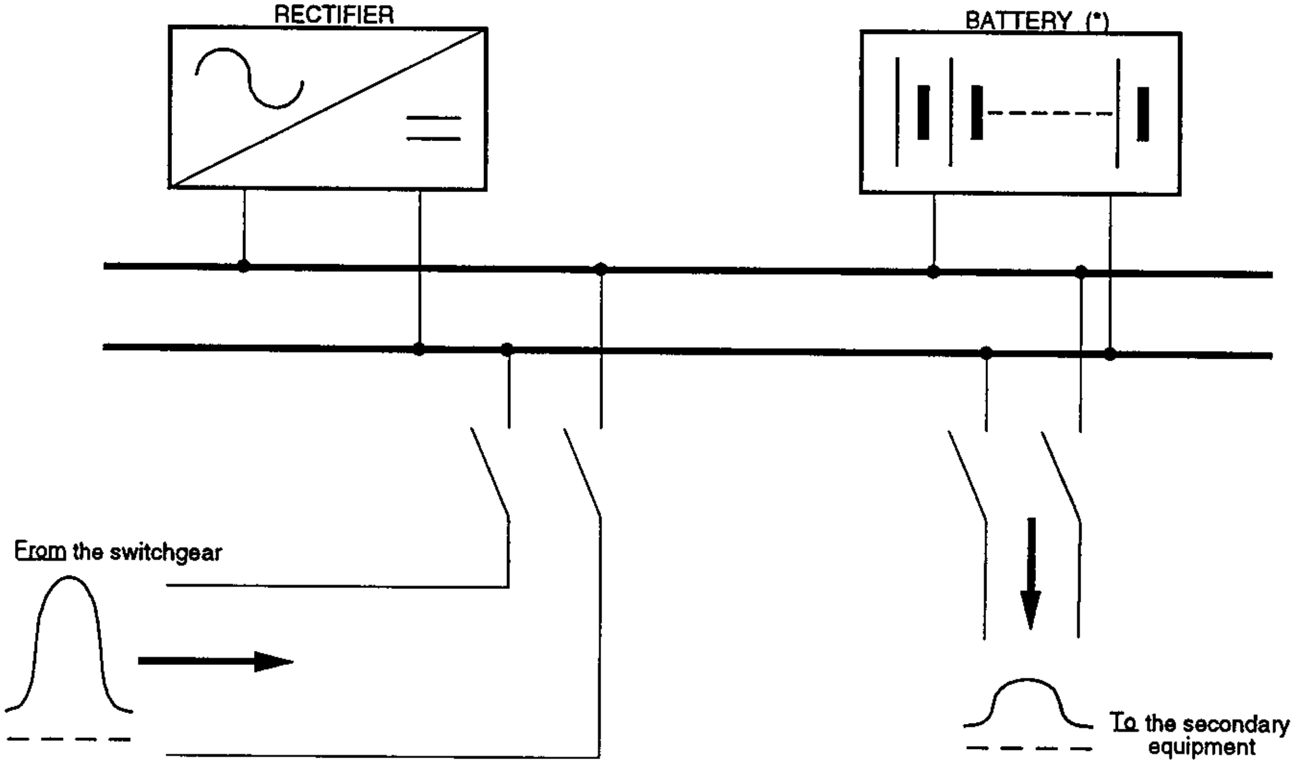
Fig. 5.2.2 Alternative Battery Arrgt. for Substation with De-cetralised Relay Rooms



EACH BATTERY SYSTEM RATED AT 100% LOAD
i.e. LOAD A + LOAD B

BT - battery
C - charger
D - distribution board

Fig. 5.3 Battery Arrgt. For Substation with Common Relay Room



(*) : The battery is acting as a filter reducing electromagnetic interferences from the HV equipment

Fig. 5.4 Battery Connection To Distribution Board

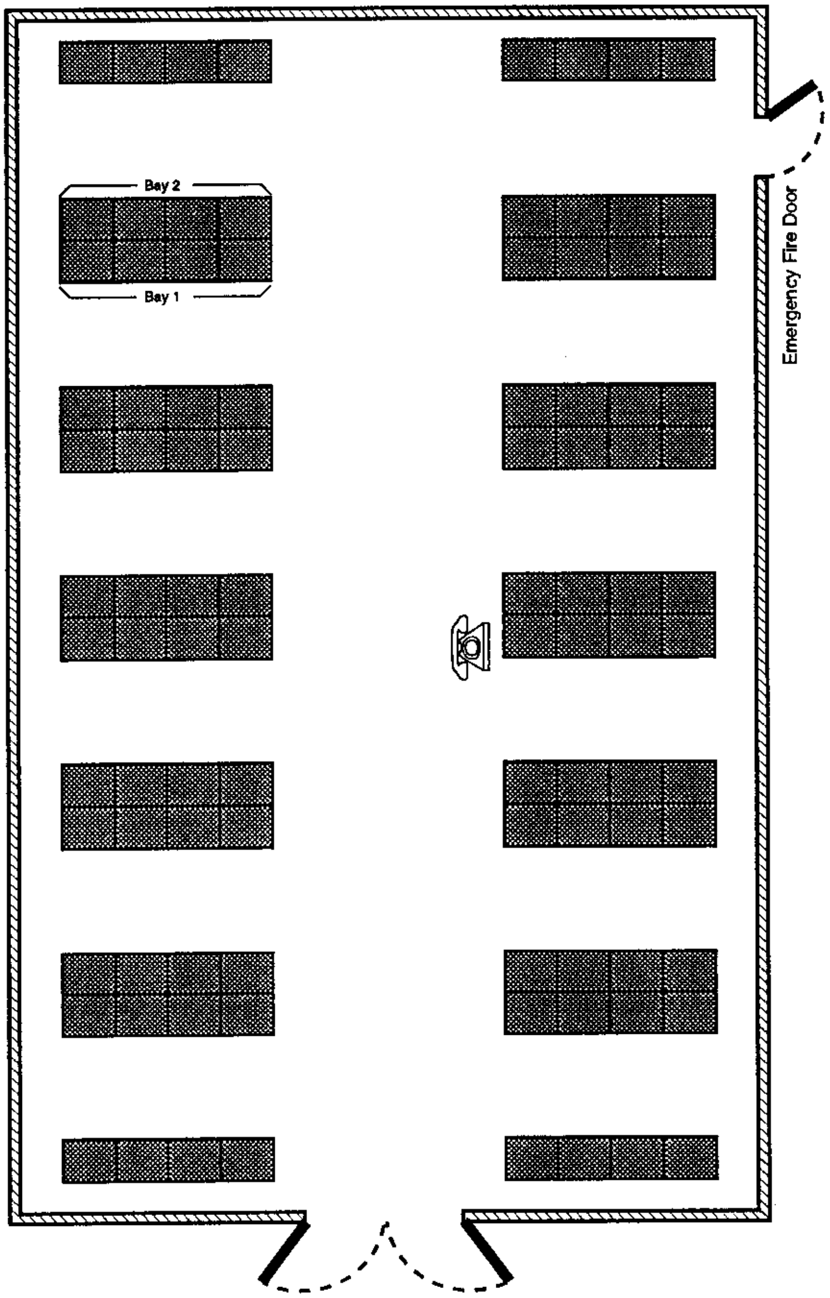


Fig. 5.5 Typical Relay Room Layout in a Centralised Configuration

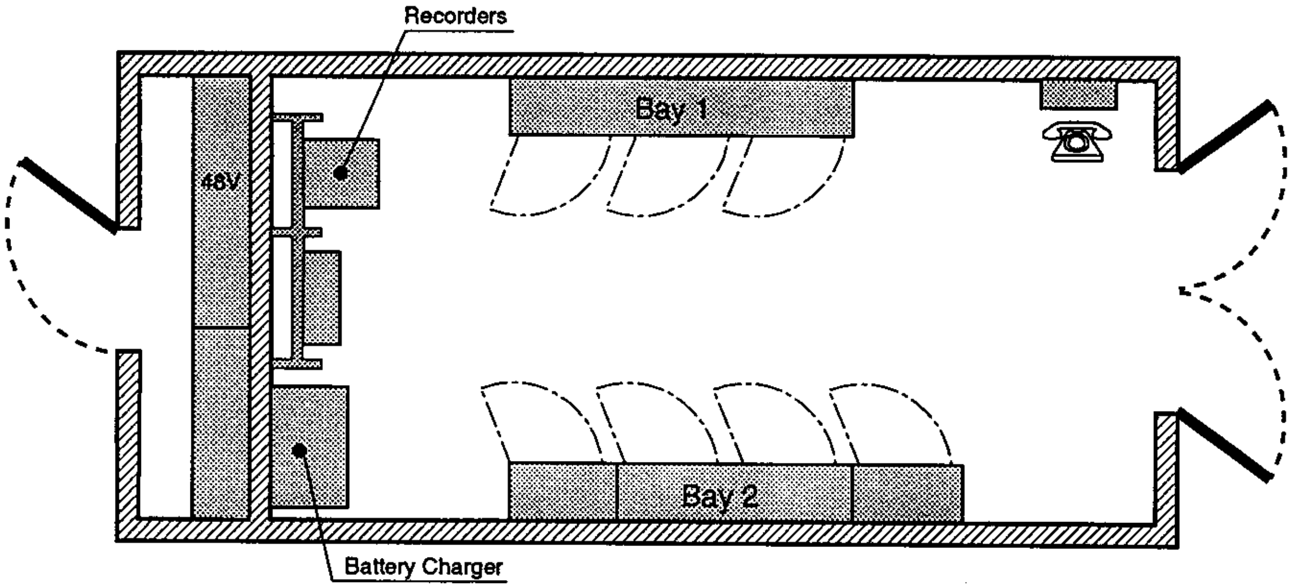
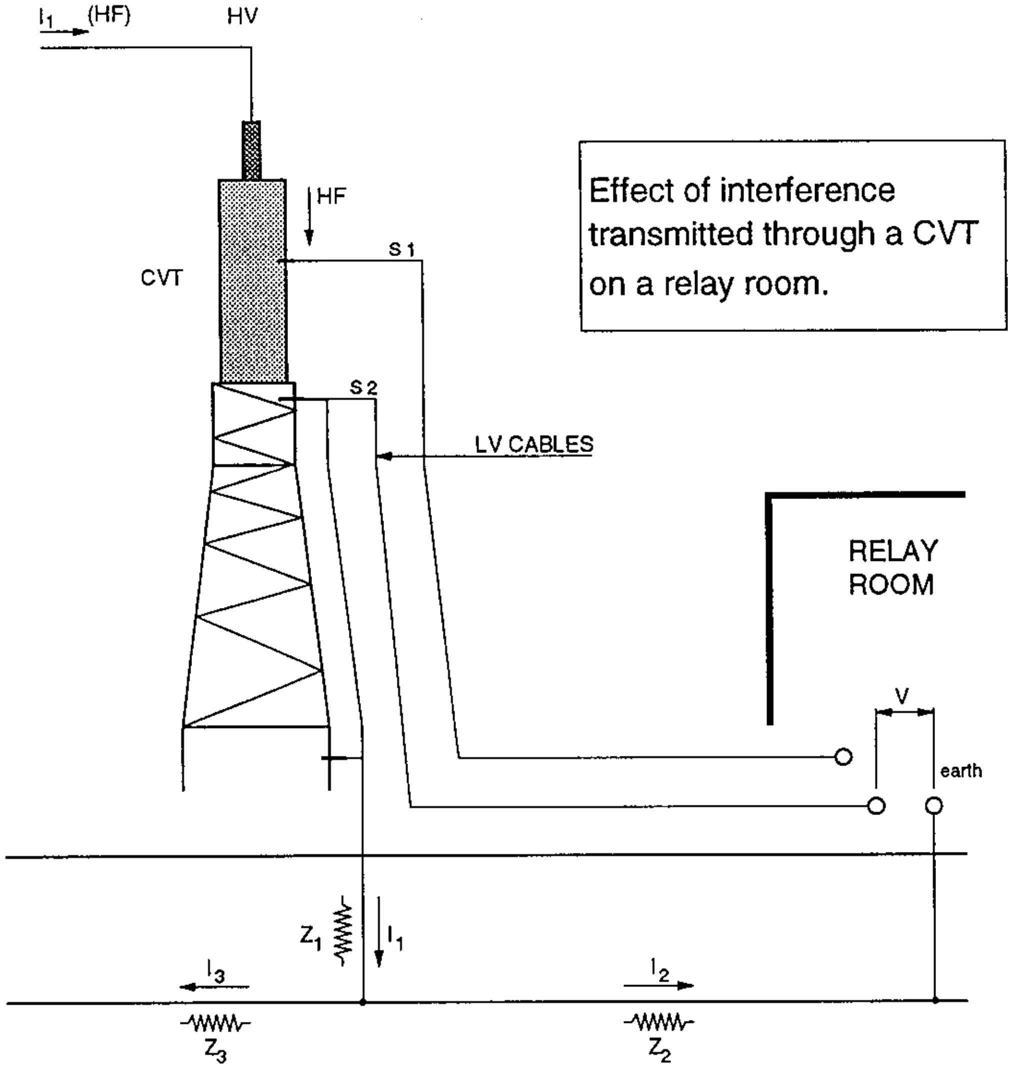
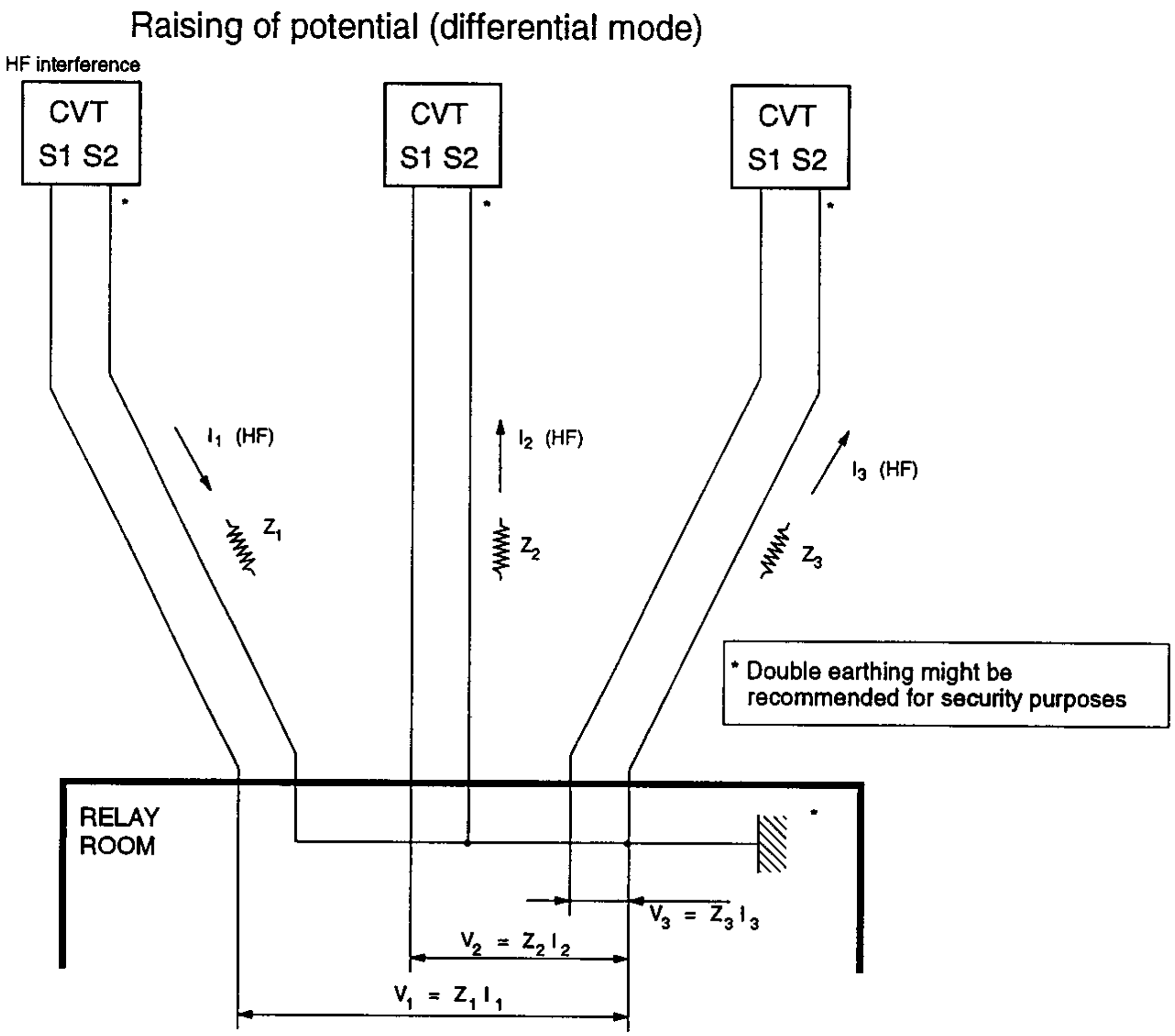


Fig. 5.6 Typical Layout of Secondary Equipment in a Dispersed Relay Room



$V = Z_1 I_1 + Z_2 I_2$ raising of potential (common mode)

Fig. 5.7.1 Earthing Practice



* Double earthing might be recommended for security purposes

Fig. 5.7.2 Earthing Practice

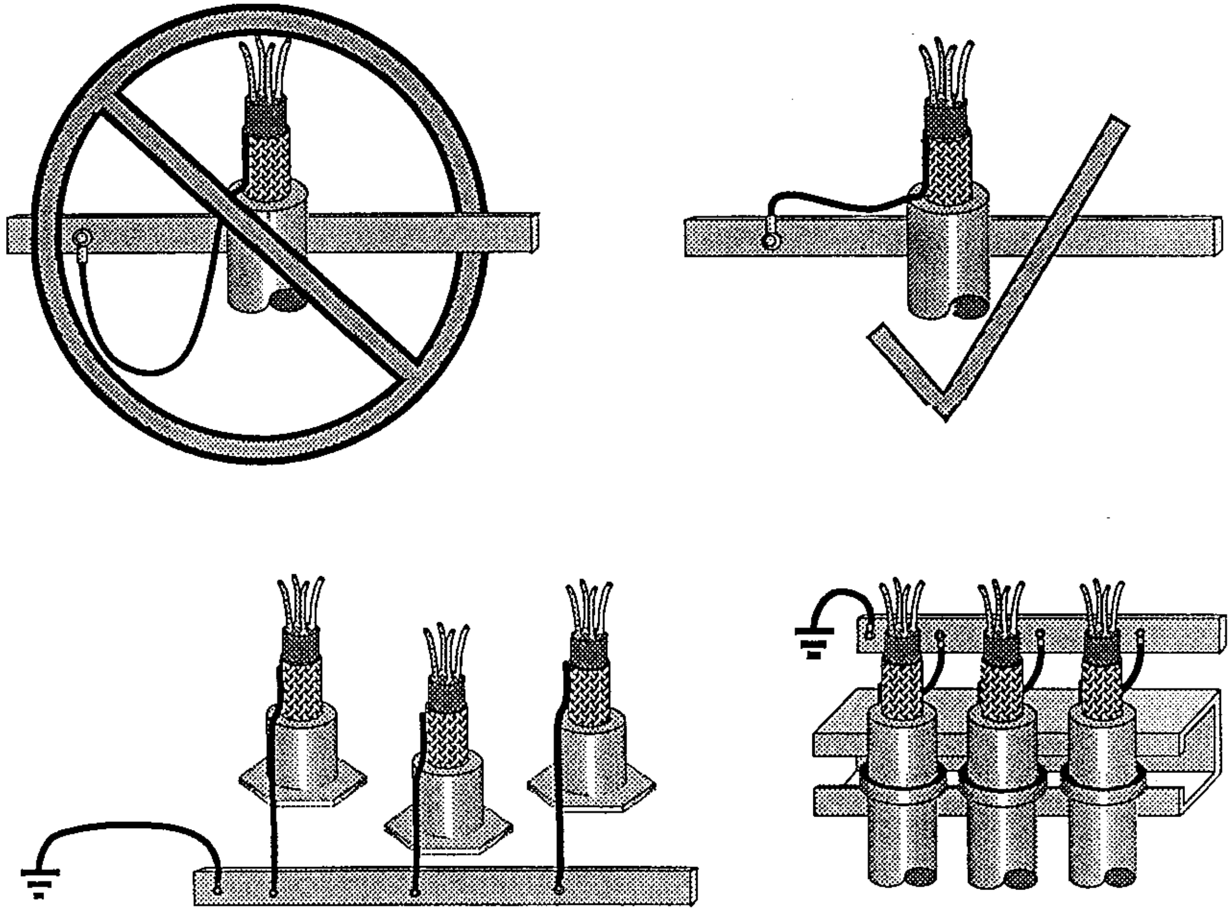


Fig. 5.8.1 Earthing Practice

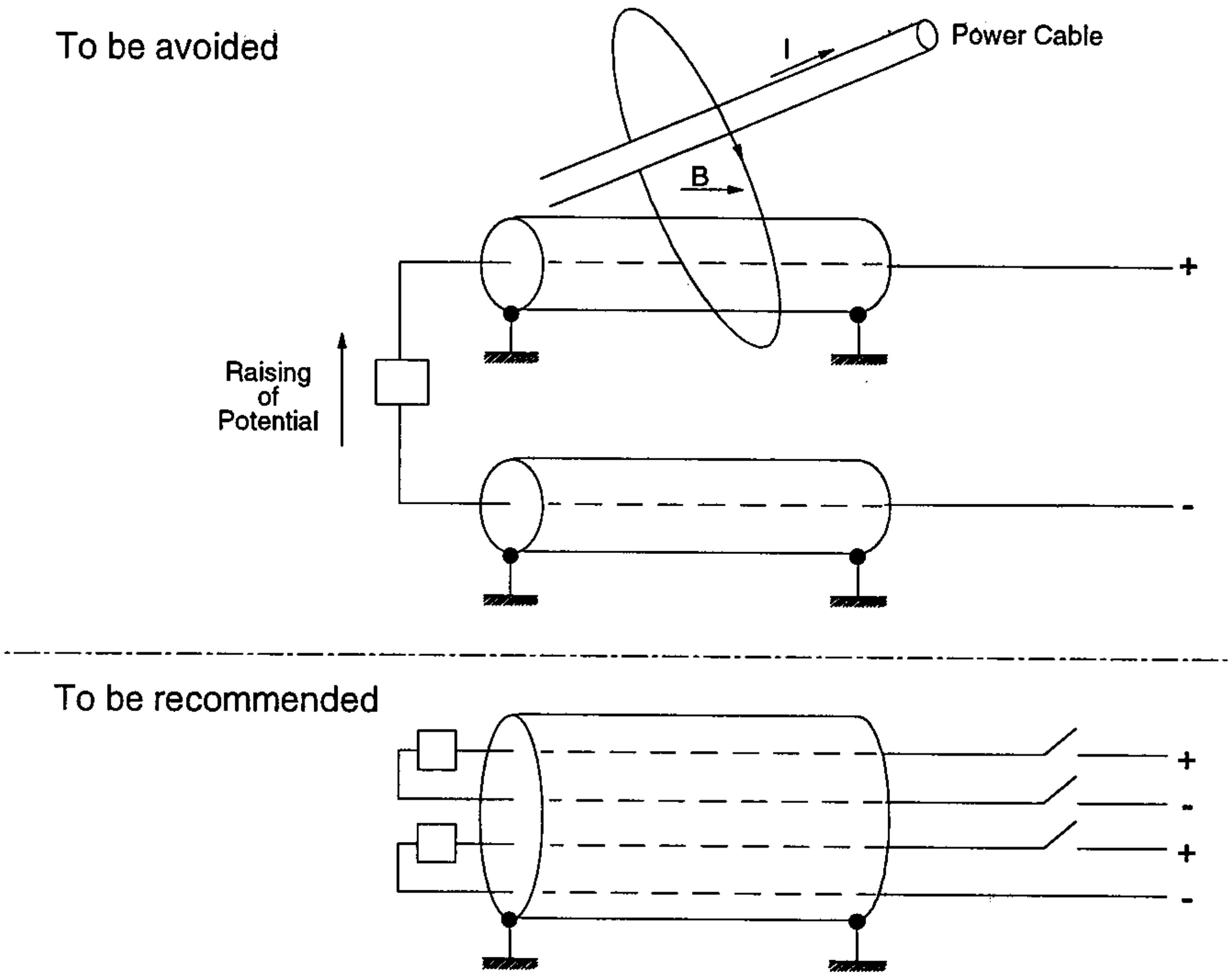


Fig. 5.8.2 Earthing Practice

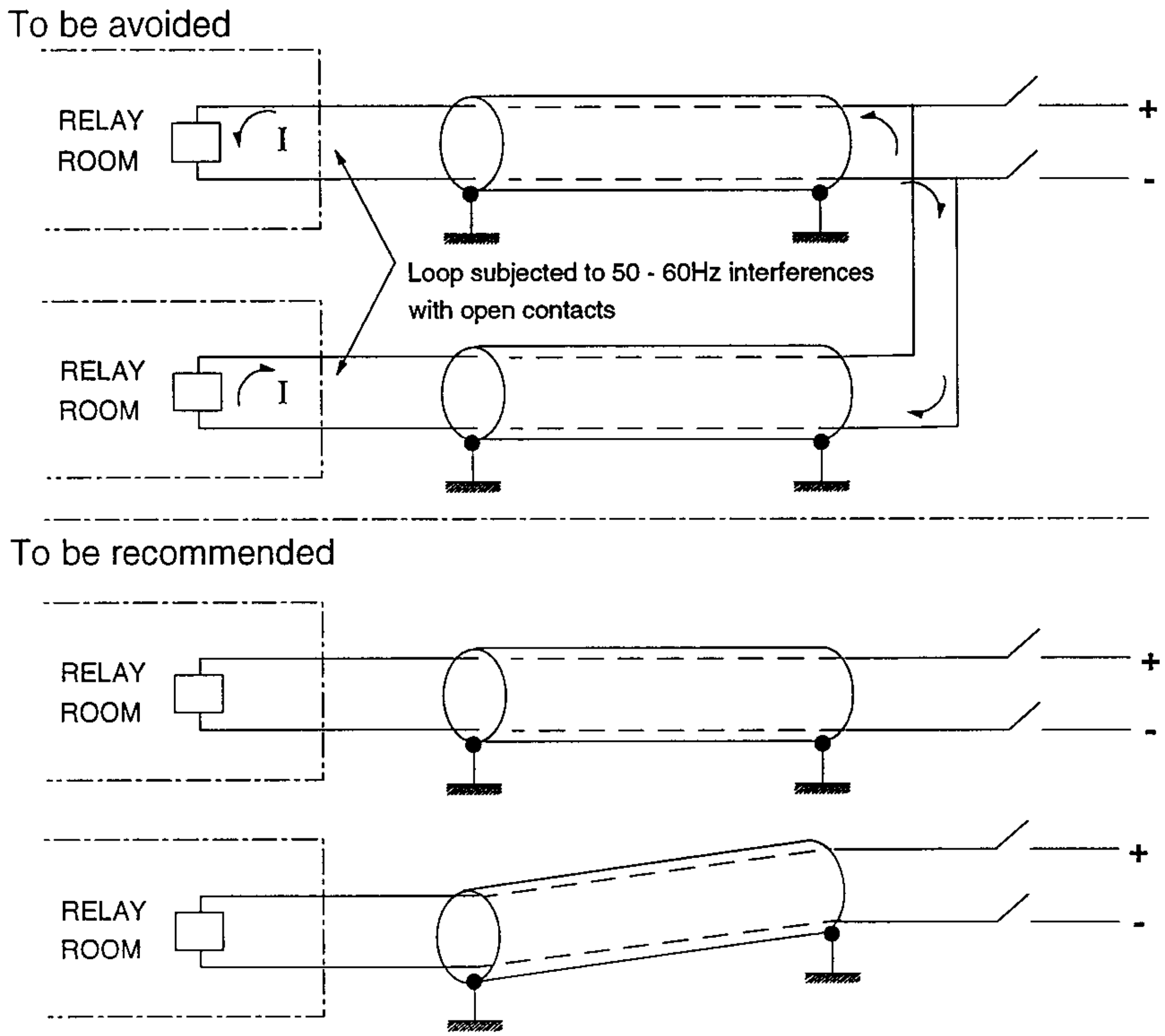


Fig. 5.8.3 Earthing Practice

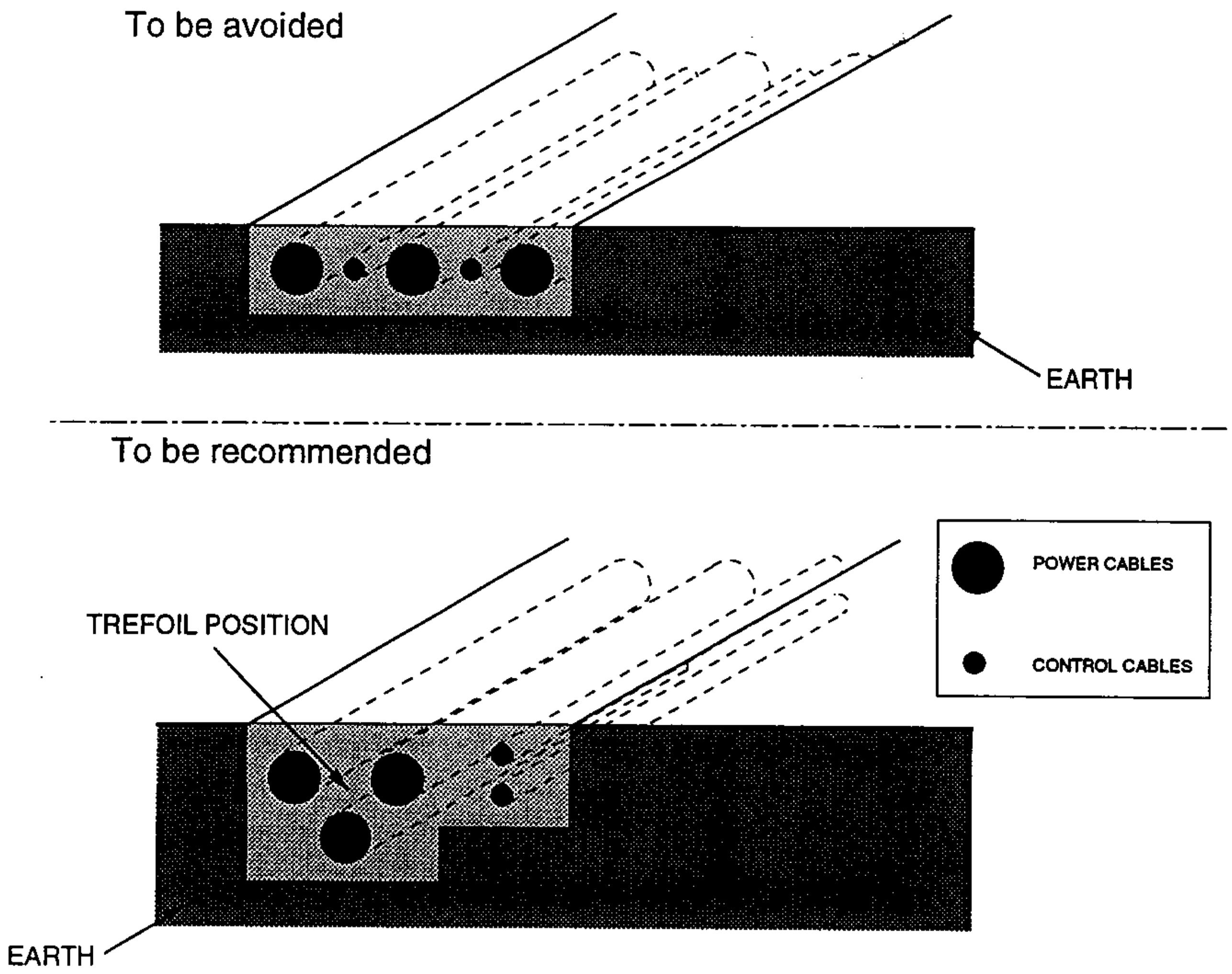


Fig. 5.8.4 Earthing Practice

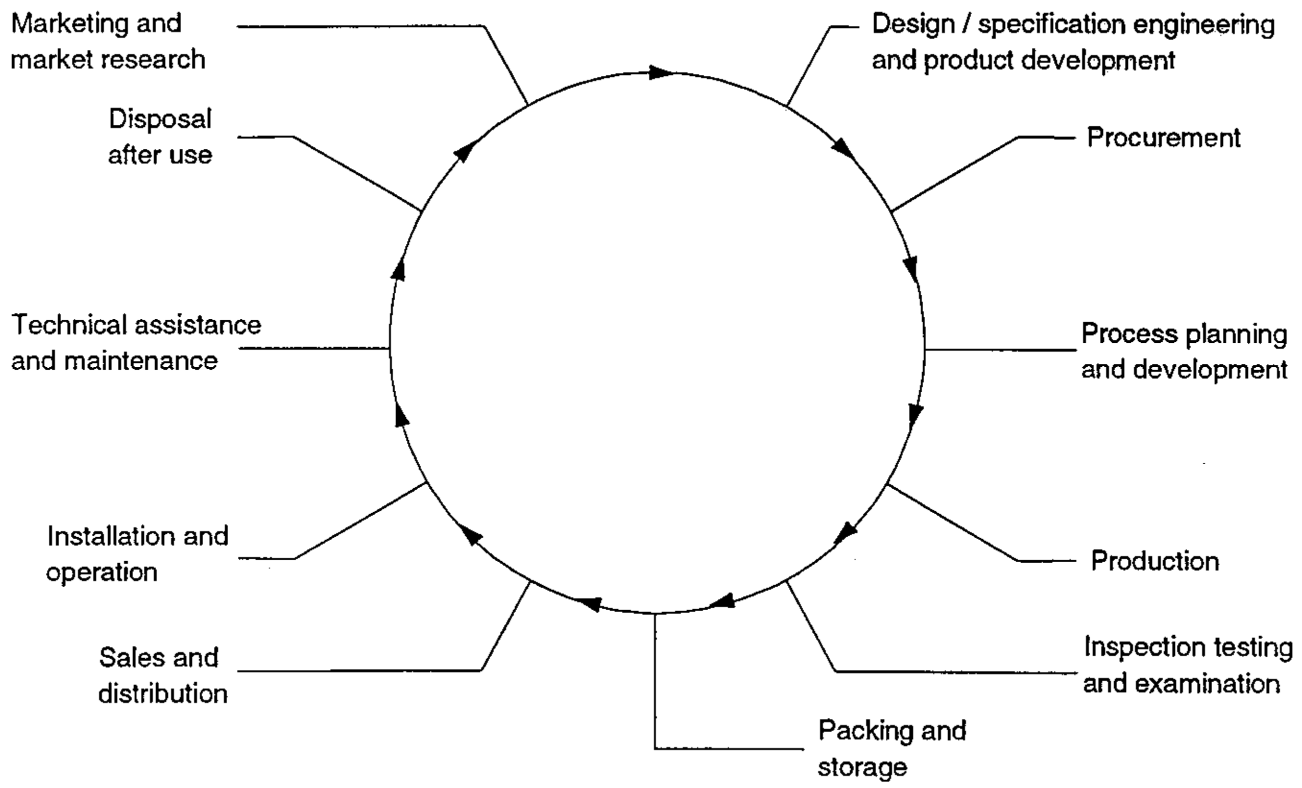


Fig. 6.1 QUALITY LOOP

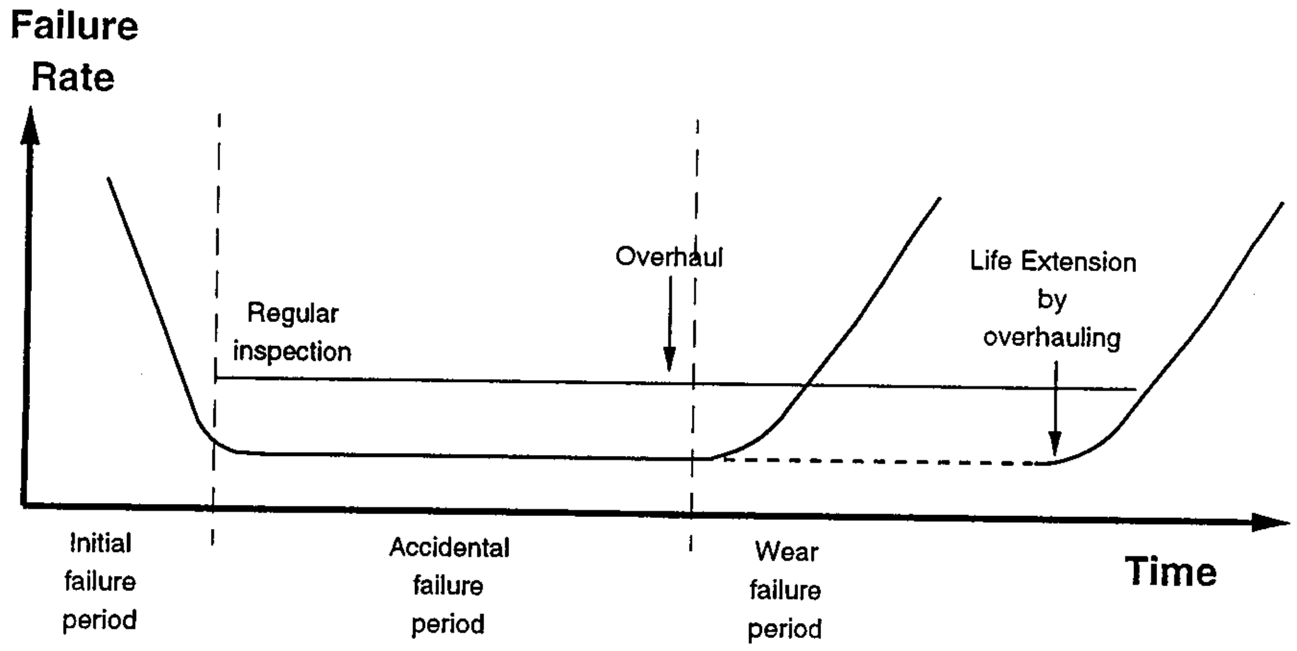


Fig. 7.1 Failure Rate Curve

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